Active Rocket Stabilization and Altitude Control

California State University Los Angeles, Mechanical Engineering

Team Members
Sean Luu
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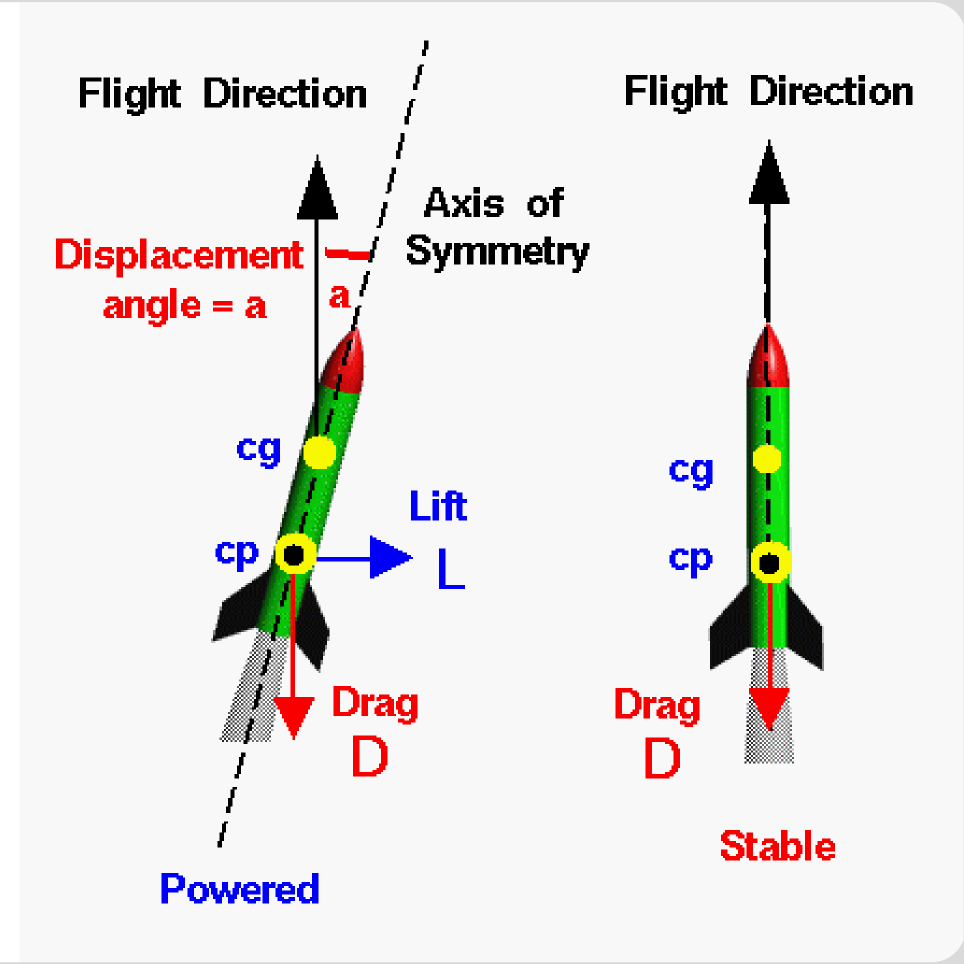
Faculty Advisor: Dr. Nurullah Arslan
Sponsor: Eagle Rocketry

Agenda

- Intro/Background
- Project Management
- Technical Details
- Summary

Background Material



- Eagle Rocketry: Rocket body + Motor
- Fins: Stability
- Airbrake: Altitude Control
- CG: Mass
- CP: Drag/Lift

Objective

- Stability & Altitude
- Additions:
  - Actuated fins
  - Static fins
  - Airbrakes
- Competition: Spaceport America
- Apogee: 30,000 feet

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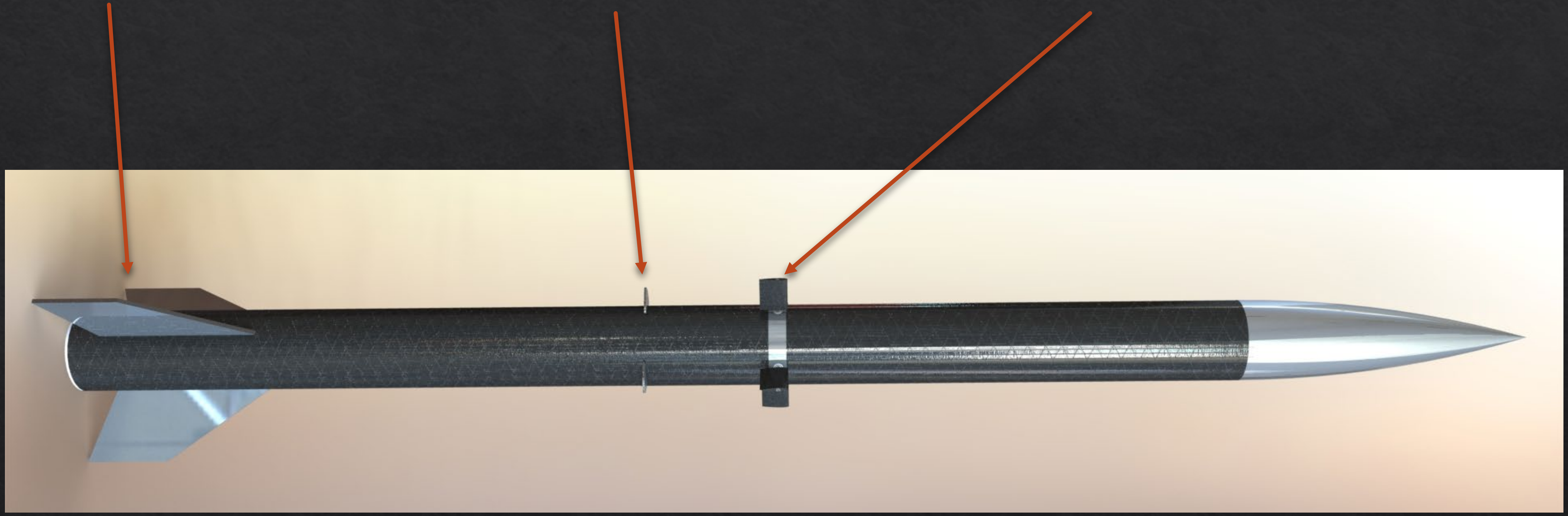
- Technical Details
- Conclusions

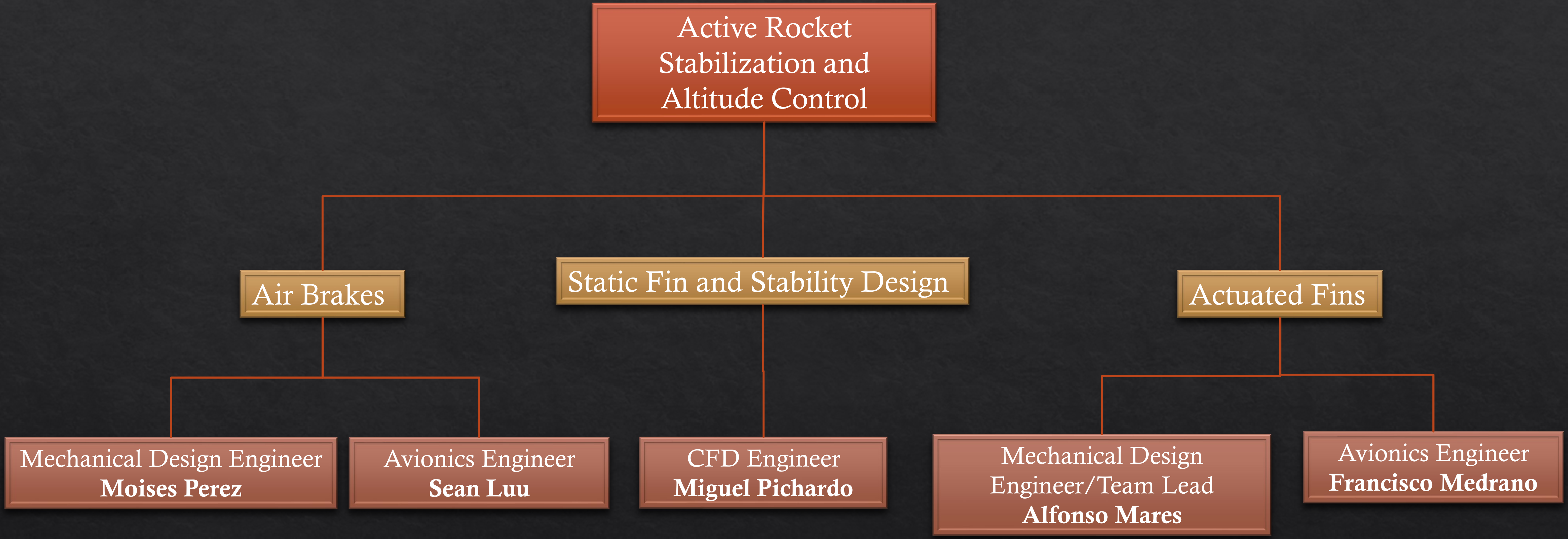
System Overview



Requirement Table

Subsystems	Requirements	Simulation Software
Static Fins	Provide initial stability	ANSYS, Open Rocket
Actuated Fins	Use force to torque rocket and maintain vertical flight	ANSYS, MATLAB Simulink
Rocket Dynamic Control	Correcting flight with PID controls to communicate with actuated fins	MATLAB Simulink
Airbrakes	Decelerate rocket to achieve target apogee	ANSYS SolidWorks
Altitude Controls	Trigger airbrakes to decelerate and attain targeted apogee.	MATLAB Simulink

Team Roles


Active Rocket Stabilization and Altitude Control
Air Brakes
Static Fin and Stability Design
Actuated Fins
Mechanical Design Engineer **Moises Perez**
Avionics Engineer **Sean Luu**
CFD Engineer **Miguel Pichardo**
Mechanical Design Engineer/Team Lead **Alfonso Mares**
Avionics Engineer **Francisco Medrano**

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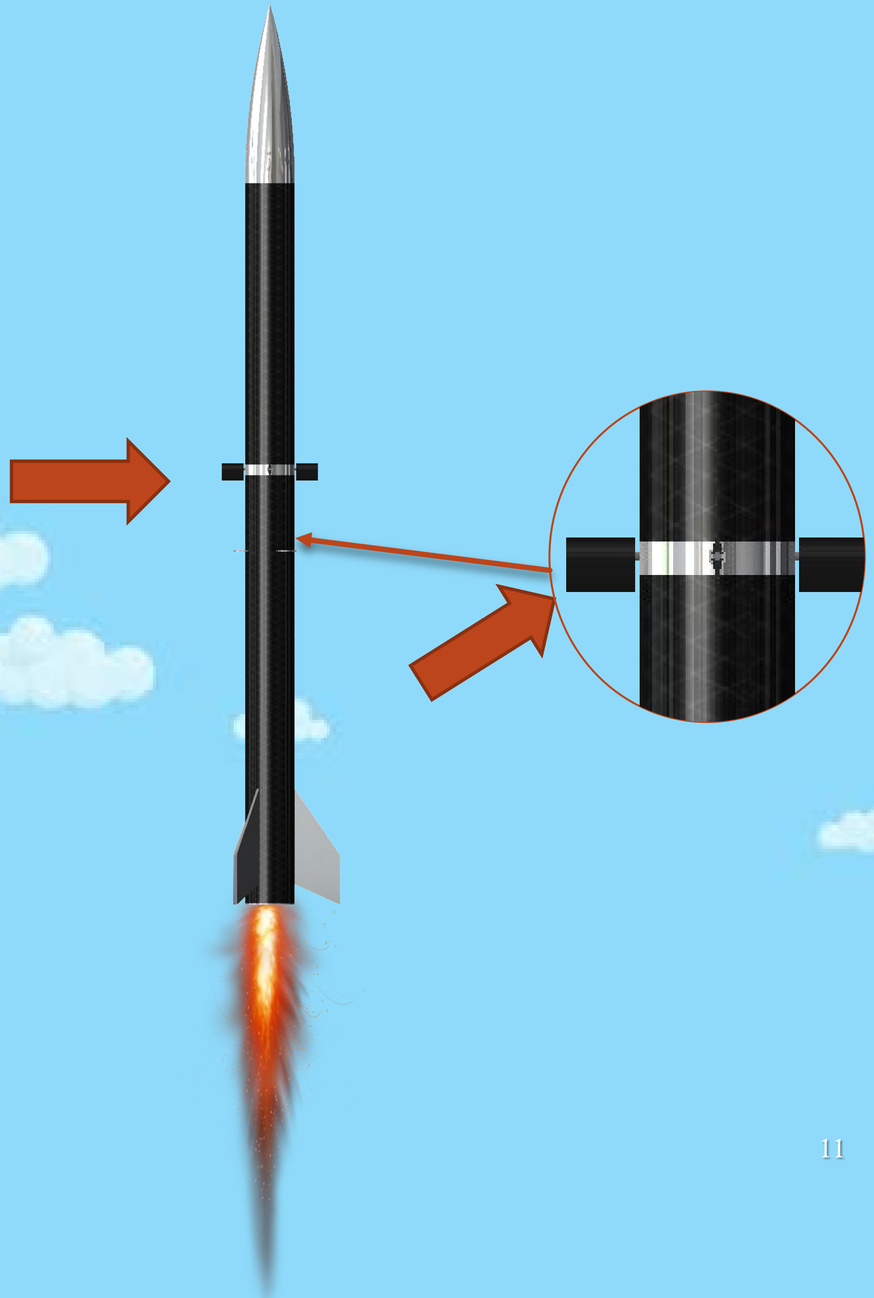
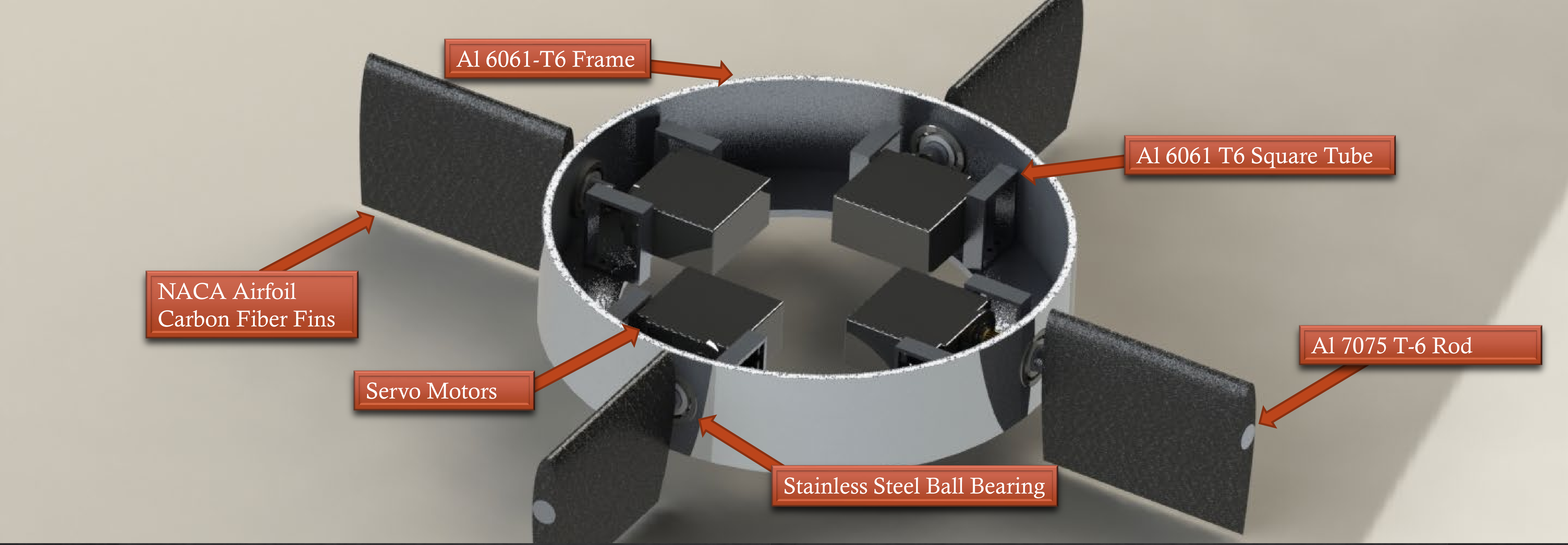
Technical Details

- Actuated Fin & Rocket Airframe Control: Alfonso
- Rocket Dynamic Controls: Francisco
- Airbrake: Moises
- Altitude Controls: Sean
- Static Fins: Miguel

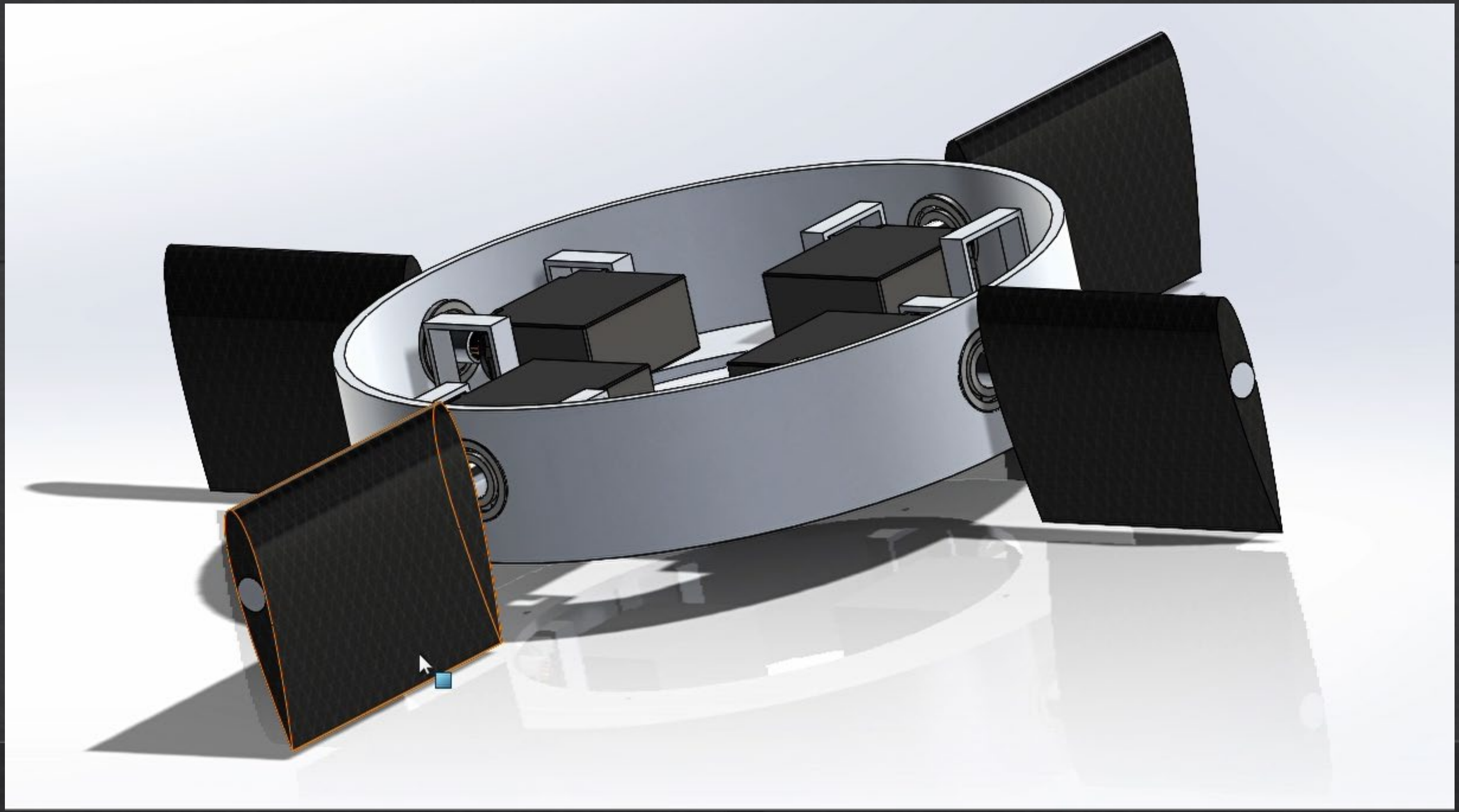
Actuated Fins & Rocket Airframe Control: Goals

- Maintain Vertical Flight
- Assist in ascension into final altitude
- Model Rocket Dynamics





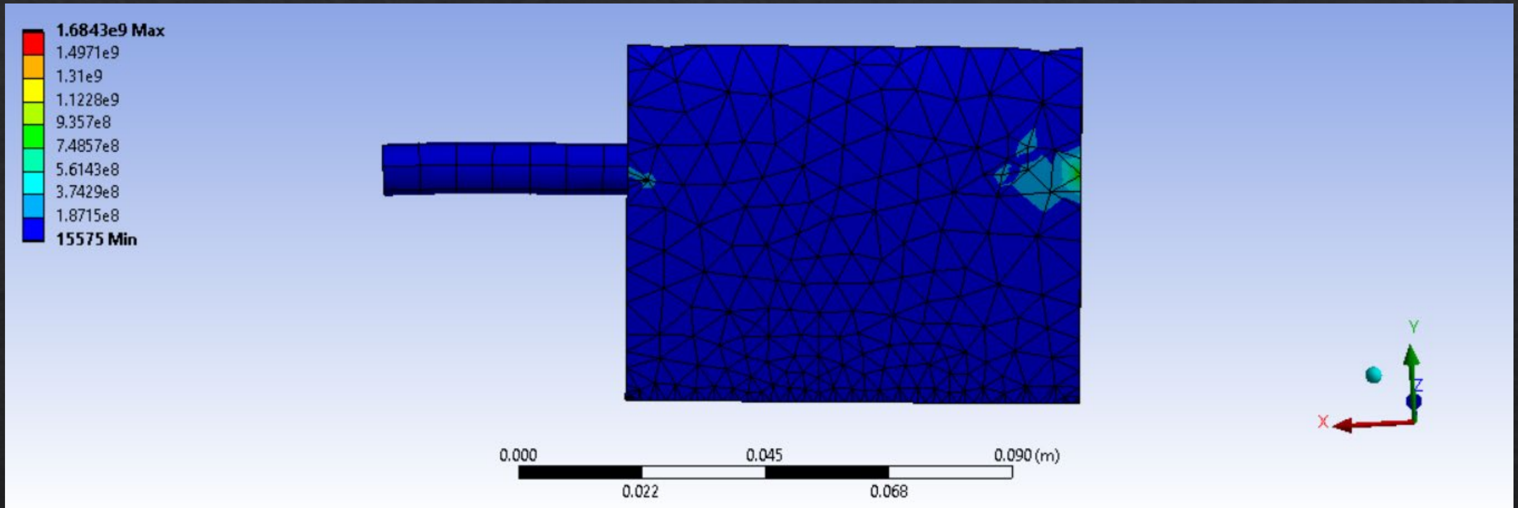
Actuated Fins



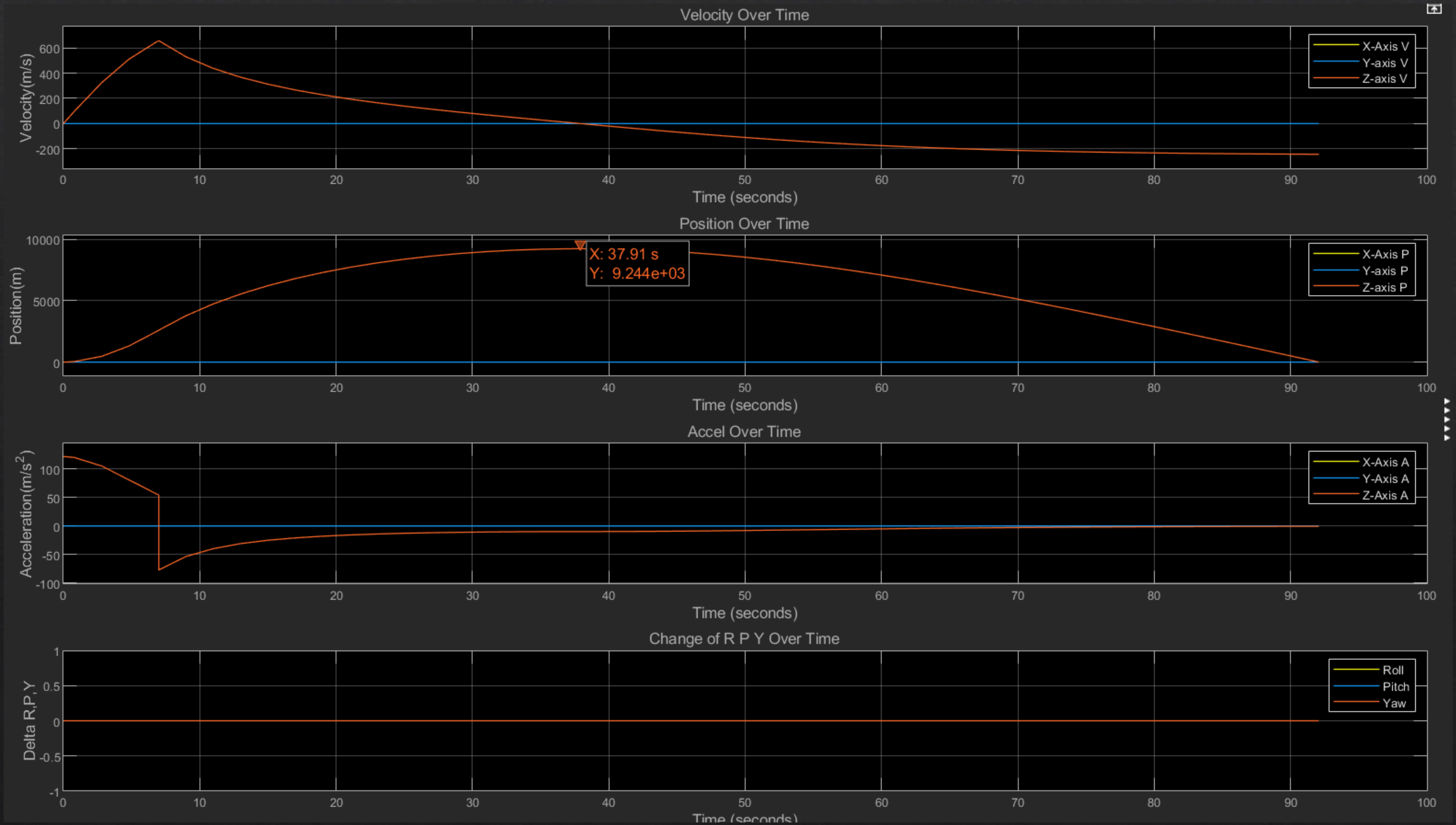
Actuated Fins:Video

Actuated Fins: Tests/Verification

Bending Stress(Pa)	3.98E+08
Allowable Stress(Pa)	3.61E+08
Factor of Safety	.91
ANSYS Structural	4.82E+08
Percent Difference	21%



MATLAB Rocket Airframe



Estimated Price for Actuated Fin Assembly

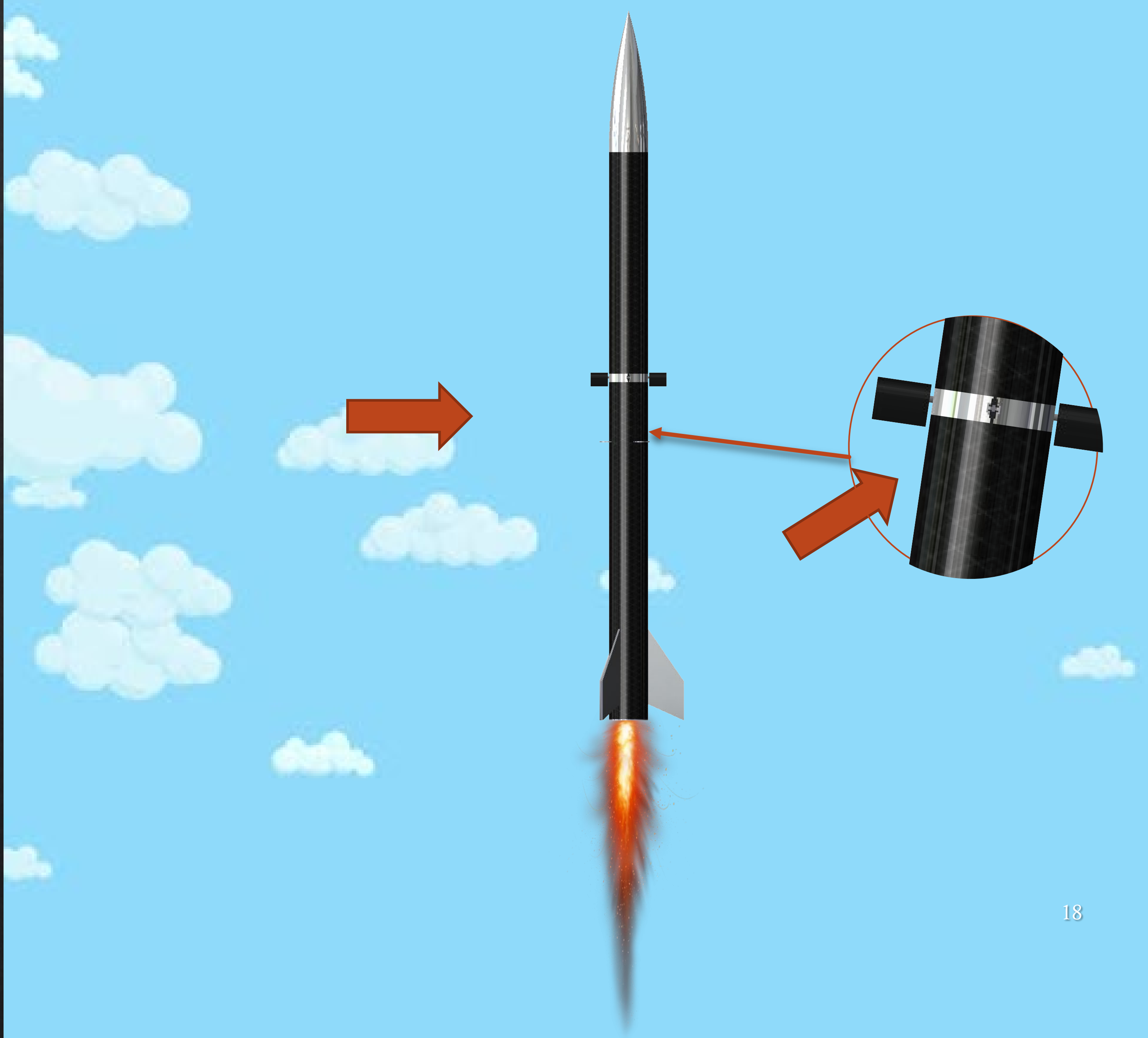
Item	Num.	Cost per	Description/Specs	What it's used for
Aluminum 7075-T6 Rod	1	$32.37	2FT of Aluminum 7075-T6 3/8" rod used for the actuated fins	Connecting the actuated fins to the frame
Steel Ball Bearings	4	$5.78	Ball Bearing shaft diameter 3/8"	Provide interface between rod and frame
Aluminum 6061-T6 Extruded square tube	1	$16.40	6061-T6 1/8" 2 ft rectangular tube	Hold the servos together motors together
MG996R Metal Gear Torque Motor	1	$19.99	A set of 4 55g MG996R Metal Gear Torque Servos	Turn the actuated fins from side to side
7.5" OD x 0.25" Wall x 7" ID Aluminum Round Tube 6061-T6-Extruded	1	97.48	7.5" OD x 0.25" Wall x 7" ID	Frame used to contain the subsystem
Total	$189.36			

Technical Details

- Actuated Fin & Rocket Airframe Control: Alfonso
- Rocket Dynamic Controls: Francisco
- Airbrake: Moises
- Altitude Controls: Sean
- Static Fins: Miguel

Rocket Dynamic Controls: Goals

- Dynamic rocket controls corrects the flight using actuated fins.
- Program the controller to be able to read IMU values and move the servo when it detects a change
- Programed in python via the Rasbery Pie-zero using the MPU 6050.



Parts Selection

Micro Controller Selection

Options:	Arduino nano	Raspberry PI - Zero	STM-32
Mandatory:			
I2C and SPI Communication Protocol	YES	YES	YES
Battery powered	YES	YES	YES

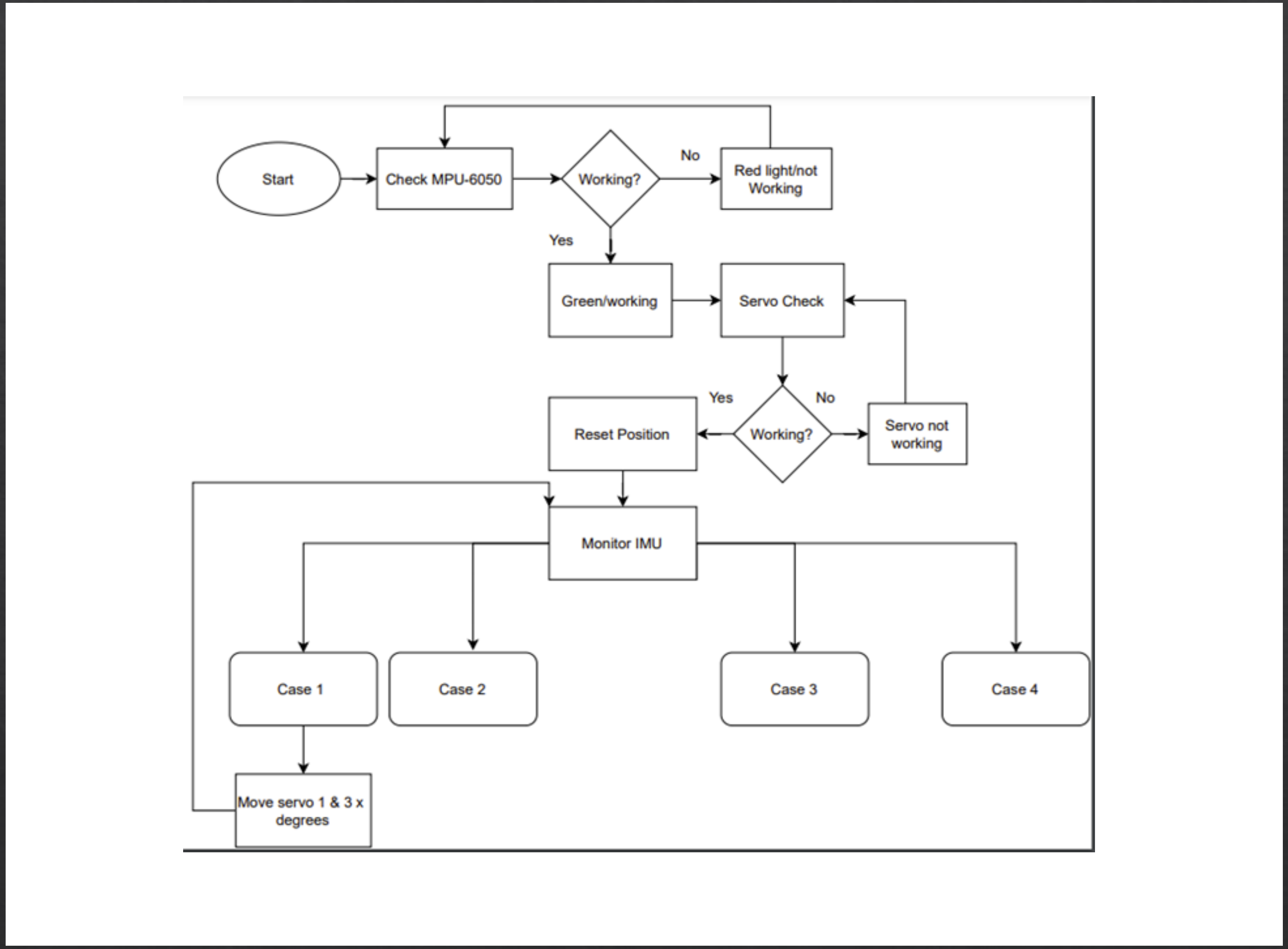
Categories	Weights	Score (A)	Score (R)	Score (S)
Price	30%	3	5	3
GPIO slots	30%	3	5	3
Weight	10%	3	1	3
Processor	30%	1	5	5
Total	10.8	2.4	4.8	3.6
Relative weight	100%	22.22%	44.44%	33.33%
Selected				

Servo Motor Selection

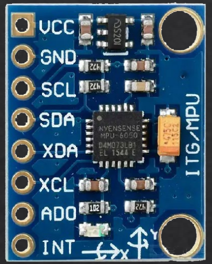
Options:	Sg 92r-sg90	SG-5010	MG995R
Mandatory:			
Works within the operational voltage	YES	YES	YES
Same relative speed	YES	YES	YES

Categories	Weights	Score	Score	Score
Price	30%	5	3	1
speed	15%	3	3	3
Weight	5%	5	3	1
Torque	50%	1	3	5
Total	9.03	2.7	3	3.33
Relative weight	100%	29.90%	33.22%	36.87%
Selected				

Decision making process



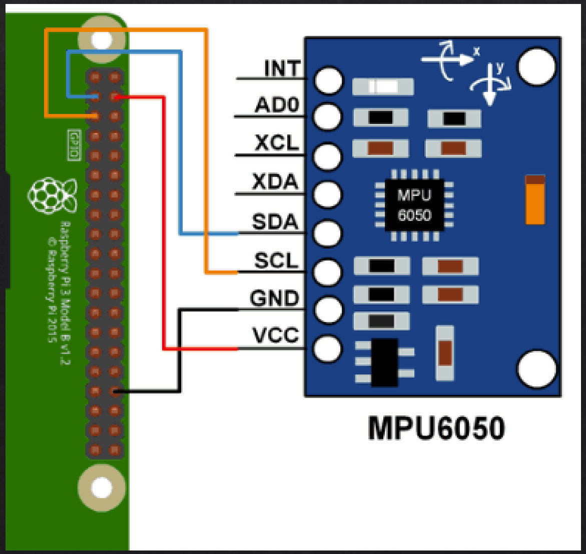
Rocket Dynamic Controls: Map



MPU 6050

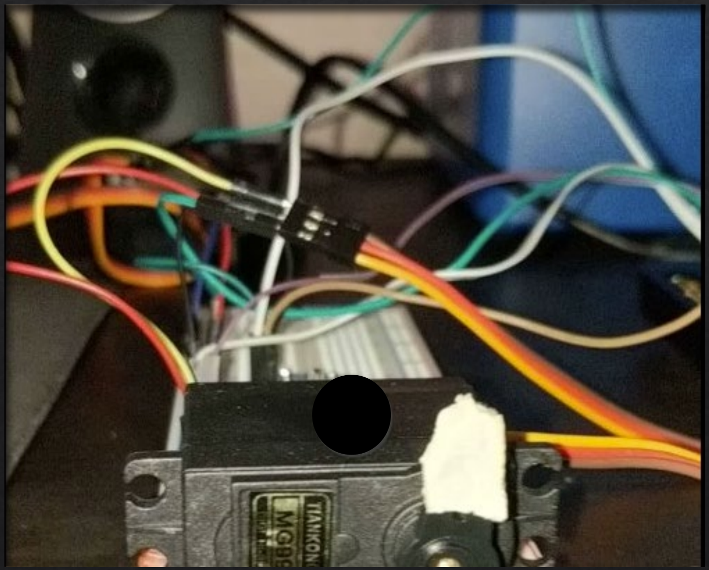
Rasbery pie zero

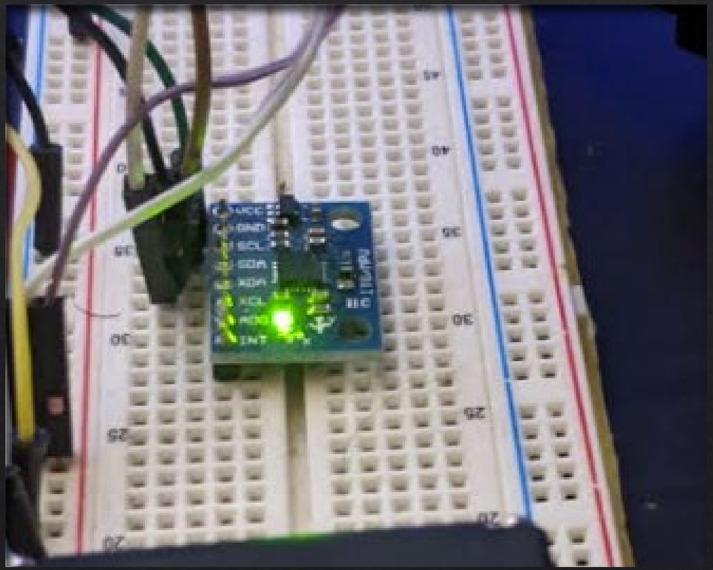
Servo motor

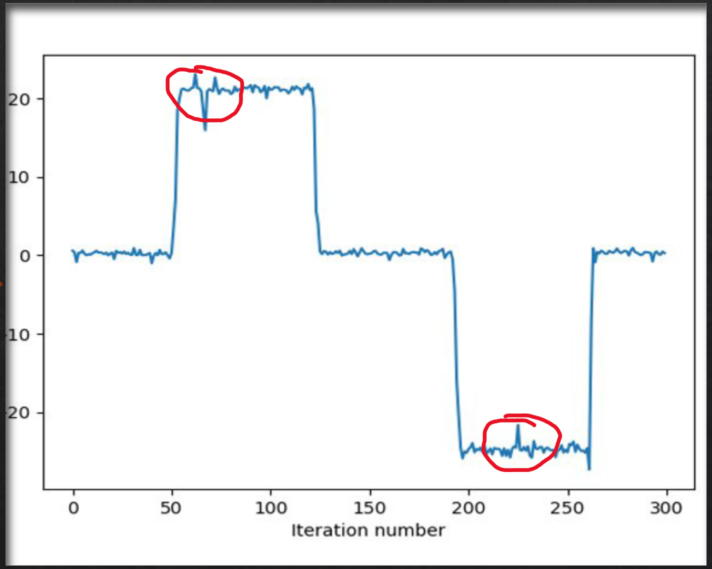


Testing the IMU and measuring angels

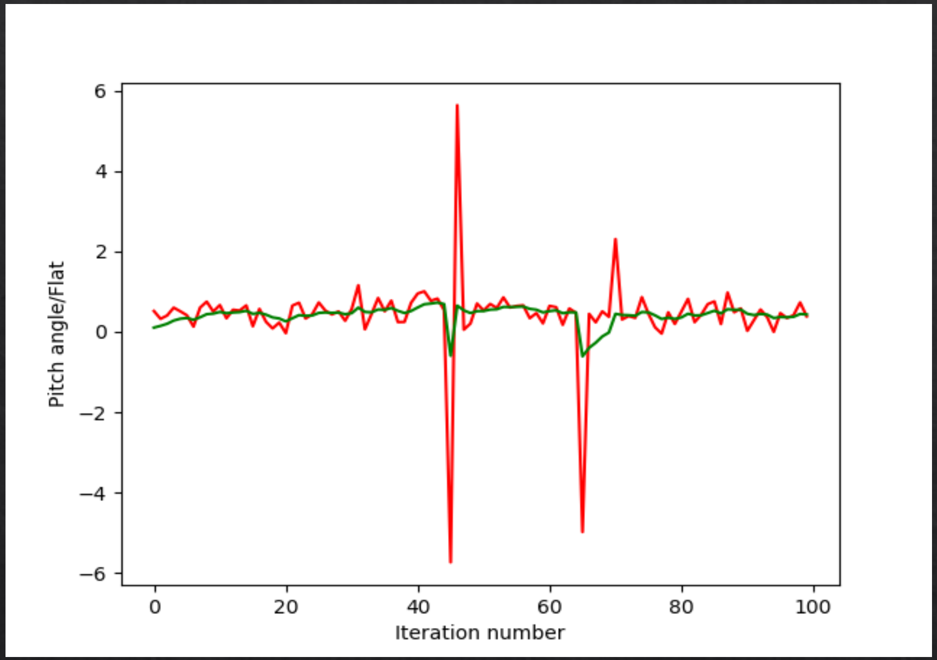
- Servo stability testing
- Servo Moter on the test table, with the MPU 6050 behind
- Angels measured over iterations: in this case it is the pitch angle that is being measured



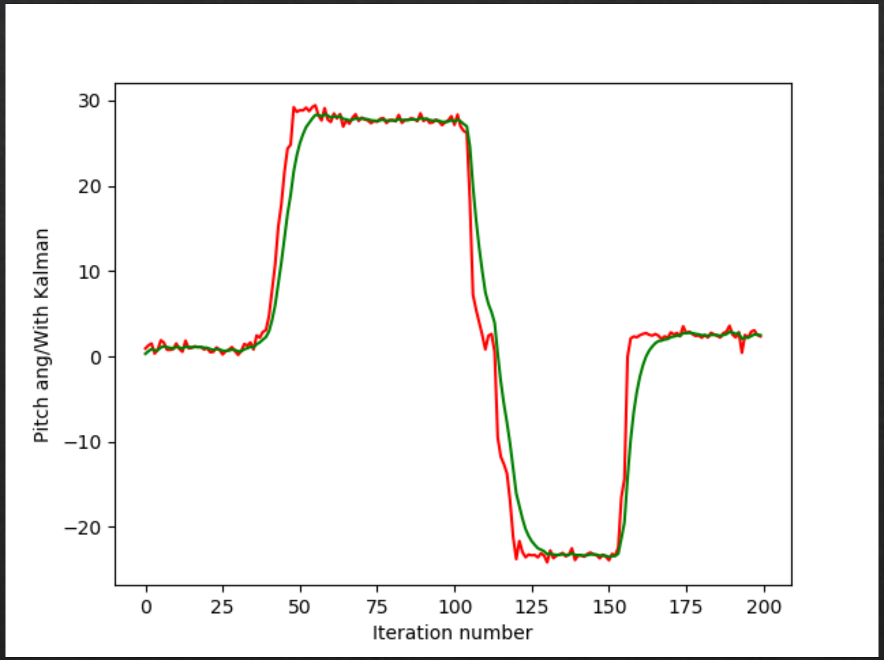




IMU data with Kalman implementation



IMU on table flat Red is without filter and green is with Kalman filter implementation



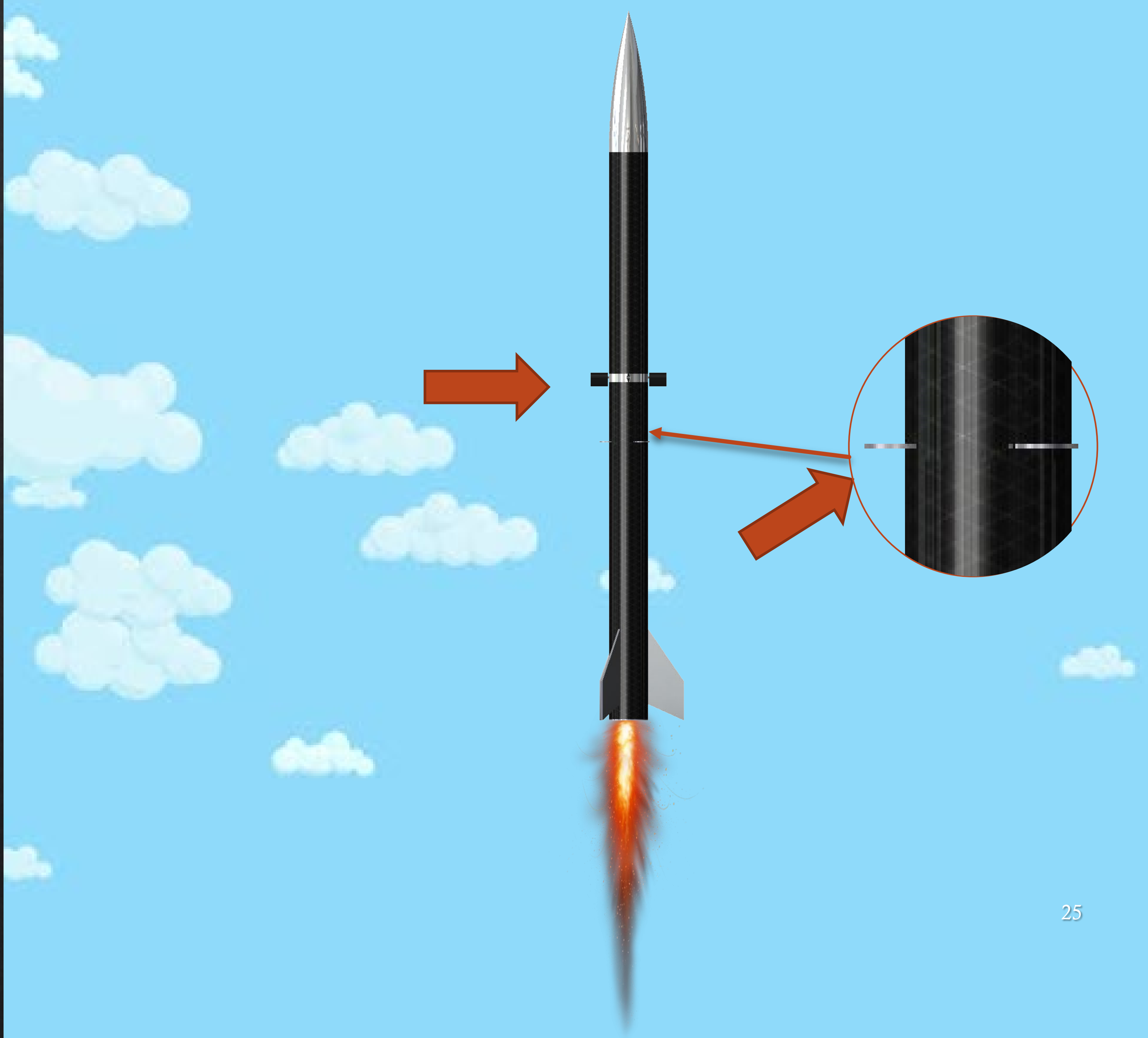
IMU movement Red is without filter and green is with Kalman filter implementation

Technical Details

- Actuated Fin & Rocket Airframe Control: Alfonso
- Rocket Dynamic Controls: Francisco
- Airbrake: Moises
- Altitude Controls: Sean
- Static Fins: Miguel

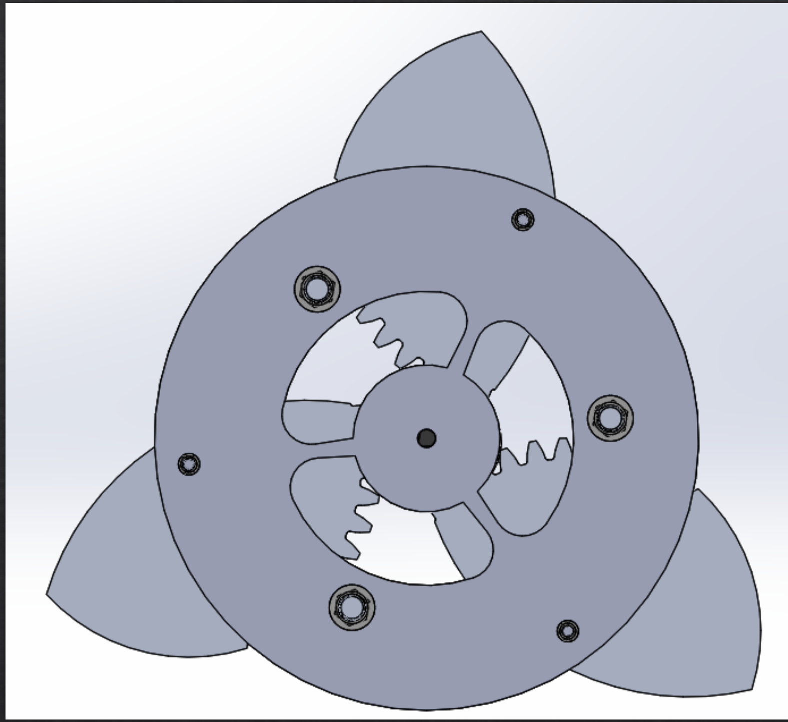
Airbrake: Goal

- Achieve targeted altitude
- Reduce the speed of rocket
- Deploy when close to target
- Drag forces increase



Airbrake: Spike System top view

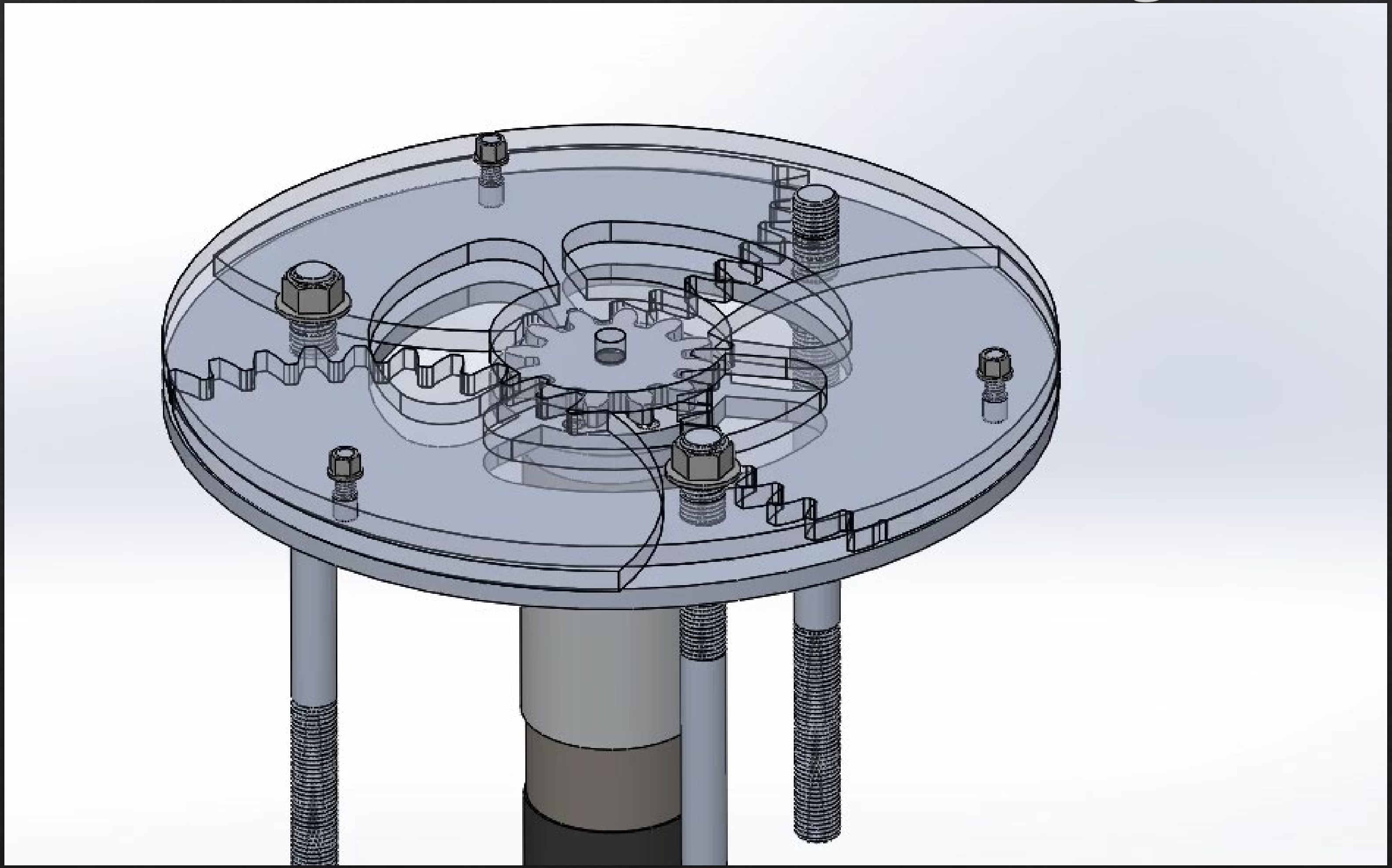
Final Version: Al 6061-T6



Work Done

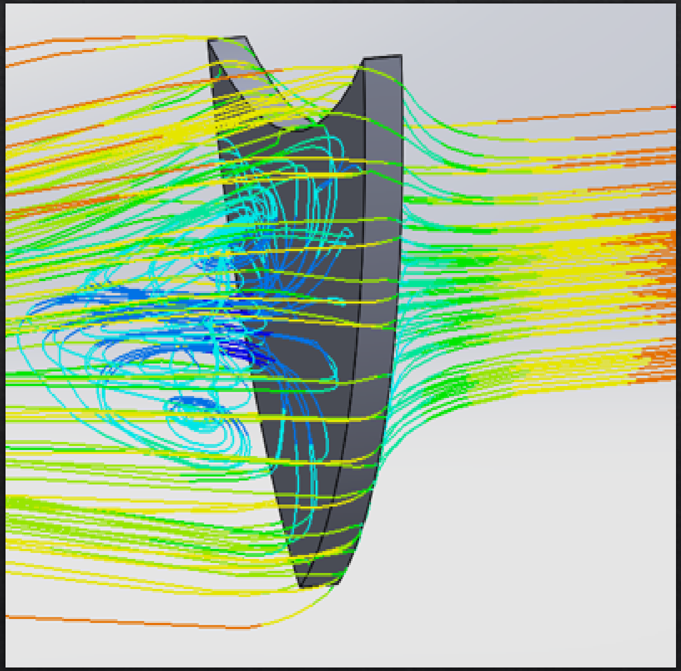
- Material from the top/bottom plate was reduced
- Less friction between plates and airbrake blades
- Motor works less
- Connected with bolts, nuts, and screws
- Manufacturing Methods: Water Jet and purchase

Airbrake: Rotates 240 Degrees

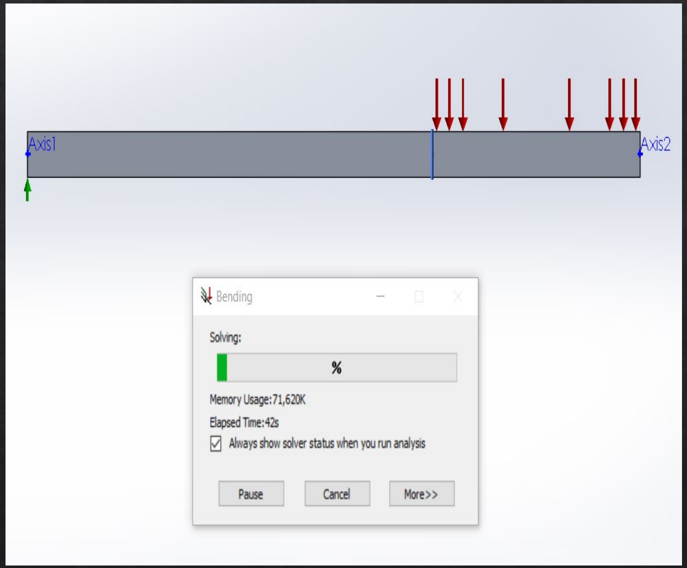


Airbrake: Verification/Testing

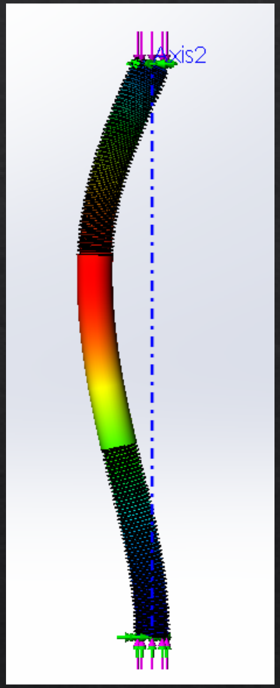
Flow Simulation (Airbrake Blade)



Bending (Airbrake Blade)

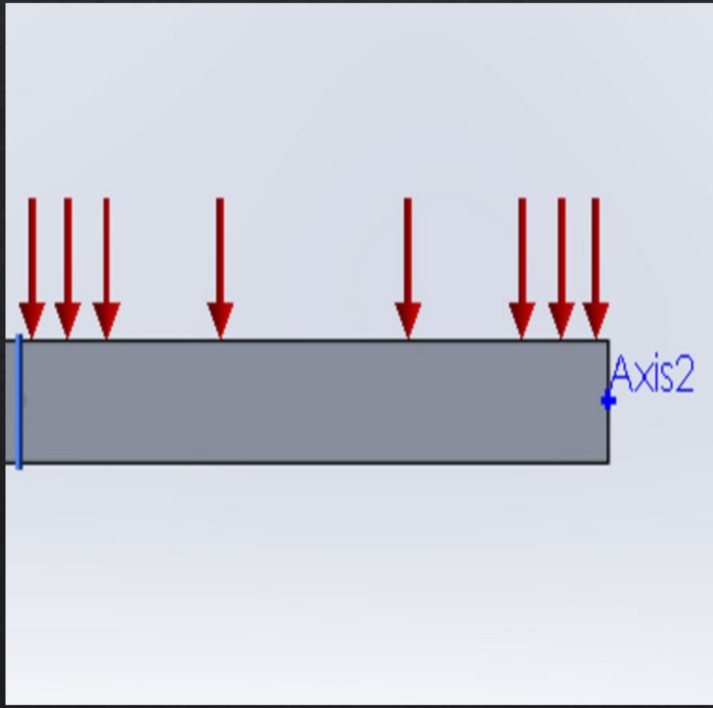


Buckling (connecting Rod)

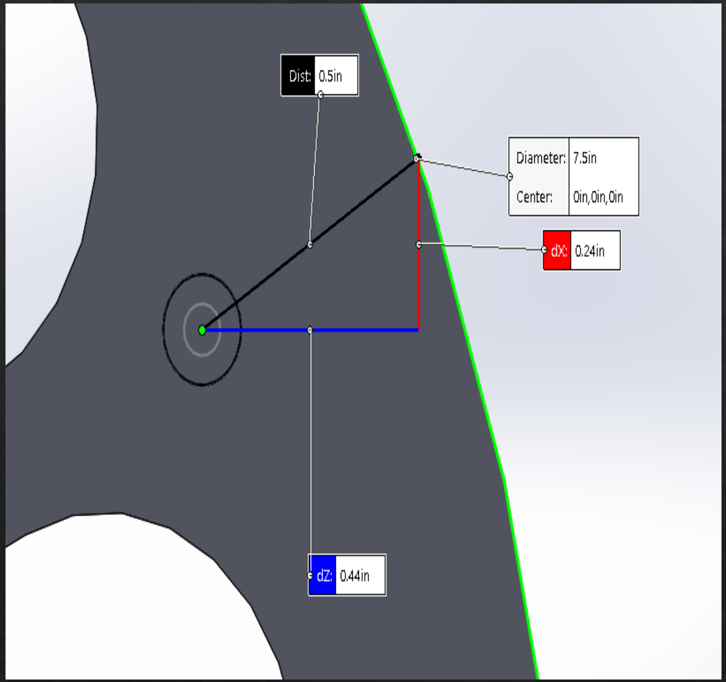


Airbrake: Verification/Testing

Shear (Airbrake Blade)



Bolt Bearing (Connection for plates)



Shear -Tear out (Connection for plates)

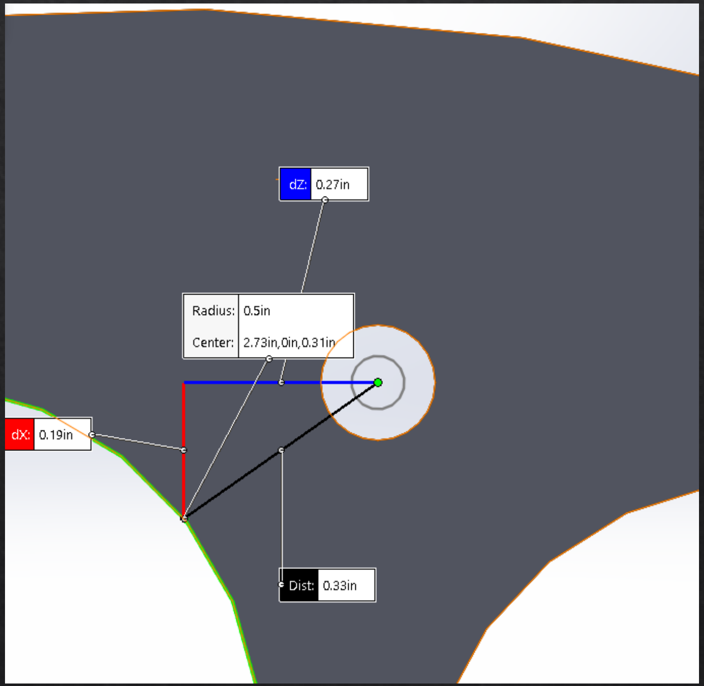


Table of results

Parts	Material	Failure Mode	M.O.S	Failure
Airbrake Blade	Al 6061-T6	Bending	0.5	2766.79 N
Airbrake Blade	Al 6061-T6	Shear	0.5	6921.43 N
Connecting Rod	Al 6061-T6	Buckling	2.9	2224 N Top/ 894 N bottom
Connection for plates	Al 6061-T6	Bolt Bearing	1.84	2224 N
Connection for plates	Al 6061-T6	Tear Out shear	4.88	2224 N

Estimated Price for Airbrake Assembly

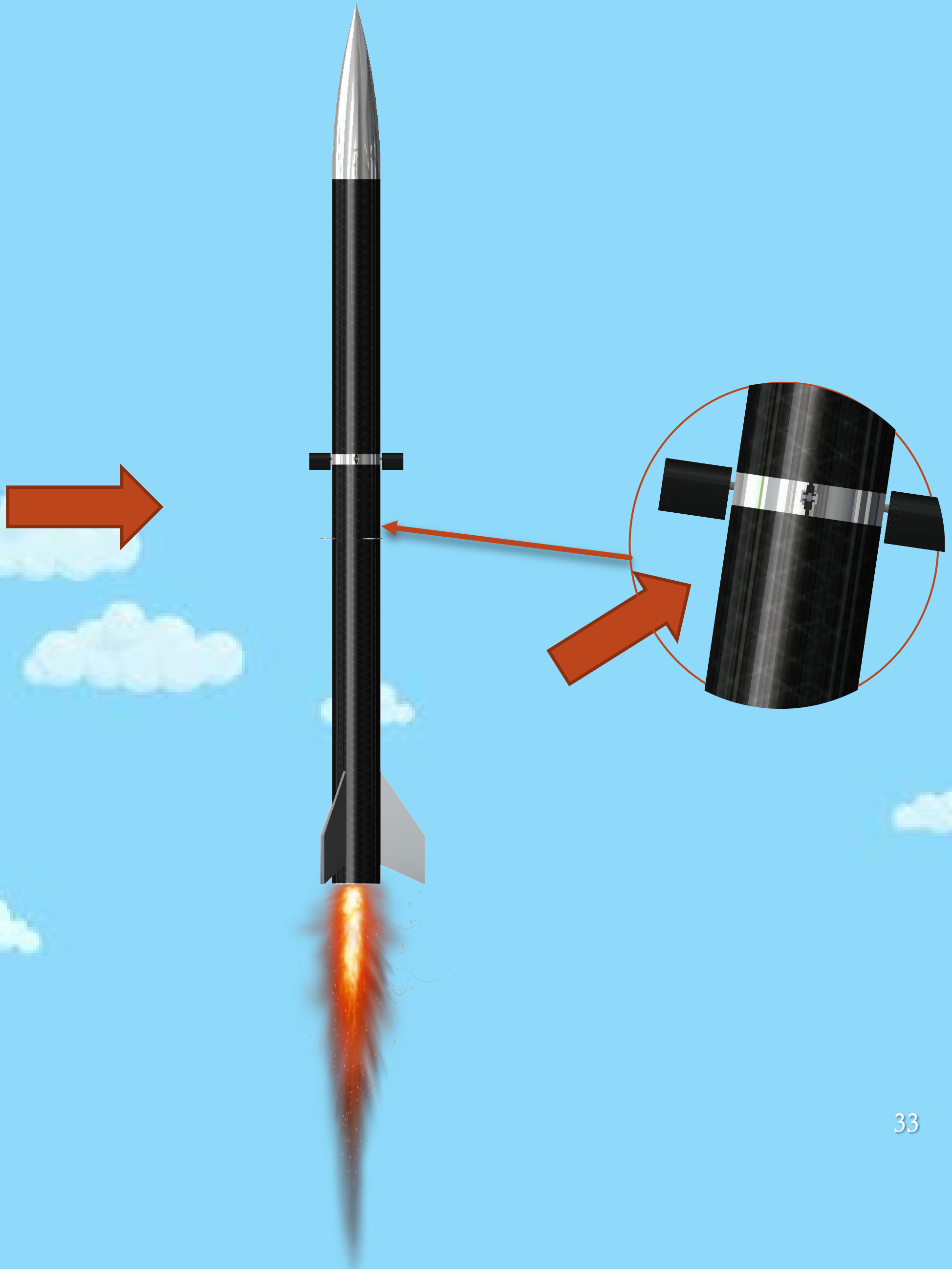
Item	Num.	Cost per	Description/Specs	What it's used for
NeveRest Classic 40 Gearmotor	1	$29.50	output power:14 W; Stall torque: 350 Oz-in; No-load speed:360 RPM; Weight: 0.767 lbs	Open airbrake system
Connecting Rod	3	$9.26	6061 Aluminum, 6" Overall Length, 3/8"-24 Thread	to attach airbrakes plates
Mil. Spec. Distorted-Thread Flange Locknut	12	$2.42	Low-Strength Steel, 3/8"-24 Thread Size, MS21042-6	to attach airbrakes plates
Mil. Spec. Distorted-Thread Flange Locknut	6	$0.67	Low-Strength Steel, 8-32 Thread Size, MS21042-08	to attach airbrakes blades
Steal plate for body	1	$53.28	12'' X 24'' thickness 0.19''	Create top/bottom plates and airbrake blades
Total	$143.60			

Technical Details

- Actuated Fin & Rocket Airframe Control: Alfonso
- Rocket Dynamic Controls: Francisco
- Airbrake: Moises
- Altitude Controls: Sean
- Static Fins: Miguel

Altitude Controls : Goals

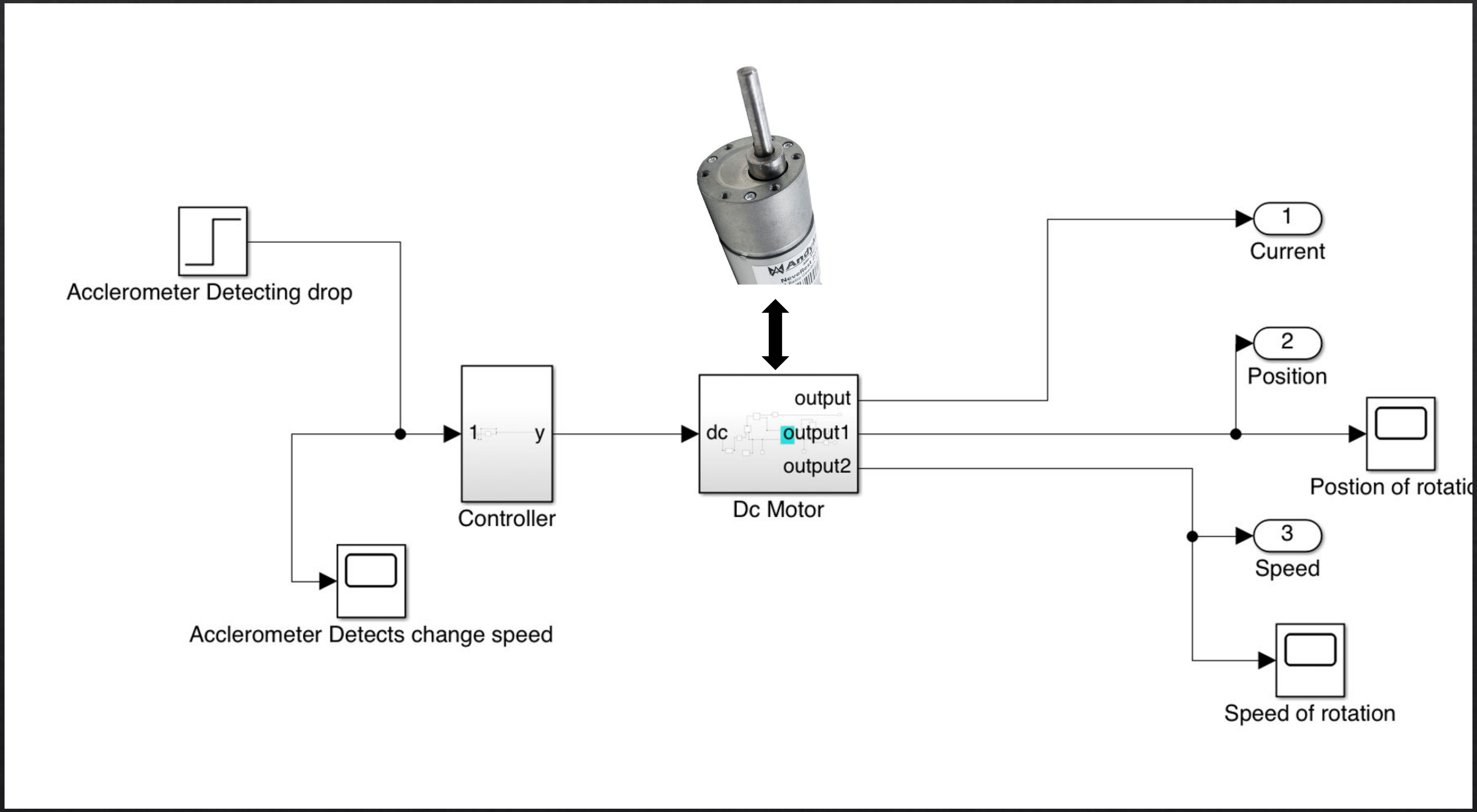
- Develop feedback system to activate motor
- System used to assist in targeted altitude



Altitude Control Conceptual

- Airbrake motor control system using PID controller to activate motor

DC Rotation deploys fins



Parts Selection

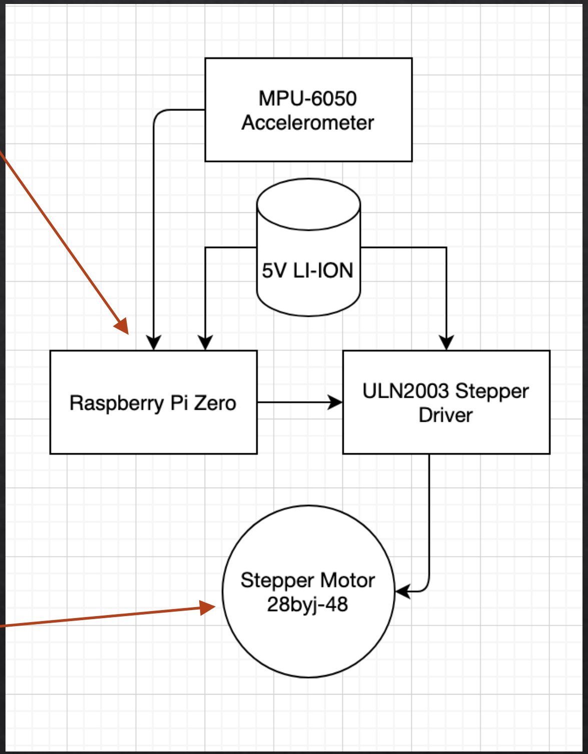
Item No.	Elements	Voltage Input (V)	Voltage Output	Power Consumption
1	Raspberry Pi Zero	5V	PWM	0.4 W
2	ULN2003	12V	50V (max)	240mA
3	Stepper Motor 28byj-48	5V	N/A	TQ Dependant
4	MPU-6050	5.0-6.0V	N/A	10mA

- Each element is listed along with the specifications that they each contain.

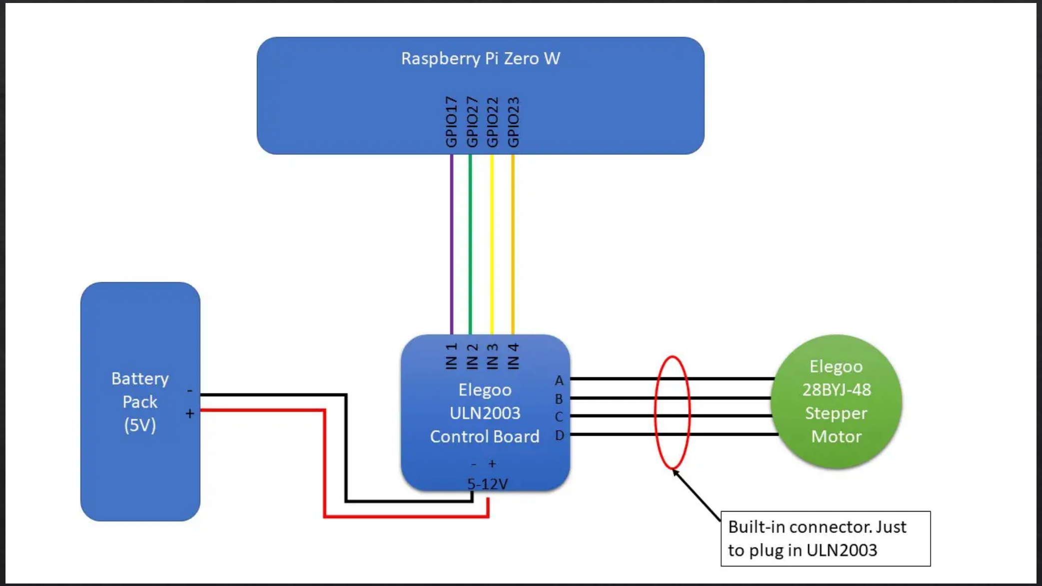
Altitude Controls

Information input

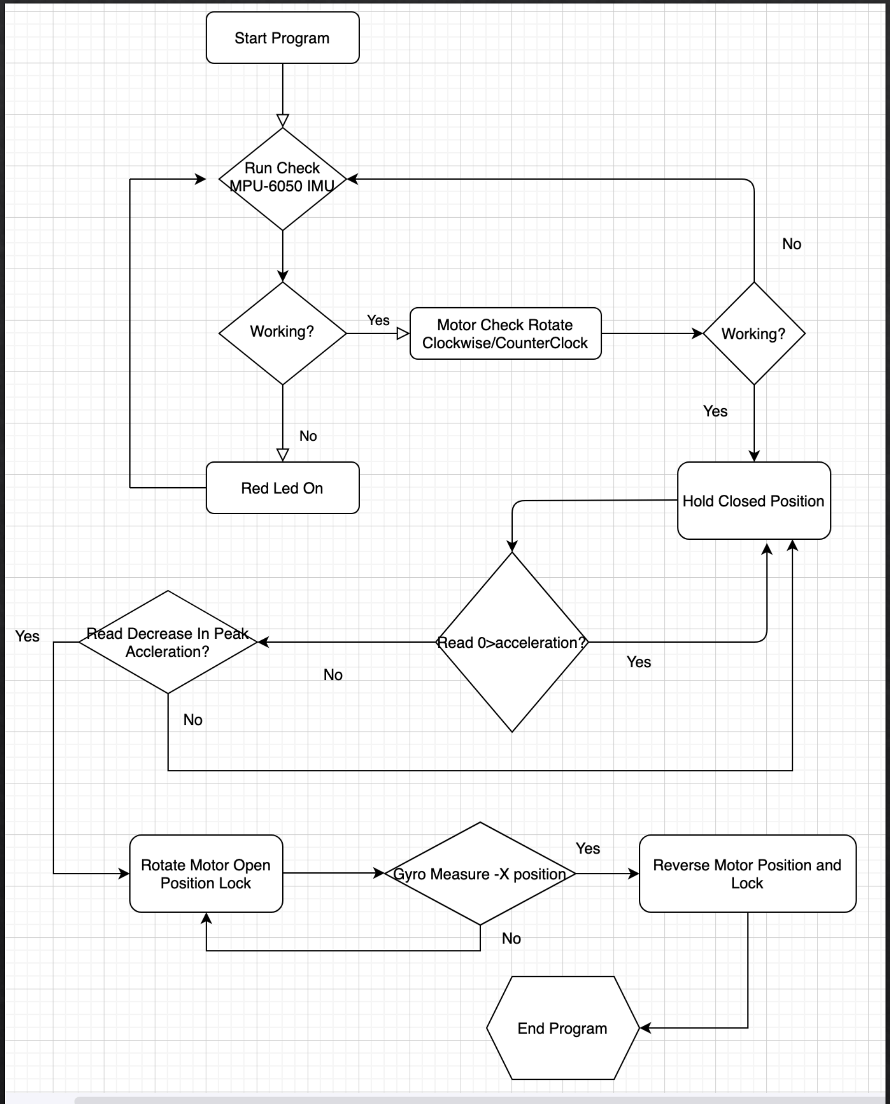
Mechanical output motor turns



- Map of how components are connected

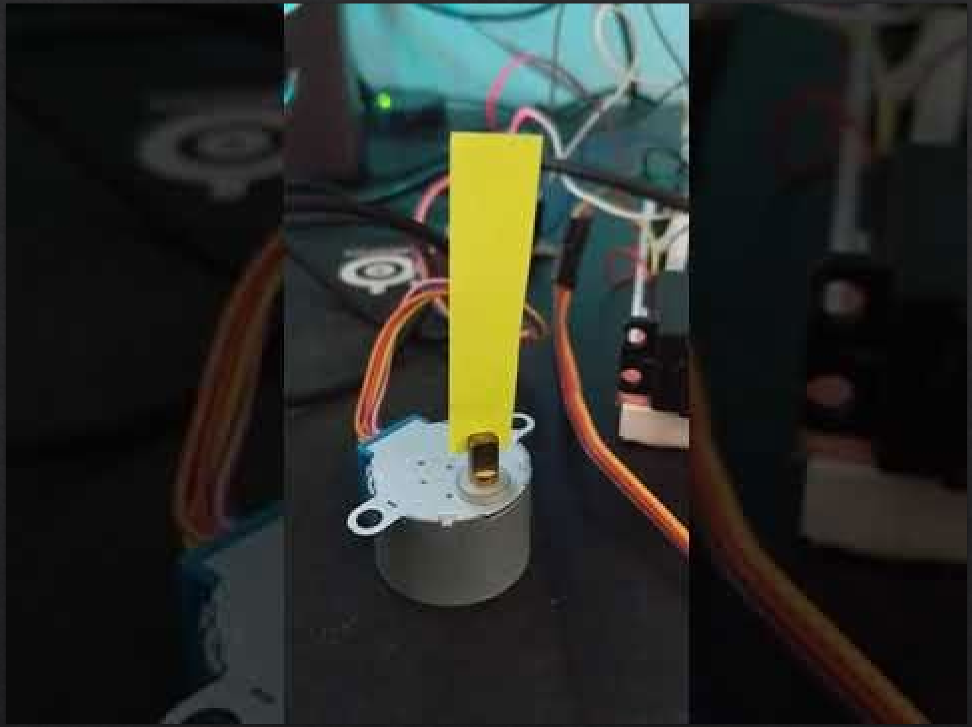


Decision Making map



- Map of the planned decision making process to program

Initiating stepper with Python and GPIO



- Showing the initiating of the stepper motor in action

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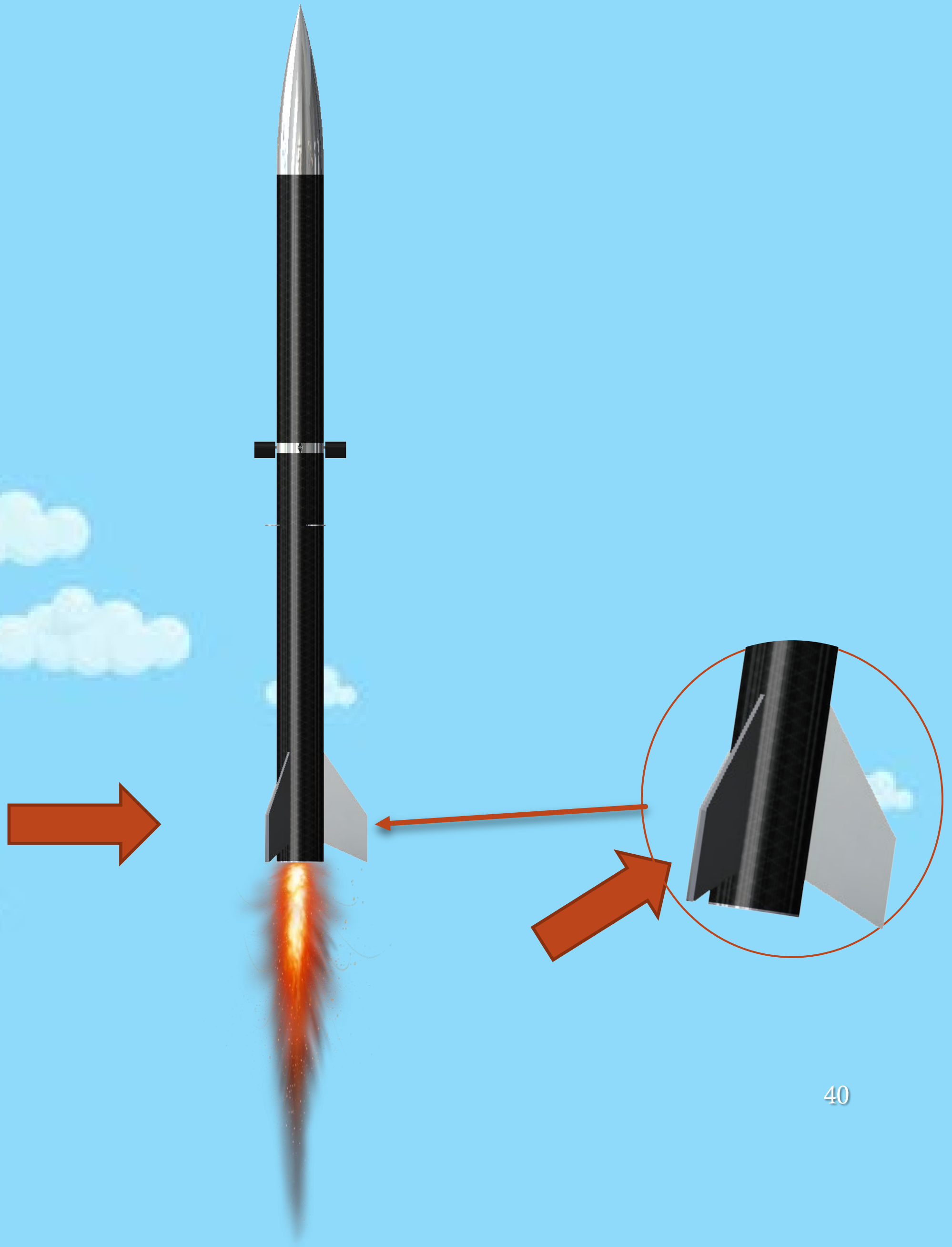
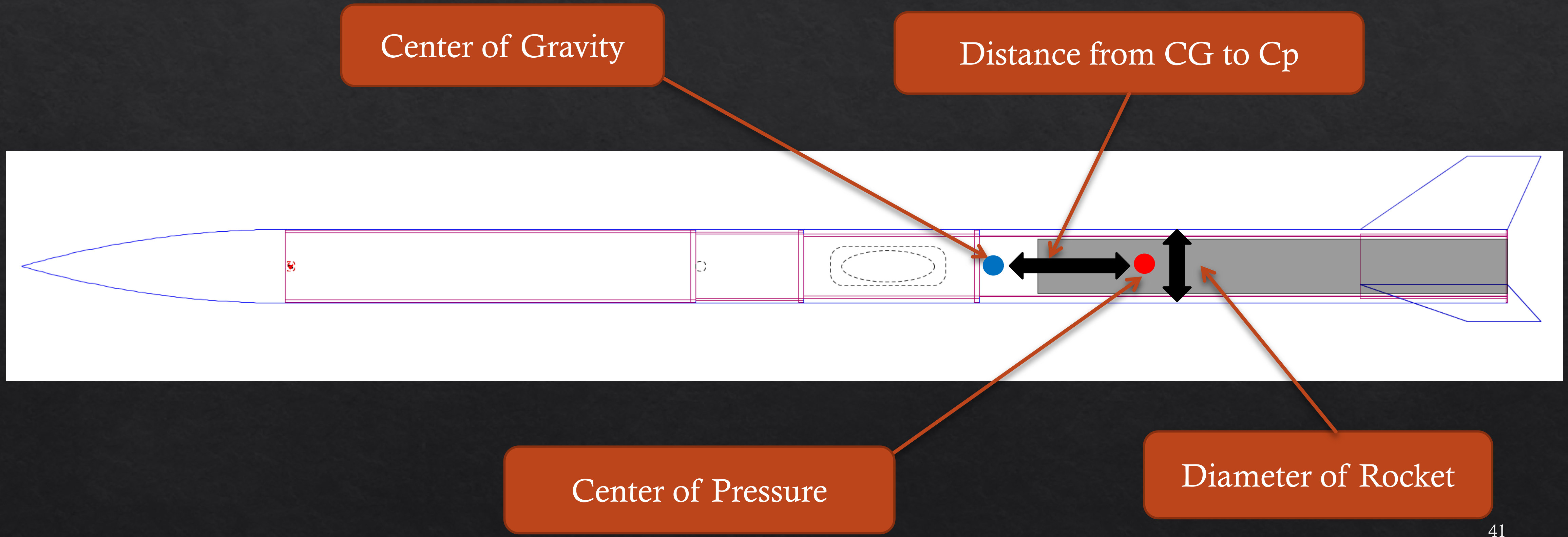
- Airbrake: Moises
- Altitude Controls: Sean
- Static Fins: Miguel

Static Fins: Goals

- Maintain stability of rocket during takeoff and minimize weather cocking effects
- Stability Caliber greater than 1 but lower than 3
- Minimum apogee of 30,000 ft (9,144m)

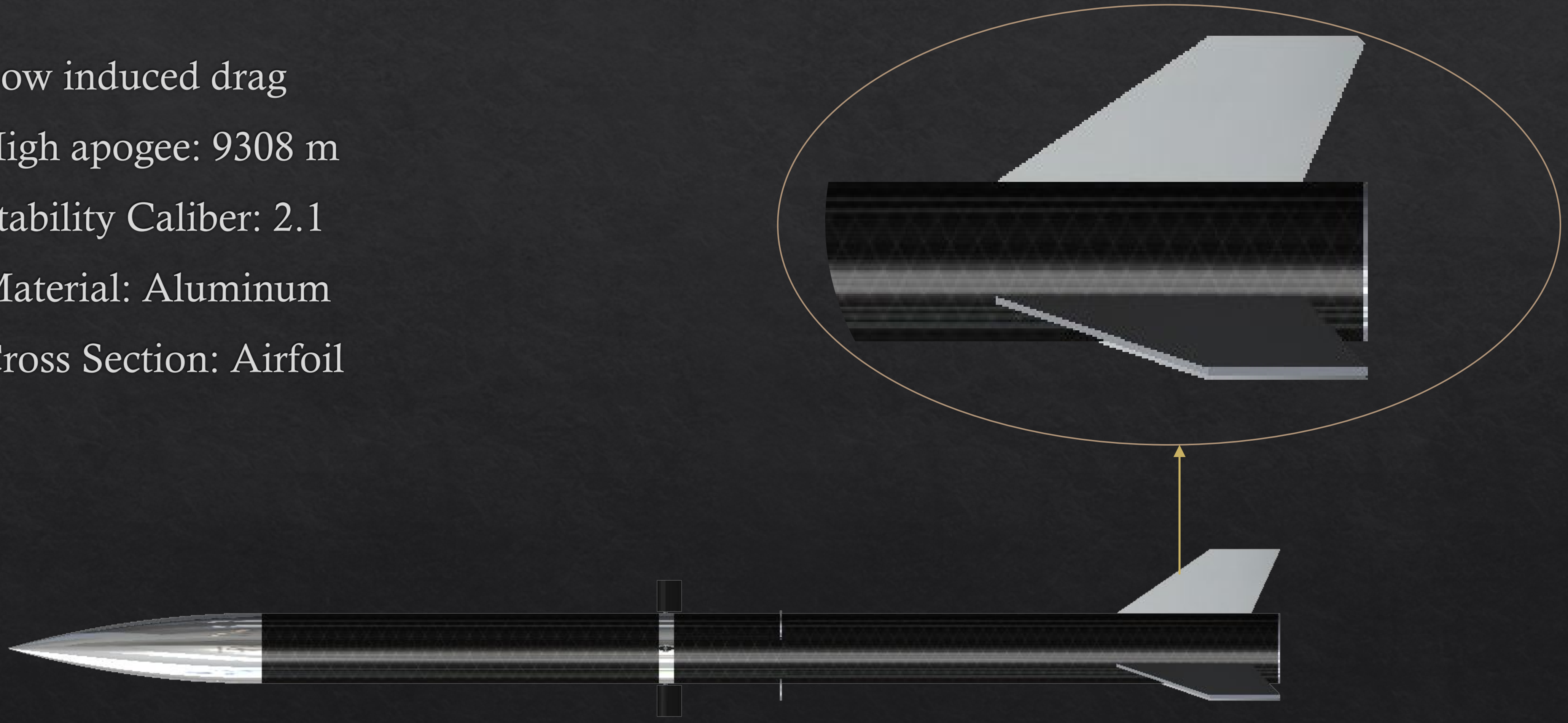


Static Fins: Stability Caliber

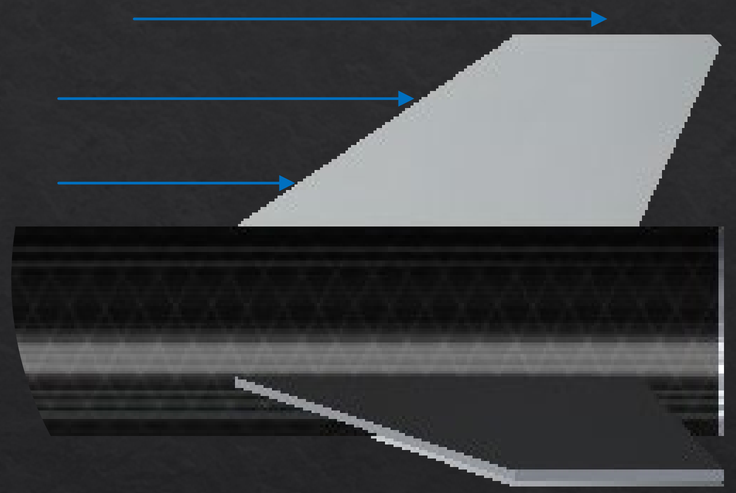


Static Fins: Clipped Delta Shape

- Low induced drag
- High apogee: 9308 m
- Stability Caliber: 2.1
- Material: Aluminum
- Cross Section: Airfoil



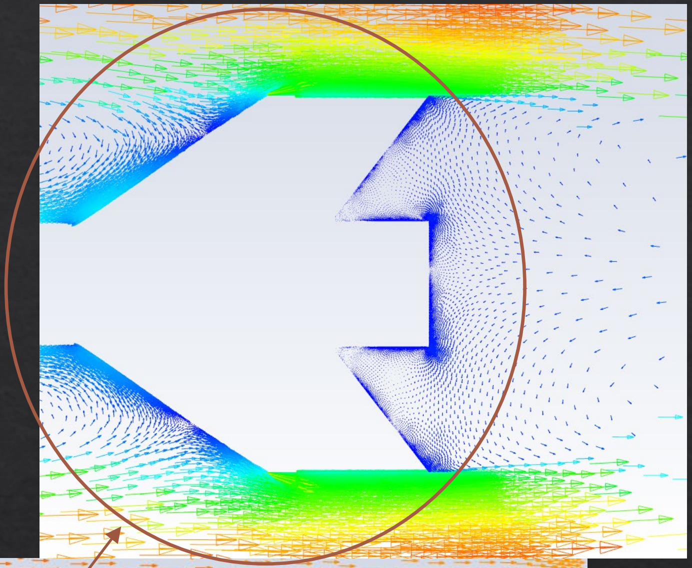
Static Fins: Fin Flutter

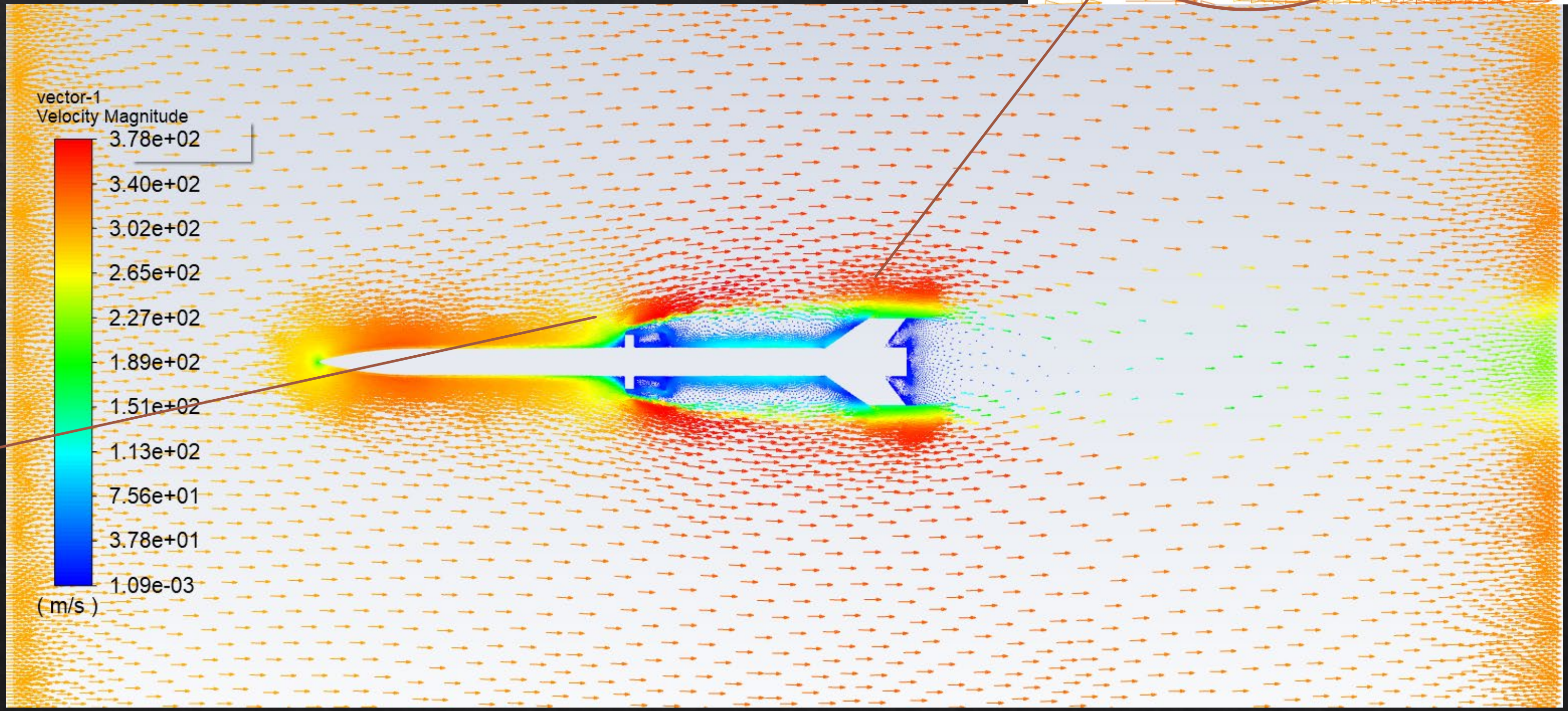


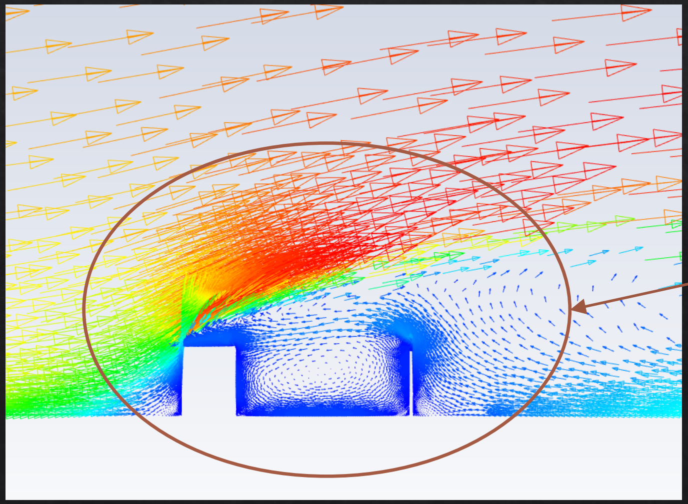
Fin Flutter Velocity (m/s)	Fin Flutter Velocity: Safety Factor 80%	Max Velocity (m/s)
802 m/s	642 m/s	594 m/s

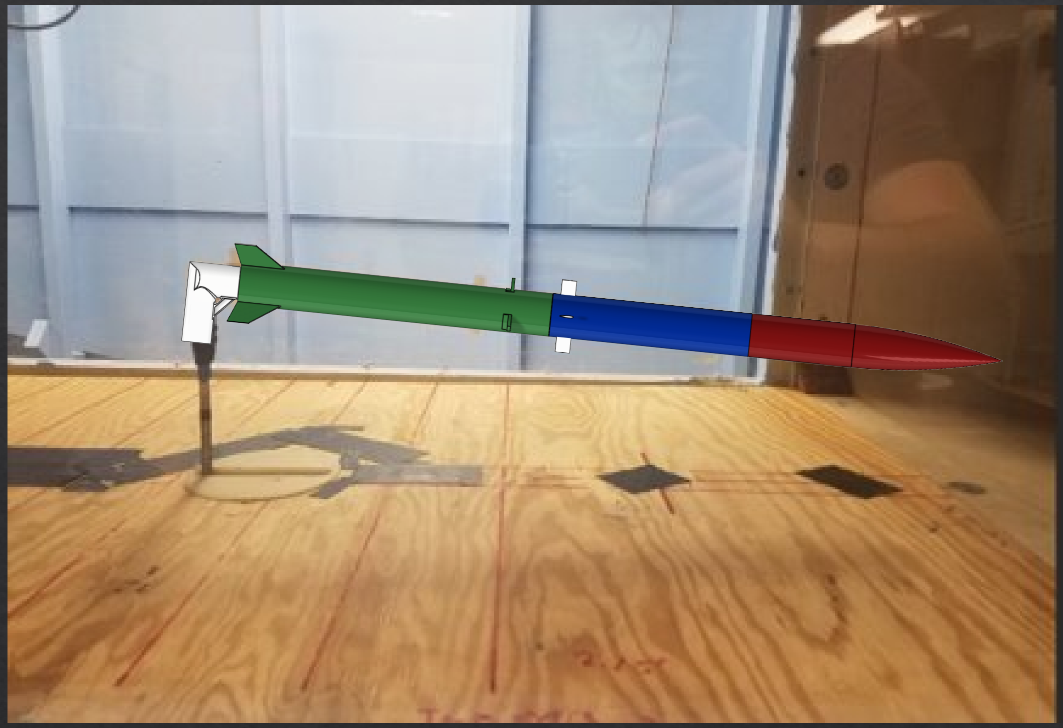
Rocket: ANSYS Fluent

- Velocity = 300 m/s
- Cd= .0825
- Drag Force = 3733 N









SolidWorks Render

Live Wind Tunnel Testing

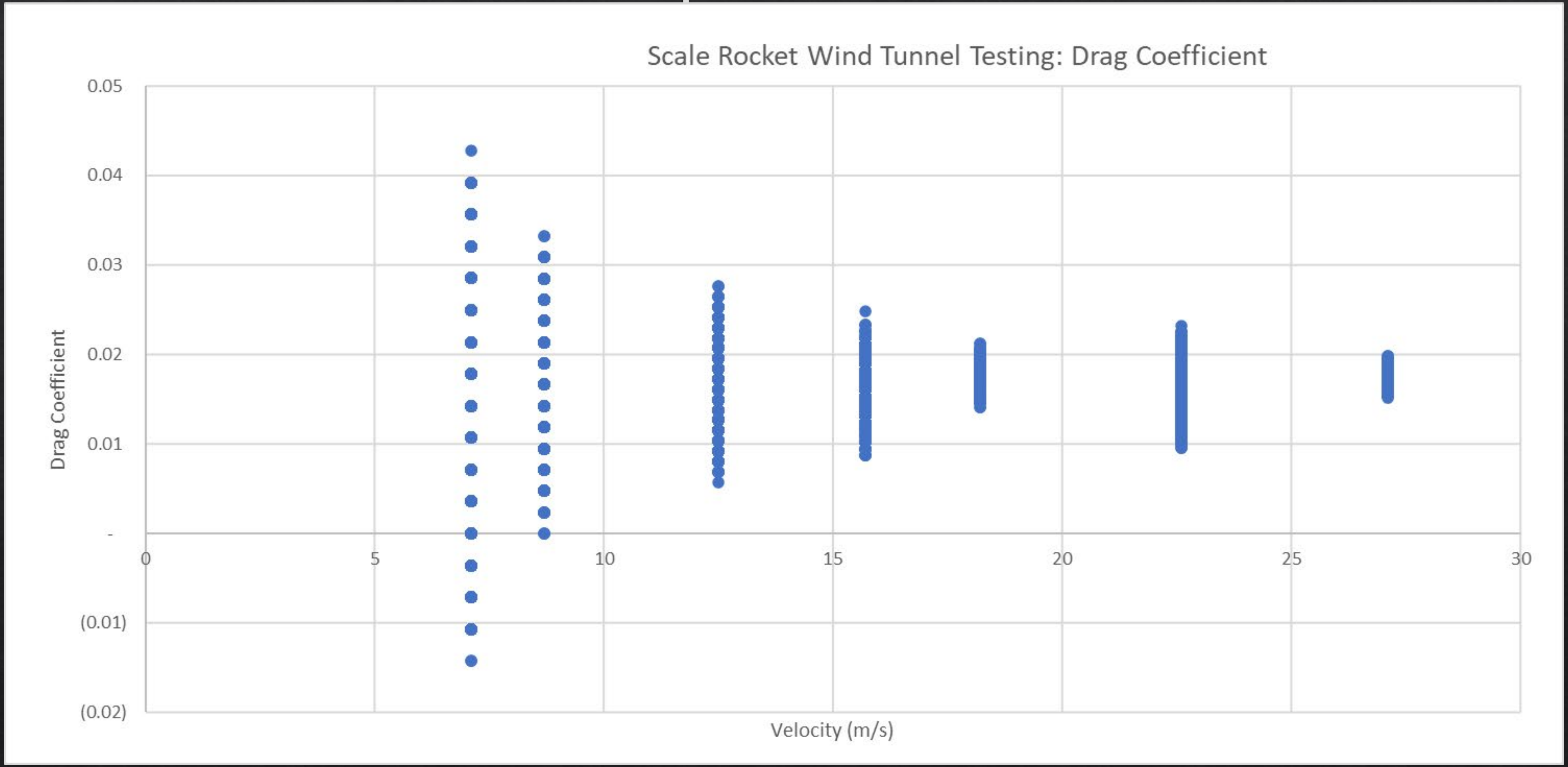
Final Testing Strategies

Experimental procedures

Scale Rocket with Air Brakes: ANSYS Fluent vs Experimental

ANSYS Fluent Results		Wind Tunnel Results
Velocity (m/s)	**Drag Coefficient**	**Drag Coefficient**
7.1	.0505	.0143 - .0428
8.7	.0504	.0137 - .0332
12.5	.0500	.0058 - .0276
15.7	.0498	.00248 - .0087
18.2	.0497	.0141 - .0212
22.6	.0496	.0095 - .0232
27.1	.0495	.0152 - .0198

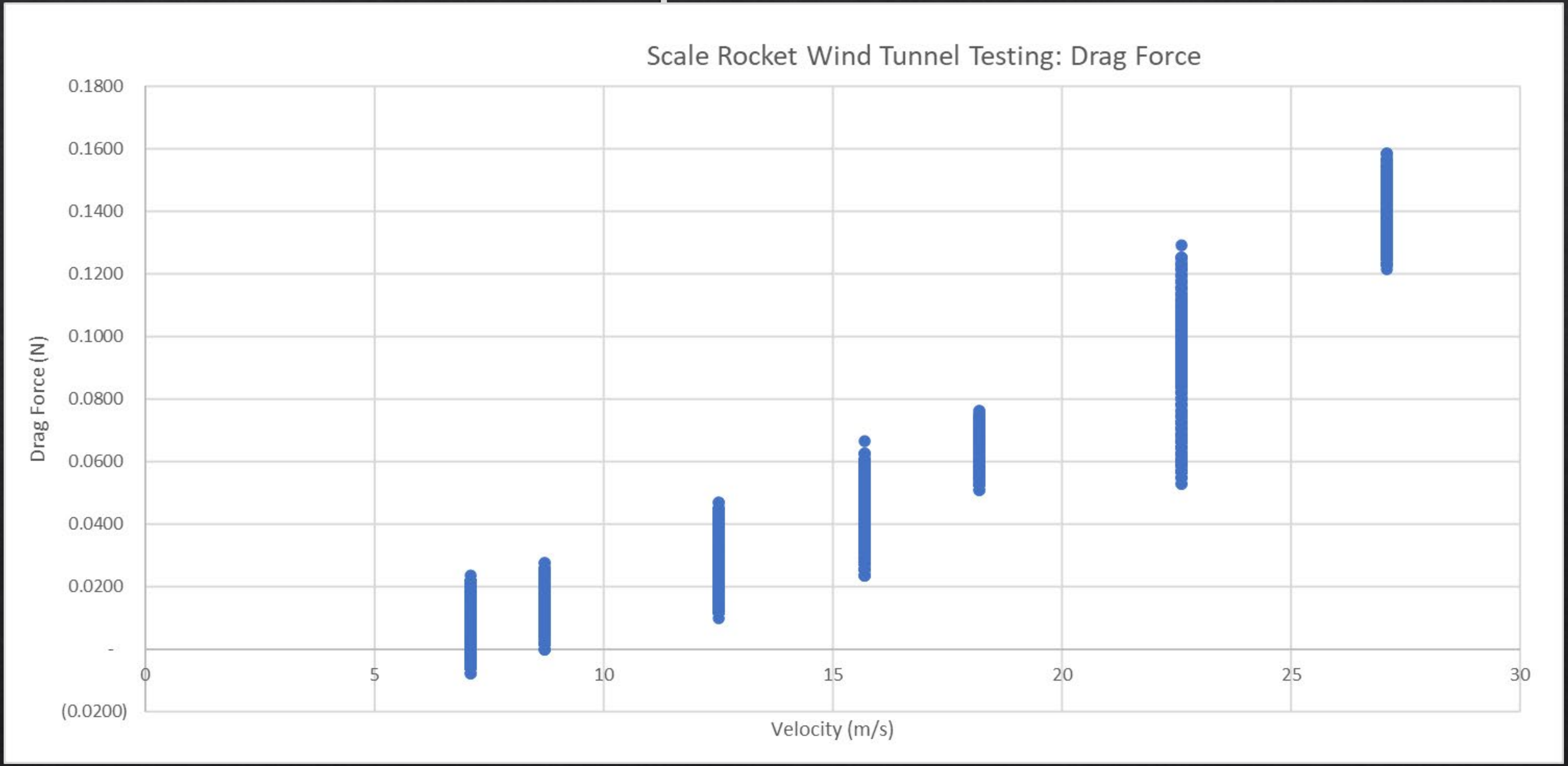
Scale Rocket with Air Brakes: ANSYS Fluent vs Experimental



Scale Rocket with Air Brakes: ANSYS Fluent vs Experimental

ANSYS Fluent Results		Wind Tunnel Results
Velocity (m/s)	**Drag Force (N)**	**Drag Force (N)**
7.1	.031	.0078 - .0235
8.7	.047	.0039 - .0274
12.5	.096	.0098 - .0470
15.7	.150	.0235 - .0665
18.2	.202	.0509 - .0763
22.6	.311	.0528 - .1292
27.1	.446	.1213 - .1585

Scale Rocket with Air Brakes: ANSYS Fluent vs Experimental



Agenda

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Conclusion

- Completed mechanical design and structural analysis of actuated fins and airbrakes
- Designed and tested rocket dynamic and altitude controls with MATLAB Simulink and physical hardware
- Performed CFD and experimental analysis, through ANSYS Fluent and the Cal State LA Wind Tunnel to find scale model Cd and Drag Force

EAGLE ROCKETRY SEDS

Acknowledgements

- Dr. Nurullah Arlsan
- Dr. Kuo
- Dr. Thorburn
- Dr. Bachman
- Jonathan Cervantes
- Eagle Rocketry
- Cal State LA ECST

CAL STATE LA COLLEGE OF ENGINEERING, COMPUTER SCIENCE, & TECHNOLOGY

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