Hi, this is Steve Nerlich from Cheap Astronomy, www.cheapastro.com and this is Orbital mechanics.

There's a persistent notion out that a clever way to manage long distance travel is to launch straight up from the ground and just hover. Then, after an hour or two, you just drop down to the ground again, where you will find yourself in New York having launched from London a couple of hours earlier – because while you've been hovering, the Earth has rotated beneath you.

Now, a small scale test should be sufficient to reveal a problem with that line of thinking. If you jump up in the air, you don't land half a metre to the west because the Earth has rotated beneath you – you land back on the same spot that you jumped up from. Having been born on a planet with an equatorial rotation velocity of nearly half a kilometre a second – you can't suddenly divest yourself of that intrinsic velocity just by jumping up in the air.

But, it is true that if you went *really* high – ignoring all the complexities of atmospheric drag – the Earth really would start rotating beneath you. That's not because you lost the intrinsic velocity you were born with, it's because the circumferential distance you have to cover to do a full orbit around the Earth becomes much greater at high altitude. So, in spite the intrinsic velocity you've retained since birth, the Earth's surface will begin racing ahead of you.

Nonetheless, there's a huge energy cost involved in achieving the sort of altitudes where the Earth really will rotate on ahead of you to any significant extent. The next generation of high-speed flying machines may work by getting above the main bulk of the atmosphere – but that's only 20 kilometres or so of altitude. You need several hundred kilometres of altitude before the Earth would start rotating significantly ahead of you. So, in a nutshell, if you want to travel quickly to the west, it's much easier (and more fuel-efficient) just to go up and then fly west – or whatever direction gets you to your destination fastest.

But putting all that aside, there is plenty of intriguing curious physics involved in launching from the surface of a rotating spherical planet that is worth thinking about. For example, it's well known that rockets from Cape Canaveral always launch to the east to take advantage of the Earth's rotation to the east. However, that advantage only arises because the Earth is a rotating sphere. There would be no advantage whatsoever if the Earth was just a flat plane in lateral motion to the east. On a moving flat plane, assuming air resistance is not a factor, it makes no difference which way you point the rocket, it will go just as far in any direction.

But it's a different story when you launch from the surface of a rotating sphere. The rocket will measurably fly further and higher when it's fired in the direction of the sphere's rotation. Technically, this is a consequence of the Coriolis effect acting in a vertical direction – which is also called the Eotvos effect. A rocket launched in the direction of Earth's rotation behaves as though it's lighter, that is, less-affected by gravity. In reality, the Eotvos effect is not a mysterious anti-gravity force, it's just a consequence of your frame of reference. But, it's no trick that rockets launch better to the East, they really do – and this is not so much about velocity additions, it's about geometry.

To explain, let's now look at things from to an external frame of reference. If a moving, but flat, Earth, moved laterally in front of you and someone on that flat Earth fired rockets with and against the direction of the Earth's motion, you would see the rocket fired in the direction of Earth's motion being visibly faster *from your perspective* due to the addition of its and Earth's velocities. But, since the Earth *is itself* moving, the Earth is almost keeping pace with that rocket. Conversely, the apparently slower moving rocket ends up covering more ground since the flat Earth is moving in the opposite direction to it. So, it turns out that both rockets end up crashing at equidistant points from their launch site – despite their seemingly different velocities.

But if you now watch from a distance as the same test is undertaken on a rotating spherical Earth, you don't get the same outcome. You will see the rocket moving in the direction of Earth's rotation moving faster due to Earth's rotational velocity adding to the rocket's velocity. But, rather than the Earth almost keeping pace with that rocket, the surface of the spherical Earth will be turning away from it. So, under these conditions, the rocket's faster velocity means the rocket achieves a greater altitude from the surface, in comparison to the rocket that is going in the opposite direction, whose nett apparent velocity is its own minus the rotational velocity of the Earth. So, assuming both rockets do crash back to Earth, the one that was fired in the direction of the Earth's rotation will crash at a further distance from its launch site than the one that was fired in the opposite direction.

So, there you go – there's some curious physics involved in launching from rotating spheres that come into play long before anyone even mentions Einstein. Of course, that whole thought experiment we just ran through ignores the effect of air resistance. But if you do put the atmosphere back into the equation, it makes even more sense to launch to the East, since, although the atmosphere is a very turbulent and chaotic thing, it is subject to a *general tendency* to move to the East because it's gravitationally held to the Earth and east is the way that the Earth rotates. Therefore, it makes sense to launch a rocket to the east, so that it flies with the wind, not against it.

And of course, if your rocket flies fast enough and far enough, then rather than falling back onto the spherical surface of Earth, your rocket might end up missing the surface entirely when it falls back down, so that it will just keep on falling around and around the planet – in other words, it will be in orbit.

So, of course if you want to orbit something at a close distance, it helps if that something is spherical. Indeed, the concepts of orbiting and spherical tend to go together. Massive objects that are able to generate sufficient gravity to hold something in orbit do tend to compress into a spherical shape.

But that's not a hard and fast rule – there are plenty non-spherical potato-like asteroids with small objects in orbit around them and we have seen cases of one planet orbiting the two stars of a binary system.

Probably the most important principle of orbital mechanics is that, for a particular object with a particular gravity field, its satellites will naturally adopt orbits of specific altitudes, which are determined by those satellite's velocities. So, on the one hand, a satellite in a close orbit needs a higher velocity than a satellite in a higher orbit. On the other hand though, if a satellite velocity increases, it will shift to a higher altitude, while if it is decelerated, it will shift to a lower altitude – or, in other words, its orbit decays.

So, although space craft have engines and thrusters to go up, down and all around – it's vastly more fuel-efficient for them to 'orbit' their way around. This is particularly true when you think that a spacecraft in orbit around a planet in orbit has either launched from that planet or arrived at that planet from somewhere else. In either case, it will have achieved that orbit by initially possessing a very rapid velocity. So, where's the point in putting the brakes on and losing that advantage once you are in orbit.

And speaking of going to another planet, a trip from Earth to Mars is also going to be all about orbital mechanics, because once you leave Earth's orbit, it will suddenly become clear that you are, and always have been, in orbit around the Sun.

So, even with such an extended interplanetary journey, it's going to be more fuel efficient to follow the natural space-time curves established by the fact that over 99% of the solar system's mass is concentrated in the Sun. So, by expending sufficient energy to leave the gravitational pull of Earth, you will suddenly find that being a son or daughter of Earth has given you an intrinsic solar orbital velocity of 30 kilometres a second with respect to the Sun – an intrinsic velocity that well exceeds Mars' orbital velocity of 24 kilometres a second. There may come a time when we have propulsion systems that are so more powerful and more efficient that all this stuff doesn't matter much anymore. But it will always matter a bit – and it totally matters now.

Indeed, the whole point of this podcast is to try and convince you that as soon as your feet leave the surface of Earth, orbital mechanics is everything and straight lines are not necessarily the shortest distance between two points.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where we really do want to launch you all into orbit, but it's nothing personal. No ads, no profit, just good science. Bye.