Design 1 Air-Brakes Preliminary Submission

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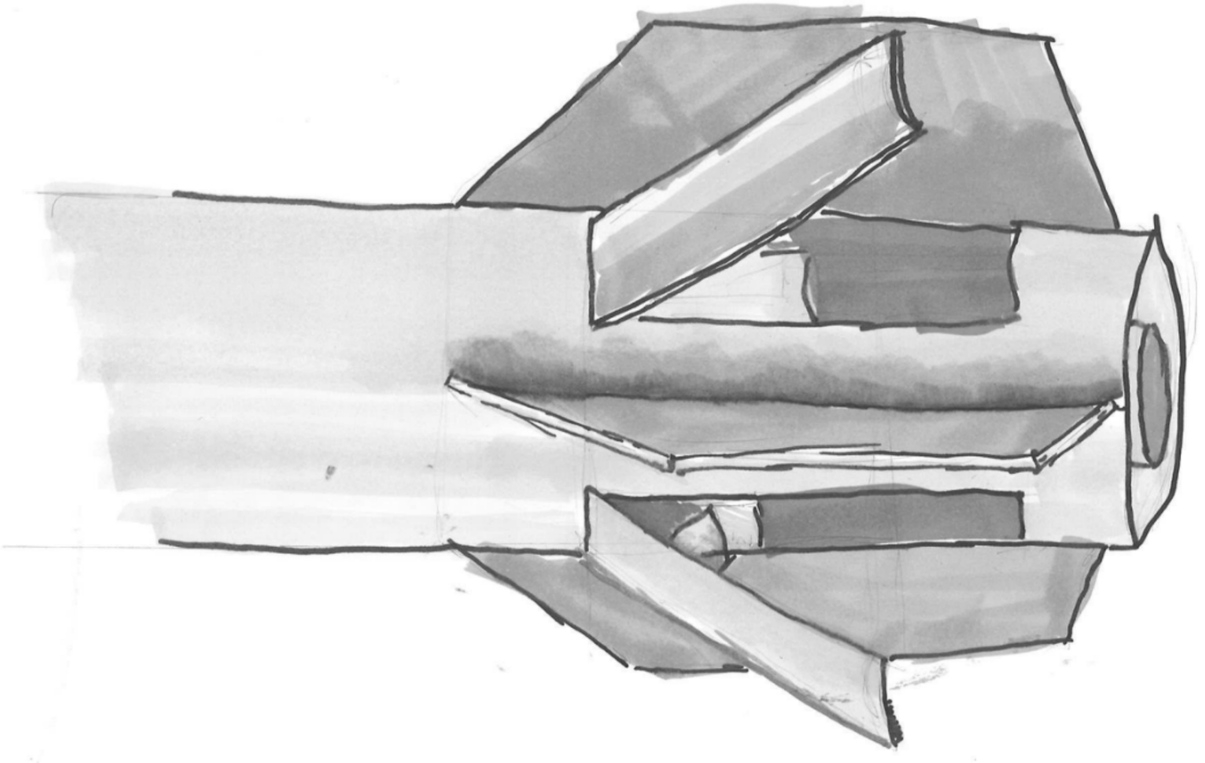

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Section 1.0 - Background research

1.1- Introduction

Air brakes have long been used in the aerospace industry to modify the trajectory of aerial vehicles. While their primary purpose is to slow down the vehicle, they may be utilised to alter trajectory, downforce, or lift. Air brakes have been incorporated into planes for decades, in the form of extendable panels to create drag [1].

Figure 1.1.1- A McDonnell Douglas F-15 Eagle combat jet with an airbrake deployed during landing [2].

In commercial airliners, air brakes are deployed before touchdown to slow down the plane in order to land safely with the use of spoilers and ailerons [3]. As flight has become a more popular and common mode of transportation, the technology surrounding air-brakes on aircraft has also evolved planes have been optimised for cheap and efficient travel. This includes air brakes, which have been designed with a complex control system to not only be pre-programmed, but react to changing conditions during flight.

Air brakes are useful in the rocket industry as an alternative to a throtattable hybrid or liquid fueled engine, this allows for a more precise altitude target to be achieved with a simpler form of propulsion using solid motors, over a heavier, more expensive hybrid or liquid engine. Air brakes also have the ability to control the attitude of the rocket such as pitch, yaw and roll depending on the mechanism and control surface used. This provides a simple and versatile form of trajectory control over thrust vectoring, which requires a heavier and more complex propulsion system or other reaction control systems (RCS) such as reaction wheels, which require a large rotating mass for any reasonable control and attitude thrusters which require their own propulsion system and involve further complexity.

Due to the fundamental nature of air brakes they have limitations. This being they require an atmosphere to be effective, and lose effectiveness at higher altitudes. Thus air brakes would not be a suitable choice for altitude control or attitude control if the rocket has an apogee far outside the lower atmosphere (troposphere [4]) as the only time a correction can be made is early in the rocket's trajectory. This leads to a less precise control of trajectory as the corrections made are far earlier in the flight causing error propagation, also potentially occurring during unfavourably high airspeeds or whilst the motor is still in burn.

Monash High Powered Rocketry (HPR), have designed a project for the unit Design 1 based around researching, designing, and implementing an air-braking system for a level 1 rocket flown on an H class motor. Undertaken during a twelve week semester, the system must be implemented into a rocket to be flown at either a Melbourne Amatuer Rocket Society (MARS) or Tripoli Rocketry Association Australia (TRAAU) launch event. The design specification states that upon burnout, the brakes must deploy and act for two seconds before retracting, with significant deceleration visible in the collected data. The design will be optimised for best possible performance, as well safety and efficiency. The final design will be utilised and expanded upon by HPR on future rockets.

1.2- Fundamental Rocket dynamics

To effectively understand and analyse rocket flight, it is vital to grasp some of the basic concepts that dictate the trajectory of vehicles through the atmosphere. Some of these vital concepts include the center of pressure/center of mass, drag and properties of fluids. The sections below summarise these fundamental concepts.

1.2.1- The centre of pressure & centre of mass

Two variables that substantially impact the stability of a rocket are the centre of mass (C_m) and the centre of pressure (C_p). The centre of mass- often also called centre of gravity- essentially describes the average position of a body based on the mass of it components. [5] It is around this point that the rocket will rotate during flight, if a large imbalanced force is applied to an end of the airframe. [6]. This value can be computed mathematically using the formula below:

$$C_g = \frac{d_1 w_1 + d_2 w_2 + d_3 w_3 + \cdots + d_n w_n}{w_{Total}}$$

Where;

d_n is the distance of a component from a certain defined reference line

w_n is the weight of the respective component

W_{Total} is the total weight of the system

[Eq 1.2.1]

The centre of mass is influenced through the positioning of components throughout the airframe

The centre of pressure, on the other hand, describes the average position of all the pressure acting on the system [7]. When considering the net aerodynamic forces acting upon the system, these forces can be considered to act through the Cp. To compute the centre of pressure acting on an object, the formula below can be used:

[Eq 1.2.2]

$$C_p = \frac{\int x\, p(x)\, dx}{\int p(x)\, dx}$$

Where,

P(x) is a function of pressure over a surface

C_p is the centre of pressure

Control surfaces like fins and air brakes manipulate the centre of pressure, by creating a larger surface for pressure forces like lift and drag to act on. As such, by adding these features to an airframe, the C_p moves toward the position of these components. To ensure the rocket remains stable throughout its flight, the centre of mass should be ahead of the centre of pressure. This is because, if an imbalanced force- like a gust of wind- is applied to the side of the rocket, if the C_p is below the C_m the rocket, the air pressure will act against the fins, and counteract the effect of the imbalanced force. Conversely, if the C_p is ahead of the C_m, the air pressure will act against the front of the rocket, and amplify the effect of the imbalanced force, and cause the rocket to begin tumbling. [8]

1.2.2 - Drag

Drag is a force that resists the movement of an object through a fluid [9]. As a rocket flies through air,
The formula below models the aerodynamic drag force of applied on the rocket:

[Eq. 1.2.3]

$$D = C \times \frac{\rho \times V^2}{2} \times A$$

Where;
D is drag
C is the coefficient of drag
p is the air density
V is the velocity
A is the area perpendicular to fluid flow

By deploying control surfaces on the rocket, the effective area of the rocket is increased, and hence the aerodynamic drag of the vehicle also increases. These added features to the profile of the rocket also manipulate the drag coefficient, however this value is generally difficult to compute by hand, and is generally found either experimentally or computationally using computational fluid dynamics software. [10] [11]

1.2.3 - Relevant Fluid properties

For the implementation of effective airbrakes it is required that the control surfaces provide sufficient drag force to decelerate the rocket faster than its natural drag. This is accomplished by the increase in either skin friction or pressure drag on the rocket.

To optimise performance of the rocket it it necessary that the control surfaces have the least impact on drag when retracted and throttleable drag when deployed. This can be achieved by deploying surfaces out into the free stream flow of the rocket.

Key variables that impact the total drag experienced by the rocket can be summarised in the following table 1.2.3.1

Table 1.2.3.1: Variables that impact airbrake drag and effectiveness

Variable	**Impact**
Free stream velocity	Directly impacts magnitude of drag on each airbrake
Boundary layer effect of nose cone	May cause turbulent flow over air brakes impacting effectiveness
Angle of brake deployment	Directly impacts pressure and skin drag
Geometry of brake	Directly impacts Cd of the brakes
Boundary layer effect of fins	May cause turbulence over the air brakes impacting drag force
Wake impact of airbrake on fins	May cause a change in drag force from the fins due to airbrake effects
Surface finish of Air brakes	Directly impacts skin drag

These variable are difficult to control and to determine a drag estimate as a function of velocity and airbrake deployment angle will be prohibitively difficult without the aid of CFD (Computational Fluid Dynamics). Due to time restraints drag calculations have been neglected for this report however preliminary CFD has been done so the team can get a better understanding of the underlying variables that impact the performance of the system. Over the next few weeks the team will research further into CFD to determine reasonable drag calculations.

Due to the complexity of potential air brake geometry and boundary layer effects from the airframe of the rocket, using a flat plate approximation will provide a drag value that can be used as a very rough estimate for drag. The thin aerofoil approximation [12] can not be used due to the stagnation points expected behind the airbrakes. Further research will bring forward a more detailed view on fluid dynamics around the rocket at various flight conditions due to future implementation of CFD.

1.3 - Methods of Mechanical actuation

A key consideration in designing the air brakes for use on rockets is the mechanical actuation system that would deploy and retract the control surfaces. Given the considerable drag generated by the brakes, it is vital the deployment system is robust and reliable, while also capable of producing sufficient force to extend and hold control surfaces in the desired configuration. Some components that could be used for mechanical actuation include cams, servos, and hydraulics, as discussed in the following sections.

Potential mechanically actuated systems include:

- Hydraulic
- Pneumatic
- Electromagnetic
- Cam and follower
- Servo actuation
- Rope and pulley
- Rack and pinion
- Elastic/spring

Due to the restricted space and weight in a Level 1 rocket only servo actuation and cam/follower actuation methods are considered in this report.

1.4- Electrical and sensor systems:

For the system to record key events during flight like burnout and apogee, and also collect relevant data, inclusion of an electrical and sensor system in the design is required.

1.4.1- Sensor systems:

1.4.1.1- Accelerometers:

To measure the effectiveness of the airbrake system at slowing-down the rocket, deceleration data would be required to analyse the effect of deploying control surfaces on trajectory. To measure values like acceleration, an accelerometer can be used. This sensor works in one of two ways. Piezoelectric accelerometers contain a crystal microstructure which becomes stressed as forces from change in velocity are applied to it. The structures produce voltage in response to the force applied to them, which is read by the processor and used to calculate the acceleration the sensor is under. The second general category of accelerometer are “capacitive” variants. This variety monitors the capacitance between crystal structures, and uses the fluctuations in this capacitance to measure accelerative or decelerative motion [13].

1.4.1.2- Recovery system sensors:

The rocket that will be used to test the effectiveness of brake designs must be capable of analysing altitude, in order to track apogee of the vehicle, and also trigger deployment or recovery devices. As altitude changes, air pressure decreases, and so one possible method of measuring altitude is using a barometric pressure sensor. This type of sensor is provided to the team by HPR in the form of a Rocket Recovery Controller 3 (RRC3). This device contains a pressure, and temperature sensor, and also has the ability to store recorded data and coordinate the delivery of an ejection charge once a desired altitude is attained. Furthermore, based on the rate of change of altitude, the device can also compute the velocity of the rocket in real time, this also can be used to track the effectiveness of the airbrake after deployment. As such, this component will form an integral part of the system design by tracking and storing a variety of data values, and also controlling deployment events [14].

1.4.2- General Electrical Systems:

1.4.2.1- Control Systems:

To control the deployment and retraction of the air brake, there must be a control system embedded in the design capable of directing the action of the mechanical actuation system. As the design brief requires provision for microprocessors and sensors to be integrated into the system in future, it is important that the prototype is designed around such systems to ensure compatibility. One control unit that can be used with the system is an Arduino pictured in figure 1.4.1. Arduino is an open-source hardware platform based around a simple microcontroller. The system can reprogrammed using a computer, and interface with a number of sensory inputs and outputs [15]. As the design is open source, several variants of the product with differing specifications and functionality are also available. For instance, the Adafruit datalogger M0 feather is another microprocessor board much like the Arduino Nano, but with an included SD card port for data storage [16].

A microprocessor system could be used to control the mechanical actuation system of the air brakes by reading the input from sensors like accelerometers and the RRC3 and after processing the values trigger the mechanical actuation system to deploy the air brakes.

Figure 1.4.1- An Arduino Nano circuit board. The microprocessor (black square) is seen in the middle of the board and a number of analogue and digital ports are found along its sides [17].

1.4.2.2- Power supply and management:

To power the onboard avionics systems as well as the actuation mechanism of the rocket, a power supply is required on board the rocket. Lithium Polymer batteries (LiPos) are a variant of the conventional rechargeable battery which contain a polymer rather than liquid electrolyte. This means they generally have a higher capacity, higher discharge rate and lower mass than comparable standard rechargeable cells [18]. As the mass of componentry onboard a rocket can significantly impact its stability, these lighter and denser cells are a more effective choice when compared to traditional cells. Fur

Another important consideration when considering power distribution in the rocket's electrical systems, is the required input voltages to the various components. Some parts of the system, like servos may require a higher voltage to operate at the desired strength, while others like processors and altimeters might require less. To convert between the various voltage levels found in different parts of the system, buck converters- which convert from high voltage to low voltage- can be used. These components have the added benefit of also boosting the current when stepping-down voltage, and so can provide high current to components like servos [19]. Where it is impractical to use step-down converters like buck converters, however, a simple component with a defined voltage drop like a diode may also be used to reliably decrease voltage values where required [20].

2.0 OFFERS Analysis

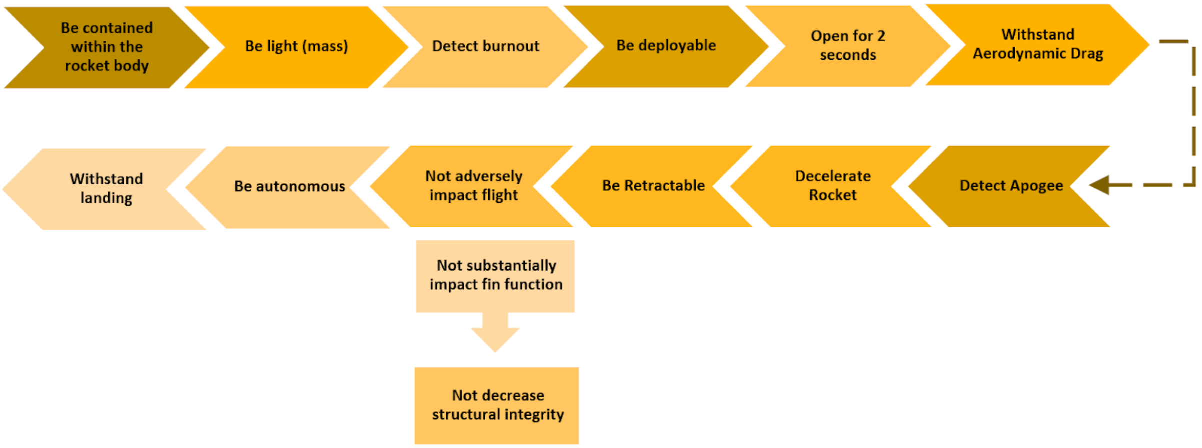
2.1 - Objective

The objective for this design task can be summarised as: “To design and implement a mechanically actuated system that slows down a rocket.”

2.2 - Functions

Figure 3.2.1 illustrates the required functions from the airbrake system in the form of a block diagram.

Figure 2.2.1: Block diagram of the required functions from the airbrake system



2.3 - Factors:

(Wo)Men:

- Be able to be designed, built, and tested by a team of three people.
- Deploy and retract without human input during flight
- Be able to be assembled and set-up by a single person

Money:

- The design should cost under $300 given a $100 contribution from each student team member.

Machines:

The team should:

- Design parts that can be manufactured using only equipment available in the student and HPR workshops.
- Ensure the system is controlled by a microcontroller capable of being reprogrammed in future.
- Ensure the mechanical actuation system is strong enough to deploy the brakes given there will be a substantial drag force associated with travelling at high speed.

Methods:

The team should:

- Ensure all manufacturing methods can be completed with the equipment and resources available in HPR/student workshops and at home
- Ensure all manufacturing methods are OH & S compliant (i.e. if cutting wood for bulkheads, ensure PPE like glasses are worn).
- Ensure the final produced product is of a high quality and aesthetically pleasing
- Ensure the assembly is not too difficult

Minutes:

The chosen concept must:

- Be designed, built, and tested within the semester, no more than 10 weeks.
- Be able to deploy at burnout and remain active for two minutes.
- Be able to deploy rapidly, and retract similarly fast

Materials:

The team should:

- Use only materials readily available to students in the student workshop, which can be appropriately machined.
- Try maintain a low mass for the total system, as not to overencumbered rockets.
- Select an appropriately robust material for use on parts under substantial stress, like control surfaces if they are used.
- Use materials that have suitable longevity so parts of the system can be reused on other vehicles.

2.4 - Effects

- If successful, this project can be used by Monash High Powered Rocketry to more accurately hit altitude targets.
- Key components of the design, like control surfaces, or the mechanical actuators could be improved upon or reused in new iterations of the design, to make the solution more effective.
- If successful, Monash High Powered Rocketry will be the first Australian Universities' Rocketry Competition (AURC) team to implement a trajectory modification device of this kind on board a rocket- adding considerably to the reputation of the club amongst the Australian teams.

2.5 - Requirements and Specifications

The requirements and specification of the design are summarised in table 2.5.1.

Table 2.5.1- The requirements and specifications of the air-brake system.

Requirement	**Criteria**	**Weight**	**Specification**
Performance			
Deceleration force	Drag in N	9	>10N
Strength	Maximum load bearing capacity of mechanical actuation system (N)	7	>100N

Stability with retracted brakes	Stability in calibers	Requirement	Between 1.5 and 2.5 at Mach 0.3
Stability off launch rail	Stability in calibers after leaving 2 meter rail.	Requirement	>1.3
Deploy at appropriate time	Time after burnout till brakes fully deployed (seconds)	4	<1s
Automatic	Braking mechanism deploys and retracts automatically without the need for interference from the ground	Requirement	No ground control
Mass	Mass of full design in Kilograms	5	<1Kg
Appearance/Design			
Aesthetically pleasing	Both when stowed and deployed	2	Will be judged
Safety			
Low risk of injury during flight and manufacture	Adhere to Monash HPR and Monash University safety standards	Requirement	All MHPR and Monash University OH & S standards must be met
Environmental Impacts	Minimal negative environmental impact	Requirement	Not shed any harmful materials or components during manufacture and flight

Cost			
Reasonably cheap	Manufacturing cost ($)	4	<$300

3.0 - Concept Generation

Table 3.0.1- Table describing alternatives to adress the functions identified during OFFERS analysis.

	Alternatives			
Function	**A**	**B**	**C**	**D**
Detect ignition	Using Accelerometer	Acoustic sensor	Tilt switch	
Detect burnout	Detect sudden loss in acceleration using onboard accelerometer	Timer from ignition	Tilt switch	
Be deployable	Servos	Pistons	Spring	Electromagnetic
Remain open (for two seconds)	High Torque servo	Locking clip	Electromagnet	
Withstand drag (Mechanical Actuation systems)	Use high torque servo	Include a dual deployment solution- combination of actuation methods	Make deployment components from steel	Make deployment components from aluminium
Withstand drag (Control Surfaces)	Make control surfaces out of 100% Infill ABS	Make control surfaces out of sheet aluminium	Make control surfaces from sheet steel	
Be retractable	Servos	Pistons	Winch	Electromagnet
Decelerate rocket	Flaps	Holes in Nosecone	Canards	
Retract brakes	Servos	Pistons	Winch with spring	Electromagnet
Be autonomous	Control system with a microcontroller like an Arduino/Raspberry Pi	Have a purely mechanical burnout detection and deployment/retraction system		

4.0 - Design Proposals

4.1 - Design 1: *Holes in the Nose cone*

4.1.1 - Overview

The first possible design proposes 4 equally spaced holes in the nose cone connected to angled tunnels leading to the sides of the rocket, lower down in the airframe. This would serve to redirect the air, while converting some of the energy of the on-rushing air into rotational motion of the rocket. This would cause the rocket to spin which would serve to increase stability using gyroscopic stabilisation while also ensuring a drag force is also applied, and hence slowing the rocket.
The Nose cone will be comprised of two pieces, connected together with a gap inbetween to allow the redirected air to flow out.

Within the cone with holes will be another, smaller cone with identical holes but rotated. The holes will be closed in this fashion until burn out is detected, when a servo will rotate the inner cone to align with the hole of the outer cone, hence opening the holes. The larger, external cone will be fixed to the main body with a rod, with the internal cone would be able to rotate freely around the rod. The inner servo would be programmed to activate when burn out is detected, and rotate in the opposite direction two seconds later to close the holes.

The nose cone will be created out of a 3D printed ABS plastic, with the aid of Solidworks to create a three dimensional render of the final component and printed. Both the cones will be made out of the same material, as will by the tubes through which the air will flow. The flow tube will be hollow aluminium. The tubing will be offset in such a way to produce a fast roll rate after actuation as seen in figure 2.1.1.1

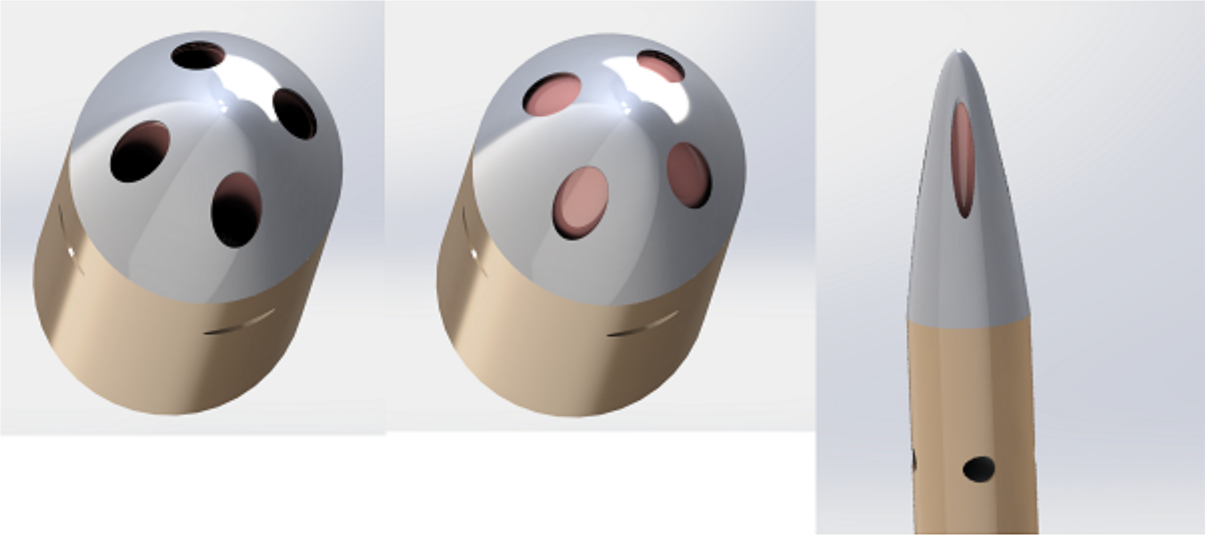


Figure 2.1.1.1: Nosecone actuated drag system

There will be no strong external force to counter when rotating, as the forces due to gravity, drag, and air resistance will be acting downwards, which is not the direction at which the servo has to rotate. Hence, the servos do not need to be very powerful, allowing for smaller, cheaper, lighter servos.

This design has significant issues. The energy conversion to torque is unlikely to significantly slow down the rocket. And the drag experienced with a different nose cone geometry is likely to cause instability shifting the centre of pressure forwards.

The drag produced by the fins from a high rotational rate is difficult to estimate due to the "*impeller*" like rotation of the fins at high speeds. Hence this design is hard to optimise for stability and fast deceleration.

Furthermore, the system will be difficult to control. The only adjustable variable is how much all the holes are open. As it is designed, there is no possibility of designing a way to only operate select holes. The system is not able to be used to control the rocket's flight trajectory in a modulated throttalable way.

4.1.2 - Advantages

- Low required actuation force
- Higher retracted stability as weight is forward in the nose
- No impact on boundary layer of rocket body when retracted

4.1.3 - Disadvantages

- Not enough conversion to torque to significantly slow down the rocket
- Unlikely to decelerate rapidly
- Not Throttleable, either deployed or not
- Greater forward drag moments due to force being applied forwards of the center of mass, resulting in instability
- Difficult to design and implement for larger rockets

4.2 - Design 2: *Radially deployed flaps*

4.2.1 - Overview

The second possible design is three identical flaps which will be operated radially to the body tube. When burnout is detected, the flaps will be rotated out and held open by servos extending out into the air flow around the rocket. attached to a rotating servo. As part of the design guidelines, the brakes will remain deployed for two seconds, after which the servo will rotate back to the starting position. The overall design can be seen in figure 2.2.1.1 with the flaps retracted versus when deployed.

Figure 4.2.1.1: Radially actuated fins deployed (right) versus retracted (left).

This design can be operated using a single rotational servo in the center of the body tube. This design has several advantages over the other designs, this being a simple and easy to actuate mechanism. The drag forces will be perpendicular to the rotational forces so the servo mechanism does not need to overcome significant aerodynamic forces. This will allow for a smaller lighter and faster servo. Due to minimal moving components this system will be reliable and unlikely to run into actuation issues. This design also allows the mechanism to be placed anywhere along the body tube of the rocket that is above the motor mount allowing for flexibility in the case of restricted volume.

This design also allows throtallablity of the flaps using the rotational servo depending on the angle of actuation. The flaps will be manufactured from 3mm aluminium sheet and cut to the correct shape as a contour of the body tube.

This design although simple has several severe drawbacks, this being the relatively small and non symmetrical flaps. This would mean the total drag force experienced may be less then compared to other designs and due to the asymmetrical shape of the flaps this could also induce roll instability in the rocket and cause issues with trajectory.

As these flaps operate radially, they must be mounted in a section of body tube that is above the fins and motor mount, this means after deployment turbulence will be experienced over the fins and will move the centre of pressure forwards potentially causing instability and further leading to trajectory issues.

Estimated drag for this design is a maximum of 27N at burnout. This drag calculation can be seen in appendix B. This is less drag than other designs and can be attributed to the low overall deployment area of the flaps.

4.2.2 - Advantages

- Can alter the angle at which the flaps open
- Light weight
- Simple mechanism
- Can be located anywhere in the body tube
- Mechanism is not load bearing

4.2.3 - Disadvantages

- Limited surface for breaking low drag
- Instability issues if located far forwards
- Potential roll issues due to asymmetrical flaps

4.3 - Design 3: *Flaps between fins*

4.3.1 - Overview

This design utilises 3 flaps placed between the airframe and the internal motor mount. The flaps will deploy and retract against the side of the rocket body using a mechanically actuated cam and follower type design. This design allows for the use of non-linear cams allowing for a higher effective *lever ratio* as the flaps are deployed into the free stream flow, the drag force will be greater with a higher deployment angle. This cam design helps with this extra drag loading This mechanism can be seen in figure 2.3.1.1

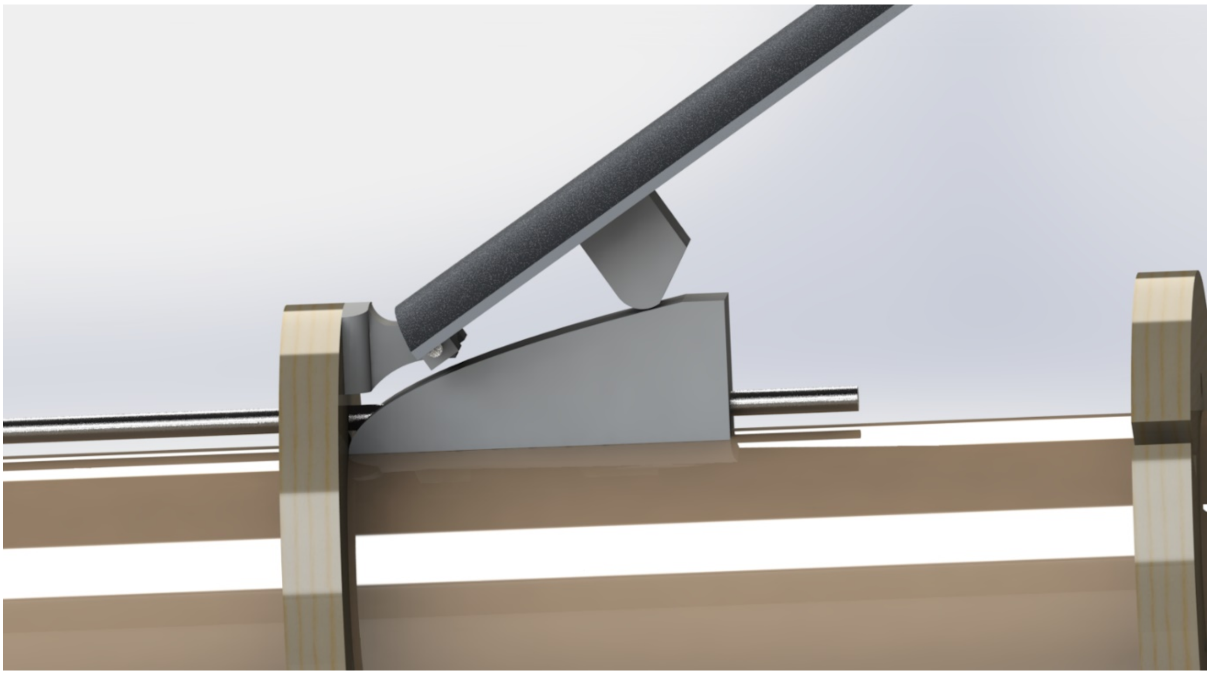


Figure 4.3.1.1: Cam actuated flap

Upon detecting burnout, the panels will be deployed for two seconds, then retracted. Due to the limited time frame, the servos must actuate rapidly in order to deploy the air brakes promptly. This is achieved using a single high torque servo connected to each of the 3 actuator rods which actuate the air brakes.

The airbrake flaps for this design are 80mm long and are a 60 degree arc of the body tube section. This allows for the rocket to maintain an aerodynamic profile until the brakes are deployed, at which case the angle of deployment can be adjusted from 0-30 degrees. This design allows for modulated braking if so desired by the flight computer. The deployed air brakes can be seen positioned between the fins in figure 4.3.1.2.

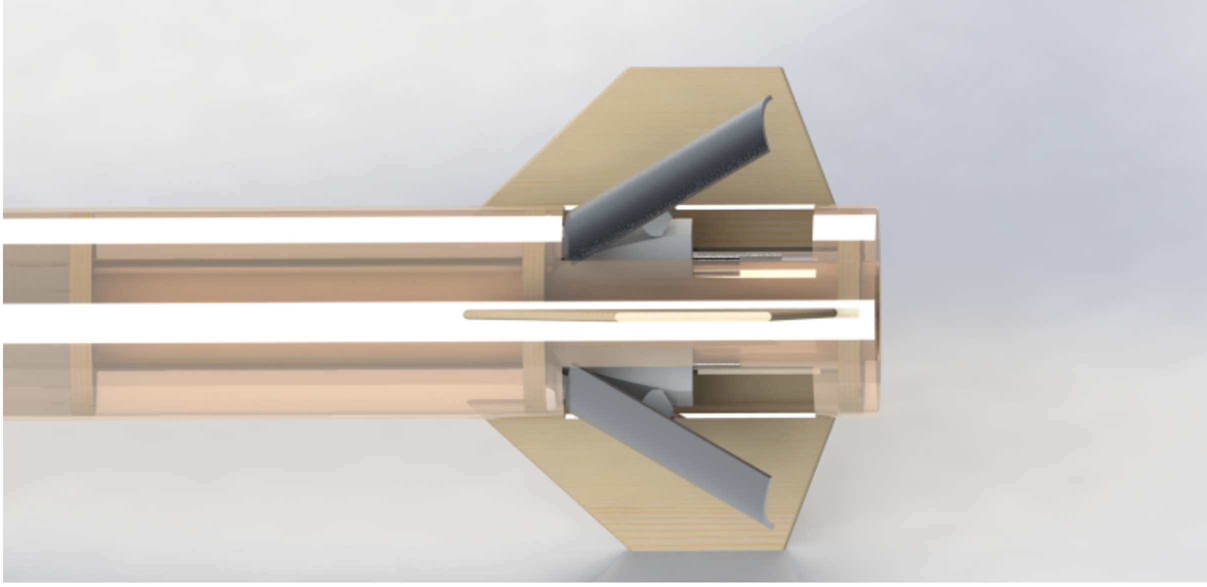


Figure 4.3.1.2: Air brakes at full 30 degrees deployment

This design has multiple advantages over other designs. The flaps being located as far rearward on the rocket ensures that stability is maintained during deployment as it ensures that the center of pressure will not go forward of the centre of mass causing stability issues. It also has reduced turbulence over the fins compared to the other designs due to the rearward flaps. This design also has throttleable braking by varying the deployment angle of the air brakes. This design also lends itself to being easily modified to have attitude control due to 3 seperate flaps with 3 separate actuator rods if used on larger rockets. This allows for pitch and yaw control if desired, roll control would not be possible however. Due to the restricted diameter of this rocket, implementing an extra 2 servos required for attitude control would cause unnecessary complexity and reliability issues and was not considered for this rocket, hence the 3 actuator rods are connected using a single connection plate and operated with a single larger servo. This design is also compact and produces a 30 degree deployment angle with only 16.5mm of internal spacing between the motor wall and airframe using the actuator cams.

This design has some critical disadvantages and may pose issues during the flight. Due to the operation of the system, it is required that the load on the air brakes be supported by the mechanical actuator, this means the mechanism is required to be strong enough to resist deployment and overcome drag forces as the flaps are extended. This requires a larger servo and heavier actuation components, all of which are aftward of the rocket and may negatively impact stability. Furthermore, since components are between the airframe and motortube they will also be harder to repair in the event of a problem due to accessibility issues, and may require that centering rings and bulkheads be bolted rather then epoxied to improve the serviceability of the system.

The actuator servo will need to be be forward of the motor bulkhead, this means that the motor ejection charge can not be used and a seperate altimeter operated ejection charge is required. This further adds to complexity, mass and potential reliability issues.

4.3.2 - Advantages

- Compact and able to have large deployment surface for rockets with close to minimum diameter (must have space greater than 16mm between airframe and motor)
- Throttleable deployment via variable angle (0-30 degrees)
- Easily modifiable to add pitch and yaw control with the addition of two servos
- Minimal stability impact during deployment due to rearward flaps
- Easily scalable to larger rockets
- Simple cam actuated flaps, minimal mechanical linkages for issues

4.3.3 - Disadvantages

- Potential stability issues due to an increase in rearward mass
- Requirement of separate deployment device over motor ejection due to forward mounted servo
- Mechanical actuators must take the drag load of the fins, larger servo

5.0 - Decision Making

To compare the merits of the various designs and select the final design, a composite criterion method analysis was employed. This analysis is performed in **Table 5.1.1**.

Table

Requirement	**Specification**		**Weight**	**Criteria**	**Design #1- Holes in the nose cone**			**Design #2- Radially deployed fins**			**Design #3- Flaps between fins**		
	Min	**Max**			**Mag**	**Score**	**WxS**	**Mag**	**Score**	**WxS**	**Mag**	**Score**	**WxS**
Performance													
Deceleration Force (N)	50	150	9	Deceleration force induced by air brakes (N)	50 (estimate)	1	9	75 (estimate)	2.5	23	150 (estimate)	10	90
Strength (N)	100	300	7	Maximum load bearing capacity of mechanical actuation system (N)	250	7.5	53	200	6.67	47	175	3.75	26
Stability with retracted brakes	1.5	2.5	Req	Stability in calibers	Satisfied	-	-	Satisfied	-	-	Satisfied	-	-
Stability off launch rail	1.3	2	Req	Stability in calibers after leaving 2 meter rail.	Satisfied	-	-	Satisfied	-	-	Satisfied	-	-
Deploy at appropriate time	0.1	1	4	Time after burnout till brakes fully deployed (seconds)- lower desired	0.5	4.44	20	18	1	4	0.7	3	12
Automatic	No ground control	-	Req	Braking mechanism deploys and retracts automatically without the need for interference from the ground	Satisfied	-	-	Satisfied	-	-	Satisfied	-	-
Mass	100	1000	5	Mass of fully assembled design (g)	400	5.55	28	500	4.44	22	320	7.03	35
Appearance													

Aesthetically Pleasing	-	-	2	Appearance when stowed and deployed. Judged on a scale of high (3), medium (2) and low (1)	High	3	6	Medium	2	4	Medium	2	4
Safety													
Low risk of injury during flight and manufacture	Adhere to Monash HPR and Monash University safety standards	-	Req	All MHPR and Monash University OH & S standards must be met	Satisfied	-	-	Satisfied	-	-	Satisfied	-	-
Environmental Impacts	Not shed any harmful materials or components during manufacture and flight	-	Req	Minimal negative environmental impact	Satsified	-	-	Satisfied	-	-	Satisfied	-	-
Cost													
Estimated cost of all components	100.00	300.00	4	Net cost ($)	200	5	20	250	3.33	13	300	1	4
Total					136			113			171		
Ranking					3			2			1		

The sensitivity of this method is given by the formula:

Sensitivity = Smallest increment x largest weighting [X]

In the case of this composite criterion analysis, the smallest increment was 1, and the largest weighting 9. As a result, the sensitivity is 9. The difference between the top two performing designs was 35, while the difference between the bottom two performing designs was 23. As a result, the rankings produced by this analysis hold statistical significance.

Based on the composite criterion method analysis detailed above, design 3- where flaps are placed between fins- is the most suitable alternative.

6.0 - Final Design

The final design chosen can be seen in figure 6.0.1, this shows the rocket with its flaps extended, retracted and a view looking from above at the maximum extension of 30 degrees.

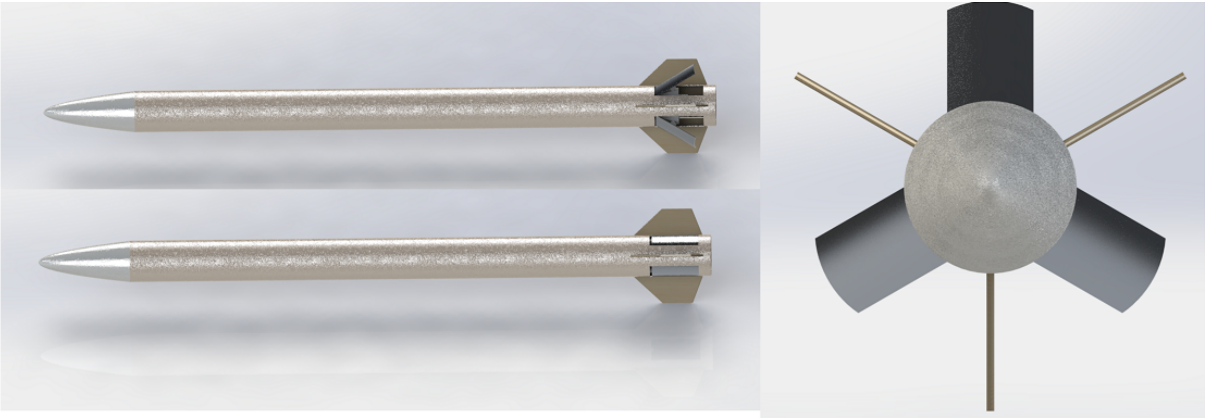


Figure 6.0.1: Rocket with air brakes extended (left top) and retracted (left bottom) with a head on view of the vehicle with brakes deployed (right)

6.1 - Group conclusions

Based on the composite criterion decision making method, design 3 "*Flaps between fins"* was found to satisfy the requirements best. The main considerations when applying this method were deceleration performance and strength. This design is least likely to cause stability issues due to the rearward braking control surfaces are placed between the fins. Furthermore, as this design is simplistic in nature with the actuation surfaces being a simple wedge type cammed design, it can also be predicted to be a reliable alternative.

Furthermore, though at this stage of the design process it is not a key consideration this concept can effectively be scaled to larger rockets. This is because its actuation system allows for retractable and throttleable control surfaces which, with minor modifications, can also offer pitch and yaw control and allow for more precise altitude targeting.

As at this stage a number of key performance characteristics of the design, such as the drag output and failure loading (strength) are estimates. In the coming weeks the team will employ computational fluid dynamics (CFD) software along with more hands-on testing to verify these values, and add more rigour to the specifications of the system.

At this stage in the design process the chosen concept is a prototype and will likely experience changes due to potential unexpected external factors. Materials availability, time constraints, potential manufacturing issues and funding are all possible issues that would need to be closely monitored. As more testing and simulations are run, the data and collected experience gained will help mould this concept prototype into the final design whilst maintaining as many of the initial design choices as possible.

6.2 - Manufacturing Methods

6.2.1 - Airframe and Motor Mount

The chosen airframe is 65mm (ID) x 1.6mm phenolic tubing from Public Missiles [21]. The tubing will be 85cm long and cut to length using a handsaw with a jig to ensure a straight cut. The rough slots for the air brakes and fins will be hand cut using a dremel with marked lines, and finished with a hand file for accuracy. Holes will be drilled accordingly along the length of tubing for fixing of centering rings using bolts. The airframe will be cut above the motor bulkhead and the servo mount serving as the coupling surface, this will be bolted into for the forward section of body tube. This is necessary as to access the actuation mechanism as well to access the deployment device. The motor mount is also phenolic tubing and is 29mm ID x 1.6mm and cut to 250mm long for the motor to reside.

6.2.2 - Fins

The fins will be cut using a laser cutter out of 3mm plywood and have the leading and trailing edges sanded to a rough filleted profile to reduce drag. The fins are tabbed and will lock into the middle and aft centering rings.

6.2.3 - Bulkheads and Centering rings

These will be cut from 7mm plywood using a laser cutter and fixed into place along the motor mount using epoxy. The centering rings will have holes cut to allow for the passage of the actuator linkage. Due to the complexity of the design and serviceability requirement of the rocket neither centering rings or bulkheads will be epoxied into the rocket. Rather 4 screws will secure each of the 3 bulkhead and centering rings into the airframe. This is to ensure that the mechanism can be modified if an issue arises and be removed from the airframe. This was chosen over epoxy solely for this reason, all other non critical components will be epoxied such as cams to the actuators rods.

6.2.4 - Airbrake Mechanism

The airbrake flaps will be either made from rolled 1.6mm aluminium sheet metal or cut out of the appropriate 65mm 1.6mm thick aluminium tubing. The cam wedges will be 3D printed out of ABS plastic, and acetone smoother for a reduced friction surface for rapid deployment. The cams will be connected to the 3mm circular aluminium actuator plate using nuts to fix them in place. The actuator rod is a 270mm section of 3mm steel push rod. The ends of the 3mm push rod will be threaded, this will be done by running a die over the rod. These are connected to the servo using 2.5mm servo linkage. The assemble is seen in figure 6.2.4.1

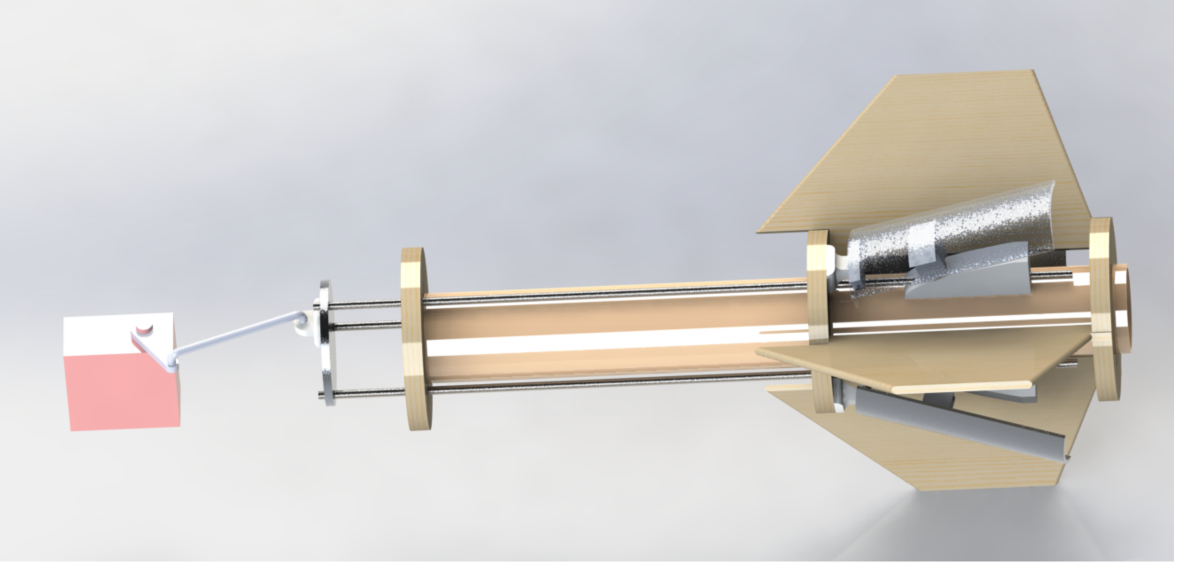


Figure 6.2.4.1: Fin actuation mechanism

The airbrakes pivot off the middle internal centering ring using bolted in place 3D printed ABS lugs with a m2 bolt as the pivot, the second lug is epoxied to the internal surface of the aluminium airbake and provides a means of attachment to the rocket.

The servo mount will be manufactured from 3D printed ABS and will be affixed to the motor bulkhead using 3 M4 bolts, this servo mount also serves as the joining coupler and separation point for the forward section of body tube and will have nuts epoxied to the inside of this mount allowing for the forward section to be bolted to the coupler.

6.2.5 - Nose cone and avionics bay

The nose cone will be made from 3d printed ABS and acetone smoothed for good surface finish at the leading edge of the nose. The nose cone is hollow and has a rear threaded cap, this allows for the an avionics sled to be installed inside, this is made from laser cut 3mm acrylic and provides a rigid mounting surface for the electronics. This was mounted in the nose for stability reasons and to maintain room in the deployment bay for shock cord and either a parachute or streamer. The nose cone design can be seen in figure 6.2.5.1

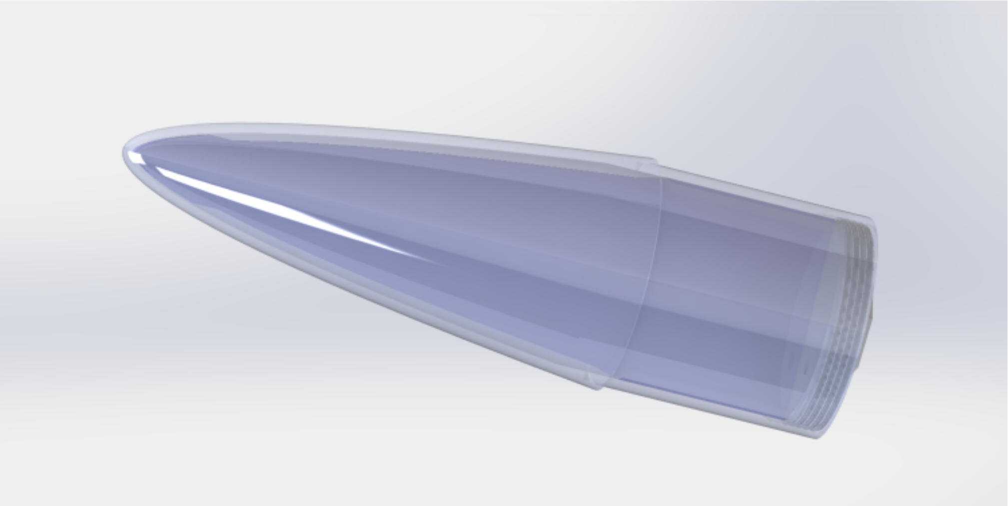


Figure 6.2.5.1: Nose cone with acrylic avionics sled

6.2.6 - Deployment Device and Shock Cord

Deployment of this rocket will be achieved using a custom designed black powder system as the motor ejection charge can not be used. This is due to the location of the actuation system directly above the motor. The deployment device will be either made from aluminium tubing or 3D printed out of PLA, testing is to be done to see if PLA could be used here. This is controlled using the nose cone mounted avionics and mounted above the servo mount as seen in figure 6.2.6.1

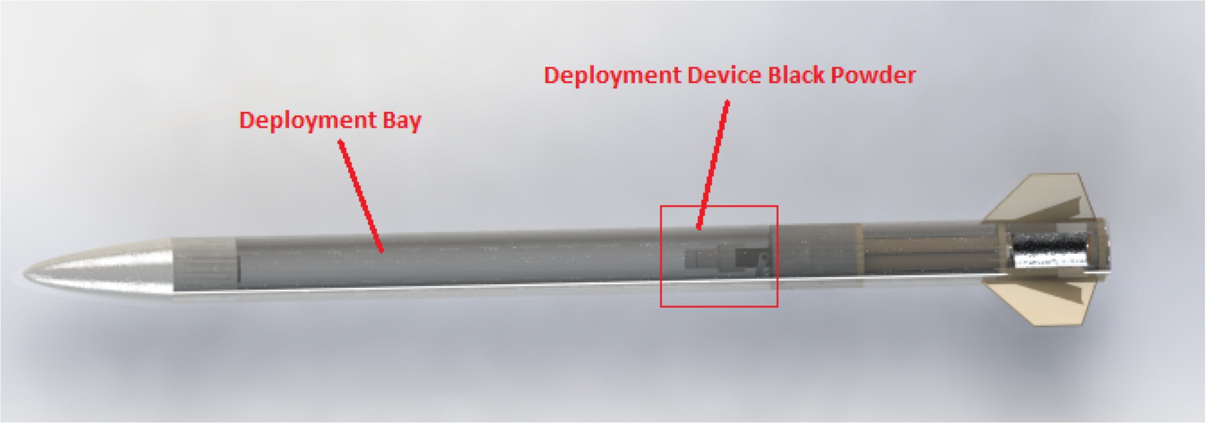


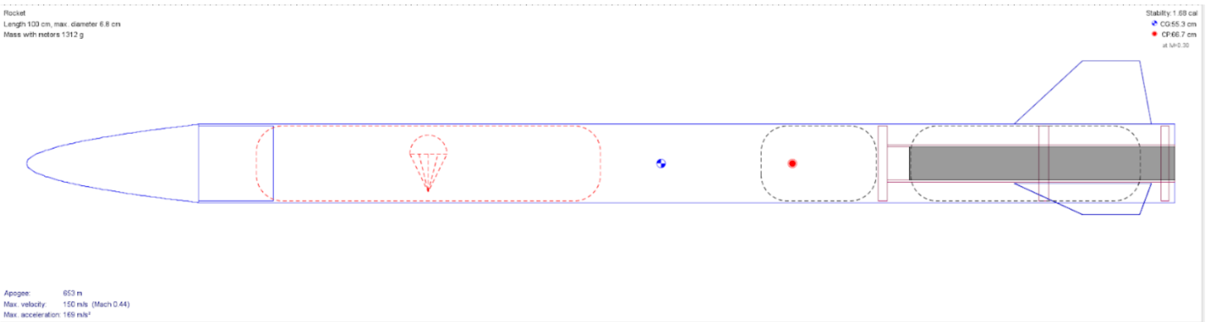
Figure 6.2.6.1: Deployment system above motor bulkhead

6.3 - Design Considerations and Performance

Due to stability reasons, the flight electronics have been moved to the nose cone to bring the centre of mass forwards. This means wires will need to run down from the nose cone to the deployment device and servo. The wires will need to be longer than the length of shock cord and secure to ensure that wires won't be torn during deployment.

After the air brakes have been deployed, during the retraction process the natural aerodynamic drag will aid in retraction, and to keep the brakes retracted (also during acceleration) 6 small neodymium magnets will be epoxied to the flaps and phenolic motor tubing to keep them retracted unless actuated intentionally.

To determine if this design will be stable and provide a safe launch preliminary mass calculations have been done using all the expected avionics and hardware. Mass of each section can be seen in appendix A. under the current configuration with correct masses this gives a stability caliber 1.68 at Mach 0.3. Figure 6.3.1 shows the current configuration in open rocket.


Rocket
Length 100 cm, max. diameter 6.8 cm
Mass with motors 1312 g

Stability: 1.68 cal
CG:55.3 cm
CP:66.7 cm
at M=0.30

Apogee: 653 m
Max. velocity: 150 m/s (Mach 0.44)
Max. acceleration: 169 m/s²

Figure 6.3.1: Open Rocket configuration

This preliminary design shows that using a rear mounted air brake system the rocket will remain stable when the air brakes are retracted. This also shows that if more mass is required rear wards during construction this can be corrected without too many issues as ballast can be added to the nose or increase a change in fin geometry can be implemented.

Table 6.3.1 Preliminary Open Rocket Data Without Air brake Actuation

Motor type	Ceseroni H170
Impulse (burntime)	217 Ns (1.3seconds)

Avg thrust (Peak Thrust)	169N (240N)
Length	100 cm
Mass (burnout)	1312g (1200g)
Max Velocity	150m/s (M = 0.44)
Max Accel	169 m/s^2
Altitude	653m
Thrust/Weight ratio	18.4
Stability margin M0.3	1.68
Stability off rail	1.51
Velocity of rail 2m	24.5 m/s

Table 6.3.1 shows the expected data if the air brakes are kept retracted throughout the launch, this will provide as a useful comparison to the real collected data on launch to determine how effective this air braking system is.

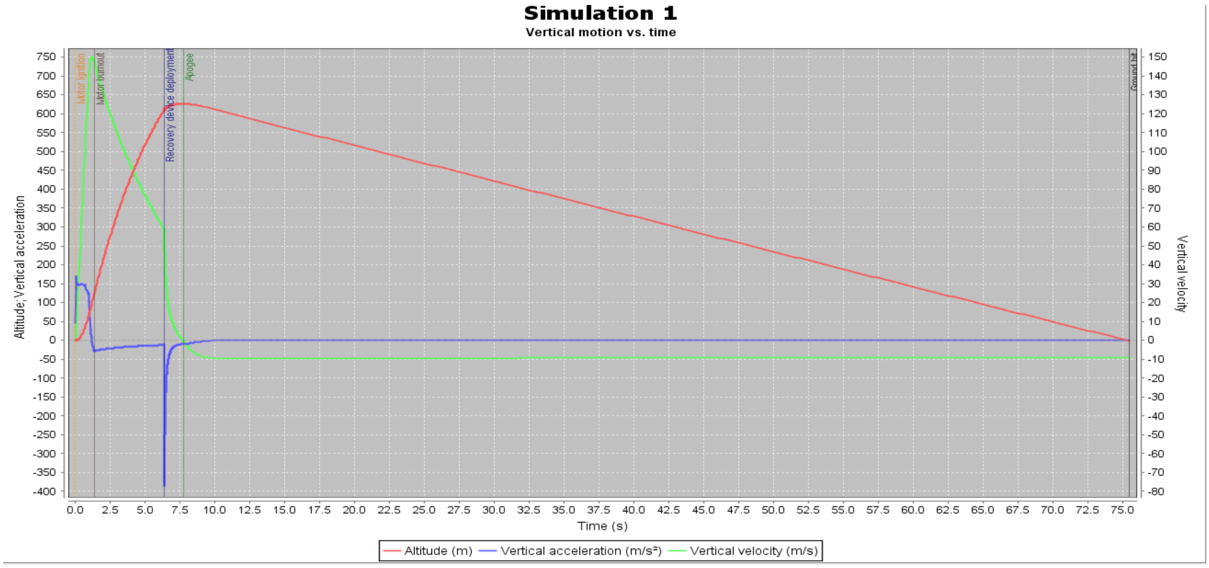


Figure 6.3.2: Open rocket plot of altitude acceleration and velocity without deployed air brakes

The simulated altitude acceleration and velocity is seen in figure 6.3.2 without the air brakes deployed. The expected maximum altitude is 950m, to determine the performance of the rocket the real altitude will be compared to the expected altitude.

The estimated drag per airbrake was done using a flat plate assumption looking from top down over the rocket, this will be a rough estimation of the total drag experienced at motor burn out with a 30 degree angle of actuation. This calculation can be seen in appendix B, the estimated drag is is 27N per airbrake. This produces approximately 80N of drag at max velocity. This is a substantial amount of drag and will produce a deceleration of 6G, these preliminary drag calculations show potential for this design.

6.4 - Electrical System and Components

The onboard sensors include a high G accelerometer used for motor ignition and burnout detection and a Missile Works RRC3 altimeter [22] used for deployment. The processing is done using an Adafruit adalogger feather M0 [23], this was chosen over an arduino nano for the onboard micro sd card reader, which allows for the acceleration data to be captured and stored. This was decided as vital data to analyse the performance of the air brakes after flight.

The onboard electrical system is powered using a 950 mAh 2s LiPo battery. This provides sufficient voltage and amperage to power the altimeter and servo directly without the need for voltage regulation, and with the use of a 5V 3A buck converter the adalogger and accelerometer can be powered.

After the microprocessor detects burnout from acceleration, it will send a signal to the servo to open the air brakes to full 30 degree deployment, wait 2 seconds then retract.

7.0 - Gantt Chart

Table 7.1- Gantt chart depicting the proposed timeline for task completed by the team.

	Week											
	1	2	3	4	5	6	7	8	9	10	11	12
Establish Team	x	x										
Research		x	x									
Preliminary Design			x	x								
First Report Writing			x	x	x							
First Report Due					x							
Simulate Design					x	x						
Build Initial Design					x	x	x					
Test Design						x	x					
Research							x	x				
Further Simulations							x	x				

Task	Design Changes								x	x	x		
	CAD Designs									x	x	x	
	Build Final Design										x	x	x
	Present Final Design												x
	Second Report Submission												x
	Fly Final Design												x

8.0 - Isometric Drawings

8.1 - Design 1: *Nosecone Actuation - Thomas Mackellar*

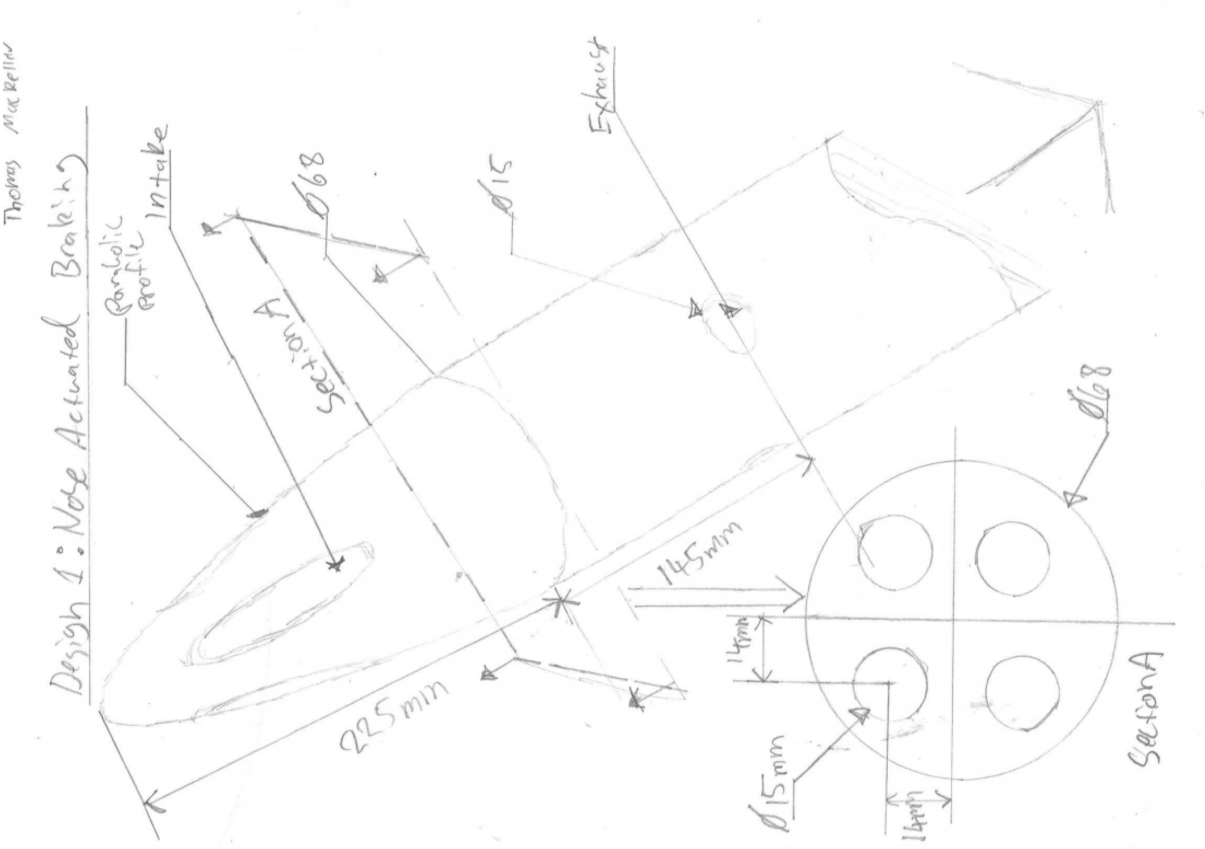


Figure 8.1.1 Nosecone actuated braking

8.2 - Design 2: *Radially Actuated brakes - Siddhant Tandon*

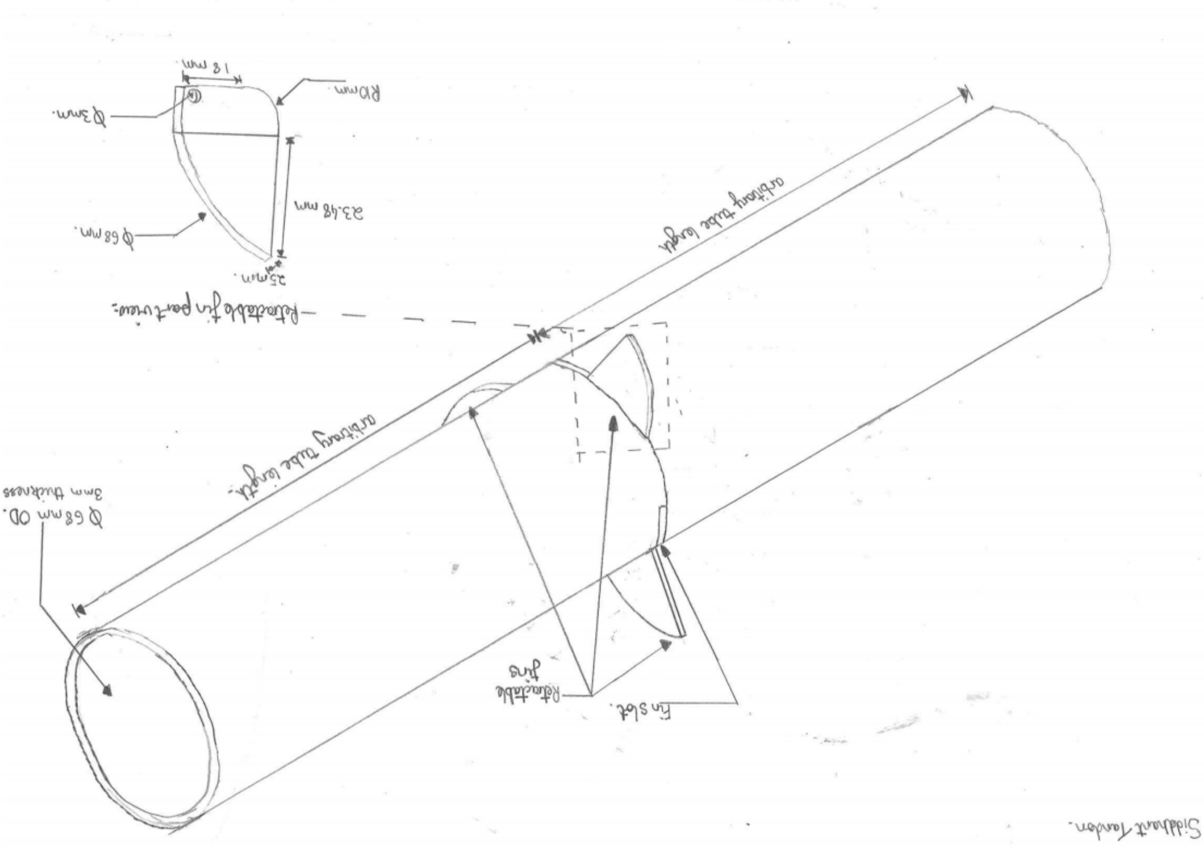


Figure 8.2.1: Radially actuated brakes

8.3 - Design 3: ***Flaps between fins - Nicole Tryndoch***

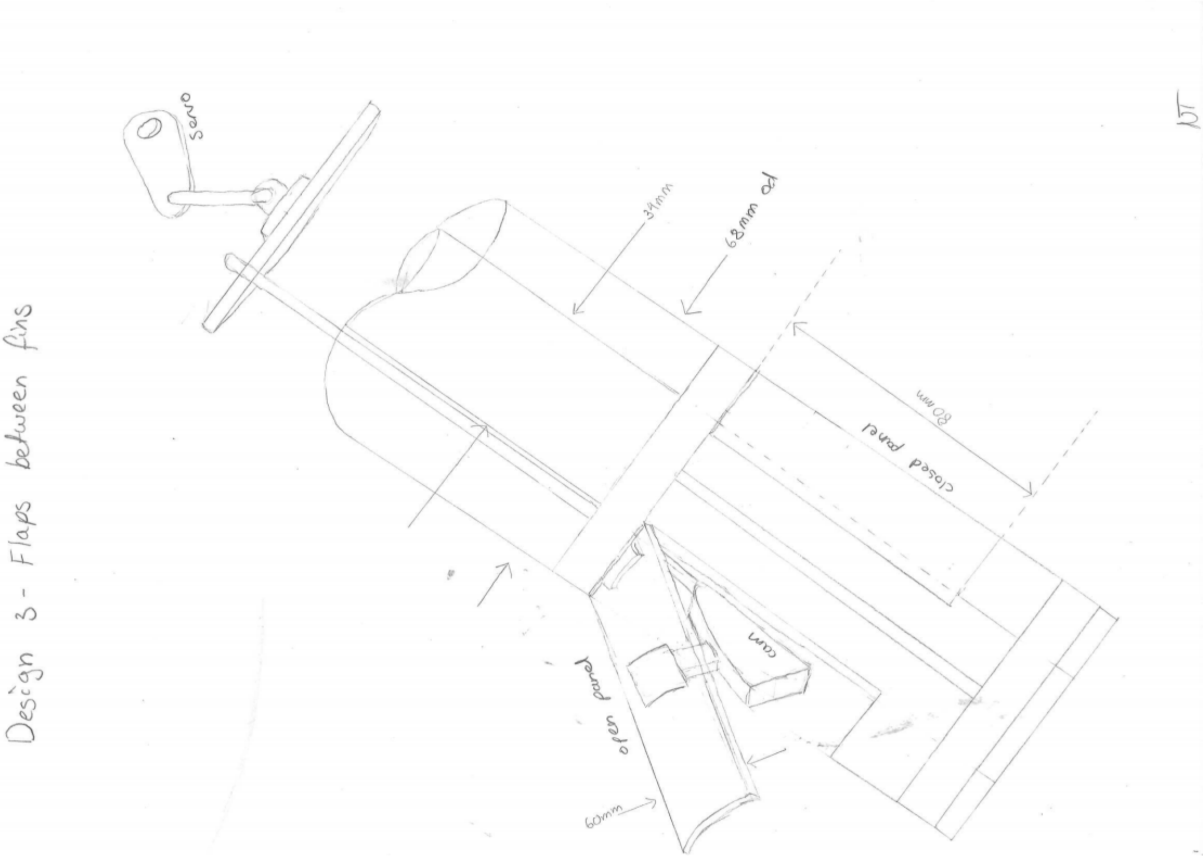


Figure 8.3.1: Overall actuation mechanism Flaps Between Fins

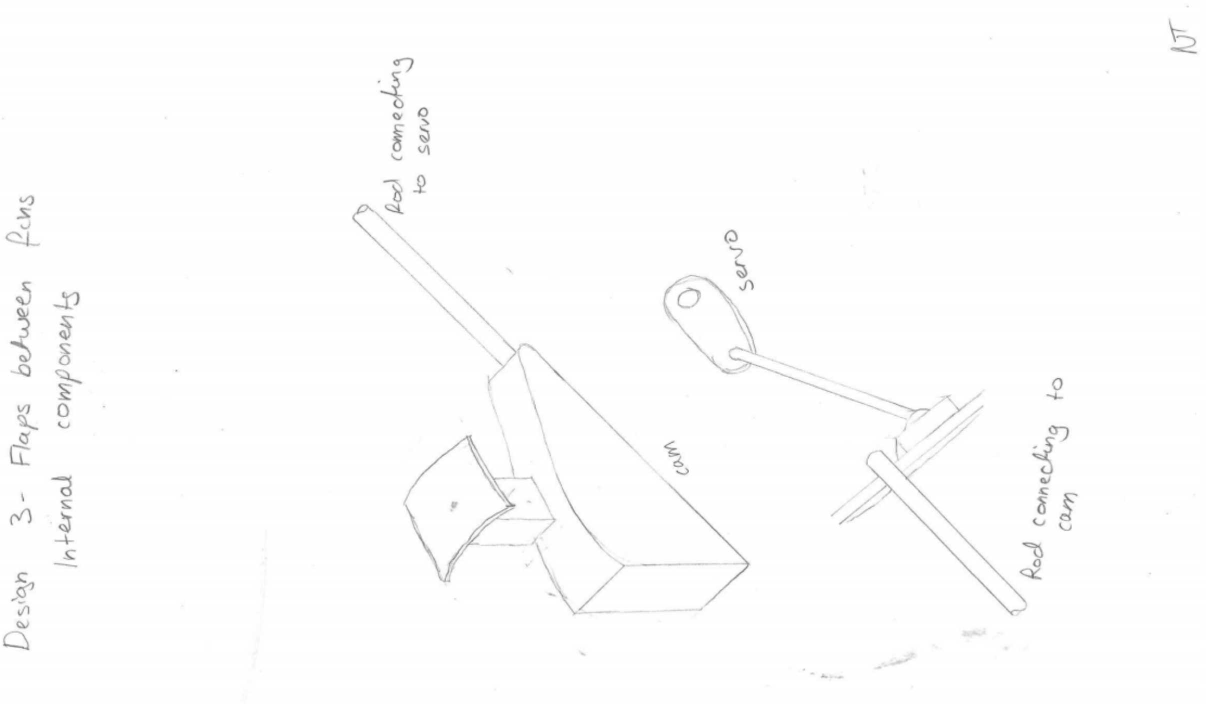


Figure 8.3.2: Can mechanism for Flaps Between Fins

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Appendix A:

Estimated mass balance for preliminary chosen design:

Component	**Mass g**	**Estimation source**	**Location in rocket**
Adalogger + microSD	5.3	**supplier**	**Nosecone**
Accelerometer	**1.5**	**supplier**	**Nosecone**
RRC3 Altimeter	**17**	**supplier**	**Nosecone**
2s 950mAh LiPo	**46**	**supplier**	**Nosecone**
6v 3A BEC	**12.5**	**supplier**	**Nosecone**
Misc electronics wires etc..	**30**	**estimation**	**Nosecone**
Nosecone + acrylic sled	**190**	**Cura 3d printing estimation + solidworks**	**Nosecone**
Phenolic airframe	**250**	**Open Rocket**	**Airframe**
Motor mount	**31**	**Open Rocket**	**Fincan**
Centering rings	**15**	**Solidworks mass estimation**	**Fincan**
Servo	**66**	**supplier**	**Forward motor mount**
Linkage mechanism	**50**	**estimation**	**Forward motor mount and fincan**

Airbrake flaps	**20**	**Solidworks mass estimation**	**Fincan**
Fin	**13**	**Open Rocket**	**Fincan**
Misc epoxy and fasteners for construction	**40**	**Estimation**	**Fincan**
Shock cord and streamer	**150**	**Estimation**	**Forward motor mount**
Loaded Motor	**232**	**Open Rocket**	**Fincan**

Appendix B:

Drag calculations for Design 2 *Radially operated flaps:*

Assume flat plate drag for radial flaps. This will be a very rough estimation but still provide useful insight into expected performance. The velocity used was the max velocity expected at burnout

Using the equation below:

Drag = *v2*Cd *A*0.5

And substituting values from the table below

Variable	Description	Value
	Density Air	1.22km/m^3
v	Velocity Free stream	150 m/s
Cd	Coefficient of drag	1.2
A	Cross sectional area per flap	545 *10^-6 m^2

This gives drag of 9N per radial flap. This gives a total of 27N for the whole system.

Drag calculations for Design 3 *Flaps between fins:*

Using the same equation as above and using the variables below:

Variable	Description	Value
	Density Air	1.22km/m^3
v	Velocity Free stream	150 m/s
Cd	Coefficient of drag	1.2
A	Cross sectional area per flap	1625 *10^-6 m^2

This gives a drag value of 27N per flap for a total drag of 80N over 3 brakes.