Can’t Sweep This Under the Carpet

OR

AE 6015 Bonus Project

Madeleine Graham Macy

4/17/2024

Introduction

The objective of this project is to calculate the total lift coefficient and induced drag of a non-twisted, non-tapered wing that is parametrically swept and verify with other results in order to observe the isolated effects of sweep.

The method I will use to conduct these calculations is a program called AVL (Athena Vortex Lattice.). AVL uses Prandtl's lifting line theory, applying a series of vortex filaments over the span of a lifting surface in horseshoe shapes. The use can determine how many panels to divide the lifting surface into, the shape and aspect ratio of the lifting surface, the airfoil shape(s), and some other parameters not relevant here.

For this experiment, I used 20 spanwise panels (10 semi-spanwise panels) and 10 chordwise panels. The aspect ratio I used was 5, which resulted in a span of 5 units and a chord of 1 unit. I provided AVL with 5 wings with different sweep angles: 0, 15, 30, 45, and 60 degrees. (Figures 1-4) I executed runs for each wing at angles of attack of 2.1, 4.2, 6.3, 8.4, and 10.5 degrees.

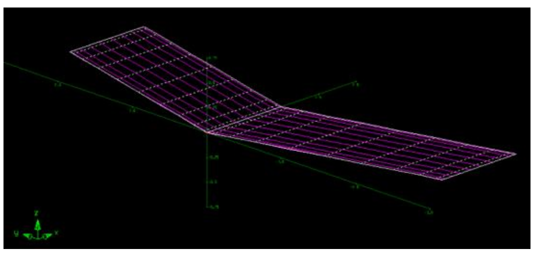

Figure 1: 15 degree sweep angle

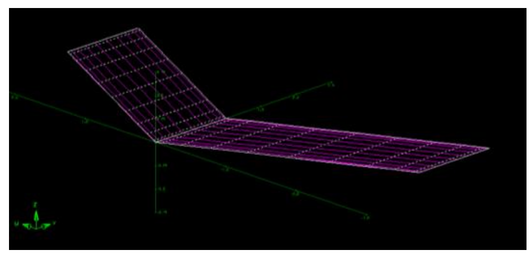

Figure 2: 30 degree sweep angle

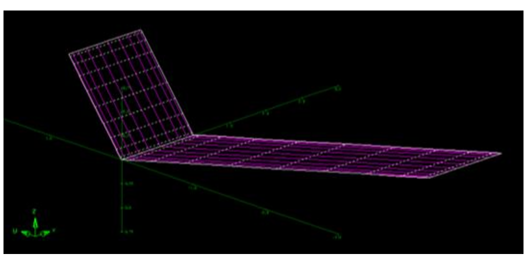

Figure 3: 45 degree sweep angle

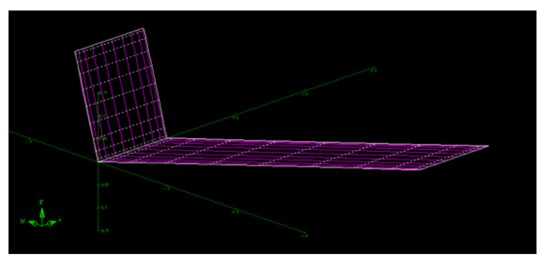

Figure 4: 60 degree sweep angle

Results

Table I shows that the CL for each angle of attack decreases with sweep angle. The induced drag also decreases for each sweep angle. As sweep angle increases and at high angles of attack, the effect of sweep on CL and CDi increases. This can be seen in figures 5 and 6.

Table I: AVL Results

Sweep angle	Angle of attack (deg)	CL	CDi
0	2.1	0.14482	0.0013497
0	4.2	0.28914	0.0053808
0	6.3	0.43249	0.0120391
0	8.4	0.57439	0.0212351
0	10.5	0.71436	0.0328452
15	2.1	0.14202	0.0013637
15	4.2	0.28356	0.0054364
15	6.3	0.42411	0.0121636
15	8.4	0.56322	0.0214547
15	10.5	0.70041	0.0331848
30	2.1	0.13558	0.0012804
30	4.2	0.27070	0.0051044
30	6.3	0.40489	0.0114207
30	8.4	0.53771	0.0201444
30	10.5	0.66872	0.0311581
45	2.1	0.12797	0.0011659
45	4.2	0.25552	0.0046479
45	6.3	0.38221	0.0103992
45	8.4	0.50763	0.0183426
45	10.5	0.63138	0.0283712
60	2.1	0.12151	0.0010658

60	4.2	0.24262	0.0042491
60	6.3	0.36293	0.0095070
60	8.4	0.48207	0.0167688
60	10.5	0.59966	0.0259370

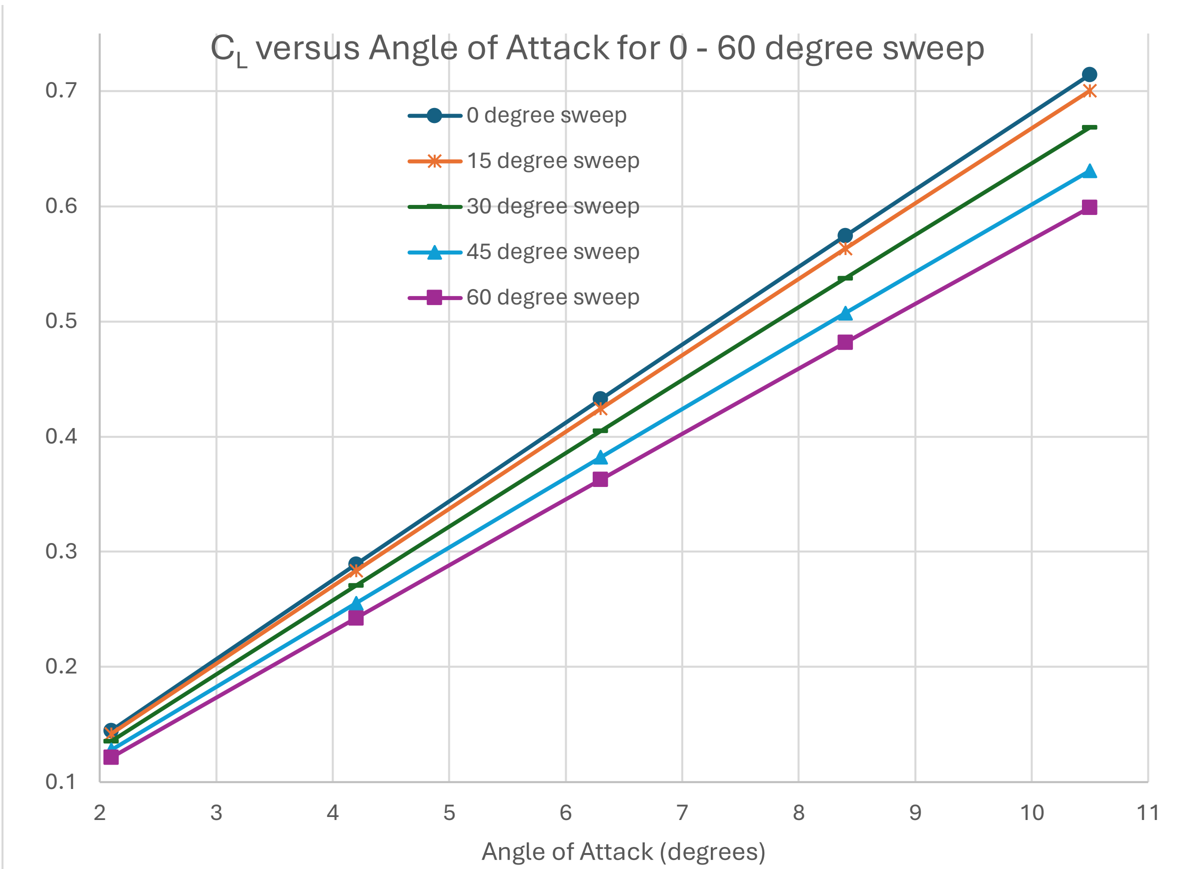

Figure 5: The coefficient of lift over the entire wing with varying angles of attack as well as varying degrees of wing sweep.

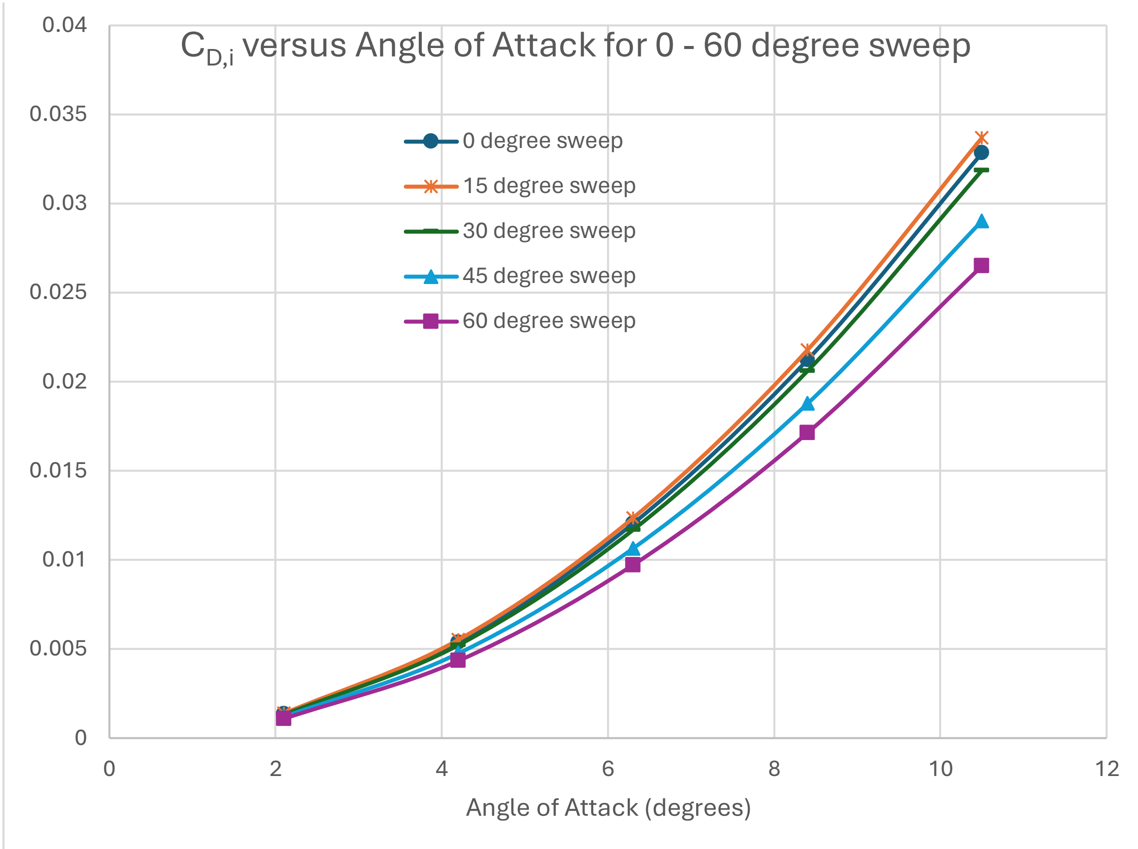

Figure 6: Coefficient of induced drag for the entire wing over varying angles of attack as well as different degrees of wing sweep.

Figure 7 shows that the lift curve slope of the AVL-generated data is similar to wind tunnel data by Weber & Brebner [2] but not exactly the same. Figure 8 also shows that the data is not exactly the same between the AVL simulation and Weber & Brebner's wind tunnel data, but the trend is similar.

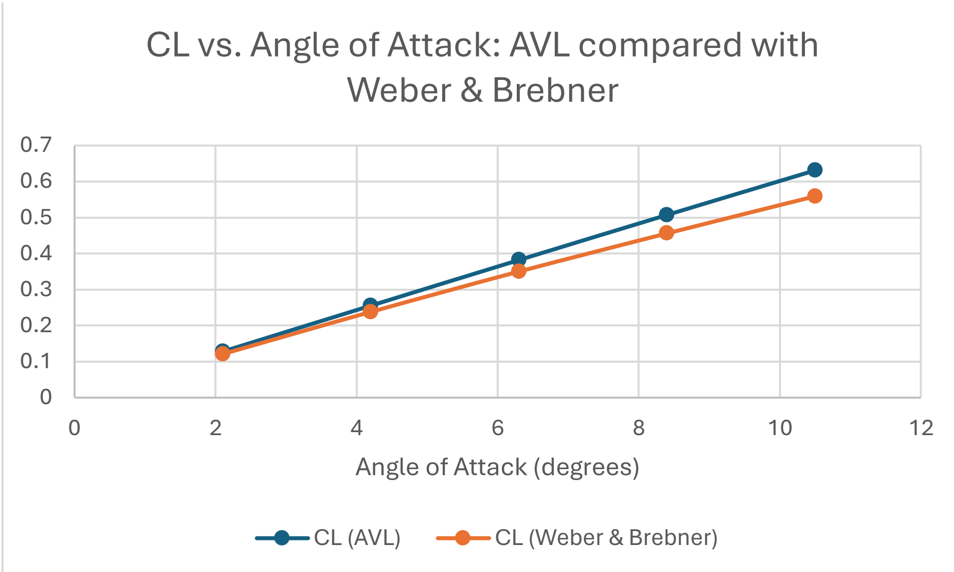

Figure 7: Comparison of coefficient of lift at different angles of attack for a 45-degree swept wing between the data computed with AVL and the data acquired by Weber & Brebner.

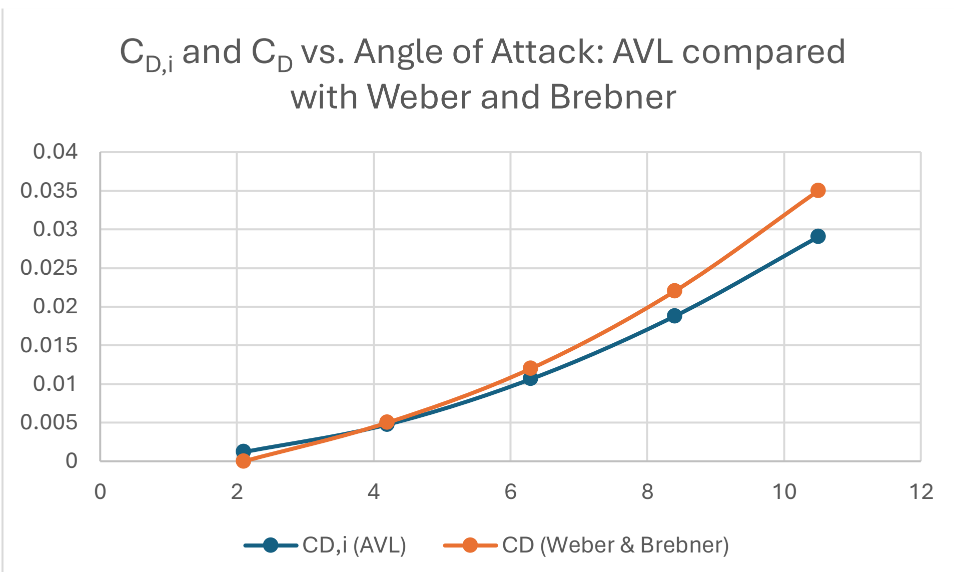

Figure 8: Comparison of coefficient of induced drag at different angles of attack for a 45-degree swept wing between the data computed with AVL and the data acquired by Weber & Brebner.

Lastly, there is a curve fit by DATCOM [5] using the equation in Figure 10 for calculating lift-curve slope. Figure 9 compares the AVL data to the DATCOM data, and shows that the AVL simulation data most closely matches at a sweep angle of 45 degrees, but shows slight differences at all other sweep angles including a sweep angle of 0 degrees.

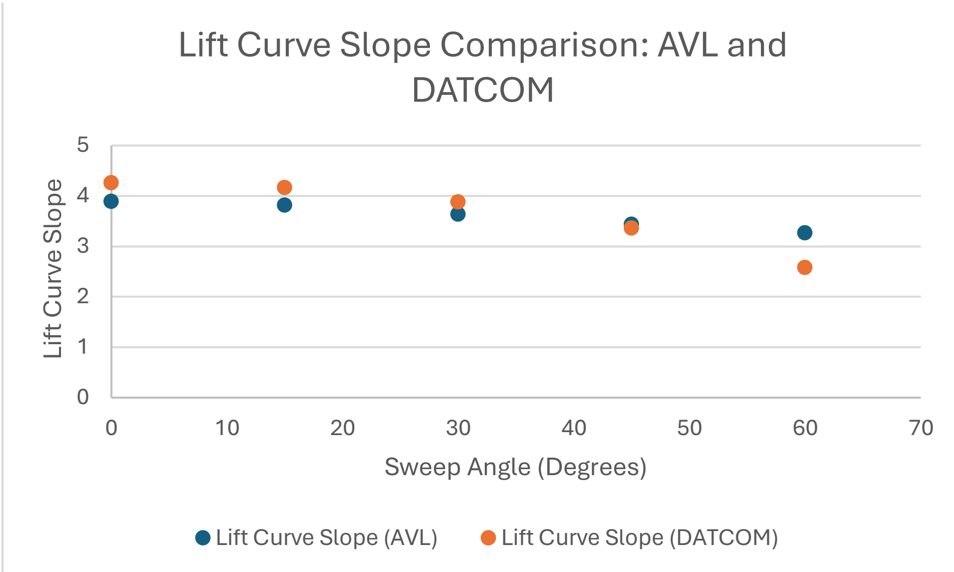

Figure 9: A comparison between the lift-curve slopes using the equation provided by DATCOM and the simulation done by AVL.

$$a = \frac{2\pi AR}{2 + \sqrt{\frac{AR^2(1-M^2)}{k^2}\left[1 + \frac{\tan^2 \Lambda_{1/2}}{(1-M^2)}\right] + 4}}$$

Figure 10: The equation for calculating lift-curve slope provided by DATCOM. AR is aspect ratio, L is the sweep angle (radians), M is the Mach number (modelled at 0) and k is the taper ratio (modelled at 1).

Discussion

As Figure 5 clearly shows, the further the wings are swept back, there is less and less lift generated. This makes sense because with a swept wing, the freestream velocity is coming in at an angle with respect to the chord (x). Since the air does not flow directly along the chord, I propose that the effectiveness of the airfoil geometry in producing lift is reduced.

Figure 6 is less of a linear relation, but still distinctly show that as sweep angle increases, coefficient of induced drag decreases. Because induced drag is caused by downwash, one can perhaps conclude from Figure 6 that sweeping the wings backward reduces the effect of downwash.

In comparing AVL-simulated data to Weber & Brebner's data from 1958, the computational values are very close, but in both cases of lift and drag, seem to increase at a greater rate. This suggests there are more factors influencing lift than what is calculated with the limited parameters provided to AVL. Perhaps Weber & Brebner were seeing the results of some viscous effects that increased the drag and lowered the coefficient of lift.

Lastly, in comparing AVL-simulated data to DATCOM data in Figure 9, there are major discrepancies with the lift-curve slope, especially in the 0 and 60-degree sweep regime, which I cannot comment on with my scope of knowledge.

Conclusion

Induced drag is a non-negligible effect, however there are many different ways to model it, none of which entirely represent reality. One must also be extremely careful about one's assumptions: for example, this model does not work for faster speeds (transonic, sonic, and supersonic) because it assumes incompressible flow. If anything, I have learned that empirical data for the most part is the most useful in representing the behavior of various airfoils under certain conditions. I feel that I have a lot to owe to the scientists like Weber and Brebner who spent decades modeling and testing these airfoils.

References

[1] Prandtl L (1921) Applications of modern hydrodynamics to aeronautics, NACA Report No 116 (Washington, DC).

[2] Weber J. and Brebner G., "Low-Speed Tests on 45-Deg Swept-Back Wings, Part I," Ministry of Supply Aeronautical Research Council TR 2882, May 1958.

[3] ANDERSON, JR., John D., 2001, Fundamentals of Aerodynamics, 3th Edition, McGraw-Hill,New York, 892 p.

[4] AVL (mit.edu)

[5] USAF Digital Datcom (pdas.com)