BYU Flow Lab Assignment 2

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1 Introduction

In real life, wings are finite and 3-dimensional. The purpose of this paper is to explore some basic differences in wing design by using a low-fidelity computational fluid analysis of the finite wing. The method used in this paper is the vortex-lattice method. This method works by creating an infinitely thin wing in 3-dimensional space with horseshoe vortices attached to the wing in a lattice formation. In this paper, the effect of aspect ratio on the lift coefficient will be discussed. In addition to this, the effect of tail-volume ratio on wing stability derivatives will be discussed. Lastly, the angle of attack's effect on the lift coefficient will be discussed based on this finite wing theory.

2 Methods

2.1 Aspect Ratio Program

This program utilized a vortex-lattice package in Julia called VortexLattice.jl to create finite wing geometry and implement the vortex-lattice method onto the geometry. The function outputs force and moment coefficients relative to the specified coordinate system of the user. In this case the standard Euclidean coordinate system was used with points being measured relative to the origin which was placed at the center of the wing span-wise and leading edge of the chord. The units are all arbitrary.

For this experiment the wing was assumed to be rectangular. The wing was given 7 units of length whilst the chord was calculated from the given aspect ratio and wing length. A program was written in Julia which inputted a specified wingspan and aspect ratio to calculate the chord length. These parameters were inserted into VortexLattice.jl which subsequently returned the lift-coefficient for a variety of angles of attack. The angles of attack for this experiment were chosen to be from -15 to 14 degrees. Multiple test were conducted for differing aspect ratios. For each test the wingspan was held constant while the chord changed to fit the specified aspect ratio. The outputs were subsequently returned to a CSV file and plotted. Results will be shown in section 3.1.

2.2 Tail Volume Coefficient Program

The tail volume coefficient program was created with the purpose of exploring the effect that the tail volume coefficient has on an aircraft's stability derivatives. The program was coded in Julia using the previously stated vortex lattice package. The specific stability derivative in this experiment was pitch stability. More information is contained in the appendix. The wing was assumed to be rectangular with constant dimensions for each experiment. The center of lift for the horizontal stabilizer and wing were kept a constant distance away from the center of gravity.

This program works by taking the specified horizontal stabilizer dimensions and scaling them by specified constants. The ratio between the chord and span remained the same whilst their total area was scaled proportionally which increased the tail volume coefficient. The dimensions for the original wing were a chord length of 4 units and a span of 10 units. The horizontal stabilizer had a chord of 0.5 units and a span of 2 units. The tail was a distance of 10 units away from the center of gravity and the wing was a distance of 2 units away from the center of gravity. The results are shown in section 3.2.

2.3 Angle of Attack for a Finite Wing

The purpose of this last experiment is to simply explore the effects of angle of attack on a finite wing. The experiment was simple. Input a square wing into the vortex lattice method and plot the resulting lift coefficient for each incremental angle of attack. Since the aspect ratio program plots angle of attack vs lift efficiency the results are also shown in section 3.1.

3 Results

3.1 Aspect Ratio Effect on Lift Coefficient

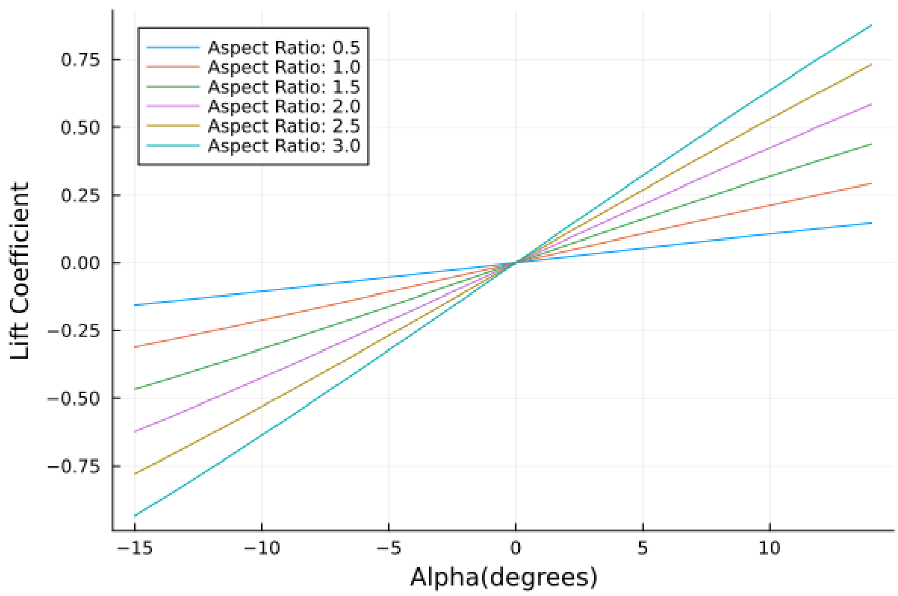

Figure 1: Lift Coefficient Plotted for Differing Aspect Ratios

The results form this test show linear relationships between the lift coefficient and the angle of attack. As the aspect ratio increased, the slope of the lines increased. All the lines intersect at the origin. Not shown in the figure but analyzed in the CSV files generated was the result that the drag in the near field was linear whilst the drag in the far field was not linear.

3.2 Tail Volume Coefficient Effect on Pitch Stability Derivatives

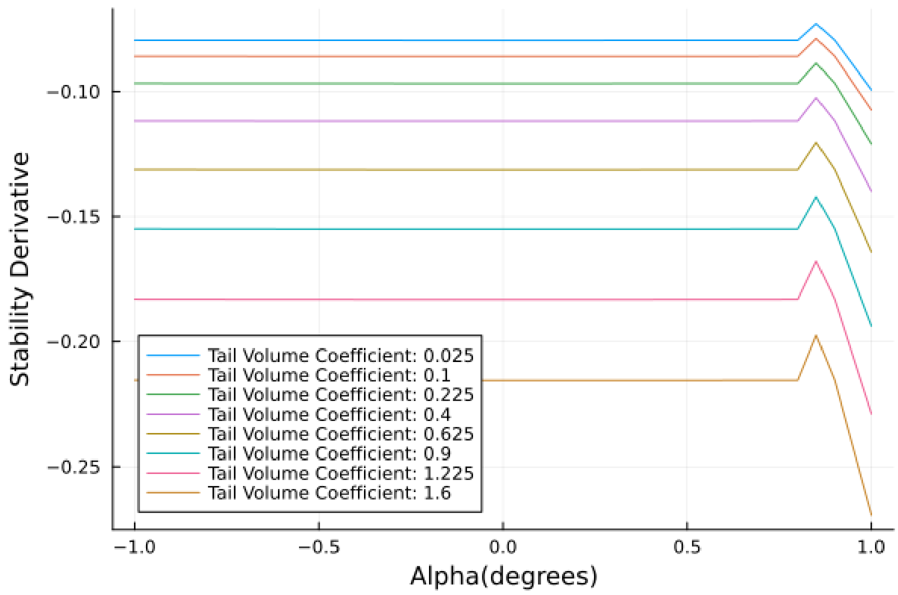

Figure 2: Stability Derivative's For Differing Tail Volume Coefficients

The results from this test shows that the stability derivative for this small angle of attack from -1 to 1 degree have a constant value for each tail volume coefficient. The spacing between this constant values seems to increase exponentially as the tail volume coefficient increase. Around 1 degree angle of attack, the stability derivative seems to have a large drop-off.

4 Discussion

4.1 Aspect Ratio Effect on Lift Coefficient for a Finite Wing

For a finite wing, when the aspect ratio was increased, the slope of the lift coefficient vs angle of attack graph also increased. This shows that with increasing aspect ratio, you get greater lift. This is in agreement with the research done by Hammer et al. Their research shows that by increasing the span and therefore the aspect ratio, the lift-curve slope will be greater. They also found that increasing aspect ratio also granted greater advanced lift stall Hammer et al. (2021).

4.2 Tail Volume Coefficient Effect on Pitch Stability Derivatives

From figure 2 it is clear that by having the Tail Volume Coefficient increase, the pitch stability derivative becomes increasingly negative. That means that as the tail becomes larger, the aircraft will experience a greater moment trying to return the wing back to trim state when a disturbance comes.

The stability derivative is also fairly constant across the range of small angles of attack. It only starts to drop off right around 1 degree angle of attack in which the stability derivative becomes much more negative. This shows that as an aircraft moves further away from its trim point, it will experience a much greater force trying to move it to trim position.

Other research has shown that this stability derivative is fairly constant across a wide range of angles of attack Motoda (2023). However; there is no evidence from this study to show a drop off at an angle of attack greater than 1 2023. More research needs to be done to draw a confident correlation there.

4.3 Effect of Angle of Attack on Lift Coefficient

From figure 1 it can be clearly seen that increasing the lift coefficient will increase the lift coefficient. This is in agreement with other studies including high fidelity studies Hammer et al. (2021).

This lift coefficient also displayed a linear relationship with the angle of attack. This matches the data in other studies for finite wings Hammer et al. (2021). The main difference with this from other studies is that the airfoil itself excluding the finite wing will produce a non-linear lift curve. But the fact that these results closely model higher fidelity research is a good sign that these results are accurate.

5 Appendix

Aspect Ratio: The mathematical ratio between the square of the wingspan and the projected area of the wing. It is defined as

$$\frac{b^2}{S}$$

where b is the the wingspan and S is the projected wing area.

Angle of Attack: The angle of the wing relative to the incoming free stream.

Free-stream Velocity (V_∞): It is the speed of the fluid relative to the wing. Basically it is the speed of the aircraft.

Lift coefficient: A non-dimensional number used to calculate the actual lift force. It is defined as the ratio between the lift force and dynamic pressure. It is defined as

$$\frac{L}{\frac{1}{2}\rho V_\infty^2 S}$$

where ρ is fluid density, V_∞ is the Free-stream velocity, and S is the wing projected area.

Vortex Lattice Method: A numerical method that approximates flow over a finite wing. This method utilizes potential flow vortices found from Laplace's equation. As a result of the linearity of the function, a superposition of these vortices with the boundary conditions that flow is always tangent to each vortex panel that is used. This method seeks to account for the effect of downwash on the aerodynamics of a 3d aircraft. Wing geometries are accounted for in the boundary conditions meaning that the wing is divided into panels which create the geometry and therefore flow tang-ency. This method is computationally efficient to optimize basic wing designs. It assumes in-viscid and irrotational flow.

Moment Coefficient: This is a non-dimensional quantity that is used to determine the net moment about a point on the aircraft due to its aerodynamics. It is defined mathematically as

$$\frac{M}{\frac{1}{2}\rho V_\infty^2 C^2}$$

where M is the net moment, ρ is the fluid density, V_∞ is the free-stream velocity, and C is the chord length.

Stability Derivatives: These are derivatives with respect to the angle of attack on the function of moment coefficient. The stability derivative in this paper explored was the pitch stability derivative. This is the derivative of the moment coefficient about the span-wise axis and the center of gravity. It is a measure of the moment created for a change in the angle of attack. For an aircraft to be statically stable, it's pitch stability derivative must be less than 0 (Ning, 2018, p 91).

Static Stability: This is a measure of an aircraft's ability to return to its stable position when faced with a disturbance.

Tail Volume Coefficient: A ratio between the size of the tail vs the size of the wing. It is defined mathematically as

$$\frac{S_t x_t}{S_w c_w}$$

where S_t is the tail area, x_t is the tail chord, S_w is the wing area, and c_w is the wing chord.

Trim Stability: This is a measure of an aircraft's pitching moment about steady conditions with no control input. This value should be 0 for any aircraft that wants to fly straight.

References

Hammer, P. R., Garmann, D. J., and Visbal, M. R. (2021). Effect of aspect ratio on finite wing dynamic stall. pages 1 – 21, Virtual, Online. Aspect-ratio;Dynamic stalls;Finite wings;Freestream mach number;High-fidelity;Large-eddy simulations;Pitching moments;Reynold number;Trailing edges;Wing tips;.

Motoda, T. (2023). Random generation of aerodynamic derivatives for monte carlo evaluation. *Transactions of the Japan Society for Aeronautical and Space Sciences*, 66(6):187 – 198. Aerodynamic derivatives;Control derivatives;Flight control;Flight systems;Flight vehicles;Monte Carlo's simulation;Preflight evaluation;Random generation;Uncertain parameters;Uncertainty;.

Ning, A. (2018). *Flight Vehicle Design*. Brigham Young University.