ARES Workshop - Project Phobos Part 2

Cas Kent & Ann Phan

Workshops Update!

- Exciting new workshop timetable 🚀
- We want you to **design and 3D print your own rockets!**
- Adding two weeks of **OpenRocket** workshops
- Onshape workshops after mid-sem break
- FEA and CFD advanced workshops pushed to Sem 2

	Date		Workshop
Week 1	1 Mar	5 Mar	Meet and Greet Workshop
Week 2	8 Mar	12 Mar	Project Phobos Part 1
Week 3	15 Mar	19 Mar	Project Phobos Part 2
Week 4	22 Mar	26 Mar	OpenRocket Part 1
Week 5	29 Mar	2 Apr	OpenRocket Part 2
	5 Apr	**9 Apr**	**Mid Sem**
Week 6	12 Apr	16 Apr	No Workshop
Week 7	19 Apr	23 Apr	LaTeX
Week 8	26 Apr	30 Apr	Onshape Part 1
Week 9	3 May	7 May	Onshape Part 2
Week 10	10 May	14 May	3D Printing Part 1
Week 11	17 May	21 May	3D Printing Part 2
Week 12	24 May	28 May	No Workshop

New Home for Workshops

- **github.com/ares-unimelb/ARES-Workshops-2021**
- Access all workshop material including latest **slides, links and recordings**
- We'll send everyone here from now on

ARES Workshops 2021

Weekly workshop slides created and presesnted by Cas & Ann 🚀

Workshops will be delivered either online (zoom) or in-person at 5:30 pm on Wednesday. The online workshops will be uploaded to our YouTube channel. Follow us on Facebook and LinkedIn for upcoming events, career opportunities and other exciting things.

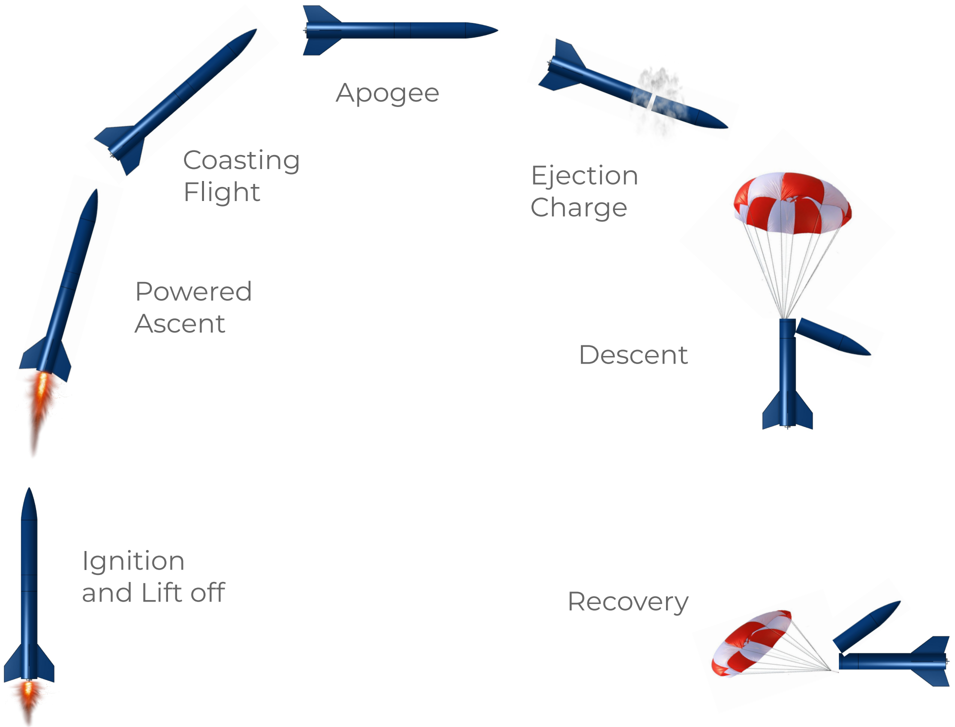
Week	Workshop	Method of Delivery
01	Meet & Greet	In-person at South Lawn
02	Project Phobos	Online - See Recording
03	Project Phobos Part 2	Online

Week 2 Revision

Index

Phases of Flight

1. Ignition and Lift off
2. Powered Ascent
3. Coasting Flight
4. Apogee
5. Ejection Charge
6. Descent
7. Recovery

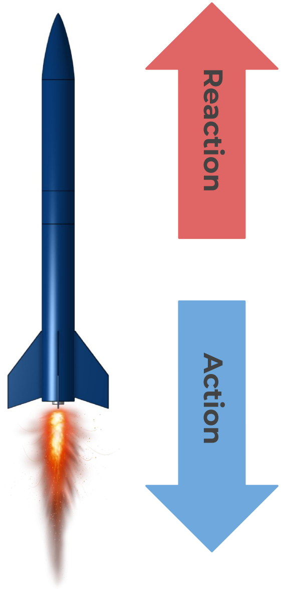


Newton's Laws of Motion

First Law: Unbalanced force is required to be exerted for a rocket to lift off

Second Law: The thrust produced from a rocket engine is dependent on the mass of fuel burnt and how fast the gas is escaping from the nozzle

Third Law: The motion of the rocket (**reaction**) is equal to the **action** due to the expulsion of gas

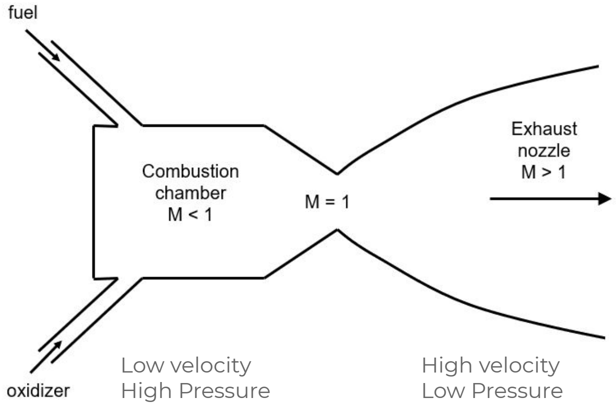


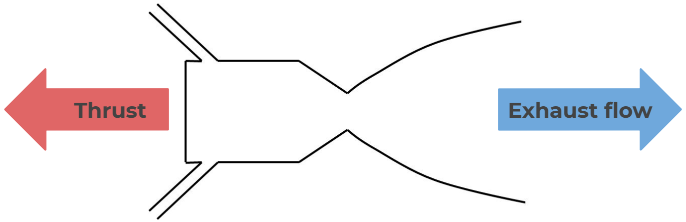
Propulsion

Fuel in a rocket motor is burned with the oxidiser to produce hot gases.

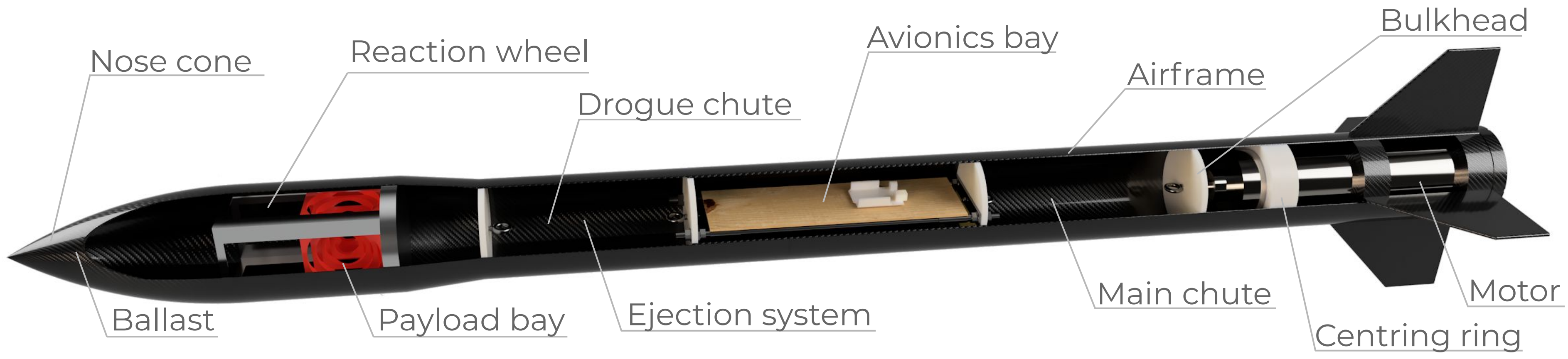
Gas accumulate in the combustion chamber creating high pressure which forces some of the gas to accelerate through the nozzle.

The reaction to the acceleration of the working fluid is the thrust force which acts on the rocket engine.





Anatomy of a Rocket



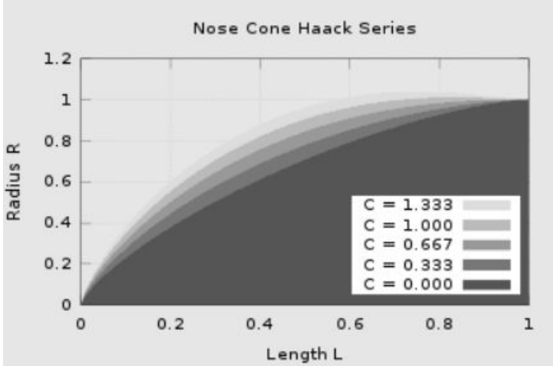
Anatomy of a Rocket

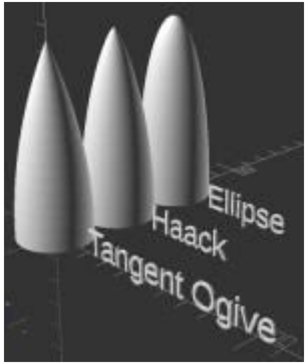
Minimise aerodynamic **drag**

Shapes include Ogive (*oh-jyve*), conical, **Haack**

Endure **pressure forces**, aerodynamic heating

Carbon fibre (CFRP), **fibreglass**





Anatomy of a Rocket

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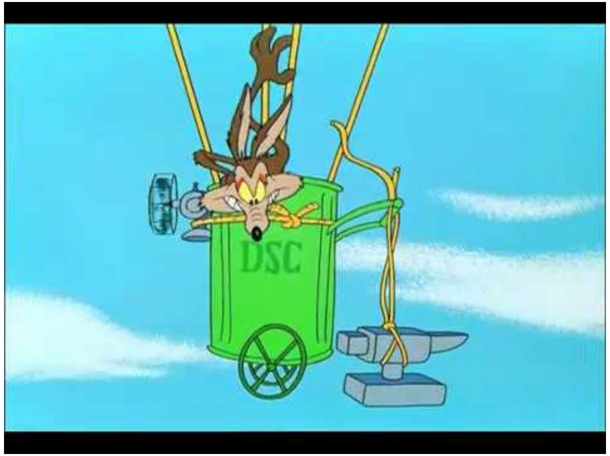
Ballast

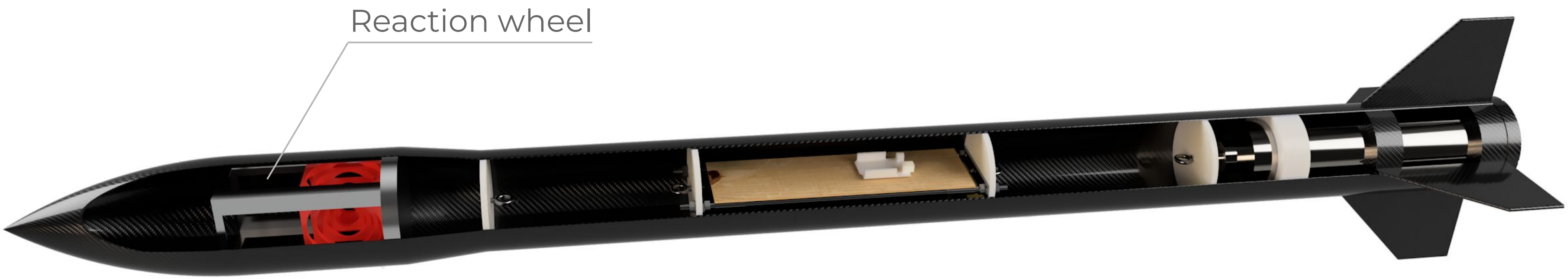
Allows for consistent **apogee** in different environmental (weather) conditions

Launch angle can also tune apogee

Use simulation data to estimate ballast mass



Anatomy of a Rocket

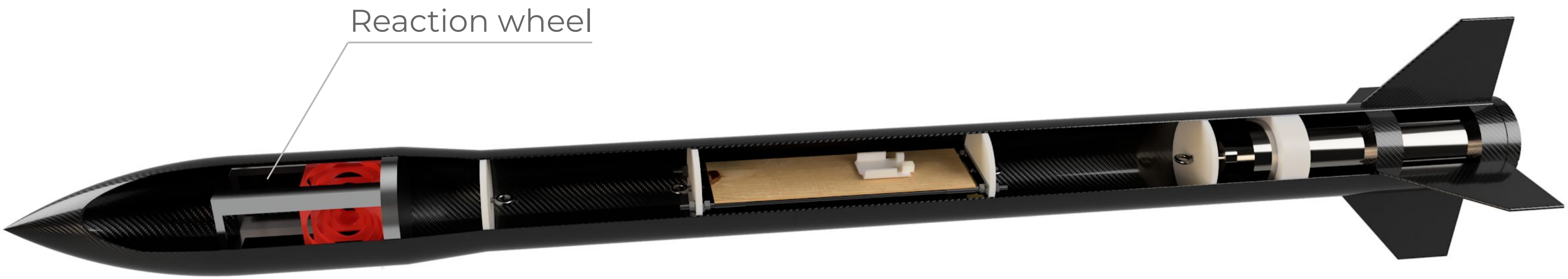


Stabilise **angular momentum**

Adjust **angular velocity** of wheel mass to exert angular momentum on rocket

Often includes **3 DOFs** plus one redundancy

Anatomy of a Rocket



Relay data between **Inertial Measurement Unit (IMU)** and reaction wheels

DC motors with encoders

PID control system on angular position

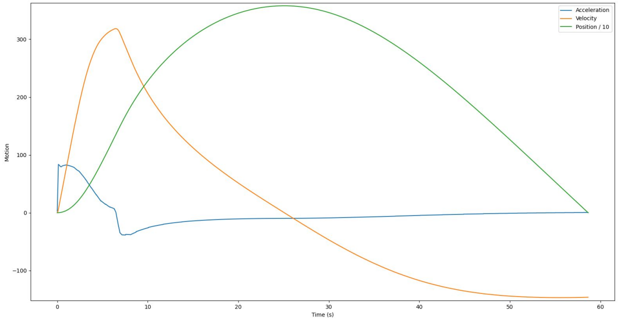
Anatomy of a Rocket

Functional system for performing tasks

CubeSat - standardised **miniature satellite**

form factor, **1U** - 10cm x 10cm x 10cm

Reduces cost of satellite deployment



Anatomy of a Rocket

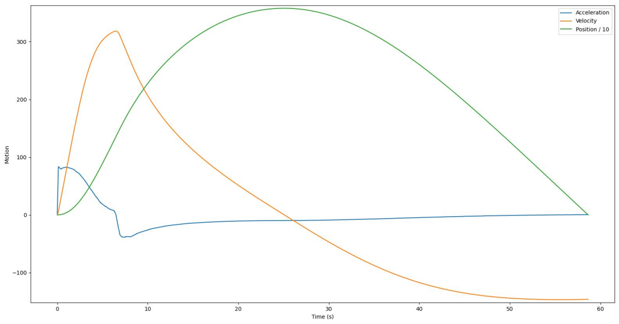
telemetry /tɪˈlɛmɪtri/
in situ **collection of data** on rocket and automatic **transmission** to receiving equipment

Telecommunications & flight **tracking system**

Altitude, attitude and velocity of the rocket

without a GPS signal

GPS '**ground truth**' signal



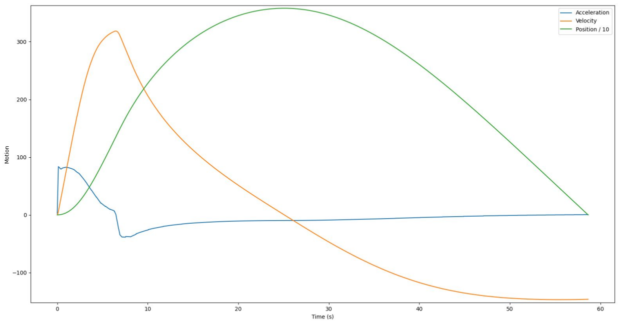
Anatomy of a Rocket

Communicate with ground simulations

in real time

Onboard camera

Capstone project



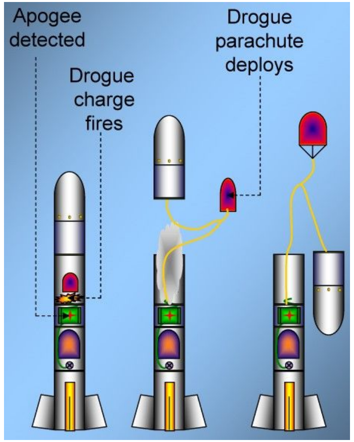
Anatomy of a Rocket

First stage of **dual-deployment** chute system

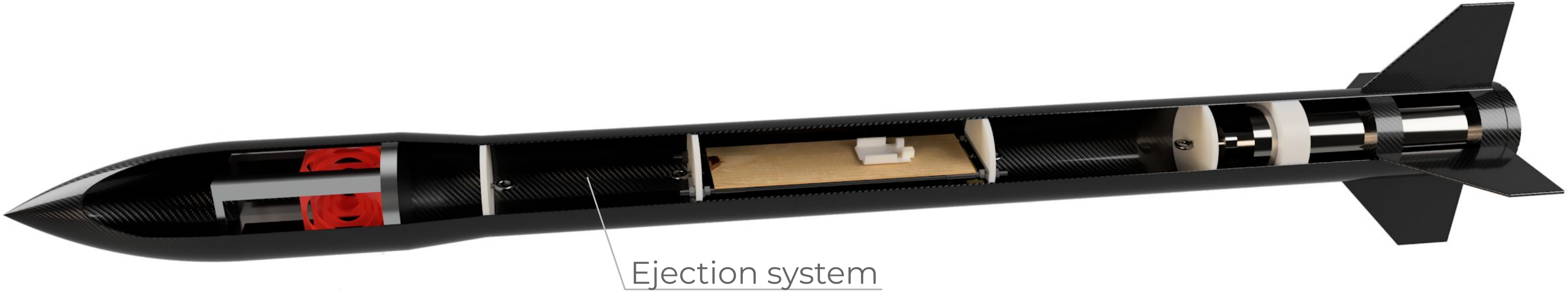
Deployed at apogee

Smaller chute reduces velocity to ~30m/s

Stabilises descent to stop main chute failing



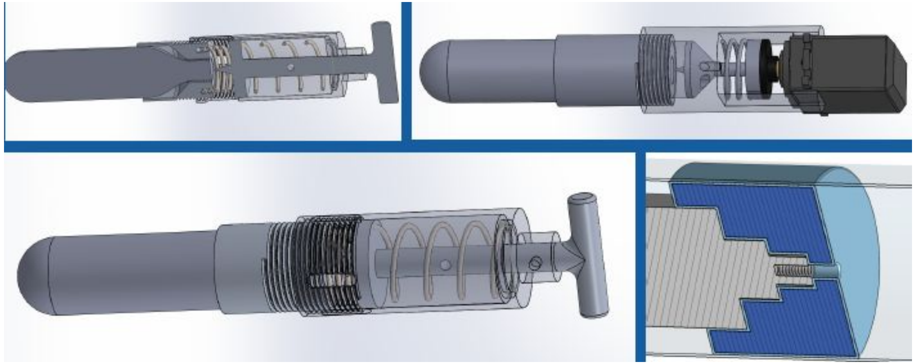
Anatomy of a Rocket



Eject pressurised gas to deploy the parachutes

Servomotor drives pin into CO_2 canister

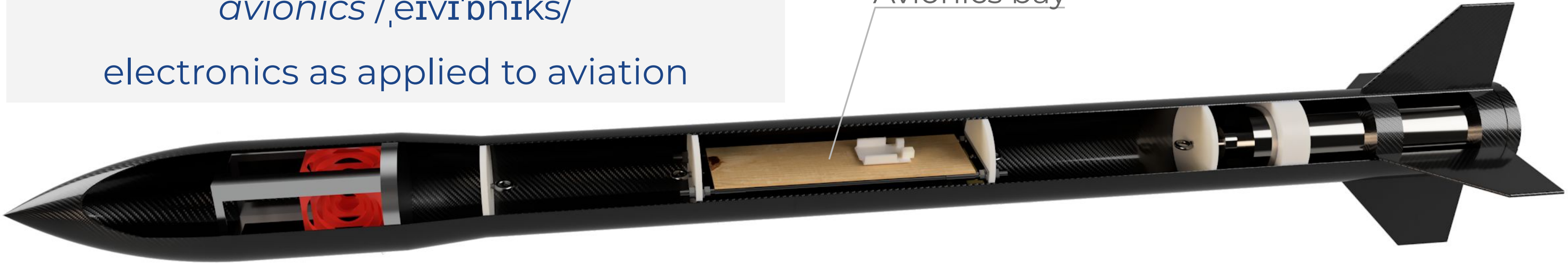
Pressure forces applied to **bulkheads,** snap **shear pins** & split **airframe** into several lengths



Anatomy of a Rocket

avionics /ˌeɪvɪˈɒnɪks/

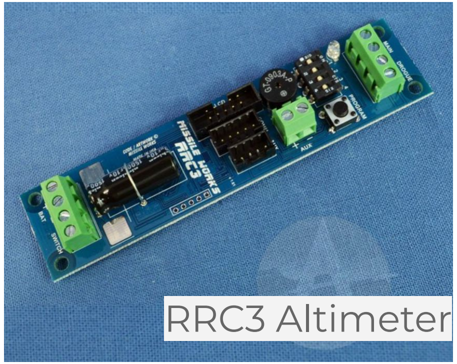
electronics as applied to aviation



Fundamental electronics necessary for flight

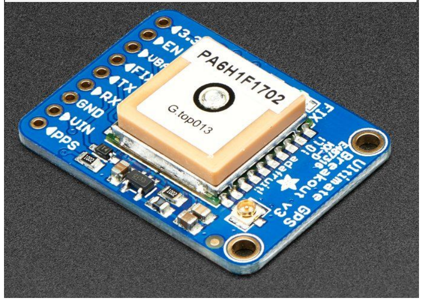
IMUs, **altimeters, GPS, transceivers,** radios etc

Altimeters include **barometric** transducers and accelerometer-based



RRC3 Altimeter

Adafruit BMP390 GPS



Anatomy of a Rocket

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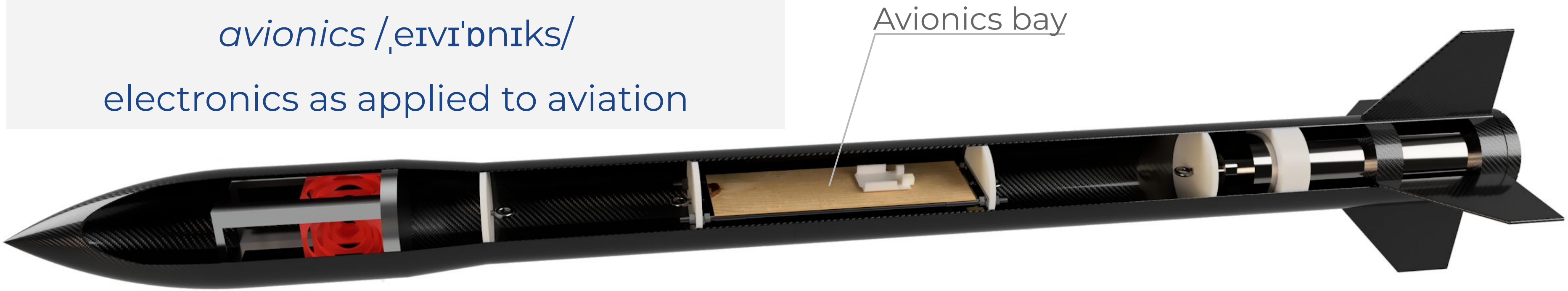
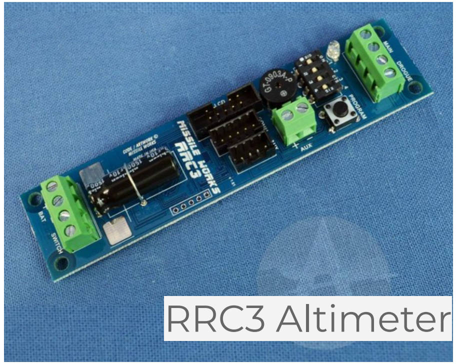


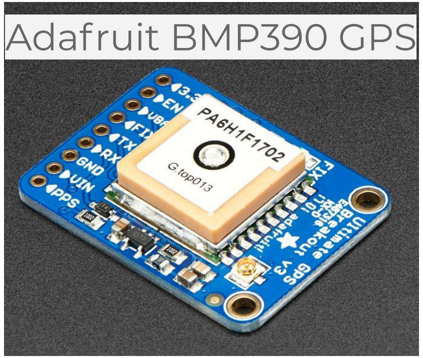
Logic control - **Arduino** Mega 2560

Threaded rod to withstand chute line tension

Vibration resistance

Redundancy





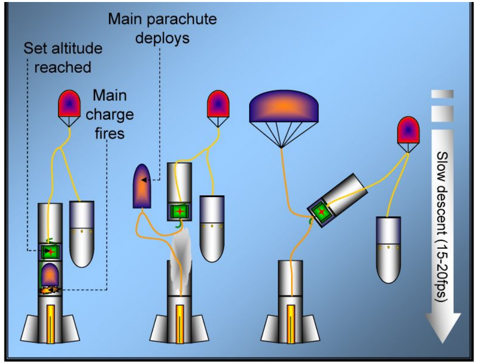
Anatomy of a Rocket

Deployed following sufficient deceleration

from drogue chute

Reduces descent velocity to **~4m/s**

Similar ejection system to drogue



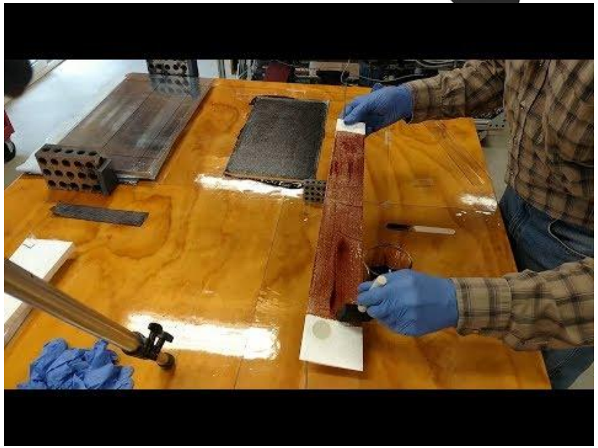
Anatomy of a Rocket

a.k.a. **Fuselage.** Material should withstand compression due to motor thrust and nose cone pushing against the air.

Surface roughness increases drag

Carbon fibre (CFRP), **fibreglass**

Layup - **epoxy** resin, hardener and fibre

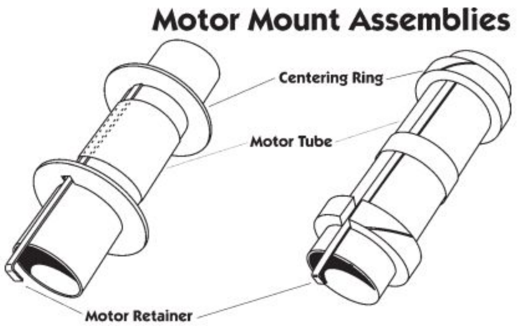


Anatomy of a Rocket

Used to mount and centre motor tube inside the airframe.

Transfers the thrust of the motor to the airframe.

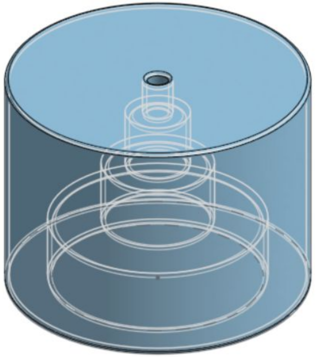
Polycarbonate (PC) - strong, tough polymer



Anatomy of a Rocket

Transfer motor thrust to entire airframe

Protect avionics and payload bays from heat and pressure of ejection charges



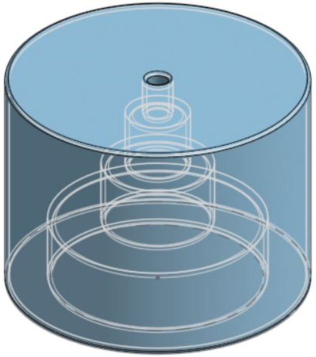
Anatomy of a Rocket

Compression from ejection charges

Tension from chute lines

Eye nut and threaded rod to transfer tension

Polycarbonate (PC), **XPS** coated in **fibreglass**

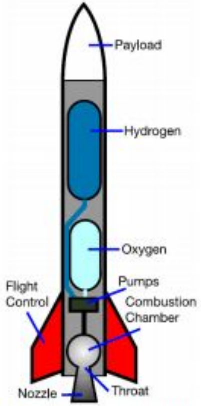


Anatomy of a Rocket

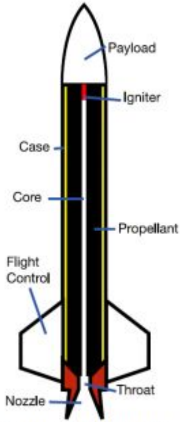
Solid Rocket Motors: The oxidiser and fuel are mixed together as solids.

Liquid Rocket Motor: The fuel and oxidisers are stored separately as liquids.

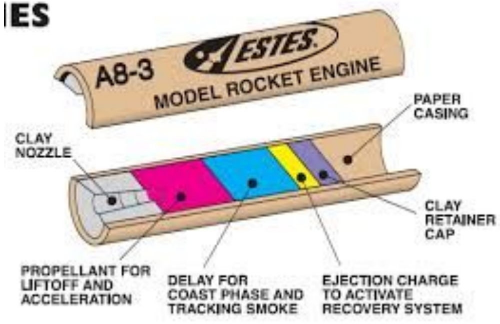
Hybrid: Most commonly a liquid oxidiser and solid fuel.



Liquid propellant rocket.



Solid Propellant Rocket.



Certifications

Australian Model Rocket Society (AMRS)

Motor Impulse Class
Motors for high-powered rockets are classified by **total impulse (Ns)** using a lettering system from **A-S**. Later letters indicate larger installed impulse.

L1 Certification
Encouraged for team members. Allows better understanding of manufacturing process and safety awareness.
Must be **18 years and older**. Build, launch and successfully recover a rocket using a certified HPR motor in the H to I impulse range. Total installed impulse **160-640 Ns**.

L2 Certification
Team members required to complete L2 to participate in the competition.
Must hold L1 certification. Pass the Level 2 **written examination** and then build, fly and recover successfully a rocket using a certified HPR motor in the J to L impulse range. Total installed impulse **640-5,120 Ns**.

Flight Stability

Centre of Pressure (COP) - the point on the rocket upon which the sum of all aerodynamic forces act.

Centre of Gravity (COG) - the weighted centroid of all distributed mass. This is the point to which a force may be applied to cause a linear acceleration without an angular acceleration.

$$C_P = \frac{\iiint_V \vec{r} * P(\vec{r})dV}{\iiint_V P(\vec{r})dV}$$

$$C_G = \frac{\iiint_V \vec{r} * \rho(\vec{r})dV}{m}$$

Flight Stability

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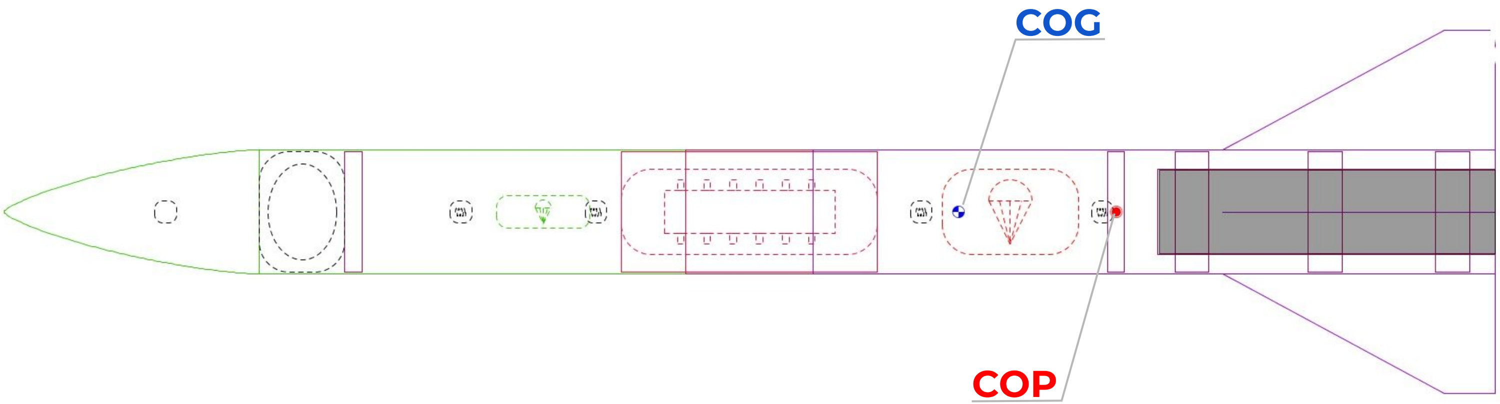
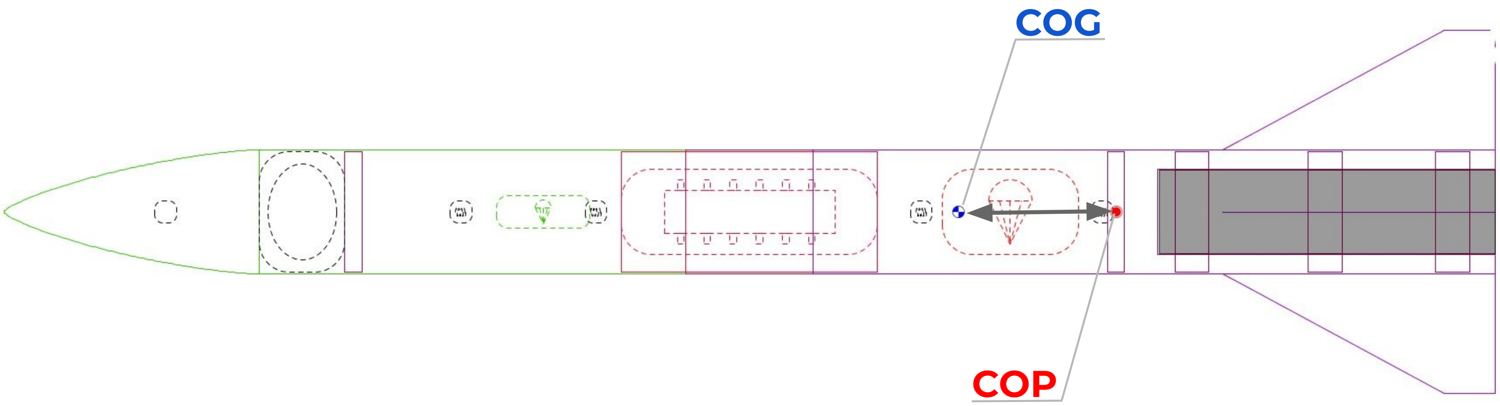


Flight Stability

Rotational motion pivots around COG. If COP is aft of COG and the rocket tilts to one side, the drag force will act to **stabilise** the rocket by straightening it.

Rule of thumb - **COP should be 1-2 calibres** (body tube diameters) **aft of the COG.**

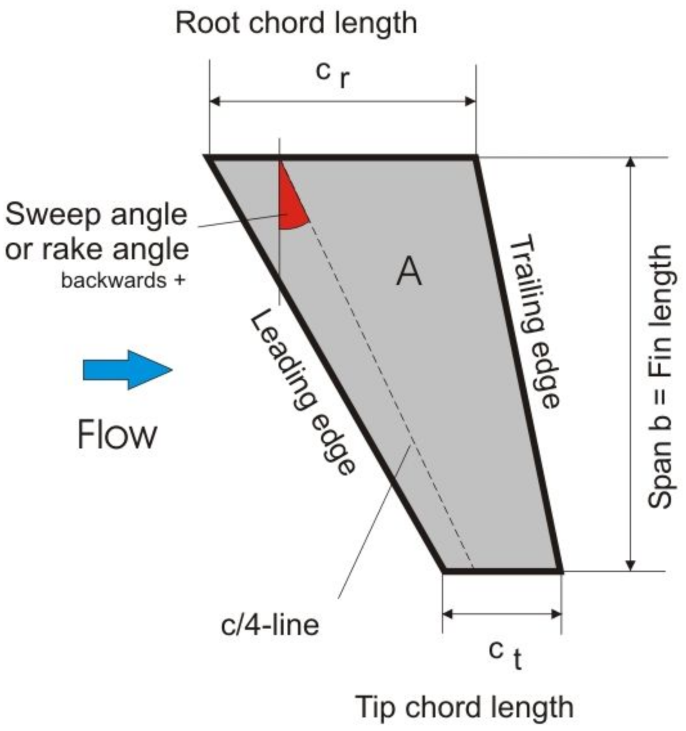


Fin Geometry

Fins provide guidance and moves the CP rearward for flight stability

During flight air flows over the leading edge to trailing edge. If a rocket turns the fins opposite to the turn are moved in the airflow. This reorients the rocket back to its initial position.

Fins can fail due to aerodynamic flutter or disattaching from the rocket body.

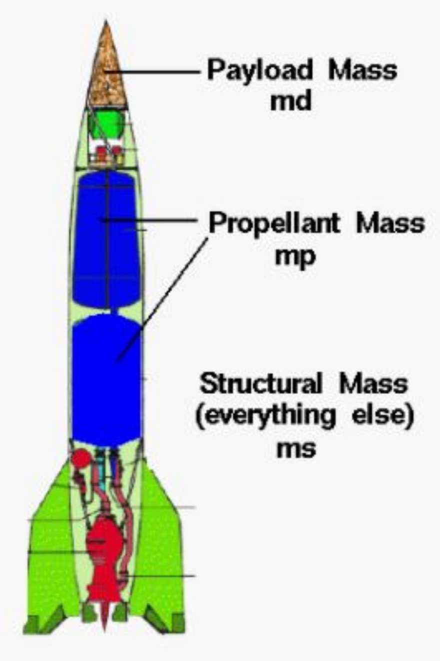


Mass

A proportion of a rocket's mass is due to its propellant. Mass factor may be used to aid in determining the rocket's performance.

MF = propellant mass / total mass

The MF for rockets can go up to 0.8-0.9, while model rockets may be as low as 0.15



Safety

Safety of every single system must be thoroughly and **systematically** analysed.

Failure Modes and Effects Analysis (FMEA) - identifying possible failure modes of each component, their relative likelihood and consequences. Systematically applies a score to each failure mode. Used to identify critical failure modes.

FMEA item ref.	Process	Phase	Potential failure mode	Potential failure effect	S	Root causes	O	Process controls & indicators	D	RPN	Recommended actions	Comments
1.1	Epoxy curing during carbon fibre layup	Manufacturing	Inadequate curing of epoxy during layup	1. Reduced yield strength & rigidity 2. Reduced overall performance of material	7	1. Epoxy did not reach the sufficient temperature for proper curing to take place 2. Manufacturer's info sheet not followed properly	2	1. Visual inspections may indicate inadequate curing 2. Lab testing of material can indicate subpar performance (from expected / indicated)	2	28	1. Ensure kiln / furnace can adequately cure epoxy at recommended temperatures (Manufacturer's info sheet) 2. Ensure heating is constant along length of tube being cured	Severity score justified due to direct impact it will have on flight (rocket will experience failure under force of launch)
1.2	Separation of body tube from coupler	Testing / Launching	Separation fails to occur	1. Internal pressure from ejection charge may plastically deform rocket tube 2. Lawn dart (if catastrophic failure has not yet occurred) 3. Ballistic descent	8	1. Friction between body tube & coupler is too high for separation to occur (ejection charge fails) 2. Shear pins did not break when ejection charge goes off	5	Rough internal surfaces (where coupler & body tube attach) may indicate high friction	7	280	1. Proper sanding of internal surfaces to allow for decoupling 2. Lab / site tests to determine whether ejection charge is capable of decoupling	Severity score indicates potential for catastrophic failure. Potential for detection is small.

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Safety of every single system must be thoroughly and **systematically** analysed.

Failure Modes and Effects Analysis (FMEA) -

Severity (**S**) x Occurrence (**O**) x Detectability (**D**) = Risk Priority Number (**RPN**)

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Risk Register - identify potential pre- and post-launch risks, and **proposed solutions** to mitigate these risks.

	Consequence				
Likelihood	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
5 - Almost certain	M	H	E	E	E
4 - Likely	M	H	H	E	E
3 - Possible	L	M	H	H	H
2 - Unlikely	L	L	M	H	H
1 - Rare	L	L	L	M	H

Safety

Safety of every single system must be thoroughly and **systematically** analysed.

Risk Register - identify potential pre- and post-launch risks, and **proposed solutions** to mitigate these risks. Goal is to reduce the likelihood and consequence of these risks through implementing safety measures.

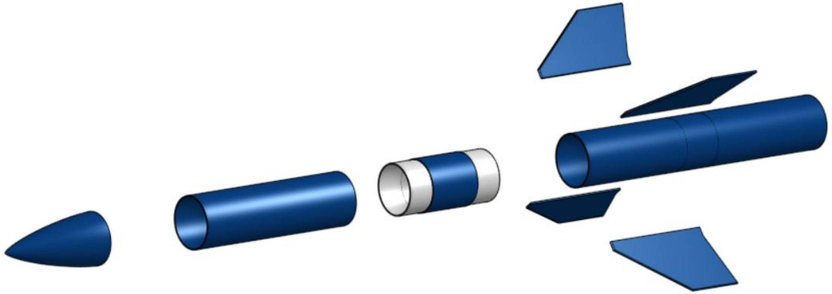
Risk identification				Risk analysis & evaluation			Risk evaluation & treatment				
				Original risk				Residual risk			
Risk ID	Hazard	Risk title	Description of consequences	Likelihood	Consequence	PI score	Proposed risk treatment	Likelihood	Consequence	PI score	Control effectiveness
Preflight											
A	Public presence around workstation	Exposed rocket parts, sharp tools or live wires may be present at the workstation	Physical injury to bystanders (e.g. cut, electrocution etc)	2	2	L	- Restrict non-authorised personnel from handling material at workstation (appropriate signage, verbal warning) - Constant supervision of workstation - PLI in case of accident	1	1	L	Overall risk reduction in terms of likelihood due to appropriate warnings, as well as consequences through a PLI

Computer Aided Design (CAD)

ARES

CAD - computer aided development, modification, and optimization of the design process - 3D modeling of the product..

Onshape - cloud-based CAD design tool used by Project Phobos.



onshape®

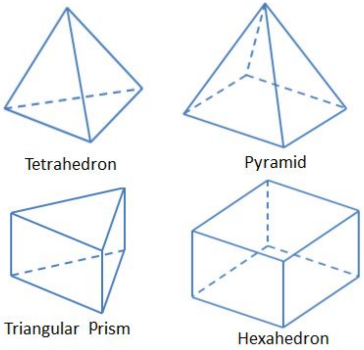
AUTODESK® FUSION 360™

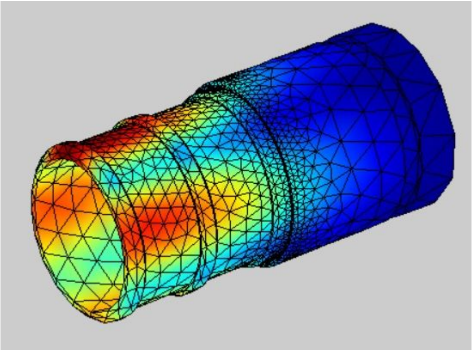
SolidWorks

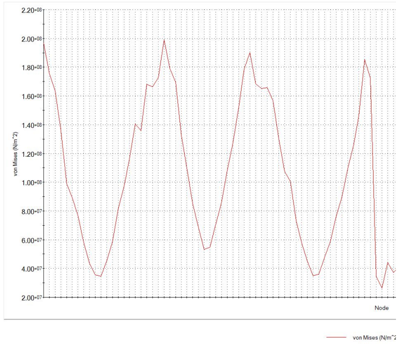
Finite Element Analysis (FEA)

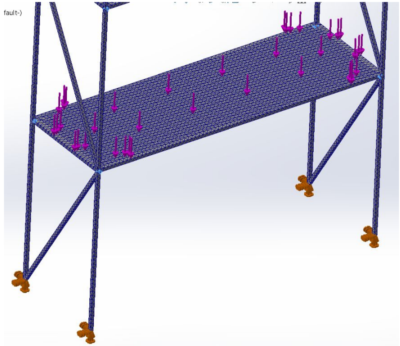
FEA - discretising a solid component into a finite number of nodes and performing numerical analysis. Used for solving solid mechanics problems such as displacement or stress within the solid.

Meshing - breaking the 3D model into a “mesh” of polygons - **tet** or **hex**





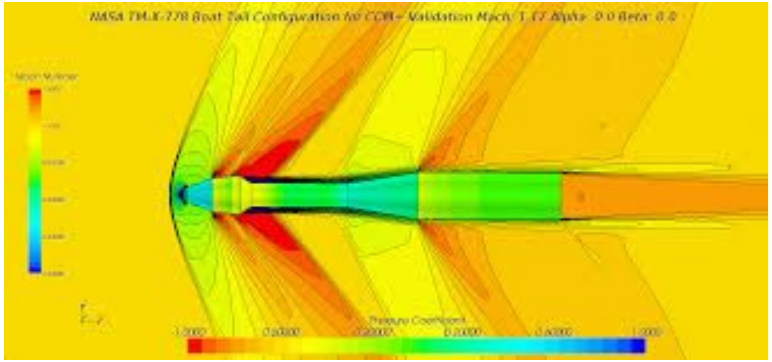


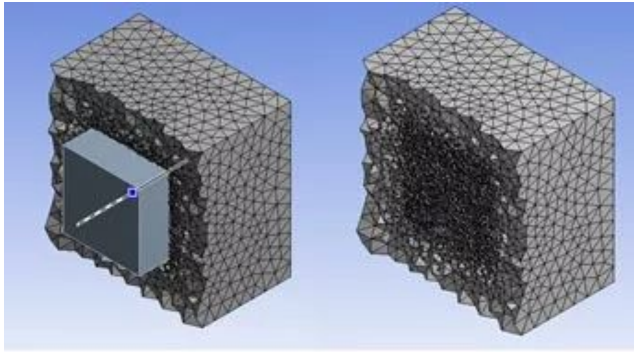


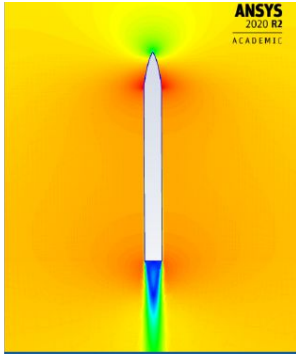
Computational Fluid Dynamics (CFD)

CFD - simulating fluid and heat flow using numerical analysis.

Fluid flow around different parts of the rocket, and effect on flight trajectory. Information from the CFD simulations is used in the flight simulation calculations.



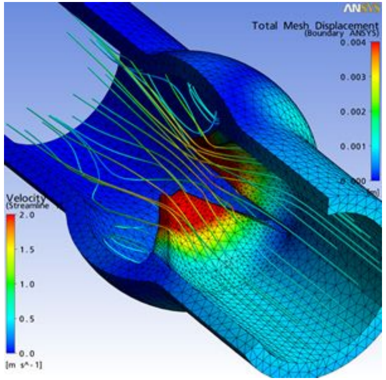


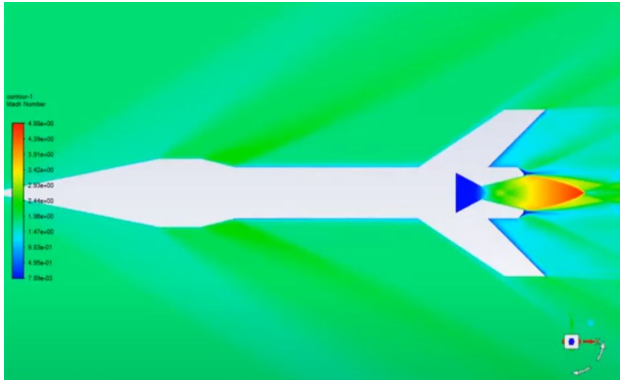


Ansys

Ansys - powerful software capable of CAD, FEA, CFD and much more. The simulation software of choice for Project Phobos. Utilises task-based workflow.

Multiphysics simulation - coupled mechanical and fluid simulation.

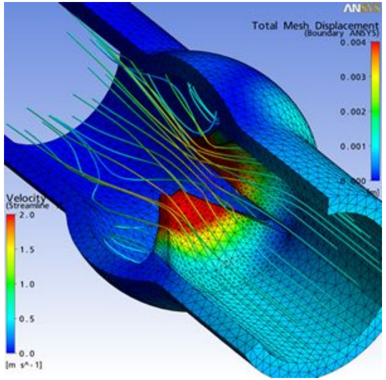


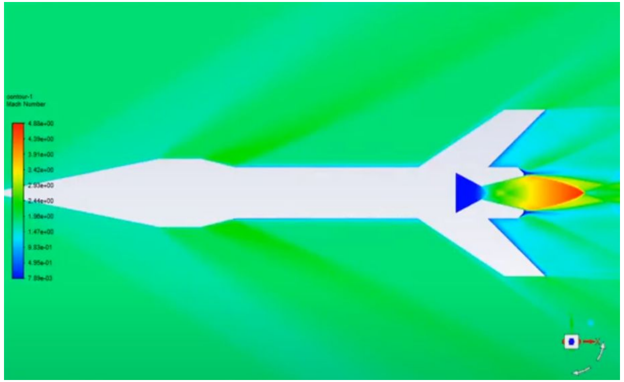


Ansys

Ansys Composite PrepPost (ACP) - Ansys toolset for design and analysis of composite materials (think airframe and fins).

Ansys Fluent - Ansys toolset for fluid simulation and CFD





ARES Partners

LEAP Australia

Engineering Software Consultants

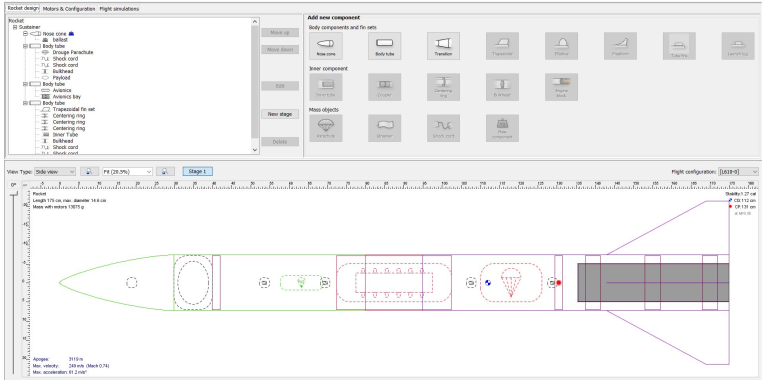
LEAP Australia have partnered with the Project Phobos team act as mentors for modelling and simulation software. In particular, LEAP provide us assistance with the Ansys and Onshape software packages.

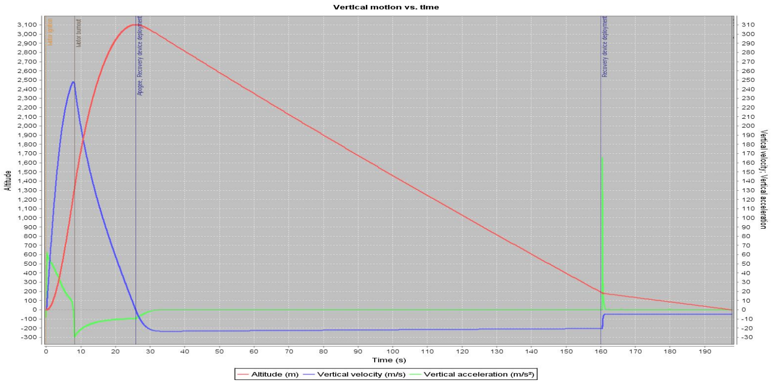
OpenRocket

Open-source rocket simulation software

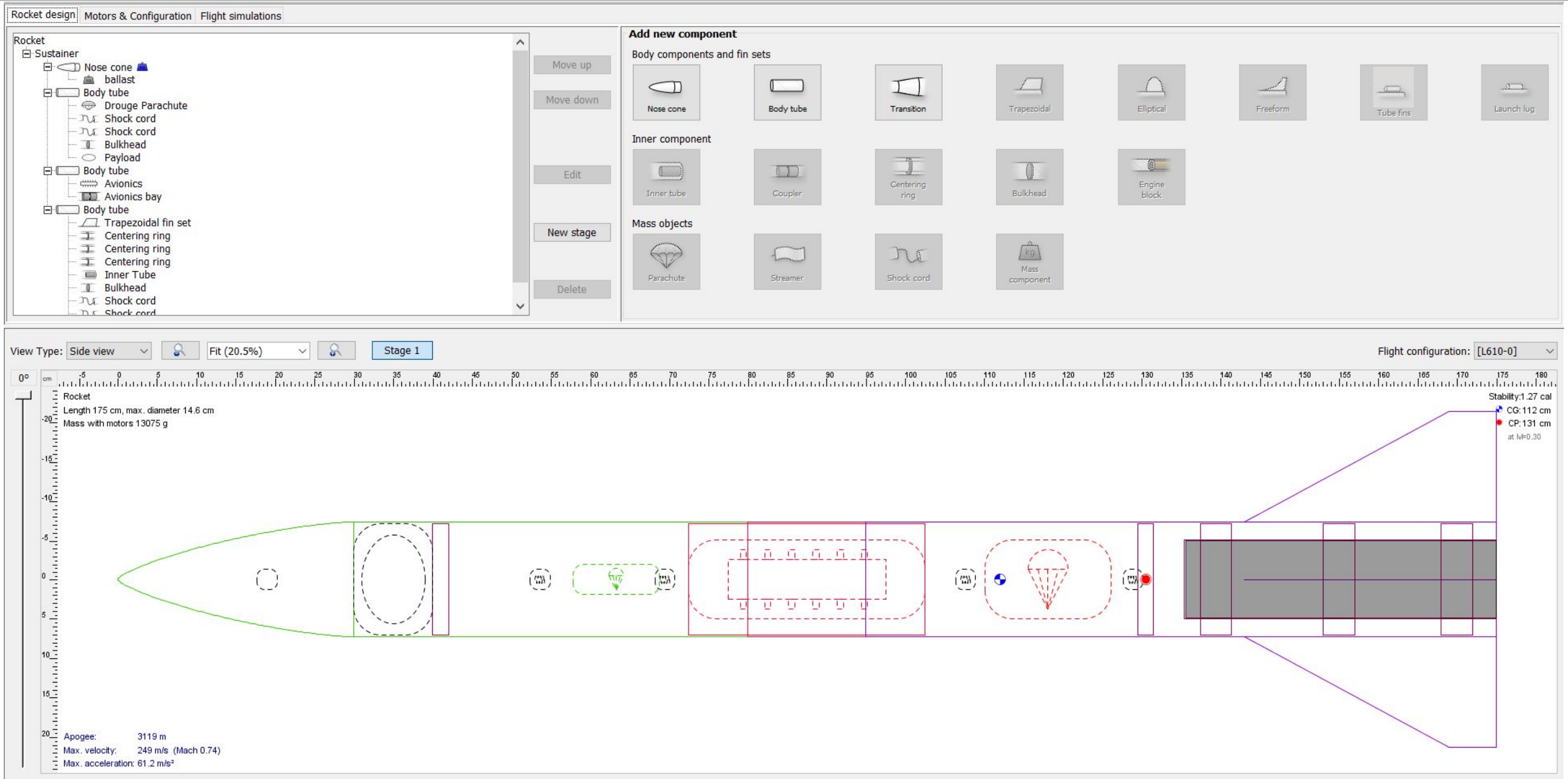
Optimise design and simulate various launch conditions

Augmented with custom **Python** code - drag, thrust and gravity in 2D



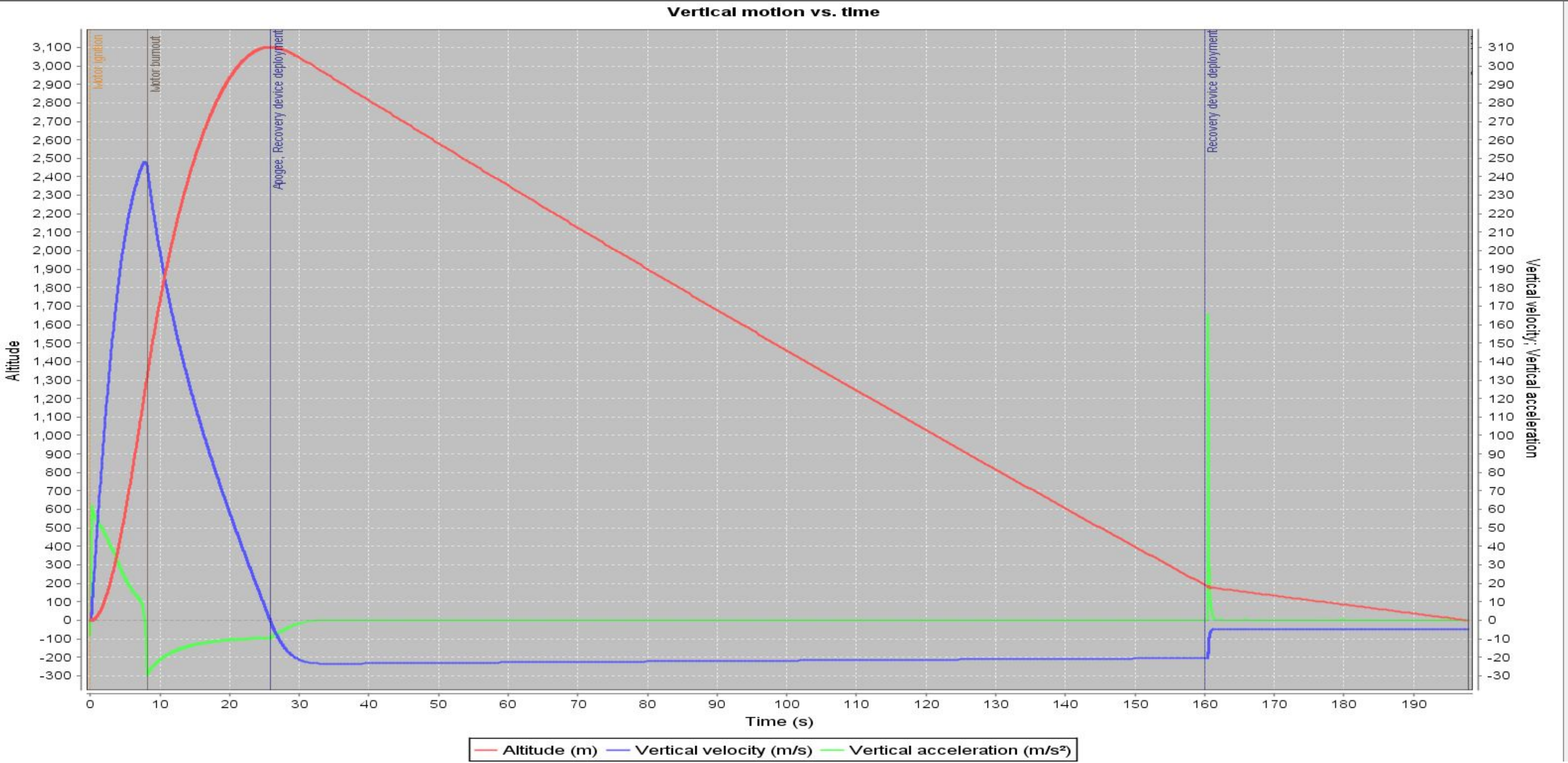


OpenRocket

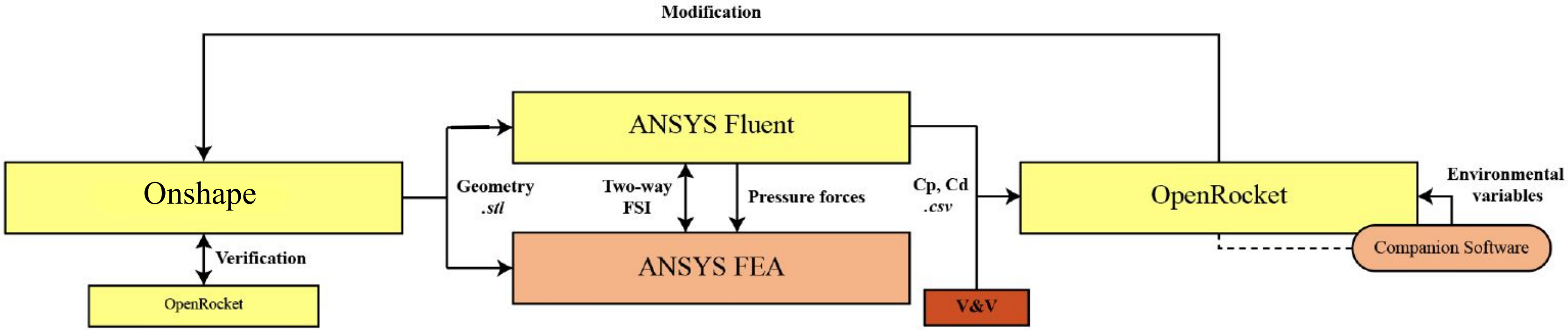


Rocket design
Motors & Configuration
Flight simulations
Rocket
Sustainer
Nose cone
ballast
Body tube
Drouge Parachute
Shock cord
Shock cord
Bulkhead
Payload
Body tube
Avionics
Avionics bay
Body tube
Trapezoidal fin set
Centering ring
Centering ring
Centering ring
Inner Tube
Bulkhead
Shock cord
Shock cord
Move up
Move down
Edit
New stage
Delete
Add new component
Body components and fin sets
Nose cone
Body tube
Transition
Trapezoidal
Elliptical
Freeform
Tube fins
Launch lug
Inner component
Inner tube
Coupler
Centering ring
Bulkhead
Engine block
Mass objects
Parachute
Streamer
Shock cord
Mass component
View Type:
Side view
Fit (20.5%)
Stage 1
Flight configuration:
[L610-0]
Rocket
Length 175 cm, max. diameter 14.6 cm
Mass with motors 13075 g
Stability: 1.27 cal
CG: 112 cm
CP: 131 cm
at M=0.30
Apogee: 3119 m
Max. velocity: 249 m/s (Mach 0.74)
Max. acceleration: 61.2 m/s²

OpenRocket


Vertical motion vs. time
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Altitude
Vertical velocity, Vertical acceleration
Time (s)
Altitude (m)
Vertical velocity (m/s)
Vertical acceleration (m/s²)

Phobos Workflow



Next week - OpenRocket Basics

See you next week! :)