Active Air-Braking System
Preliminary Design Review

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Society of Aeronautics and Rocketry

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Table 1: Commonly used acronyms.

Acronym	Meaning
ABS	Active Air-Braking System
CFD	Computational Fluid Dynamics
CFD	Computer Fluid Dynamics
PID	Proportional Integral Derivative
SOAR	Society of Aeronautics and Rocketry
USLI	University Student Launch Initiative

1 Introduction

The main purpose of the Active Air-Braking System (ABS) is to reduce the altitude error between the predicted altitude at apogee and actual recorded altitude at apogee to a minimum. USF's Society of Aeronautics and Rocketry has the ambitious goal to achieve a spot within the top five teams in the 2025 University Student Launch Initiative (USLI) formerly known as Nasa Student Launch. To achieve this goal, the team must maximize points in crucial categories. One of the most crucial criteria for USLI is altitude. Altitude alone is one of the most heavily weighted categories, it consists of 10% of the total scoring. Designing an ABS system capable of controlling altitude is imperative for maximizing points as the altitude scoring is a variable with the potential to make or break a team's overall score.

The ABS will consist of 4 plates that extrude from the airframe, generating a sudden increase in drag. Through the use of a PID system, the degree of deployment and total drag will be changed, decreasing the maximum altitude and converging to the desired apogee. Powered by two independent lipo batteries, the ABS generates a maximum of 160 N of additional drag at Mach 0.6. It is expected that the inclusion of this system in the rocket entry for USLI 2025 will provide a significant scoring advantage in the altitude category.

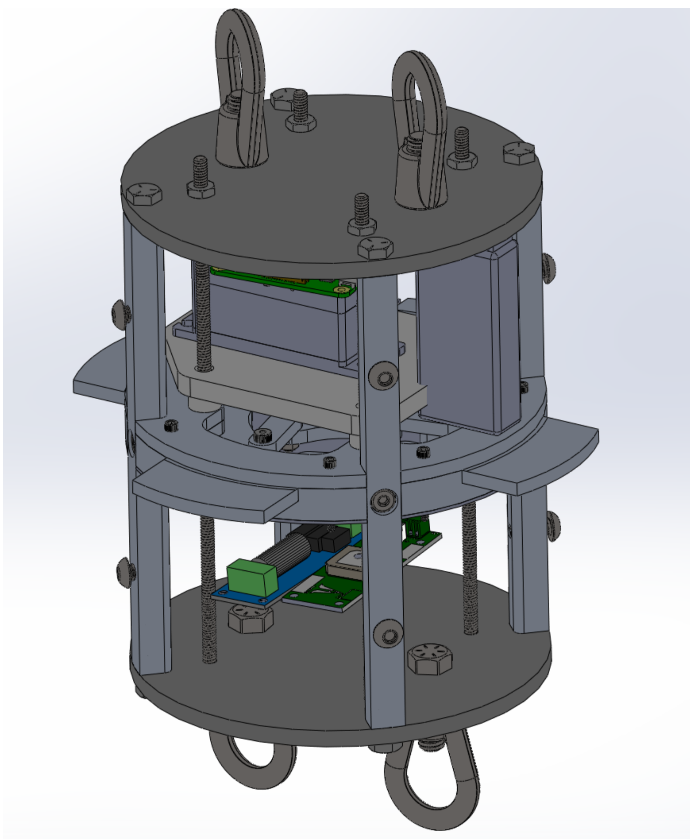

Figure 1: Preliminary Airbrakes Design

2 Requirements and Constrains

Table 2: Requirements for the Active Air-Braking System (ABS).

Req. ID	Description	Rationale	Parent Req	Verification Method
ABS-1	The ABS shall be capable of producing additional drag	Additional drag reduces the maximum apogee of the rocket	-	Test
ABS-1.1	The ABS shall extrude plates to locally increase the reference area and drag coefficient	Increased reference area and drag coefficient directly correlate to total drag force	ABS-1	Inspection
ABS-2	The ABS shall be capable of regulating the additional drag	The additional drag needs to be closely controlled to converge the altitude to a specific value	-	Test
ABS-2.1	The total drag force shall be known by the team at any actuation degree and velocity	How close the predicted values are to the actual ones directly correlates to the performance of the ABS	ABS-1.1, ABS-2	Analysis
ABS-2.2	The ABS shall be able to react at XX Hz	A high reaction time will allow the ABS to re-adjust the deployment degree according to new data	ABS-2	Inspection
ABS-3	The ABS shall be able to be on through the duration of apogee	With no power, the airbrakes won't run	-	Test
ABS-3.1	The electronics shall be able to last for 3 hours on the launch pad	Derived requirement from NSL Handbook	ABS-3	Test
ABS-4	The ABS total mass shall not be greater than 6 lb	Excessive mass will compromise other subsystems as well as increasing the difficulty of the mission	-	Inspection

3 Drag

In order to compute the impact of the ABS design on the drag force using a Computer Fluid Dynamics (CFD) program, it is important to understand the fundamentals of drag and how it affects the performance of the rocket. The following is the governing equation for drag force on an object:

$$F_D = 0.5u^2\rho C_d A \tag{1}$$

Where FD is the drag force, rho is the density of the fluid, u is the velocity of the fluid relative to the object, CD is the drag coefficient, and A is the cross-sectional area of the object. To find the drag force caused by the ABS system, the fluid density used is the density of air, which is approximately 1.204kg/m$\hat{3}$ for dry air at 20°C. The velocity is the instantaneous velocity of the rocket, assuming wind speeds are negligible. The cross-sectional area is the cross section of the airbrake panels.

The drag coefficient varies wildly as a function of speed, viscosity, roughness, and most importantly the shape of the object. Considering the sheer difficulty in predicting the drag force of any given airbrake design using theory alone, a CFD simulation was used instead to model the fluid flow through the different ABS iterations in order to find the greatest possible drag coefficient for a finite area, thus yielding the greatest drag force.

4 Mechanical Design

4.1 Linkage Assembly

The Link hub assembly is the core design of the ABS. Being composed of two plates, 5 links and 4 plates, this assembly is in charge of transforming the rotational movement of the servo into linear motion. This linear motion pushes the plates outside of the airframe.

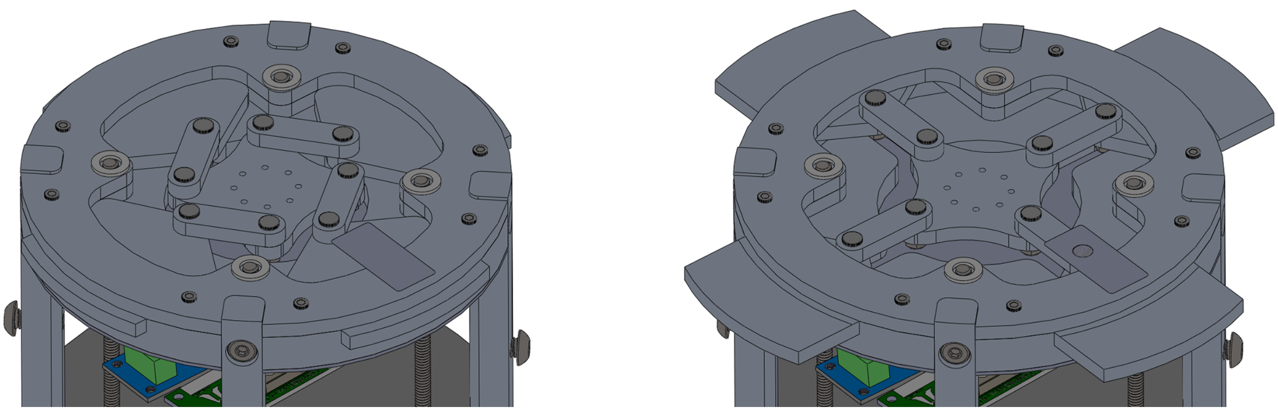

Figure 2: Extension Mechanism

4.1.1 Drag Plate

The plates, often referred as flaps, are what is being extruded out of the airframe, generating all the extra drag. These flaps have a thickness of 0.2 in. This part is load bearing as it is receiving the full force of air resistance. The drag plates were designed to sit flushed with the airframe in it stowed configuration. Given that the drag plates are the only surface in contact with the airflow, the reference area is the section that extrudes from the rocket.

Shoulder bolts will be attached to the drag plate and connect them to the links, allowing for a pinned connection. The geometry was optimized to fully retract the drag plates while still maximizing the reference area. As shown in Figure 6, there is no mechanical collision.

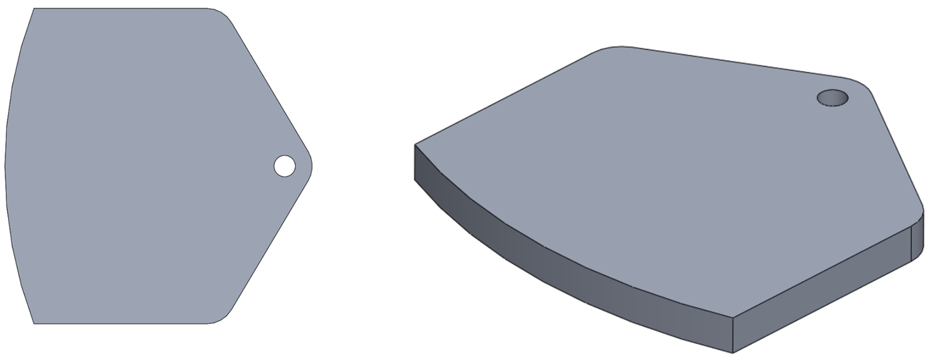

Figure 3: Drag Plate

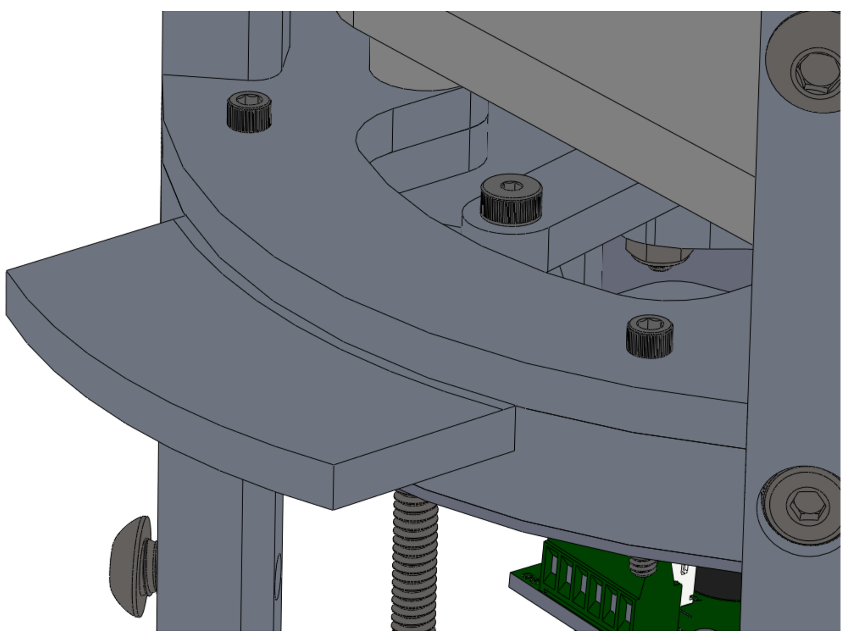

Figure 4: Extension closeup

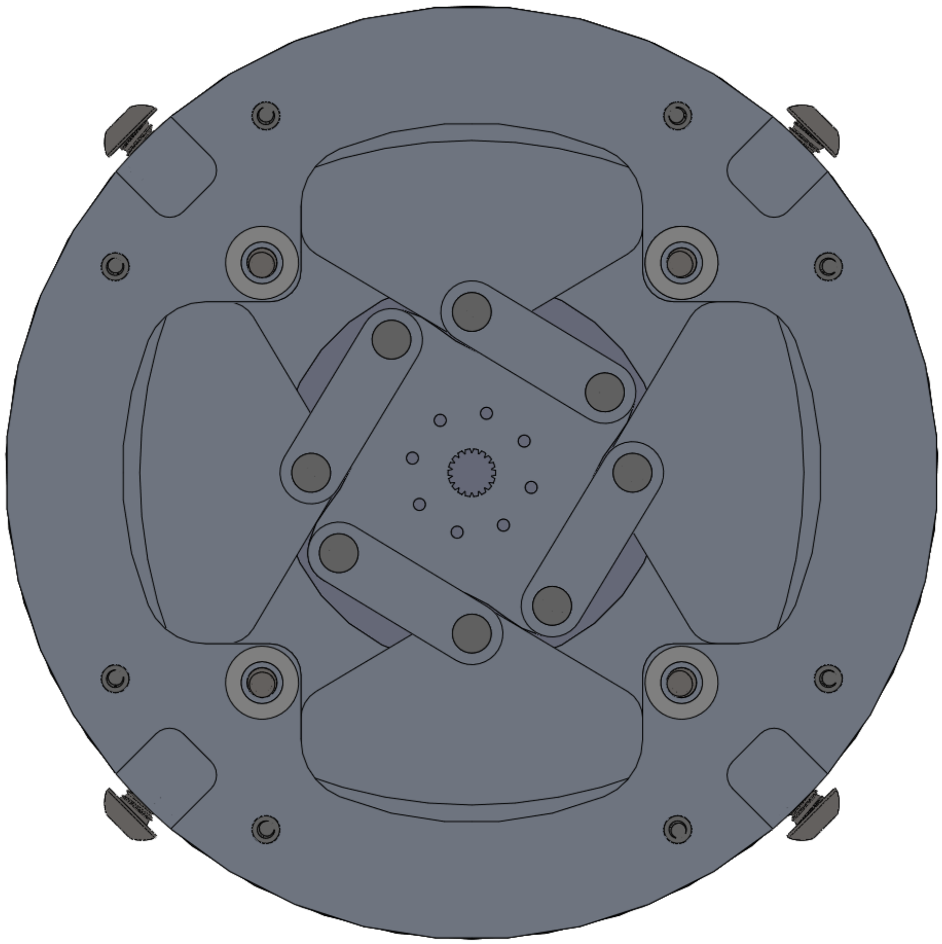

Figure 5: Top View cut-out setcion

4.1.2 Base Plate

The Base Plate is the thickest bulkhead in the ABS assembly. It contains channels for the drag plates to move, a cut-out hole in the center to allow for the clearance of links, pins and other electronics. Additionally, it has 4 1/4in tapped holes for the inclusion of the integration rods. Moreover, it has 8 1/8in straight holes to fix the Top Plate and Bottom Plate together and 4 1/4 straight holes for possible structural reinforcement.

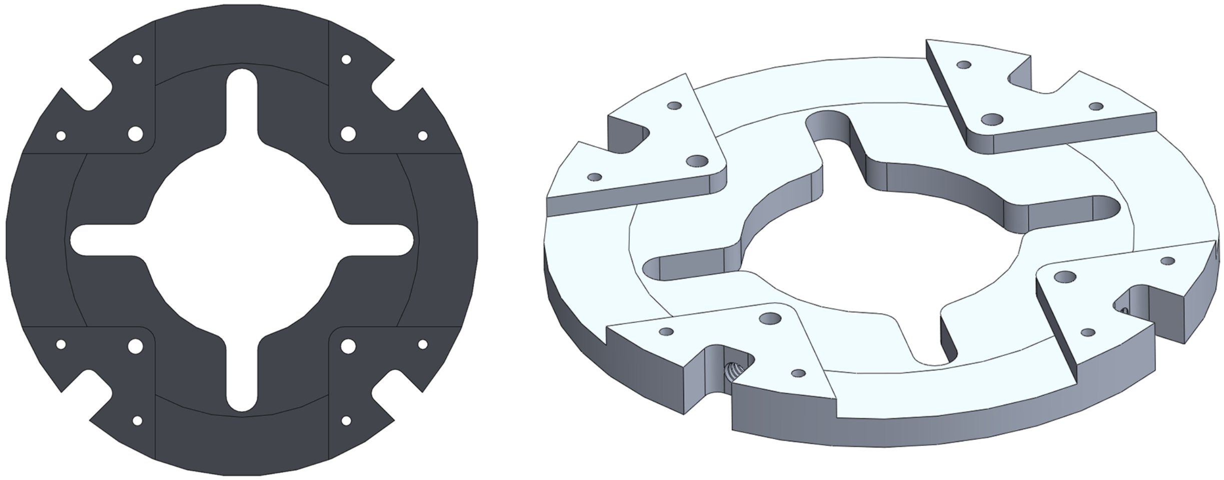

Figure 6: Base Plate Top and Isometric View

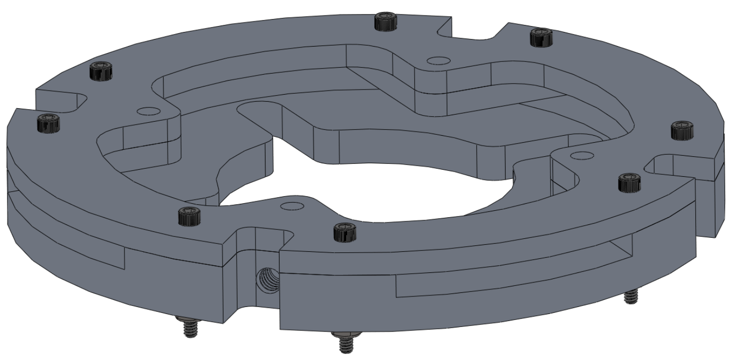

Figure 7: Top Top and Bottom Plate

The drag plates channel are projected to be the same depth as the height of the drag plates. The purpose of this addition was to restrain rotation and movement in other axis than the one aligned with the normal direction from the center.

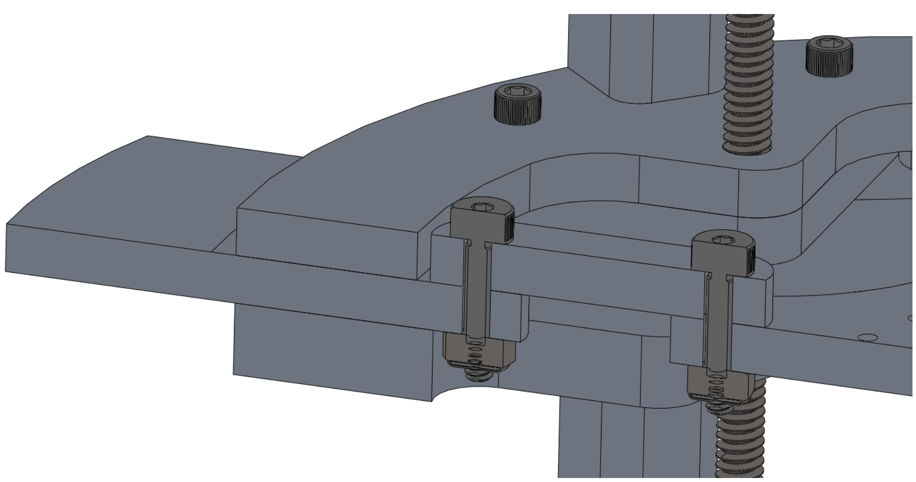

Figure 8: Cutout Section, Drag Channel Plates

4.1.3 Top Plate

The Top Plate is complimentary to the Base Plate. The geometry of these two plates is almost identical. The only difference is that the Top Plate is much thinner and has no channels for the flaps. The main purpose of this piece is to have constrain the drag plates in the vertical direction. The hole in the center is significantly much wider than the base plate. This was done to optimize the mass of the part while still exerting its intended purpose.

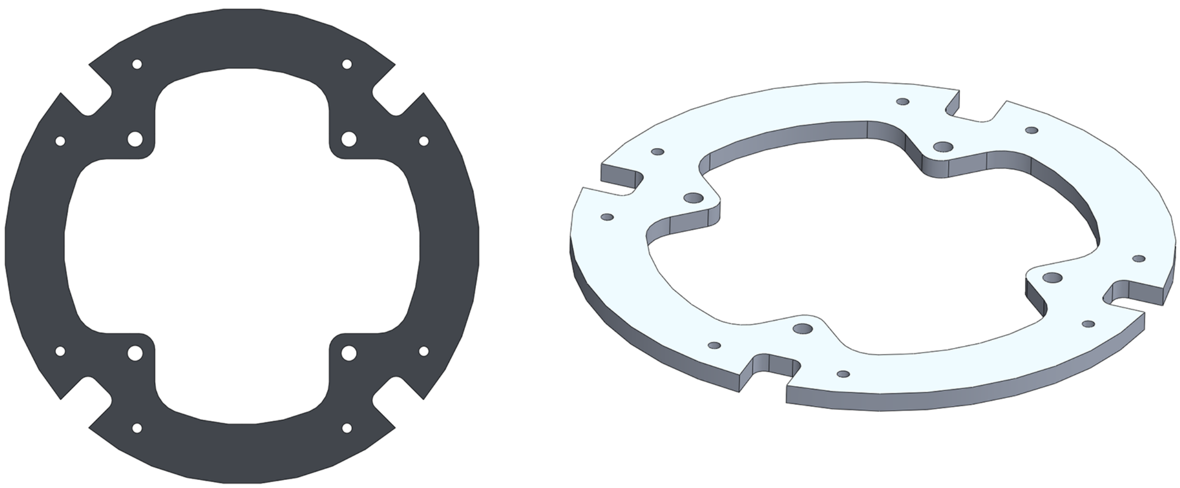

Figure 9: Top Plate Top and Isometric View

4.1.4 Links

The links transform rotational motion from the servo into linear motion. These aluminum pieces are connected to each other through shoulder bolts, which makes a pinned connection. In the ABS preliminary design, there are a total of 5 links: 4 linear pins and a link hub. The link hub connects the servo to the linear pins.

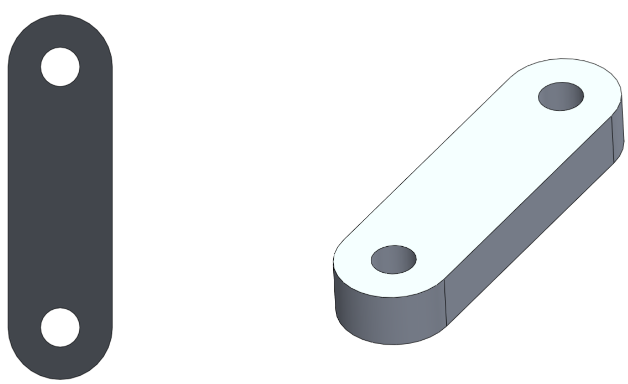

Figure 10: Linear Pin Top and Isometric View

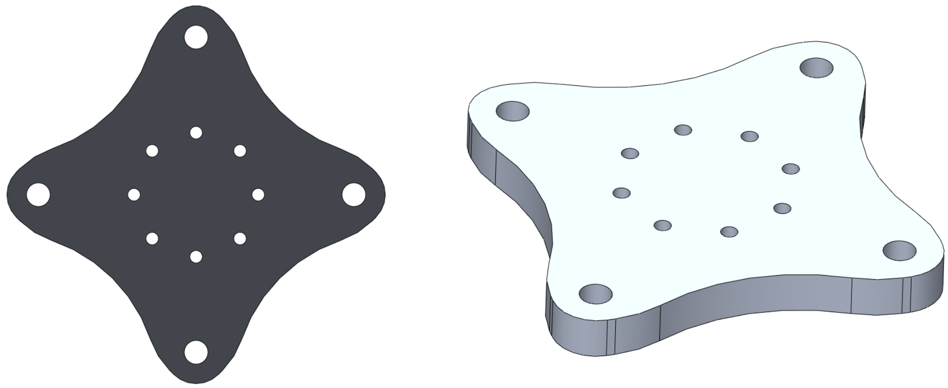

Figure 11: Link Hub Top and Isometric View

5 Integration

Having holes in the airframe is necessary to deploy the airbrakes. There is no way around it. Therefore, it is important to analyze the structural impact that these holes may have on the airframe. Having a reduced cross-sectional reduction in perimeter of approximately 50%, the structural integrity is compromised. Fiberglass G12 was selected as the primary material for the airframe. Given that this material is a composite, it is complicated to accurately predict stress concentrations. However, an educated approximation was made assuming that the material is isotropic. A Finite Element Analysis (FEA) simulation was done on the geometry of the airframe with those assumptions. Below is the stress distribution of the then airframe design. The stress values are not included as they would not be accurate.

6 Software Approach

6.1 Sensors

For the electrical implementation of the air brakes system, two BNO055 IMU sensors will be used to get live velocity readings, and a BMP390 barometer will be used for live altitude readings. The central control/processor will be a Raspberry Pi Zero, and to actuate the servo controlling the flaps, a PCA9685 Servo Driver will be used for more accurate and efficient PWM signaling.

7 Simulation

7.1 Computer Fluid Dynamics

At the same time the team is trying to make the design sturdy and strong, the team is also trying to maximize the drag produced by the plates. Calculating this number by hand can turn out to be quite a challenge. Fortunately, technology is available to us. It is possible to simulate the exact conditions the airbrakes will experience during flight through the use of simulation software. Computer Fluid Dynamics (CFD) was a tool used to optimize the design for a higher drag coefficient. The studies were based on two variables. The first one, controlled by the flight computer, is the degree of deployment. This variable increases the reference area of the ABS system. Thus, increasing the total drag. The second variable is the speed of the rocket relative to the fluid, in this case, the air. The team was little control over this variable. However, in the drag formula the velocity is quadratic. Therefore, its impact on the overall drag is higher than the reference area, which is driven by the degree of deployment.

Running CFD on a computer is very computationally expensive. Some simulations can run for hours on end. Adam Raynard, the current payload lead, was kind enough to run this task on his computer. The setup of the test was the following. The values ranged from 0% to 100% and 0 m/s to 200 m/s for degree of deployment and speed respectively. Looking for a high data resolution, both data ranges were split into 60 points, adding up to a total of 3600 data points. The test took 9 days of continuous running to complete. Results are shown below.

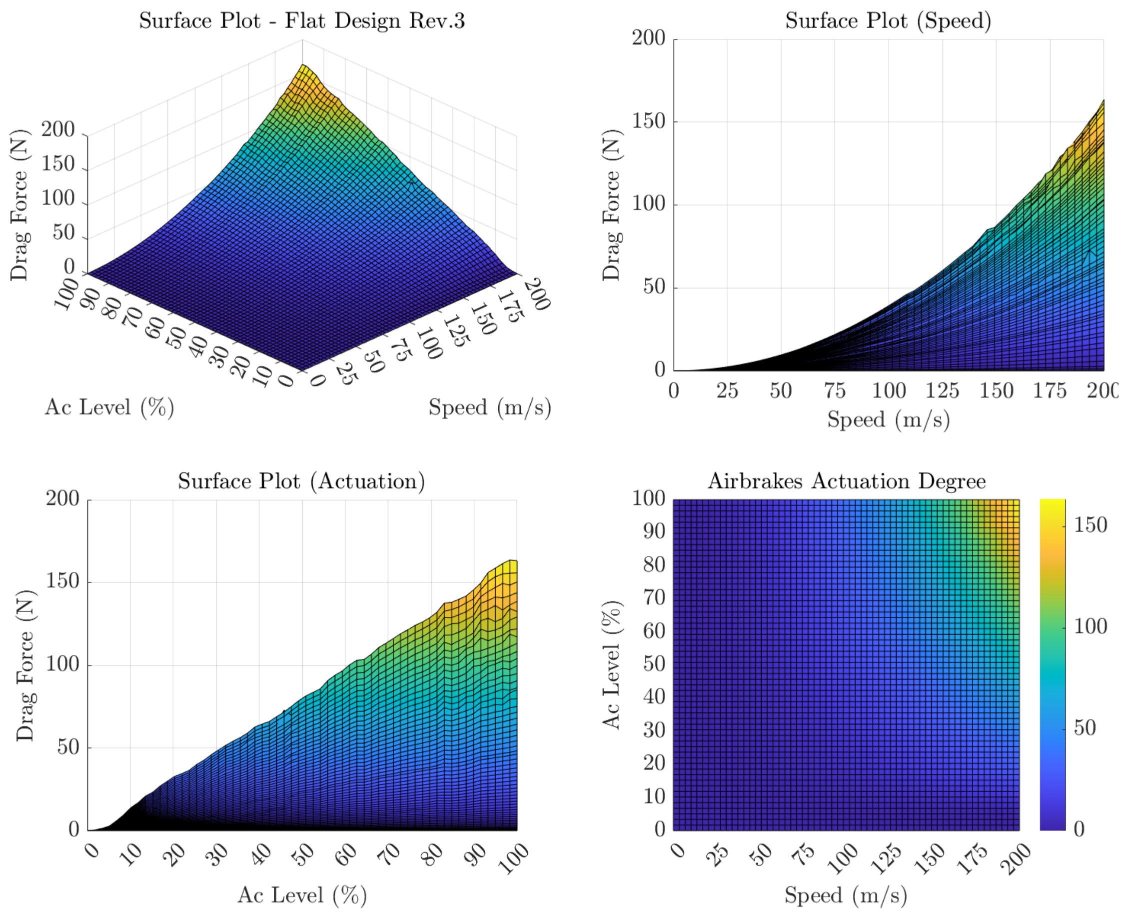

Figure 12: CFD Data

The end result is quite beautiful, a graph that increases both quadratically and linearly at the same time. Keeping actuation degree constant, it is possible to create a 2D graph of velocity and how it increases as speed increases. The behavior of this graph is quadratic, which is in line with the drag equation. The same phenomenon occurs when the opposite is done. Looking at Actuation Degree as the active variable, the graph appears to have a linear behavior. Similarly, in the drag equation the drag coefficient, which is influenced by the degree of deployment is linear.

Given that the team has acquired a substantial amount of data, it is possible to read in between the lines and interpolate for any combination of velocity and actuation. This would remove the need to use the drag equation as the drag prediction would be run using only the data obtained from the CFD simulations. This is more optimal as the minimal changes in the drag coefficient as the reference area of the plates changes is already accounted for in the dataset. Therefore, a polynomial fit of 3rd degree was run on the dataset. The results are shown below.

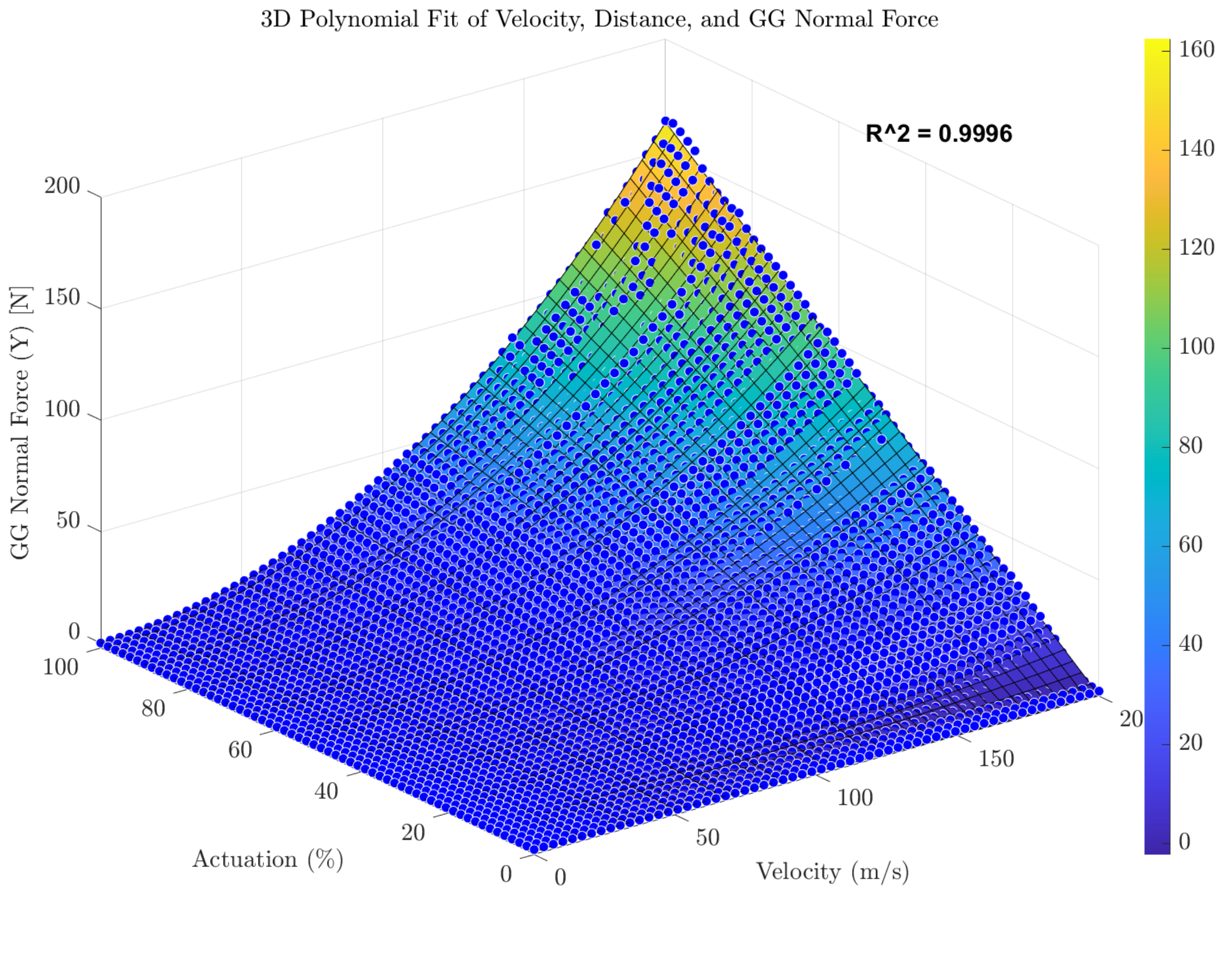

Figure 13: CFD Interpolation

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Linear model Poly33:

    fitresult(x,y) = p00 + p10*x + p01*y + p20*x^2
                     + p11*x*y + p02*y^2 + p30*x^3
                     + p21*x^2*y + p12*x*y^2 + p03*y^3

    Coefficients (with 95% confidence bounds):

    p00 =      -0.9836   (-1.155, -0.8122)
    p10 =      0.05443   (0.05, 0.05886)
    p01 =      0.01959   (0.01074, 0.02845)
    p20 =    -0.000741   (-0.0007844, -0.0006975)
    p11 =   -0.0005349   (-0.0006042, -0.0004657)
    p02 =   -9.198e-05   (-0.0002658, 8.185e-05)
    p30 =    2.221e-06   (2.084e-06, 2.358e-06)
    p21 =    4.338e-05   (4.314e-05, 4.362e-05)
    p12 =    2.592e-07   (-2.222e-07, 7.407e-07)
    p03 =    6.651e-08   (-1.031e-06, 1.164e-06)

    R^2 value: 0.999577
```

Something incredible about having so many data points close to each other, is that the interpolation turns out to be very accurate. The $R\hat{2}$ value of the interpolation surface and the dataset is almost 1. Having now the polynomial equation, it is possible to input any combination of velocity and actuation and get the estimated drag as an output. This linear model is going to be included in the code to predict apogee.