MAE 5510 : Glider Project

I. Introduction

You have been entered in the 2024 Dynamics of Atmospheric Flight Glider Competition! The goal of this competition is to design a virtual glider that maximizes range during a simulated flight. You will first walk through a simple design and perform static and dynamic analyses on a baseline glider. This will allow you to make sure your analysis is set up correctly. You will then use these tools to design your own glider for the competition. The following is a list of guidelines for the design and flight of your glider.

A. Materials

Your glider must be virtually designed from the following materials:

- 9 ft^2 sheet of EPS foam of thickness large enough for your airfoil
- 6 feet of carbon-fiber tubing (3/4 inch outer diameter, 9/16 inch inner diameter) to act as a fuselage
- 1 tungsten washer ballast (3/4 inch inner diameter; outer diameter and thickness determined by need)
- Glue of the same density and strength as the EPS foam

B. Design Requirements

Your glider must be designed within the following constraints and requirements:

- All lifting surfaces must use NACA 2412 or NACA 0012 airfoils.
- The root quarter chord of the main wing must be located at the origin of the coordinate system.
- All lifting-surfaces must connect to the fuselage at the root quarter-chord of the lifting surface.
- All lifting surface sections must be able to be formed using a hot-wire technique (constant sweep and dihedral, linear variation of twist and chord), though each lifting surface may consist of multiple sections.
- The main wing and horizontal stabilizer surfaces must have aspect ratios that satisfy the following relation to ensure that the bending moments within the wings stay within the strength of the EPS foam:

$$R_A \leq \frac{16(t_{max}/c)\sigma_{max}W_w}{21W_f b\gamma} \tag{1}$$

  where W_w is the wing weight, W_f is the fuselage weight (dowel + ballast), and the parameters σ_{max} and γ are given EPS foam structural parameters.
- The tungsten ballast must be positioned along the fuselage dowel such that it does not extend past the end of the dowel.
- No control surfaces are allowed.

C. Launch Conditions

Your glider will be launched

- from a platform 50 ft above the ground in Logan, Utah (about 5,000 ft above sea level)
- at 0 deg fuselage angle of attack and 0 deg elevation angle
- with a kinetic energy of your choosing up to 20 ft-lbf

D. Useful Relations and Equations

1. Airfoil Properties

The airfoil properties for the two airfoils allowed on the glider are

Coefficient	NACA 0012	NACA 2412
α_{L0} [rad]	0.0	-0.0455
$\tilde{C}_{L,\alpha}$	6.118	5.736
$\tilde{C}_{m,L0}$	0.0	-0.0388
$\tilde{C}_{m,\alpha}$	0.0	-0.08
$\tilde{C}_{D0}$	0.0058	0.0064
$\tilde{C}_{D1}$	0.0	-0.0021
$\tilde{C}_{D2}$	0.0059	0.0062
$\tilde{C}_{L\max}$	1.2	1.4

2. Material Properties

The construction materials have the following properties:

- EPS foam density: 0.025 slug/ft^3
- EPS foam max stress (σ_{max}): 7,200 lbf/ft^2
- EPS foam specific weight (γ): 0.804 lbf/ft^3
- Carbon Fiber density: 0.75 slug/ft^3
- Tungsten density: 37.3 slug/ft^3

3. Atmospheric Properties

At the launch altitude of 5,000 ft, the atmospheric properties can be estimated as

- density (ρ): 0.0020482 slug/ft^3
- dynamic viscosity (μ): 3.6366e-7 slug/(ft-s)

4. Energy and Velocity

The glider's launch velocity V in ft/s is related to the glider's total weight W in lbf and kinetic energy E_k in ft-lbf according to

$$V = \sqrt{2E_k g/W} \tag{2}$$

where g is the gravity (32.174 ft/s^2).

5. Mass and Weight

The mass of an object in slugs is the density of the object (slug/ft^3) multiplied by the volume of the object in ft^3. The weight of the object in lbf is the mass in slugs multiplied by gravity (32.174 ft/s^2).

6. Mass and Inertia

The inertia for the glider will be calculated using MachUp 6. A writeup about the equations used in MachUp 6 can be found here.

7. Drag of Fuselage

The drag of the entire glider can be estimated by adding the drag from the lifting surfaces to estimates for the drag from the carbon-fiber tubing and tungsten ballast. As an estimate in this project, we will assume that the drag from the tubing and ballast are independent, and can each be estimated from known relations for drag on a closed cylinder with an axis aligned with the flow.

The drag from a closed cylinder aligned with the flow can be estimated from two main components: 1) frontal area drag due to the blunt ends of the cylinder, and 2) skin-friction drag on the side of the cylinder. For a cylinder with radius R and length L, the frontal or cross-sectional area of the cylinder is

$$A_f = \pi R^2 \tag{3}$$

and the surface area along the side of the cylinder is

$$A_s = 2\pi RL \tag{4}$$

The drag due to frontal area of a cylinder can be estimated from

$$D_f = \frac{1.12}{2}\rho V^2 A_f \tag{5}$$

The drag due to skin-friction along the side of the cylinder can be estimated from

$$D_s = 1.15 C_f \frac{1}{2}\rho V^2 A_s \tag{6}$$

where C_f is the skin-friction coefficient. Assuming the flow is turbulent due to the blunt nose of the cylinder, the skin friction can be estimated from

$$C_f = \frac{0.455}{(\ln 0.06 R_e)^2} \tag{7}$$

where the Reynolds number based on the total length of the cylinder R_e is computed from the density ρ, velocity V, length L, and dynamic viscosity μ as

$$R_e = \frac{\rho V L}{\mu} \tag{8}$$

The contribution to the aircraft zero-lift drag coefficient C_{D0} from a single cylinder is then

$$(\Delta C_{D0})_{\text{cylinder}} = \frac{1.12 A_f + 1.15 C_f A_s}{S_w} \tag{9}$$

II. Design and Static Analysis

A. Baseline Glider

For the following questions, create your own analysis spreadsheet in Excel or Google Sheets for your calculations, and post your solutions on the Baseline Glider Sheet.

Consider a baseline glider with lifting-surface properties as shown in Table 2. All wings are rectangular with taper ratios $R_T = 1.0$. It uses the full length of carbon tubing, and a tungsten ballast 1/2 inch thick with 1.5 inch outer diameter.

Property	Main Wing	Horizontal Stabilizer	Vertical Stabilizer
airfoil	NACA 2412	NACA 0012	NACA 0012
semispan [ft]	4.5	1.0	1.0
mean chord [ft]	0.75	0.75	0.75
planform area [ft^2]	6.75	1.5	0.75

A1. Create all the components of the glider in MachUp 6, and estimate the weight of the following:
- main wing
- horizontal stabilizer
- vertical stabilizer
- fuselage tube
- ballast
- the complete aircraft

Note that the location of the components does not matter at this point, since we are only interested in estimating the weight of the aircraft at this point.

A2. In your own analysis spreadsheet, add inputs or equations to include the following:
- area of the main wing
- aspect ratio of the main wing
- atmospheric density at launch
- launch velocity if the glider is launched with a kinetic energy of 20 ft-lbf
- lift coefficient at launch

A3. In your own spreadsheet, add a computation to ensure the structural integrity of the main wing. Recall that the weight of the fuselage is the combination of the dowel and ballast weights.

A4. Based on an estimate for the total weight of your aircraft, use what you know about the glide ratio to compute the velocity that will maximize the no-wind glide ratio for your glider. Assume an Oswald efficiency of $e = 0.8$ and a zero-lift drag coefficient of $C_{D0} = 0.013$. Compute the corresponding lift coefficient at that speed. This will be our design speed and design lift coefficient.

A5. Create the main wing using MachUp 6, including the section airfoil information.

A6. To maximize efficiency, we wish to mount this wing relative to the fuselage so that it provides all the lift at the trim condition and requires no lift on the horizontal stabilizer to trim the aircraft. Using MachUp 6, find the mounting angle of the main wing such that the main wing will be at the design lift coefficient with zero angle of attack. You may find the "Target CL" run command to be useful in this process.

A7. In order for the aircraft to be trim using only the lift on the main wing, the wing must be placed relative to the center of gravity such that there is zero pitching moment about the center of gravity. We cannot move the main wing, but we can move the center of gravity at this point in the design process. We will control the center of gravity location later in the design process by moving the tungsten ballast to the location that gives us our desired center of gravity. Using MachUp 6, find the x location of the center of gravity such that the aircraft will be trim at the design lift coefficient with zero angle of attack.

A8. Create the horizontal stabilizer using MachUp 6, including the section airfoil information. Deselect "Main Wing" for the horizontal stabilizer surface so its area is not included in your main wing reference area. Be sure the name for each lifting surface is unique. Place the horizontal stabilizer such that the glider has a static margin of $\sigma = 20.0\%$. You may find the "Performance Derivatives" run command to be useful.

A9. Create the vertical stabilizer using MachUp 6, including the section airfoil information. **If your vertical stabilizer is set to "Both" the solver will hang and not be able to produce a solution.** Deselect "Main Wing" for the vertical stabilizer surface so its area is not included in your main wing reference area. Be sure the name for each lifting surface is unique. Place the vertical stabilizer such that the glider has a yaw-stability derivative of $C_{n,\beta} = 0.10$. You may find the "Performance Derivatives" run command to be useful.

A10. Add dihedral to the main wing until the glider has a roll-stability derivative of $C_{\ell,\beta} = -0.15$. This is higher than most aircraft, but we wish our aircraft to be very stable in roll to avoid a spiral mode.

A11. Using MachUp, Find the mounting angle of the horizontal stabilizer such that the aircraft is trim in pitch at zero degrees angle of attack (i.e. $C_m = 0$).

A12. Add the dowel as a cylinder to your model in MachUp. Locate the dowel such that the aft end is coincident with the quarter-chord of the lifting surface that is furthest aft.

A13. Add the ballast to your model in MachUp. Find the location of the ballast that results in the same x-location for center of gravity computed in problem A7.

A14. Using the drag approximations for cylinders given in D.6, estimate ΔC_{D0} for the dowel and ballast.

A15. For this finalized configuration, compute the following at zero degrees angle of attack: C_L, C_D (remember to add in the cylinder drag), C_m, $C_{L,\alpha}$, $C_{m,\alpha}$, $C_{Y,\beta}$, $C_{\ell,\beta}$, $C_{n,\beta}$, and the static margin σ.

A16. Because the glider is stable in pitch, it will seek the angle of attack and velocity that satisfy trim. Assuming the glider flies at exactly zero degrees angle of attack, estimate the zero-wind glide ratio and distance this glider would travel starting from a height above ground of 50 ft.

A17. Use MachUp to compute the lift and drag coefficients as a function of angle of attack from −5 degrees to +5 degrees in increments of 5 degrees. Plot total drag coefficient (including the cylinder drag) as a function of lift coefficient. Compute the three drag coefficients C_{D0}, C_{D1}, and C_{D2} that describe the drag of the entire aircraft as a function of lift in the equation

$$C_D = C_{D0} + C_{D1} C_L + C_{D2} C_L^2 \tag{10}$$

Compute the Oswald Efficiency for your aircraft from C_{D2}.

A18. Use MachUp to compute the following as a function of angle of attack from −6 degrees to +14 degrees in increments of 2 degrees and fill your data in the group's tab of the Baseline Glider Sheet.

- C_L
- C_D
- C_m
- L/D
- Velocity [ft/s] required for the lift to be equal to the weight at the angle of attack of interest

- Drag [lbf]
- Required Power [ft-lbf/s]
- Static Margin
- No-Wind Glide Ratio
- Sink Rate [ft/s]
- Pitch, Roll, and Yaw stability derivatives

A19. Plot the following as a function of velocity from the data computed for Problem A18.
- C_L
- C_D
- C_m
- L/D
- Drag [lbf]
- Required Power [ft-lbf/s]
- Static Margin
- No-Wind Glide Ratio
- Sink Rate [ft/s]
- Pitch, Roll, and Yaw stability derivatives

A20. Compute the stall speed (V_{min}), minimum drag airspeed (V_{MD}), and minimum power airspeed (V_{MDV}). You may use the "Stall Onset" function in MachUp 6 to find the maximum lift coefficient of your aircraft.

A21. Plot the locus of aerodynamic centers for your aircraft as a function of angle of attack from the data computed for Problem A18.

B. Your Glider Design

You will now design your own glider within the constraints listed in the Introduction. Your glider must travel further than the baseline glider to get full credit on the project. Here are a few ideas for improving the glider design:

- We designed the baseline glider to have a specific CG location. We create that CG location by choosing the size and location of the ballast. The weight of the ballast can be decreased by increasing the moment arm of the ballast relative to the CG location. Decreasing the ballast weight will decrease overall aircraft weight and drag.
- Increase the aspect ratio of your wing to decrease drag until it hits the structural limit. The aspect ratio can increase as the weight of the glider decreases.
- You may want to trim your aircraft to fly at max L/D velocity.
- You may be able to further decrease drag by changing the taper ratio and twist of the main wing.
- For an example of optimizing the baseline glider performance, see this video.

Once you have designed your glider, create a new column in this spreadsheet, and enter your glider parameters. Your ID number is your team number or last 4 digits of your A#. Submit the following on Canvas: (name the files with your ID number):
- Image of your glider with roughly a 2x1 aspect ratio (####.jpg)
- Simulator input file for your glider (####.json formatted like this file). You can watch this video for step-by-step instructions if needed.
- MachUp 6 file for your glider (####.mu)

III. Dynamic Analysis

A. Baseline Glider

For the following questions, create your own spreadsheet for your calculations, and post your solutions on the Baseline Glider Sheet.

A1. Use MachUp 6 to estimate the aircraft moment of inertia about the center of gravity.

A2. Use MachUp 6 to compute the following damping derivatives for the baseline glider at zero degrees angle of attack:
- $C_{Y,\bar{p}}$, $C_{\ell,\bar{p}}$, $C_{n,\bar{p}}$
- $C_{L,\bar{q}}$, $C_{D,\bar{q}}$, $C_{m,\bar{q}}$
- $C_{Y,\bar{r}}$, $C_{\ell,\bar{r}}$, $C_{n,\bar{r}}$

A3. Estimate $C_{L,\hat{\alpha}}$ and $C_{m,\hat{\alpha}}$ from the geometry of the aircraft and Eq. (7.7.9) in the textbook.

A4. From the results of Part A and the previous three problems, we now have sufficient information to create a .json file for the baseline glider of the form 0000.json available here. Download this file and use it for the following problems.

A5. Using the Python programming language, write a computer code to find the eigenvalues and eigenvectors of the linearized longitudinal equations of motion. Use the reference lift coefficient, operating weight, and density to compute the equilibrium velocity. Note that you will also need to compute values for C_{Do} and $C_{D,\alpha}$ from the information included in the input .json file. For these computations you may want to review Eqs. (10.48) and (10.59) in the Handbook. Test the code using the information for the baseline glider given in B4. Compare your [A] and [B] matrices as well as the resulting eigenvalues and eigenvectors to the results available here. These results were obtained using $g = 32.17$ ft/s^2. Make sure your program provides the following outputs:
- The dimensionless eigenvalues
- The dimensionless eigenvectors
- The amplitude and phase for each component of the eigenvectors
- The damping rate [1/sec]
- The 99% damping time for convergent modes [sec]
- The doubling time for divergent modes [sec]
- The damped natural frequency [rad/sec], if appropriate.
- The period, if appropriate [sec]

A6. From your results for problem B5, compute the following:
- Short Period Damping Rate [1/sec]
- Short Period 99% Damping Time [sec]
- Short Period Damped Frequency [rad/sec]
- Short Period Period [sec]
- Phugoid Damping Rate [1/sec]
- Phugoid 99% Damping Time [sec]
- Phugoid Damped Frequency [rad/sec]
- Phugoid Period [sec]

A7. Using the Python programming language, write a computer code to find the eigenvalues and eigenvectors of the linearized lateral equations of motion. Test the code using the information for the baseline glider given in B4. Use the reference lift coefficient, operating weight, and density to compute the equilibrium velocity. Compare your [A] and [B] matrices as well as the resulting eigenvalues and eigenvectors to the results available here. These results were obtained using $g = 32.17$ ft/s^2. Make sure your program provides the following outputs:
- The dimensionless eigenvalues

- The dimensionless eigenvectors
- The amplitude and phase for each component of the eigenvectors
- The damping rate [1/sec]
- The 99% damping time for convergent modes [sec]
- The doubling time for divergent modes [sec]
- The damped natural frequency [rad/sec], if appropriate
- The period, if appropriate [sec]

A8. From your results for problem B7, compute the following:
- Roll Mode Damping Rate [1/sec]
- Roll Mode 99% Damping Time [sec]
- Spiral Mode Damping Rate [1/sec]
- Spiral Mode 99% Damping Time [sec] if convergent or Time to Double [sec] if divergent
- Dutch Roll Damping Rate [1/sec]
- Dutch Roll 99% Damping Time [sec]
- Dutch Roll Damped Frequency [rad/sec]
- Dutch Roll Period [sec]

A9. Add the short-period approximation given in the Linearized Dynamics overview document to your longitudinal dynamics analysis code. Use this to approximate the following:
- Short Period Damping Rate [1/sec]
- Short Period 99% Damping Time [sec]
- Short Period Damped Frequency [rad/sec]
- Short Period Period [sec]

What percent error is this approximation from the true values resulting from the longitudinal eigenproblem?

A10. Add the phugoid approximation given in the Linearized Dynamics overview document to your longitudinal dynamics analysis code. Use this to approximate the following:
- Phugoid Damping Rate [1/sec]
- Phugoid 99% Damping Time [sec]
- Phugoid Damped Frequency [rad/sec]
- Phugoid Period [sec]

What percent error is this approximation from the true values resulting from the longitudinal eigenproblem?

A11. Add the roll mode approximation given in the Linearized Dynamics overview document to your lateral dynamics analysis code. Use this to approximate the following:
- Roll Mode Damping Rate [1/sec]
- Roll Mode 99% Damping Time [sec]

What percent error is this approximation from the true values resulting from the lateral eigenproblem?

A12. Add the spiral mode approximation given in the Linearized Dynamics overview document to your lateral dynamics analysis code. Use this to approximate the following:
- Spiral Mode Damping Rate [1/sec]
- Spiral Mode 99% Damping Time [sec] if convergent or Time to Double [sec] if divergent

What percent error is this approximation from the true values resulting from the lateral eigenproblem?

A13. Add the Dutch roll approximation given in the Linearized Dynamics overview document to your lateral dynamics analysis code. Use this to approximate the following:
- Dutch Roll Damping Rate [1/sec]
- Dutch Roll 99% Damping Time [sec]
- Dutch Roll Damped Frequency [rad/sec]
- Dutch Roll Period [sec]

What percent error is this approximation from the true values resulting from the lateral eigenproblem?

A14. Plot the **dimensional** eigenvalues of the short period, phugoid, roll, spiral, and dutch roll modes on a single complex-plane plot.

A15. Compute the undamped natural frequency of the short-period mode, and the resulting control anticipation parameter (CAP) for the baseline glider.

A16. Compute the handling qualities for the baseline glider in Category B flight phases for the following
1) Short-Period
2) Phugoid
3) Roll
4) Spiral
5) Dutch Roll

B. Your Glider Design

You may choose to make some modifications to your glider design based on dynamic considerations. Here are a few ideas for improving the glider design:

- We chose an horizontal stabilizer location for the baseline glider that gives a static margin of 20%. You may want to revisit this based on dynamic performance rather than static.
- We chose a vertical stabilizer location for the baseline glider that gives a yaw stability derivative of 0.10. You may want to revisit this based on dynamic performance rather than static.
- We chose dihedral for the baseline glider that gives a roll stability derivative of -0.15. You may want to revisit this based on dynamic performance rather than static.

IV. Final Project: Computer Code and Report

This section outlines what you will submit for your final project.

A. Computer Code

Write a computer program that can be used to solve the 6x6 longitudinal and 6x6 lateral eigenproblems associated with the homogeneous linearized dynamic equations. The program must import all required data from an input file of the same format as the sample file 0000_new.json available here. Using only the data obtained from the input file, the program should fill out the dimensionless matrices needed for the generalized eigenproblem. The program should then use a generalized eigensolver to obtain the eigenvalues and eigenvectors from these matrices. A special eigensolver can be used if the system is first numerically reduced to the special eigenproblem. Be sure that all computations are done in double precision.
The program must include at least the following:

1) The program must import all required data from an input file of the same format as the sample file 0000_new.json.
2) The program must compute and display the dimensionless [A] and [B] matrices for both the longitudinal and lateral dynamics.
3) The program must display the following information, for each dynamic mode, in a clearly labeled manner.
    - The dimensionless eigenvalues.
    - The dimensionless eigenvectors.
    - The amplitude and phase for each component of the eigenvectors.
    - The damping rate.
    - The 99% damping time for convergent modes.
    - The doubling time for divergent modes.
    - The damped natural frequency, if appropriate.
    - The period, if appropriate.
    - The damping ratio for each complex eigenvalues pair.
    - The undamped natural frequency for each complex eigenvalues pair.

B. Report

Use AIAA Conference Paper Format complete with an Abstract and Nomenclature. You can download a Word template from this link. Your report will be used to compare your design to the baseline glider design, and must include the following:

1) An abstract that is a stand-alone overview of the complete project and summarizes what you have learned.
2) A description and technical drawing of your glider including dimensions, wing properties (airfoil, twist, sweep, dihedral, etc.).
3) Mass properties of your glider including total weight, fuselage weight, CG location, ballast dimensions and location, and inertia tensor.
4) A table with the planform area of each lifting surface demonstrating that the total lifting-surface area is within the constraints of the project.
5) A calculation demonstrating that your lifting surfaces are structurally sound.
6) A description of the trim state of your glider including lift coefficient, angle of attack, and trim velocity.
7) A description of your design process for your glider.
8) Plots of the following for both the baseline glider AND your glider design as a function of velocity using data from angles of attack from −10 degrees to +10 degrees in increments no larger than 2 degrees:
    1) C_L
    2) C_D
    3) C_m
    4) L/D
    5) Drag [lbf]
    6) Required Power [ft-lbf/s]
    7) Static Margin
    8) No-Wind Glide Ratio
    9) Sink Rate [ft/s]
    10) Pitch, Roll, and Yaw stability derivatives
9) A plot showing the locus of aerodynamic centers as a function of angle of attack for both the baseline glider AND your glider design
10) The stall speed ($V_{\min}$), minimum drag airspeed (V_{MD}), and minimum power airspeed (V_{MDV}) for both the baseline glider AND your glider design. Include values for parameters needed in these equations.
11) A complex-plane plot showing the following **dimensional** eigenvalues all on the same plot and each mode labeled:
    - short period
    - phugoid
    - roll
    - spiral
    - Dutch roll

    On the same plot, include results for both the baseline glider AND your glider design. Discuss the differences.
12) Computation of the CAP of your glider.
13) A table showing the handling qualities of both glider designs for Category B flight phases. It should be formatted as follows:

Table 1 Handling Qualities of both gliders for Category B flight phases.

Mode	Baseline Glider at Trim (V =?)	New Glider at Trim (V =?)
Short-Period		
Phugoid		
Roll		
Spiral		
Dutch Roll		

14) A conclusions section, which includes lessons learned and recommendations for future changes to the glider.
15) An appendix with a copy of the glider data file used for the dynamic analysis.

16) An appendix with your dynamic stability analysis program code.

Each figure must be referenced and discussed in the text.

C. Final Submission

Submit the following on Canvas (name the files with your team number or last 4 digits of your A#):

- Python code for the linearized dynamic analysis in a single file
- Report in pdf format
- jpg image of your glider with roughly a 2x1 aspect ratio.
- Simulator input file for your glider (formatted like 0000_new.json)
- MachUp file for your glider (.mu)

V. Modifications to Computer Code and Input File

A. Computer Code

The aerodynamic model used in the simulator captures the dependence of the aerodynamic parameters on angle of attack. For the glider without any control surfaces, it can be summarized as

$$C_{L_1} = C_{L_0} + C_{L,\alpha}\alpha \tag{11}$$

$$C_L = C_{L_1} + C_{L,\overline{q}}\overline{q} + C_{L,\hat{\alpha}}\hat{\alpha} \tag{12}$$

$$C_S = C_{S,\beta}\beta + (C_{S,L\overline{p}}C_{L_1} + C_{S,\overline{p}})\overline{p} + C_{S,\overline{r}}\overline{r} \tag{13}$$

$$C_D = C_{D_{L0}} + C_{D,L}C_{L_1} + C_{D,L^2}C_{L_1}^2 + C_{D,S^2}C_S^2 + (C_{D,L^2\overline{q}}C_{L_1}^2 + C_{D,L\overline{q}}C_{L_1} + C_{D,\overline{q}})\overline{q} \tag{14}$$

$$C_\ell = C_{\ell,\beta}\beta + C_{\ell,\overline{p}}\overline{p} + (C_{\ell,L\overline{r}}C_{L_1} + C_{\ell,\overline{r}})\overline{r} \tag{15}$$

$$C_m = C_{m_0} + C_{m,\alpha}\alpha + C_{m,\overline{q}}\overline{q} + C_{m,\hat{\alpha}}\hat{\alpha} \tag{16}$$

$$C_n = C_{n,\beta}\beta + (C_{n,L\overline{p}}C_{L_1} + C_{n,\overline{p}})\overline{p} + C_{n,\overline{r}}\overline{r} \tag{17}$$

This model is useful for predicting the aerodynamics of the aircraft over a range of angles of attack. However, our analysis code is designed to evaluate the dynamics of the aircraft at zero angle of attack, i.e. $C_{L_1} = C_{L_0}$. Whereas most of the coefficients are independent of angle of attack, four of these coefficients depend on angle of attack according to this aerodynamic model. These are $C_{Y,\overline{p}}$, $C_{D,\overline{q}}$, $C_{\ell,\overline{r}}$, and $C_{n,\overline{p}}$. Therefore, rather than simply reading these in and using them directly in our code, we must read in the aerodynamic model information and estimate these coefficients at zero angle of attack. This can be done by changing only four lines in our Linearized Analysis code, one line for each parameter.

For example, the estimate of $C_{Y,\overline{p}}$ can be computed from

$$C_{Y,\overline{p}} = (C_{S,L\overline{p}}C_{L_0} + C_{S,\overline{p}}) \tag{18}$$

In my code, I changed the line of code that originally read

```
CYp = json_vals["aerodynamics"]["CY"]["pbar"]
```

to the following

```
CYp = json_vals["aerodynamics"]["CS"]["Lpbar"]*CLo + json_vals["aerodynamics"]["CS"]["pbar"]
```

B. Input File

The complete aerodynamic and dynamic analysis file for a glider can be generated in MachUp 6 by selecting Analysis -> Simulate Flight -> Update Model. This will produce a .json file that contains all of the information needed for the simulator AND your linearized analysis code with one exception. Your analysis code requires the density at which you wish the analysis to be performed. Hence, after downloading the .json file from MachUp 6, you must add the following before using the file in your own analysis code:

```
"analysis" : {
    "density[slugs/ft^3]" : 0.0020664
},
```

You can see how this is done in the example 0000_new.json file for the Baseline Glider available here.