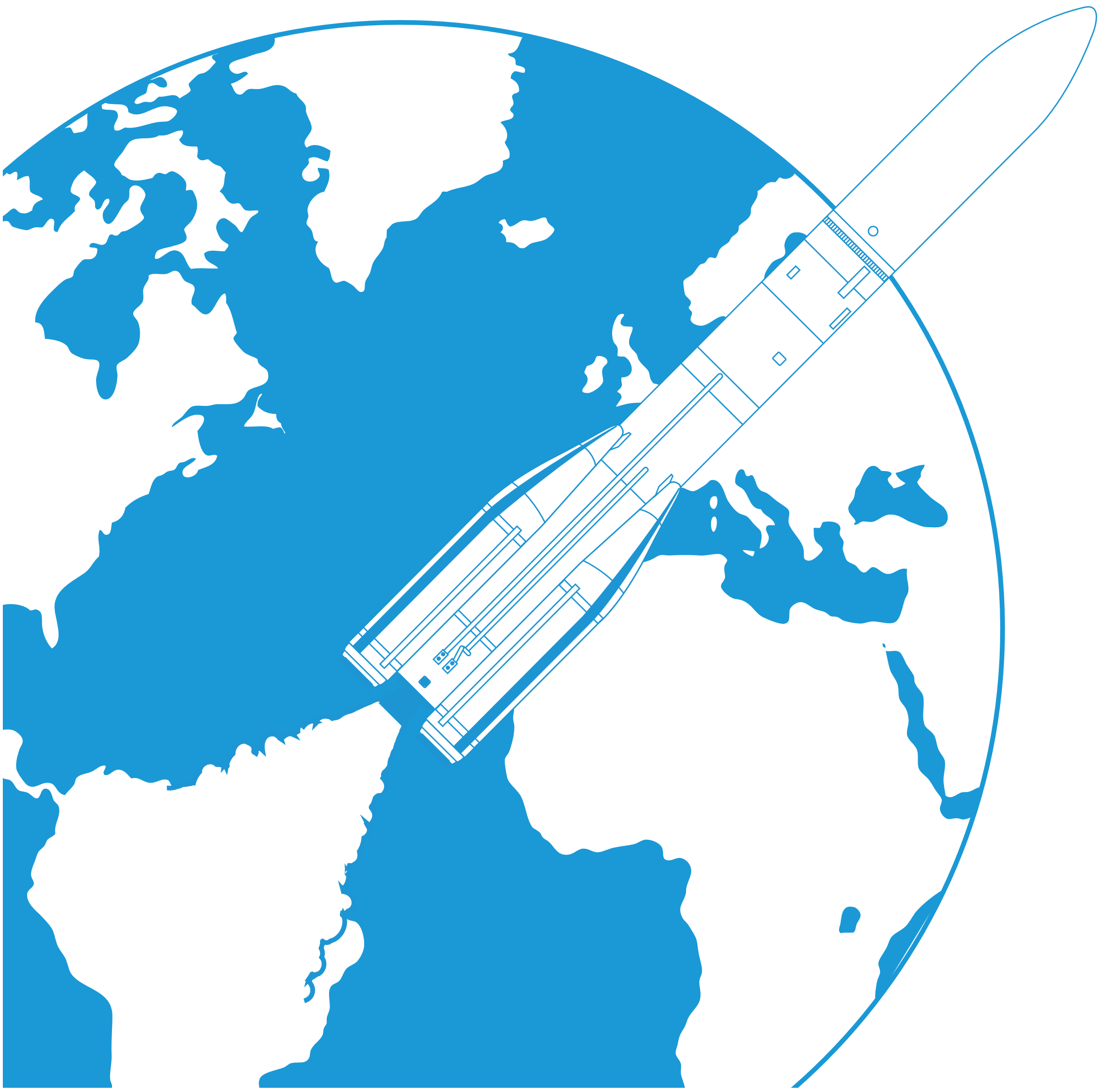
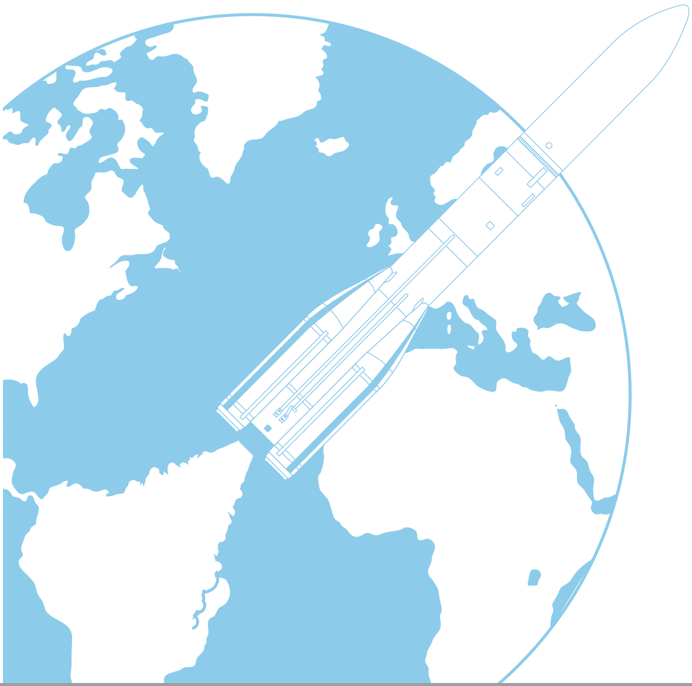
teach with space

→ 3…2…1 LIFT-OFF!

Building your own paper rocket





Teacher Guide

teach with space – 3...2...1 lift-off! | P17
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The ESA Education Office welcomes feedback and comments
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Activity concept developed by ESERO Nordic and ESERO Poland

An ESA Education production

→ 3…2…1 LIFT-OFF!

Building your own paper rocket

Fast facts

Subject: Physics
Age range: 14-16 years old
Type: student activity
Complexity: medium
Lesson time required: 2 hours
Cost: low (5-10 euros)
Location: Indoors and outdoors
Includes the use of: Self build launch system (see Annex 1 + 2)
Keywords: Physics, Rockets, Parabolic motion, Aerodynamics, Centre of mass, Centre of pressure, Escape velocity, Orbital velocity, Velocity, Acceleration

Outline

In this set of 3 activities students will design and build their own paper rockets and launch them. They will learn what it takes in order for a rocket to be stable and they will calculate the rocket's trajectory and velocity. They will learn about the velocity required to leave Earth in a rocket and uncover why the Moon has the potential to be a stepping stone for further space exploration. Lastly, they will calculate the acceleration of their rocket at launch and put this into a context of the G-force experienced by astronauts during launch.

Students will learn

- Learning about the centre of mass and centre of pressure.
- Investigating projectile motion and parabolas.
- Calculating velocity and acceleration.
- Understanding forces.
- Improving scientific thinking and ability to work as a team.

→ Summary of activities

Summary of activities					
	Title	Description	Outcome	Requirements	Time
1	Build your own paper rocket	Design and build a paper rocket.	Learning about rockets, aerodynamics, centre of mass and centre of pressure and what makes a rocket stable.	none	30 minutes
2	Launch your rocket	Launching the rocket, calculating the initial speed as it leaves the launch platform. Relate this to the escape velocity of Earth and the Moon.	Learning about forces, projectile motion, velocity and escape velocity.	Completion of Activity 1. A launch system (Annex 1 or 2). The launch has to be done in an open space, preferably outdoors.	45 minutes
3	Human Spaceflight	Calculate the acceleration of the paper rocket as it blasts off. Relate with the G-force experienced by astronauts.	Learning about acceleration and G-force.	Completion of Activity 2.	45 minutes

➔ Introduction

Space agencies use rockets on a regular basis; to send crews to the International Space Station (ISS), to carry probes that will explore our Solar System, and to launch satellites into orbit around Earth. Rockets vary in size, design and type of fuel they use, all depending on their purpose.

ESA's family of launch vehicles includes the Vega, Vega-C and Ariane 5. A new, more efficient rocket is being developed to launch satellite missions and probes: the Ariane 6 (which will come in the form of Ariane 62 and Ariane 64). These launch vehicles are able to launch a huge range of missions into space - from communication satellites to Solar System missions. Their powerful engines provide the energy needed to escape Earth's gravity.

Figure 1

↑ ESA'S 'Family' of launch vehicles.

ESA launches their rockets from their spaceport located in French Guiana in South America, which is only 500 km north of the equator. The Earth's rotation is fastest at the equator and rockets can profit from the 'slingshot' effect. This increases the rocket's speed by 460 m/s, which saves fuel and money. This location is also ideal for launches into geostationary transfer orbit as few changes have to be made to a satellite's trajectory. Safety is also taken into consideration for launch sites. French Guiana is scarcely populated and 90% of the country is covered by equatorial forests. In addition there is no risk of cyclones or earthquakes. All of these factors make ESA's spaceport an optimal launch site.

Figure 2

↑ Orion with European Service Module

In order to get to the Moon with a crewed mission, we have to launch a powerful rocket! One of the most powerful rockets ever launched was the Saturn V, which took humans to the Moon as part of the Apollo program in the 60s and 70s. Humans have not set foot on the Moon since that time.

NASA's Orion spacecraft in combination with the European Service Module, being developed by ESA, will be launched on a new generation of rockets rockets. They will allow astronauts to reach further into space, beyond the Moon to asteroids and even Mars.

In this set of activities, students will be rocket scientists and design and launch their own rocket to go back to the Moon!

→ Activity 1: Build your own paper rocket

In this activity, students will build a paper rocket. They will find the centre of mass and the centre of pressure and try to make their rockets as aerodynamic as possible. They will test the stability of their rocket and consider which variables in their rocket design will influence the performance of their rocket.

Equipment per group

- Printed student worksheet
- 2 A4 sheets of paper
- Scissors
- Sticky tape
- Plasticine
- Cardboard
- Fins and nose template (optional) – Annex 3

Exercise

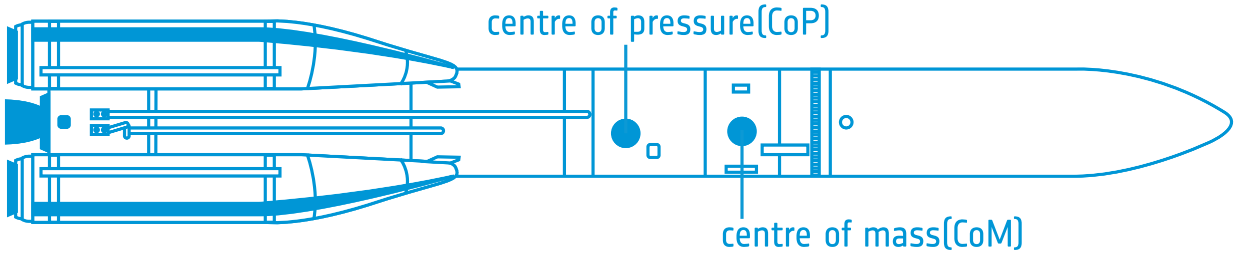
1. Divide the class into groups of up to three students and ask them to build a rocket out of the materials provided. It is important to emphasise that the rocket body has to fit on the launch system you have prepared. The students should be creative with their design of the rocket and decide themselves the size and number of fins. However, in Annex 3, you will find a template for fins and nose-cone as inspiration.

2. Ask the students to find the centre of mass (CoM) of their rockets. The CoM is the average position of all the mass in a system so they can find the point by balancing their rocket using a string. Note: some sources will interchange CoM with "centre of gravity".

3. Ask the students to find the centre of pressure (CoP) of their rocket. The centre of pressure is the geometric centre of the rocket where all of the aerodynamic forces act. If the rocket was homogeneous inside, the CoM and CoP would coincide. We can find the CoP by adding up the individual forces acting on the wings, tail surfaces, drag, etc., but this can be difficult to calculate. A simple way to find an approximate point is by cutting out the silhouette of the rocket in cardboard and balancing it on a ledge. This allows the balance of the projected area to be found.

4. The students should mark both CoM and CoP on their rocket and reflect over the connection between these important points. Ask the students to perform a swing test and evaluate how the position and relation between CoM and CoP affects the stability of their rocket.

5. Example of how the CoM and the CoP should be located in order to have a stable paper rocket.



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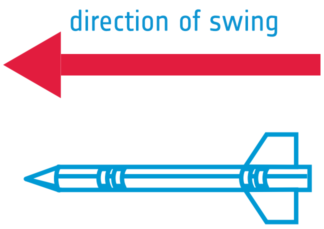
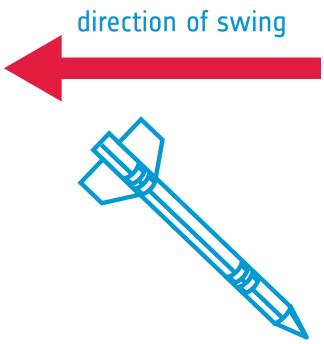
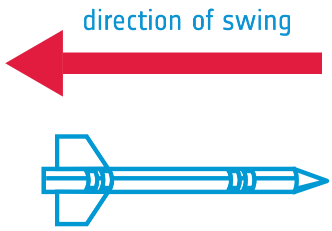


Stable flight, nose forward. CoM is in front of CoP. The example presented would be in this situation, which is the ideal configuration.



Cartwheeling. CoM is too close to CoP



Rocket flying backwards. CoP is in front of CoM

7. In the table are some of the variables that can be changed in the design and launch of the rocket.

Variable	How will changing this variable influence the performance of your rocket?
Number of fins	It will affect the centre of mass, as more weight is added in the back of the rocket. It might also change the location of the centre of pressure if the surface area changes. If the number of fins is asymmetrical, it can also affect the stability and drag.
Size and shape of fins	Bigger fins will move the centre of pressure backwards.
Weather conditions	Different weather conditions will benefit or complicate launches differently depending on the design. For example, a rocket with large fins will be more subjectable to strong winds. Generally paper rockets perform poorly in wind and especially in rain.
Length of the rocket	The length of the rocket will affect the centre of pressure. The rocket can also be so short that the aerodynamic abilities are lost. Or it can be so long that the structure cannot hold itself (since the rocket is made of paper).
Weight of the rocket	The weight distribution of the rocket will determine the centre of mass. A heavy nose-cone will move the CoM forward. This can be done by putting plasticine in the nose cone.

Note: If your class has access to computers, you can download the free rocket simulation tool http://openrocket.info/. In this simulation, the students can play around with the dimensions and design of their rockets, and investigate the relationship between the centre of mass and centre of pressure.

→ Activity 2: Launch your rocket

In this activity the students will uncover that mathematics is an integral part of rocket science. They will learn about forces and have to draw free-body diagrams. Both before and after launch they will have a look at the trajectory of the rocket and do calculations involving velocity.

Equipment

- Printed student worksheet per group
- Launch system (see Annexes 1 and 2)
- Self-build paper rocket
- Long measuring tape
- Protractor (optional)

Health and Safety

Ensure that the launch area is clear of people. Do not aim the rocket at anyone. Eye protection is advisable.

Exercise

When launching the rockets remember to have a lot of space and a flat surface (a football field would work well). If you use the launch platform from Annex 2, the rockets may fly 100 m or more! Instruct the students that the maximum pressure should not be above 7 bar.

Let the students debate at which angle is best to launch. Later in the discussion section you can talk about the optimal angle in order to gain maximum distance. You can have the students all launch at the same angle to compare which team's rocket is best or you can allow the students to trial their rocket, launching them at different angles to find the optimum angle.

You can make the launch a competition and reward the teams with the furthest travelling rockets. We have provided you with a table in Annex 3 to note down how far each rocket went (this information will be needed later).

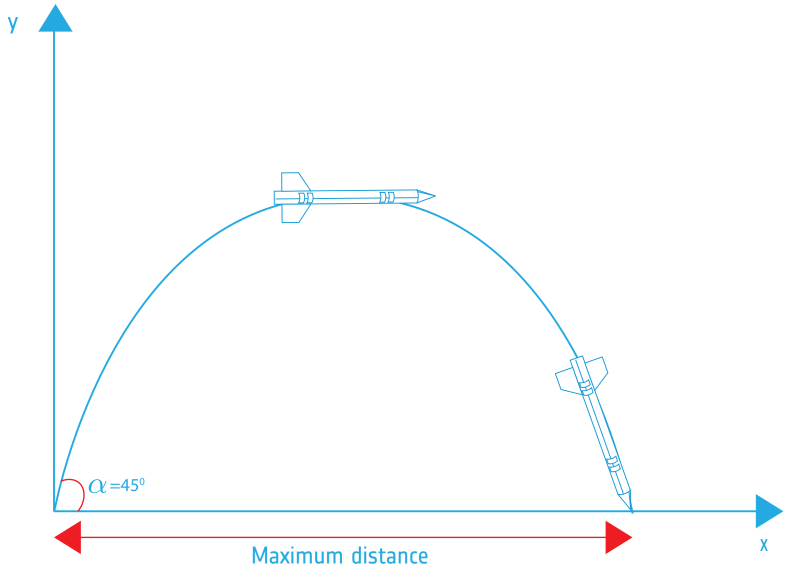
After the launch, talk about how rockets accelerate upwards and why they follow a parabolic path. Introduce Newton's three laws of motion and the force due to gravity. Introduce the concepts of escape velocity and orbital velocity and compare the launch of the paper rockets with launching an actual rocket to the Moon.

Results

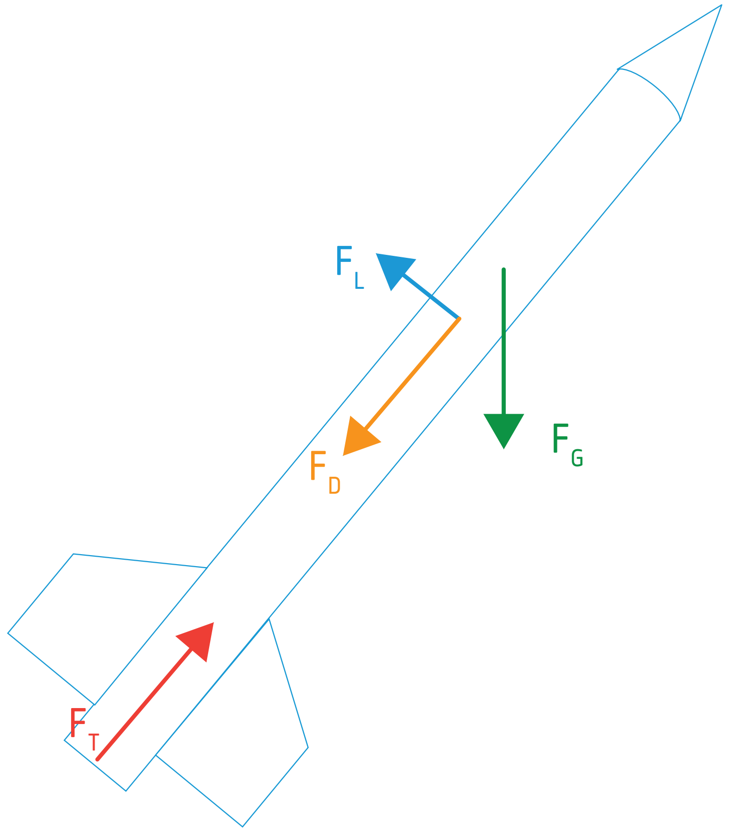
1. Scheme of the trajectory that the rocket will follow.

2. To maximise the distance travelled the launch should be done at an angle of 45°.

4. Possible initial conditions which may impact the trajectory of your rocket.
   - Wind
   - Initial velocity given to the rocket
   - Angle of launch



5. Force diagram showing the forces that act on the rocket shown above in the thrust phase.



F_T = Thrust
The thrust force from the rocket will only work for a very short time during launch, giving the rocket a push. This force is what makes the rocket fly.

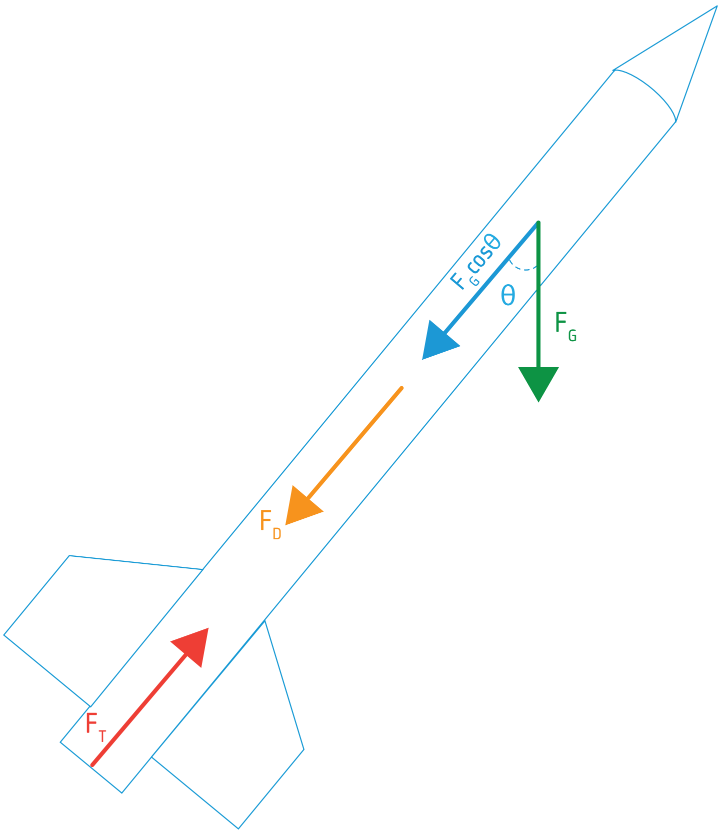
F_G = Gravitational force
The gravitational force will be approximately constant throughout the whole flight.

F_D = Drag force
The drag force is dependent on the density, viscosity and compressibility of the air, as well as the velocity, shape and inclination of the rocket.

F_L = Lift force
The lift force is dependent on the density, viscosity and compressibility of the air, as well as the velocity, shape and inclination of the rocket. For this activity we will consider the lift force negligible.

6.
a. In a real ESA rocket (e.g. Ariane 5) this phase will last a few minutes, whereas in our paper rocket it lasts barely a second.
b. In the direction of motion the resultant of forces, F, is given by:

$$F=-F_D+F_T-F_G\cos\theta$$



Where F is: F=ma, m is the mass and a is the acceleration.

Where F_T is: F_T=-u_e dm/dt, u_e is the exhaust velocity of the gases with respect to the rocket and dm/dt is the rate of change of the mass of the rocket.

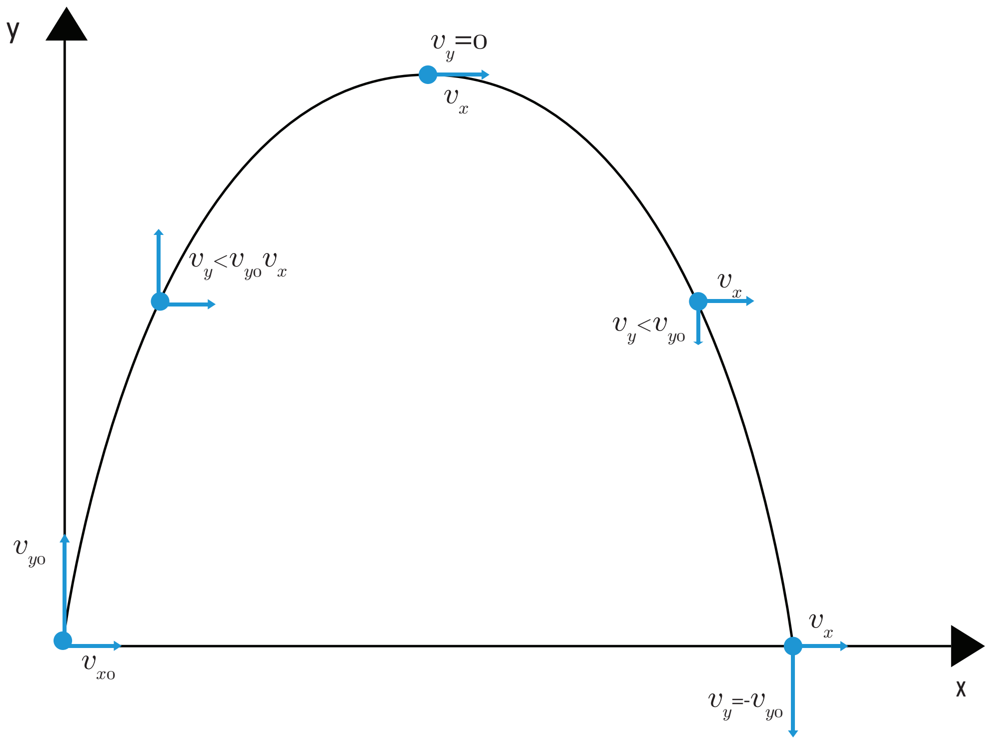
Where $F_G\cos\theta$ is the force due to gravity in the direction of motion of the rocket. F_G=mg, m is the mass and g is the gravitational acceleration and is the angle between the direction of motion of the rocket and direction of F_G.

Where F_D is the drag force.

c. Substituting these terms and dividing by *m* we get the acceleration:

$$a = -\frac{F_D}{m} - \frac{u_e}{m}\frac{dm}{dt} - g\cos(\theta)$$

7. a. Graph with the horizontal and vertical velocity components. Students are encouraged to consider the forces acting on the rocket at each point and why that results in the parabolic motion we see.



7. b. The rocket is quickly accelerated during the thrust phase while on the launch pad. Once the rocket leaves the launch pad there is no longer any thrust. Ignoring drag, this means that there is no force working on the rocket in the x-axis, so from Newton's first law the x-velocity component (v_x) is constant. In the y-axis, we have the gravitational force working on the rocket in the direction of the centre of the Earth (perpendicular to the surface), hence the y-velocity component (v_y) will change.

8. Isolating velocity in the equation:

$$v=\sqrt{\frac{d\,g}{\sin(2\alpha)}}$$

9. Using a distance **d = 40 m**, angle α=**45°**:

$$v=\sqrt{\frac{40\times 9.81}{\sin(2\times 45^{o})}}$$

$$v=\sqrt{\frac{392.40}{1}}=19.81\,m/s$$

10.

$$v=\left(\frac{19.81}{1000}\right)\times 60\times 60=71.3\ \ km/h$$

11. Escape velocity of Earth can be calculated like below:

$$v_e=\sqrt{\frac{2\times 6.67\times 10^{-11}\times 5.97\times 10^{24}}{6.371\times 10^{6}}}=1.12\times 10^{4}m/s=4.03\times 10^{4}km/h$$

12. Velocity required to put a spacecraft in orbit around the Earth at 300 km above the Earth's surface.

$$v_{orbital}=\sqrt{\frac{6.67\times 10^{-11}*5.97\times 10^{24}}{6.371\times 10^{6}+3.00\times 10^{5}}}=7.73\times 10^{3}\ m/s=2.78\times 10^{4}km/h$$

Where r is the orbit radius (from centre of the Earth) so 6371 km + 300 km.

13. Comparing to the example in question 9 this is $2.78\times 10^4/71.3$ = 390 times faster than the velocity of the self-built rocket

14. The escape velocity from the Moon is much smaller, as the Moon has considerably less mass for its radius, when compared to Earth.

15. The escape velocity of the Moon can be calculated like below:

$$v_e=\sqrt{\frac{2\times 6.67\times 10^{-11}\times 7.35\times 10^{22}}{1.737\times 10^{6}}}=2.38\times 10^{3}m/s=8.57\times 10^{3}km/h$$

16. Because the escape velocity of the Moon is lower it needs much less energy (and thereby fuel) to launch a spacecraft from the Moon, making it easier to launch big payloads from the surface of the Moon.

Discussion

Summarise the results in class. What did each group do to make their rocket go further? Did it work? Why or why not?

Ask the students why it could be useful to launch rockets from the Moon, when going further into space – like Mars? Help them understand that since both the orbital velocity and the escape velocity are so much smaller on the Moon, than on Earth, we would need less fuel, meaning it would cost much less to launch. You can also discuss why rockets are launched from locations near the equator using the information in the introduction.

Talk about the simplifications and assumptions that you made in the calculations. For example, we did not take into account any deceleration due to drag force. The drag force will increase as the velocity increases. Discuss when and where they think the drag force will have most effect on the rocket. The required escape and orbital velocity is higher on Earth than what was calculated. Talk about how this is another benefit on the Moon, since there is no atmosphere there is no air resistance and so it is easier to escape.

→ Activity 3: Human spaceflight

In this activity, students will learn about acceleration, forces and G-force. They will explore why there needs to be some extra precautions when launching manned rockets.

Exercise

Start the activity by asking the class how rockets accelerate upwards. This is an excellent opportunity to talk about Newton's three laws of motion and the force due to gravity.

Results

1. Rearranging for time (**t**) in equations (1) and (2) and equating gives:

$$\frac{2s}{u+v} = \frac{v-u}{a}$$

Then rearranging for **a** gives:

$$a = \frac{v^2 - u^2}{2s}$$

2. The initial velocity of the rocket is u = 0 m/s. If we use the launch velocity calculated in Activity 2, question 9, then we will get:

$$a = \frac{19.81^2 - 0^2}{2 \times 0.3} = \frac{392.4}{0.6} = 654\, m/s^2$$

3. The students are asked to calculate the G-force of the rocket at launch. A G-force is not a force, but rather a ratio of the total acceleration acting upon an object to the acceleration due to the gravity of the Earth. Using the answer above, we get:

$$G_{force} = \frac{654}{9.81} = 67$$

This is equivalent to 67 times the force due to Earth's gravity.

Discussion

Discuss in class why they think that an astronaut usually does not experience more than 3 to 6 G's while the number is so high for their rocket?

A human cannot tolerate a G-force as high as 67 G in real life. How much G force a human can sustain also depends on how long they are exposed to the forces: from a few seconds to minutes. Remind the students that this depends on the **acceleration** not the velocity. The acceleration is the change of velocity per time. For a crewed mission, the acceleration is smaller and the spacecraft takes a lot longer to reach the required velocity.

On completion of the three activities you can ask the students to write an individual report on their experiment. They should use the knowledge they have gained during these activities and evaluate how it went and what improvements could be made if they were to do them again.

→ 3...2...1 LIFT-OFF!

Building your own paper rocket

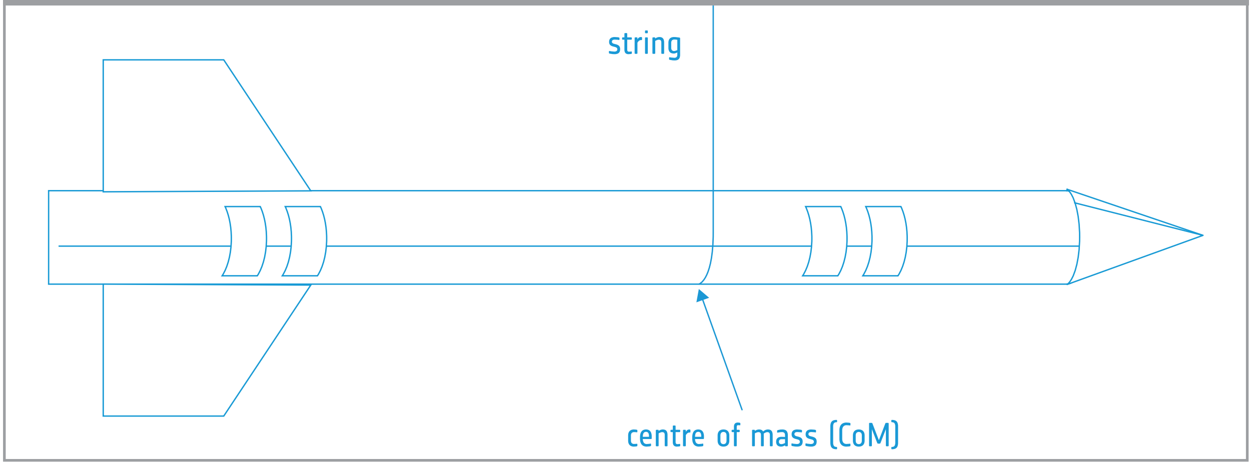
→ Activity 1: Build your own paper rocket

The basic principles behind rocketry are the same for a simple paper rocket as for space rockets. In this activity, you will design and build your own paper rocket and use it to investigate some of the variables in the design that may affect the stability and performance of your rocket.

Exercise

1. Build a paper rocket using the equipment provided by your teacher. You can build your rocket anyway you like, but be sure that it fits on the launch system that you will use.
2. Find the centre of mass (CoM) of your rocket. This is the point representing the mean position of the mass in a body or system. You can do this by tying a piece of thread around your rocket and balancing it as shown on the drawing below. Mark where you think the CoM lies with a pencil.

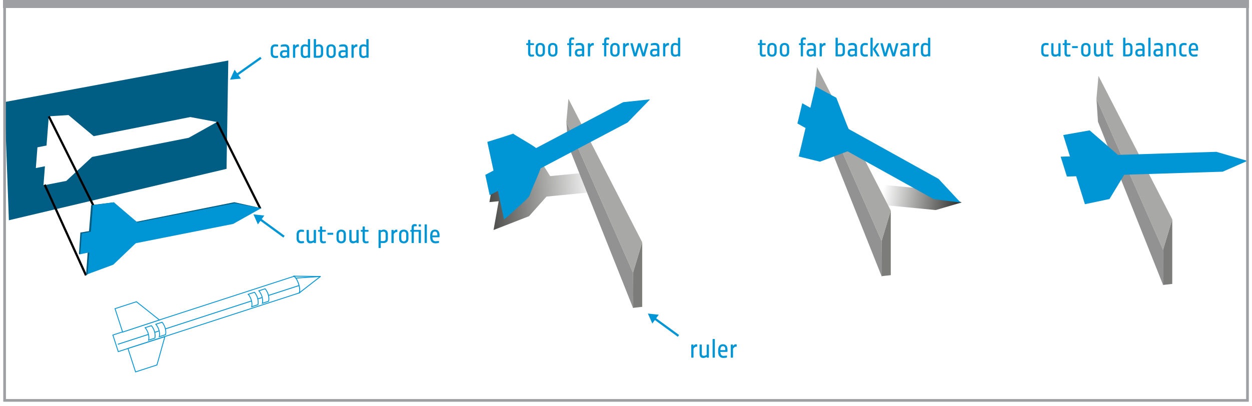
Figure A1



↑ Illustration of how to find the centre of mass of a paper rocket: The rocket is balanced, hanging from a string - the centre of mass (CoM) is where the string is tied.

3. Find the centre of pressure (CoP) of your rocket. This is the average location of the pressure acting on the rocket and, in this case, can be found by locating the balance of the rocket's projected area. You can find the CoP by cutting out a silhouette of your rocket in cardboard and balancing it on an edge. Mark the CoP on your rocket.

Figure A2



↑ Illustration of how to find the centre of pressure of a paper rocket. A silhouette of the rocket is cut out in cardboard. The centre of pressure is found where the cardboard silhouette is balanced on a ruler.

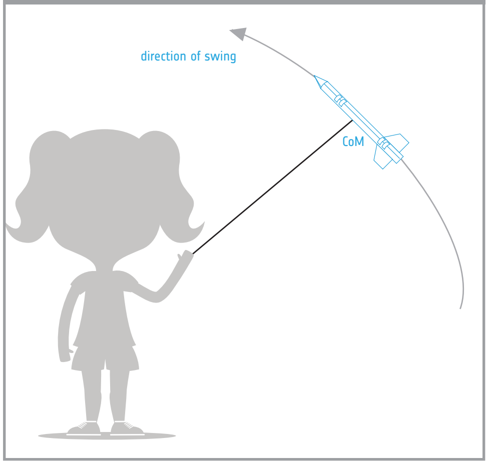
4. What is the distance between the centre of mass and the centre of pressure? __________ cm

5. Is the centre of pressure in front of the centre of mass? Yes / No

6. You can simulate a wind tunnel test by performing a swing test: Tie a piece of string to the centre of mass and swing the rocket around in a circle like on the illustration below:

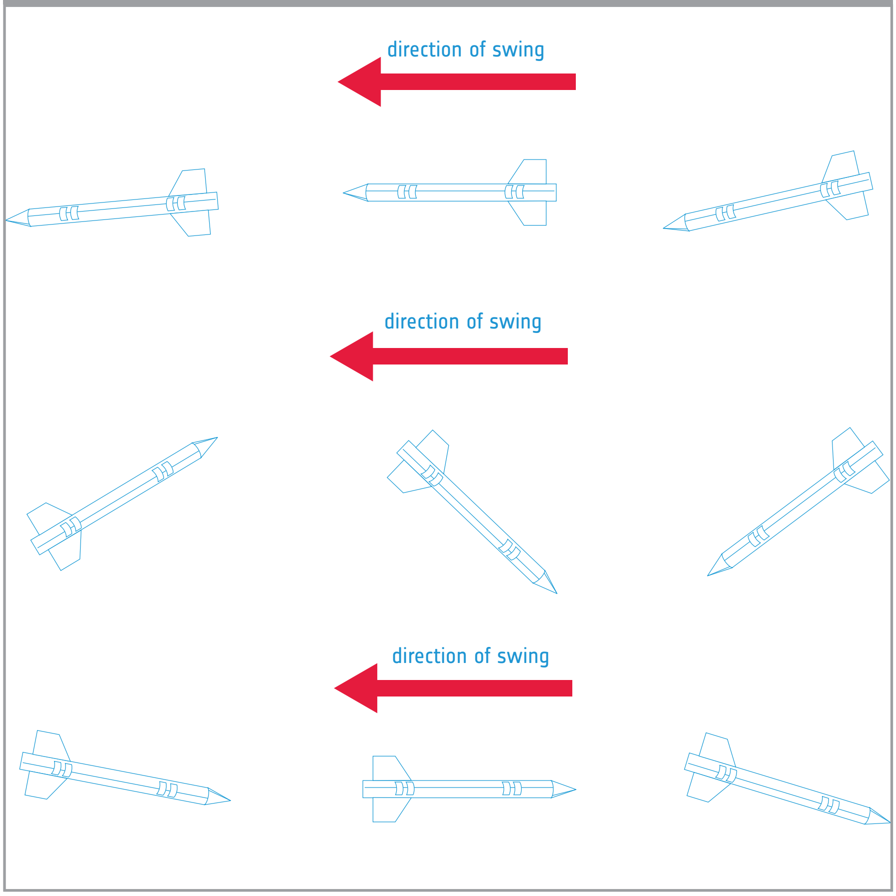
Analyse the stability of your rocket and the rockets of your classmates and try to play around with the centre of mass by putting some weight in the nose cone or in the back. What do you think the relative position of the centre of mass (CoM) is in relation to the centre of pressure (CoP) in the three examples below?

Figure A3



↑ Ilustration of swing test.The string is tied to the centre of mass and the rocket is swung around.

Figure A4



↑ Ilustration of possible behaviors of the paper rocket during the swing test.

Relative position of CoM to CoP:

___

___

___

Relative position of CoM to CoP:

___

___

___

Relative position of CoM to CoP:

___

___

___

7. Was your rocket aligned with the direction of travel throughout the swing test? If not, what do you think you should change?

8. Add more variables to the table and consider how you can change the variable in order for your rocket to be more stable.

Table A1

Variable	Description
Number of fins	
Size and shape of fins	

↑ Variables in rocket design and their influence on stability.

9. Give your rocket a cool name:

Did you know?

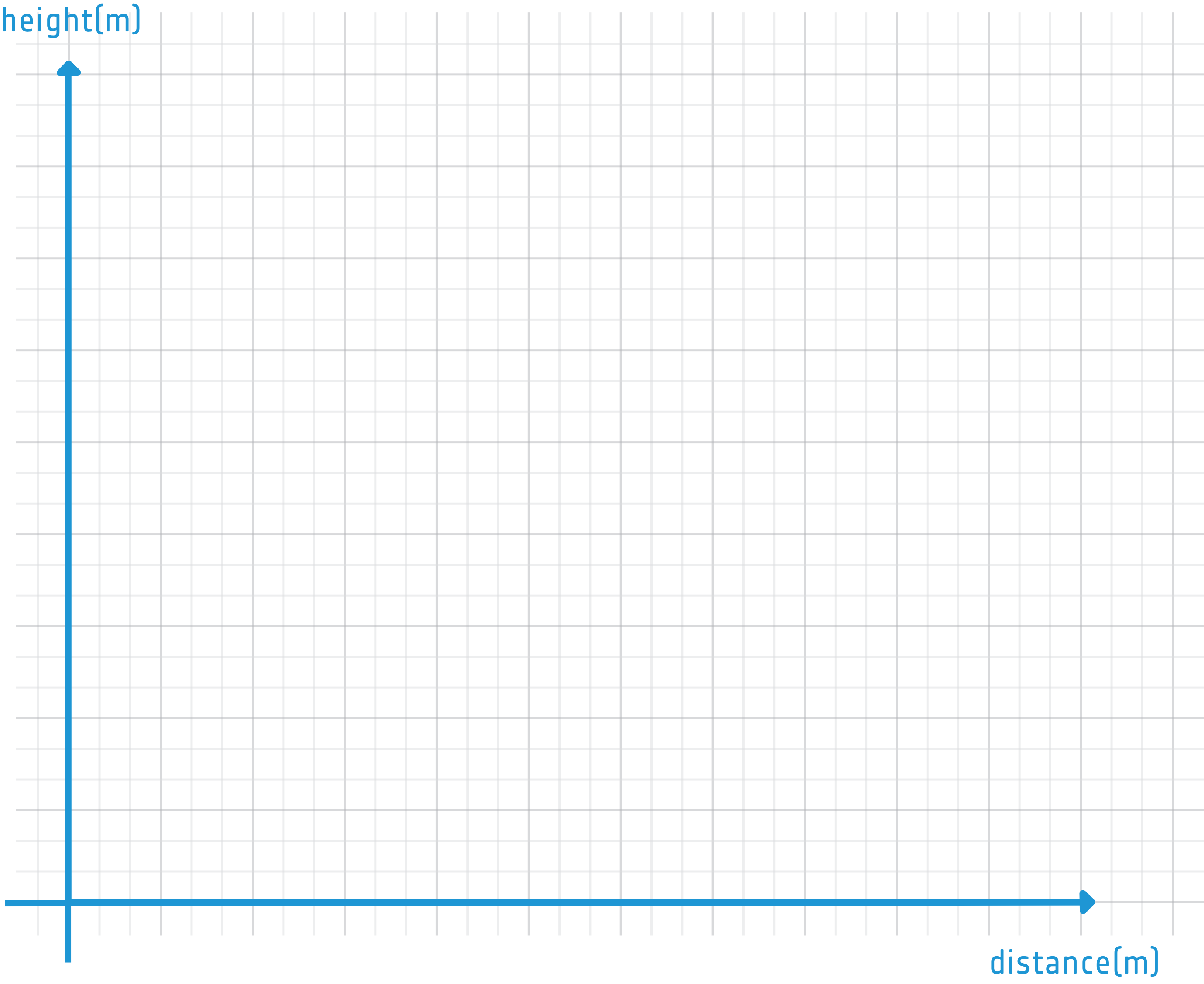
A rocket is divided into multiple smaller rockets (called stages). Each smaller rocket has its own engine and its own fuel reserve. The front of the rocket, called nose fairing, transports the payload, usually satellites or astronauts.

→ Activity 2: Launch your rocket

You are now ready to launch your rocket! A well-built paper rocket can achieve flight distances of 30 m or more! In this activity, you are going to use your results from your rocket launch to calculate its velocity and discover how fast it would have to go in order to go to the Moon.

Exercise

1. Before launching, draw the trajectory that you predict your rocket will follow when you launch it from the ground.



2. At what angle should you launch your rocket with respect to the ground to maximise the distance travelled?

____

3. How far from the launch pad did your rocket land, in meters?

____

4. Did your rocket follow the trajectory that you expected? Yes / No
From your results, identify three possible initial conditions that affected the trajectory of your rocket launch.

a. ____

b. ____

c. ____

5. Draw a force diagram showing the forces that you think would act on a rocket during the powered ascent phase (when propulsion is effective).

6. a. How long do you think the powered ascent phase lasts in a real rocket? And in your paper rocket?

____

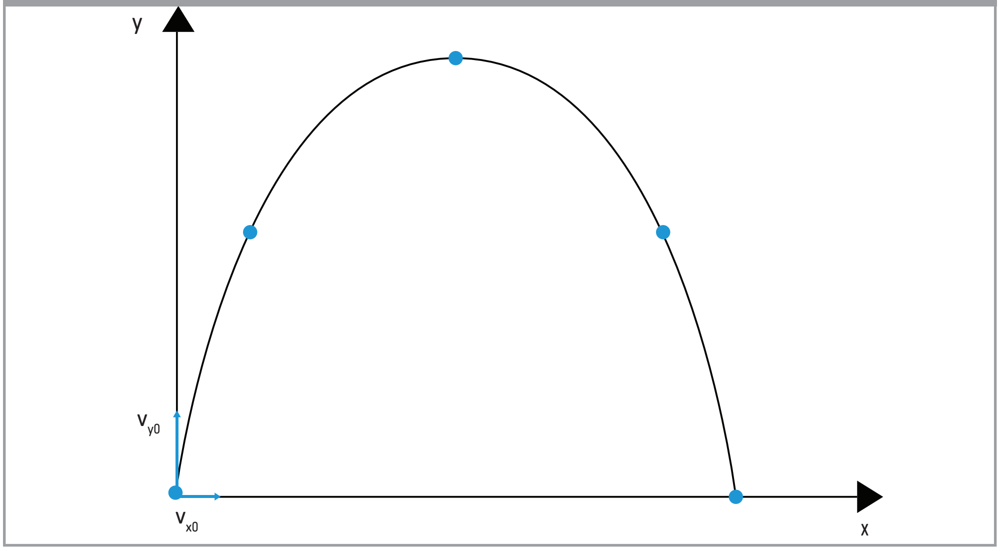
____

b. Write the resultant force equation of the rocket (taking into account only forces in the rocket's direction of motion).

c. Find an expression for the rocket's acceleration.

7. a. Complete the graph with the horizontal velocity component (v_x), and the vertical velocity component (v_y) of the rocket in the points marked on the parabola below. We have helped you by drawing the initial velocity vectors v_{xo} and v_{yo}. You should also consider the forces acting on the rocket throughout the flight and think about why it follows the trajectory it does. We are neglecting the effect of air-resistance (drag) in this question.

Figure A5



↑ Illustration of the parabolic motion of the paper rocket.

b. Describe the variation of velocity on the graph.

8. For an object to follow a parabolic trajectory near Earth's surface (where we can assume the gravitational field to be uniform), it is possible to show that distance, velocity and launch angle depend on each other as follows:

$$d = \frac{v^2 \sin(2\alpha)}{g}$$

where:
d = distance [m]
v = velocity [m/s]
α = angle of launch
g = gravitational acceleration in [m/s²]

Rearrange the above equation for velocity:

9. Use the measurement for your rocket's flight distance (in meters) from the last exercise. Use the equation from question 8 to calculate the velocity as it leaves the launch pad. Use $g=9.81\ m/s^2$.

10. Convert the result to km/h? ____________________________
11. Now that you have the velocity of your rocket, let's investigate how to get to the Moon! You have to reach **escape velocity** which is defined as:

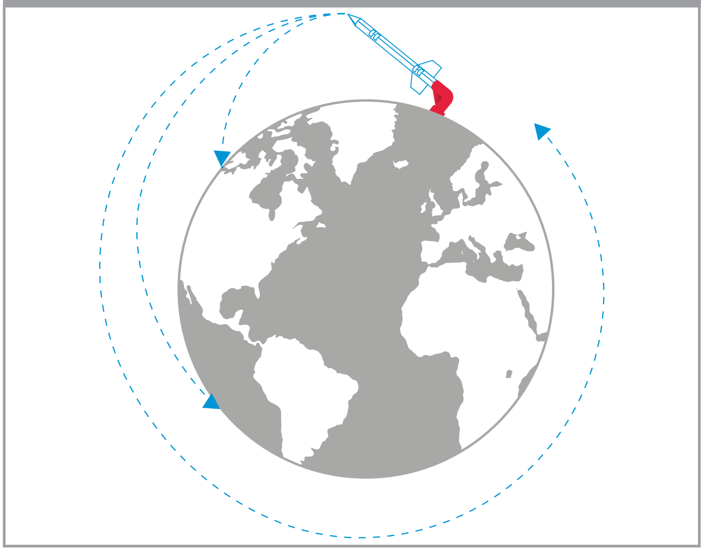
$$v_e = \sqrt{\frac{2GM}{r}}$$

G being the gravitational constant, $G = 6.67 \times 10^{-11}\ m^{-3}\,kg^{-1}\,s^{-2}$,
M being the mass of the Earth, $M = 5.97 \times 10^{24}$ kg,
r being the radius of the Earth, r = 6371 km.

Calculate the escape velocity of Earth.

Because the escape velocity of Earth is high, we currently launch rockets into orbits, before performing manoeuvres to travel further into space. If we launch the rocket straight up, it will quickly fall back to Earth. Instead, we should launch the rocket with a large tangential velocity (velocity parallel to the surface of the Earth).

Figure A6



↑Illustration of launching with a large tangential velocity (velocity parallel to the surface of the Earth). When launching with a high enough velocity, the rocket can reach Earth orbit.

12. The higher the velocity of the rocket the further it gets before falling down to Earth. At some point, we shoot so fast that it never falls back down! It goes into orbit! The velocity required for this to happen is called orbital velocity. Orbital velocity can be calculated with this equation:

$$v=\sqrt{\frac{GM}{r}}$$

G = gravitational constant
r = radius of the orbit (add the radius of Earth to the altitude of the orbit)
M = the mass of Earth

Calculate the velocity we need to put a spacecraft in orbit around the Earth at 300 km above the Earth's surface.

13. How many times more is this than the velocity of your rocket?

14. After landing on the Moon we would like to either return home to Earth, or use the Moon to travel further into space. This requires being able to take off from the Moon. Escape velocity is directly proportional to the mass of the object and inversely proportional to the radius of the object.

$M_{Moon} = 7.35 \times 10^{22}$ kg
$r_{Moon} = 1737$ km

Is the escape velocity of the Moon bigger or smaller than Earth's? ______________

15. Calculate the escape velocity of the Moon:

16. Discuss why it is convenient to use the Moon as a stepping stone for traveling further into space.

____

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Did you know?

Europe's Spaceport is situated in French Guiana in South America, near the equator. The Earth's rotation is fastest at the equator and rockets can profit from the 'slingshot' effect. This increases the rocket's speed by 460 m/s, which saves fuel and money. This location is also ideal for launches into geostationary transfer orbit as few changes have to be made to a satellite's trajectory.

→ Activity 3: Human Spaceflight

In this activity you will explore how acceleration and forces are important for human spaceflight.

Exercise

Let's now further analyse the launch of the paper rocket. In Activity 2, question 9, you calculated the speed, *v*, of the rocket when it leaves the launch pad. Before the launch, the rocket was still on the launch pipe, this means that its initial speed, u, is 0 m/s. We will now estimate the acceleration of the rocket over this very short period of time.

$$(1) \qquad a=\frac{v-u}{t}$$

where

u = initial velocity
v = launch velocity
a = acceleration
t = time

However, it is hard to measure the time it takes for the rocket to leave the pipe.
So we would like to rewrite the equation without including t. We can use the approximation that the distance travelled (s, which in this case corresponds to the length of the launch pipe) equals the average speed multiplied by time:

$$(2) \qquad s=\frac{(u+v)}{2}t$$

1. Use equations (1) and (2) to find an expression for the acceleration, a.

2. Assuming constant acceleration, use the equation to calculate the acceleration of the rocket just before it leaves the launch platform. Consider the length of the 'launch pipe' (s) to be 30 cm and use the velocity calculated in Activity 2 (if you have not calculated a value for velocity use the value 19.81 ms^{-1}).

Did you know?

A G-force is not a force, but rather a ratio of the total acceleration of an object to the acceleration due to the gravity of Earth. Exposure to high G-forces can affect us in different ways. For example, a slap on the face may briefly impose hundreds of G locally and do little damage but constant exposure to 16 G for a minute can be deadly. Usually during launch, astronauts can experience between 3 G and 6 G! They are able to handle such high G forces by training in a centrifuge like the one in the picture.

3. Calculate the G-force an astronaut in your paper rocket would experience during launch. You can do this by dividing the acceleration you calculate in question 2 by $g = 9.81 m/s^2$.

→ Links

ESA resources

Model of a simple launch elbow that can be 3D printed
https://esamultimedia.esa.int/docs/edu/1PBL.zip

Moon Camp Challenge
esa.int/Education/Moon_Camp

Animations about how to get to the Moon
esa.int/Education/Teach_with_the_Moon/Travelling_to_the_Moon

ESA classroom resources
esa.int/Education/Classroom_resources

How rockets work
esa.int/kids/en/learn/Technology/Rockets/How_does_a_rocket_work

ESA missions

Orion
esa.int/Our_Activities/Human_and_Robotic_Exploration/Orion

ESA Launch vehicles
esa.int/Our_Activities/Space_Transportation/Launch_vehicles/Europe_s_launchers

ESA Space Transportation
esa.int/Our_Activities/Space_Transportation

Ariane 6
ariane6.esa.int

Europe's spaceport
blogs.esa.int/spaceport

Extra information

Open rocket, a free rocket simulation tool
http://openrocket.info

To space! But on which rocket?
esa.int/spaceinimages/Images/2019/06/To_space!_But_on_which_rocket

→ Annex 1: Preparing a simple launch system

Use a plastic bottle and a 3D printed launch elbow to build a launch platform that the students can use to launch a paper rocket. You will need to use a 3D printer to print an elbow which attaches the bottle to the rocket. To print this (https://esamultimedia.esa.int/docs/edu/1PBL.zip), you can use either: your own 3D printer; a 3D printer at a MakerSpace (or equivalent); or an online service which can print an object from a file. This elbow can be replaced by a DIY version for example using cardboard or a plastic pipe elbow.

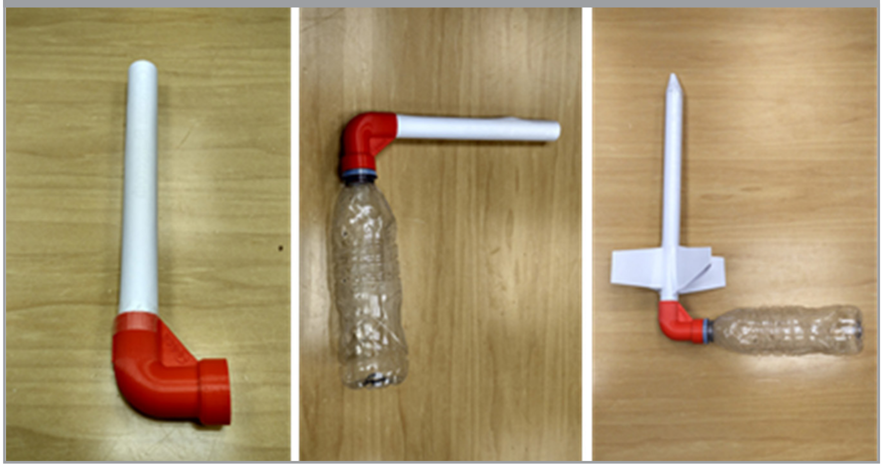
Equipment

- 1 A4 sheet of paper
- 1 3D printed launch elbow
- 1 500ml plastic water bottle

Assemble the simple launch platform

1. Roll up the piece of paper into a tight cylinder.
2. Insert the cylinder into the launch elbow and release it so that it unravels to be the same size as the hole in the launch elbow.
3. Screw the water bottle onto the other side of the launch elbow.
4. Your rocket launch system is ready.

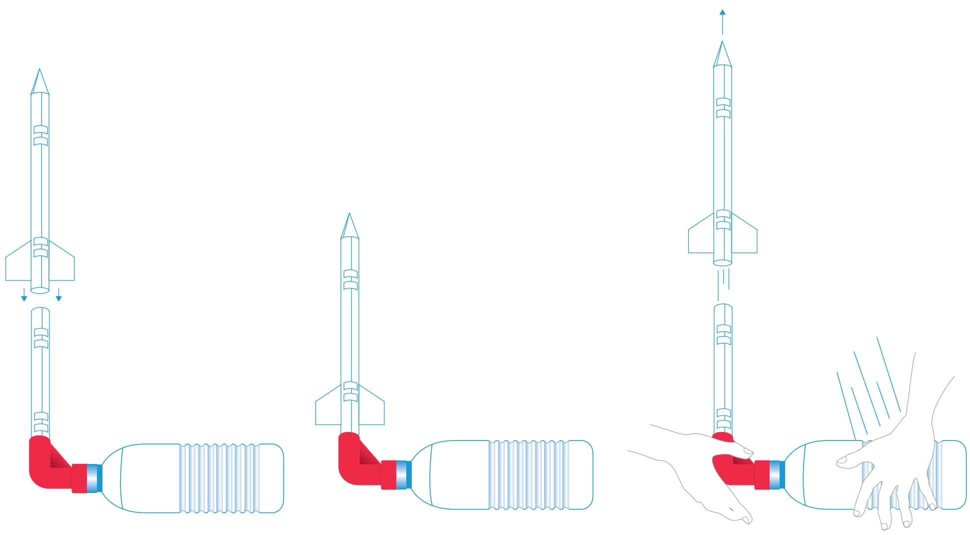
Figure 1



↑ Rocket launch system

Using the launch system

1. Slide your rocket onto the paper pipe connected to the launch elbow.
2. Place the rocket launch system and the rocket on the floor.
3. Step or press hard on the bottle to launch your rocket.



→ Annex 2: Preparing a pressurised launch platform

Instructions for building a compressed-air rocket launch pipe platform.

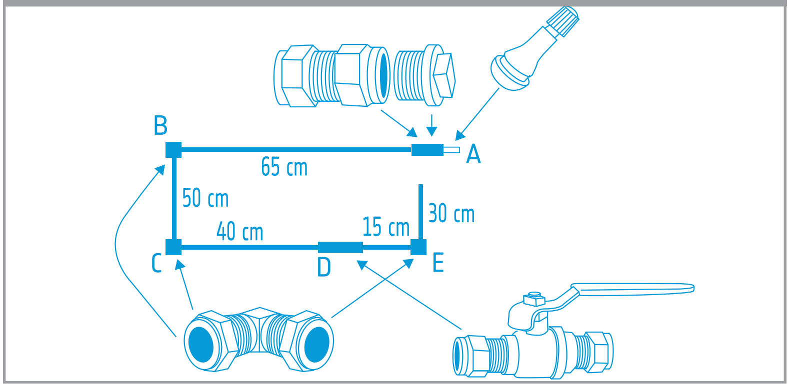
Equipment

- Copper pipes (diameter: 22 mm, lengths: 65 cm, 50 cm, 40 cm, 30 cm, 15 cm)
- 3 angle connectors
- 1 Pipe junction (regular connector on one end and internal connection on the other)
- 1 pipe plug
- 1 ball valve
- 1 air valve
- Air pump or air compressor

Assemble the pressurised launch platform:

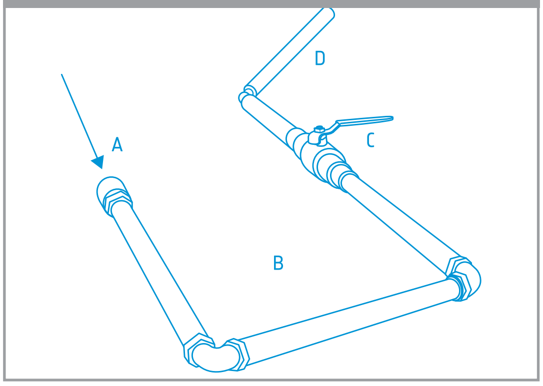
1. Drill a hole in the pipe plug and insert the valve.
2. Connect the valve to the pipe junction.
3. Do not tighten the third angle connector too much as this will allow you to change the angle of the rocket launch pad.
4. Connect the rest of the pipes and pipe junctions as shown below:

Figure 2



↑ Representation of the assembled rocket launch system. A – connection of the straight fitting, plug and tyre valve; B – elbow fitting; C – elbow fitting; D – ball valve, to release the pressure within the launch pad; E – third elbow fitting

Figure 3



↑ Diagram of the assembled rocket launch system.

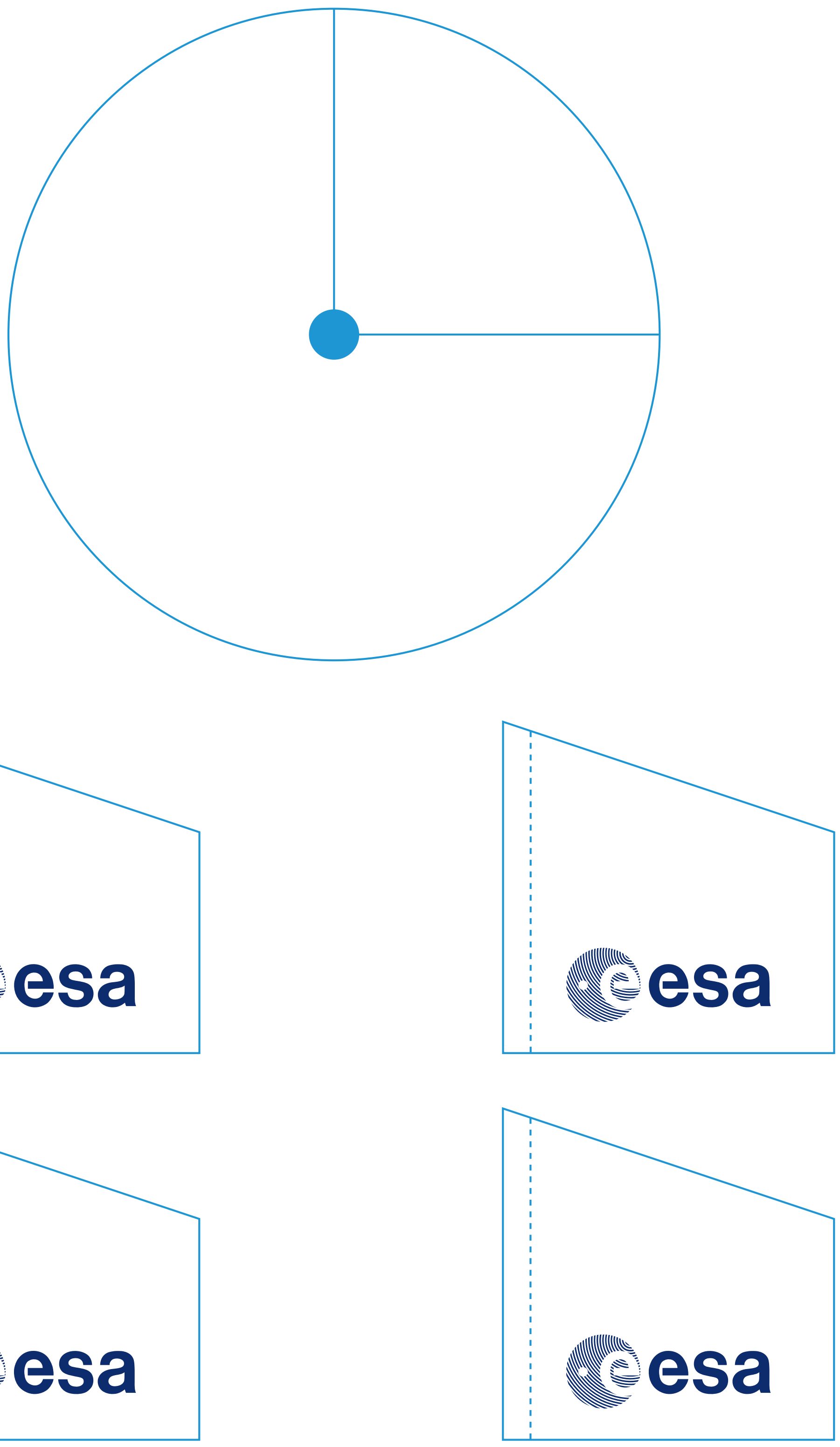
Using the launch system

1. Adjust the angle of the launch pad.
2. Close the valve so no air can escape.
3. Pump the system to a maximum of 7 bar using a bike pump.
4. Open the valve and let the compressed air into the system (this launches the rocket).

Health and Safety

- Check and tighten the pipe connections regularly as they might untighten with use.
- Keep a foot on the launch pad to keep it from moving.
- Make sure no one is standing in front of the launch pad when it is pressurised.
- Maximum pressure on the launch is 7 bar or 101 psi.

➜ Annex 3: Fins and nose cone for Activity 1



→ Annex 4: Table for recording flight distance

Name of Rocket	Launch angle (°)	Distance travelled (m)