

SCIENCE - AGES 6 TO 11

The planes that talk

Four lessons about how every plane in the sky tells the world where it is, and how we can listen. By the end you will be able to explain the whole thing from start to finish, and you will have built part of it yourself.

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LESSON 1

The busy sky and the talking plane

Right now, above your school, there is almost certainly a plane. Probably more than one. You cannot see them because they are ten kilometres up, higher than the highest mountain in Europe, and they are moving at 900 kilometres an hour, which is 250 metres every second. On a normal day about thirty thousand planes cross Europe. None of them can see the others properly, and none of them has a road to follow. So somebody on the ground has to know where every one of them is, all the time, to keep them apart. That person is an air traffic controller. But how can a person in a room on the ground know where a plane is, ten kilometres up, behind the clouds?

For a long time, the answer was radar: a huge spinning dish that sends out a pulse of radio and listens for the faint echo bouncing back from the plane. Radar still exists. But today most planes do something cleverer. Every modern plane has a satellite receiver on board, the same kind of thing that makes the map in a car or a phone work, so the plane always knows exactly where it is. And the plane has a small radio. So instead of waiting for someone on the ground to find it, **the plane simply tells everybody where it is**. About twice every second, its radio sends out a short message: who I am, where I am, how high I am, how fast I am going. Nobody asks for it. Nobody presses a button. It just goes out, over and over, to anyone who is listening.

The message cannot be made of words. A radio can only do one thing: send a tiny pulse, or not. So the message is made of yes-or-no answers, 112 of them in a row, and everyone has agreed what each one means. The first 24 answers spell the plane's name, a code it is given when it is built and keeps forever, like a number plate. There are nearly 17 million different ways to answer 24 yes-or-no questions, so every plane in the world can have its own. The last 24 answers are a check: the listener does a sum on the message, and if the sum does not match, the message got muddled on the way and is thrown away. The plane sends it again half a second later anyway.

Here is the thing to remember from this lesson, because lots of grown-ups get it wrong: **nobody finds the plane. The plane announces itself.** The satellites do not watch it; they only tell it the time, and it works out the rest.

In class: the control tower game

Half of you are planes, walking across a grid on the floor and calling out your message every few steps: your name, your square, your height, your speed. The other half are the control tower, drawing every plane on a paper grid. Then swap. Then try it with the planes allowed to speak only once a minute, and watch the tower's drawing fall apart. That is why real planes talk twice a second.

LESSON 2**Invisible light: what the message travels on**

The message leaves the plane as a radio wave. And a radio wave is light. Not something like light: the very same thing that comes out of a torch or the sun, travelling at the same speed, 300 000 kilometres every second, seven times round the Earth in the time it takes to say "one".

So why can't you see it? Shake a rope slowly and you make long, lazy waves; shake it fast and you make short, busy ones. Light is a wave too, and different colours are different speeds of wiggling. Red wiggles fast; violet wiggles faster. Our eyes can only notice a narrow band of wiggle-speeds, the colours of the rainbow. Radio wiggles far too slowly for eyes to catch, even though the plane's wave still wiggles more than a thousand million times a second. Radio is a colour we cannot see. Dogs hear whistles we cannot hear; bees see patterns on flowers we cannot see; and an antenna sees a colour of light that we cannot.

Because the plane's wave wiggles slowly, it is long: from one ripple to the next, it measures 27 centimetres, about the length of a ruler. Hold a ruler up. Thousands of ripples that size are passing through the classroom right now, from every plane within 400 kilometres, and nobody can feel them.

Now the most important sentence in this lesson. **Radio is not sound.** The box called "a radio" makes sound, which is confusing, but radio waves themselves are silent light. Sound is air pushing on air; it needs air to travel through, and it is slow, about 340 metres a second, which is why you see lightning before you hear thunder. Radio needs nothing: it crosses the empty space between the satellites and the plane, where there is no air at all. And it is nearly a million times faster than sound. The roar of a plane's engines is sound, and it reaches you long after the plane has gone by. The plane's message is light, and it reaches an antenna 20 kilometres away in less than one ten-thousandth of a second.

In class: the rope and the race

In pairs, make rope waves: slow and long, then fast and short, and measure them. Then the fastest-messenger race: a whispered word passed down a line of twenty people against a torch flashed across the hall. The whisper is like sound, passed from one bit of air to the next. The torch is like the plane's message.

LESSON 3

Metal ears and the round Earth

If radio is a colour we cannot see, what can? A piece of metal called an **antenna**. When a radio wave passes a piece of metal, it makes the electricity inside the metal wobble back and forth in time with the wave. That tiny wobble is the hearing, and a machine called a receiver reads the plane's pulses from it. Look around: the Wi-Fi box has antennas, the car has one on its roof, your phone has one hidden inside its edge, and there are probably several on the school roof.

An antenna is a tuned ear. A swing goes highest when you push it in time with its own to-and-fro, and a piece of metal "swings" best, electrically, when it is the right size for the wave: a quarter of the wave's length. The plane's wave is 27 centimetres, so the best antenna for it is about 7 centimetres tall. That is why the real thing, on the plane and on the ground, is a small stub and not a big dish. Bigger is not better here. The right size is what matters, and the right size is small.

Now, how far away can a metal ear hear a plane? Something surprising decides it: **the Earth is round**. Radio is light, light goes in straight lines, and it cannot go through the ground. So a straight line from an antenna on a roof soon runs into the curve of the Earth, and any plane behind that curve is hidden, however loud it is, like a ship that has sailed over the horizon. The higher you are, the further you can see over the curve; you know this from standing on a chair to see over a crowd. That is why antennas go on roofs and masts and hills. From a roof, an antenna can hear a plane ten kilometres high from more than 400 kilometres away, further than Brussels to Paris and back. But a plane that has just taken off from an airport 50 kilometres away may be completely hidden behind the Earth until it climbs high enough to peep over.

In class: build the antenna, then go outside

Cut a strip of card 7 centimetres long, wrap it in foil, and stand it on a foil-covered square. That is the right size and the right shape for the real thing; a real receiver adds a radio and a computer to read the pulses. Then, in the playground: crouch, stand, climb on a bench. What appears each time? That is what a roof does for an antenna.

LESSON 4

Many ears make one map

One antenna on one roof hears the planes in a circle of sky a few hundred kilometres across. To see all of Europe you need hundreds of antennas, on houses and airports and schools, spread out so that their circles overlap. Each one sends what it hears, over the internet, to a computer, and the computer fits the circles together like a jigsaw. The same plane is usually heard by ten or twenty antennas at once; the computer notices it is the same plane and draws it only once. If one antenna reports a plane somewhere that all the other antennas disagree with, the computer knows that report is probably a mistake and leaves it out.

The result is the live map: every plane that is talking, where it is, how high, how fast, which way, updated every second. And you now know the whole chain, from start to finish. The plane listens to the satellites and works out where it is. It says so twice a second, in a message of 112 yes-or-no answers. The

message rides on a wave of invisible light. A tuned metal ear on a roof catches it, as long as the plane is above the curve of the Earth. And hundreds of ears together, sharing what they hear, make the map. Nobody on the ground measured anything. The planes told us, and we listened.

One last question, the kind a good scientist always asks. Does the map show every plane? No. It shows the planes that are talking. Nearly all the big airliners talk. Some small planes, gliders and balloons do not have the radio, and some military planes choose not to use it. So the map is honest, but it is not complete. No map is.

In class: the jigsaw, then the real map

First the floor grid again, but now each tower can only hear its own corner of the room. Lay the sheets side by side: together they show every plane. Then the real map, zoomed in on the school. Your group follows one plane for ten minutes: its name, its height, its speed, where it came from and where it is going. Then tell the whole story of how it got onto the map, step by step, in your own words.

Sky Listener quiz

Choose an answer. If it is wrong, think again and try another; the point is to work out why.

1. 1. How often does a plane send its message?

- A. Once a day
- B. About twice every second
- C. Only when the pilot presses a button

2. 2. Who finds out where the plane is?

- A. The satellites watch it from space
- B. The plane works it out itself and tells everyone
- C. The air traffic controller guesses

3. 3. What is a radio wave?

- A. A loud sound
- B. A kind of light our eyes cannot see
- C. A kind of wind

4. 4. Why is the antenna put on the roof?

- A. To be closer to the planes
- B. So its straight line of sight reaches further over the curve of the Earth
- C. Because birds like it

5. 5. Why does the map need hundreds of antennas?

- A. One antenna only hears a circle of sky a few hundred kilometres across
- B. Antennas break easily
- C. Each plane needs its own antenna

THE END

Build the metal ears

You now know the whole story: the plane that talks, the invisible light, the metal ears and the round Earth, and the map made by many listeners. The last step is to be one of the listeners. Your teacher has a page that explains how to build a real receiver for the school, with a real antenna on the roof or at a window. When it works, the planes above your school will be on the big map because your class heard them.

Ask your teacher about the workshop <https://radar.dataero.eu/learning/workshop>

Answers

1. 1. How often does a plane send its message?

B. About twice every second In one minute a plane moves 15 kilometres. If it only spoke once a minute, the map would always be wrong. Twice a second keeps it up to date, and nobody has to press anything.

2. 2. Who finds out where the plane is?

B. The plane works it out itself and tells everyone The satellites only call out the time. The plane measures how late each call arrives, works out its own position, and announces it. Nobody finds the plane; the plane tells.

3. 3. What is a radio wave?

B. A kind of light our eyes cannot see Radio is light of a colour our eyes cannot see. It needs no air, crosses empty space, and goes nearly a million times faster than sound.

4. 4. Why is the antenna put on the roof?

B. So its straight line of sight reaches further over the curve of the Earth The distance up to a plane hardly changes from a roof. What changes is how far the straight line of sight reaches before it hits the curved ground. Higher means further.

5. 5. Why does the map need hundreds of antennas?

A. One antenna only hears a circle of sky a few hundred kilometres across Each antenna hears only the planes above its own horizon. Many antennas, spread out, with their circles overlapping, cover a whole continent, and the computer fits the circles together.