EGR 4810-03 Senior Project - Active Stabilization

Winter Semester Final Progress Report

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Executive Summary

This report is for the Active Stabilization project, which is a project that primary goal is to develop a modular drop-in active stabilization system for amateur sounding rockets. The secondary goals of this project is to develop a launch vehicle platform that can carry this system as well as carry an autonomous glider payload. As well as develop the launch vehicle platform to be able to compete in the FAR 1030 competition. The project has been separated into many smaller specialized sub-teams. These teams are as following: Launch Vehicle, Aerodynamics, Structures and Manufacturing, Avionics, Guidance, Navigation, and Controls, Propulsion, Payload, Testing, Systems, and Marketing. The marketing team updates are labeled as general updates in this report. Each sub-team report will feature a sub-team goal, which explains the need and goal for that team. Each team will discuss completed, current, and future tasks and goals, as well as a status report to explain where each team is standing in terms of the general project scheduling.

1.0 Launch Vehicle Update

Goal:

The goal of this team was to model and manufacture the launch vehicle as well as design and handle the recovery system for the project. This launch vehicle is designed to provide the most compact form factor possible and as a method to carry the fin control mechanism to greater than Mach speed as well as to carry an autonomous glider to 10,000 feet. This vehicle in addition is designed to be competitive against other platforms in the FAR 1030 competition in the 10K category.

Key Characteristics of this Launch Vehicle is shown below

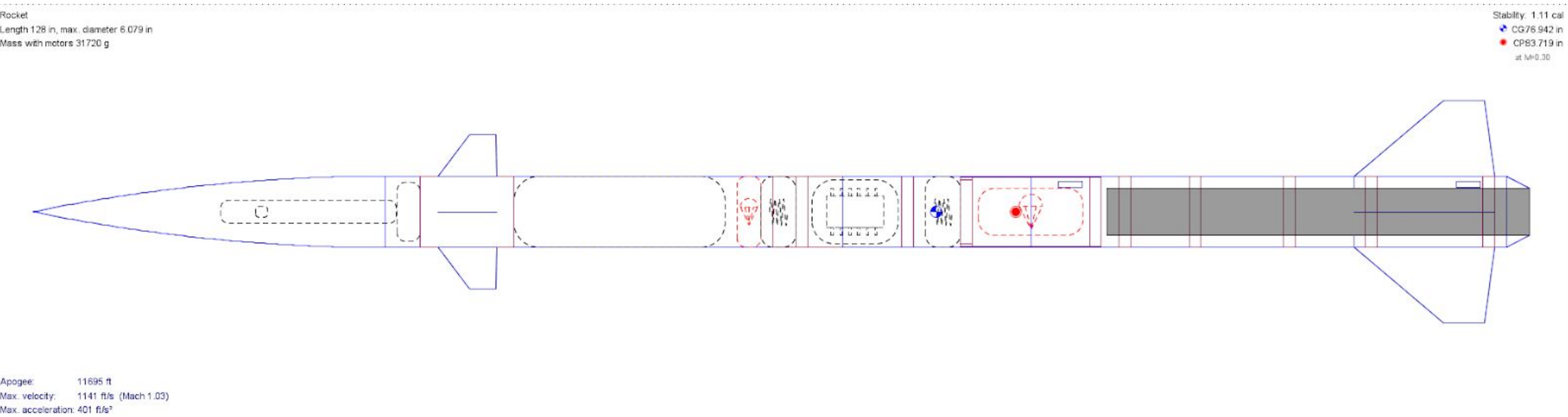
Key Attributes	
Length	11 feet
Diameter	6 in
Total Weight	70 lb
Max Speed	1.03 M
Max Accel.	12.4 G's
Motor	N3200

Status Update:

The launch vehicle team is on track in terms of schedule. The rough full-scale vehicle should be assembled and be ready to accept the fin control mechanism by the end of January 2020.

Completed Tasks:

- Design a suitable launch vehicle that can carry a payload and the fin control mechanism
  - The image below shows the OpenRocket file that shows the layout of the rocket.



- Size the vehicle to have the smallest possible length, to reduce the slenderness of the original vehicle design
- Size the parachutes and determine the layout and connections for the recovery system

Lb	42.2	lb
Cd	1.1	
rho	0.001756	slug/ft^3
g	32.174	ft^2
m	1.310559006	slugs
Altitude calculated for	10000	ft

		Parachute Sizes for respective descent velocity		
Descent Velocity		Diameter (in)	Diameter (ft)	Area (ft^2)
5	ft/s	565.9963509	47.16636257	1746.36262
10	ft/s	282.9981754	23.58318129	436.5906551
15	**ft/s**	188.6654503	15.72212086	194.0402911
20	**ft/s**	**141.4990877**	**11.79159064**	109.1476638
25	ft/s	113.1992702	9.433272514	69.85450481
30	ft/s	94.33272514	7.861060429	48.51007278
40	ft/s	70.74954386	5.895795322	27.28691594
50	ft/s	56.59963509	4.716636257	17.4636262
60	ft/s	47.16636257	3.930530214	12.1275182
70	ft/s	40.42831078	3.369025898	8.910013369
80	ft/s	**35.37477193**	**2.947897661**	6.821728985
90	ft/s	31.44424171	2.620353476	5.390008087
100	ft/s	28.29981754	2.358318129	4.365906551

- Blue Highlight is for main parachute sizing and green is for drogue parachute sizing
- Determine the booster fin geometry
- Determine the layout of the components in order to achieve a desirable static stability margin (SM > 1 caliber)

In Progress Tasks:

- Determine the structural loading on the recovery hard points
- Design a removable motor mount that can incorporate easily replaceable fins
- Fiberglass the airframe sections of the rocket in order to increase the stiffness and strength of the airframe

- Complete blue tube bending and compression test analysis

Future Goals:

- Fiberglass the coupler sections and cut the airframe sections to length
- Machine the centering rings and bulk plates and assemble rocket sections.
- Work with avionics to develop the internal mounting structure for the avionic system's electronics
- Size the amount of shear pins required for the system
- Purchase the necessary equipment to finish the launch vehicle
- Assemble and integrate all the components for the launch vehicle and prepare for a test launch.

2.0 Structures and Manufacturing

Goal:

The goals for this team was to design the full fin actuation system, verify fin/system loading, and create single fin prototype to test motor configuration. Additionally we were tasked with designing the motor retainer/ tail cone for the launch vehicle, and to determine/ simulate stresses on rocket in flight using Solidworks.

Status Update:

The structures team is on or ahead of schedule for each goal. All fin actuation system goals were reached at or before week 12. The motor retainer/tail cone has been completed, and we are waiting on getting the material properties of blue tube in order to run simulations. Over break machining and assembly of the full fin actuation system will be started.

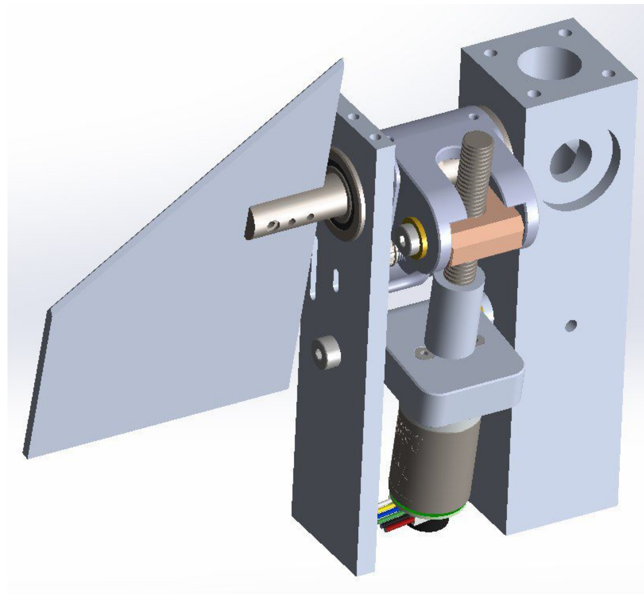
Completed Tasks:

- Stress and strengths analysis of fin and shaft loadings
- FEA simulations of loadings
- Parts ordered and sized to fit rocket dimensions
- Prototype of module with single fin actuation
- Determined fin bonding to be bolted with threadlocker, not brazed

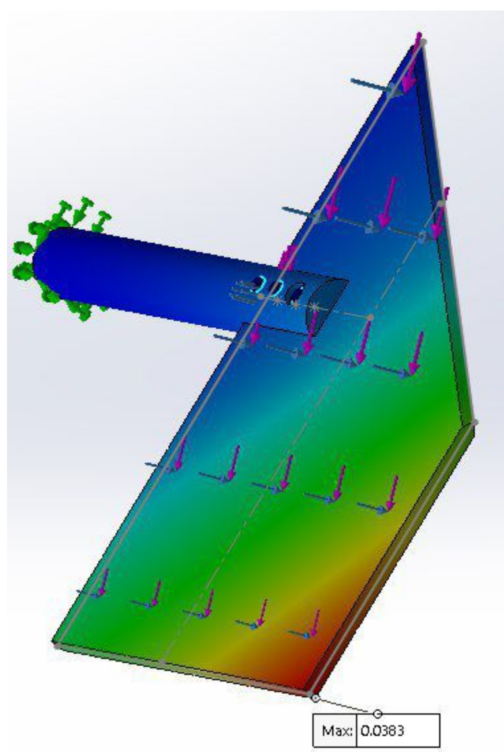
Below is the power screw loading analysis done to determine the exact type of motor and ACME rod we were going to use for the module. We chose the Pololu 4751 37mm diameter motor with the ⅜ -8-2 ACME rod.

					3/8-8-2	
Motor	Package	RPM(no load)	Stall Torque(oz-in)	Torque in lb-in	Force(lb) raise	Speed(deg/s)
1.1	25D	10,200	5.5	0.103125	2.472542579	2783.01994
4.4:1	25D	2250	23	0.43125	10.33972351	613.9014574
9.7:1	25D	1030	44	0.825	19.78034063	281.030445
20.4:1	25D	500	85	1.59375	38.21202167	136.4225461
34:1	25D	290	120	2.25	53.94638354	79.12507674
47:1	25D	210	165	3.09375	74.17627736	57.29746936
75:1	25D	130	240	4.5	107.8927671	35.46986199
99:1	25D	100	300	5.625	134.8659588	27.28450922
4750	37D	10,000	7	0.13125	3.146872373	2728.450922
4751	37D	540	120	2.25	53.94638354	147.3363498
4752	37D	330	190	3.5625	85.41510727	90.03888043
4753	37D	200	290	5.4375	130.3704269	54.56901844
4754	37D	150	380	7.125	170.8302145	40.92676383
4755	37D	100	470	8.8125	211.2900022	27.28450922
4756	37D	76	630	11.8125	283.2185136	20.73622701
2827	37D	67	680	12.75	305.6961734	18.28062118

On the right is the Solidworks assembly of a single fin actuation module and on the left is the to scale prototype that was 3D printed using the HP Multijet fusion. The prototype confirmed the movement and fits of the components so that the remaining parts can be made or ordered.



On the right is an example of one of the fin loading simulations we ran on Solidworks. The maximum deflection at the tip is shown to be 0.0383in. The values that the simulation determined were close to the values that we computed by hand. On the left is our team modifying the load bearing threaded nut that will connect the spinning ACME rod to the pivoting arm.



In Progress Tasks:

- Verify adhesive donation from Loctite.
- Order remaining parts for fin mechanism.
- Manufacture and assemble fin mechanism.

Future Goals:

The future goals for the structures team is to manufacture, assemble, and integrate the full fin actuation system into the launch vehicle. Additionally, the team will test and validate adhesives for attaching the fin to the shaft, and finish running simulations on vehicle once all material data is acquired.

3.0 Aerodynamics

Goal:

The primary objectives for the Active Stabilization Aerodynamics Team involve:

- Analyzation of Aerodynamic loading on nose cone
- Aerodynamic Stability verification during flight
- Support Wind Tunnel testing with integration of "GNC Module"
- Trade studies for configuration involving aerodynamic characteristics of vehicles (launch vehicle and payload)

Status Update:

The Active Stabilization Aerodynamic team is currently on track with the defined schedule. Measures have been implemented to ensure that similar progress will be made.

Completed Tasks:

- CFD Modeling of Forward Canard (Son)
- Trade Study of Payload Tail Design
- Calculate projected area of launch vehicle at braking configuration

As of current, the Aerodynamic team has verified the proposed downwards V-tail and suggests that a propeller be placed behind the tail to counteract downwash. However, should things go awry, a traditional vertical and horizontal control surfaces are recommended.

- Cooperate with Structures Team for verification of analysis
- Canard Velocity Analyzed

In Progress Tasks:

- CFD Modeling of Nose Cone
- CFD Modeling to updated Launch vehicle configuration
- Validation of hand calculations to canard local
- Verification of local velocity over canard using CFD

Future Goals:

- Support the Testing Team for Wind Tunnel Testing
- Perform Aerodynamic Analysis of Payload Vehicle
- Aerodynamic Stability verification for updated launch vehicle with measured masses

4.0 Guidance and Controls

Goals:

Throughout the course of the semester, the primary objectives of the Active Stabilization Guidance, Navigation, and Control were the following:

- Develop and test a means to close the loop and program position feedback sensing involving a chosen DC Motor
- Develop a flowchart for the "GNC Module" to begin coding; be nearly complete by the beginning of Winter Break
- Find the coefficients of interest and provide support to Aerodynamics team for Six-Degree-of-Freedom Trajectory Simulation that includes braking; create flowchart for simulation
- Develop flowchart and program for drone in helping Payload Team

Each objective was divided into smaller tasks that would, in amalgamation, lead to the desired overall result (as listed previously). More tasks will be created in order to support or resolve deficiencies that arise during the timeline of the project.

Status Update:

As of current, the Active Stabilization Guidance, Navigation, and Control group is behind by approximately three weeks. These are for the following reasons:

- Academic Priorities - Homework and examinations have taken significant amounts of time away from work necessary
- Outsourcing to help other teams - Members were dispatched to do other work that were prioritized at the time (particularly for that of Aerodynamics)

The team plans to regain control and return to being on schedule by increasing efforts during Winter Break.

Completed Tasks:

Tasks completed include the following:

- DATCOM Aero Modeling and generation of stability and aerodynamic coefficients as a function of Mach and Angle of Attack

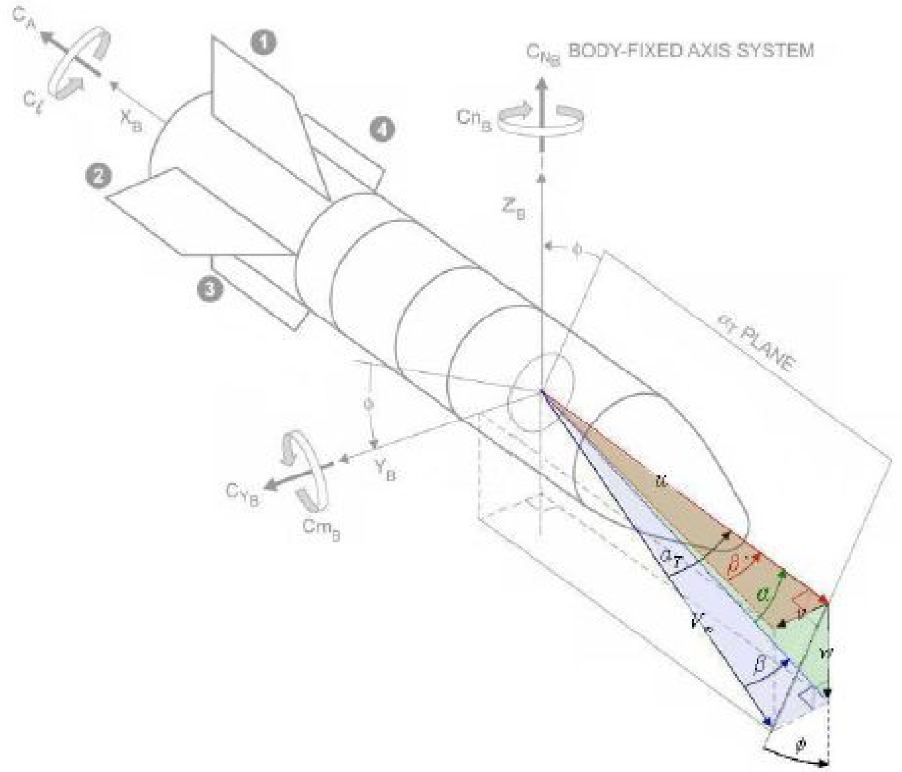
DATCOM was utilized to produce aerodynamic and stability coefficients as a function of Mach Number and Angle of Attack under no external environmental loading (no crosswinds, etc…).

The test card takes into account fin configuration, nose cone shape, Mach numbers, and pitching angles at which to produce results.

The image below shows the file for003.dat, which displays aerodynamic data at the users request. The values of the coefficients are optimized for each Mach case (from Mach 0 to 1.7, neglecting MACH 0.7 due to inexplicable singularity). The values represent the variables displayed at the top of the page from left to right (first column shows angle of attack then normal moment coefficient, then pitching moment coefficient, and others. The system was coded with the coordinate system in mind.

```
VARIABLES=ALPHA,CN,CM,CA,CY,CLN,CLL,DELTA,CL,CD
ZONE T="NO TRIM MACH=  0.10"
   0.00     0.0000     0.0000     0.4676     0.0000     0.0000     0.0000     0.1000     0.0000     0.4676
   1.00     0.2971    -0.2420     0.4669     0.0000     0.0000     0.0000     0.1000     0.2889     0.4720
   2.00     0.6527    -0.7351     0.4647     0.0000     0.0000     0.0000     0.1000     0.6361     0.4872
   3.00     1.0556    -1.4017     0.4605     0.0000     0.0000     0.0000     0.1000     1.0301     0.5151
   4.00     1.4959    -2.1919     0.4548     0.0000     0.0000     0.0000     0.1000     1.4606     0.5580
   5.00     1.9366    -2.8634     0.4473     0.0000     0.0000     0.0000     0.1000     1.8903     0.6144
   6.00     2.4095    -3.6411     0.4382     0.0000     0.0000     0.0000     0.1000     2.3505     0.6876
   7.00     2.9049    -4.4511     0.4265     0.0000     0.0000     0.0000     0.1000     2.8313     0.7773
   8.00     3.4381    -5.4896     0.4122     0.0000     0.0000     0.0000     0.1000     3.3473     0.8867
   9.00     3.9948    -6.7256     0.3925     0.0000     0.0000     0.0000     0.1000     3.8843     1.0126
  10.00     4.5633    -8.0907     0.3664     0.0000     0.0000     0.0000     0.1000     4.4304     1.1533
  11.00     5.1147    -9.3563     0.3326     0.0000     0.0000     0.0000     0.1000     4.9573     1.3024
  12.00     5.6650   -10.5862     0.2917     0.0000     0.0000     0.0000     0.1000     5.4805     1.4632
  13.00     6.2140   -11.7723     0.2461     0.0000     0.0000     0.0000     0.1000     5.9994     1.6376
  14.00     6.7549   -12.9137     0.1957     0.0000     0.0000     0.0000     0.1000     6.5069     1.8240
  15.00     7.3031   -14.1173     0.1418     0.0000     0.0000     0.0000     0.1000     7.0175     2.0271
ZONE T="NO TRIM MACH=  0.20"
   0.00     0.0000     0.0000     0.4437     0.0000     0.0000     0.0000     0.2000     0.0000     0.4437
   1.00     0.2977    -0.2452     0.4430     0.0000     0.0000     0.0000     0.2000     0.2900     0.4481
   2.00     0.6543    -0.7439     0.4409     0.0000     0.0000     0.0000     0.2000     0.6385     0.4635
   3.00     1.0581    -1.4174     0.4369     0.0000     0.0000     0.0000     0.2000     1.0338     0.4917
   4.00     1.5001    -2.2162     0.4315     0.0000     0.0000     0.0000     0.2000     1.4663     0.5351
   5.00     1.9426    -2.8945     0.4245     0.0000     0.0000     0.0000     0.2000     1.8983     0.5922
   6.00     2.4178    -3.6794     0.4160     0.0000     0.0000     0.0000     0.2000     2.3611     0.6664
   7.00     2.9151    -4.4962     0.4052     0.0000     0.0000     0.0000     0.2000     2.8440     0.7574
   8.00     3.4502    -5.5457     0.3920     0.0000     0.0000     0.0000     0.2000     3.3621     0.8684
   9.00     4.0083    -6.7981     0.3739     0.0000     0.0000     0.0000     0.2000     3.9005     0.9964
  10.00     4.5777    -8.1811     0.3498     0.0000     0.0000     0.0000     0.2000     4.4474     1.1394
  11.00     5.1283    -9.4544     0.3183     0.0000     0.0000     0.0000     0.2000     4.9734     1.2910
  12.00     5.6766   -10.6865     0.2803     0.0000     0.0000     0.0000     0.2000     5.4943     1.4544
  13.00     6.2192   -11.8704     0.2383     0.0000     0.0000     0.0000     0.2000     6.0062     1.6312
  14.00     6.6984   -12.9424     0.1987     0.0000     0.0000     0.0000     0.2000     6.4514     1.8133
  15.00     7.1716   -14.0634     0.1584     0.0000     0.0000     0.0000     0.2000     6.8863     2.0092
```

The image above shows the file for003.dat, which displays aerodynamic data at the users request. The values of the coefficients are optimized for each Mach case (from Mach 0 to 1.7, neglecting MACH 0.7 due to inexplicable singularity). The values represent the variables displayed at the top of the page from left to right (first column shows angle of attack then normal moment coefficient, then pitching moment coefficient, and others. The system was coded with the coordinate system in mind.



DATCOM also produced the body pressure coefficients across the body of the launch vehicle. It defined it by setting a coordinate system at one end of the launch vehicle and outputting the value at each “x”, relative to the defined zero. The displayed data does not represent the entire output, but rather a portion of it.

```
VARIABLES=X/D,CP(0),CP(30),CP(60),CP(90),CP(120),CP(150),CP(180)
ZONE T="BODY CP AT MACH=  1.30 ALPHA=  0.00"
        0.000000   0.18976   0.18976   0.18976   0.18976   0.18976   0.18976   0.18976
        0.088125   0.18429   0.18429   0.18429   0.18429   0.18429   0.18429   0.18429
        0.176251   0.17813   0.17813   0.17813   0.17813   0.17813   0.17813   0.17813
        0.264376   0.17176   0.17176   0.17176   0.17176   0.17176   0.17176   0.17176
        0.352502   0.16556   0.16556   0.16556   0.16556   0.16556   0.16556   0.16556
        0.440627   0.15950   0.15950   0.15950   0.15950   0.15950   0.15950   0.15950
        0.528752   0.15354   0.15354   0.15354   0.15354   0.15354   0.15354   0.15354
        0.616878   0.14766   0.14766   0.14766   0.14766   0.14766   0.14766   0.14766
        0.705003   0.14188   0.14188   0.14188   0.14188   0.14188   0.14188   0.14188
        0.793129   0.13616   0.13616   0.13616   0.13616   0.13616   0.13616   0.13616
        0.881254   0.13051   0.13051   0.13051   0.13051   0.13051   0.13051   0.13051
        0.969379   0.12493   0.12493   0.12493   0.12493   0.12493   0.12493   0.12493
        1.057505   0.11942   0.11942   0.11942   0.11942   0.11942   0.11942   0.11942
        1.145630   0.11398   0.11398   0.11398   0.11398   0.11398   0.11398   0.11398
        1.233756   0.10861   0.10861   0.10861   0.10861   0.10861   0.10861   0.10861
        1.321881   0.10330   0.10330   0.10330   0.10330   0.10330   0.10330   0.10330
        1.410006   0.09807   0.09807   0.09807   0.09807   0.09807   0.09807   0.09807
        1.498132   0.09288   0.09288   0.09288   0.09288   0.09288   0.09288   0.09288
        1.586257   0.08777   0.08777   0.08777   0.08777   0.08777   0.08777   0.08777
        1.674383   0.08273   0.08273   0.08273   0.08273   0.08273   0.08273   0.08273
        1.762508   0.07775   0.07775   0.07775   0.07775   0.07775   0.07775   0.07775
        1.850633   0.07282   0.07282   0.07282   0.07282   0.07282   0.07282   0.07282
        1.938759   0.06797   0.06797   0.06797   0.06797   0.06797   0.06797   0.06797
        2.026884   0.06318   0.06318   0.06318   0.06318   0.06318   0.06318   0.06318
        2.115010   0.05845   0.05845   0.05845   0.05845   0.05845   0.05845   0.05845
        2.203135   0.05378   0.05378   0.05378   0.05378   0.05378   0.05378   0.05378
        2.291260   0.04919   0.04919   0.04919   0.04919   0.04919   0.04919   0.04919
        2.379386   0.04465   0.04465   0.04465   0.04465   0.04465   0.04465   0.04465
        2.467511   0.04018   0.04018   0.04018   0.04018   0.04018   0.04018   0.04018
        2.555637   0.03577   0.03577   0.03577   0.03577   0.03577   0.03577   0.03577
        2.643762   0.03143   0.03143   0.03143   0.03143   0.03143   0.03143   0.03143
        2.731888   0.02716   0.02716   0.02716   0.02716   0.02716   0.02716   0.02716
        2.820013   0.02295   0.02295   0.02295   0.02295   0.02295   0.02295   0.02295
        2.908138   0.01880   0.01880   0.01880   0.01880   0.01880   0.01880   0.01880
        2.996264   0.01472   0.01472   0.01472   0.01472   0.01472   0.01472   0.01472
        3.084389   0.01071   0.01071   0.01071   0.01071   0.01071   0.01071   0.01071
        3.172514   0.00677   0.00677   0.00677   0.00677   0.00677   0.00677   0.00677
        3.260640   0.00289   0.00289   0.00289   0.00289   0.00289   0.00289   0.00289
        3.348765  -0.00092  -0.00092  -0.00092  -0.00092  -0.00092  -0.00092  -0.00092
        3.436891  -0.00466  -0.00466  -0.00466  -0.00466  -0.00466  -0.00466  -0.00466
        3.525016  -0.00832  -0.00832  -0.00832  -0.00832  -0.00832  -0.00832  -0.00832
        3.613141  -0.01192  -0.01192  -0.01192  -0.01192  -0.01192  -0.01192  -0.01192
        3.701267  -0.01545  -0.01545  -0.01545  -0.01545  -0.01545  -0.01545  -0.01545
        3.789392  -0.01890  -0.01890  -0.01890  -0.01890  -0.01890  -0.01890  -0.01890
        3.877517  -0.02228  -0.02228  -0.02228  -0.02228  -0.02228  -0.02228  -0.02228
        3.965643  -0.02559  -0.02559  -0.02559  -0.02559  -0.02559  -0.02559  -0.02559
```

- Simplistic DC Motor derivation for position feedback control system modeling and preparation (for Polo)

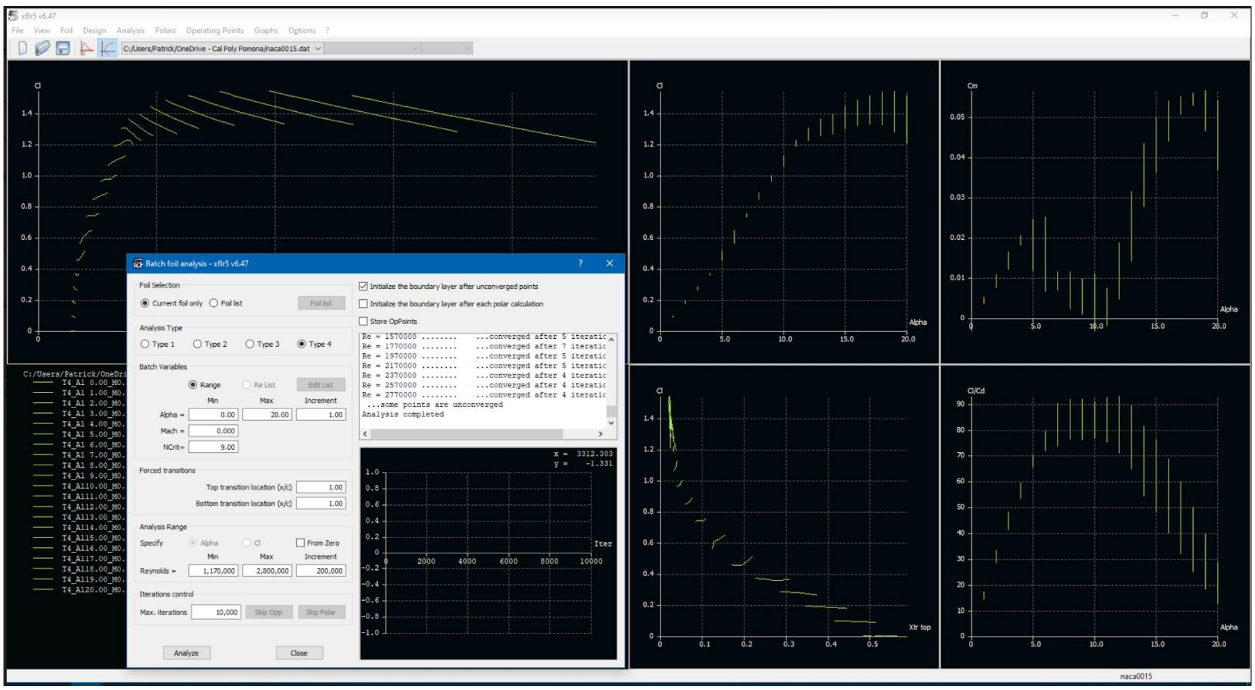
The DC motor position feedback loop was created so far with a simple plant closed feedback loop with an unspecified gain and potentiometer gain values and external torque disturbance. (Polo write some stuff and insert screenshot of Simulink Model here).

- Get “GNC Module” to actuate with RoboClaw and 9 Volt Battery

The GNC module was successfully controlled with a system involving a RoboClaw and a 9V battery. By doing so, the team now possesses a better perspective on how to optimize the system for actual deployment. PID gain tuning was also found in the software integrated.

- XFLR5 Verification of DATCOM model to as a function of Reynold’s number, fin airfoil as a function of pitching angle and Reynold’s number.

The XFLR 5 Lattice aerodynamic analysis program cannot be varied as a function of Mach. As such, the Reynolds Number was varied in order to reflect a change in velocity. The results turned out to mostly be in agreement with the coefficients produced by DATCOM by approximately 90 percent.



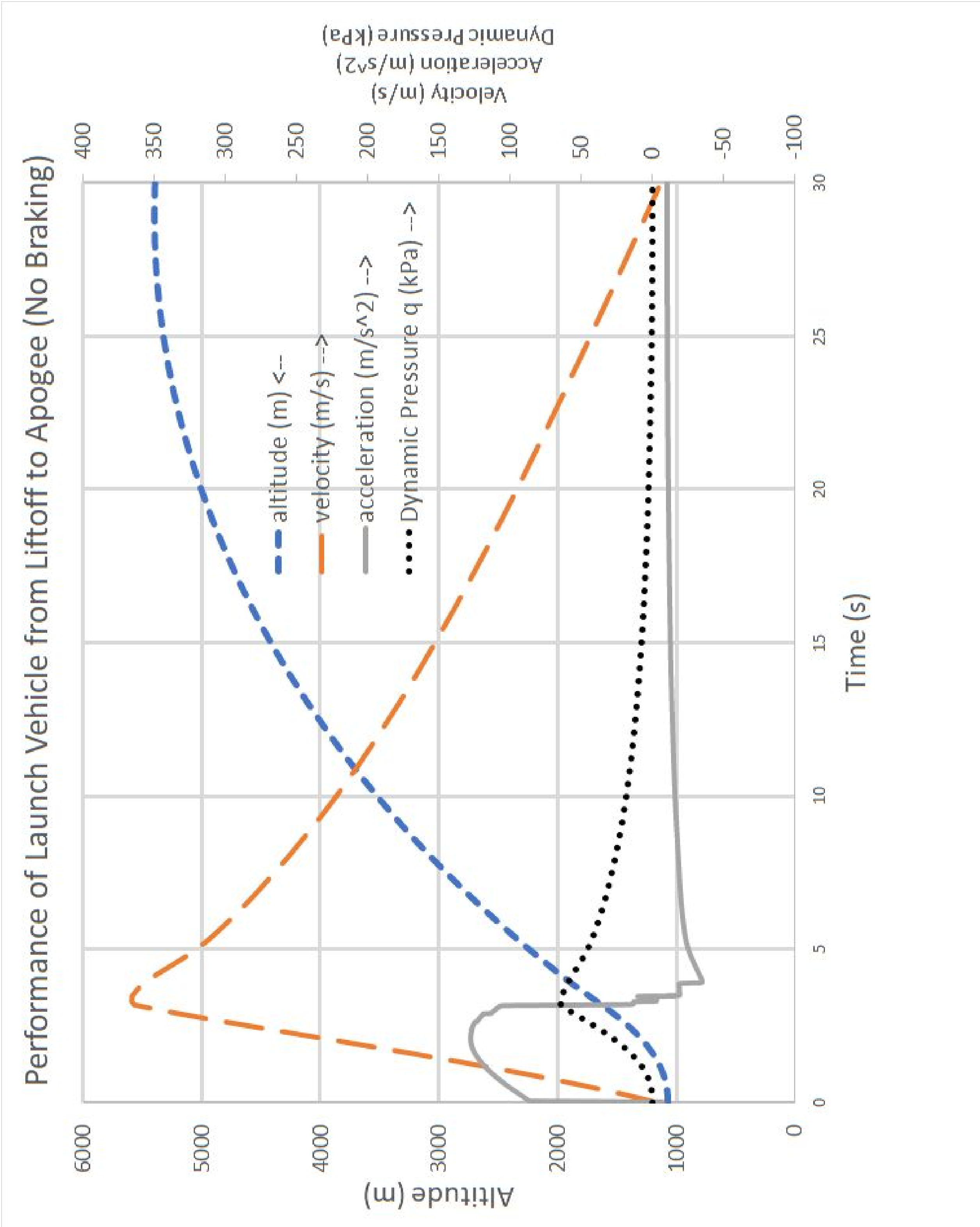
In Progress Tasks:

- DC Motor selection trade study and selection

The Active Stabilization Guidance, Navigation, and Control Team is in the process of doing a trade study to decide between a 25D or a 37D DC Motor. As of current, the report containing researched justification and hypotheses has been finished. The team is testing the motors individually to verify these findings and finalize the motor selection.

- Trajectory simulation

As of current trajectory simulation is under way. As of current, a simplistic trajectory simulation assuming braking configuration and level flight is being optimized within Excel. Below is a trajectory simulation of the Launch Vehicle from lift off to apogee without any breaking apply.

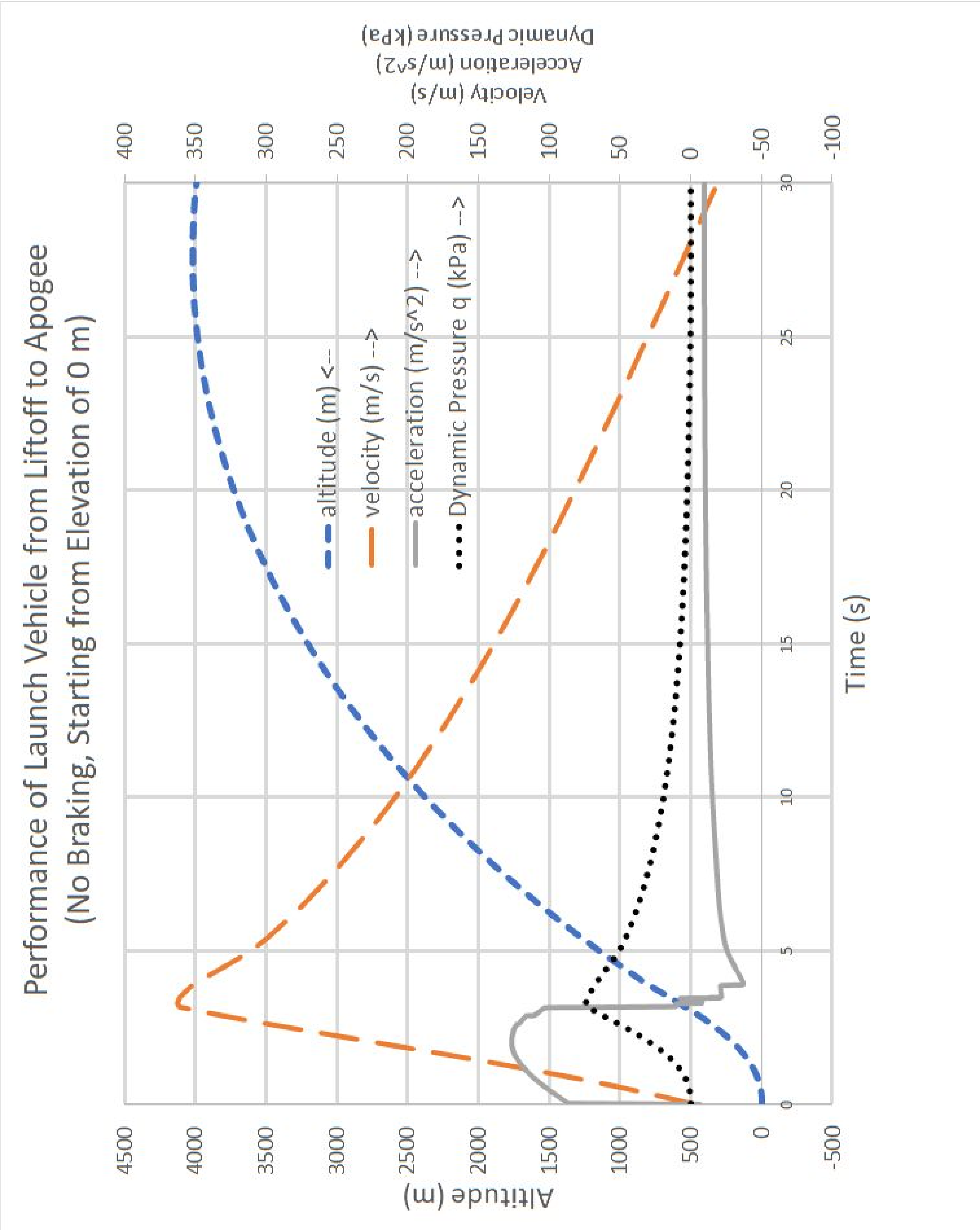


Performance of Launch Vehicle from Liftoff to Apogee (No Braking)
Altitude (m)
6000
5000
4000
3000
2000
1000
0
Time (s)
0
5
10
15
20
25
30
Velocity (m/s)
Acceleration (m/s^2)
Dynamic Pressure (kPa)
400
350
300
250
200
150
100
50
0
-50
-100
altitude (m) <--
velocity (m/s) -->
acceleration (m/s^2) -->
Dynamic Pressure q (kPa) -->

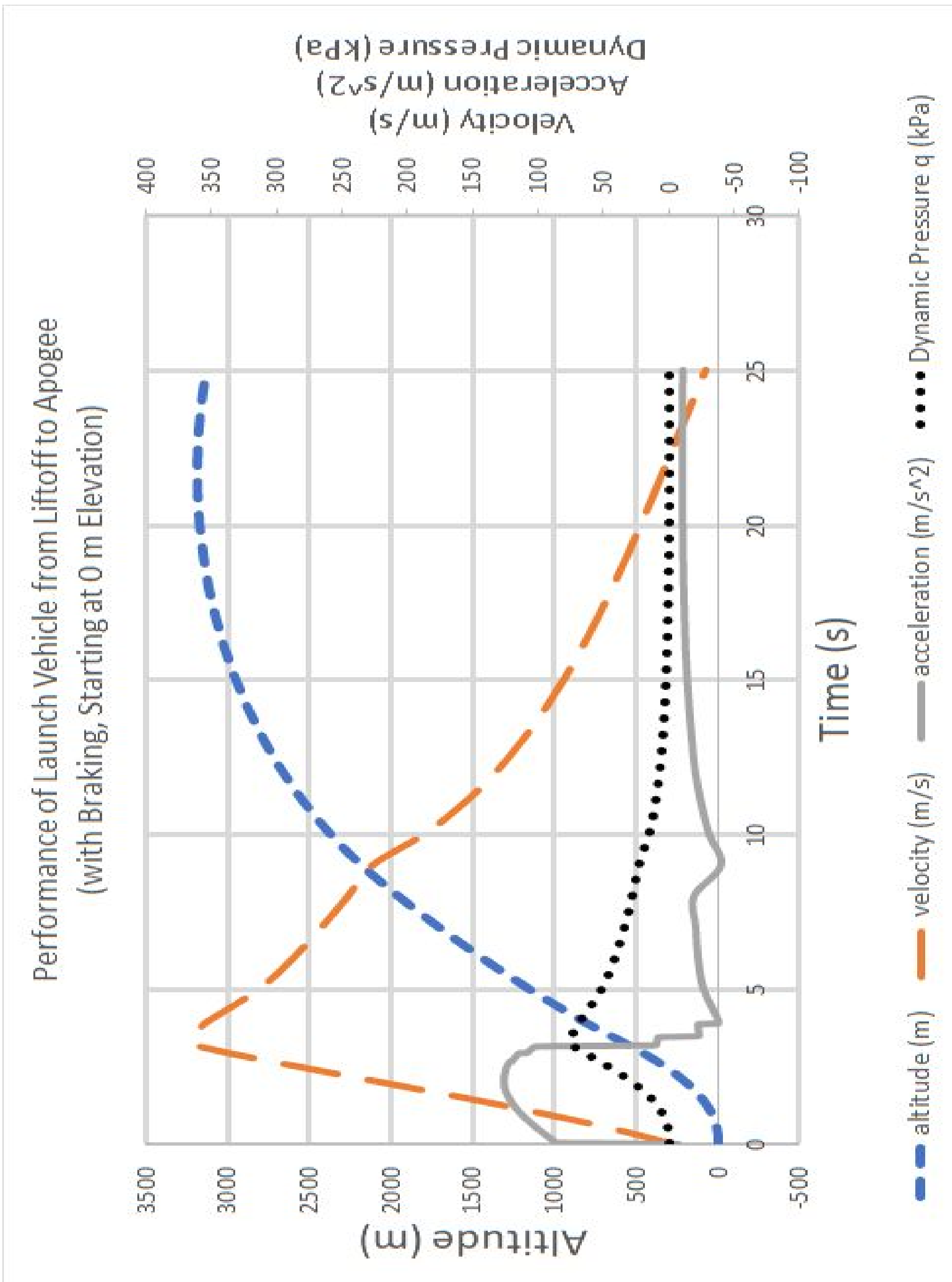
This simulation takes into account the initial elevation of Ransberg, the expected launch site for the competition, of about 1.07 km (3,504 ft) above sea level. The parameters assumed for this simulation is the thrust and mass profile changing with a time step of 0.02 sec generated by OpenRocket. From these assumptions, the instantaneous velocity, acceleration, altitude, and dynamic pressures of the Launch Vehicle at each time step are calculated using Euler Integration Method in Excel. After the burnout time of about 3.896 sec, a new time step of 1 sec is used to simplify the simulation and facilitate the analyzing process after the data is generated. To further increase the accuracy of the simulation, a profile of the Launch Vehicle's Coefficient of Drag with respect to Mach Number is generated by DATCOM and applied to the simulation. The results show the Launch Vehicle reaching an apogee of 5.4 km (17,710 ft) after about 30 sec since take off. This does not correlate well with the maximum altitude predicted by OpenRocket of about 13,000 ft. A possible explanation for this 4,000 ft difference in altitude could be due to the initial assumption made of launching 3,504 ft above sea level. Another possible explanation is that since the Launch Vehicle achieved a highest Mach of about 1.1, it has to go through the Transonic regime, which is difficult to simulate accurately.

A new scenario is then generated to solve the difference in altitude problem. This scenario change the initial altitude to 0 m. The results shown below are much closer to the OpenRocket altitude prediction. The highest altitude reached in this scenario is about 4 km (13,100 ft), which is very close to the 13,000 ft prediction from OpenRocket. Therefore, the assumption of 0 m initial altitude will be applied when generating a braking simulation for the Launch Vehicle.

To simulate braking, the Cd profile for the Launch Vehicle is changed using DATCOM. The initial assumptions and Cd of the Launch Vehicle up until the event of braking is unchanged and the new Cd profile will be applied after the braking occurs. In addition, the braking event is assumed to happen instantaneously, meaning there is no delay in time when the canard is deflected. Furthermore, the cannard is assumed to deflect to 15° and stay there rather than deflecting at a small degrees per second. It is not ideal to assume the braking event happens this way because deflecting instantly to 15° would introduce a huge amount of stress onto the canard's shaft. There is also a possibility that the motor cannot generate enough Torque to move the canard at a large increment of angle in such a small amount of time, which will cause the motor to stall and the braking system to fail consequently thereafter. These new assumptions are initially made to help understand the behaviors of the Launch Vehicle when braking, such as the declaration characteristics of the Launch Vehicle and the reduction in altitude and total flight time. Once a better understanding of this braking event is achieved, the team will be able to vary the amount of deflected angles over time to ensure that the braking system will not fail. The Launch Vehicle time of brake is decided from inspection of the initial non-braking trajectory to ensure that the Launch Vehicle would be able to reach the targeted altitude of 10,000 ft, a requirement from the FAR 1030 competition.


Performance of Launch Vehicle from Liftoff to Apogee
(No Braking, Starting from Elevation of 0 m)
altitude (m) <--
velocity (m/s) -->
acceleration (m/s^2) -->
Dynamic Pressure q (kPa) -->
Altitude (m)
Velocity (m/s)
Acceleration (m/s^2)
Dynamic Pressure (kPa)
Time (s)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
400
350
300
250
200
150
100
50
0
-50
-100
0
5
10
15
20
25
30

For this simulation, the braking occurs at time t = 9 sec from takeoff, where the Launch Vehicle is at an altitude of 2.2 km (7,200 ft), traveling at Mach 0.68. The Launch Vehicle reached a maximum altitude of 3.1 km (10,450 ft) before descending at time t = 22 sec, which is very close to the targeted altitude of 10,000 ft. A graph of the trajectory simulation is shown below. To improve this simulation to a closer altitude to 10,000 ft, the time when braking occurs and braking at an angle increment per second will be further explored throughout Winter Break.



The team is in the process of learning about missile simulation, trajectory simulation, and exploring alternatives to employ Quaternions instead of Euler Angles.

- Conceptual Dynamic Verification

As of current, the Guidance, Navigation, and Control Team is creating the Free Body Diagram to begin our Flow Chart for coding. There has been some misunderstandings involving the coordinate systems. The Free-Body-Diagram currently accounts for two-dimensional forces in two coordinates.

Vehicle Coordinate System

a. Vehicle Body System: x,y,z origin at C.M.
    i. X-axis: vehicle roll axis, positive up
    ii. Y-axis: vehicle pitch axis, positive out of paper
    iii. Z-axis: vehicle yaw axis, in pitch plane
b. Wind System
    i. Velocity direction = wind axis
c. Inertial Coordinates
    i. Vertical, horizontal = inertial coordinates

List of Symbols

∞ = velocity vector

$\boldsymbol{\alpha}$ = angle of attack

γ = flight path angle (90° ~ braking work properly to make LV ascent straight up)

θ = pitch angle

L = Lift

D = Drag

F_{az} = lateral aerodynamic force (along vehicle z-axis)

F_{ax} = axial aerodynamic force (along vehicle x-axis)

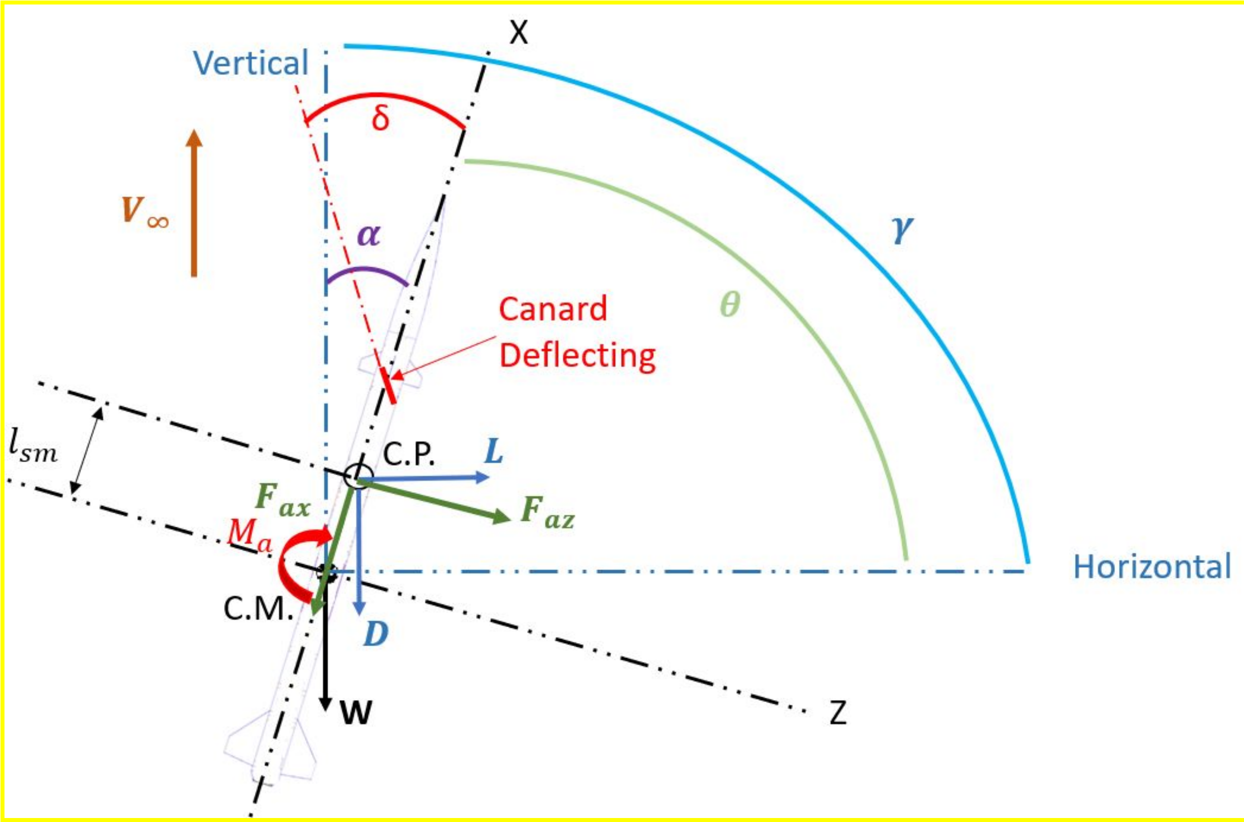
M_a = aerodynamic pitching moment

l_{sm} = length, static margin: CP to CM

q = dynamic pressure = $\frac{1}{2}\rho v^2$

d = vehicle diameter

S = vehicle reference area = $d^2/4$



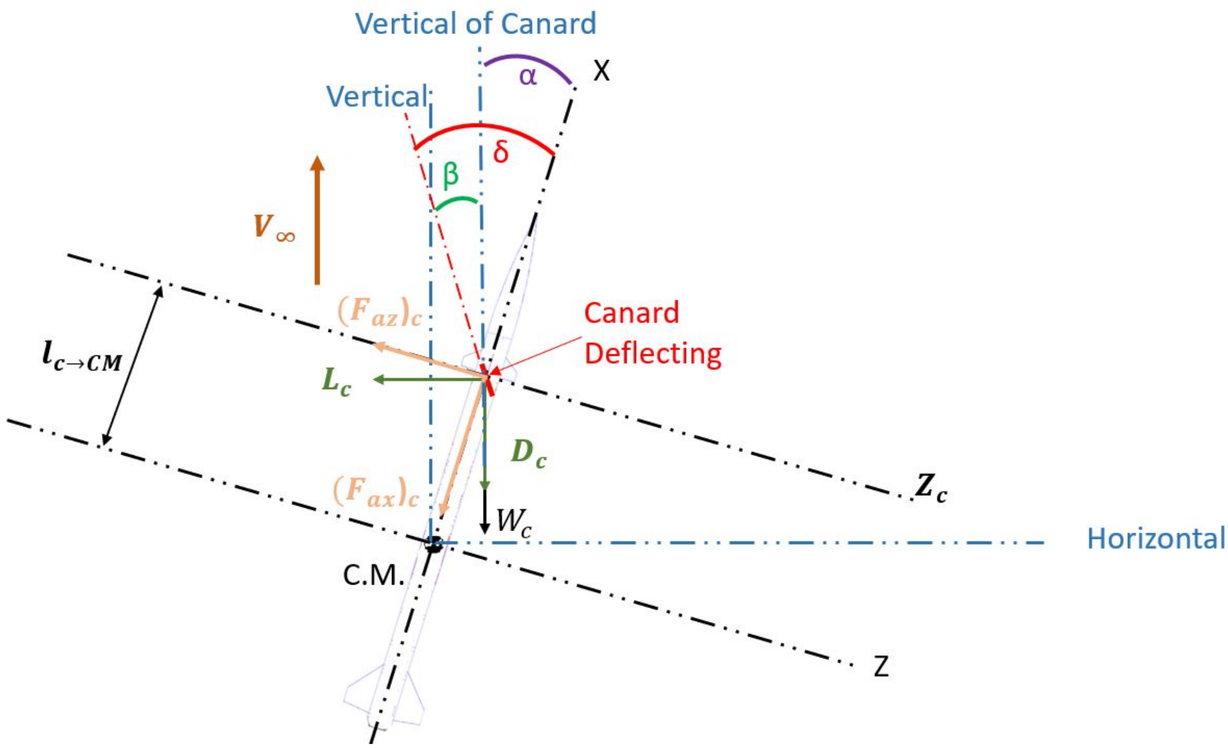
First, consider only the rocket without any canard deflection:

$F_{az} = C_z$ qS , where $C_z = (C_z)\boldsymbol{\alpha}$qS; (C_z) retrieve from DATCOM

$F_{ax} = C_x$ qS , where $C_x = (C_x)\boldsymbol{\alpha}$qS; (C_x) retrieve from DATCOM

$M_a = F_{az}\ l_{sm} = C_z$ qS l_{sm}

Then, consider the FBD of the canard deflecting



Where:
δ = canard deflection angle from canard body x-axis
β = canard deflection angle from vertical of canard = δ - **α**
$(F_{az})_c$ = lateral aerodynamic force of canard (along vehicle z-axis)
$(F_{ax})_c$ = axial aerodynamic force of canard (along vehicle z-axis)
W_c = weight of canard
L_c = Lift of canard
D_c = Drag of canard
$l_{c->CM}$ = distance from canard to cm
Z_c = canard Z-axis

We have:

$(F_{az})_c = -L_c \cos\boldsymbol{\alpha} + (W_c + D_c)\sin\boldsymbol{\alpha}$

$(F_{ax})_c = L_c \sin\boldsymbol{\alpha} + (W_c + D_c)\cos\boldsymbol{\alpha}$

$$M_{\dot{\theta}} = C_{M\dot{\theta}} \frac{qd^2S}{2v} \dot{\theta}$$

Where:
$L_c = (C_L)$ qS = (C_z) (δ - **α**)qS
$D_c = (C_D)$ qS = (C_D) (δ - **α**)qS

When summing the forces of the canard and rocket body, the resultants Equation of Motion (EOM) is:

$$\text{x: } (\sum F_x)_{rocket} = F_{ax} + (F_{ax})_c = m\ddot{x}$$

$$\text{z: } (\sum F_z)_{rocket} = F_{az} + (F_{az})_c = m\ddot{z}$$

$$\text{CM: } M_{canard} - M_a = (\sum F_x)_{rocket}\sin\theta + F_z\cos\theta = \text{mv}\dot{\gamma}$$

$$\text{Roll: } (F_{az})_c\left(\frac{d}{2}\right) + C_{M\dot{\theta}}\frac{qd^2S}{2v}\dot{\theta} = \text{Iy}\ddot{\theta}$$

Future Goals:

The Active Stabilization Guidance, Navigation, and Control Team intends to do the following tasks in the near future:

- Verify the EOM and improve it by introducing more degree of freedoms
- Perform the Laplace Transform to obtain transfer functions for the simulink model
- Support the Wind Tunnel Test involving the “GNC Module”
- Begin coding for “GNC Module” as soon as possible
- Finish Trajectory Simulation and integrate into MATLAB for increased accuracy

5.0 Propulsion

Goals: The Propulsion Subteam is tasked with certifying and designing the propulsion element for the Launch Vehicle. This goal is achieved by the following milestones.

- Select a propellant formulation that exhibits desirable characteristics
- Procure commercially-produced hardware that can accept self-made propellant
- Complete standardized procedures for manufacturing and testing
- Develop a Data Acquisition (DAQ) system that records thrust and chamber pressure
- Test a motor
- Fly a motor
- Research advanced technologies for future propulsion elements

Status Update: The team is currently performing within nominal parameters with respect to the schedule and anticipated events.

Completed Tasks: Utilizing thermochemistry software, an ideal mix of ingredients has been selected that will deliver healthy performance that balances efficiency, thrust, burn rate, and cost to manufacture. The contact that was made with an industry company last year has been maintained and has allowed us to procure our ingredients at less than 25% of the market cost. Procurement of the commercial hardware was completed after rigorous simulations that verified chamber pressure and thrust values that fell within the safety and performance margins dictated by the needs of the vehicle. In tandem, the team has worked to perfect Standard Operating Procedures (SOPs) for handling, mixing, integration, testing, and safety.

In Progress Tasks: The team is currently researching advanced technologies for nozzle fabrication and casing design. We have recently secured a donation from a plastics manufacturer that will aid in this development. Procurement has been progressing slowly but steadily, and the first mix has already been scheduled for late January. Motor hardware is expected to arrive by the first week of January. DAQ hardware is being selected and will be procured by the end of January.

Future Goals: Pending the arrival of all chemicals and hardware, the first motor will be manufactured and assembled. A successful testing campaign will ensue, comprising of one static fire test and 2 flight tests. The DAQ system is designed to be integrated both on a stand and on the flight vehicle to obtain data.

6.0 Payload

Goal:

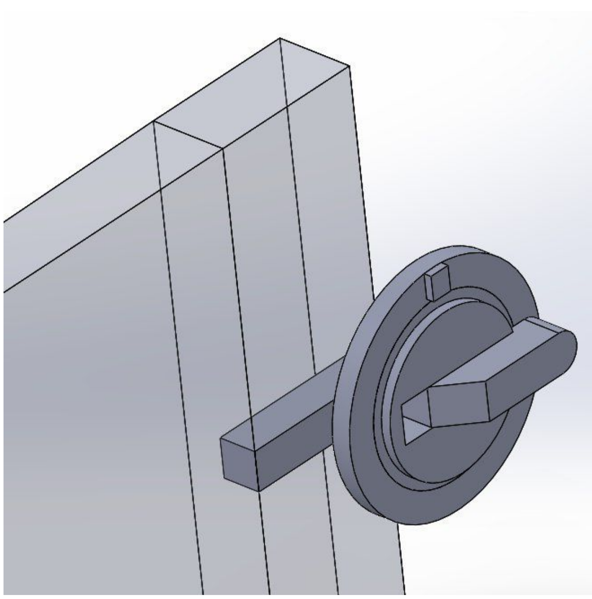
The goal for the payload team was to verify competition requirements, design payload that meets the requirements, creating a prototype to validate the design, and look into the electronics required for autonomous flight.

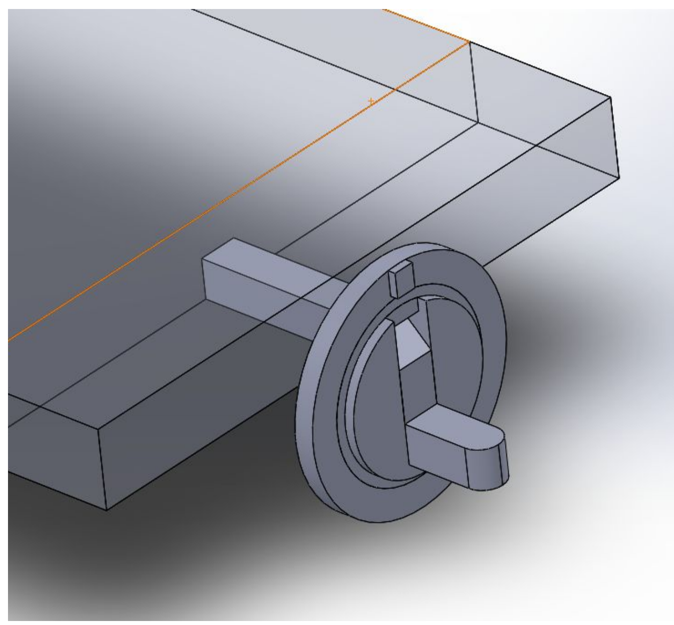
Status Update:

The payload team is on schedule. An autonomous glider has been selected for payload. Preliminary payload design has been completed. Manufacturing of folding wing mechanism is under way, and we are looking into the required electronics

Completed Tasks:

- Come up with payload requirements that fit within competition regulations
- Design folding wing mechanism for the prototype (pictured below)





In Progress Tasks:

- Manufacture parts for folding wing mechanism
- Build folding wing prototype
- Work out what electronics will be required for autonomous flight

This glider will be used to test the electronics; this glider is approximately the same size as the folding glider will be.

Future Goals:

The future goals of the Payload team are to design, manufacture, assemble and test the final glider payload.

7.0 Testing

Goal:

During the Fall semester, the Testing team's objectives for the were to develop testing procedures for

- Verification of calculated coefficients of interest in the Subsonic Wind Tunnel
- Backlash testing for the fin motor

More tasks will be added to meet the needs of the other subteams when data from testing is required as the project goes on.

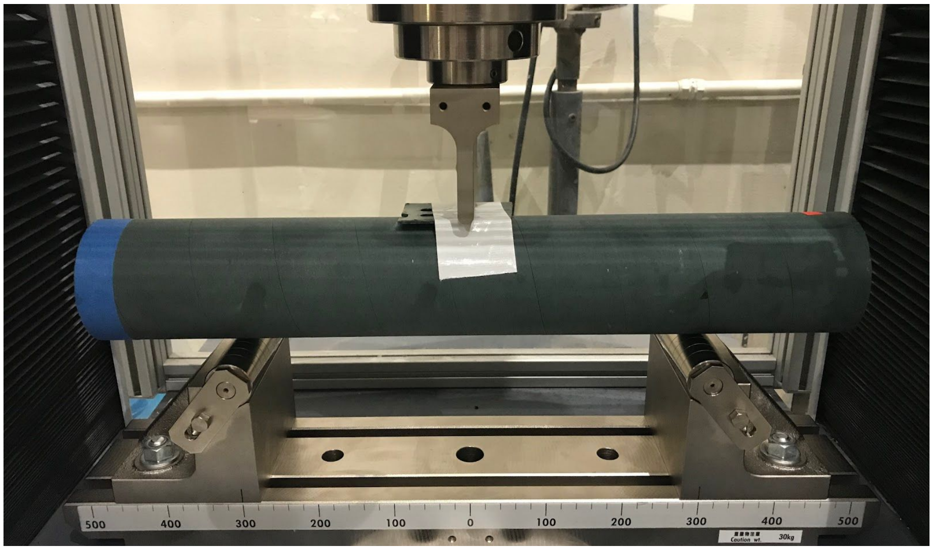
Status Update:

The Testing team is behind about five weeks due to the following considerations:

- The team members' homework and exams took dedicated time away from completing defined objectives
- The testing team was comprised of one person until about week 10, so the amount of work that could be completed was limited by that as well

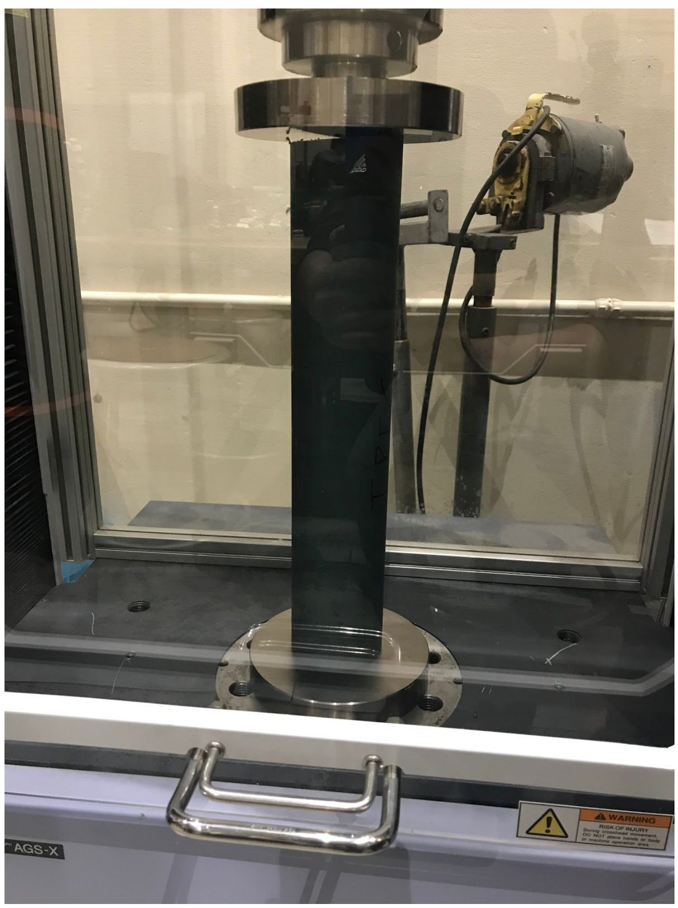
Completed Tasks:

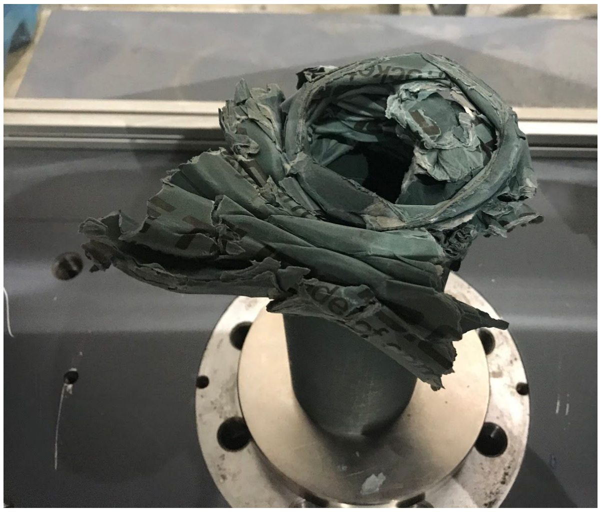
The Testing group has completed Blue Tube Bending Testing. This test was conducted to obtain the modulus of elasticity as well as the F_{TU} of blue tube in order to predict the resilience of the rocket to a bending moment. The tube was subjected to a direct shear force as shown below.



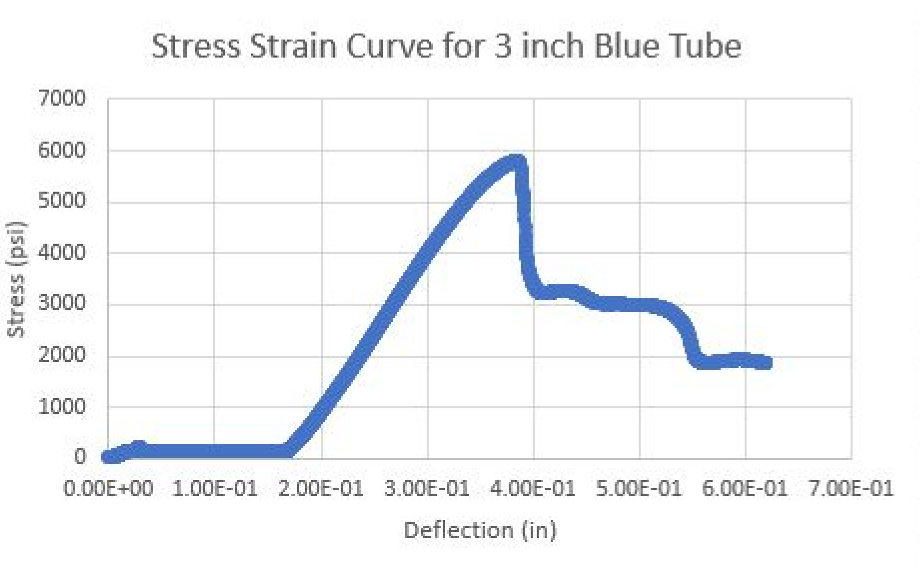
Blue Tube Bending via Direct Shear

The tube was also subjected to a compressive force as shown below.



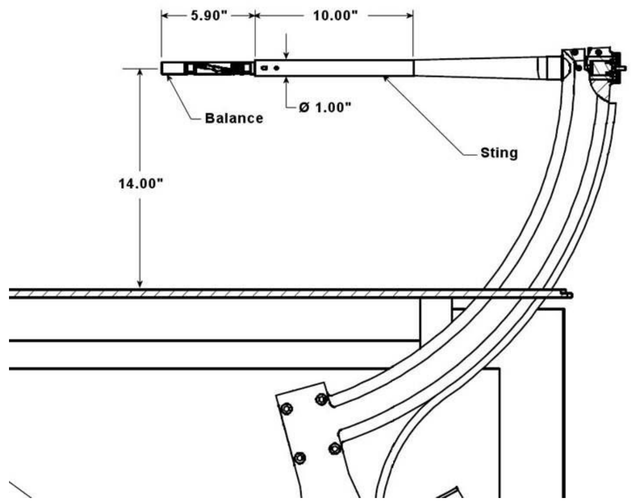


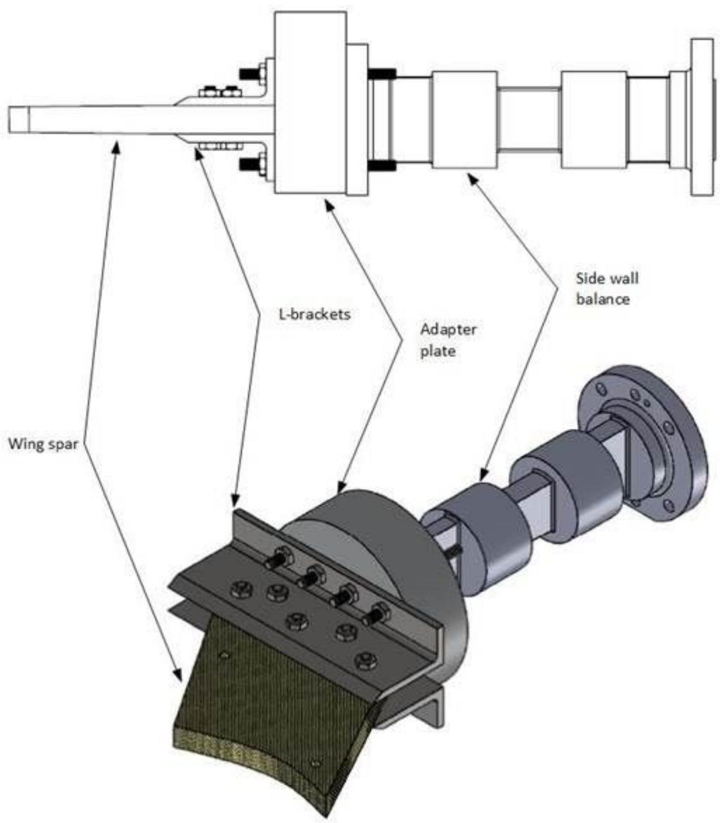
Blue Tube Subjected to Axial Compression



Above is the stress versus strain curve for a 3 inch blue tube test section under compression loads.

The Testing team has also acquired the dimensions and mounting requirements for the Subsonic Wind Tunnel.





In Progress Tasks:

Currently in progress tasks are:

- Writing the Subsonic Wind Tunnel testing procedure

- Writing the Backlash testing procedure

Future Goals:

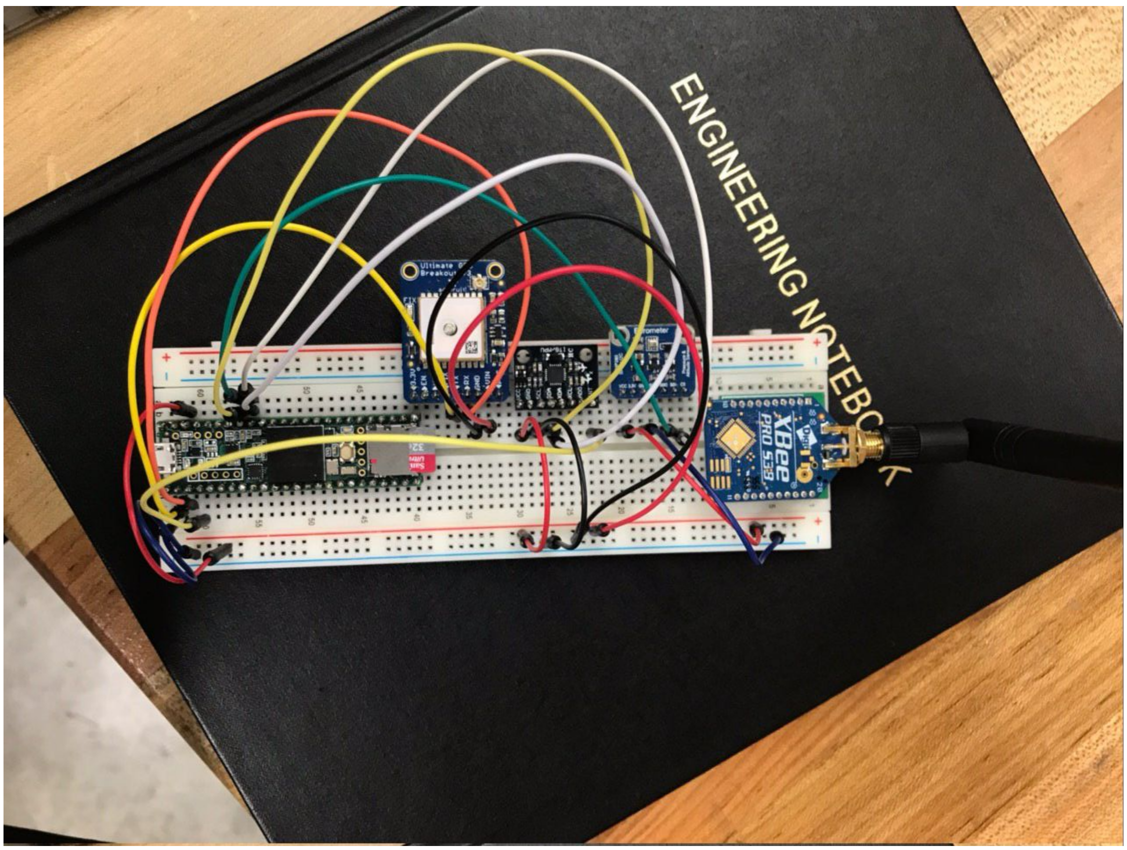
Over winter break, the testing team's goal is to:

- Complete the Subsonic Wind Tunnel testing procedure
- Complete the Backlash testing procedure

8.0 Avionics

Goal:

The goal of the Avionics team is to develop a working flight computer. This flight computer will have the capabilities of controlling the recovery charges and data acquisition. The flight computer will be recording pitch, yaw, roll, altitude, vertical velocity, latitude and longitude, and horizontal velocity. In addition, the module would be able to transmit live data through RF transmission.



Status Update:

Currently, the Avionics system is slightly behind schedule. This will be made up during the winter break and hopefully be completed by the time the new semester starts.

Completed Tasks:

The tasks that have been completed since the beginning of the semester is that all the sensors, barometer, IMU, and GPS, are working and the data from the sensors are being logged in the microSD card. In addition, the system has successfully transferred from the Arduino Mega system to work on the Teensy 3.5.

In Progress Tasks:
Currently, the Avionics team is working on getting RF communication working and finishing the programming for the controlling the recovery charges.

Future Goals:
Future goals for this team once the in progress tasks are completed is to transition it to a custom PCB or solder everything together so it can be used and tested in flight.

9.0 Systems

Goal:

- To develop, implement, and evaluate the launch vehicle system testing, including scripts, specifications, and procedures.
- Assist in preparing test schedules with the testing team and defining tasks.
- Prepare and present reports on system test results, assisting the team with system design.

Status Update:

- The system engineering team is about three weeks behind in updating schedules and project works due to:
  - Rapidly changing design configurations.
  - Team lead prioritizing aerodynamic works due to a lack of team members in the aerodynamic team. Since aerodynamic calculations is a key design driver, it has to be prioritized over other tasks.

Completed Tasks:

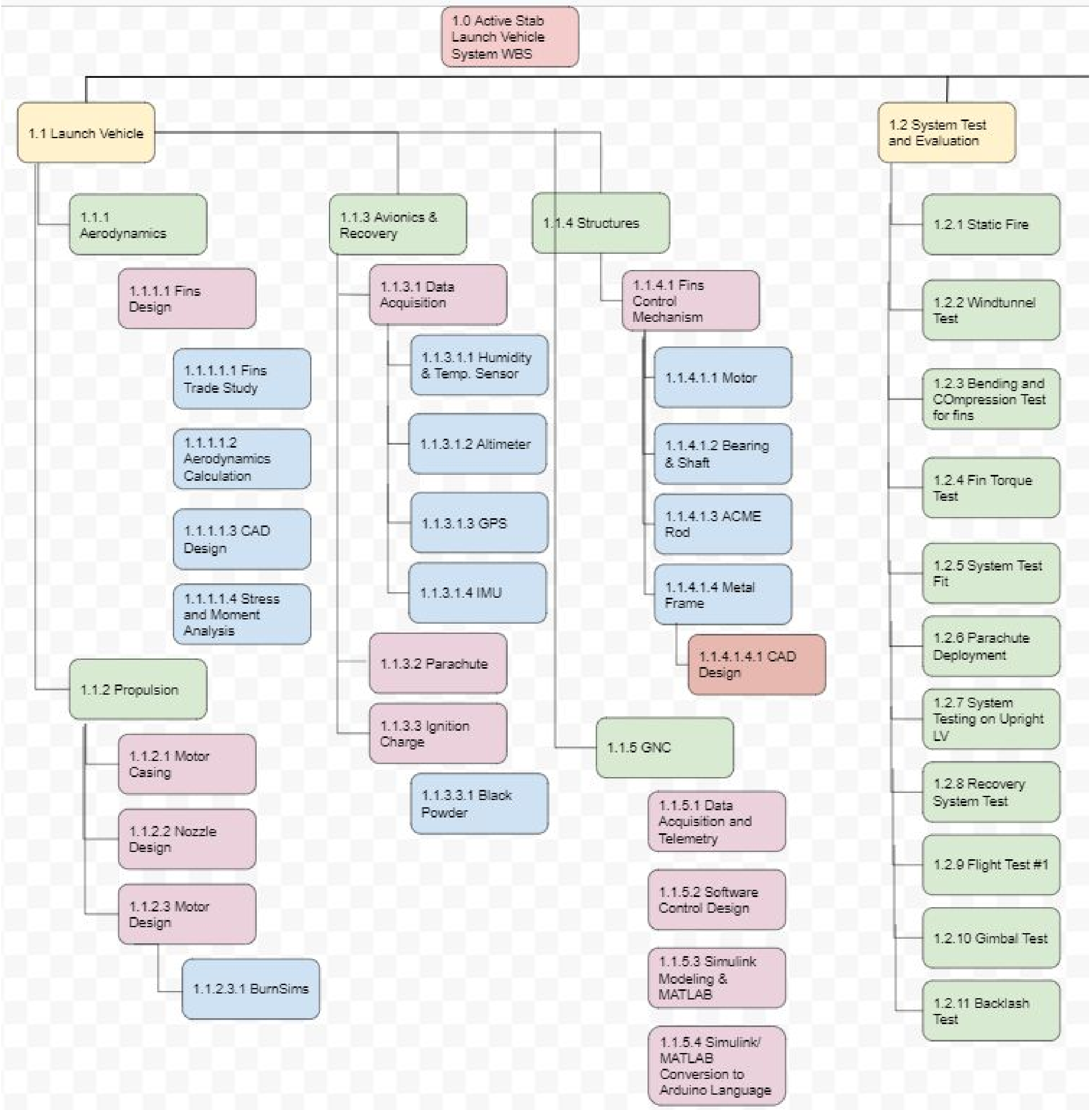
- Work Breakdown Structure (WBS) for the team, shown below
- Derived Requirements, mentioned in the goal portion at the beginning of the report
- Preliminary Gantt Chart (still need to be updated due to rapid changing in design configurations and tasks)
- A Con-Ops of the Launch Vehicle System, shown below. This Con-Ops includes:

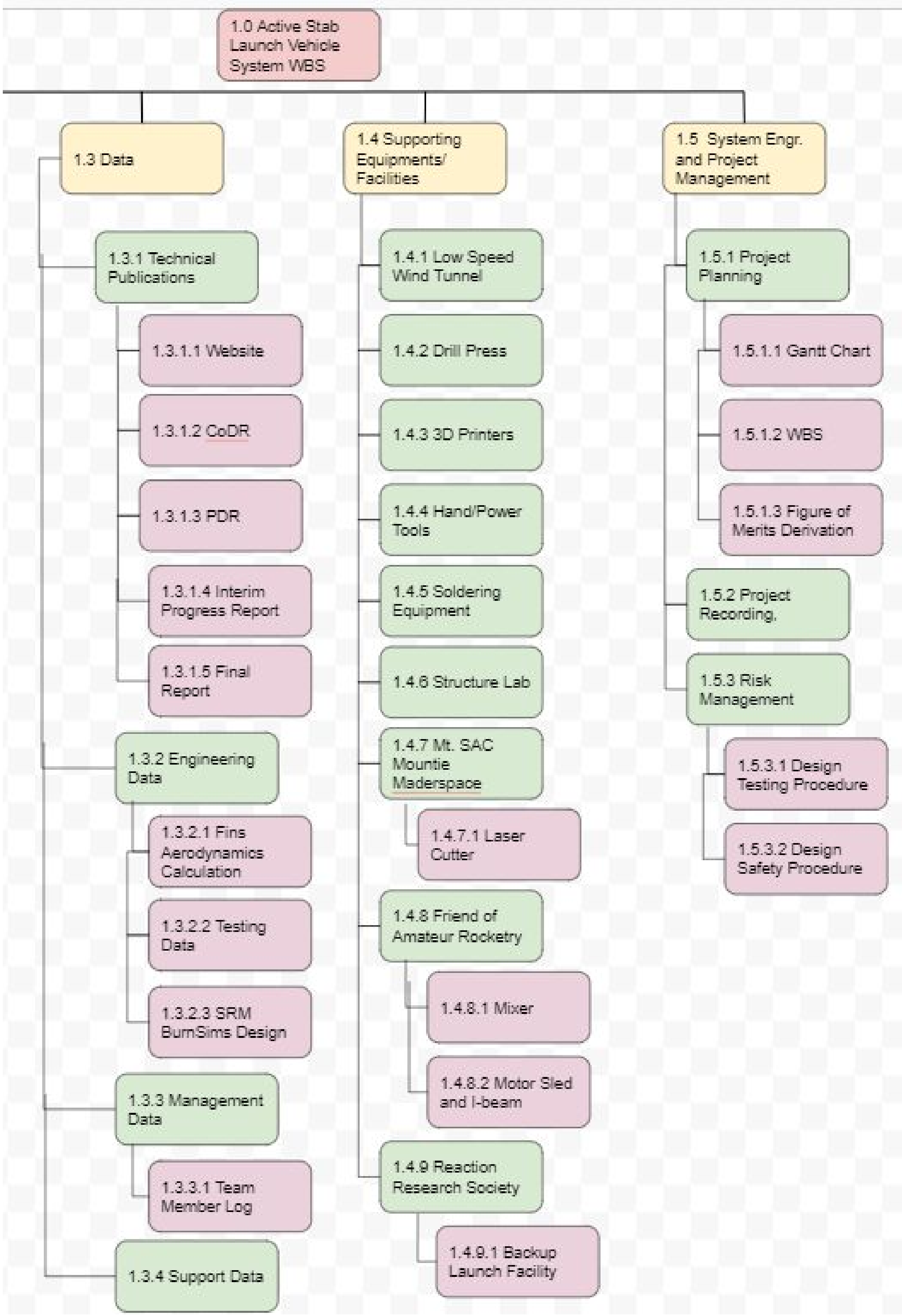
In Progress Tasks:

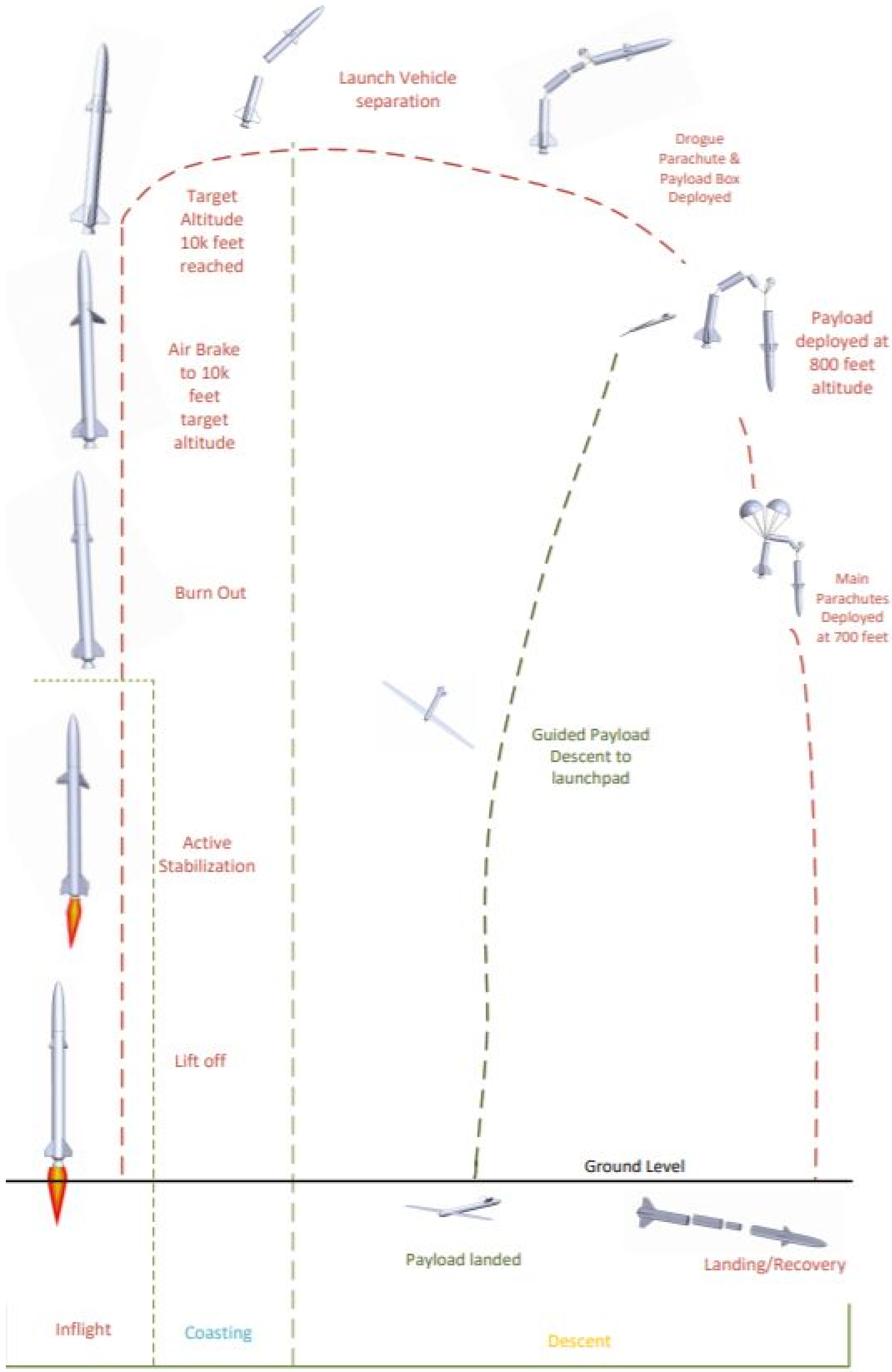
- Updating completed tasks to Gantt Chart
- Document completed tasks into a compliance matrix

Future Goals:

- Updating Gantt Chart weekly
- Assist Testing Team in wind tunnel testing during Spring Semester; document and analyze tests
- Organize team progress into a formal report due at the end of Spring Semester
- Finalizing Con-Ops by the end of Spring Semester with actual data such as velocity, altitude, and time at each event


1.0 Active Stab Launch Vehicle System WBS
1.1 Launch Vehicle
1.1.1 Aerodynamics
1.1.1.1 Fins Design
1.1.1.1.1 Fins Trade Study
1.1.1.1.2 Aerodynamics Calculation
1.1.1.1.3 CAD Design
1.1.1.1.4 Stress and Moment Analysis
1.1.2 Propulsion
1.1.2.1 Motor Casing
1.1.2.2 Nozzle Design
1.1.2.3 Motor Design
1.1.2.3.1 BurnSims
1.1.3 Avionics & Recovery
1.1.3.1 Data Acquisition
1.1.3.1.1 Humidity & Temp. Sensor
1.1.3.1.2 Altimeter
1.1.3.1.3 GPS
1.1.3.1.4 IMU
1.1.3.2 Parachute
1.1.3.3 Ignition Charge
1.1.3.3.1 Black Powder
1.1.4 Structures
1.1.4.1 Fins Control Mechanism
1.1.4.1.1 Motor
1.1.4.1.2 Bearing & Shaft
1.1.4.1.3 ACME Rod
1.1.4.1.4 Metal Frame
1.1.4.1.4.1 CAD Design
1.1.5 GNC
1.1.5.1 Data Acquisition and Telemetry
1.1.5.2 Software Control Design
1.1.5.3 Simulink Modeling & MATLAB
1.1.5.4 Simulink/ MATLAB Conversion to Arduino Language
1.2 System Test and Evaluation
1.2.1 Static Fire
1.2.2 Windtunnel Test
1.2.3 Bending and COmpression Test for fins
1.2.4 Fin Torque Test
1.2.5 System Test Fit
1.2.6 Parachute Deployment
1.2.7 System Testing on Upright LV
1.2.8 Recovery System Test
1.2.9 Flight Test #1
1.2.10 Gimbal Test
1.2.11 Backlash Test


1.0 Active Stab Launch Vehicle System WBS
1.3 Data
1.3.1 Technical Publications
1.3.1.1 Website
1.3.1.2 CoDR
1.3.1.3 PDR
1.3.1.4 Interim Progress Report
1.3.1.5 Final Report
1.3.2 Engineering Data
1.3.2.1 Fins Aerodynamics Calculation
1.3.2.2 Testing Data
1.3.2.3 SRM BurnSims Design
1.3.3 Management Data
1.3.3.1 Team Member Log
1.3.4 Support Data
1.4 Supporting Equipments/ Facilities
1.4.1 Low Speed Wind Tunnel
1.4.2 Drill Press
1.4.3 3D Printers
1.4.4 Hand/Power Tools
1.4.5 Soldering Equipment
1.4.6 Structure Lab
1.4.7 Mt. SAC Mountie Maderspace
1.4.7.1 Laser Cutter
1.4.8 Friend of Amateur Rocketry
1.4.8.1 Mixer
1.4.8.2 Motor Sled and I-beam
1.4.9 Reaction Research Society
1.4.9.1 Backup Launch Facility
1.5 System Engr. and Project Management
1.5.1 Project Planning
1.5.1.1 Gantt Chart
1.5.1.2 WBS
1.5.1.3 Figure of Merits Derivation
1.5.2 Project Recording,
1.5.3 Risk Management
1.5.3.1 Design Testing Procedure
1.5.3.2 Design Safety Procedure

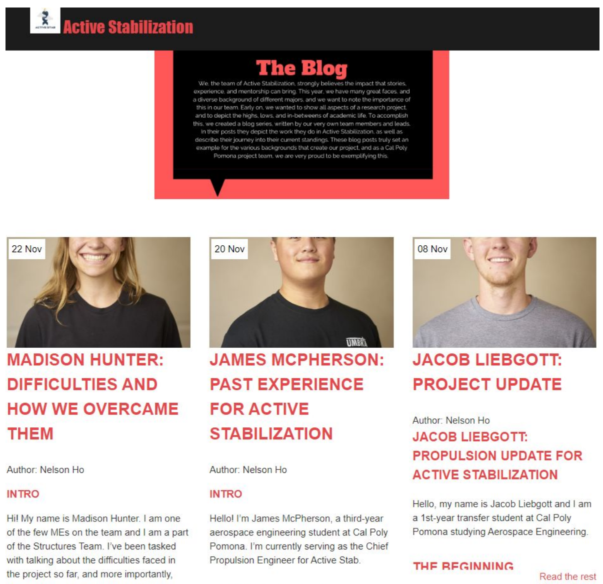

Launch Vehicle separation
Drogue Parachute & Payload Box Deployed
Target Altitude 10k feet reached
Air Brake to 10k feet target altitude
Payload deployed at 800 feet altitude
Burn Out
Main Parachutes Deployed at 700 feet
Guided Payload Descent to launchpad
Active Stabilization
Lift off
Ground Level
Payload landed
Landing/Recovery
Inflight
Coasting
Descent

10.0 General Updates

Goal: This section is to talk about updates that do not correlate to engineering decisions, but rather to the marketing decisions of the project.

Completed Tasks:

- Social media outreach
  - Facebook: https://www.facebook.com/cppactivestab/
  - Instagram: https://www.instagram.com/cppactivestab/?hl=en
- Lay out blog format: http://active-stabilization.com/blog.html



In Progress Tasks:

- Currently working on and improving the project website: http://active-stabilization.com/
- Improvement of Timeline
- Updating mission
- Improve general layout

Future Goals:

- Look for sponsors or companies willing to financial support the payload system
- Re-take team picture and biography
- More pictures