Launch of Renu sounding rocket

Image courtesy of Arve Jørgen Tokheim

Sky-high science: building rockets at school

Ever wanted to launch a rocket? **Jan-Erik Rønningen**, **Frida Vestnes**, **Rohan Sheth** and **Maria Råken** from the European Space Camp explain how.

Space science is a fascinating field of study, whether at school or, in our case, at the one-week European Space Camp in Norway (see box on page 39). One hands-on aspect that can be easily introduced in the classroom is rocketry.

Paper rockets are small and relatively simple to construct, and can achieve flight distances of 50 metres or more, enabling students to compete in terms of either height or distance, depending on the space available. Students can also be creative, designing visually appealing rockets or using different types of material. Making a paper rocket is the perfect way to have fun and learn plenty of physics at the same time. Here, we describe a simple rocket that we built and launched during the 2011 European Space Camp.

Building paper rockets enables students to tie together many different concepts in physics – in particular, the equations of motion linking velocity, acceleration, distance and time, as well as the principles of aerodynamics. It also provides an exciting introduction to what it is like to be a scientist: designing a rocket from theoretical principles, carrying out an experiment by launching rockets, and finally analysing the results, drawing conclusions and identifying points for improvement for the future.

Building your rocket

Materials

- Two pieces of A4 paper
- Scissors
- Sticky tape
- Putty or Plasticine®

REVIEW

- Physics
- Space Science
- Maths
- Ages 13-19

Building and launching rockets is definitely a unique experience that students can enjoy with their peers. It is one way of merging old and contemporary science, as it applies standard equations and theories to advanced techniques used for space exploration.

The activity described in the article would definitely create excitement among school students, most of whom would try their best to build the best possible rocket. Before attempting to build their rocket, they should explore and discuss how the shape, dimensions and materials used will affect the range, apogee and time of travel of the rocket. After the activity, a new dimension of discussion, re-modelling and evaluation can be explored, with students discussing their individual results with the whole class and seeing which methods and models worked better and why. Furthermore, they can try to improve their model and re-test their hypotheses.

Some topics, not all of them scientific, can be discussed with the class, before or after the activity, including:

- Human curiosity about our Universe
- Space missions that were successful
- Missions that were less successful
- Justifying the budget involved in some of these missions in view of current economic problems
- Academic, physical and psychological training required by astronauts.

This activity involves a wide range of physics topics ideal for ages 13-16, and also involves physics concepts, equations and mathematics suitable for students aged 16+. The teachers can adapt the calculations involved according to the level of their class. The topics involved are gravitation and escape velocity; stability and centre of gravity; projectile motion; air resistance in relation to mass and shape of rocket; conservation of momentum and energy during launching; and material properties.

Catherine Cutajar, Malta

Procedure

The aim when building the rocket is to minimise drag (air resistance). Drag is mostly dependent on the velocity, but also on the frontal surface area of the rocket and its overall shape – important considerations when designing a rocket.

Rocket body:

1. Roll one piece of paper into a cylinder to form the body of the rocket.
2. Seal one of the open ends of the cylinder with tape, making the front of the rocket. Check that the seal is airtight by blowing into it.

Nosecone:

1. From the other piece of paper, cut out a circle (diameter 7.5 cm), then cut a sector of approximately 90 degrees from the circle.
2. Twist the remaining piece into a cone and place a small ball of putty inside the tip of the cone before fastening the cone to the sealed end of the rocket body with tape.

Fins:

1. Cut four paper triangles of exactly the same size and fold one of the sides of each triangle to form a flap, which will be attached to the rocket.

Students should think about the optimal shape of the fin – some fin profiles will cause the rocket to spin more, others less. Is spin desirable in a rocket?

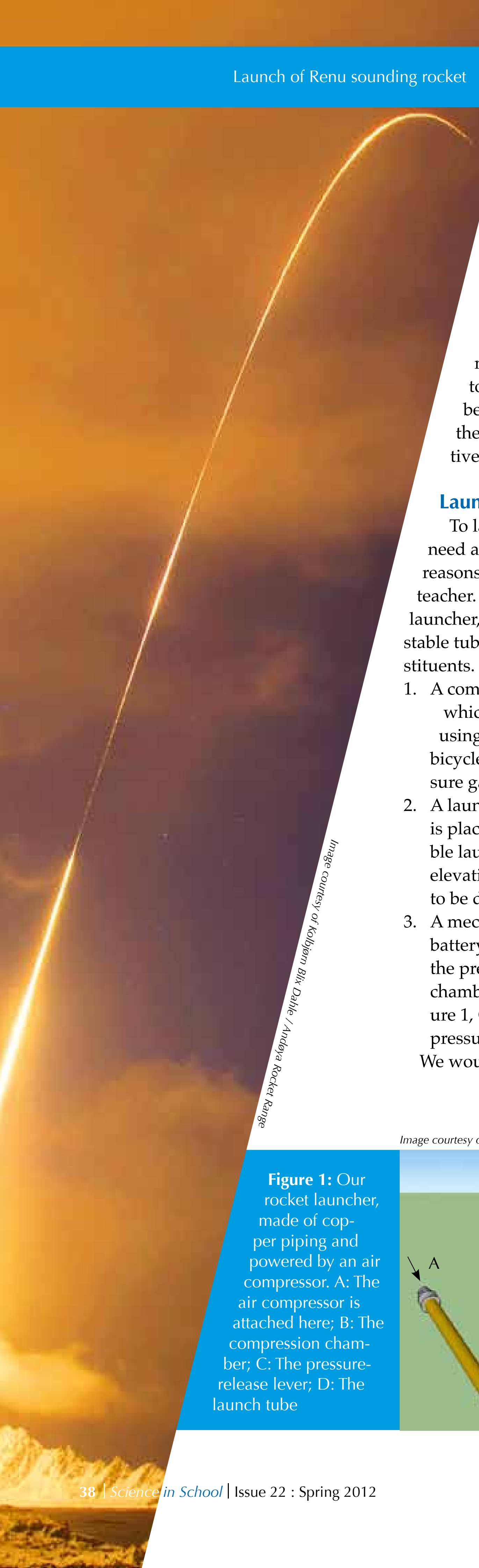
Stability

The stability of a rocket depends on where the centre of gravity and the centre of pressure are in relation to each other. For a stable rocket, the centre of gravity should be in front of the centre of pressure at all times. Simply put, the centre of pressure is where the sum of all drag forces acts.

If the centre of pressure is in front of the centre of gravity, a turning moment will occur, causing the rocket to flip over in mid-flight. This is why

Image courtesy of the European Space Camp

Forming the nosecone



Launch of Renu sounding rocket

Image courtesy of Kolbjørn Blix Dahle / Andøya Rocket Range

ballast is usually applied to the nosecone.

If the relative distance between the centre of gravity and centre of pressure is too large, either because too much mass has been applied to the front of the rocket or because the fins are oversized, the rocket will be more sensitive to wind.

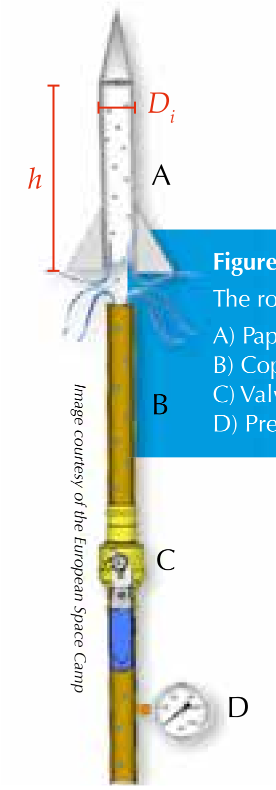


Image courtesy of the European Space Camp

Figure 2: The rocket launcher
A) Paper rocket
B) Copper tube
C) Valve
D) Pressure gauge

Launching the rocket

To launch the rocket, you will need a launcher, which for safety reasons should be built by the teacher. There are many types of launcher, but all are essentially a stable tube with the same three constituents.

1. A compression chamber in which the air is pressurised, using either a compressor or a bicycle pump with a built-in pressure gauge (Figure 1, A+B).
2. A launch tube on which the rocket is placed (Figure 1, D). An adjustable launch tube allows the angle of elevation of the rocket at take-off to be determined.
3. A mechanism (e.g. a lever or a battery-powered valve) to release the pressure from the compression chamber into the launch tube (Figure 1, C). The sudden release of pressurised air launches the rocket.

We would recommend building a robust launcher out of metal piping, with an adjustable launch tube. This allows reproducible launches, with different angles of elevation. At the European Space Camp, we used a launching system in which air was pumped into a copper pipe system using a low-cost air compressor, a robust and stable system that can be used over and over again. For downloadable instructions, see the *Science in School* website[w1]. A robust launcher can also be built out of PVC, using materials readily available from hardware shops, as described on the NASA website[w2].

When launching your rocket, note that higher air pressure does not necessary lead to better flight performances. This is because aerodynamic drag on the rocket increases with velocity: the rocket's fins may be distorted, increasing drag and reducing performance.

Before deciding on the angle at which to launch their rocket, the students should think about how the angle of elevation affects the total distance travelled and the rocket's apogee (its highest point above the ground).

Image courtesy of the European Space Camp

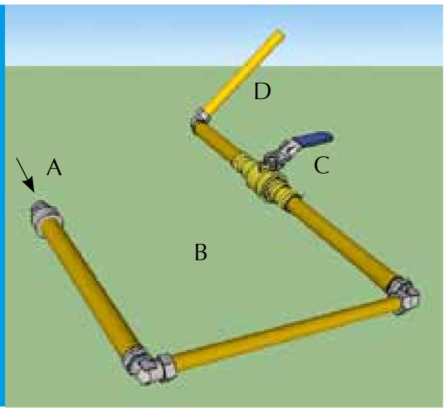


Figure 1: Our rocket launcher, made of copper piping and powered by an air compressor. A: The air compressor is attached here; B: The compression chamber; C: The pressure-release lever; D: The launch tube

Image courtesy of Kolbjørn Blix Dahle / Andøya Rocket Range

Our rocket launcher, made of copper piping and powered by a bicycle pump. A: The compression chamber; B: The pressure-release lever

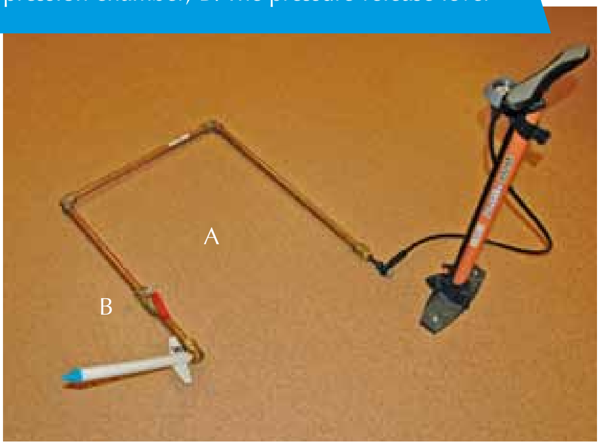


Image courtesy of the European Space Camp

Images courtesy of the European Space Camp

Launching the rocket

Safety

Safety is important when launching rockets. Students should wear safety glasses and stand behind the launcher at all times to avoid being hit by the paper rockets. When using a compressor for the launcher, be sure not to exceed the pressure limit, which could cause parts of the launcher to fall apart or even rupture. The exact limit will depend on the materials you use: the copper launcher we built at the European Space Camp[w1] could withstand more than 8.3 bar (120 psi) of pressure; the NASA PVC launcher[w2] is limited to 2.0 bar (30 psi).

Follow-up

After the launch, the students can analyse the rocket's trajectory to calculate the maximum height (apogee) attained by the rocket and also its initial velocity. To perform the trajectory analysis, some measurements need to be taken before the launch (see Figure 2):

- Length of the rocket body (h, in m)
- Inner diameter of the launch tube (D_i, in m)
- Pressure within the launcher (P, in Pascal) before launch while the valve is closed; this can be read off the foot pump or the compressor, and converted from psi or bar into Pascal. (The pressure is assumed to be constant across the length of the tube.)
- Mass of the rocket (m_r, in kg)
- Angle of elevation (θ, in degrees; Figure 3, page 40).

BACKGROUND

The European Space Camp

The European Space Camp focuses on topics important in the space industry, motivating and inspiring young students by showing them how theoretical ideas can be put into practice.

During the one-week camp at the Andøya Rocket Range in Norway, the northernmost permanent launch facility in the world, 24 students aged 17-20 are treated as real rocket scientists, using professional equipment and solving advanced problems in international teams.

Each team addresses a different aspect of rocketry such as system design, experimental instrumentation, payload assembly or telemetry, all working towards the launch of a 'sounding rocket' to carry instruments. Participants also receive lectures from some of Europe's best scientists, on topics ranging from rocket physics to the Northern Lights. Some of the lectures are supplemented by fascinating hands-on activities, such as building the paper rocket described in this article.

Students interested in applying to participate in the 2012 camp (24 June – 2 July 2012) should visit the website[w3] or email contact@spacecamp.no.

A successful flight

1. The first step is to calculate the initial velocity (ν_0) of the rocket. This is equal to the acceleration (a) of the rocket multiplied by the time (t_0) for which the force was acting on it:

$$\nu_0 = a \cdot t_0 \qquad (1)$$

2. The force acting on the rocket can be calculated using two equations. A_i is the cross-sectional area of the rocket body.

$$F = P \cdot A_i = P \cdot \frac{\pi \cdot D_i^2}{4} \qquad (2)$$

$$F = m_r \cdot a \qquad (3)$$

3. The acceleration of the rocket can be expressed by combining these two equations:

$$a = \frac{P \cdot \frac{\pi \cdot D_i^2}{4}}{m_r} \qquad (4)$$

4. By time t_0, the rocket has travelled a distance equal to the length of the rocket body (h), and this length can be expressed by:

$$h = ½\, a \cdot t_0^2 \qquad (5)$$

5. To find an expression for t_0, Equation 5 can be rearranged:

$$t_0^2 = \frac{2h}{a} \quad <\!-\!> \quad t_0 = \sqrt{\frac{2h}{a}} \qquad (6)$$

The rocket's initial velocity (ν_0) can now be expressed in terms of known variables, by inserting the expressions for the time t_0 (Equation 6) and acceleration a (Equation 4) into the equation for initial velocity (Equation 1):

$$\nu_0 = \frac{P \cdot \frac{\pi \cdot D_i^2}{4}}{m_r} \cdot \sqrt{\frac{2h}{\frac{P \cdot \frac{\pi \cdot D_i^2}{4}}{m_r}}} \quad <\!-\!> \quad \nu_0 = \sqrt{\frac{2h \cdot P \cdot \frac{\pi \cdot D_i^2}{4}}{m_r^4}} \qquad (7)$$

We assume that the rocket has a parabolic flight path, and this allows us to calculate the equation for the trajectory of the rocket.

1. By decomposing the initial velocity vector ν_0 into the x and y directions, the distance travelled by the rocket in these directions will then be:

$$x = \nu_0 \cos(\theta) \cdot t \qquad (8)$$

$$y = \nu_0 \sin(\theta) \cdot t - ½ g t^2 \qquad (9)$$

where g is the gravitational constant.

2. From the equation for the distance travelled in the x direction (Equation 8), an expression of the time t can be inserted into the equation for the distance travelled in the y direction (Equation 9), and this gives us the equation for the trajectory of the rocket:

$$t = \frac{x}{v_0 \cos(\theta)}$$

$$y(x) = v_0 \sin(\theta) \frac{x}{v_0 \cos(\theta)} - \frac{1}{2} g \left[\frac{x}{v_0 \cos(\theta)}\right]^2$$

$$\rightarrow y(x) = v_0 \tan(\theta) - \frac{1}{2} g \left[\frac{x}{v_0 \cos(\theta)}\right]^2$$

3. The apogee of the rocket (H) can then be calculated by:

$$H = \frac{v_0^2}{2 \cdot g} \cdot \sin^2(\theta)$$

Each rocket will probably be able to be launched only once, as the nosecones are usually damaged on landing. However, if the rockets are still intact, the students can carry out repeat experiments and perhaps vary the launch angle.

On the basis of their results, the students could discuss the following questions:

1. How does the weight of the rocket affect the height and distance it travels?
2. Why does wind affect the performance of the paper rocket?
3. What would happen if you placed the fins near the nosecone?
4. Where should the launcher be pointed in relation to the wind direction?

Image courtesy of the European Space Camp

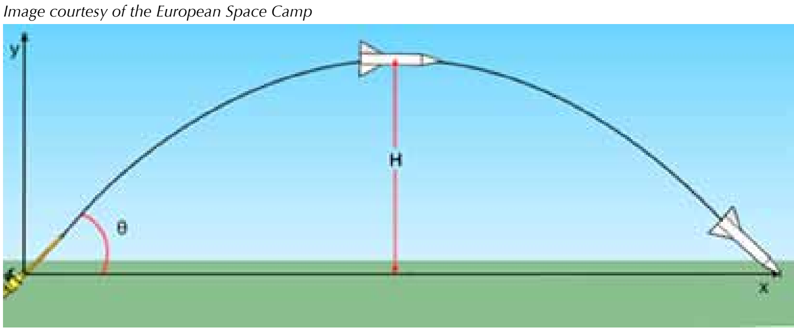


Figure 3: The flight path of the rocket

Web references

w1 – For instructions for building our rocket launcher, see the *Science in School* website: www.scienceinschool.org/2012/issue22/rockets#resources

w2 – Instructions for building a rocket launcher from PVC piping can be downloaded from the NASA website (www.nasa.gov – search for 'High-Power Paper Rocket Launcher Directions') or via the direct link: http://tinyurl.com/7lydxuc

The instructions are part of the NASA rockets educator guide, which offers many more activities for the classroom. See www.nasa.gov or use the direct link: http://tinyurl.com/yx2et6

w3 – To find out more about the European Space Camp and how to apply, see http://www.spacecamp.no

Resources

The US magazine *Make* offers downloadable instructions for building a PVC rocket launcher and paper rocket (http://blog.makezine.com; 'weekend project: compressed air rocket') or use the direct link: http://tinyurl.com/7twlba6

There's also a video showing how to build the launcher on YouTube: www.youtube.com/watch?v=eNFfK5uo6D0

You can even buy a kit with all the pieces you need (though note that the materials are all US standard, so may not be compatible with European parts). See: www.makershed.com or use the direct link: http://tinyurl.com/75vdss4

For instructions in English and Norwegian for building a water rocket, see the website of Sarepta, Using Space in Education (www.sarepta.org), or use the direct link: http://tinyurl.com/7kl7q5q

If you are interested in lessons to take you even further into space, find out how to build a space habitat in the classroom. See:

Tranfield E (2011) Building a space habitat in the classroom. *Science in School* **19**: 43-49. www.scienceinschool.org/2011/issue19/habitat

To find out how to build a CO_2-powered rocket, see:

Rau M (2011) Fizzy fun: CO_2 in primary chool science. *Science in School* **20**: 24-29. www.scienceinschool.org/2011/issue20/co2

For further space-related inspiration, why not browse the other space science articles in *Science in School*? See: www.scienceinschool.org/space

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Jan-Erik Rønningen is a propulsion engineer at Nammo Raufoss and is the leader of the rocket system design group at the European Space Camp. He has worked in the missile products division of Nammo Raufoss since 1997, developing new rocket technology and improving existing hybrid rocket technology. At the European Space Camp, he is the foremost expert on rockets and how they function.

Rohan Sheth is a third-year student at Imperial College London, UK, studying towards a master's degree in mathematics, and is currently spending a year as an Erasmus exchange student at the Humboldt University in Berlin, Germany. He is the British representative at Team Space Camp, which organises the European Space Camp together with the Norwegian Centre for Space Related Education (NAROM).

Frida Vestnes is a first-year student at the Norwegian University of Science and Technology, studying for a master's degree in mechanical engineering. She is the head of Team Space Camp.

Maria Råken is a first-year student at the University of Oslo, Norway, taking a one-year programme in science before starting a master's degree in chemistry at the Norwegian University of Science and Technology. She is a member of the Team Space Camp.

To learn how to use this code, see page 57.

Image courtesy of the European Space Camp