The Science of Flying: Relativity and GPS

Here you are flying on a new unknown slope. A mate phones to say, ‘Where are you? The weather’s good and I fancy flying.’ You switch on location (GPS), run the What3words app and send out the three words. Soon your mate is standing less than three metres away. Later in this article I will talk about GPS telemetry and its importance for us. First let’s look at the science.

The world of Physics is on the cusp of a universal law of nature. Up to now Physics has been divided into two: the macro world that we can see with our bare eyes and the micro that we can’t. Macro is the large scale world of space-time largely described by gravity and relativity. The micro is the tiny world of things that are smaller than atoms described by quantum mechanics. Macro has been well described by Newton, Einstein and others and by simple maths. Micro is a strange world of uncertainty of states and things misbehaving, described in the 1920’s by the Copenhagen group including Neils Bohr. They replaced simple maths by probability and weird equations involving waves.

We are only concerned with Einstein’s macro world here, the world of Special and General Relativity. And that is of interest to modellers for at least six reasons. They are

- Global Positioning by Satellite (GPS)
- GPS’s importance for drone guidance (lost model search only of course)
- Telling our mates where we are as mentioned above
- Metadata on photographs
- Telemetry
- Possibly a ‘radio controlled’ watch or clock

Einstein only comes into it because of the way two clocks behave at high relative velocities and the fact that light travels at a high but constant speed everywhere. This effect is complicated further by variations of time caused by gravity, called gravitational redshift. In general it is called ‘time dilation.’

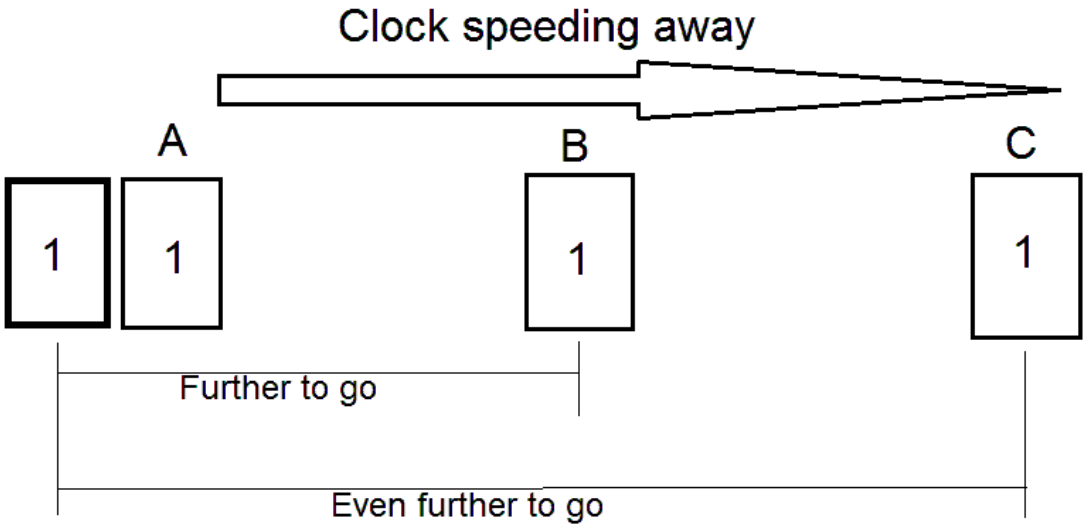
When two objects are travelling at different speeds or are accelerating relative to to each other we say that each has its own frame of reference, in other words set of three dimensions or co-ordinates.

From wiki
With current technology severely limiting the velocity of space travel, however, the differences experienced in practice are minuscule: after 6 months on the International Space Station (ISS), orbiting Earth at a speed of about 7,700 m/s, an astronaut would have aged about 0.005 seconds less than those on Earth. The cosmonauts Sergei Krikalev and Sergei Avdeyev both experienced time dilation of about 20 milliseconds compared to time that passed on Earth. [They probably aged more from the Stolichnaya vodka than their drop in age from time dilation.]

Special relativity (1905)

Let’s stick to the simplest example, which is how clocks slow down with speed. At first reading it seems absurd. If you set two clocks to read exactly the same time and send one off at very high speed they gradually get out of sync. The one travelling away slows down. Actually it is very simple. Look at Picture 1. A clock at A changes to 1 at exactly the same moment as your clock, which is shown with thicker lines. If the clock is at position B, it is further away so the light takes a little longer to reach you before its display changes to 1.

At position C the clock is even further away so the display appears to take even longer to change. Time on the moving clock **appears** to have slowed down. If you were riding on the moving clock the seconds would tick correctly.

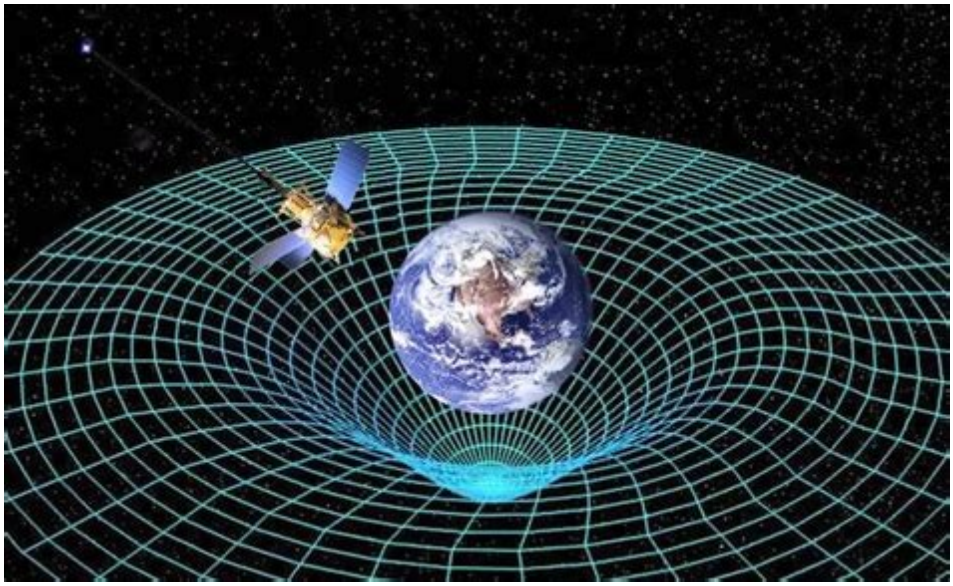


Picture 1
Peter Scott

There is a strange consequence. If the clock was now accelerated by a force the amount of the acceleration would appear less because the clock ticks more slowly and the velocity change takes place more slowly. According to the equation f = ma the only possible conclusion is that mass has increased. Physicists describe each clock as being in its own ‘frame of reference’. So the rule is that time appears to slow down and mass appears to increase when you watch a clock in a second frame of reference travelling away at high velocity.

General relativity 1915

Einstein saw the universe as a three-dimensional grid that he called space-time. Given the fact that light speed is always the same, space and time are effectively the same. The uniformity of the grid is distorted by mass as you see in two dimensions in Picture 2. A very great mass distorts the grid so much that another smaller mass close by is deflected by the curvature. Its path curves, looked at from the frame of reference of the larger mass. Picture 2 shows that the curved path follows the curves of the grid so someone on the smaller object should feel as though its path is straight.



Picture 2
From pinterest.com

We can also say that the small mass could be pulled downhill towards the large one by ‘gravity’. Someone on the smaller mass is not aware of the deflecting pull. He or she is in free fall so feels weightless. When huge mass movements occur, such as in star explosions, gravity waves travel out in space-time and can be detected on earth. One weird consequence of gravity is that if you travel for a very, very, very long time, and are deflected by many masses, in the end you will finish where you started. Einstein said that therefore the universe is bounded but infinite.

Another oddity is that time slows down the more gravity there is.

Albert Einstein (1879 - 1955)

Albert Einstein was born in Ulm, in the German Empire on 14 March 1879 into a family of secular Ashkenazi Jews.His parents were Hermann, a salesman and engineer, and Pauline Koch. In 1880, the family moved to Munich, where Einstein's father and his uncle Jakob founded Elektrotechnische Fabrik J. Einstein & Cie, a company that manufactured electrical equipment based on direct current.

Albert attended a Catholic Elementart School in Munich, from the age of five, for three years. At the age of eight, he was transferred to the Luitpold-Gymnasium (now known as the Albert-Einstein-Gynasium), where he received advanced primary and secondary school education until he left the German Empire seven years later.

Einstein moved to Switzerland in 1895, forsaking his German citizenship the following year. In 1897, at the age of 17, he enrolled in the mathematics and physics teaching diploma program at the Swiss Federal Polytechnic School in Zurich, graduating in 1900. In 1901,he acquired Swiss citizenship, which he kept for the rest of his life, and in 1903 he secured a permanent position at the Swiss Patent Office in Bern. In 1905, he was awarded a PhD by the University of Zurich. In 1914, Einstein moved to Berlin in order to join the Prussian Academy of Sciences and the Humboldt University of Berlin. In 1917, Einstein became director of the Kaiser Wilhelm Institute for Physics. He also became a German citizen again, this time Prussian.

In 1933, while Einstein was visiting the United States, Adolf Hitler came to power in Germany. Einstein, as a Jew, objected to the policies of the newly elected Nazi government; he settled in the United States and became an American citizen in 1940. On the eve of World War II, he endorsed a letter to President F.D. Roosevelt alerting him to the potential German nuclear weapons program and recommending that the US begin similar research [the Manhattan Project]. Einstein supported the Allies but generally denounced the idea of nuclear weapons. [He joined with Bertrand Russell and others at Pugwash, Nova Scotia in 1955 to start the Pugwash Conferences to assess the dangers of weapons of mass destruction.]

From wikipedia

Why does relativity matter to model flyers?

The reason is Global Positioning by Satellite (GPS). Started in 1973 by the US, this is a system of satellites each of which has a clock synchronised with all the others. Each sends out radio clock signals on carrier waves of 1 – 1.5 GHz that can be picked up by receivers. A satellite that is close will show a shorter signal delay than one further away. Each satellite has an accurate position as it sends the clock signal which is fixed by fixed base stations on the earth. If the receiver can 'see' at least four satellites it can work out how far away they are by how long the signals take to arrive and hence, by trigonometry, exactly where the Rx is anywhere on the earth in three dimensions. To do that requires very accurate clocks on each satellite that are exactly in step – synchronous. Initially GPS was only used by the military. Then it was released for civil use but with some blurring of the positioning. Now it is available to all at full accuracy. There are now four GPS systems, all of which can be read and used simultaneously by a suitable receiver. The Russian system is called Russian Global Navigation Satellite System GLONASS (2000's), the Chinese is called BeiDou Navigation Satellite System (BDS) (2011) and the European one is called Galileo (2016). Currently the inherent accuracies are GPS 23 mm, GLONASS and BeiDou 40 to 60 mm and Galileo 16 mm. In practice the accuracies are a few metres.

The satellites are travelling at high speed and in varying gravities so their clocks slowly get out of sync due to relativistic time dilation. Every so often the clocks are all adjusted.

Atomic clocks

As you know from the article on the Periodic Table, electrons in atoms are only allowed certain energy jumps called quanta producing particles called photons, each of which has a definite frequency. If you cool atoms you can rely on them producing the smallest quanta. Do this with Caesium 133 and you get quanta at 9,192,631,770 Hz. Count that number of the waves and you have an exact second. There are about 450 of these clocks around the world, that are compared and synchronised, that between them define International Atomic Time (TAI). For reasons that are beyond me the TAI accuracy is even better than that at one part in 10^{-16} or 1 second in 3×10^{8} years. GPS satellites have two Caesium clocks and sometimes up to two using Rubidium as well. TAI forms the basis for the Universal Co-ordinated Time (UTC) standard used in GPS and, for example, the radio clock transmitters. National laboratories sell calibration services for lesser measuring devices.

Optical clocks are coming using Ytterbium 171 and Strontium 87. These should have at least one more power of ten accuracy. When we get to one in 1.23×10^{-18}, accuracy will be one second in the whole life of the universe.

What a piece of work is a man (Hamlet, when ‘man’ meant all humans)

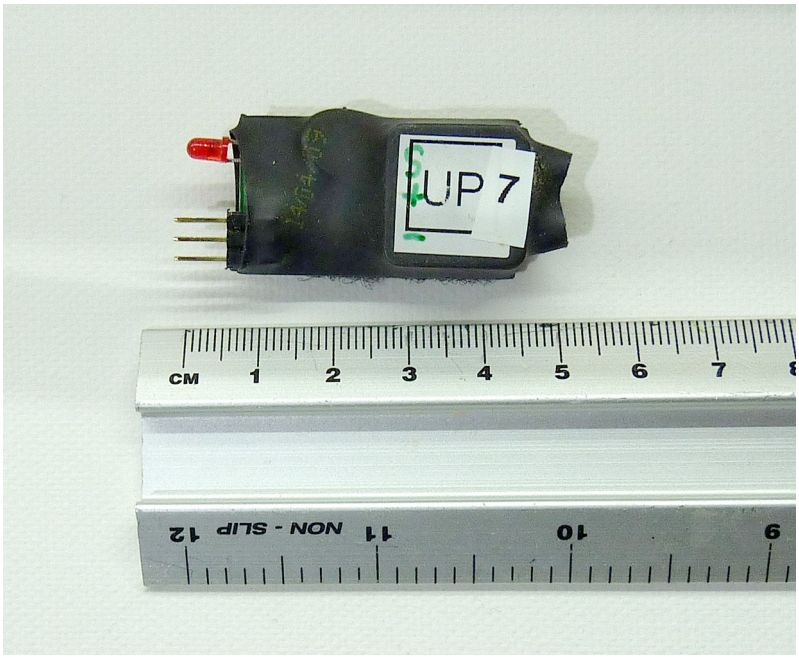
The above numbers are staggering. That a life form could evolve from single cells to the amazing creatures that we are now is impressive, and more so to be able to understand the nature of the rest of the universe. Mind you, earth has been relatively stable as long as the universe made planets possible (4.3 thousand million years). It is pretty certain from pure statistics and astronomy that there is life elsewhere, but due to the time we have been around we might be the most advanced. Advanced creatures don’t have to have green skin, funny ears and grooves in their heads. Even if greed causes human life to end due to climate change and resource exhaustion, the fact that we have done it shows that others can as well. They probably are already. Perhaps they will have the sense not to allow their worlds to be taken over and ruined by uncontrolled super-rich people and companies.

I think it’s funny that disaster films always show people becoming aggressive. In real life the reverse is usually true. Humans have thrived by being caring and co-operative. Look at how we react in real disasters, such as the recent floods, forest fires and earthquakes. It’s a shame that the ‘flogging a dead horse’ school of blockbuster film making doesn’t take note, though no doubt some think the gritted teeth, shouting or screaming people and the enormous fake explosions made with gas are exciting rather than predictable and dull. Have you noticed how the actors get blown over just before the explosion blast?

If someone has a crash or flyaway doesn’t every abled-bodied person at the field help to sort it? It’s what we do. Or most of us. It was Lord Acton who in 1887 wrote, ‘Power tends to corrupt and absolute power corrupts absolutely. Great men are almost always bad men.’ The last sentence is almost always omitted but illustrates why we humans can sometimes act out of our natural character from fear of, or misguided admiration for, such people. I was asked once how otherwise good people in the Nazi or Japanese armies could have behaved as they did in the Second World War. Blind obedience, I replied.

GPS telemetry

Some radio control system makers sell GPS sensors. In Picture 3 is the FrSky one that I use. It connects to the receiver SmartPort through a female to female servo type lead, daisy chained if other sensors are also in use. There is no set up. You just position it in your model so the UP label is facing the sky and unshielded by carbon or metal. You display the data on a transmitter telemetry screen. Data is altitude above sea level, position, ground speed and time. I think that telemetry is the greatest development in RC for a long time. My colleague at the field called Bob always makes fun of my telemetry, not that I care of course. I got my own back the other day when I asked if his car had a satnav and tyre pressure reading.



Picture 3
Peter Scott

How can we use GPS?

I use a small Garmin GPS when walking or riding my bike. However let's stick to model flying. Let me remind you what data items you can get. As a minimum you will have an absolute position in three dimensions to a few metres accuracy. The height of course will not be the altitude above the ground at your flying site. For that you need a zeroed variometer. Your GPS sensor will also probably give you ground speed and time.

Location of a model
Some RC systems, such as my FrSky, allow you to record telemetry data on your transmitter. If you crash or have a fly away you can read the data up to the last recorded location and set your sat nav or phone to take you to the model.

Location of a site
A GPS device will tell you your exact map reference. These are long numbers and are awkward to use. A phone with location GPS enabled will allow you to specify where you are anywhere using What3words. The whole world is divided into squares of 3 metre sides. Yes, the whole world! Give those three words to someone else with the same app and they will be guided to where you are. It also helps with delivery of your next model if you live in the depths of the country as I do. And if you get caught in an unexpected snow storm, rescue will soon find you even if you end up under a snowdrift. Swapping two of the words around is a good game. I usually finish in China for some reason.

Flight data
Your flying data can be displayed on your transmitter. If you record the data you can later transform that into picture form with suitable mapping software on your computer.

Return to base
Drone transmitters usually have a button that automatically returns the machine to the point from which it took off. This usually also works on transmitter signal loss or low

battery. Drones are simple devices to fly. Our models less so. However it is conceivable that soon a return function will appear on fixed wing models. You could even program an arduino yourself to carry out the flight control. My mate Keith is very keen on the idea but foolishly I take a purist line and disagree.

Photograph metadata

Metadata is the information stored by your camera in the picture file along with the image data - such things as resolution, lens and exposure settings and camera type. The latest cameras often have GPS circuitry and add the exact place where you took the photograph. Metadata can be searched so if you have lots of photos and you know there were some you took on such and such a slope and date you can find them. By the way I hope you keep your own backups on your computer and don't rely on 'cloud' storage on the Internet. So many tears have been shed. It pays to have a further backup using 'Save a Copy' onto a large capacity USB drive that you can unplug from your computer in case of a virus.

Conspicuity

Those of you who do not live in or near the European Union won't be familiar with that ridiculous word. The EU loves to invent new words, the uglier the better. This one means that all unmanned flying objects will perhaps at some point in the future have to appear identified on air traffic data. This is of course impossible technically at present, due to the cost and weight of suitable transponders even if they existed. In principle I wouldn't object to it if the transponders weighed 5 g and cost £10. You would need one in each model. They did suggest using bluetooth or 5G but as usual their scientific ignorance means they don't realise the futility of those approaches.

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