ASEN 3111 Computational Lab #5: Flow Over Finite Wings

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I. Introduction

Understanding and analyzing wing performance of an aircraft is a fundamental part of the field of aerodynamics. There are many different strategies in the engineering world that are used to determine the necessary fluid dynamics involved – some of these strategies are better than others. In theory, aircraft wing performance can be determined accurately by solving the Navier Stokes equations – the set of equations that govern the motion of viscous fluids. However, solving for the general solution to these equations analytically cannot be done because the theory involved is incredibly complex. Though a mathematical approach is fruitless, solving the Navier Stokes equations can be done numerically. Direct numerical simulation (DNS) is a method used to analyze fluid dynamics over a wing, and it involves solving the Navier Stokes equations directly. This approach, while it provides the most accurate results, can take months to compute due to its complexity. DNS programs can run for months at a time at an enormous computational cost, and thus DNS methods are usually impractical for engineering needs. This impracticality causes aerodynamic study to turn to simpler models – the lowered cost and computational time makes up for the loss of accuracy that simpler models provide.

There are two simpler models in use that can provide relative accuracy if certain assumptions are made: the thin airfoil theory and the vortex panel method. Thin airfoil approximation works well in specific areas and is simple enough that it can be solved with linear theory providing analytical approximations. The vortex panel method is slightly more sophisticated and encompasses a wider range of variables – this method can be solved computationally with highly accurate results. One drawback that exists for both of these models is that the fluid flow that is analyzed must be steady – flow separation is not included in the methods. However, turbulence and flow separation play a vital role in studying aerodynamics: this phenomena is abundant in nature despite the difficulty it causes in study. Flow separation is what leads to stalls in wings, and neither of the methods addressed above can accurately predict when a wing will stall. Thus, more complicated approaches must be used.

In this lab, a turbulent Reynolds-Averaging Navier-Stokes (RANS) model is used to predict the lift slope (a), zero lift angle of attack, stall angle (), and maximum sectional coefficient of lift () of two different airfoil meshes: a NACA 0012 airfoil and a NACA 4412. Ansys Fluent software is implemented to compute these values – a RANS model is an acceptable middle-ground between Direct Numerical Simulation and simple analytical models. The values obtained are analyzed for accuracy against experimental data.

II. Methodology

This lab uses a Reynolds Average Navier Stokes (RANS) turbulence model to find necessary values to describe turbulent airflow. The RANS model, while less accurate than the DNS model, is much more efficient to run because it averages all solutions. Though the approximate solutions obtained by RANS lose the small intricacies of turbulent flow, the overall characteristics are preserved and computational costs are cut. Thus,

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the use of this model is an acceptable compromise in the engineering field. Figure 1 shows a comparison of the various methods used for solving the Navier Stokes equations.

As shown in Figure 1, RANS analysis captures the essence of flow separation: the simulation captures just enough information to provide a rough estimate of the flow's behavior even though the smaller dynamic characteristics calculated from DNS are left out of the computation.

The flow that is modeled in this lab is important to understand, because it allows the intermediate level dynamics to be ignored and the RANS model to be applicable.

Several modifications were made to the flow parameters to obtain the required Reynolds number for each airfoil. For the NACA 0012, a value of six million was used, and for NACA 4412, the Reynolds number was three million. Two different values were used because we wanted to compare our simulation results with experimental results – the experimental results provided were obtained using the two different RE numbers. Also, it is useful to test more than one RE value to expand our results. These Reynolds numbers were acquired by adjusting the flow state and viscosity of the farfield. The flow state was considered to be steady in the far field to ensure constant velocity, and the viscosity was also held constant. Enforcing these conditions ensured the Reynolds number remained constant as well, though the air was considered an ideal gas to keep the density, and thus the viscosity, constant. An ideal gas assumption also allowed for compressibility properties – compressible air is more accurate in nature, so our results would reflect this change. These changes ensured that the turbulent flow was as accurate as possible.

Once the Reynolds numbers were established for each airfoil, the RANS program was implemented. The software involved solves the RANS equations and Turbulence equations at the same time through a method called coupled solving. The solver converges to the correct answer given infinite time – since time was limited, the constraints were loosened to allow convergence within a given tolerance (the tolerances varied with each angle of attack). The method used, though computational time is increased, provides accurate results. Meshes of each airfoil were provided to expedite the process. Each mesh was tested for different angles of attack ranging from _ to _, and for each angle, the maximum iteration number was set to 3000 to ensure that, in the event that there is no convergence, data oscillations would be removed from the calculations. The maximum iteration number introduces error within the data because the final values are affected. Overall, this process took a significant amount of time, but the software was user- friendly while providing relatively accurate results.

III. Results

IV. Discussion

Acknowledgments

References

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