Dodging bullets

Hypervelocity and the ISS

An AstroPi resource for secondary school teachers.
Introduction

Missiles, bullets, planes... when objects collide on earth at high speed, the effects can be damaging and life-threatening. These collisions happen at a fraction of the speeds reached by objects in space, however, as there is no air resistance to slow things down.

A collision involving the International Space Station could spell disaster – it is hoped the two permanent ‘lifeboats’ attached to the ISS are never needed!

This Astro-Pi resource looks at motion in this exciting context, and is targeted at students in the lower-to-middle years of secondary school.

How to use this guide:

This teacher guide, and the resources that accompany it, can be used in different ways:

1. Following the activities in sequence will cover all the curriculum links listed below. This might be done as part of a collapsed timetable day, or over a series of sessions. This would give a thorough preparation for meeting the challenges and entering the competition, regardless of prior learning.
2. Teachers can pick and choose which activities, resources and links to use and when – they can be used independently of each other. This might enhance the ways in which space and magnetism topics are currently taught. If teachers have specific challenges in mind that align with their interests and those of the children, the supporting learning activities might be selectively chosen.
3. Teachers may wish to present students, in class or as part of an extra-curricular activity, with the challenges only. Please note – the challenges are merely suggestions, and schools are completely free to use the AstroPi in any way they see fit to enter the competition.

Other information accompanying this guide available at Astro-Pi.org:
- information from the Raspberry Pi foundation, all about the AstroPi and Raspberry Pi,
- information from organisations within UK Space, explaining the importance of several themes of space exploration and technology,
- AstroPi competition details and entry form,
- Competition entry project planning guidance for teachers and students.
Curriculum Links

Science

- processes that involve energy transfer such changing motion

- forces: associated with deforming objects; with rubbing and friction between surfaces, with pushing things out of the way; resistance to motion in air

- speed and the quantitative relationship between average speed, distance and time (speed = distance ÷ time)
  - the representation of a journey on a distance-time graph
  - relative motion: trains and cars passing one another.

- explain the vector-scalar distinction as it applies to displacement, distance, velocity and speed

- explain with examples that motion in a circular orbit involves constant speed but changing velocity (qualitative only)

- calculate speeds, and make and use graphs of these to determine the speeds and accelerations involved

- forces being needed to cause objects to stop or start moving, or to change their speed or direction of motion (qualitative only)
Learning Activities

1. **A review of learning** prior to embarking on deeper coverage of the topic might include:
   - qualitative discussion of the link between acceleration and forces;
   - the idea of balanced and unbalanced forces and the effect on speed or the deformation of materials;
   - Calculations involving average speed, distance and time
   - [This whiteboard resource](#) can be used for starters or reviews of learning relating to distance-time graphs.

2. **Equations and Graphs of Motion**

   [This Bloodhound SSC resource](#) examines high velocity motion and acceleration, featuring velocity-time and acceleration-time graphs. It provides some insight into the accelerations possible with rockets.

   After some challenging preliminary calculations, it is possible for students to construct a distance-time graph showing the distance travelled in a circle of the ISS.
   - Height above the Earth (approx.) = 410km
   - Mean radius of the of the Earth = 6371 km
   - Orbital period = 92 minutes

3. **Projectile and self-propelled motion**

   [This extensive teacher resource](#), complete with student activities, assists with the teaching of projectiles and self-propelled rockets. It links prior learning about forces as vectors, represented by arrows, to equations of motion and distance-time graphs for objects moving under gravity.

4. **Junk with Hypervelocity**

   Space Junk is a term referring to discarded or waste materials in orbit around the Earth. [This resource from the Science Museum](#) gives background information about the dangers threatened by orbiting junk, to satellites and other craft such as the ISS.

   Other objects might move through space with even higher speeds than space junk, such as micrometeoroids. [This ESA micro-site](#) contains in-depth information on space
debris and other projectiles, and [this NASA site](#) explains how shields for spacecraft are tested to protect vital components and people against hypervelocity collisions. Also shown is a globe showing the ‘cloud’ of space debris orbiting the Earth. The larger of these objects (greater than 10cm diameter) are tracked using ground-based radar and the ISS makes avoidance manoeuvres if they are predicted to come too close for comfort.

Students might be asked to research space debris, and include news articles about collisions and incidents, and how spacecraft are protected with Whipple shields.

### 5. Relative motion and high-speed collisions

Relative motion can be introduced using the example of two trains (A, B) in motion on parallel tracks – the trains may be travelling in the same or opposite directions. Calculations of relative velocity should be modelled – from the rest frames of:

- Train A,
- Train B,
- The stationary platform.

Assuming the speed of a piece of space debris is 7.5 km/s, and the ISS moves at around 7.7 km/s, students can be challenged to calculate the maximum (opposite direction of travel) and minimum (same direction of travel) relative speed in a collision.

Answers: minimum = 200 m/s, maximum = 15.2 km/s

Further calculation using micrometeoroid speed of 42 km/s is possible, and using a mass of 1 gram the kinetic energy of the impact can be calculated using $KE = \frac{1}{2} mv^2$

Solution:

$KE = \frac{1}{2} \times 0.001 \times (42 \times 1000)^2$

= 882 KJ

(or approximately 1700 times the energy of a bullet fired from a 9mm pistol)

This energy is converted, upon collision, into heat and energy to distort the material. The projectile is often vaporised – a Whipple shield relies on this, changing the state of the projectile before it hits the actual skin of the ISS. More information is available on [this NASA site](#).
Further Information:

The Astro-Pi primary resource ‘Stay Sharp’ can be adapted for use at secondary level – it includes methods of measuring human reaction times (including the development and use of computer programs) and associates this with distance travelled.

The film Gravity (Certificate 12A) contains some scientifically accurate portrayals of the effect of collisions with high velocity, and can prompt discussion of the dangers of larger projectiles that carry significant momentum.
Orbital boosts and debris avoidance manoeuvres both involve firing of rockets attached to the ISS.

Some of the rocket engines used are permanently attached, and sometimes the engines of visiting spacecraft are used for an extra push.

Can you measure the resulting changes in motion? Speed as well as direction of travel may be affected.

Can information be provided to the astronauts using the Astro-Pi LED screen?

Image: ESA
While the air is extremely thin at altitude of 400km, there are enough gas molecules to slow down the ISS as it orbits.

As it slows down it orbits lower – encountering more gas molecules as the density of air begins to increase.

How might the speed of the ISS be measured using the Astro-Pi? How might a relationship with orbital height be investigated?

Image: ESA
Micrometeoroids collide with the ISS quite regularly – luckily it is well protected.

Can the astronauts tell when a strike has happened?

How can you find out?

Can pictures be taken?

Image: ESA
Astronauts have lots of leisure time on the ISS, and can’t simply go for a walk!

Could you develop an Astro-Pi computer game based on space debris and making use of the screen, buttons and joystick?

It would be great practice for the real manoeuvres that must be made if a large object is found on possible collision course.

Image: ESA