

ARES Workshop - Project Phobos

Part 2

Cas Kent & Ann Phan





Week 2 Revision

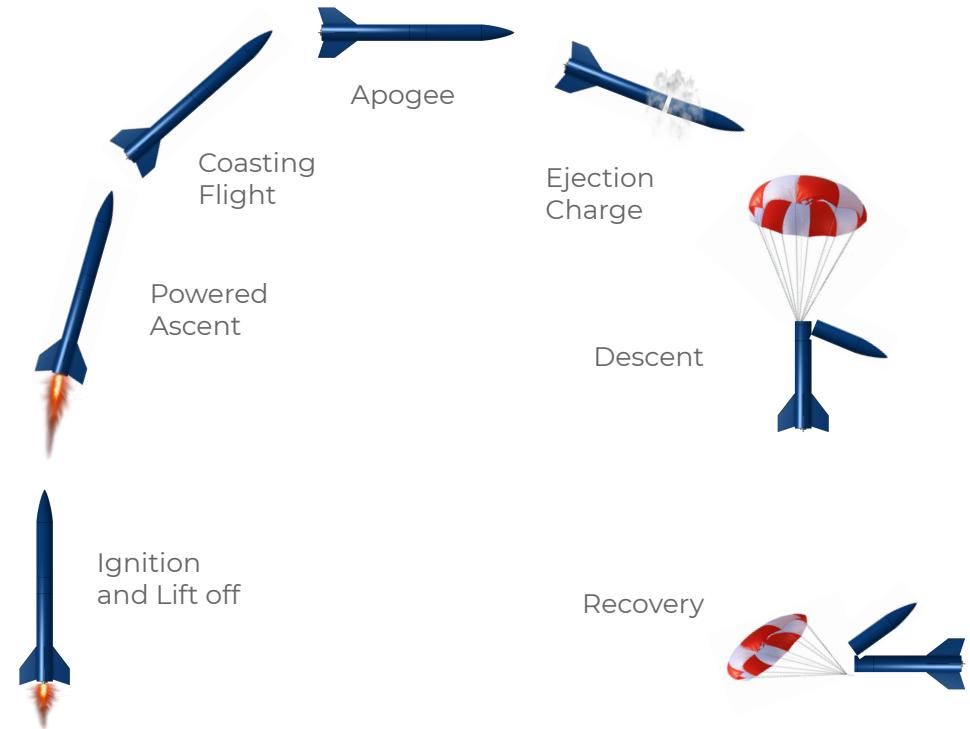


Index

Ansys Composite PrepPost (ACP), aerodynamic heating, aft, Ansys, airframe, apogee, avionics, ballast, bulkhead, calibre, carbon fibre (CFRP), centring ring, Computational Fluid Dynamics (CFD), Centre of Gravity (COG), Centre of Pressure (COP), Computer Aided Design (CAD), CubeSat, drogue chute, ejection system, epoxy, eye nut, Finite Element Analysis (FEA), Fluent, Failure Modes and Effects Analysis (FMEA), forward, fuselage, Haack, Inertial Measurement Unit (IMU), L1/L2, LEAP, main chute, meshing, multiphysics simulation, Ogive, Onshape, OpenRocket, payload, PID, Python, reaction wheel, Risk Register, Risk Priority Number (RPN), root chord, shear pins, sweep angle, telemetry

Phases of Flight

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

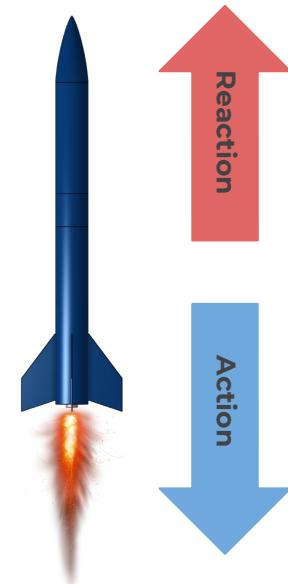


Newton's Laws of Motion

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

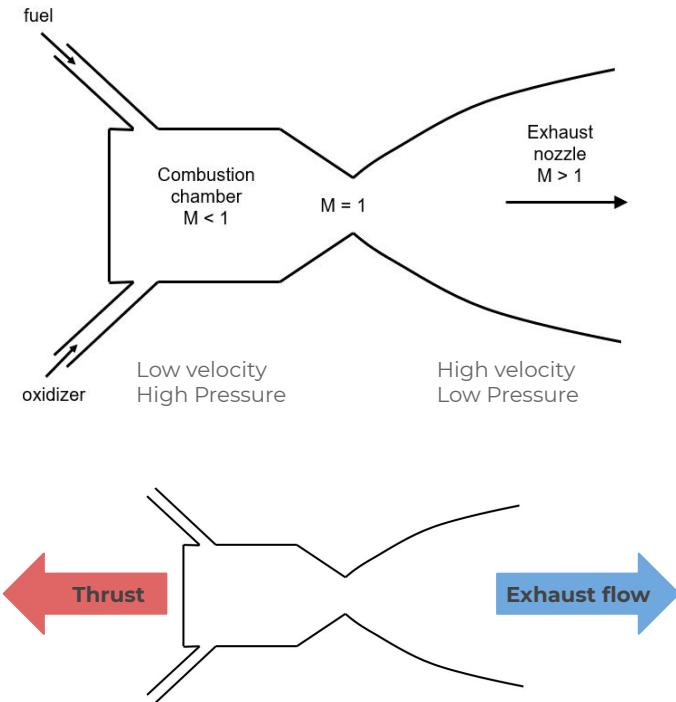


Propulsion

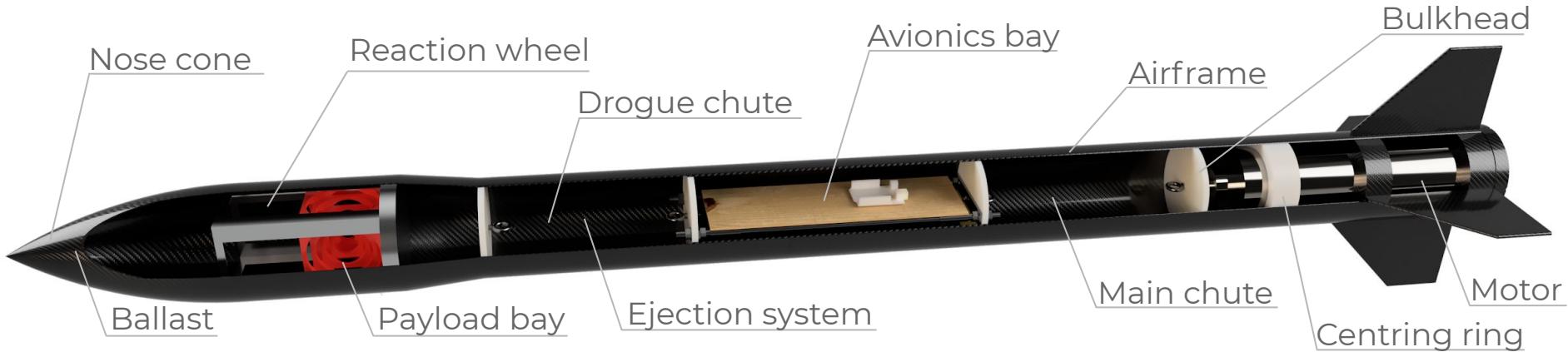
Fuel in a rocket motor is burned with the oxidiser to produce hot gases.

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



Forward

Aft

Anatomy of a Rocket

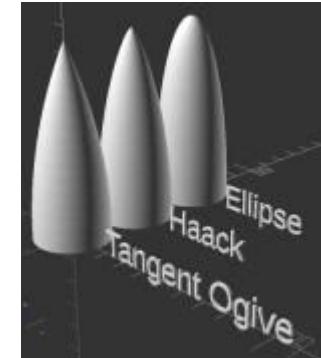
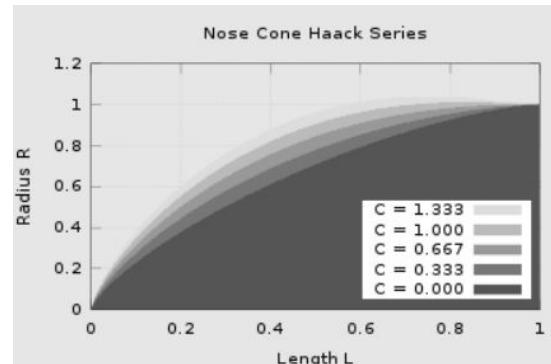


Minimise aerodynamic **drag**

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

Endure **pressure forces**, aerodynamic heating

Carbon fibre (CFRP), **fibreglass**



Anatomy of a Rocket



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

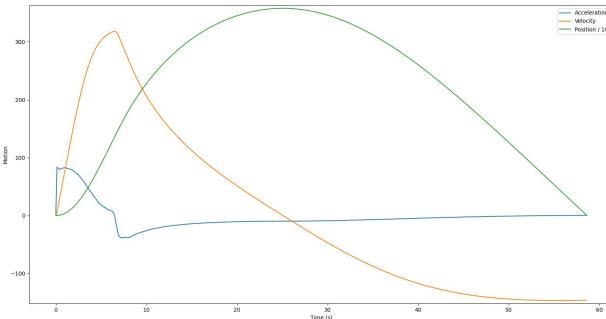


Functional system for performing tasks

CubeSat - standardised **miniature satellite**

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

Reduces cost of satellite deployment



Anatomy of a Rocket

telemetry /tɪ'lɛmɪtri/

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

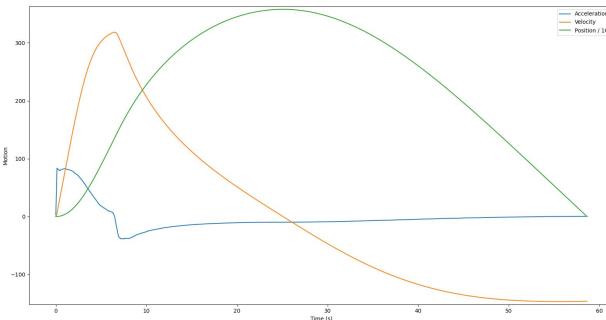


Telecommunications & flight **tracking system**

Altitude, attitude and velocity of the rocket

without a GPS signal

GPS 'ground truth' signal



Anatomy of a Rocket

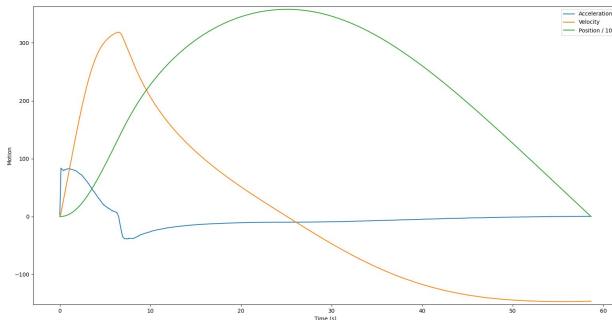


Communicate with ground simulations

in real time

Onboard camera

Capstone project



Anatomy of a Rocket

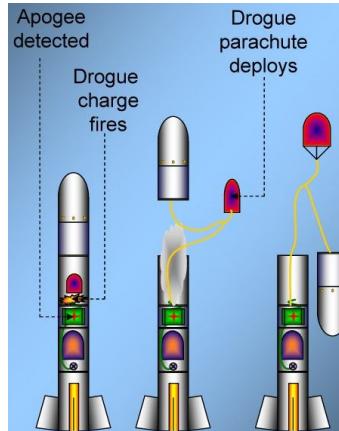


First stage of **dual-deployment** chute system

Deployed at apogee

Smaller chute reduces velocity to ~30m/s

Stabilises descent to stop main chute failing



Anatomy of a Rocket

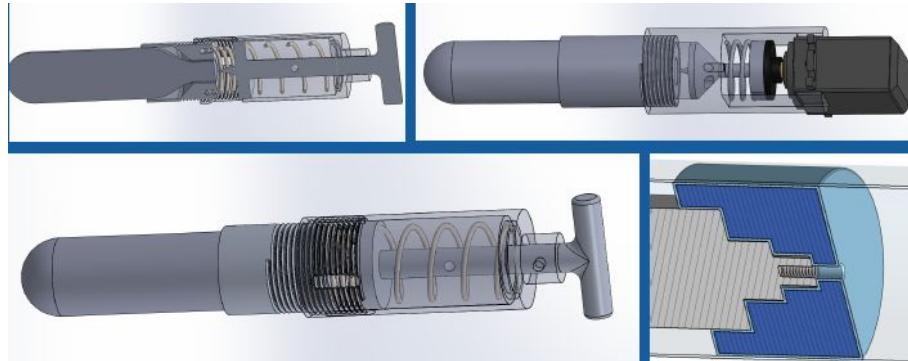


Eject pressurised gas to deploy the parachutes

Servomotor drives pin into CO₂ canister

Pressure forces applied to **bulkheads**, snap

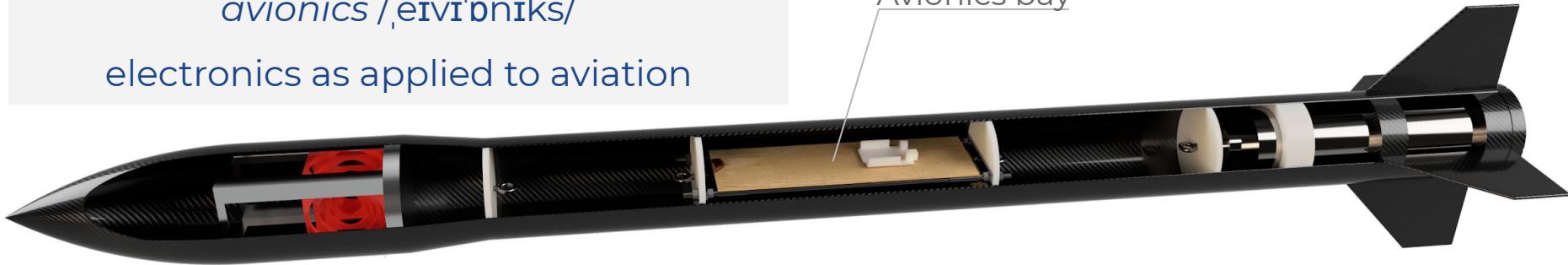
shear pins & split **airframe** into several lengths



Anatomy of a Rocket

avionics /əɪvɪ'ɒnɪks/

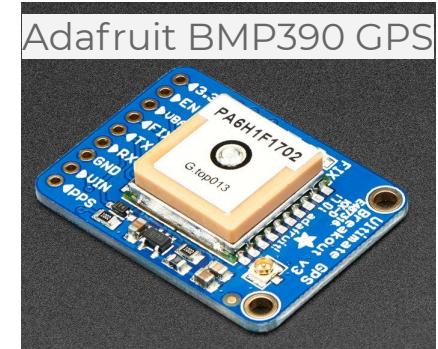
electronics as applied to aviation



Fundamental electronics necessary for flight

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

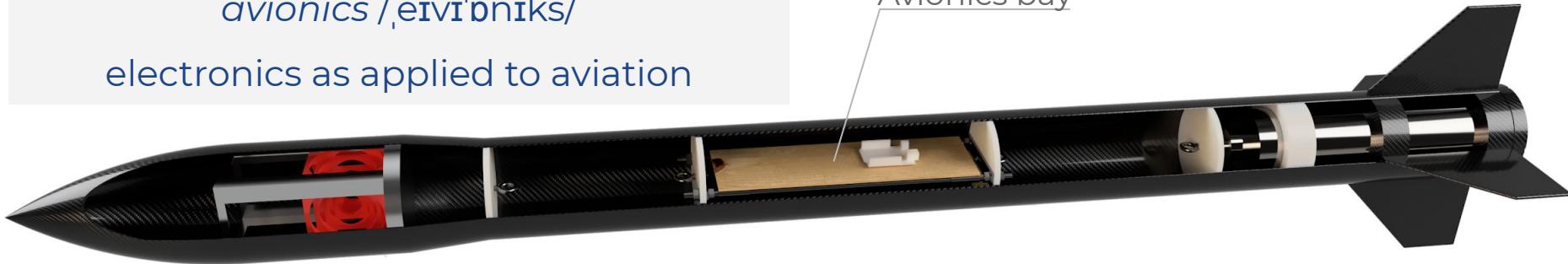
Altimeters include **barometric** transducers and
accelerometer-based



Anatomy of a Rocket

avionics /əɪvɪ'ɒnɪks/

electronics as applied to aviation

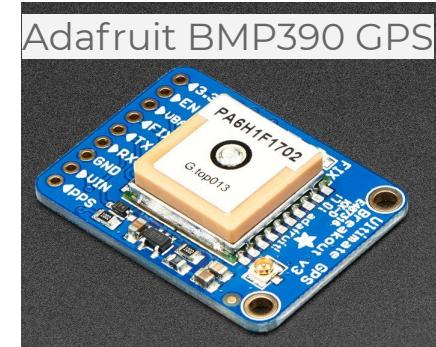


Logic control - **Arduino** Mega 2560

Threaded rod to withstand chute line tension

Vibration resistance

Redundancy



Anatomy of a Rocket

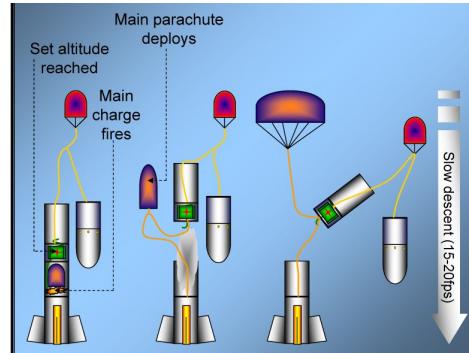


Deployed following sufficient deceleration

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



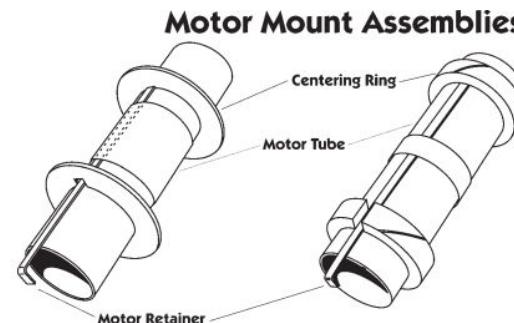
Anatomy of a Rocket



Used to mount and centre motor tube inside the airframe.

Transfers the thrust of the motor to the airframe.

Polycarbonate (PC) - strong, tough polymer

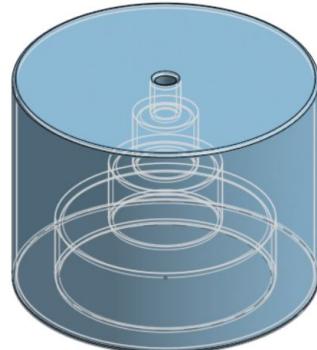


Anatomy of a Rocket



Transfer motor thrust to entire airframe

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



Anatomy of a Rocket

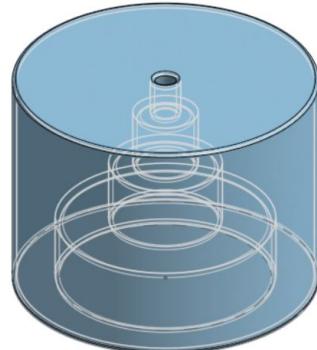


Compression from ejection charges

Tension from chute lines

Eye nut and threaded rod to transfer tension

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



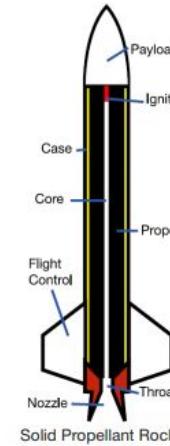
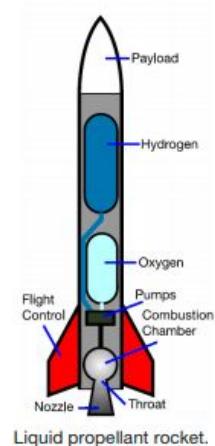
Anatomy of a Rocket



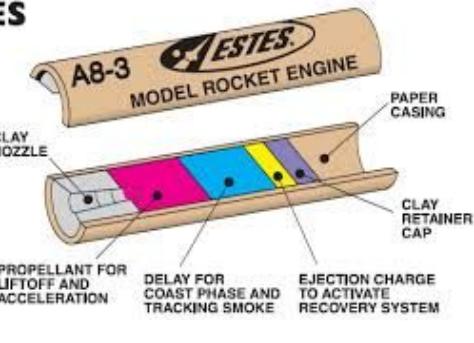
Solid Rocket Motors: The oxidiser and fuel are mixed together as solids.

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

Hybrid: Most commonly a liquid oxidiser and solid fuel.



ESTES





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.

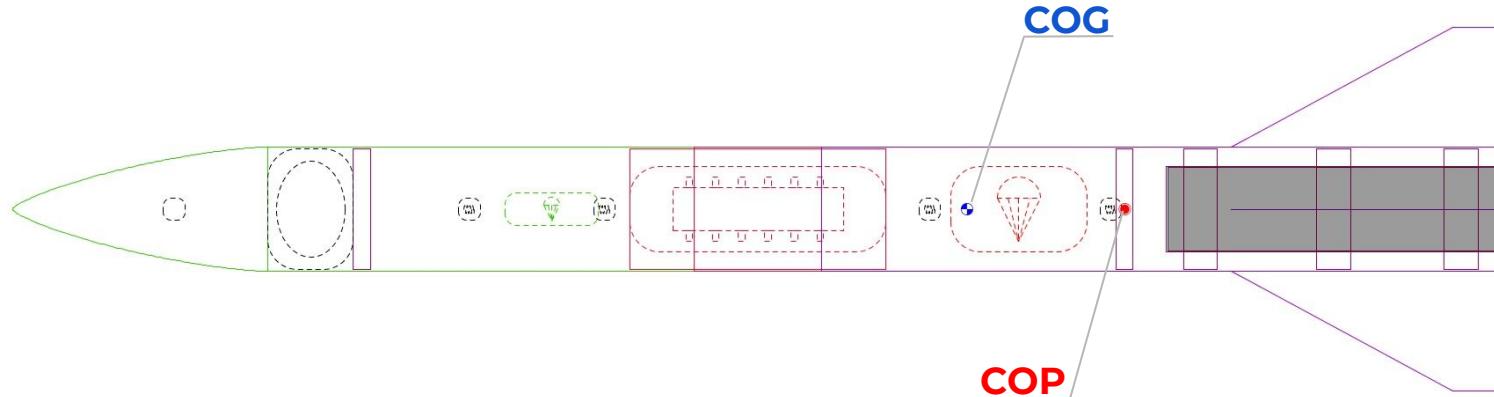
$$C_P = \frac{\iiint_V \vec{r} * P(\vec{r}) dV}{\iiint_V P(\vec{r}) dV}$$

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

Flight Stability

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

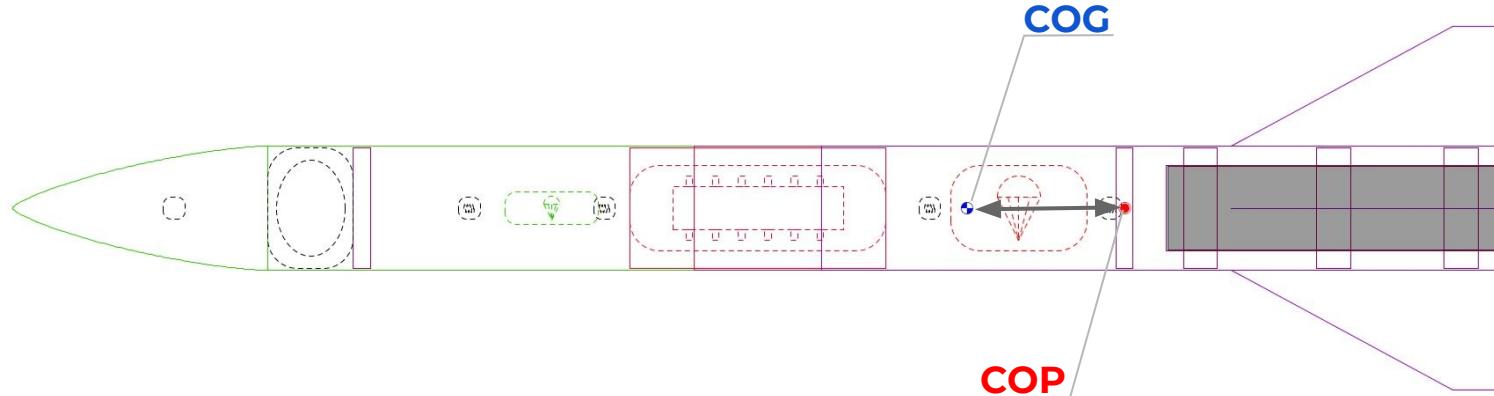
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Flight Stability

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**.

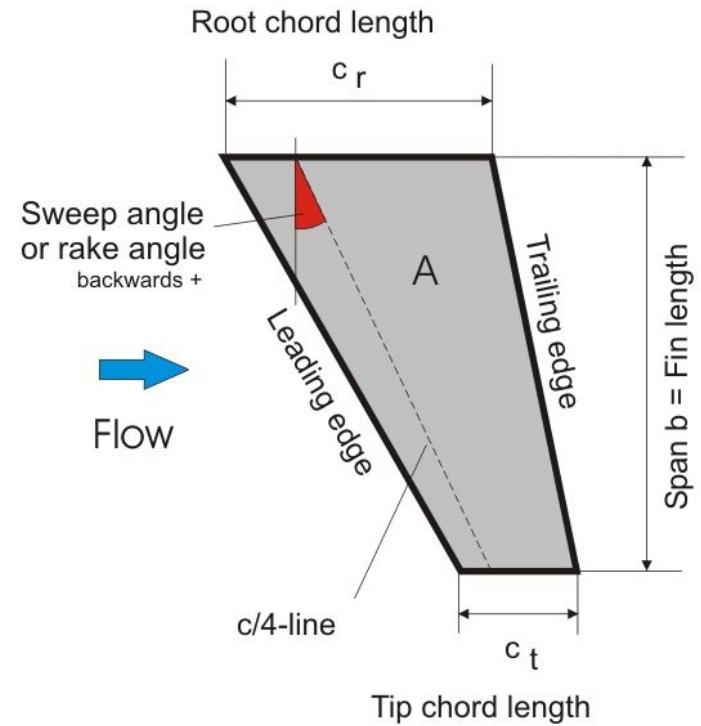


Fin Geometry

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.

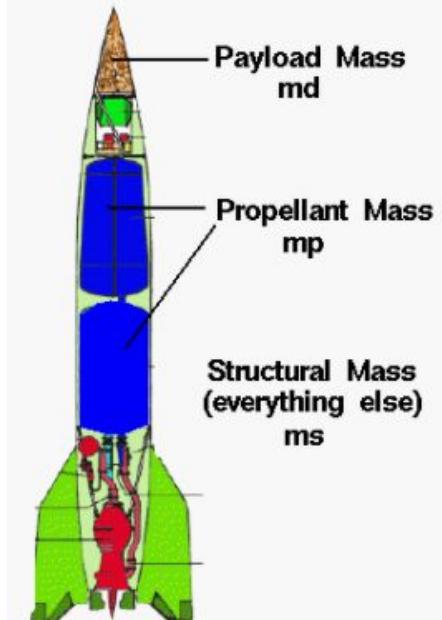


Mass

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.

$$\text{MF} = \text{propellant mass} / \text{total mass}$$

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.

Safety

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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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.

		Consequence				
		1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
Likelihood	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.

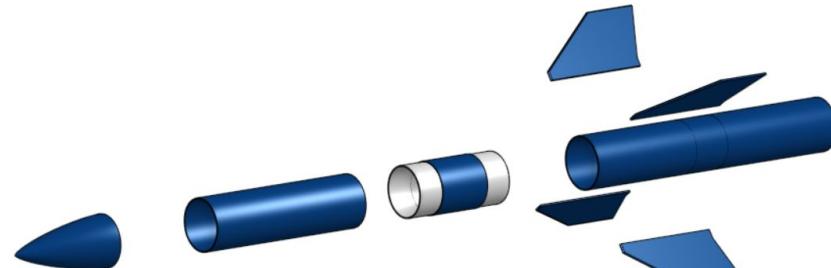
Risk identification				Risk analysis & evaluation			Risk evaluation & treatment				
Risk ID	Hazard	Risk title	Description of consequences	Original risk			Proposed risk treatment	Residual risk			
				Likelihood	Consequence	PI score		Likelihood	Consequence	PI score	
Preflight											
A	Public presence 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)



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

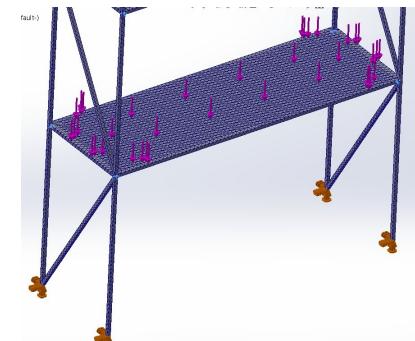
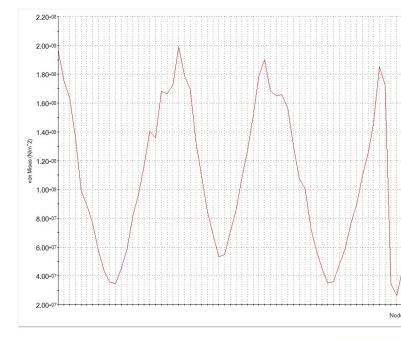
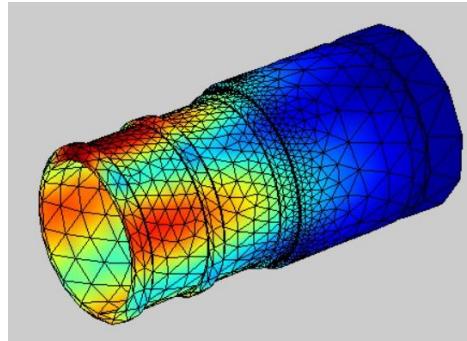
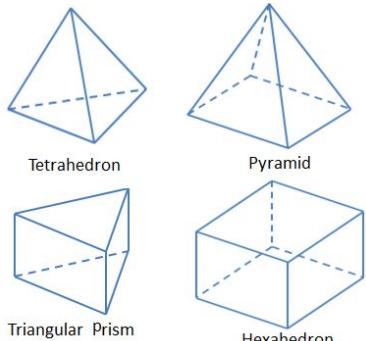
Onshape - cloud-based CAD design tool used by Project Phobos.



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**

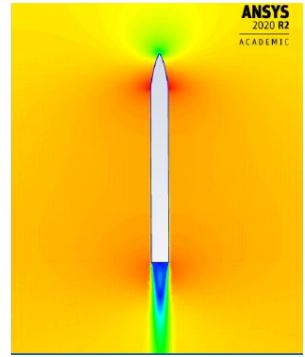
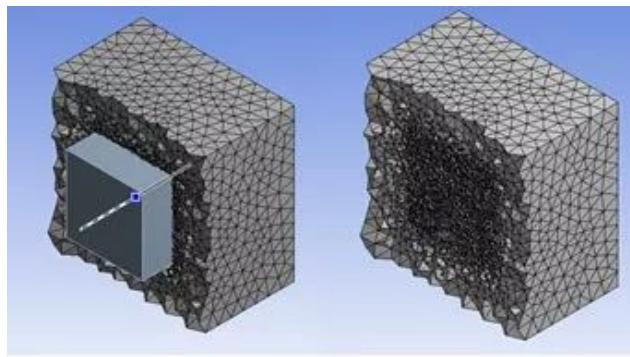
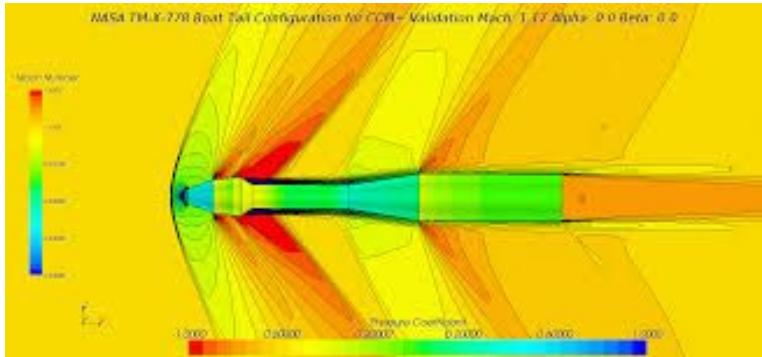


Computational Fluid Dynamics (CFD)



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.



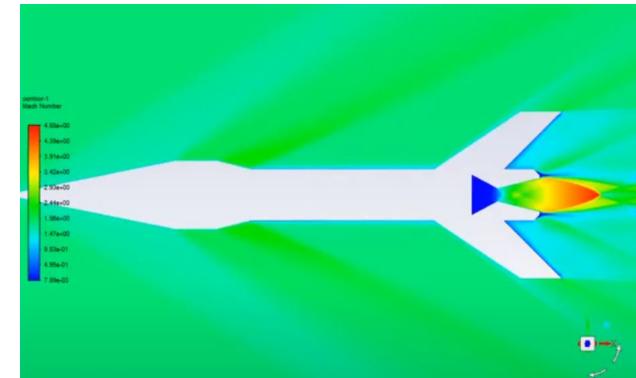
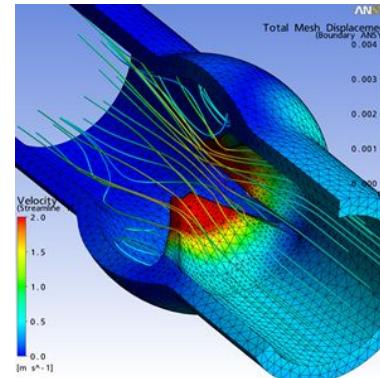
Ansys



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



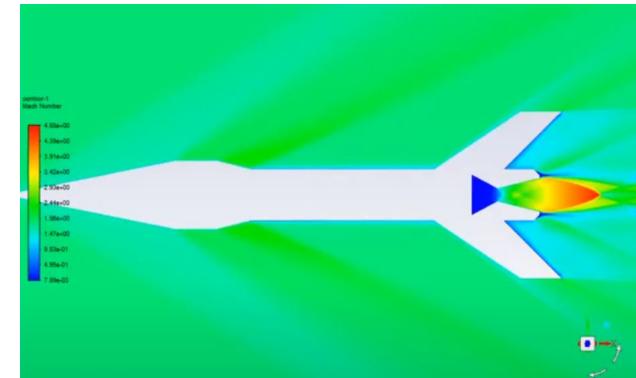
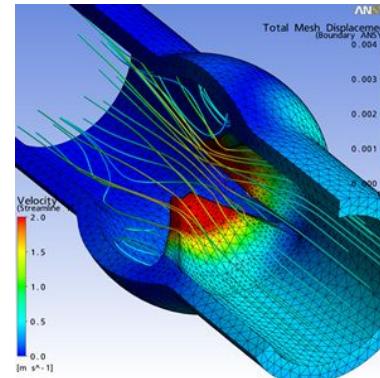
Ansys



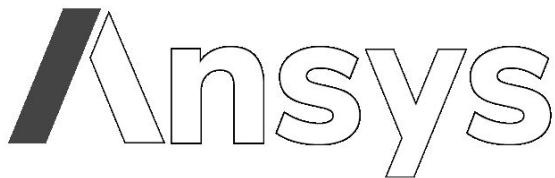
Ansys Composite PrepPost (ACP) - Ansys toolset for design and analysis of composite materials (think airframe and fins).

Ansys Fluent - Ansys toolset for fluid simulation and CFD

Ansys



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.

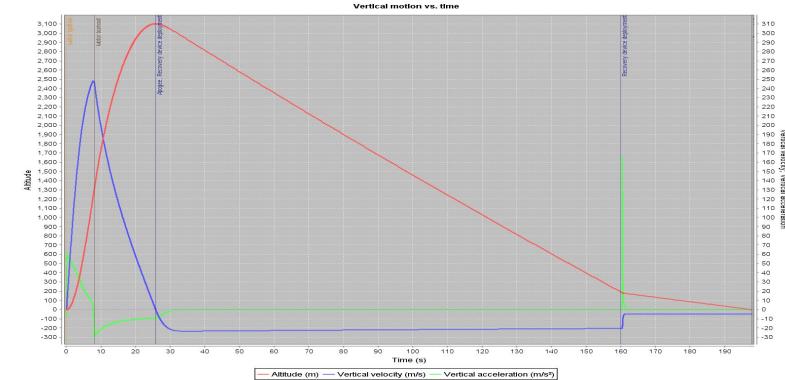
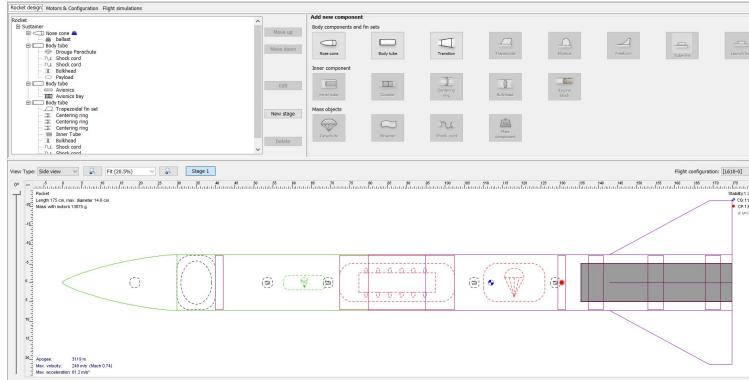


OpenRocket

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
 - Body tube
 - Drogue 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

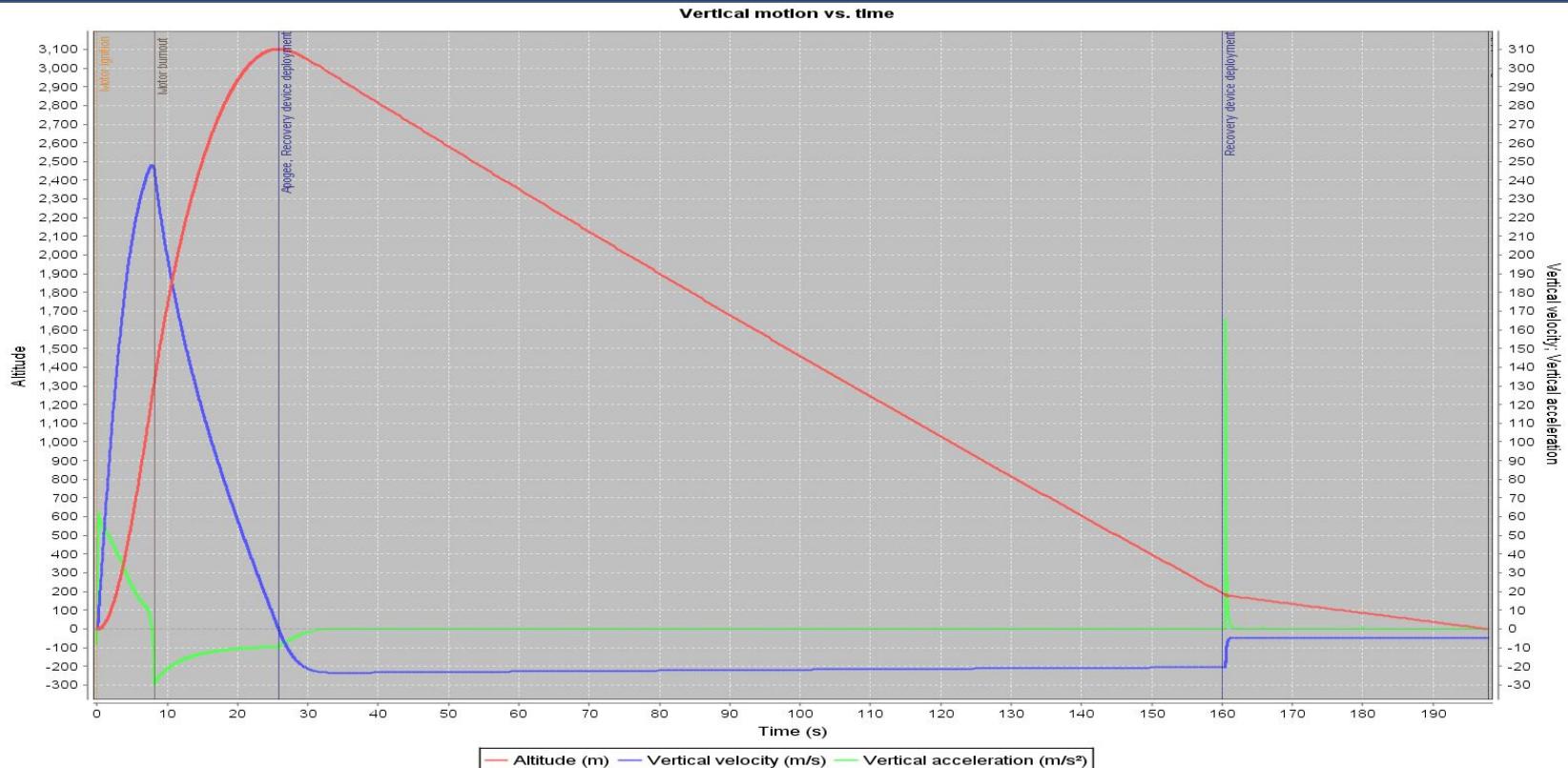
- Parachute
- Streamer
- Shock cord
- Mass component

View Type: Side view | Fit (20.5%) | Stage 1 | Flight configuration: [L610-0] | Stability: 1.27 cal | CG: 112 cm | CP: 131 cm at M=0.30

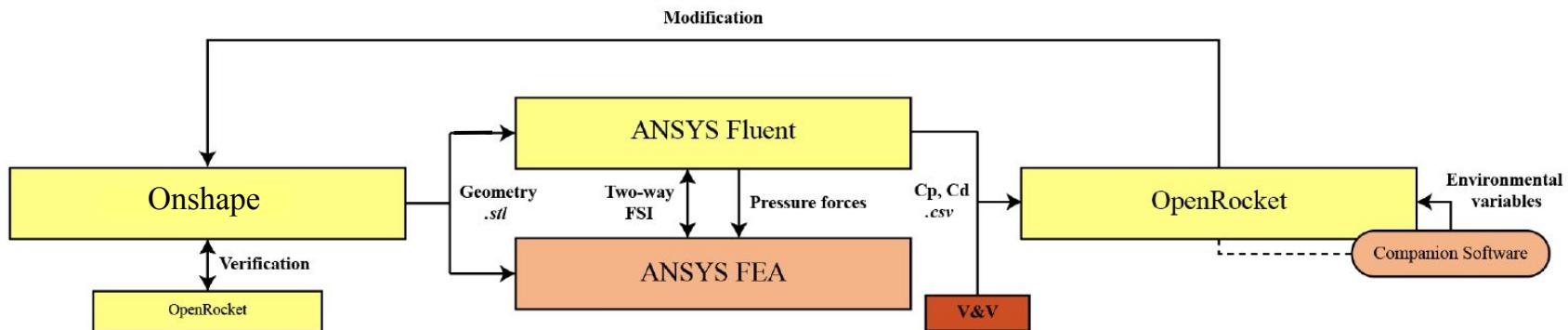
Rocket
Length 175 cm, max. diameter 14.6 cm
Mass with motors 13075 g

Apogee: 3119 m
Max. velocity: 249 m/s (Mach 0.74)
Max. acceleration: 61.2 m/s²

OpenRocket



Phobos Workflow



Next week - Onshape (CAD)

See you next week! :)

