**Rockets: Ascent and re-entry**

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On a bright day near the lake, we threw a stone into the water. It fell far away, making a splash. We kept throwing the stones, trying to out-compete ourselves and ask, “Who can throw the stone farthest?” However, we could not progress further after hitting a particular mark. You may think that is natural. But would you believe me if I said a specific throw exists so that the stone never makes a touch-down but instead goes around the Earth itself?!

Of course, such a throw requires super-human strength, and it will require a high-velocity swing of your hand, which may even tear upon execution. If what I say to you is true, ask yourself a simple question: why does a high-speed meteor or missiles from space crash on Earth, burning, instead of rotating around the planet? The reasons are the atmosphere, gravity, and trajectory.

Below are the pictures of a rocket or missile launched into space. One of them shows the launch of the Space-X rocket, while the other shows a student rocket launch by ALU in 2018. First, look at the leading edge, that is, the front part of the spacecraft. Now, look at the next set of images: one shows an intercontinental ballistic missile approaching a target. Another shows the Endeavour space shuttle returning from the International space station. The third shows a crashing meteor. In all the cases, the leading edge facing the atmosphere is burning. Ask yourself another question: why does something ascending from the Earth not burn, whereas the descending one does? The reason is interlinked with what we told before.

**Launching into space**

Newton's first law of linear motion states that all bodies remain in a state of rest or in steady motion unless acted on by an external force. For example, if you throw a stone at an angle in space, it continues to go along the line you threw it for a short time. However, the body experiences two dominating external forces in time: drag (friction due to air) and gravitational pull. Because of this, the stone slows down, or *decelerates*. As the body continuously decelerates due to external forces, it follows a parabolic trajectory and crashes down on the Earth (See box).

**BOX: Projectile motion**

The motion of all bodies is governed by Newton’s laws of motion. When a body is thrown vertically upwards, it falls back to the same place. This is because it is acted on by Earth’s gravitational force which is always pulling it back. As It travels upwards, its velocity keeps on decreasing. At one point, the velocity falls to zero. After this, there is only the downward force of gravity, which makes it fall faster and faster to Earth.

What happens if you throw the stone at an angle? The key point in solving this problem is to note that there is NO change in the horizontal velocity of the stone. Only the vertical velocity keeps decreasing because of gravity. At some point. The vertical velocity becomes zero and the changes sign. The stone starts to fall, but always moving forward (due to its constant horizontal velocity). The path of such a stone is a parabola, a beautiful symmetric curve that goes up and then comes down the same way. The larger the initial velocity, the farther away the stone reaches before it touches the ground.

What happens if there is friction due to air? Then the horizontal velocity also starts to become smaller. Since the horizontal velocity is always decreasing, the stone falls faster than it rises, giving an asymmetric curve.

**END OF BOX**

**Reaching orbital speed**

What happens if you start out with higher velocity? If you apply sufficiently a more significant power that can overcome the drag and gravitational pull, the body can propel further and move far away from you. If you keep on increasing the velocity, the object goes into an orbit around the Earth! See the picture to understand how this works.

There is another complication: drag. If the body crosses 100 km altitude during the throw, the *drag* force vanishes. Why? There is no atmosphere, or it is very thin above 100 km. The body is officially flying into space from now on. Then the only force that balances the forward thrust is gravity. So less velocity is required to put the object in orbit if it is flying higher. At 100 km above the Earth, the object has to have a speed of 7.9 km/sec (28,440 km per hour) to stay in orbit. That is a high speed. For comparison, a high-speed sniper bullet exits at more than 2000 km/hr from a gun which experiences drag and decelerates quickly.

We already saw that one could achieve an orbital motion practically by staying away from the atmosphere and flying at high speed. However, the atmosphere creates drag, and one may not have enough fuel to continuously supply such high velocities needed for orbital motion except through rocket propulsion. Hence, rockets carry a lot of fuel and a small payload to achieve high velocity in the atmosphere until it crosses 100 km. For example, a car takes 4% of its total load as fuel. At the same time, a rocket carries 85% of its total weight as fuel. The point mentioned above is one of the reasons why we see only a tiny capsule reaching space but not the whole rocket frame. Also, remember the rockets are launched vertically. Because in that way, they can cross the 100 km atmosphere as quickly as possible. Then the rocket enters a curved path, and the gravity does the rest to put it in an orbital motion. The International Space Station (ISS) and the Hubble telescope are kept in space using the earlier idea.

BOX: **Some interesting facts on ISS and Hubble**

Our International space station is at an altitude of 408 km above the Earth's surface. The Earth's radius itself is 6371 km. Hence a total altitude of 6779 km corresponds to an orbital velocity of 7.7 km/s (27,720 km/hr). The Hubble telescope is kept at 559 km above the Earth's surface to avoid the density-related light refractions in the atmosphere to monitor the stars and galaxies.

**END OF BOX**

As the body is propelled into space, the engineers ensure the rockets reach only a particular low velocity (<1 km/s or <3600 km/hr) in the atmosphere. In that way, the load exerted by the atmosphere on the body remains minimal. As a result, the rockets gain much higher velocity after crossing the atmosphere, which is relatively easy with minimal fuel expenditure. That's why we do not see any burning on the leading edge of the vehicle. Now let us consider a body coming from space that enters Earth's atmosphere. It now possesses a whopping speed . When such a high-speed body meets the atmosphere, the body starts to burn due to friction. Why does it burn?

**Friction and heat**

Take your hand and rub it vigorously for some time. Do you feel the heating sensation in your palm? We do this always on a cold day during the winter season. Rubbing for a few seconds can raise your palm temperature between 1 to 2 deg celsius. When the rocket re-enters the atmosphere at high speed, extreme friction is created between the air and the metal, resulting in a rise in surface temperature to 3000 degrees!

The high temperature on the metal surface will melt away the metal (aluminum melting point is 660C). Similarly, at such a high temperature, molecules in the air begin to dissociate to an ionized state, causing a bright glow, which we see in the re-entry pictures. Hence, we *shield* the leading edge with heat-shield materials instead of metals. If the heat shields fail, the capsule burns away, like in the unfortunate case of our famous astronaut Kalpana Chawla, leading to her death.

Meteors generally do not possess such heat shields. Any meteors smaller than 100 m burn in the atmosphere due to the extreme heat. However, if any meteors are far more significant than those entering our atmosphere, the impact will be catastrophic. For example, a meteor of 10 km hit our Earth 65 million years ago and wiped out most of the living things, including dinosaurs.

**Moon and meteors**

If you look at the surface of the moon, craters are visible. It is because the meteor impacts make the craters. Moon does not have an atmosphere, and it cannot protect its surface from meteor impacts. However, Earth has a protective atmospheric shield that saves us from many meteor crashes. On average, we get hit by 6,100 meteors per year. We should be thankful to our atmosphere for safeguarding us from such meteors and other re-entering bodies.

But how come Earth has an atmosphere, but the moon does not. That is one more an exciting topic to discuss. We will see it in the next article.