58.5: Gravity Assist Maneuvers

To send a spacecraft to another planet, one may often get a "free" boost in velocity by flying by another planet along the way, thus shortening the trip. These free velocity increases are called gravity assist maneuvers..

To see how this works, consider Fig. 58.5.1, which shows a spacecraft flying past the planet Jupiter, where Jupiter is assumed to be stationary in space. The spacecraft speeds up as it heads toward Jupiter, then slows down again as it moves away from Jupiter. The net result is that the spacecraft leave the encounter having its velocity vector change direction, but without any change in magnitude.

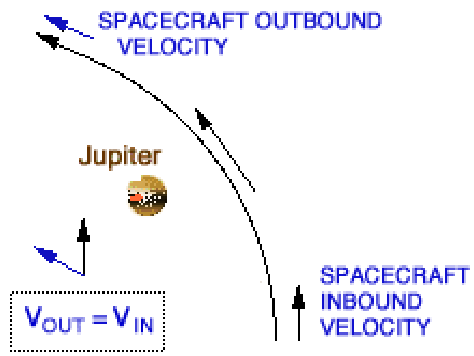

Figure 58.5.1: Spacecraft flying past a stationary Jupiter. Credit: NASA Jet Propulsion Laboratory.

Now consider the same situation, but with Jupiter moving in its orbit around the Sun (Fig. 58.5.2). In the figure, the spacecraft is flying "behind" Jupiter (i.e. so that at the point where the spacecraft passes Jupiter's orbit, Jupiter is moving away from the spacecraft). The velocity of Jupiter in its orbit around the Sun (or a significant portion of it) is added to velocity vector of the spacecraft, as shown in the two vector diagrams. As you can see from the vector diagrams, the velocity vector increases in magnitude after the Jupiter flyby, so that the spacecraft has gained speed.

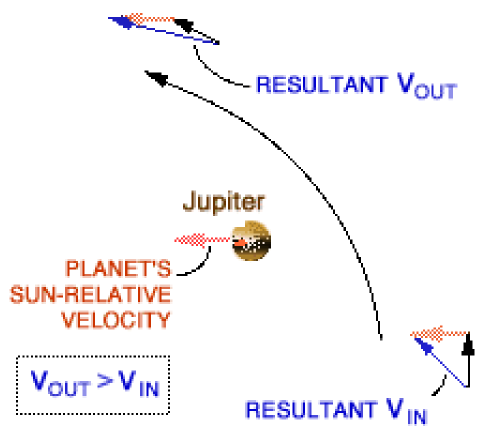

Figure 58.5.1: Spacecraft flying past a moving Jupiter; Jupiter is moving to the left in its orbit around the Sun. In this case, the spacecraft is passing "behind" Jupiter, and gains speed during the encounter. Credit: NASA Jet Propulsion Laboratory.

How is this possible? The spacecraft has gained energy, but energy is conserved; where did the extra energy come from? The answer is: Jupiter. When the spacecraft flies behind Jupiter, it tugs on Jupiter a bit, due to the gravitational attraction between Jupiter and the spacecraft. This causes Jupiter to slow down a tiny bit, thereby losing orbital energy, so it moves in toward the Sun a tiny bit. Of course, Jupiter is so massive that this movement toward the Sun is immeasurably tiny, but the effect on the spacecraft is significant.

This gravity assist maneuver is often used to send spacecraft to the outer Solar System; it allows the spacecraft to reach their destinations sooner, and does not require extra fuel to gain the extra speed. In fact, it is often advantageous to send a spacecraft first to the inner Solar System to take advantage of gravitational flybys before sending it to the planets. For example, when the Cassini spacecraft was sent to orbit Saturn, it was first sent to Venus for two gravity assists from that planet; it then flew past Earth and Jupiter for two additional gravity assists before arriving at Saturn.

Similarly, Voyager 2 made gravity-assist flybys of Jupiter, Saturn, and Uranus, and it made studies of each of those planets as it flew past them. After its encounter with Uranus, Voyager 2 flew past Neptune and made observations there; however, it flew over Neptune's north pole, so it did not gain extra speed from the Neptune encounter. The spacecraft has now reached the outer boundary of the Solar System and is entering interstellar space. In about 40,000 years, Voyager 2 will pass 1.7 light-years from the star Ross 248 and in about 296,000 years, it will pass 4.3 light-years from Sirius, the brightest star in the sky. Both Voyager 2 and its sister spacecraft Voyager 1 will travel through the Milky Way galaxy indefinitely

Contrariwise, if the spacecraft were to fly in front of Jupiter (so that Jupiter is moving toward it when it crosses Jupiter's orbit), then the spacecraft would lose speed. This was used to advantage during the Apollo missions to the Moon, when this type of gravity assist maneuver with the Moon was used to reduce the amount of fuel needed to place the spacecraft into lunar orbit (Fig. $58.5.3$).

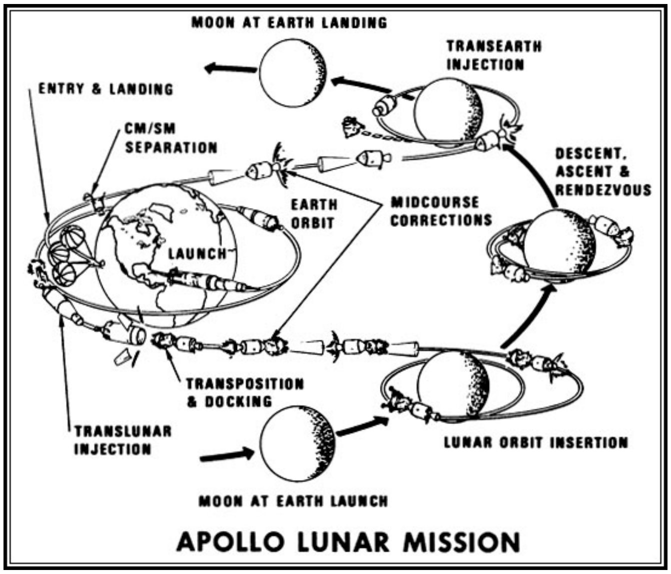

Figure $58.5.1$: Orbits of Apollo spacecraft 8 and 10-17. The spacecraft enters lunar orbit in front of the Moon, to help slow its velocity. (Credit: NASA.)