Royal Academy of Engineering

THIS IS ENGINEERING

DRONES: FRIEND OR FOE?

Safe delivery

This resource is based on the idea that drones could be used as delivery vehicles. It looks both theoretically and practically at the engineering involved in creating a safe way to deliver goods and humanitarian aid.

SAFE DELIVERY

Introduction

Companies have already looked into the possibility of using drone technology to deliver goods over short distances. Depending on what was being delivered, the parcel could be dropped from a height while the drone hovers. If this delivery method were to be used, the company would need to make sure the parcel does not get damaged in the fall.

Activity 1 – Calculation

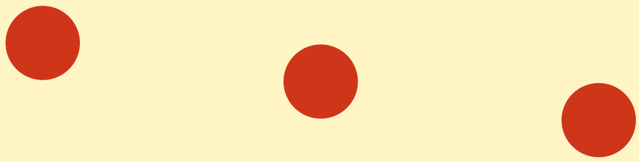
What forces will be acting on the box when it is falling?

A company wants to deliver a parcel weighing 1kg to a customer. They would like to know the impact force on the parcel when it is dropped from flight height (120m), and from door height (approximately 2m).

- In each case what would the impact force be on the parcel when it hits the ground?

Step 1

First you need to use what you know about conservation of energy to work out the kinetic energy of the parcel as it hits the ground. The law of conservation of energy states that energy cannot be created or destroyed, only converted from one form to another; the total energy at the start of the drop is the same as the total energy at end of the drop. Assuming there is no air resistance and no energy is lost as heat or sound, all of the gravitational potential energy (GPE) stored in the parcel at the beginning is converted to kinetic (movement) energy (KE) by the time the parcel hits the floor.



High up	Falling	Just before impact
GPE – maximum	GPE – decreasing	GPE – none
KE – none	KE – increasing	KE – maximum

The equation for gravitational potential energy is:

$$GPE = m \times g \times h$$

Where m = the mass of the parcel (kg)
g = gravitational field strength on Earth (9.8 N/kg)
h = height of the parcel above ground (m)

If all of the GPE is converted to KE then

$$\text{change in kinetic energy} = \text{change in GPE} = m \times g \times h$$

Step 2

The impact force can be calculated by using:

$$\text{impact force (N)} = \frac{\text{change in kinetic energy (J)}}{\text{distance travelled through impact (m)}}$$

For this we will assume that the parcel has fallen into mud and has sunk into the ground by 1cm. This is the distance travelled during the impact.

Where would it be best to drop the parcel from?

What is the difference in the forces in each case?

Why would companies want to drop parcels rather than land the drone?

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Activity 2 – Design a lander

Design the lander for a water balloon filled with 200ml of water being delivered by a drone to ensure it does not get broken.

Use this equation to think about how you can reduce the impact force:

$$\textit{impact force} = \frac{\textit{change in kinetic energy}}{\textit{distance travelled during impact}}$$

How can you increase the distance travelled during the impact?

How can you decrease the kinetic energy just before the impact?

Plan and carry out an investigation to answer the following question:

What is the maximum height the water balloon can be dropped from without breaking on impact?

Why is it important each balloon is filled with the same amount of water each time?

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Car crumple zones increase the distance travelled during the impact to decrease the force on the people in the car

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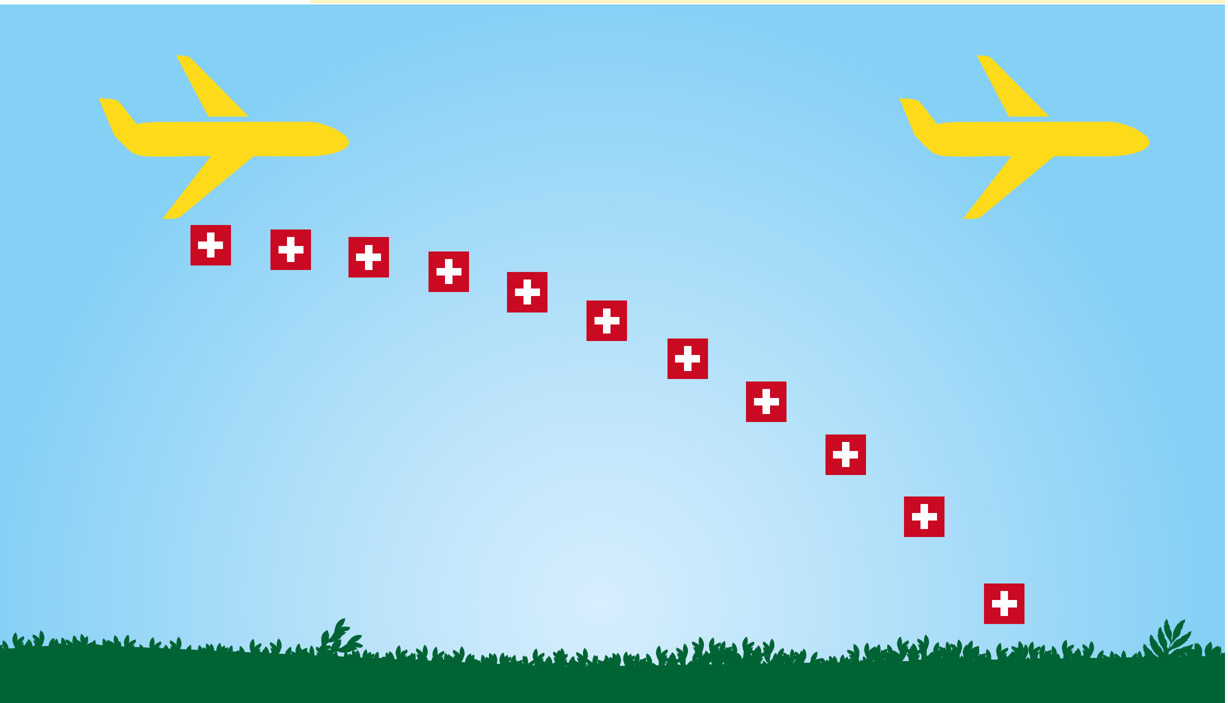
Lunar and Mars rovers use jets to slow down before impact; this decreases the kinetic energy, and therefore the impact force

Stretch and challenge

We could also use drones to deliver humanitarian aid. To ensure the safety of the drones, the delivery is dropped while the drone is still moving. This means the drone controller has to work out when to release the load in order for it to land where they want it to.

When you release the load, it will still have a constant forward velocity. However, weight will be the only vertical force acting on the load because the reaction force from the drone has been removed, so the load will accelerate downwards. This means the load will fall like a projectile.



The motion of a box dropped from a moving plane

If a drone was travelling at a height of 490m with a velocity of 45m/s when it dropped the parcel, where would it land?

Step 1

To work out the horizontal distance we would use:

$$v = \frac{s}{t}$$

Where v = horizontal speed (m/s)
s = horizontal distance (m)
t = time (t)

However, we do not know the time the load took to fall to the floor. To work this out we look at the vertical motion of the load. For this we need to use the 'SUVAT' equations because the load is accelerating downwards.

We will use:

$$s_v = ut + \frac{1}{2}at^2$$

Where s_v = vertical distance (m)
u = initial vertical velocity (m/s)
v = final vertical velocity (m/s)
a = acceleration (m/s2)
t = time (s)

At the moment the parcel is released from the drone, the initial vertical velocity (u) of the parcel is zero as it is not moving vertically, so the equation becomes:

$$s_v = \frac{1}{2}at^2$$

As we are looking for time, the equation is rearranged to:

$$t = \sqrt{\frac{2s_v}{a}}$$

s_v = distance the parcel falls = 490m

a = acceleration due to gravity = 9.8m/s^2

$$t = \sqrt{\frac{2 \times 490}{9.8}} = 10s$$

So it takes 10 seconds for the parcel to drop to the floor.

Step 2

Now we are able to work out how far forward the parcel will travel in this time. This will tell us how far away from the drop point we need to release the load. Since the load is not accelerating in the horizontal plane, we can use:

$$v = \frac{s}{t}$$

The parcel will be moving forward with the same velocity as the drone, and will be travelling for 10 seconds until it hits the ground. So we can rearrange the equation to:

$$s = v \times t = 45 \times 10 = 450m$$

So the parcel will land 450m from where it was dropped.

Now try these:

1. If a drone was travelling at a height of 420m with a velocity of 50m/s when it dropped the parcel, where would it land?
2. If a drone was travelling at a height of 500m with a velocity of 40m/s when it dropped the parcel, where would it land?
3. If a drone was travelling at a height of 200m and the parcel hits the floor 320m away from where it was released, how fast is the drone travelling?
4. If a drone was travelling at a height of 300m and the parcel hits the floor 234m away from where it was released, how fast is the drone travelling?
5. If a drone was travelling with a velocity of 100m/s and the parcel hits the floor 452m away from where it was released, at what height is the drone flying?

Try your solutions in the Air Package Drop simulation in which you have to drop an aid package on an island. Download the simulation here: **tinyurl.com/airdropsim**

For these examples we have ignored the effects of air resistance. Change the settings on the simulation to see what happens when air resistance is included. This can be done by turning on *air friction*.

How do you think wind speed or direction will affect the parcel?

NOTES FOR TEACHERS

Activity 1

For this, students will need to make the assumption that all of the potential energy of the parcel is converted into kinetic energy.

1. Dropped from 120m.

Kinetic energy at the ground = Gravitational potential energy when dropped = m x g x h

Where m = the mass of the parcel (kg)
g = gravitational field strength on Earth (9.8 N/kg)
h = height of the parcel above ground (m)

KE = m x g x h = 1 x 9.8 x 120 = 1176J

$$\textit{impact force (N)} = \frac{\textit{change in kinetic energy (J)}}{\textit{distance travelled during impact (m)}}$$

$$= \frac{1176}{0.01} = 117600N$$

If students use g = $10m/s^2$, the kinetic energy will be 120J and therefore the impact force would be 120000N

This is about the same amount of force applied by a seat belt and airbag to restrain a passenger when a car hits a stationary barrier at 60mph.

2. Dropped from 2m.

Kinetic energy at the ground = Gravitational potential energy when dropped = m x g x h

KE = m x g x h = 1 x 9.8 x 2 = 19.6J

$$\textit{impact force (N)} = \frac{\textit{change in kinetic energy (J)}}{\textit{distance travelled during impact (m)}}$$

$$= \frac{19.6}{0.01} = 1960N$$

If students use g = $10m/s^2$, the kinetic energy will be 20J and therefore the impact force would be 2000N

These two examples show us that the force felt by the parcel and the height in which it is dropped are proportional. When the height is reduced by a factor of 100, the force is also reduced by a factor of 100. Students could work out the force felt if the parcel is dropped from 1.2m to prove this further.

Activity 2

In this activity students should work in pairs to design and make a lander for the water balloon.

It is important that each balloon is filled with the same volume of water so that they all weight the same. This will ensure the reliability of the results.

Stretch and challenge

For this activity the students will need access to a computer to test their working. They will need to open the Air Package Drop (*compadre*) simulation which can be downloaded here: **tinyurl.com/airdropsim**

It is possible to change the height and speed of the plane by changing the numbers at the bottom of the simulation, and pressing enter so the number is no longer highlighted yellow.

Answers

1. **In the vertical direction:**

$$t = \sqrt{\frac{2 \times 420}{9.8}} = 9.3$$

In the horizontal direction

$$s = v \times t = 50 \times 9.3 = 465m$$

2. **In the vertical direction:**

$$t = \sqrt{\frac{2 \times 500}{9.8}} = 10.1$$

In the horizontal direction

$$s = v \times t = 40 \times 10.1 = 404m$$

3. **In the vertical direction:**

$$t = \sqrt{\frac{2 \times 200}{9.8}} = 6.4$$

In the horizontal direction

$$s_v = s \div t = 320 \div 6.4 = 50m/s$$

4. **In the vertical direction:**

$$t = \sqrt{\frac{2 \times 300}{9.8}} = 7.8$$

In the horizontal direction

$$v = s \div t = 234 \div 7.8 = 30m/s$$

5. **For this question, students will have to work backwards, first working out the time using the horizontal speed and distance:**

$$t = \frac{s}{v} = \frac{452}{100} = 4.52$$

Then use this to work out the vertical distance:

$$s = ut + \frac{1}{2}at^2 = \frac{1}{2}at^2 = \frac{1}{2} \times 9.8 \times 4.52^2 = 100m$$

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