Finding the Aerodynamic Coefficients using AVL

For my final project I used a program developed by Mark Drela and Harold Youngren from MIT to calculate the aerodynamic coefficients of two small fixed wing aircraft, namely a Pelican and Zagi model. Athena Vortex Lattice (AVL) is designed to be used on wing designs that are thin and are subject to small angles of attack. The program breaks up a specified lifting surface into discretized sections both spanwise and chordwise. The program then applies horseshoe vortex calculations across these sections. AVL also has the capability of modeling slender fuselages, though they are not required to calculate the plane's various parameters.

To begin my project, I first measured both plane's physical dimensions which are listed below in table 1. A note on the values: AVL doesn't care about the units, just as long as you are consistent with the magnitudes.

Parameter	Pelican (m)	Zagi (in)
S	.1892 (m^2)	225.87 (in^2)
b	.86	47
Root Chord	.22	15
Tip Chord	.22	5.5
MAC	.22	9.75
Center of Gravity	.185	9.6
Sweep	0	17.5
Horizontal Tail		-----
Length	.35	
Chord	.130	
Vertical tail		------
Root Chord	.23	
Tip Chord	.120	

Table 1

Figure 2 -- Zagi model

Figure 1 -- Pelican from CrashTestHobbies.com

In calculating the parameters for the Zagi model, I found the web app shown in Figure 3 to be extremely convenient. A link to the page is given in the Appendix.

AVL requires only one file to run, however, three types of input files are accepted for performing tests. The first, and only required file, is the physical geometry as described in an x, y, z coordinate frame. Instead of a north, east, down configuration, the axis reflects a downstream, right wing, up position. The second file describes the mass and inertia distribution while the third input file is a run case where you can initialize different test conditions rather than inserting them into the running program. The proper text file format is given in the documentation available online through the link given in the Appendix. For my tests, I only ran AVL with the geometry file which allowed me to calculate the aerodynamic coefficients. With the mass distribution, you can run an Eigenmode analysis to gain further information on the aircrafts design.

When inputting the geometric values, you need to supply a data point set describing the camber of the airfoil. The University of Iowa has made available an extensive online database with short descriptions of the general use of each airfoil listed. I found by trial and error that AVL requires that these points be in a trailing-to-leading-to-trailing orientation to be drawn correctly in the geometry

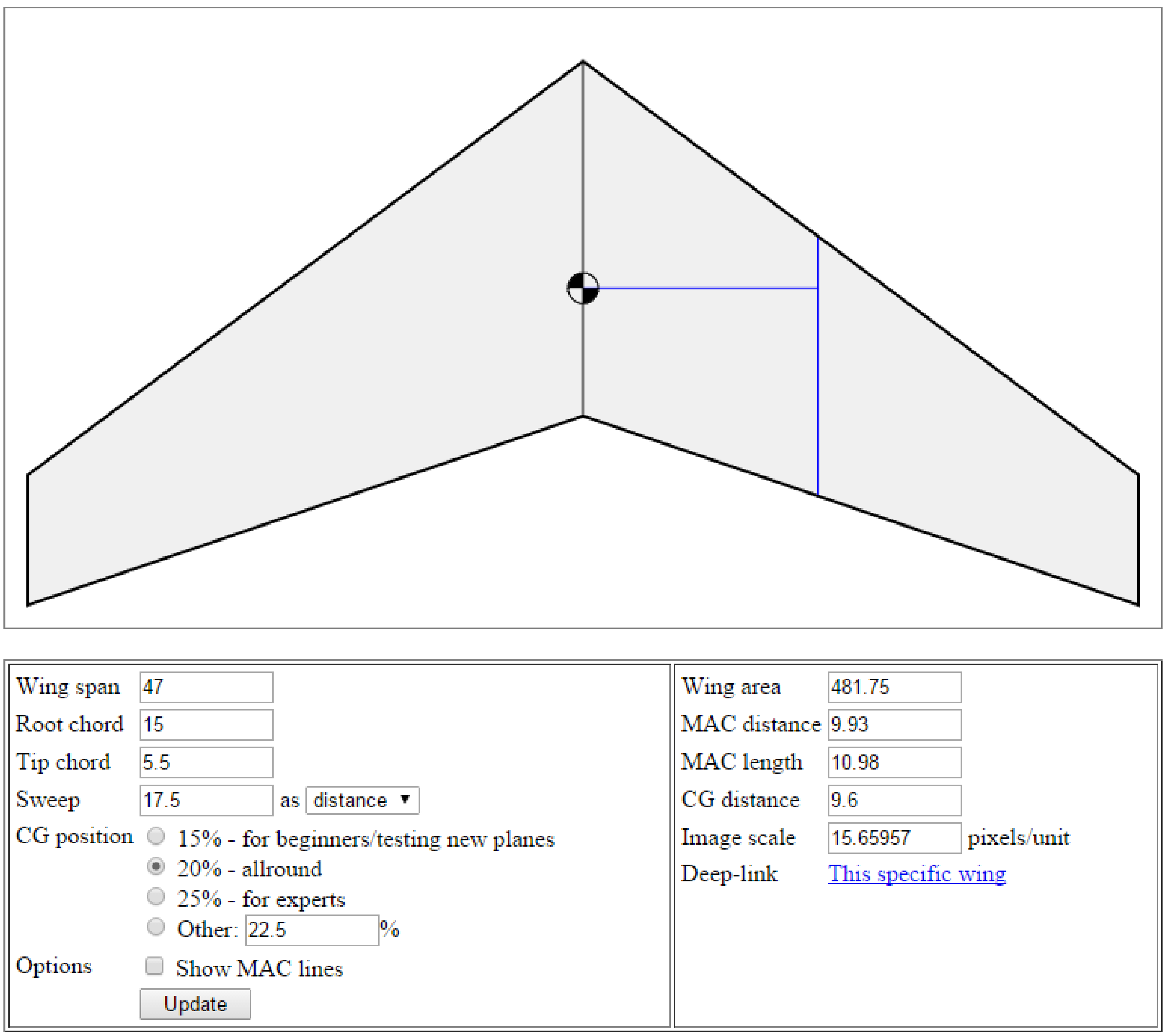

Figure 3 -- Online app for designing Zagi type model planes

viewer. You can check to make sure the orientation is correct by activating the camber lines ("CA" command) while in the geometry viewer. Figure 4 shows a profile of the camber lines.

Once the geometry is loaded into AVL, you can begin tests by typing "OPER". Type "x" to run an initial test with test conditions all set to zero. Test conditions include elements such as control surface angles of deflection, angle of attack or sideslip, and various other parameters. Once the calculations are done, typing "g", then "lo" will show the loading on the lift surfaces. An example is shown in Figures 5 and 8. The leading edge can be seen to provide a negative load, whereas the rest of wing area provides a positive load producing lift. In Figure 6, the angle of attack was changed to 3 degrees and the calculations were run again by typing "x". The leading edge has significantly reduced negative load while the winglets provide a lateral load toward the center of the plane, adding stability. It can also be seen that a positive load is applied to elevons.

Running the calculations again with the angle of attack set back to zero and then typing "st" will show the stability derivatives. These can be printed to a file, or directly onto the terminal. Both the Zagi's and the Pelican's data are presented below. Figures 7 through 9 show the same run settings as the Zagi, but for the Pelican.

This AVL program has some learning curve to it, but proves to be extremely useful once the format is figured out. I was able to find a paper done by a group in Australia that compared AVL results to actual wind tunnel testing of their small airframe. In the paper's results, they showed that AVL is more accurate than a full 3-d panel derived calculation program called PanAir. I feel that AVL will be a good addition to the research going on not only in the 674 class, but in the MAGICC lab as well. I was only able to explore a few of the capabilities of this program, but I hope future students of the class can learn more from it.

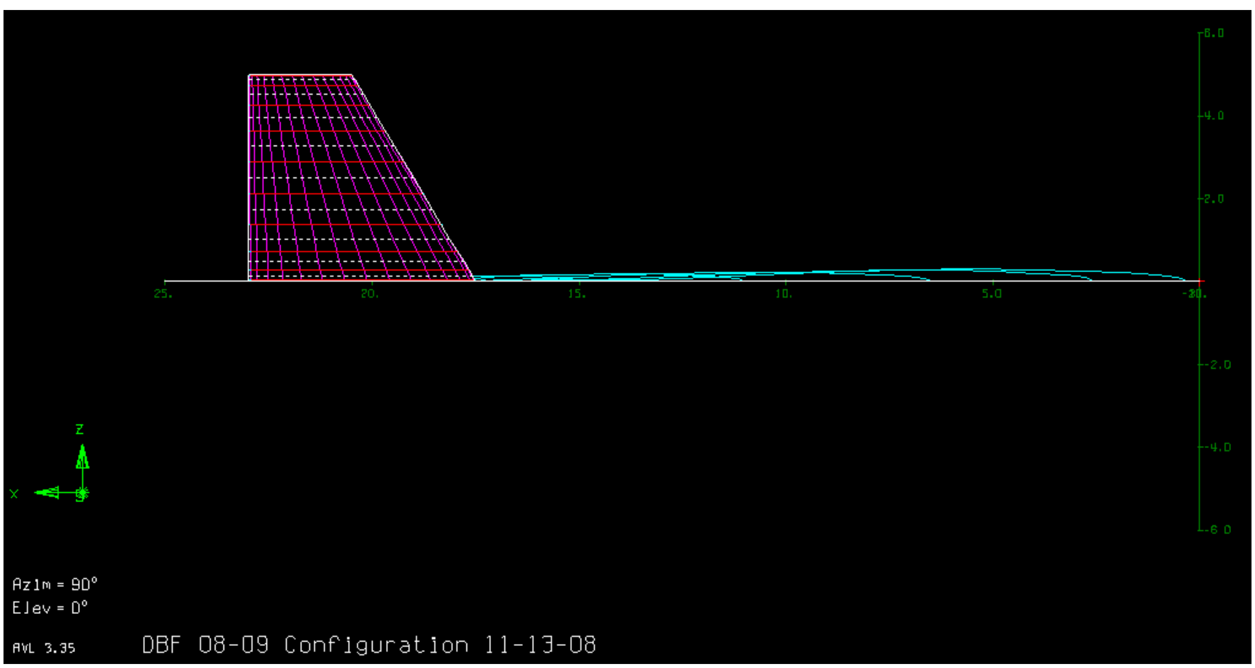

Figure 4 -- Correct orientation of camber data points

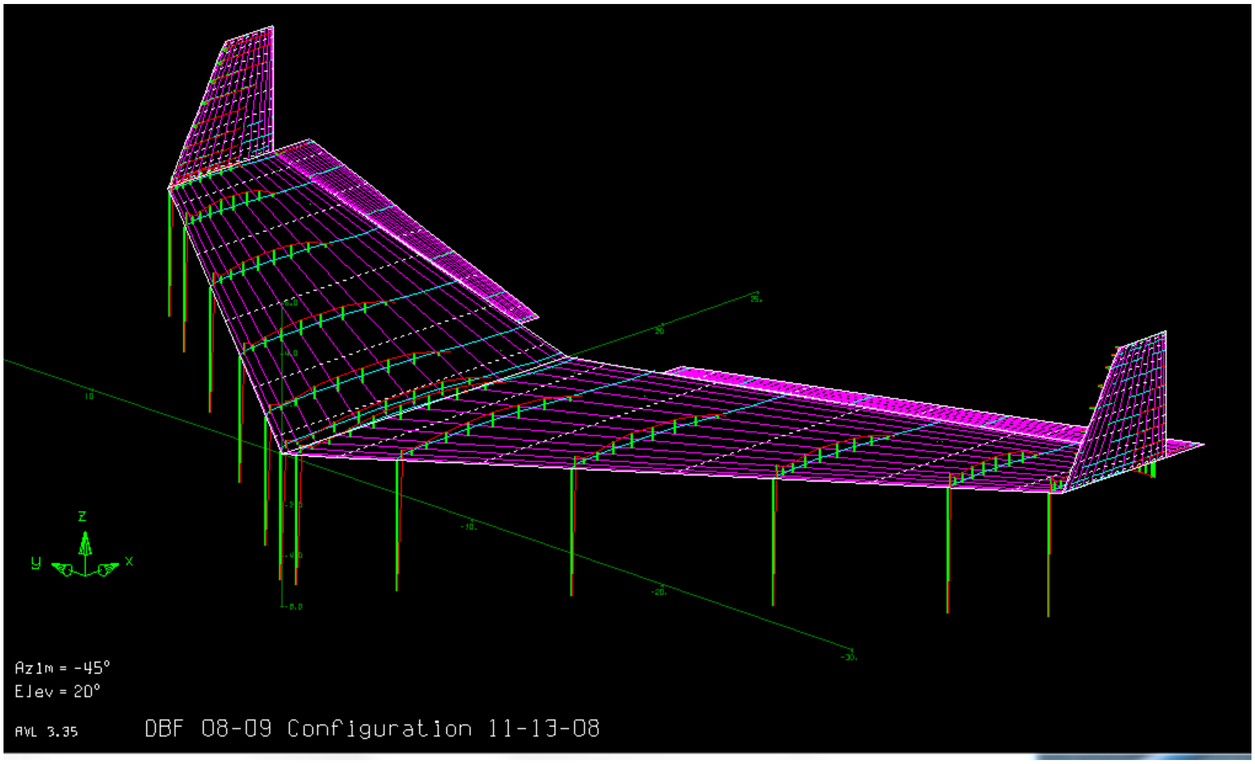

Figure 5 -- Zero angle of attack loading on the wings

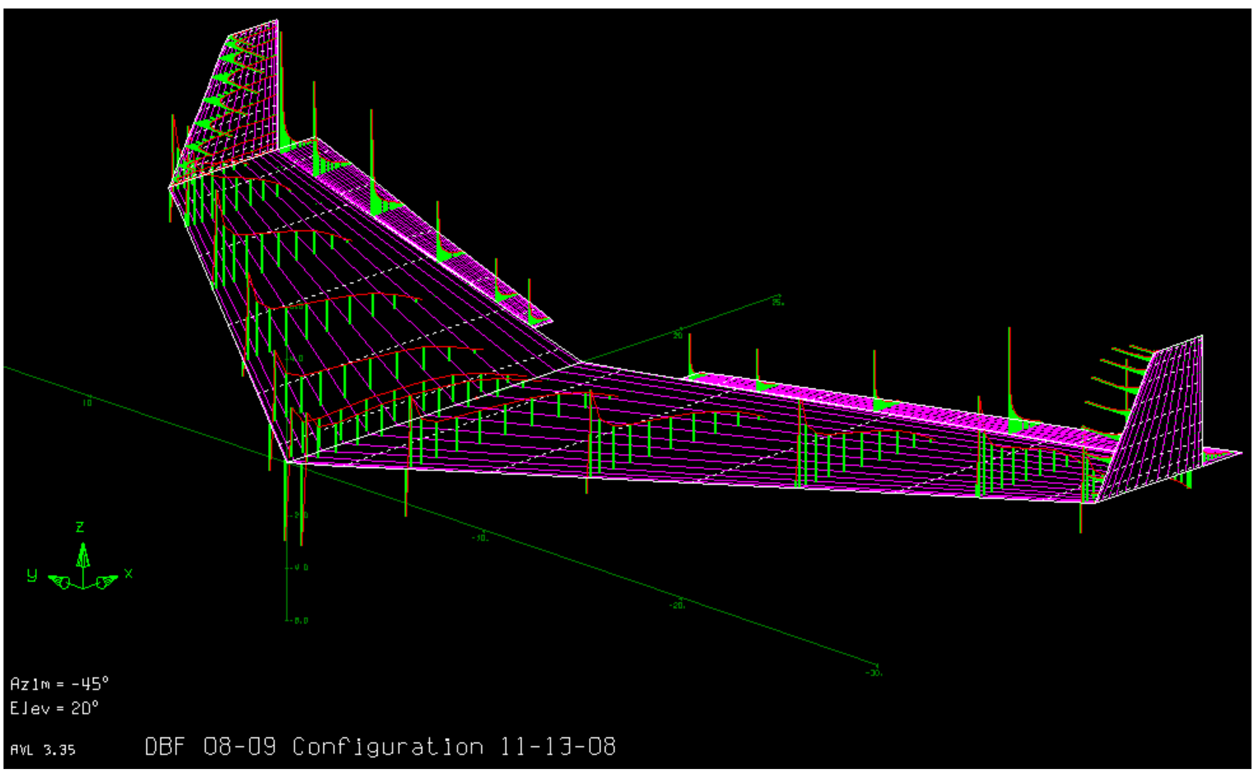

Figure 6 – 3 degree angle of attack loading on the wings

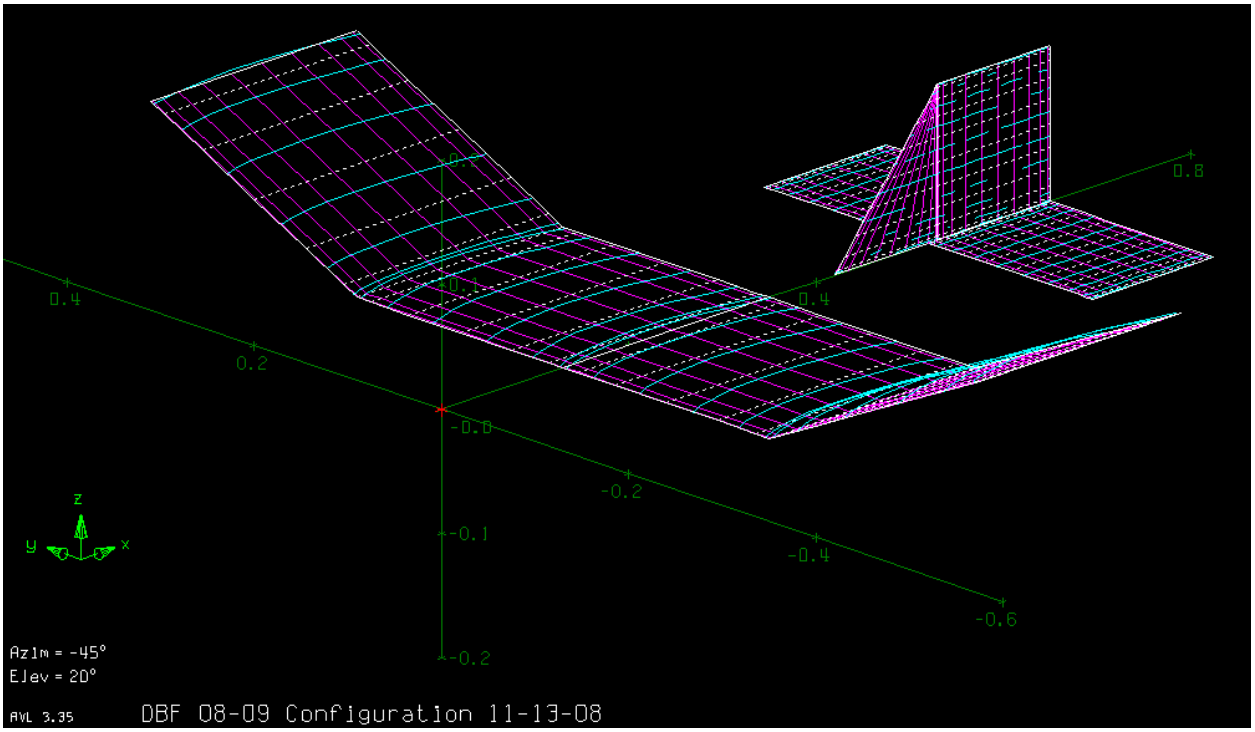

Figure 7 -- Pelican Geometry plot

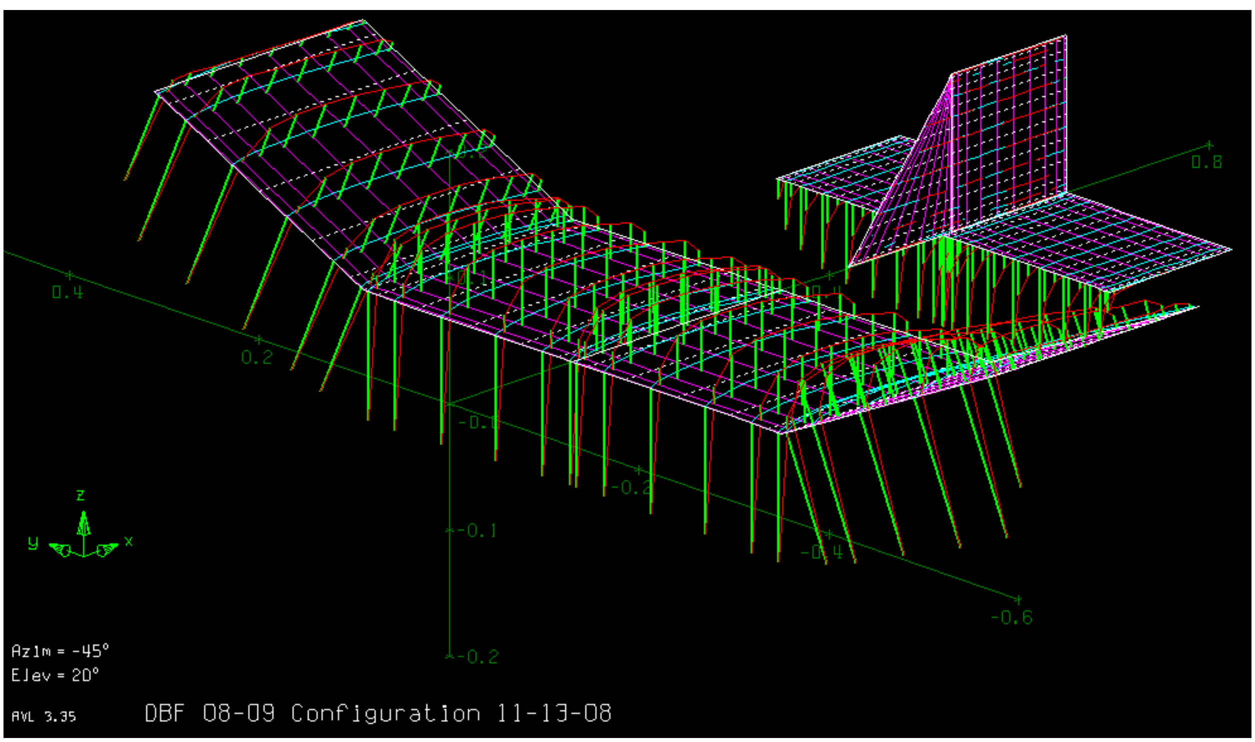

Figure 8 -- Zero angle of attack loading on the wings

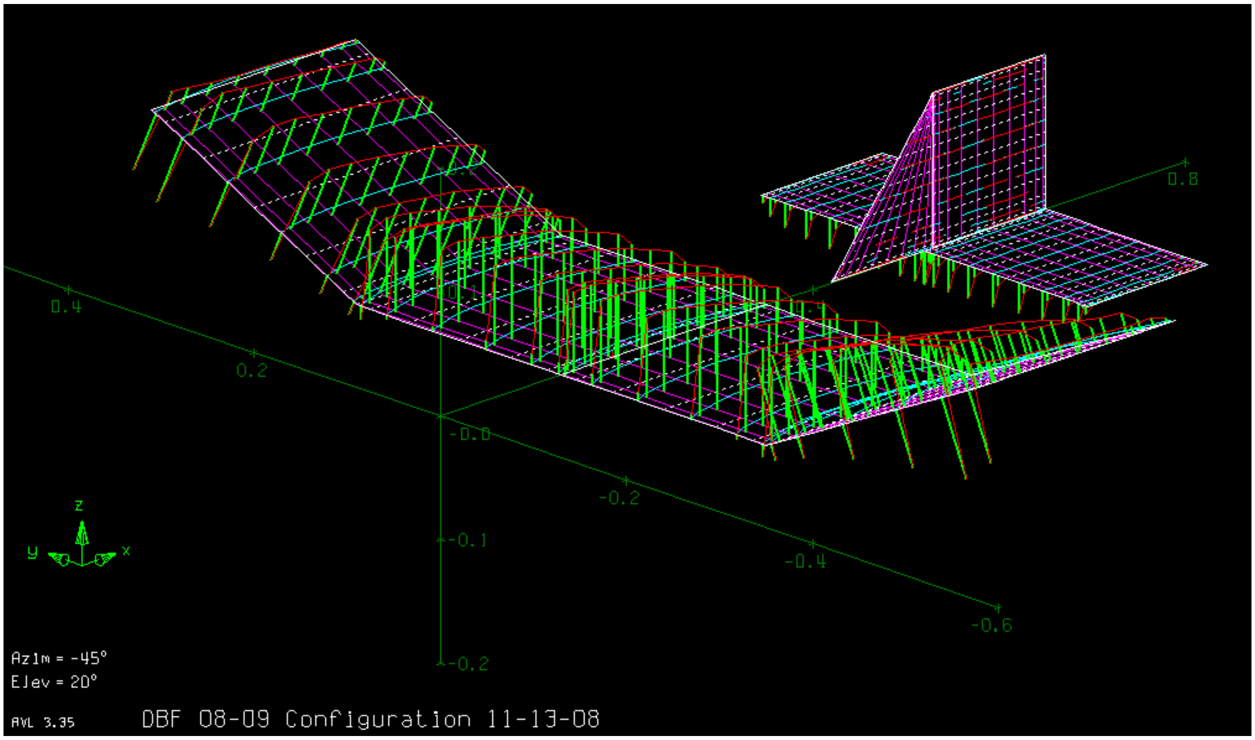

Figure 1 -- 3 degree angle of attack loading on wings

Summary of results

An important note: According to the tutorial, AVL calculates each stability derivative in terms of per radian, however the control surface derivatives are in per degree. The values given in the tables below are converted to radians as is required in the equations calculated in the class book (top of page 45). Additional confirmation of the values for the control derivatives should be made. The values for C_{D_α} and C_{D_q} were not directly available through AVL that I could tell and I could not find a reliable method for calculating them. Also, the values for the pelican's $C_{Y_{\delta_r}}$ and $C_{l_{\delta_r}}$ seem to me to be incorrect, however, I could not find the source of the problem.

Parameters for a Zagi flying wing

Longitudinal Coef.	Value	Lateral Coef.	Value
C_{L_0}	0.03677	C_{Y_0}	0
C_{D_0}	0.00023	C_{l_0}	0
C_{m_0}	0.01494	C_{n_0}	0
C_{L_α}	8.5664667	C_{Y_β}	-0.313003
C_{D_α}		C_{l_β}	-0.073745
C_{m_α}	-1.344343	C_{n_β}	0.067539
C_{L_q}	12.109495	C_{Y_p}	-0.096733
C_{D_q}		C_{l_p}	-0.880695
C_{m_q}	-6.035727	C_{n_p}	0.019766
$C_{L_{\delta_e}}$	1.50029	C_{Y_r}	0.170065
$C_{D_{\delta_e}}$	0.0328305	C_{l_r}	0.042363
$C_{m_{\delta_e}}$	-1.321928	C_{n_r}	-0.037605
		$C_{Y_{\delta_a}}$	-0.022173
		$C_{l_{\delta_a}}$	-0.392418
		$C_{n_{\delta_a}}$	0.005156

Parameters for a Pelican

Longitudinal Coef.	Value	Lateral Coef.	Value
C_{L_0}	0.2584	C_{Y_0}	0
C_{D_0}	0.00572	C_{l_0}	0
C_{m_0}	-0.04195	C_{n_0}	0
C_{L_α}	4.133332	C_{Y_β}	-0.310058
C_{D_α}		C_{l_β}	-0.219796
C_{m_α}	-0.527943	C_{n_β}	0.036787
C_{L_q}	6.567588	C_{Y_p}	-0.301672
C_{D_q}		C_{l_p}	-0.398326
C_{m_q}	-4.706846	C_{n_p}	-0.025965
$C_{L_{\delta_e}}$	0.594902	C_{Y_r}	0.25436
$C_{D_{\delta_e}}$	0.192857	C_{l_r}	0.138131
$C_{m_{\delta_e}}$	-0.951053	C_{n_r}	-0.06322
		$C_{Y_{\delta_r}}$	0
		$C_{l_{\delta_r}}$	0

Appendix

MIT AVL main page

http://web.mit.edu/drela/Public/web/avl/

AVL User guide

http://web.mit.edu/drela/Public/web/avl/avl_doc.txt

University of Iowa airfoil database

http://m-selig.ae.illinois.edu/ads/coord_database.html#E

Flight labs descriptions of Axes and Derivatives

http://www.flightlab.net/Flightlab.net/Download_Course_Notes_files/1_%20AxesDerivatives.pdf

ICAS paper

http://www.icas.org/ICAS_ARCHIVE/ICAS2012/PAPERS/675.PDF