AA241x Problem Set 1

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April 2017

1 Bixler 3 R/C Flight

Responsibility: Chonuttida

Building and flying of our Bixler is documented in the team logbook - The Logbook of Dustdevils.

From working on the Bixler, we created a testing procedure that would also be useful once we fly our own aircraft:

Testing procedure

1. Preflight checklist
   - ❏ Inspect control surfaces for symmetry
   - ❏ Ensure propeller is properly mounted and secured(!)
   - ❏ Secure battery all the way forward into nose compartment, power Pixhawk
   - ❏ Start QGroundControl, check for any error messages, calibrate(!)
   - ❏ Check transmitter voltage, center sticks, zero throttle, trims and switches **(ensure it is in manual mode!)**
   - ❏ Toggle arming switch (ARMED!) **Power-cycle if it refuses to arm**
   - ❏ Secure cockpit with electronics with velcro strap
   - ❏ Check control surfaces deflection direction with transmitter inputs, reverse if necessary on the transmitter
   - ❏ Hold rudder right (or left) to arm the motor
   - ❏ Increase throttle, check propeller spin
     (folding propeller should be unfolded or it would violently vibrate!)
   - ❏ Start screen recording, slowly increase to full throttle, ready to launch
     Take good pictures of the plane, as if it were the last flight

2. Manual flight
   - Pilot calls out “taking off”, launcher releases aircraft at full throttle
   - Climb to safe altitude and reduce throttle
   - Check stability, trim as necessary
   - Try turning in both directions, adjust throttle to wind
   - Follow racecourse or “8” loop, try level flight, roll, pitch, yaw (singlets/doublet)
   - Measure stall speed
     - One person watch speed telemetry
     - Start high and cut throttle, keep level while increasing angle of attack
     - Maintain altitude and reduce speed until stall
     - Pilot calls out “stall”
     - Repeat as space and time allows
   - Land into the wind, pilot calls out landing direction and starts to glide
   - Flare at close distance to ground to prevent damage
   - Once grounded, stop screen recording
   - Pilot calls out “on the field”, keep throttle down, go to disarm aircraft
   - Inspect for any damage/loose parts
     - If any part missing, mark landing position for later search
   - Return to ground station, disconnect battery, power off electronics
   - Repair any insignificant damage with duct tape
   - Inspect battery voltage reading
     Power-cycle before arming next time

2 Flight Data Analysis

Responsibility: Yutao

Visualization of our flight path is accessible through our team Google site - DustDevils/PS#1. Some example plots of the logged data including the throttle setting, pitch, battery levels, and altitude are shown in Figure 1.

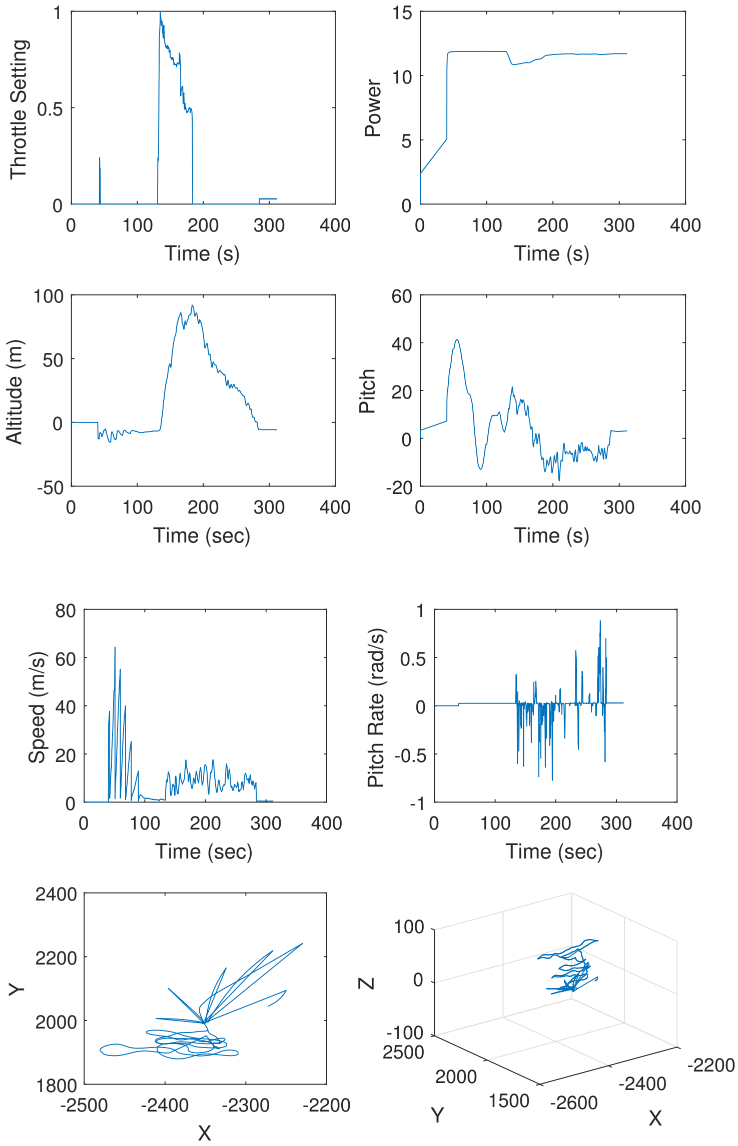


Figure 1: Example of logged data for a >3 min flight

With the updated firmware, we could access `ADAT_u,v,w` for body velocities u, v, w, as well as `ATT_Roll,Pitch,Yaw` for body angular rates p, q, r, both of which are useful for identifying segments of data pertaining to each flight maneuver. After calculating airspeed $V = \|[u, v, w]\|$, the lift and pitching moment coefficients could be estimated as

$$C_l = \frac{mg}{\frac{1}{2}\rho V^2 S}, \qquad C_M = \frac{I_y \ddot{\theta}}{\frac{1}{2}\rho V^2 Sc}$$

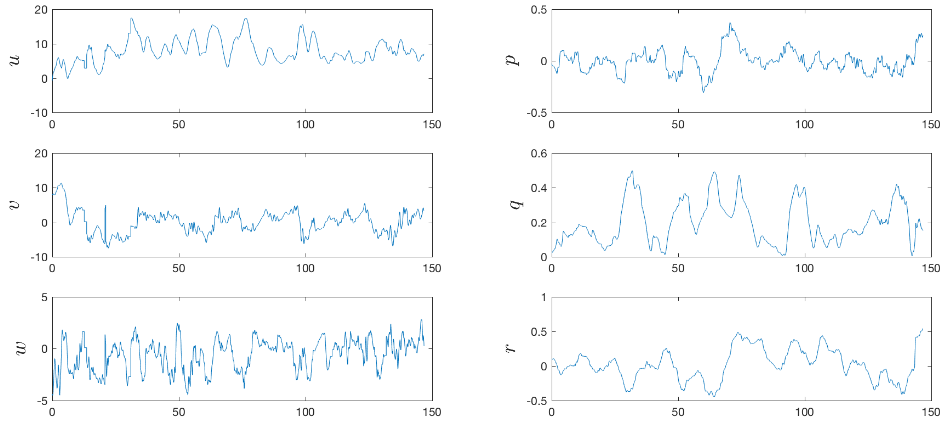


Figure 2: Linear and angular velocities in the body frame

The angle of attack $\alpha = \arctan(w/u)$, which can be differentiated to get $\dot{\alpha}$. But due to numerical errors it is better to use pitch rate p for $\dot{\alpha}$. Consider fitting a linear model

$$\begin{bmatrix} C_l \\ C_M \end{bmatrix} = \begin{bmatrix} C_{l\alpha} & C_{lq} & C_{l\delta e} \\ C_{M\alpha} & C_{Mq} & C_{M\delta e} \end{bmatrix} \begin{bmatrix} \alpha \\ q \\ \delta e \end{bmatrix} + \begin{bmatrix} C_{l0} \\ C_{M0} \end{bmatrix}$$

Given data $C_l, \alpha, q, \delta e$ over a period of pitching flight in 4241353.csv from $t = 156.10s$ to $t = 157.35s$, we attempt to fit a hyperplane in the parameter space to estimate the partial derivatives using MATLAB function \ , which effectively solves the least-squares problem.

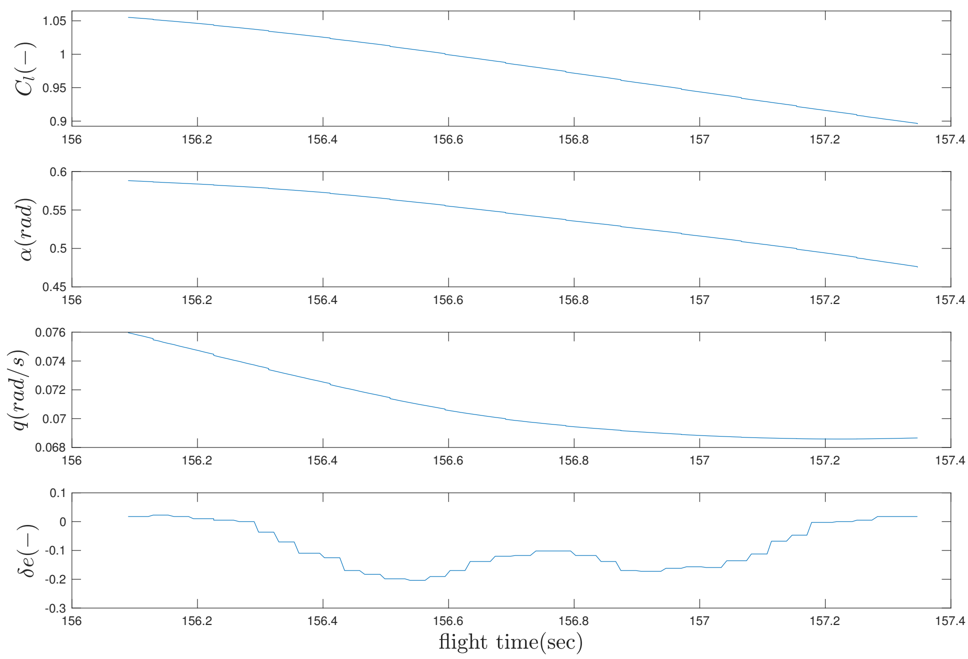


Figure 3: Relevant data for C_l fitting

$$C_{l\alpha} = 1.8194 \qquad C_{lq} = 0.0370 \qquad C_{l\delta e} = 0.0004$$
$$C_{M\alpha} = -0.0008 \quad C_{Mq} = 0.0030 \quad C_{M\delta e} = -0.0030$$

The results above show numerical instability and does not agree with either theoretical prediction or the perceived handling quality. This could be attributed to the poor quality of the data, due to improper calibration, unexperienced piloting and the Bixler's susceptibility to turbulent environments.

For brevity, this section only covered the longitudinal dynamics. Lateral-directional dynamics would involve more parameters, but we expect the analysis to follow a similar procedure. Before that, however, we need to investigate better methods of obtaining the stability derivatives, perhaps by fitting an affine model, or by solving an optimization problem.

3 Theoretical vs. Experimental Data

Responsibility: Michelle

3.1 Experimental

From our experimental data, the lift coefficient can be computed by use of the classical definition $C_L = \frac{Lift}{\frac{1}{2}\rho V^2 S}$. When the plane is trimmed and gliding at a level altitude, we can approximate the lift force to be balanced by the total weight of the aircraft. Our data shows that during a gliding flight, the velocity fluctuates between 7 to 10 m/s. As such, the C_L ranges from 1.4 to 0.3, respectively; thus, the maximum C_L is 1.4. Due to the fluctuations in data, MATLAB's built-in `smooth` function over 1000 points was used for parameters such as ADAT velocity, IMU acceleration, etc. data.

To calculate the maximum lift-to-drag ratio, the drag coefficient must also be determined during gliding flight. A scatter plot is fit with a drag polar–or square root function–obtained during this flight segment.The maximum lift-to-drag ratio is defined as the point at which a tangent line from the origin to the drag polar intersects; hence, our experimental maximum lift-to-drag ratio is approximately 12. These points are highlighted in Figure 4. Based on this plot, the zero lift drag coefficient (C_{D0}) is 0.025. Large variations in data due to sensor noise is a limitation in this measurement method of the aerodynamic parameters.

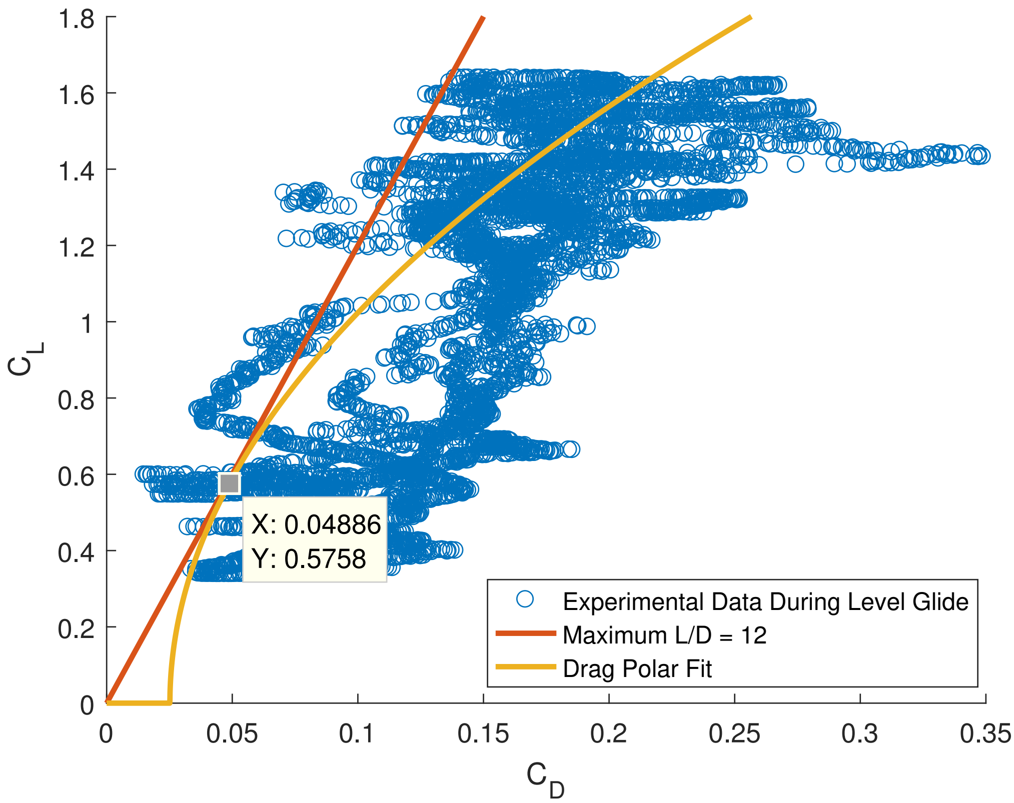


Figure 4: Drag Polar Fit to Gliding Segment of Data

As the lift increases, the square root fit deviates from the data. This is indicative of stall as the drag continues to increase with an asymptotic C_L value near 1.4. During one of our test flights, we stalled the aircraft with a large angle of attack of 22.2° with a stall speed of 16.6 m/s.

The power consumption (illustrated as discharge rate) increases proportionally to speed as we would expect. The plot shown in Figure 5 is from a segment of level-flight that lasted for a short amount of time (5s). However, the power consumption during this segment does not vary significantly as shown by the change in the y-axis.

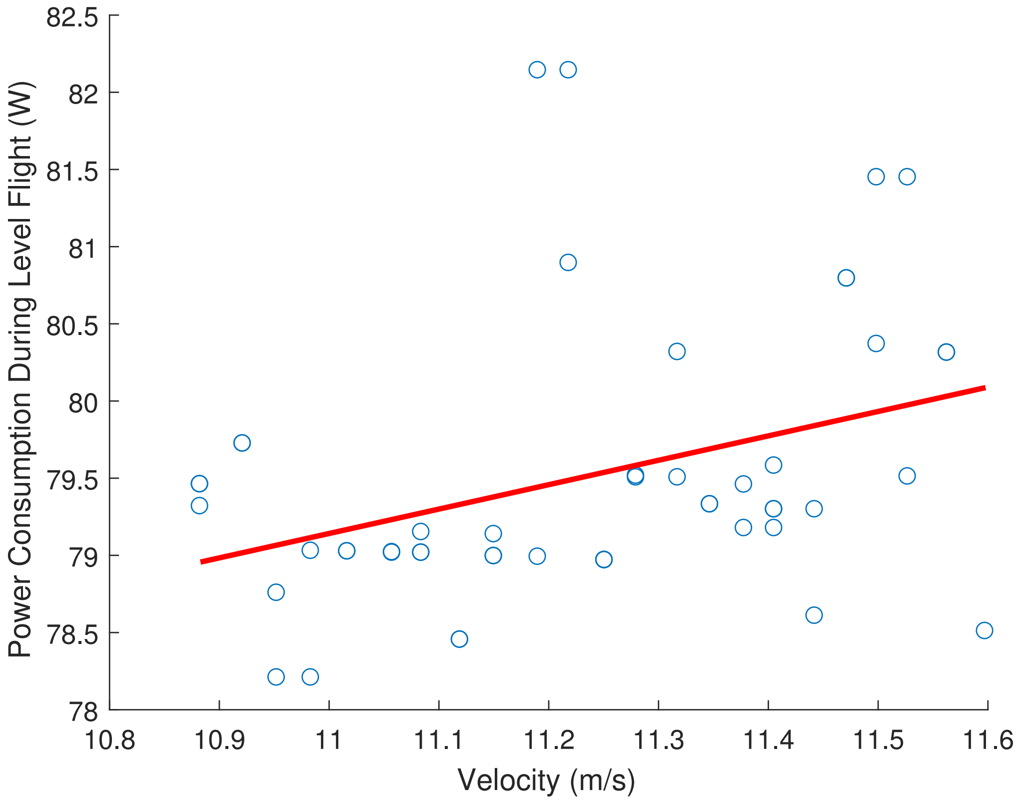


Figure 5: Power Consumption Increases for Increasing Velocity

3.2 Theoretical

A theoretical performance of the Bixler 3 aircraft can be computed with AVL. To do so, the geometry and weight distributions of our design must be accounted for as AVL input files. The first file `test.avl` reflects the geometry of the Bixler 3 and `test1.mass` accounts for the weight distributions of our design. The simulation results of a trimmed flight are shown in Figure 6 below where a CL of 0.6682, a total CD of 0.0371 are calculated for this condition. With these parameters, our lift-to-drag ratio is approximately 18. For trimmed flight, the elevator should be deflected at approximately 10.6° from the horizontal position..

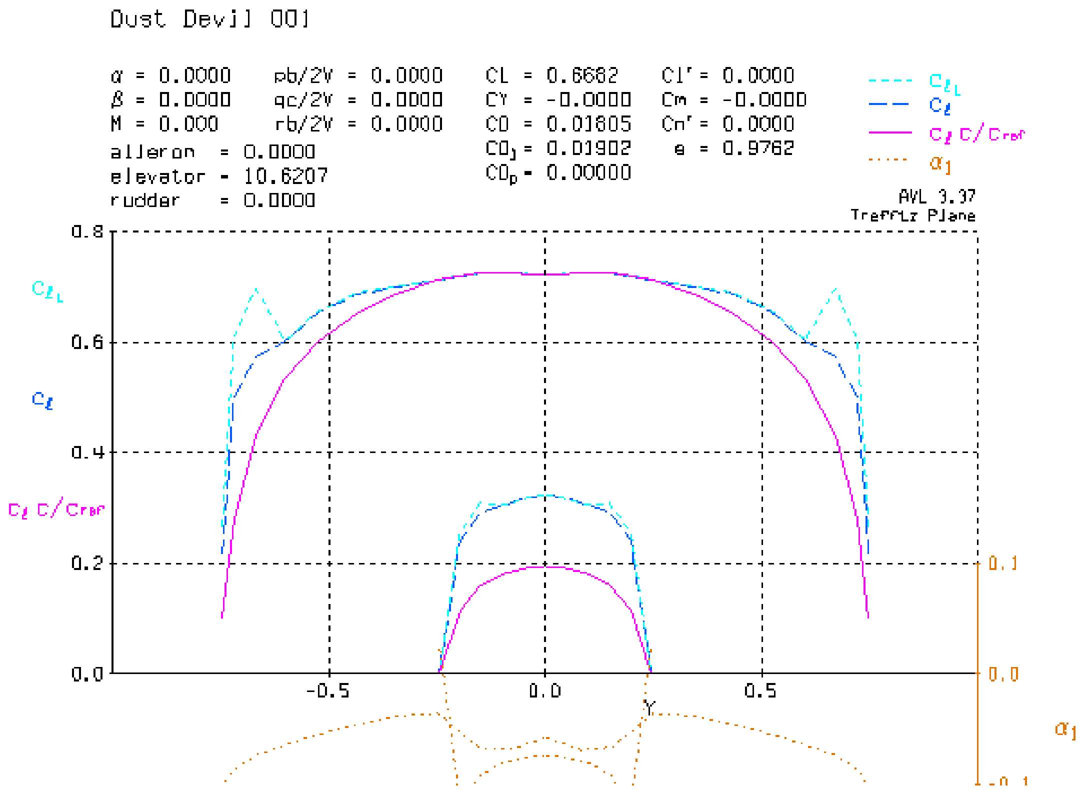


Figure 6: AVL Output of Trefftz Plane Summarizing Aerodynamic Parameters for Trimmed Flight

Furthermore, stability derivatives, center of gravity, and the neutral point are computed to assess the performance of the aircraft for various maneuvers. These output values are shown below.

```
---------------------------------------------------------------------------------

Stability-axis derivatives...

                             alpha                beta
                   ----------------    ----------------
 z' force CL |    CLa =   4.945275    CLb =  -0.000000
 y  force CY |    CYa =   0.000000    CYb =  -0.215102
 x' mom.  Cl'|    Cla =  -0.000000    Clb =  -0.152469
 y  mom.  Cm |    Cma =  -0.103954    Cmb =  -0.000000
 z' mom.  Cn'|    Cna =  -0.000000    Cnb =   0.024784

                      roll rate  p'      pitch rate  q'        yaw rate  r'
                   ----------------    ----------------    ----------------
 z' force CL |    CLp =   0.000000    CLq =   5.691254    CLr =   0.000000
 y  force CY |    CYp =  -0.042417    CYq =  -0.000000    CYr =   0.132096
 x' mom.  Cl'|    Clp =  -0.493382    Clq =  -0.000000    Clr =   0.167011
 y  mom.  Cm |    Cmp =   0.000000    Cmq =  -9.455936    Cmr =  -0.000000
 z' mom.  Cn'|    Cnp =  -0.047729    Cnq =  -0.000000    Cnr =  -0.047418

                   aileron       d1     elevator     d2     rudder        d3
                   ----------------    ----------------    ----------------
 z' force CL |   CLd1 =  -0.000000   CLd2 =   0.008063   CLd3 =  -0.000000
 y  force CY |   CYd1 =   0.002410   CYd2 =  -0.000000   CYd3 =  -0.001558
 x' mom.  Cl'|   Cld1 =   0.008001   Cld2 =  -0.000000   Cld3 =  -0.000040
 y  mom.  Cm |   Cmd1 =  -0.000000   Cmd2 =  -0.019148   Cmd3 =   0.000000
 z' mom.  Cn'|   Cnd1 =  -0.000775   Cnd2 =  -0.000000   Cnd3 =   0.000571
 Trefftz drag| CDffd1 =   0.000000 CDffd2 =   0.000643 CDffd3 =   0.000000
```

```
 span eff.    |    ed1 =  -0.000000    ed2 =  -0.009074    ed3 =  -0.000000

 Neutral point  Xnp =   0.359521

 Clb Cnr / Clr Cnb  =   1.746683    (  > 1 if spirally stable )
---------------------------------------------------------------------------------
Run Parameters...
 alpha      =   0.00000     deg
 beta       =  0.820612E-05 deg
 CL         =  0.668221
 CDo        =   0.00000
 bank       =   0.00000     deg
 elevation  =   0.00000     deg
 heading    =   0.00000     deg
 Mach       =   0.00000
 velocity   =   0.00000     m/s
 density    =   1.22500     kg/m^3
 grav.acc.  =   9.81000     m/s^2
 turn_rad.  =   0.00000     m
 load_fac.  =   0.00000
 X_cg       =  0.355317     Lunit
 Y_cg       =   0.00000     Lunit
 Z_cg       =  0.351164E-01 Lunit
 mass       =   1.07400     kg
 Ixx        =  0.612957E-01 kg-m^2
 Iyy        =  0.548239E-01 kg-m^2
 Izz        =  0.113390     kg-m^2
 Ixy        = -0.692904E-09 kg-m^2
 Iyz        =  0.227243E-09 kg-m^2
 Izx        =  0.318064E-03 kg-m^2
 ---------------------------------------------------------------------------------
```

The center of gravity (CG) computed by AVL is 0.3553 m from the nose and correlates well with the measured CG of our aircraft at 0.345 m from the nose. The predicted neutral point is located at 0.36 and the plane is spirally stable.

A C_L vs. α plot can be obtained by running AVL for varying angles of attack. Assuming we are only interested in trimmed conditions (no pitch, roll, and yaw moments), Figure 7 summarizes the Bixler's performance.

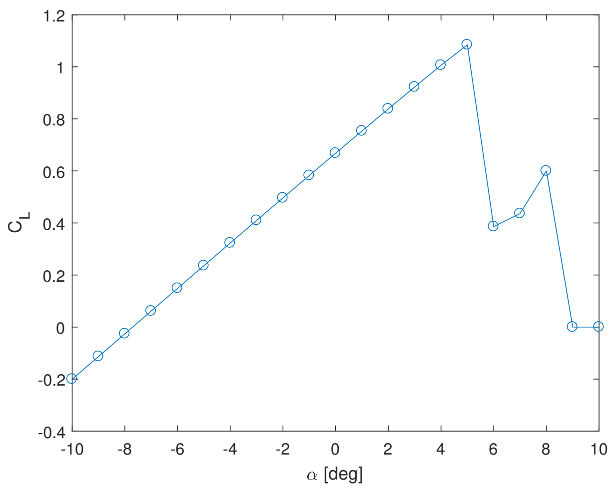


Figure 7: AVL C_L vs. α for Trimmed Flight

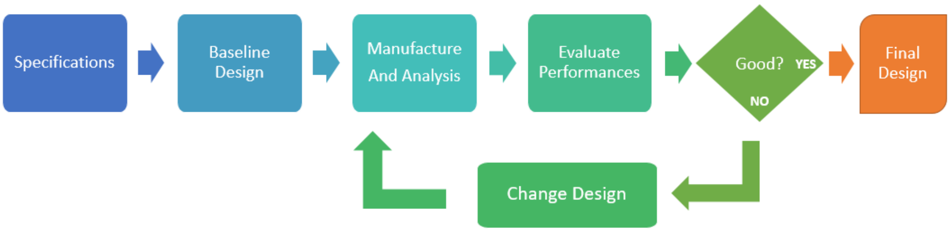
Angles above 5° resulted in large trim conditions and fluctuated depending on the sequence of α inputs; hence, the C_L values are unreliable beyond 5°. Though before 5°, the lift-curve slope is linear and approximately 4.9, which agrees with the $C_{L\alpha}$ output in the stability derivatives.

4 Mission Strategy

Responsibility: Pierre, Louise

4.1 Design process

Whatever the specifications of the mission, the design process for the mission will follow the following steps:
The specifications will be broken down into the following categories:



- Aerodynamics
- Electronics, sensors and actuators
- Stability and control
- Path planning

The steps can be broken down as follows:
Specifications

- Break down the courses requirements into the 4 categories specified above
- For each category, find documents and research papers that are relevant to the project
- Find the appropriate adimensional parameters relevant to Mars (taking into account the difference in gravity, air density)
- Write down specifications for:
  - Aerodynamics: L/D, stability for different maneuvers, maximum and minimum speed, gliding specifications
  - Electronics, Sensors and Actuators: power consumption, price, motor specifications
  - Stability and Controls: computation time, damping, stiffness, stability
  - Navigation: number of plumes, path optimization, stay within boundaries, making target choices

  Baseline design

  - Brainstorm the different shapes, electronics, controls, navigation possible

- Sketch and get feedback from the CAs
- Fast prototyping of a functioning prototype
- Preliminary Check-List

Analysis and evaluation

- Compare the results of test flights and computation tests to the specifications. Analyzing tools include: CAD modeling of the airplane, AVL analysis, Matlab and Simulink and Firmware for the implementation of the navigation code.
- Write down a report with issues to be solved in the new design

4.2 Team Organization

The required work can be separated into two separate tracks that will be pursued concurrently:

- **Aerodynamic Design and Manufacturing** which include the design and construction of the plane itself, as well as the measurements on the final product. This process will be iterative as performance and stability data comes in.
- **Flight Dynamics and Navigation** which will use theoretical and experimental parameters to stabilize flight and to design the control strategy of the plane.

Though members of the team will not strictly be separated between these two segments, separating the work flow like this rather than a linear approach will significantly accelerate the process. Teamwork coordination will be facilitated through the use of Slack as well as by having set group sessions each week, on Wednesday and Thursday night to guarantee a minimum amount of work with the entire team.

5 Goals and Plan of Action

Responsibility: Louise, Pierre

5.1 Project Goals

- Build a high performing fixed-wing drone
- Master the understanding and implementation of sensors and actuators
- Use controls techniques to stabilize the aircraft by closing loops on actuators
- Automate remote control of the aircraft to satisfy the mission's requirements

5.2 Plan of Action

Our plan of action can be summarized in the following key points:

- Continue flying the Bixler between manual/mission mode, iteratively analyze flight data and optimize mission firmware
- Use aerodynamic computations as a reference to construct CAD models for the prototype
- Conduct flight simulations to determine quality of aerodynamic/control design

- Prototype flight as early as possible, with backup plans
- Formulate mission goal as constrained optimization problem

A timeline showing our work schedule is below and can also be found at our team site.

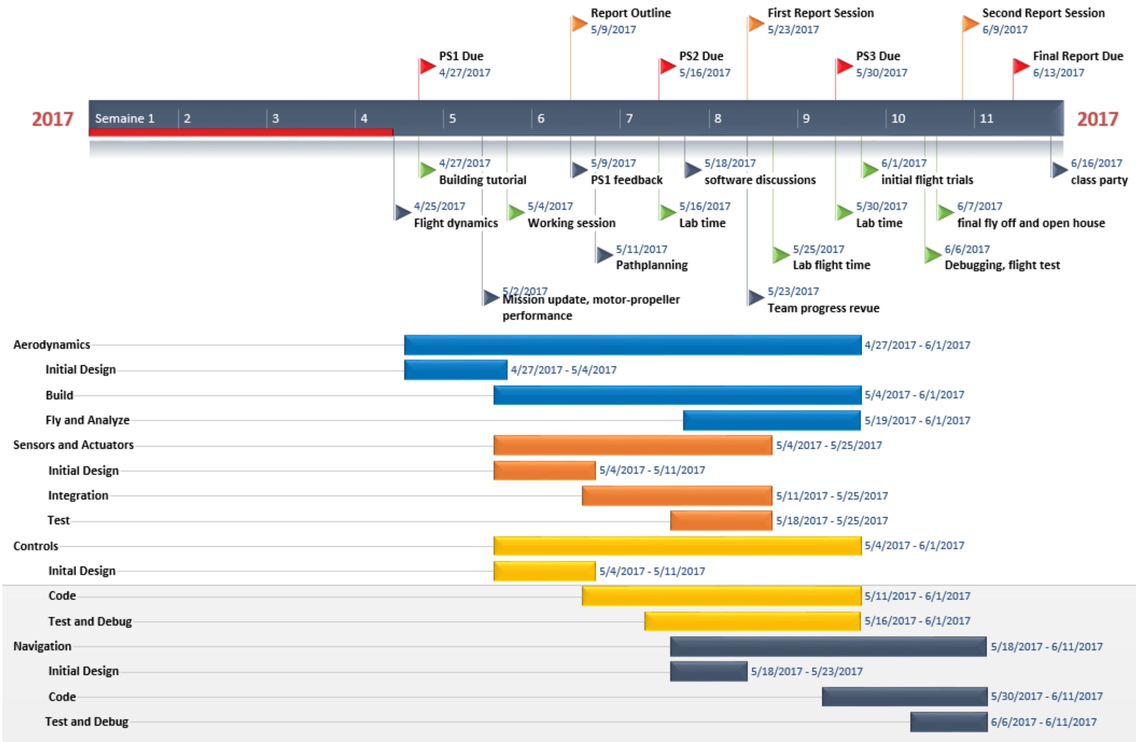


Figure 8: Mission Timeline