Airbrakes: Analysis + Integration PDR

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Purpose

Flight scoring is based on the demonstrated altitude achieved relative to target apogee and successful recovery.

One strategy in reducing the error between target apogee and flown apogee is the implementation of an Airbrake system.

The goal of the Airbrake is to lower apogee by removing kinetic energy via drag inducing elements.

The purpose of Analysis and Integration is predict the performance requirements of potential air braking systems, and successfully integrate the system within the launch Vehicle.

Requirements

Requirement Index	Requirement Explanation
SYS 1	All components on the LV that interface with the airframe shall have at least .005" clearance with the ID of the airframe
SYS 4	Structural components shall be designed to a minimum MoS of 0.5
STRUC 2	Launch vehicles shall be constructed to withstand the operating stresses and retain structural integrity under the conditions encountered during handling as well as rocket flight.
STRUC 6	Airframe joints which implement "coupling tubes" shall be designed such that the coupling tube extends no less than one body caliber on either side of the joint – measured from the separation plane.
STRUC 7	All airframe joints shall be stiff to prevent bending by more than 1°.
STRUC 20	FEA shall be conducted for all structural components of the LV.
STRUC 21	Manual stress calculations shall be conducted for all structural components of the LV.

Requirements

Requirement Index	Requirement Explanation
STRUC 23	Material trade analysis shall be conducted for all structural components.
STRUC 24	FMEA shall be conducted for all components and subsystems.
STRUC 36	All components shall be qualified by test to 1.25x limit load.
STRUC XX	The Airbrake mounts shall constrain the assembly during launch and recovery.
STRUC XX	The Airbrake mount shall fully withstand the 1.5x maximum induced drag force output, and no greater than 5x.

Comp Requirements

Requirement Index	Requirement Explanation
COMP 7.4.1	Control actuator systems (CAS) shall remain in a neutral state until: 7.4.1.1 The launch vehicle's boost phase has ended (i.e., all propulsive stages have ceased producing thrust). OR 7.4.1.2 The launch vehicle has crossed the point of maximum aerodynamic pressure (max Q) in its trajectory. OR 7.4.1.3.2 For 10K flights: an altitude of 2,000 m (6,500 ft) AGL.
COMP 8.2.1	Launch vehicles shall be constructed to withstand the operating stresses and retain structural integrity under the conditions encountered during handling and transportation and during rocket flight.
COMP 10.3.1	Launch vehicles shall maintain a dynamic stability margin of at least 1.5 body calibers,regardless of Cg movement and/or shifting center of pressure Cp location, from launch through the first recovery system deployment event.(Ascent Stability)
COMP 10.4.1	Launch vehicles shall not be "over-stable" during their ascent, defined as having a static stability margin >4 calibers or a dynamic stability margin during flight >6 calibers.

Comp Requirements

Requirement Index	Requirement Explanation
COMP 7.1.1	All launch vehicle active flight control systems shall be implemented strictly for pitch and/or roll stability augmentation, or for aerodynamic braking
COMP 7.1.2	Under no circumstances will a launch vehicle entered in the IREC be actively guided towards a designated spatial target.
COMP 7.1.4	Neutral state is defined as one which does not apply any moments to the launch vehicle (e.g., aerodynamic surfaces trimmed or retracted, gas jets off, etc.).
COMP 7.2.1	Launch vehicles implementing active flight controls shall be naturally stable without those controls being implemented

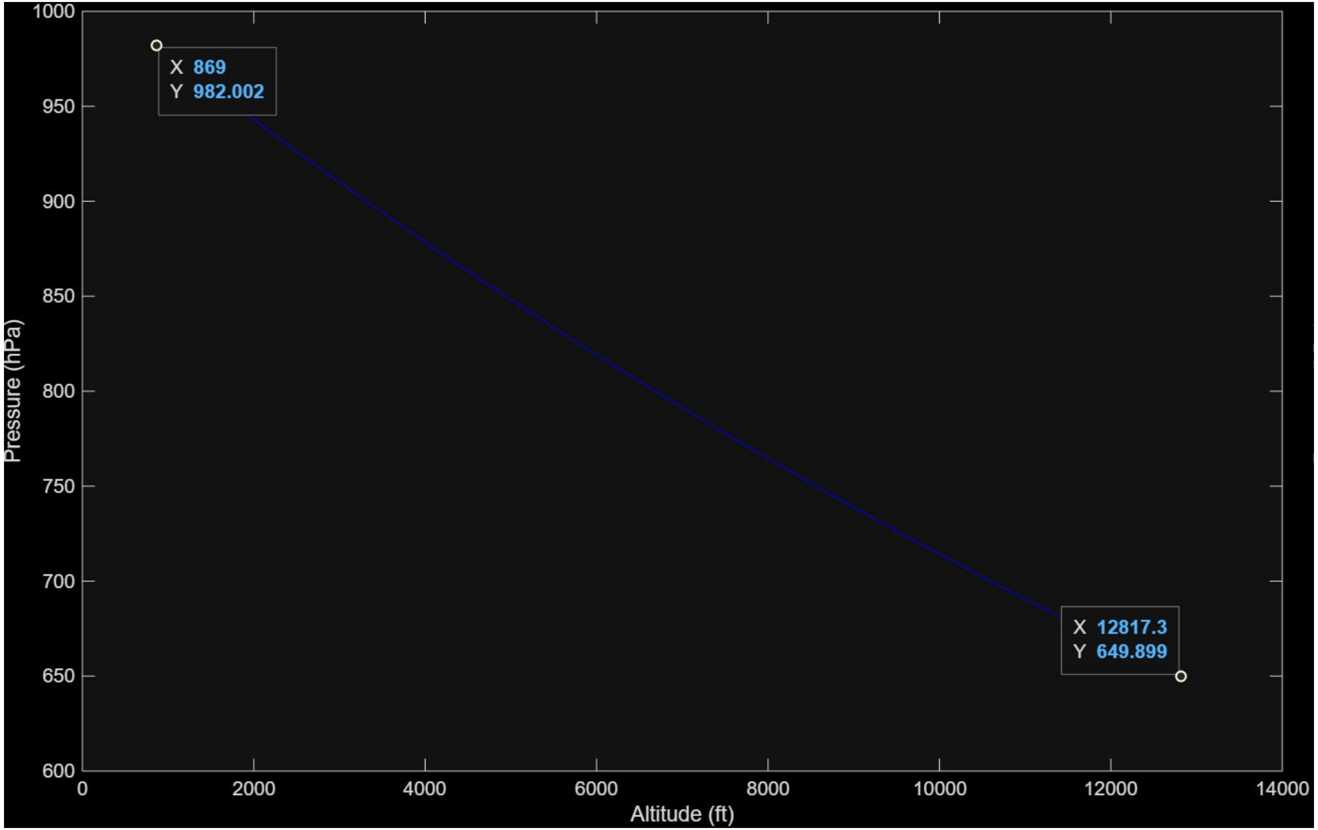
Atmospheric Model

- Model Assumptions
  - Temperature decreases literally with increase in altitude in accordance to the average environmental lapse rate
  - Pressure can be modeled using tropospheric barometric formula
  - Where
    - p_0=1013.25 hPa (Sea Level STP)
    - L = .0065 K/m (Avg. Lapse Rate)

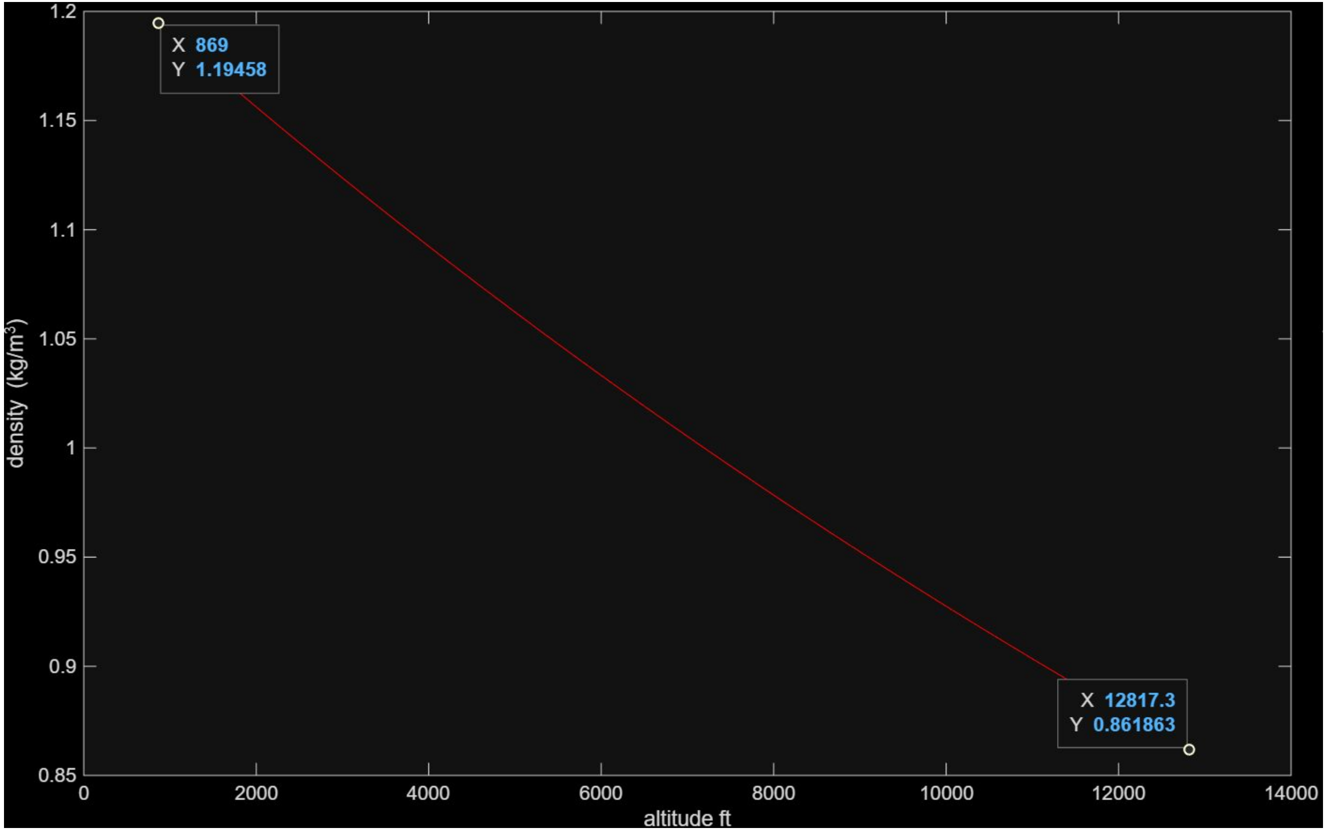
$$p = p_0 \cdot \left(1 - \frac{L \cdot h}{T_0}\right)^{\frac{g \cdot M}{R \cdot L}}$$

  - Treating (Dry) Air as an Ideal Gas
  - Density derived from Pressure and Temperature using Ideal Gas Relation

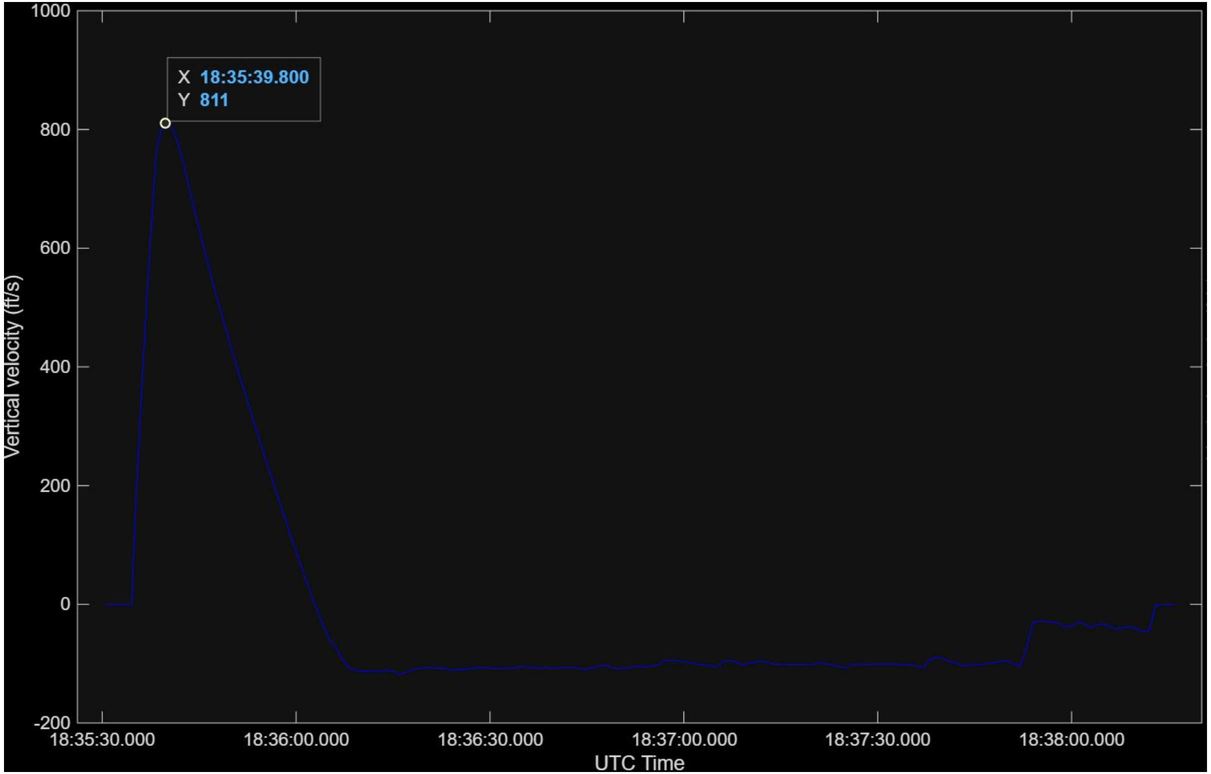
Pressure vs Altitude (ASL)



Density vs Altitude (ASL)



Velocity vs Time (Test Launch)

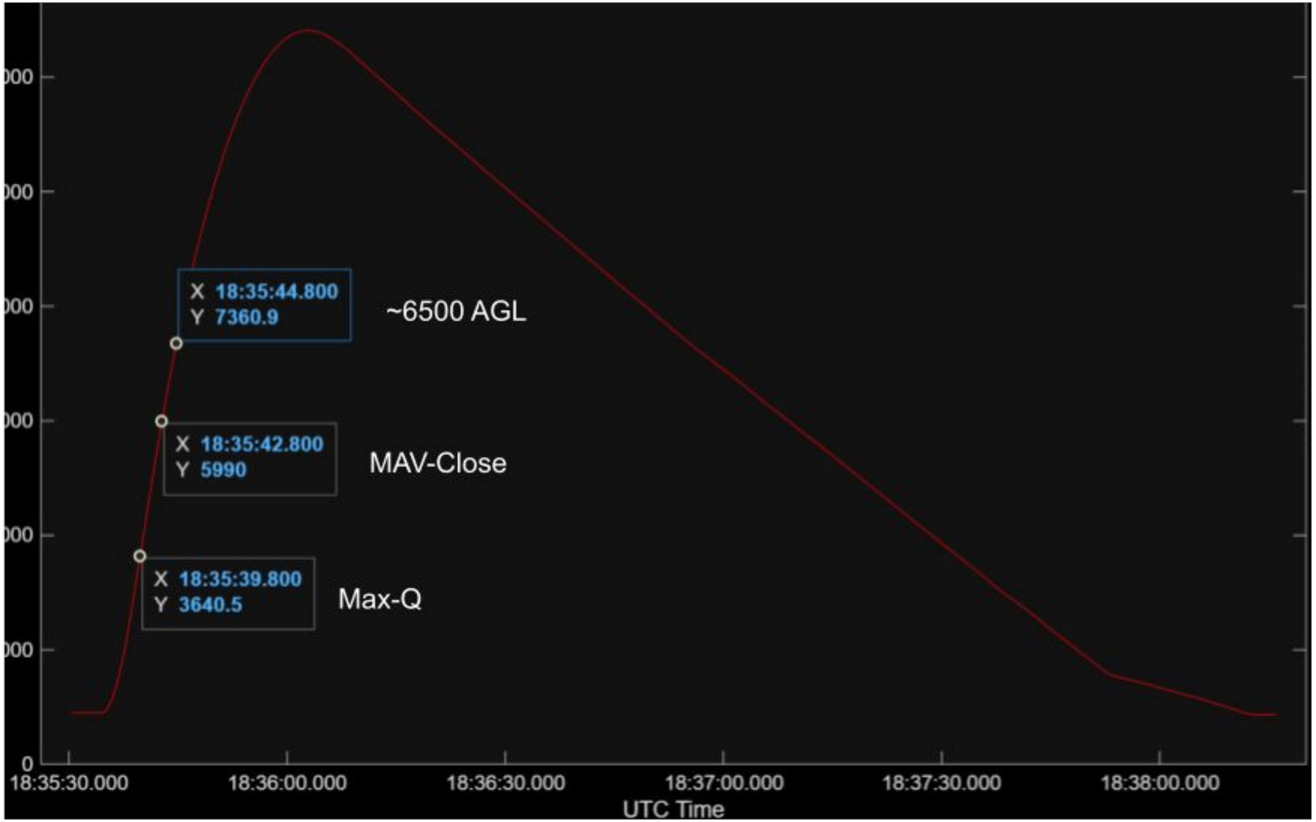


Max Velocity: 811 ft/s
Mach 0.72
T + 4.9s (18:35:39.8)

Aerodynamic Pressure vs Time (Test Launch)

Max-Q: 33.7 kPa
T + 4.9s (18:35:39.8)

Possible Deployment Conditions

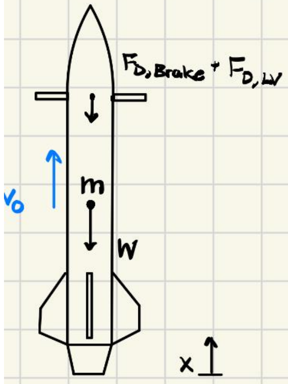


Deployment Condition Justification

Condition	Maximum Aerodynamic Pressure (Max-Q)	**Boost Phase Conclusion (MAV Close)**	Reaching Altitude of 6500 ft AGL.
Occurs	T + 4.9s	**T + 7.8s**	T + 9.8s
Pros	- Earliest deployment condition - Dense Atmosphere	**- Easier to model forces** **- Easy to determine during flight**	- Easy to determine during flight
Cons	- Difficult to model drag coefficients approaching transonic Mach Numbers - Harder to determine during flight.	**- Less time to effect drag on LV**	- Less time to effect drag on LV.

System Model

- Only force acting on rocket is gravity and pressure drag
- Motion of the Rocket is Purely Vertical (1D)
- Atmosphere Model Assumptions
- Superposition of Drag Forces
- Dry Mass of Andromeda = 50.12kg



$$\ddot{x}m = -F_{D,LV} - F_{D,BRAKE} - mg$$

$$\ddot{x} = -\frac{1}{2}\rho(x)\dot{x}^2\left(C_{D,LV} A_{LV} + C_{D,Brakes} A_{brakes}\right) - g$$

$$\begin{cases} x_2 = \dot{x}_1 \\ \dot{x}_2 = -\frac{1}{2}\rho(x)x_2^2\left(C_{D,LV} A_{LV} + C_{D,Brakes} A_{brakes}\right) - g \end{cases}$$

$$m = 50.12 \text{ kg}$$

Estimating Vehicle Drag Coefficient

Initial Condition: MAV Close

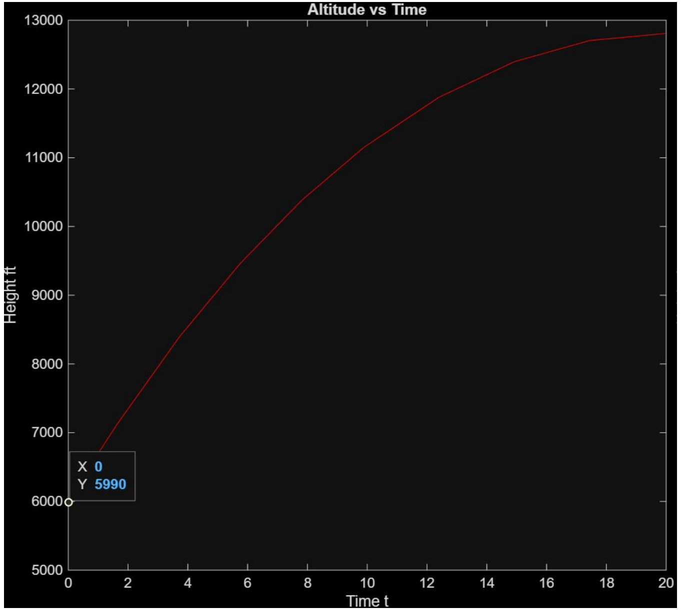
x_0= 5990 ft

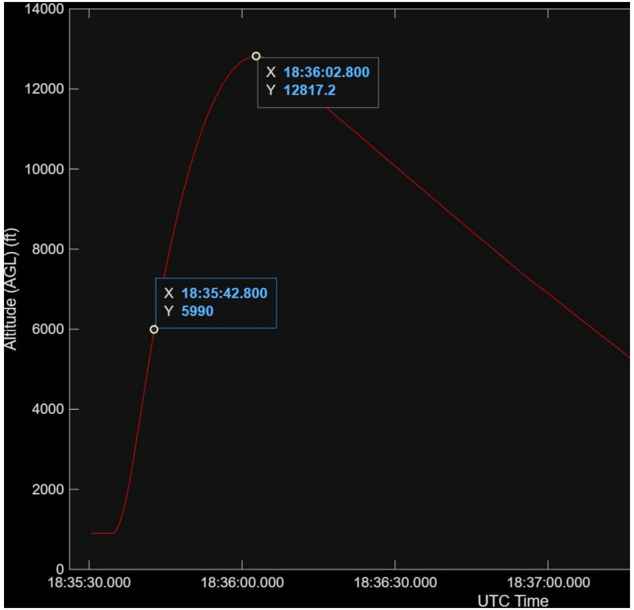
v_0= 731 ft/s

A_{brake}= 0.02 ft^2

A_{LV}= .196 ft^2

$C_{D,LV}$= .52





Brake Drag Coefficient

- How to best approximate the drag coefficient
- For now best estimate is 1.3
- Future: Determining C_D from tabulated values

For your design a drag coefficient need only be accurate within 20%. For your fluid environment (Mach 0.64 and high reynolds number) you can approximate the drag coefficient for bluff bodies to be constant and equal 1.3

Kirby Says

Performance Goals

Altitude Decrease Needed: $\Delta h = h_{max} - h_0$.

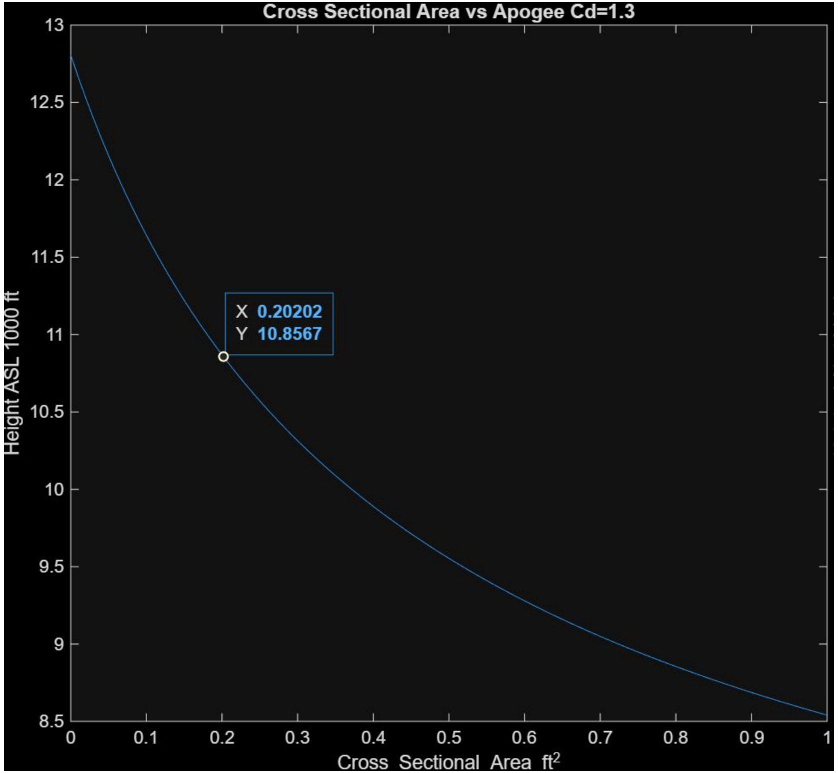
h_{max} = 12100 ft AGL - upper estimate for nominal apogee of launch vehicle

$h_0 = 10000$

$\Delta h = 2100$ ft

Determining Reference Area

- Sweep across a variety of Areas from 0 to 1 ft^2.
- Utilize numerical integrator to determine apogee.
- Identify area needed to achieve performance goal.
- A_{brake}= .202 ft

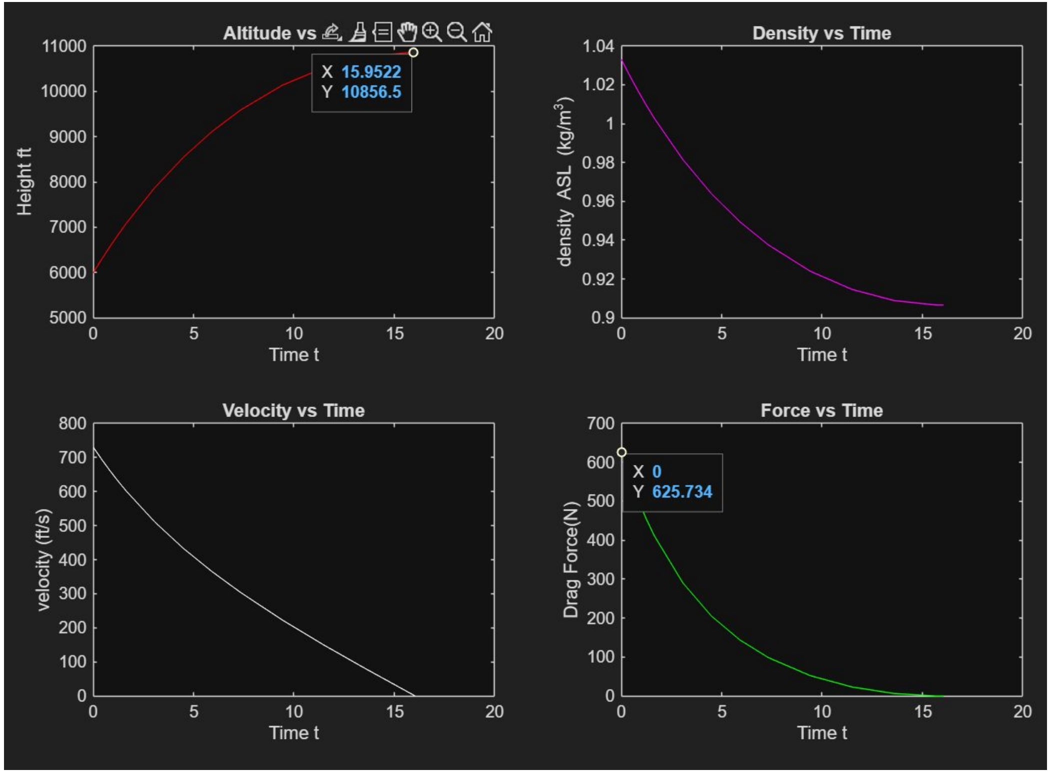


Recap: Modeling Performance of Airbrakes

- $C_{D,LV}$=0.52
- A_{LV}=.196ft^2
- $C_{D,brake}$=1.3
- A_{brake}=.202 ft^2

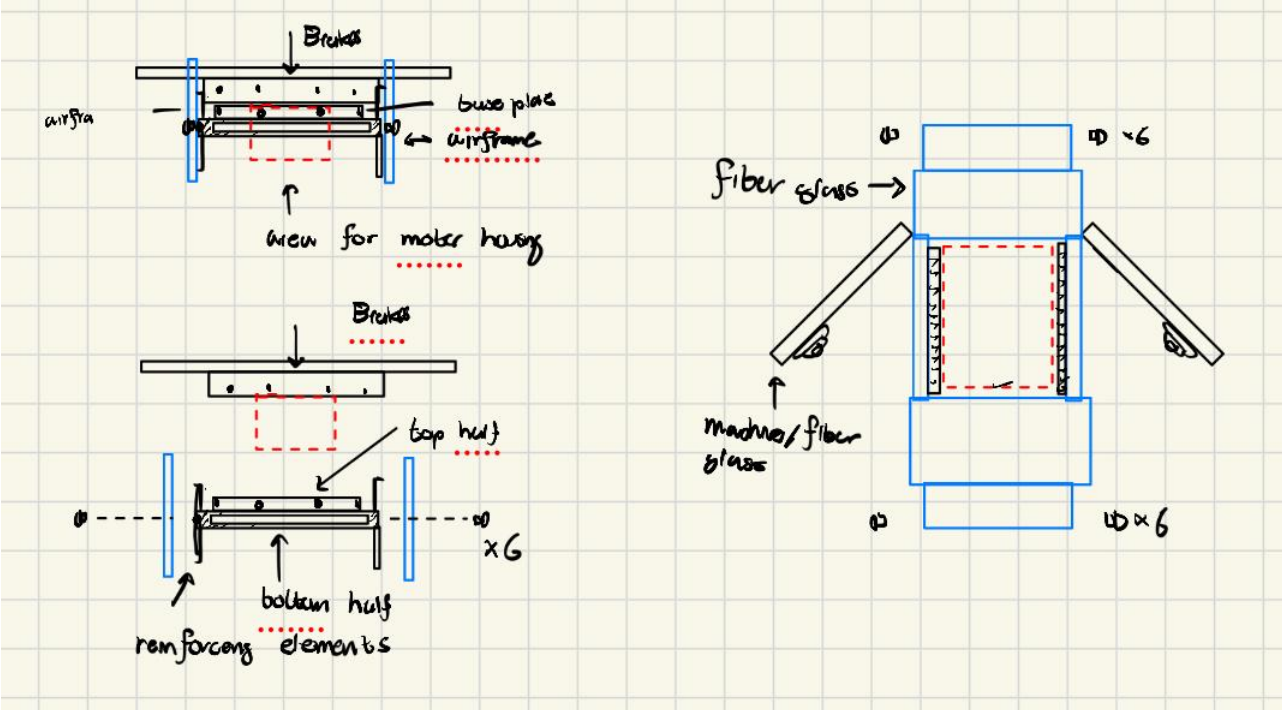
- Coast Duration: 15.86s
- F_{max}= 625.7 N

(Assuming instantaneous deployment)



Airframe Integration

- Transfer Load from brakes to Airframe. (Designed to 940 N)
- Reinforce Airframe



Commenting on Stability

- If hybrid forces the system closer to the fore of the LV, the change C_p effects can be offset with fins.
- Depends also on the mass of LV near the nose cone (payload)

Next Steps

1. Acquire Tabulated C_D values
2. Confirm tabulated values using CFD
3. Once mechanism has been finalized, starting CAD integration
4. Airframe Structural Analysis
5. Formalized the effects of Airbrake on center of pressure and stability.