4-19-2023

Inviscid Analysis of Steady and Unsteady Flow past NACA 0012 Airfoil using UVLM Based Ptera Software

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E37 MEMS 500 09 – Independent Study

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I. Introduction

Flexible wings are known to improve the aerodynamic performance of an aircraft. The key benefits of flexible airfoils/wings are the reductions in aerodynamic drag. Current flight control mechanisms operate using hinges, which significantly disrupt the airflow and even generate vortices between the control surface and the wing boundary thereby increasing drag. The ultimate goal of this project is to evaluate the performance of morphed airfoil/wings by numerical simulation. To numerically simulate the morphed airfoils/wings, the open source software called Ptera will be employed. Ptera is an unsteady vortex-lattice method (UVLM) based solver specifically designed for morphed wing analysis. Ptera Software has been previously validated with experimental data and has been demonstrated to be capable of analyzing single ornithopters [1]. This paper presents the application of Ptera software for simulation of the steady flow over a rectangular wing with NACA 0012 airfoil section and for unsteady flow due to a rectangular wing with NACA 0012 airfoil section in pitching motion. Results are compared with experimental data and computations of other investigators.

II. Application of Ptera Software to Steady and Unsteady Flow past a Rectangular Wing with NACA 0012 Airfoil Section

A. Geometry and Operating Conditions

The first part of this study involves the computation of the pressure coefficient on NACA 0012 airfoil assuming inviscid flow conditions using Ptera software. The wing geometry is shown in Figure 1 which is close to the experimental geometry. The wing replicates the wing of the Cessna 150 model with a chord length of 1.455m. The flow velocity is 56m/s. The pressure coefficients are computed at angles of attack of $\alpha = 3^o$ and 6^o. Initially, for the pressure coefficient analysis, the wing is divided into 100 chordwise panels to yield good accuracy in results.

The second part this study involves the analysis of the unsteady oscillatory inviscid flow due to a rectangular wing in sinusoidal pitching motion. The transient simulation is performed and the computations are performed over two cycles for the solution to become oscillatory. The initial test for this case was performed using only 8 chord-wise panels due to the generation of significantly large volume of data if higher number of chord-wise panel were used. Therefore this simulation simply serves as demonstration and the simulated results are not accurate. Therefore, experimental comparisons could not be made for this case. Future work will be conducted with a large number of chord-wise panels.

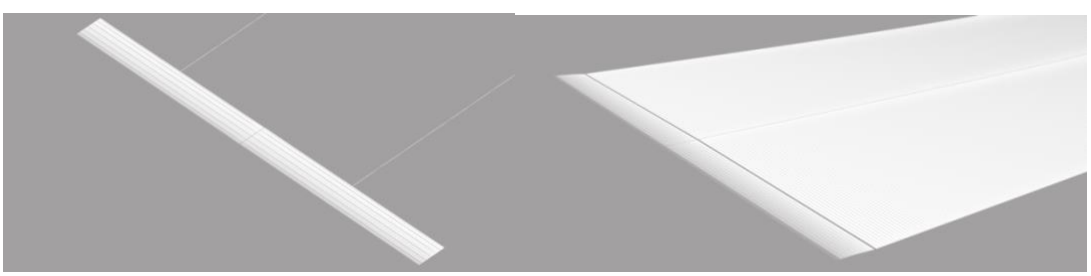

Fig. 1 The geometric layout of the wing for steady flow (left) and for pitched oscillation (right).

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B. Results

This section first shows the results of computations at M = 0.3 and angles of attack of $\alpha = 3^0$ and 6^0 for steady inviscid flow. The solution is obtained on a number of panels discretizing the airfoil surface in chord-wise direction. As expected, increasing the numbers of panels improves the accuracy of the solution and finally converges for flow quantities such as pressure and lift etc. for a certain number of panels. The number of panels varied from 8 to 100.The distribution of panels was non-uniform; the panels were divided unevenly on the length of the chord such that the front and the end of the chord had more sections compared to the center of the airfoil. In the span-wise direction, the panels were spaced uniformly with constant length along the wing span, wing being that of the Cessna 150 aircraft. Figure 1 shows the difference in pressure coefficient between the bottom and top surface of the airfoil along the chord for 3 and 6 degree angles of attack using 50 panels. It turns out 50 panels are sufficient to get a converged solution for the pressure coefficient and aerodynamic force coefficients. Unlike other Computational Fluid Dynamics (CFD) simulation platforms, Ptera software does not produce the top layer and the bottom layer pressure coefficient plots but rather produces a net pressure coefficient plot. Convergence is considered achieved when the root-mean-square (RMS) value of the lift coefficient was less than 10-^{7}.

For the second case of the pitching oscillations of NACA 0012 airfoil, a transient simulation with UVLM solver was conducted. The number of simulation cycles was set to two since the data from first cycle usually consist of lot of transient effects from the initial data and is not time-harmonic and therefore is not correct. Because of limitation of computational resources, only 8 panels in the chord-wise direction are used in this case. Analyzing the data from the second cycle, the pressure coefficient data follows a sinusoidal curve where the net pressure coefficient on the panels of the wing increases and decreases as expected due to pitching oscillations of the wing. Figure 2 and 3 show the oscillatory pressure at angles of attack of 3 and 6 degree respectively. In this case, the solution convergence study uses two nested loops to run the simulation for each chordwise discretization. After each simulation, the root-mean-square (RMS) value of lift and drag are calculated over the final pitching-cycle (second cycle). The force data from each panel are then divided by the area of the panel to determine the net pressure .Figure 5 shows the frames of pitching sinusoidal oscillation cycle of pressure at 3 degree (left) and 6 degree (right) angle of attack.

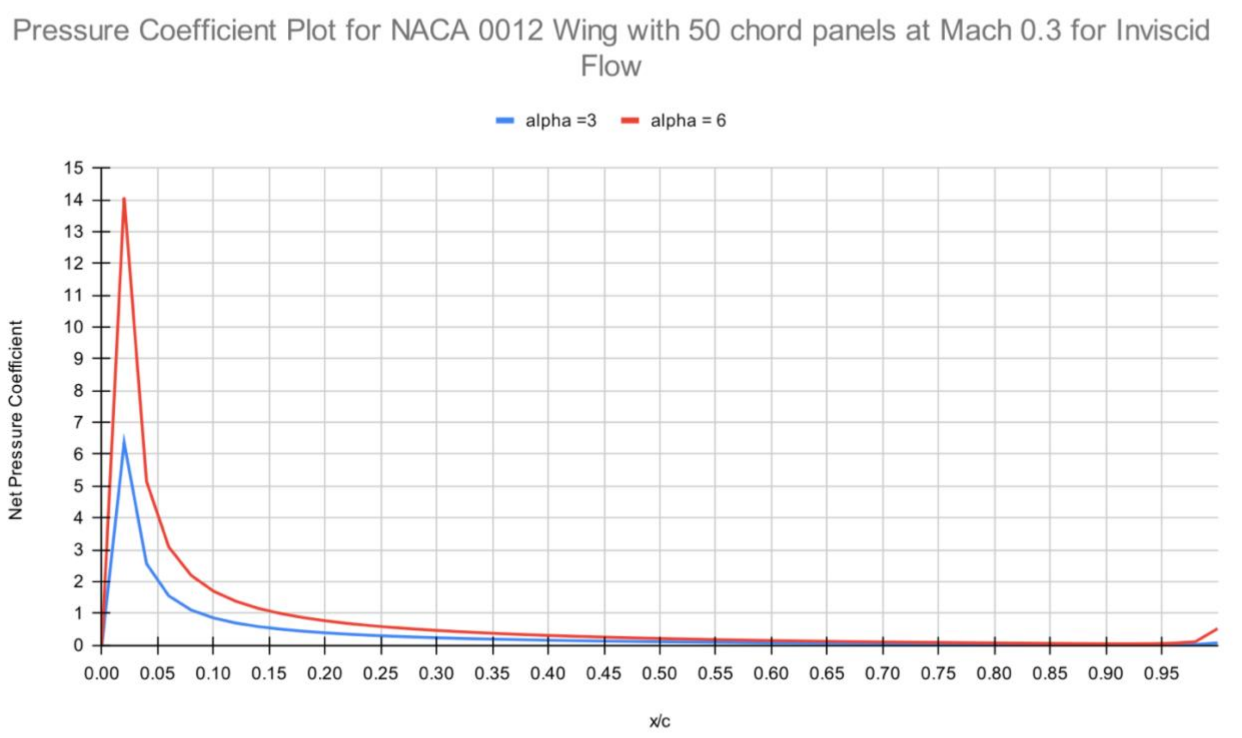

Fig. 2 The net pressure coefficient along the chord using 50 panels at the angles of attack of 3 and 6 degree

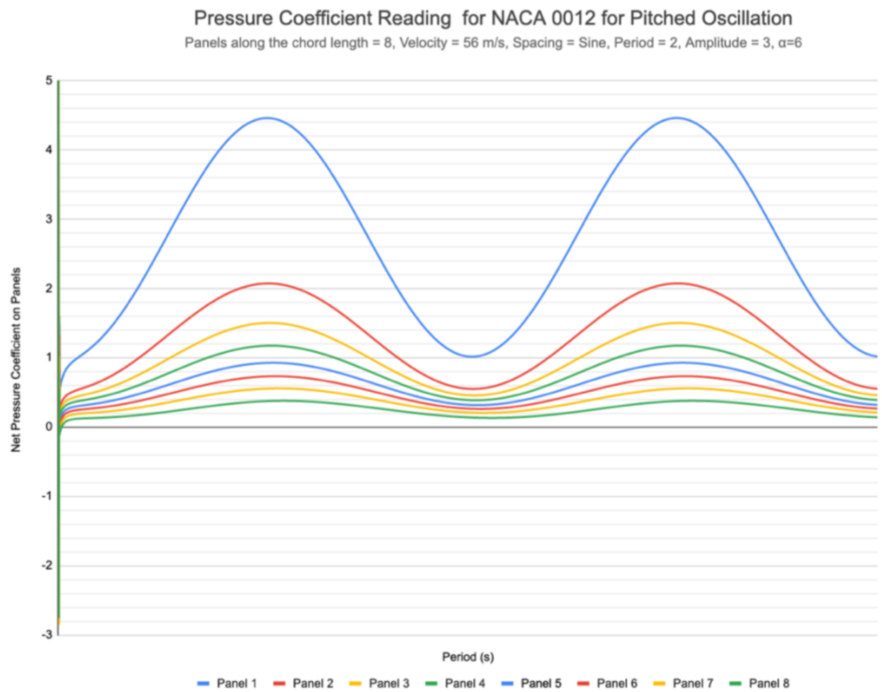

Fig. 3 The sinusoidal oscillations of pressure during the second cycle at 3 degree of angle of attack.

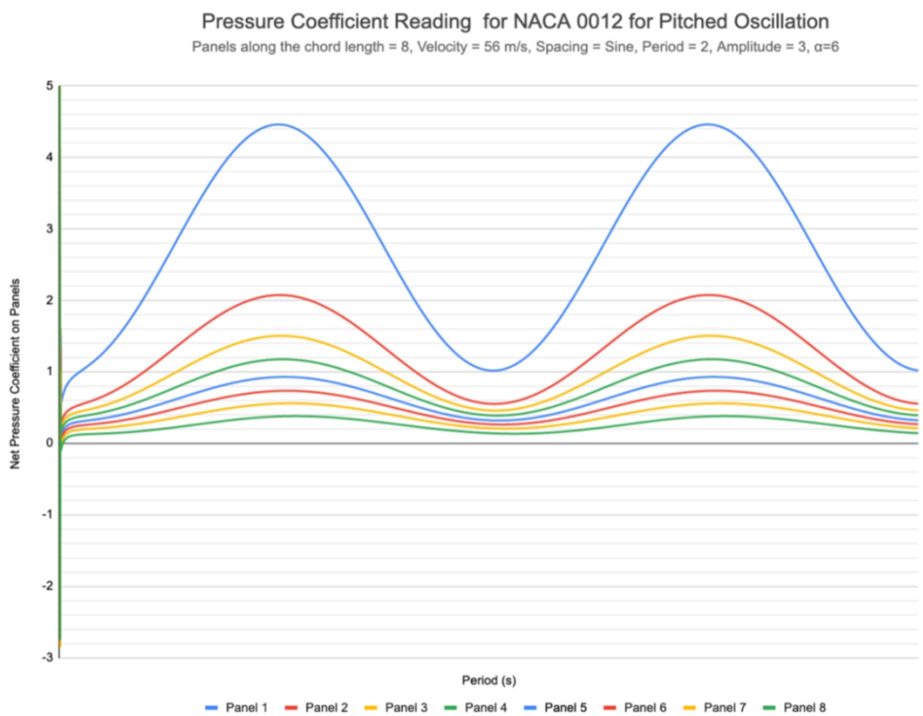

Fig. 4 The sinusoidal oscillations of pressure during the second cycle at 6 degree of angle of attack.

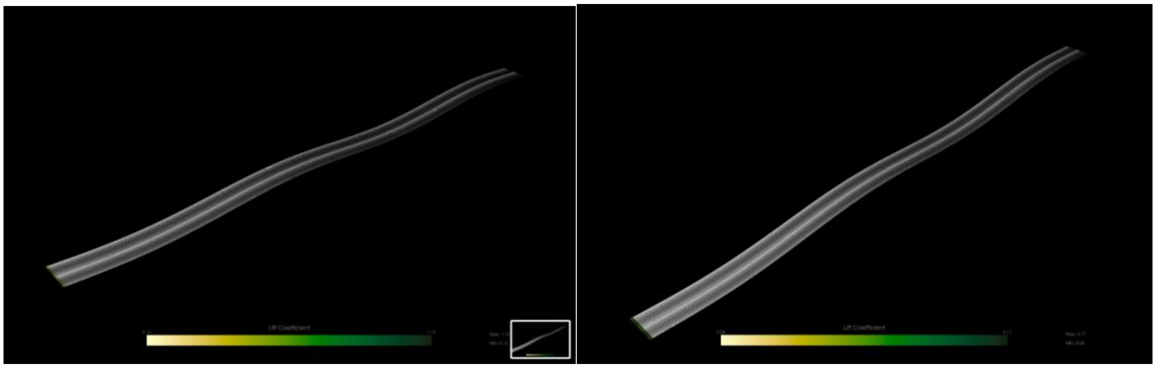

Fig. 5 Frames from pitched oscillation cycle of pressure coefficient as a function of sine at 3 degree (left) and 6 degree (right) angle of attack.

III. Conclusions and Future Work

For the case of pressure simulation for steady inviscid flow over a rectangular wing with NACA 0012 airfoil section at angle of attack $\alpha = 3^o$ and 6^o, the simulations produce a net positive pressure coefficient value which drops along the length of the chord (x/c). The net pressure coefficient generated for $\alpha = 6^o$ is higher than that at $\alpha = 3^0$ as expected.

For the case of the pitching NACA 0112 rectangular wing, the number of computational cycles was set to 2 since the data from the first cycle usually consist of lot of error due to transient simulation for initial data during the first cycle and therefore is not sinusoidal. Analyzing the data from the second cycle, the pressure coefficient follows a sinusoidal curve where the net pressure coefficient on the panels of the wing experiences rise and drop along the chord of the airfoil as expected.

The future work for both the cases will involve solutions on more number of panels and the comparison of computed solutions with the computations of other investigators.

IV. References

[1] Urban, C., and Agarwal, R., “Validation and Optimization of Ptera Software: An Open-Source Unsteady Simulator for Flapping Wings,” AIAA Paper 2022-1967, AIAA SciTech Forum 2022, San Diego, 3-7 January 2022.

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