Simulation of steady incompressible flow around a NACA0015 airfoil using Actuator Surface method and Mass Corrected Interpolation technique

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ABSTRACT

In recent years, actuator methods in aerodynamic simulations have been favored by researchers. These methods can significantly reduce the computational effort compared to full scale body resolving simulations. They are also more accurate than conventional methods that use simplified models. In this study, an Actuator Surface model is used to simulate flow around an airfoil in a steady two-dimensional incompressible flow. In these models, the geometry of airfoil is represented by volume forces distributed along the airfoil chord. For this purpose, collocated method of MCIM (Mass Corrected Interpolation Method) is coupled with the Actuator Surface Model. To determine the accuracy of results, Actuator Surface method is compared with Full-CFD simulation method. Besides, a new study is presented to investigate the effect of changing different parameters of Actuator Surface model on the accuracy of results. Finally, pressure and vorticity contours are plotted and obtained results are compared with Full-CFD results. The obtained results show that Although Actuator Surface has a moderate accuracy in calculating parameters such as velocity and pressure, it can predict aerodynamic forces and flow structures with acceptable accuracy. The method presented in this article can be used as an efficient tool in studying more complex cases.

KEYWORDS

Actuator Surface, Airfoil, Steady Flow, 2D flow, Incompressible Flow

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1. Introduction

A range of methods for performing airfoil simulations are available which are different in their capability to predict different aspects of aerodynamics behavior. Navier-Stokes simulations with fully-resolved boundaries are now precipitant. However, fully-resolved simulations come at great expense in terms of computational effort, simulation time especially when multiple airfoil and structures are present in the flow-field and complex meshes must be generated. Alternative, less expensive, non-Navier-Stokes models are available, such as momentum theory methods, panel methods and free wake models. These models suffer from assumptions in their formulation that limit their applicability[1]. It is here that the actuator concept offers the potential for simulating at less computational cost. In these models, the geometry of blades is represented by volume forces distributed along with disks or lines or surfaces. In fact, for all actuator disk, surface, or line formulations used in the analysis of airfoil aerodynamics, the surfaces or volumes modeling the airfoil are allowed to be porous to the flow. The purpose of this paper is to investigate the main parameter of actuator surface technique in airfoils simulation. In this article, the collocated method of MCIM[2] is utilized for solving two-dimensional unsteady incompressible flow at low Reynolds number [2, 3]. Therefore, the Actuator Surface technique has to be placed in the developed CFD solver to be able to predict all parameters quantitatively.

2. Methodology

The two-dimensional Navier-Stokes solver used here is the collocated method of MCIM. The code is based on a control-volume-based finite element method. AS model is included in the CFD solver, as shown in Fig. 1. But before combining this model and CFD solver, it was necessary to develop CFD solver to add source terms to the momentum equation. The CFD-AS solver described here is applied on unstructured triangular grids. The computational mesh extends 14 chord lengths downstream and 10 chord lengths upstream, above and below. To determine the accuracy of results, Actuator Surface method is compared with Full-CFD simulation method. Besides, a new study is presented to investigate the effect of changing different parameters of Actuator Surface model on the accuracy of results.

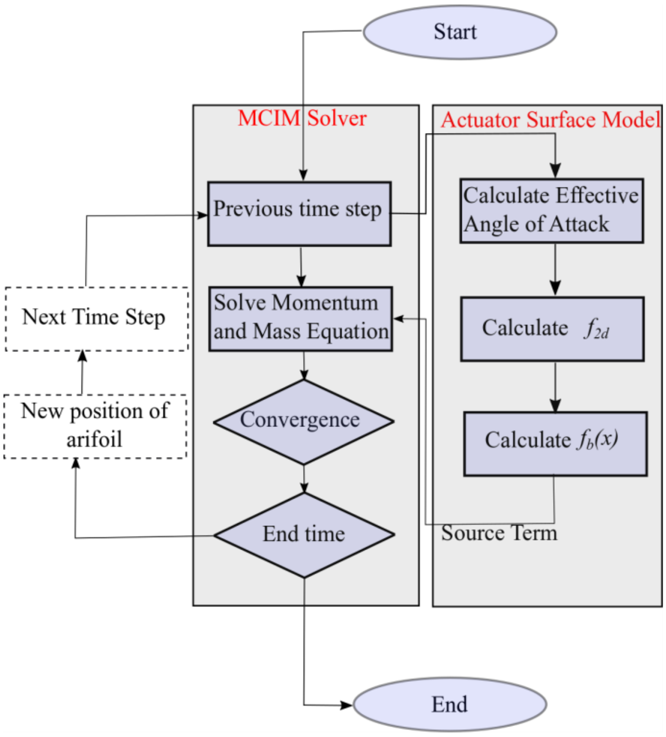

Figure 1. Process diagram of the Flow solver (combination of MCIM solver and AS).

3. Results and Discussion

As mentioned previously, in this study, for the first time, the effects of changing the effective parameters on the Actuator Surface technique and how to select their optimal values are investigated. These parameters include Gaussian filter, density of the source terms applied in cells and location of control point. All of these observations are shown in figures 2-4.

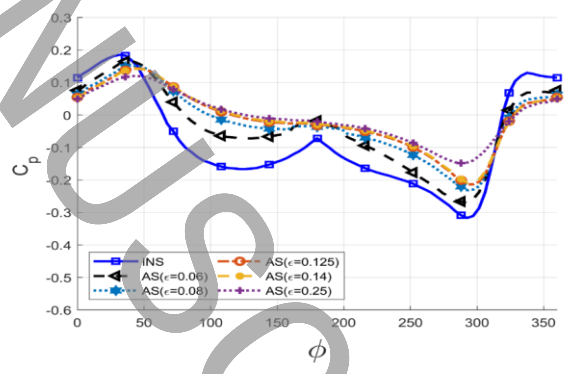

Figure 2. Comparison of pressure coefficient of CFD-AS for different Gaussian filter for Re=1100 and AOA=8 deg.

[2] Mass Corrected Interpolation Method

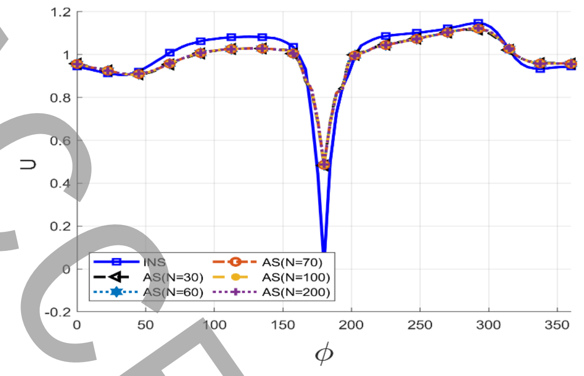

Figure 3. Comparison of x-velocity of CFD-AS for different density of the sources terms for Re=1100 and AOA=8 deg.

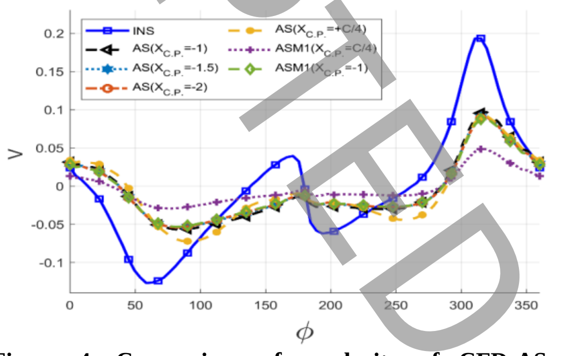

Figure 4. Comparison of y-velocity of CFD-AS for different location of control point for Re=1100 and AOA=8 deg.

Based on the results, the optimal values for the studied parameters are presented in Table 1.

Table 1. Selected values for examined parameters

Parameter	Value
Gaussian filter)ε(	0.06
Density of the source terms	100
Location of control point	-C
Number of cells	13054

In Fig. 5, pressure contours and streamlines are shown for both full-CFD and CFD-AS methods. As seen, the streamlines and pressure contours are very similar. It should be noticed that the CFD-AS method does not need a body-fitted mesh. because The geometry of airfoil is represented by volume forces. However, the streamlines do not cross the chord line which the forces are distributed along it.

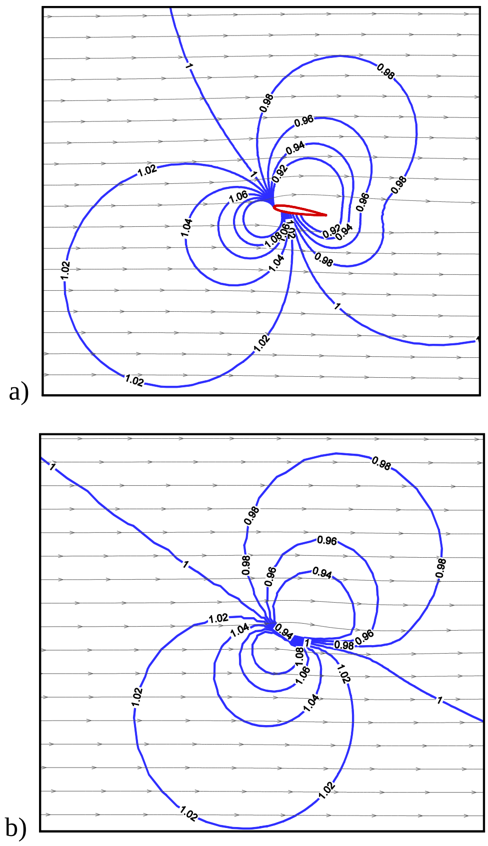

Figure 5. Streamlines and pressure contours with a)Full-CFD and b)CFD-AS; NACA0015, $Re = 1100$, Angle of attack of 8 deg.

4. Conclusion

In the present work, an actuator surface model is proposed for the CFD calculation of the flow around an airfoil. This method, called CFD-AS method requires less computation effort than the full-CFD methods. The obtained results were encouraging. It can be said that the Actuator Surface method, while drastically reducing the computational cost, has acceptable accuracy in calculating the flow around the airfoil.

5. References

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