# MAE 189 Capstone Design Midterm Report

Rocket Active Fins

Team#7

# Project Overview



Problem Definition: During rocket launches, rockets can become unstable due to things like wind gusts, changes in center of gravity due to fuel, and manufacturing mistakes.

Objectives: The Active AntFins project intends to keep the rocket stable and vertical using movable fins.

# Project Schedule

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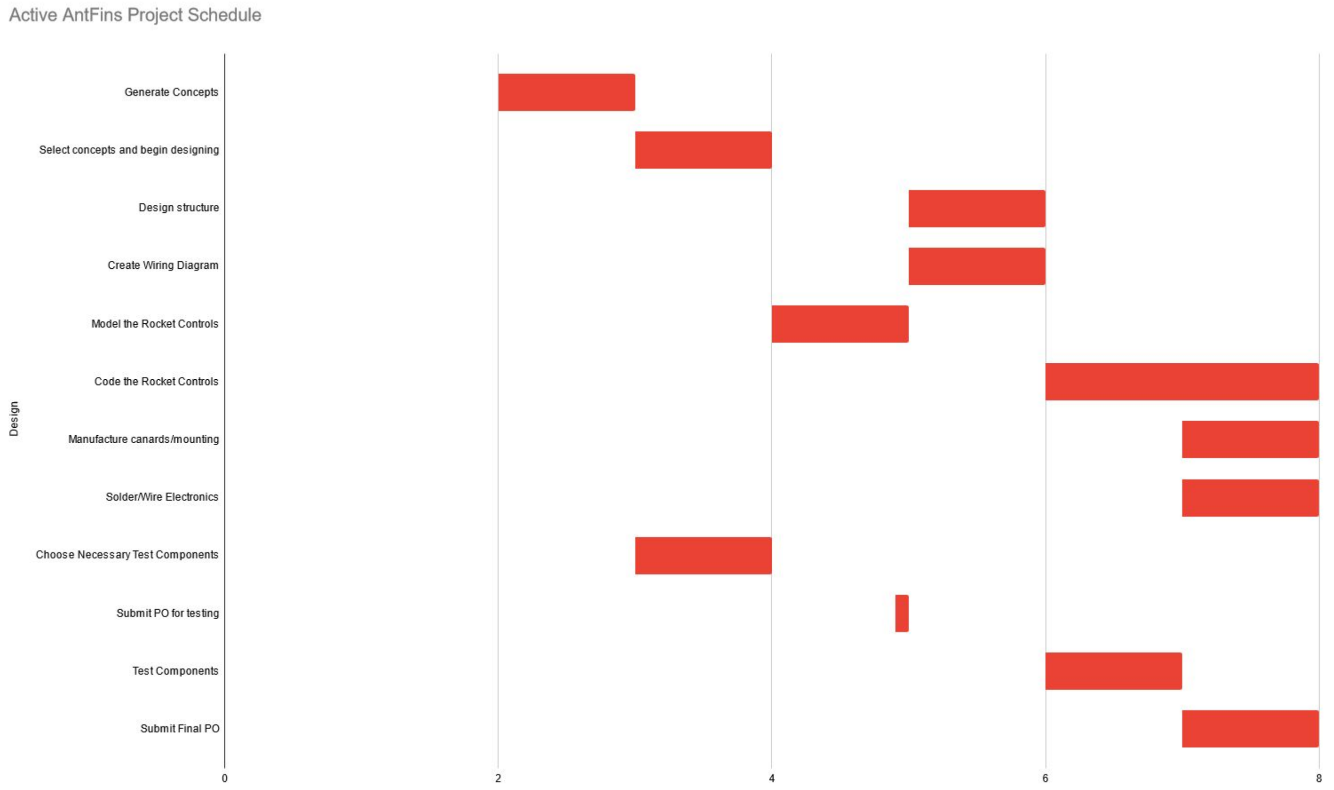


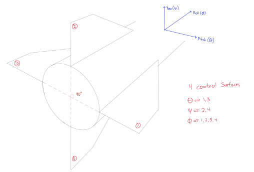
# Project Schedule

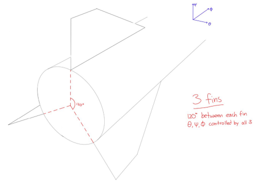


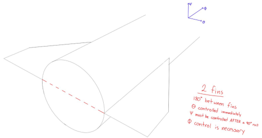
Components:

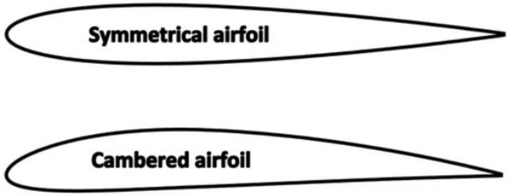
- Fins: Our control surface that will keep the rocket stable.
- Servos: Will control/move our fins.
- Servo Mounts: How will we attach the servos to our rocket (along with the other components)
- IMU: Determines the rocket's orientation, and it's distance from vertical (error)
- Microcontroller: Will take data from the IMU to determine how much to move each fin.
- Battery: Will power our system.

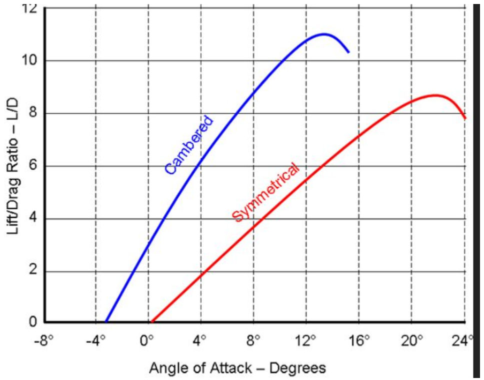
# Major Conceptual Decisions



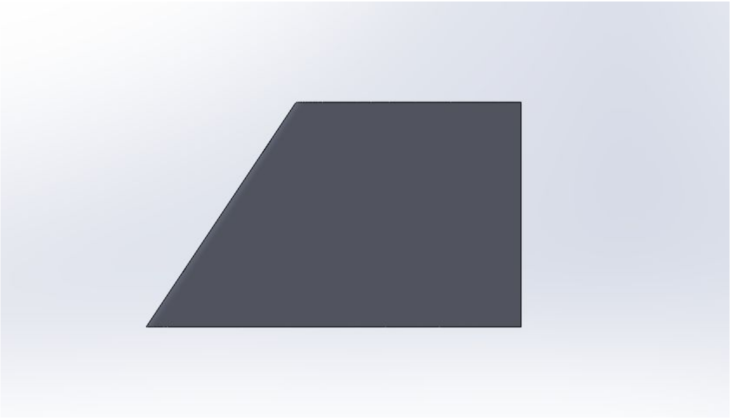



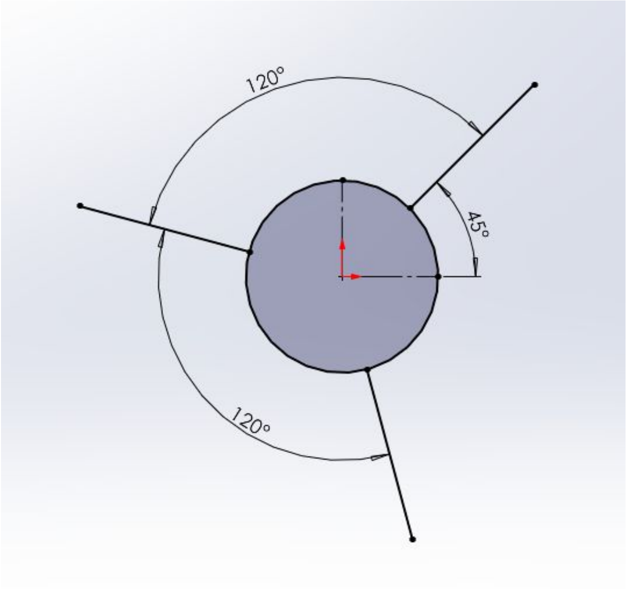




| Angle-of-Attack | | Elliptical | Trapezoidal | Square | Rectangular | Clipped Delta |
|---|---|---|---|---|---|---|
| 0° | Drag Force | 9.508 | 10.690 | 9.023 | 11.337 | 9.357 |
| 5° | Drag Force | 12.052 | 12.262 | 10.567 | 11.685 | 10.907 |



# Detailed Analysis: Control Matrix



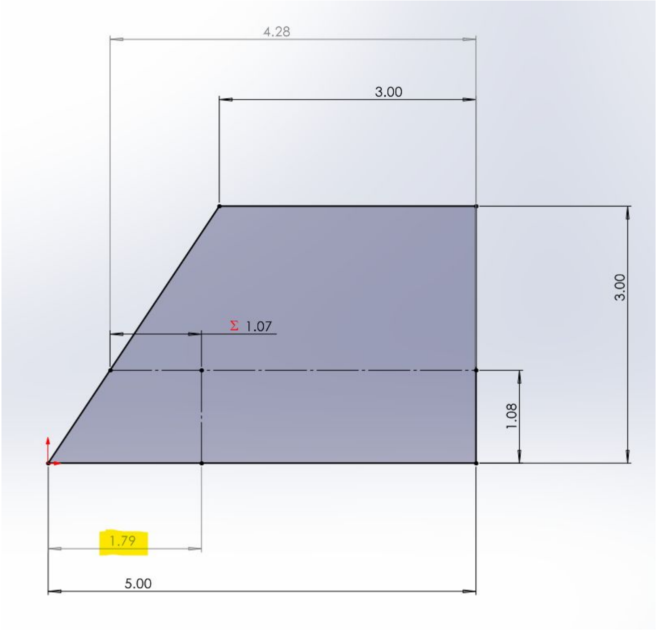

$$\begin{bmatrix} \ddot{\theta} \\ \ddot{\psi} \\ \ddot{\phi} \end{bmatrix} = \rho V^2 A_p \pi \begin{bmatrix} \frac{\Delta d sin(45)}{I_\theta} & \frac{-\Delta d cos(15)}{I_\theta} & \frac{\Delta d sin(15)}{I_\theta} \\ \frac{\Delta d cos(45)}{I_\psi} & \frac{\Delta d sin(15)}{I_\psi} & \frac{-\Delta d cos()15)}{I_\psi} \\ \frac{r_f}{I_\phi} & \frac{r_f}{I_\phi} & \frac{r_f}{I_\phi} \end{bmatrix} \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \end{bmatrix}$$

# Detailed Analysis: Fin Center of Rotation

$$C(y) = \frac{1}{b}(L_2 - L1)(y - b) + L_1$$

$$MAC = \frac{S}{2}\int_0^{\frac{b}{2}} C(y)dy$$

Aerodynamic center = 0.25*MAC



## Detailed Analysis: Battery Capacity

### HS-5085MG Servo Specs

- Idle: 3mA
- No-Load: 290mA
- Stall: 2150mA

Handle: 20min = 96.7mAh

Flight: 30sec = 17.845mAh

Total Energy = 114.55mAh

# Individual Work - <Lawrence Lu>



| Controller | Controller Comparison |
| --- | --- |
| PI | • PI Controller will have the largest overshoot in controlling the position of the rocket. However, it can use the integral controller to eliminate the steady-state error overtime. |
| PD | • PD controller can provide great performance in damping the oscillations with the quickest response time of the three. Proportional part of the controller may amplify the noise. |
| PID | • PID controller is a more robust controlling method and includes all the above characteristics.<br>• (Kalman filter can be used to optimize the performance) |
| Bangbang | Controlling the on and off state to yield step response. It is technically easier to design and apply to the active fin but it operates abruptly which is not a great choice for dealing with analog data from IMU. |

# Individual Work - <Lawrence Lu>

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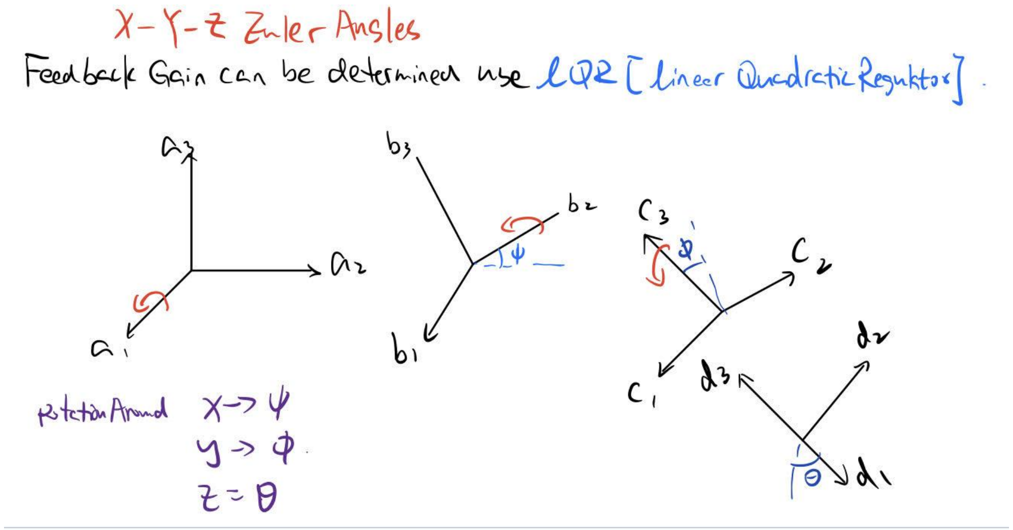
Dynamic Stability:

Inertia Tensor

$$\begin{bmatrix} \tau x \\ \tau y \\ \tau z \end{bmatrix} = \begin{bmatrix} Ixx & Ixy & Ixz \\ Iyx & Iyy & Iyz \\ Izx & Izy & Izz \end{bmatrix} \times \begin{bmatrix} d\omega x \\ d\omega y \\ d\omega z \end{bmatrix}$$

- Ixx:Moment of Inertia around x-axis w object rotates around x
- Ixy:Moment of Inertia around y axis when objects rotates around x...

# Euler Angle Representation




$${}^{A}R_{D} = {}^{A}R_{B} \times {}^{B}R_{C} \times {}^{C}R_{D}.$$

# Individual Work - <Lawrence Lu>

## 3-D Rotation Matrix:

ψ, Rotation Around z Axis:

$$M_1(\phi) = \begin{array}{c|ccc} & \hat{b}_1'' & \hat{b}_2'' & \hat{b}_3'' \\ \hat{b}_1 & 1 & 0 & 0 \\ \hat{b}_2 & 0 & \cos(\phi) & -\sin(\phi) \\ \hat{b}_3 & 0 & \sin(\phi) & \cos(\phi) \end{array}$$

(CCW positive)

$$M_2(\theta) = \begin{array}{c|ccc} & \hat{b}_1' & \hat{b}_2' & \hat{b}_3' \\ \hat{b}_1'' & \cos(\theta) & 0 & \sin(\theta) \\ \hat{b}_2'' & 0 & 1 & 0 \\ \hat{b}_3'' & -\sin(\theta) & 0 & \cos(\theta) \end{array}$$

Pure Rotation

$$M_3(\psi) = \begin{array}{c|ccc} & \hat{n}_1 & \hat{n}_2 & \hat{n}_3 \\ \hat{b}_1' & \cos(\psi) & \sin(\psi) & 0 \\ \hat{b}_2' & -\sin(\psi) & \cos(\psi) & 0 \\ \hat{b}_3' & 0 & 0 & 1 \end{array}$$

Yaw

ψ, θ, φ
z y x

DCM [Direction Cosine Matrix]

$$C_{bN}(\phi,\theta,\psi) = S(\phi)\cdot S(\theta)\, S(\psi) = \begin{bmatrix} \cos(\theta)\cos(\psi) & \cos(\theta)\sin(\psi) & -\sin(\theta) \\ \cos(\psi)\sin(\theta)\sin(\phi) - \cos\phi\sin\psi & \cos\phi\cos\psi + \sin\theta\sin\phi\sin\psi & \cos\theta\sin\phi \\ \cos(\phi)\cos(\psi)\sin(\theta) + \sin(\phi)\sin(\psi) & -\cos\psi\sin\phi + \cos\phi\sin\theta\sin\psi & \cos\theta\cos\phi \end{bmatrix}$$

Order Matters.

DCM -> unitary

$$DCM^{-1} = DCM^{T}$$

Potential Concern:

- Gimbal Lock at cos(90) due to loss of 1 dof.

# Control Matrix

$$\rho v^2 A_p \bar{r}\left[\frac{\Delta d \sin(45^\circ)}{I_\theta}\theta_{s1} - \frac{\Delta d \cos(15^\circ)}{I_\theta}\theta_{s2} + \frac{\Delta d \sin(15)}{I_\theta}\theta_{s3}\right] = \frac{2(\Delta\theta - \omega_\theta t)}{t^2}$$

$$\rho v^2 A_p \bar{r}\left[\frac{\Delta d \cos(45)}{I_\psi}\theta_{s1} + \frac{\Delta d \sin 15}{I_\psi}\theta_{s2} - \frac{\Delta d \cos(15)}{I_\psi}\theta_{s3}\right] = \frac{2(\Delta\psi - \omega_\psi t)}{t^2}$$

$$\rho v^2 A_p \bar{r}\left[\frac{r_f}{I_\phi}\theta_{s1} + \frac{r_f}{I_\phi}\theta_{s2} + \frac{r_f}{I_\phi}\theta_{s3}\right] = \frac{2(\Delta\phi - \omega_\phi t)}{t^2}$$

$$\frac{\rho v^2 A_p \bar{r} t^2}{2}\left[\frac{\Delta d \sin(45^\circ)}{I_\theta}\theta_{s1} - \frac{\Delta d \cos(15^\circ)}{I_\theta}\theta_{s2} + \frac{\Delta d \sin(15)}{I_\theta}\theta_{s3}\right] + \omega_\theta t = \Delta\theta$$

$$\frac{\rho v^2 A_p \bar{r} t^2}{2}\left[\frac{\Delta d \cos(45)}{I_\psi}\theta_{s1} + \frac{\Delta d \sin 15}{I_\psi}\theta_{s2} - \frac{\Delta d \cos(15)}{I_\psi}\theta_{s3}\right] + W_\psi t = \Delta\psi$$

$$\frac{\rho v^2 A_p \bar{r} t^2}{2}\left[\frac{r_f}{I_\phi}\theta_{s1} + \frac{r_f}{I_\phi}\theta_{s2} + \frac{r_f}{I_\phi}\theta_{s3}\right] + W_\phi t = \Delta\phi$$

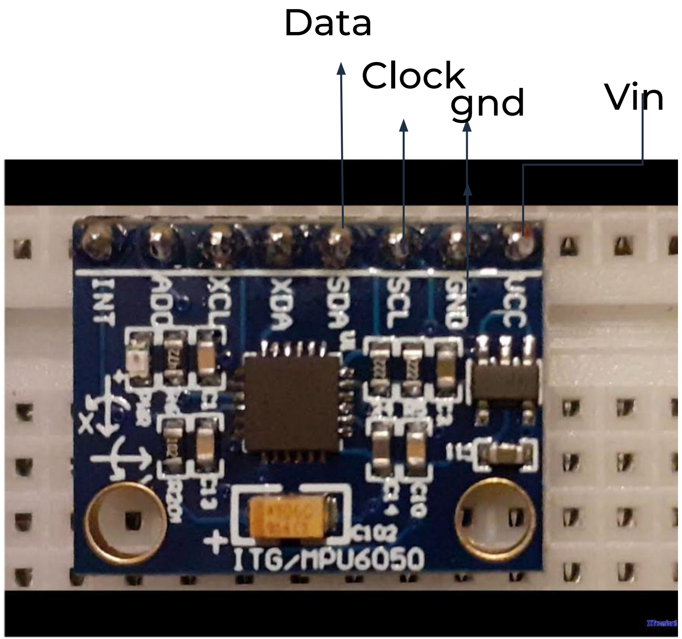
C

$$\begin{bmatrix}\Delta\theta \\ \Delta\psi \\ \Delta\phi\end{bmatrix} = \frac{\rho v^2 A_p \bar{r} t^2}{2}\begin{bmatrix}\frac{\Delta d \sin(45^\circ)}{I_\theta} & -\frac{\Delta d \cos(15^\circ)}{I_\theta} & \frac{\Delta d \sin(15)}{I_\theta} \\ \frac{\Delta d \cos(45)}{I_\psi} & \frac{\Delta d \sin 15}{I_\psi} & -\frac{\Delta d \cos(15)}{I_\psi} \\ \frac{r_f}{I_\phi} & \frac{r_f}{I_\phi} & -\frac{r_f}{I_\phi}\end{bmatrix}\begin{bmatrix}\theta_{s1} \\ \theta_{s2} \\ \theta_{s3}\end{bmatrix} + \begin{bmatrix}W_\theta t \\ W_\psi t \\ W_\phi t\end{bmatrix}$$

$$\begin{bmatrix}\theta_{s1} \\ \theta_{s2} \\ \theta_{s3}\end{bmatrix} = \begin{bmatrix}\frac{\Delta d \sin(45^\circ)}{I_\theta} & -\frac{\Delta d \cos(15^\circ)}{I_\theta} & \frac{\Delta d \sin(15)}{I_\theta} \\ \frac{\Delta d \cos(45)}{I_\psi} & \frac{\Delta d \sin 15}{I_\psi} & -\frac{\Delta d \cos(15)}{I_\psi} \\ \frac{r_f}{I_\phi} & \frac{r_f}{I_\phi} & -\frac{r_f}{I_\phi}\end{bmatrix}^{-1} \cdot \frac{2}{\rho v^2 A_p \bar{r} t^2}\left(\begin{bmatrix}\Delta\theta \\ \Delta\psi \\ \Delta\phi\end{bmatrix} - \begin{bmatrix}W_\theta t \\ W_\psi t \\ W_\phi t\end{bmatrix}\right)$$

Error

# MPU 6050




Library: MPU6050_Light

Output: Pitch/Row/Yaw

Alternative way to obtain PRY:

Using raw quaternion data from MPU6050

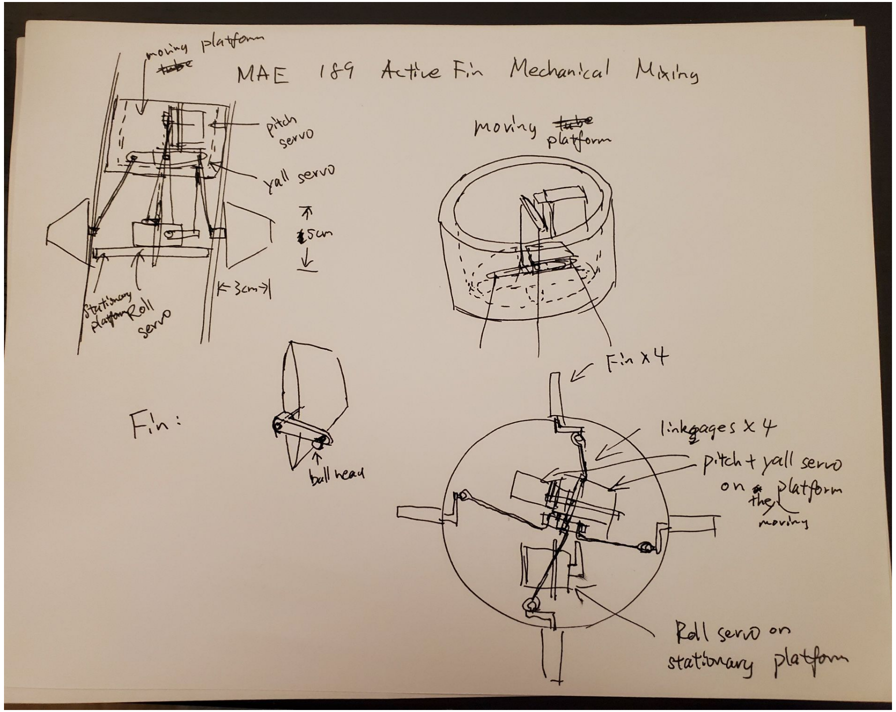
$$pitch = asin(-2*q_1*q_3 + 2*q_0*q_2)$$

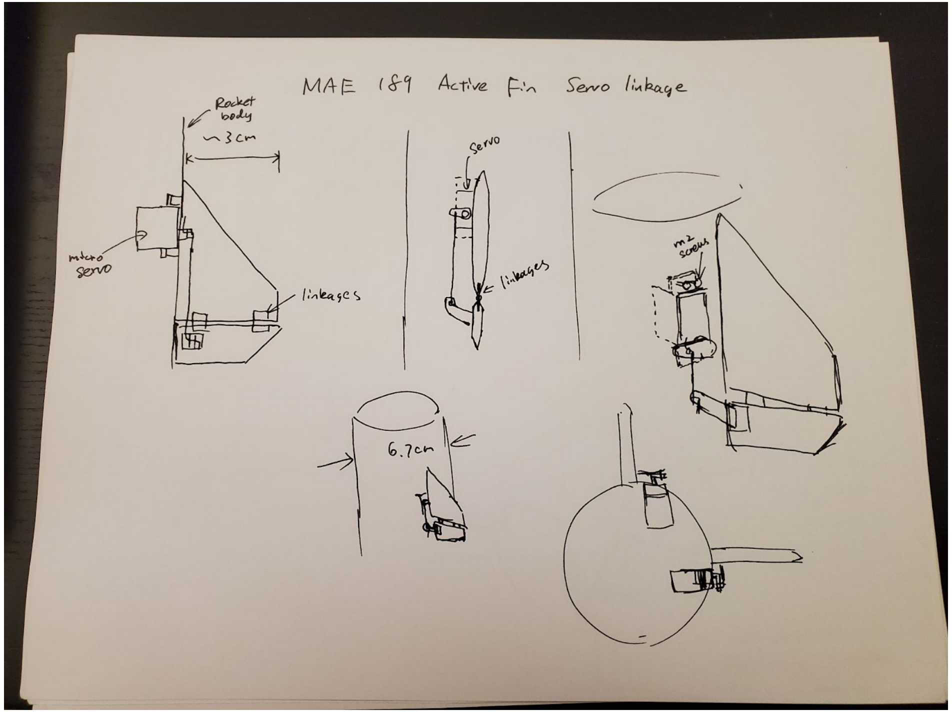
$$roll = atan2(2*q_2*q_3 + 2*q_0*q_1, -2*q_1*q_1 - 2*q_2*q_2 + 1)$$

$$Yaw = atan2(2*(q_1*q_2 + q_0*q_3), q_0*q_0 + q_1*q_1 - q_2*q_2 - q_3*q_3)$$

# Individual Work - <Jiawen Bao>

## Mechanical Design Concepts



# Individual Work - <Jiawen Bao>

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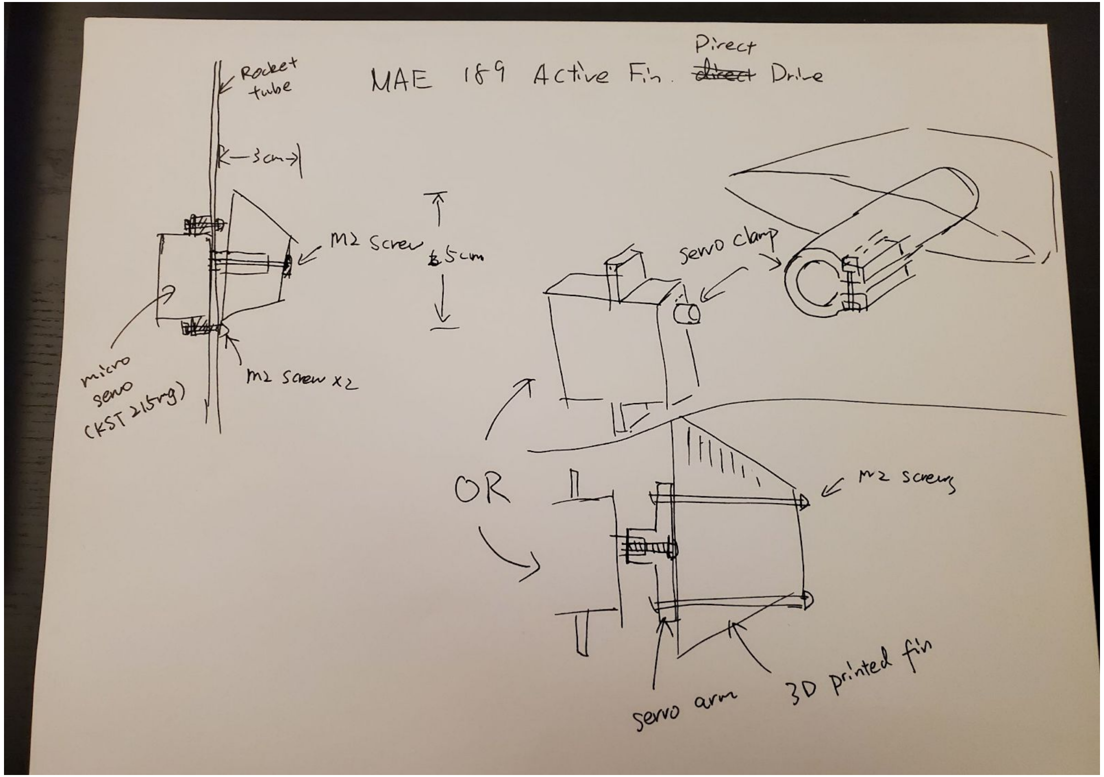
## Mechanical Design Concepts



# Individual Work - <Jiawen Bao>

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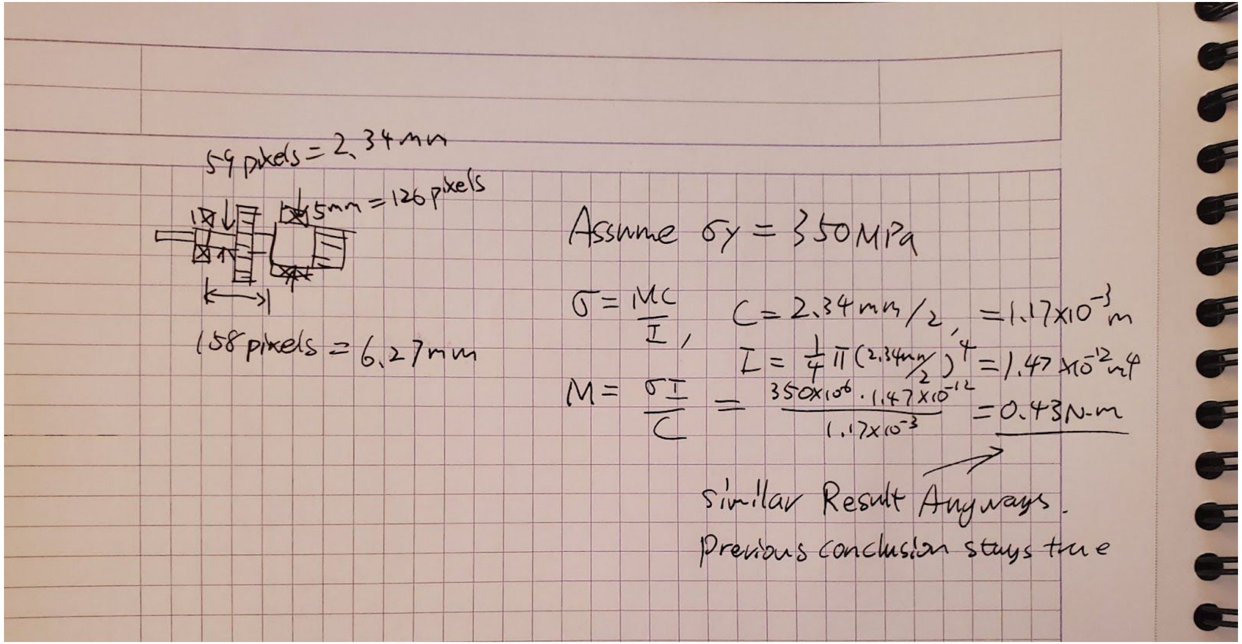
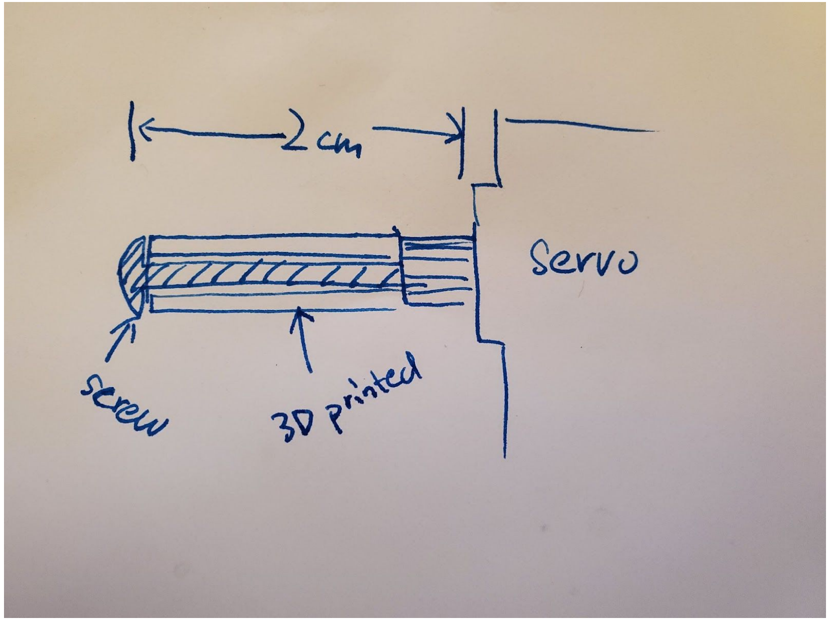
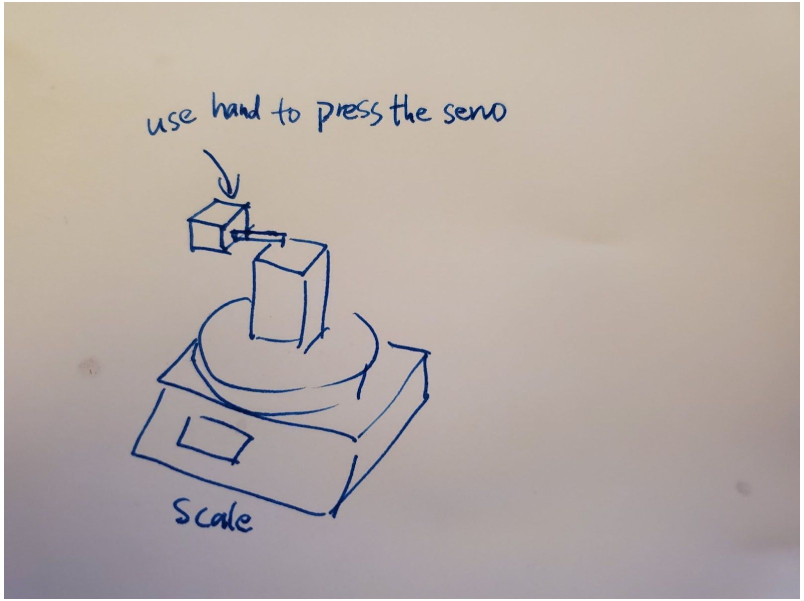
## Servo Bending Moment



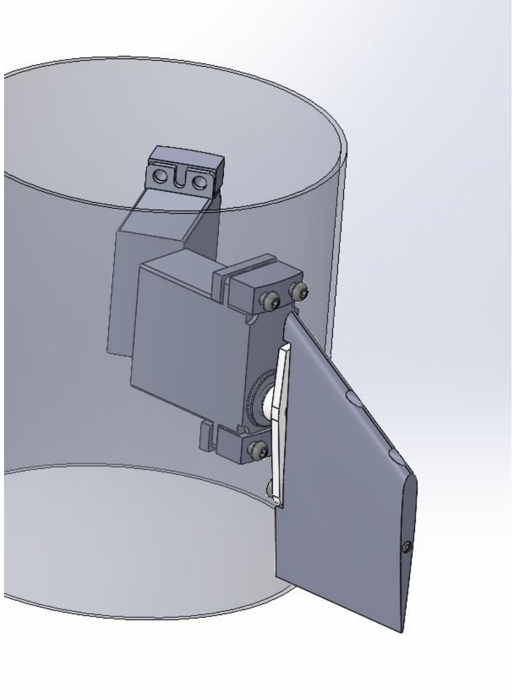
## Servo Testing Procedure

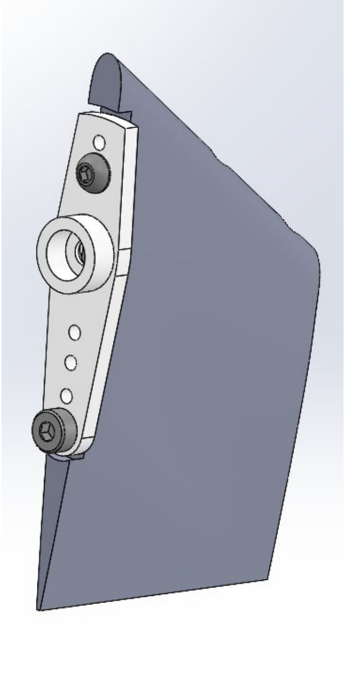


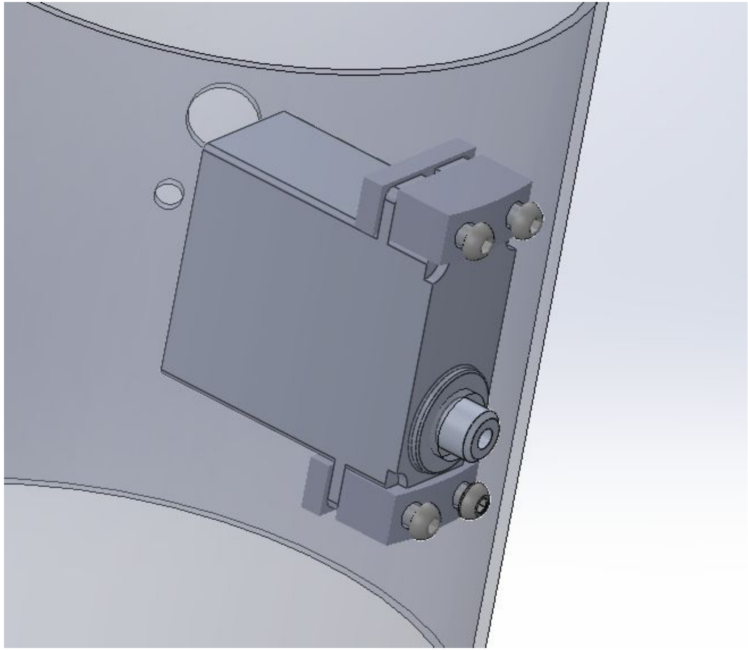



# Individual Work - <Jiawen Bao>

## Preliminary CAD







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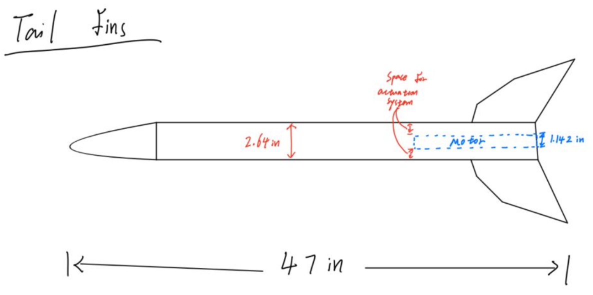
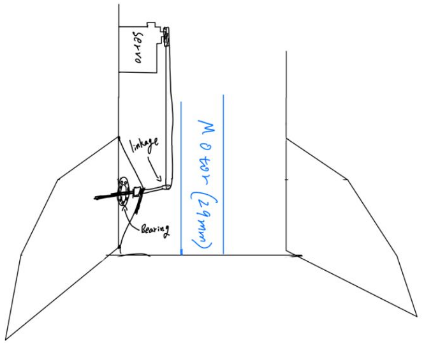
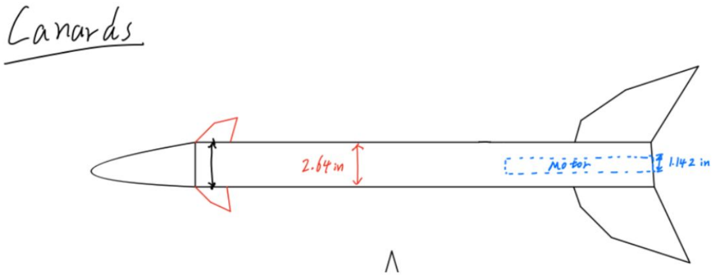
# Main system concept design

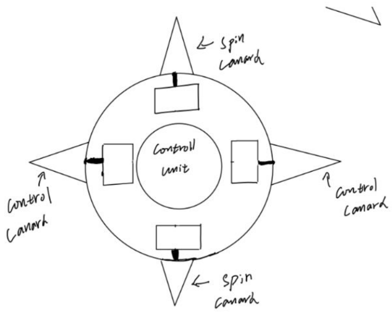



- Tail fins

- Canards



# Individual Work - <Ethan Chen>

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- Comparison between Canards and Tail Fins

| | **Advantage** | **Disadvantage** |
|---|---|---|
| **Canards** | • Better maneuverability at low angles of attack.<br>• More space for the actuation system and control unit.<br>• Effective in sharp turings<br>• Lower drag, higher speed, and longer range. | • Ineffective at high angles of attack because of flow separation that causes the surfaces to stall.<br>• Cause a destabilizing effect and require large fixed tails to keep the rocket stable.<br>• Require high-speed servos and fast responding time to keep the rocket under control. |
| **Tail Fins** | • Better maneuverability at high angles of attack.<br>• Easy to control. | • Limited space for the actuation system because of the motor.<br>• Might interfere with other parts of the rocket such as motor and centering ring.<br>• Ineffective in sharp turings |

# Individual Work - <Ethan Chen>

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- ## Concept Selection

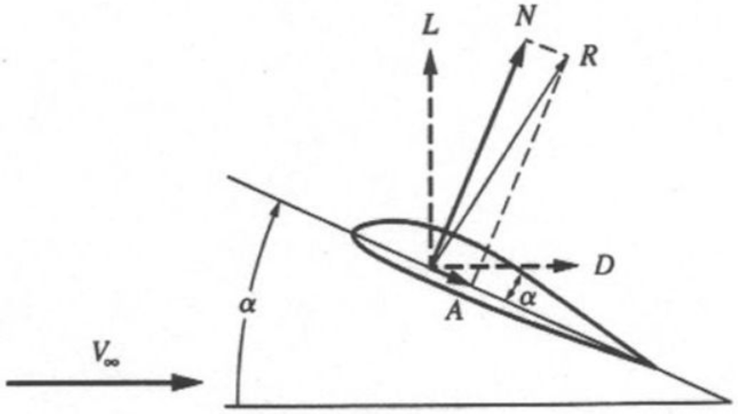
| Fin Location | | | |
|---|---|---|---|
| **Selection Criteria/Category** | **Weight (%)** | **Canards** | **Tail Fins** |
| Efficiency | 20% | 4 | 3 |
| Complexity | 20% | 3 | 4 |
| Ease of Manufacturing | 20% | 4 | 3 |
| Accuracy | 20% | 3 | 4 |
| Aerodynamic | 20% | 4 | 3 |
| | **Total Score** | **3.6** | **3.4** |

| Actuation Mechanism | | | | |
|---|---|---|---|---|
| **Selection Criteria/Category** | **Weight (%)** | **Direct Drive** | **Linkage** | **Mechanical Mixing** |
| Cost | 5% | 5 | 4 | 2 |
| Complexity | 30% | 5 | 4 | 1 |
| Ease of Manufacturing | 15% | 5 | 3 | 2 |
| Weight | 20% | 5 | 4 | 1 |
| Performance | 30% | 3 | 5 | 2 |
| | **Total Score** | **4.4** | **4.15** | **1.5** |

# Individual Work - <Ethan Chen>



- Assuming V=300 m/s, ρ=1.293 kg/m^3, **α**=10°
  - Drag force on the rocket: 39.4 N
  - Lift force on the rocket: 70.2 N
  - Pitching moment: 34.3 Nm
- Center of pressure calculated using Barrowman method is 89.1 cm from the nose cone tip.



# Individual Work - <Ethan Chen>

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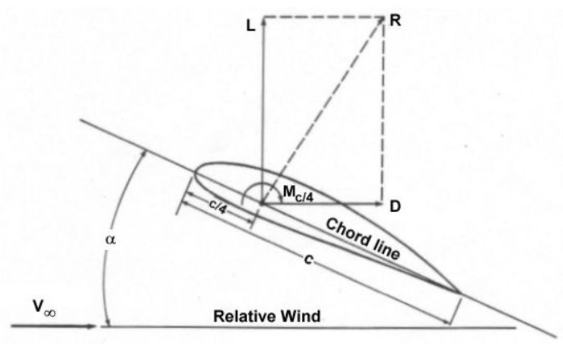
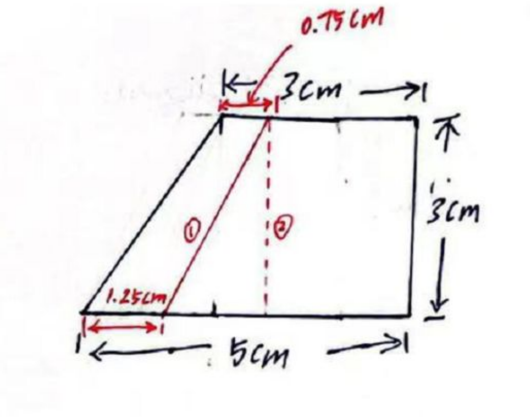
- The fin shape is chosen to be clipped delta, the size is finalized based on the calculations and OpenRocket simulations.

- The aerodynamic center is ¼ back from the leading edge for subsonic airfoils. We'll use this point for our center of rotation to eliminate the problem that CP changes with the angle of attack.



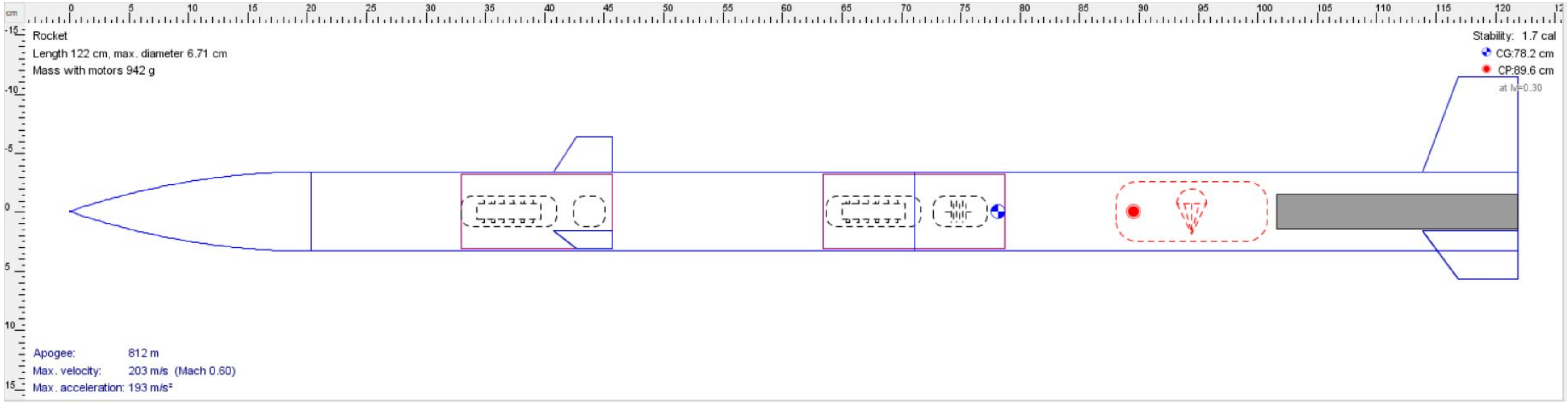
# Individual Work - <Ethan Chen>



- The canards are placed 40.7cm from the nose cone tip, it will be 3D-printed using ABS, the 3 servos, controller, mpu, etc total weights about 91 grams.

- According to OpenRocket, the stable factor is 1.7, CG is 78.2cm and CP is 89.6cm from the nose cone tip.

  OpenRocket Design



# Future Plans



- Airfoil shape: Further analysis required (NACA0008 was chosen initially)
- Control Matrix and Sensor Data Processing
- Servo verification
- Fin and Servo Mount Manufacturing
- Coding
- Final OP-order
- Final Prototype assembly

# Risks and Areas of Concern



Most of our components will be 3D printed.

Fasteners need to be ordered.

A final PO is needed after we test components bought in the first PO.

Some further guidance might be needed in regards to control equations.