Interplanetary How-To Guide

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So, you want to get to another planet. It's the same as going from Mun to Minmus. However, we're dealing with vast distances and higher velocities. It will take more precision to get there. This guide addresses getting from the orbit of one planet to the intercept of another planet using a Hohmann transfer.

Assumptions:

- Planets are in circular orbits and not inclined.
- The parking orbit of the spaceship is circular and not inclined.

Section 1: Planetary Phase Angle

It doesn't do much good to your delta-v budget if you launch at the wrong time. In fact, it could be disastrous, meaning you might not have any chance at returning home. To know the right time to launch the mission, you have to calculate a phase angle the two planets should have to each other (the angle from one planet to another with the sun at the vertex).

The process of calculating this phase angle is quite simple. First, we need to determine how much time it will take to transfer from one planet's orbit around the sun to the other planet's orbit.

$$t_H = \pi\sqrt{\frac{(r_1 + r_2)^3}{8\mu}}$$

Remember: the radii used are of the planet's orbits around the sun and the gravitational parameter used is the sun's.

Next, we need to determine how far the other will travel (in degrees) during the time the spacecraft is in transit. We calculate the angular velocity (°/s) and multiply it by the transit time: $\sqrt{\frac{\mu}{r_2}} \cdot \frac{t_H}{r_2} \cdot \frac{180}{\pi}$

Since the spacecraft travels through 180°, we can easily get the phase angle between planets at the start of the transfer: $\mathit{Phase\ angle} = 180\,° - \sqrt{\frac{\mu}{r_2}} \cdot \frac{t_H}{r_2} \cdot \frac{180}{\pi}$

For the purposes of this guide, positive values indicate the target planet starts out in front. Negative values mean the target planet starts behind.

Section 2: Velocity

To get to the other planet, you need to know what velocity you need to achieve from the planet you're currently orbiting around. This requires two steps: 1) Determine the velocity difference between the velocity needed to get to the other planet's orbit and the velocity of the current planet, and 2) The velocity needed at your current orbit to achieve the needed velocity once out of the sphere of influence.

First, we calculate the change in velocity needed for the Hohmann transfer:

$$\Delta v_1 = \sqrt{\frac{\mu}{r_1}}\left(\sqrt{\frac{2r_2}{r_1+r_2}}-1\right)$$

We will need to be going that much faster than our planet of origin at the start of the Hohmann transfer. The value just calculated is the velocity we need to be at just prior to exiting the planet's SOI.

Using conservation of specific orbital energy, we can calculate the velocity needed at our parking orbit to exit the SOI at the correct velocity (we'll refer to this as our ejection velocity):

$$v_1=\sqrt{\frac{r_1(r_2\cdot v_2^2-2\mu)+2r_2\cdot\mu}{r_1\cdot r_2}}$$

where:
r_1 = parking orbit radius
r_2 = SOI radius
v_1 = ejection velocity
v_2 = SOI exit velocity (absolute value)
μ = gravitational parameter of origin planet

Section 3: Transfer Burn Point

Exiting the sphere of influence heading in the wrong direction would screw up everything we've worked through in the last two sections. It would not only increase the delta-v needed for a transfer, but also change the transfer time. You'll either have to spend even more delta-v to salvage your situation, or suffer embarrassment as you miss the target planet. Knowing when in your parking orbit to perform your ejection burn is critical for interplanetary travel.

A lot of people will think "that's easy, just do the burn at midnight/noon." That is wrong. Your trajectory will be curved by the planet and can be off by around 30° from your intended direction of travel.

I'm going to let you loose on these equations.

r = parking orbit radius
v = ejection velocity
μ = gravitational parameter of origin planet

$$\epsilon = \frac{v^2}{2} - \frac{\mu}{r}$$

$$\mathbf{h} = \mathbf{r} \times \mathbf{v}$$

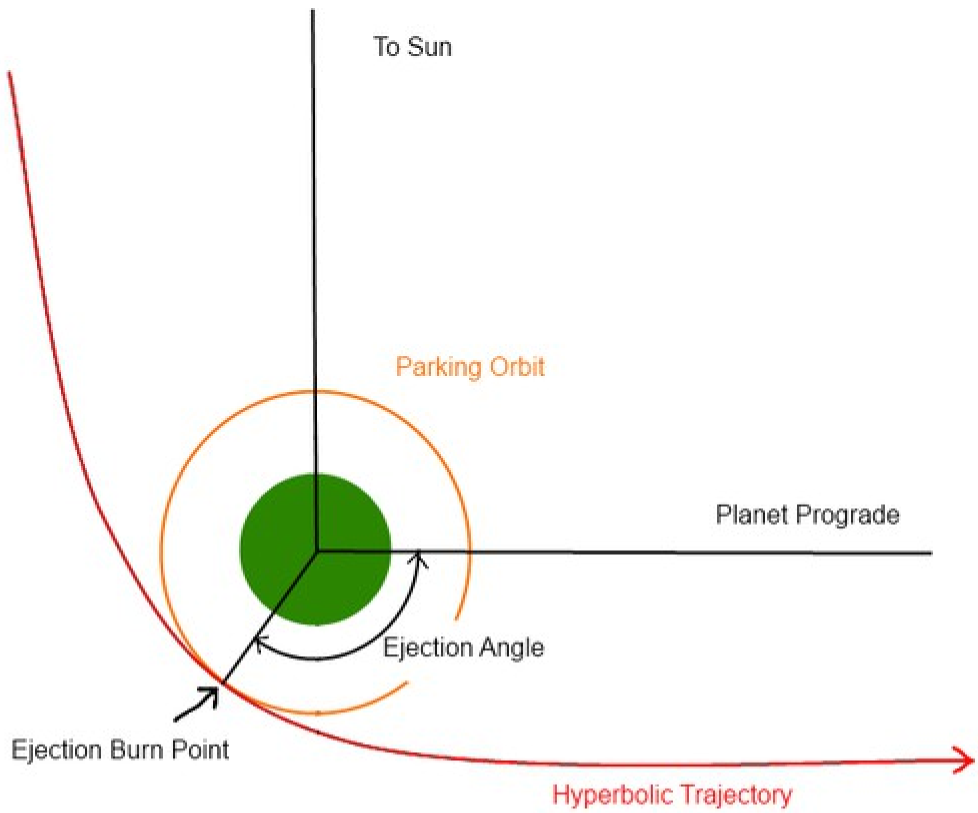
$$e = \sqrt{1 + \frac{2\epsilon h^2}{\mu^2}}$$

$$\theta = \cos^{-1}(1/e)$$

(have this value in degrees, not radians)

Ejection Angle = 180° - θ

This is the angle from your travel direction as your get farther from the planet to your ejection burn point. Here is a picture to illustrate (planet prograde is the desired direction of travel in this case):



Practice Problems:
Kerbin orbital radius: 13.5Gm (or 13,500,000 km)
μ_{Kerbin}: 3530.461 km3/s2
μ_{Sun}: 1.167922e9 km3/s2

A spaceship needs to get from Kerbin to a planet that is orbiting at 3x Kerbin's orbit.

Answers:
t_H = 1.2897e7 seconds
Planetary Phase Angle = 82.0°
Hohmann Δv_1 = 2.0904 km/s
Ejection Velocity = 3.7909 km/s
Ejection Angle = 122.7°

A spaceship needs to get from Kerbin to a planet that is orbiting at 0.7x Kerbin's orbit.

Answers:
t_H = 3.5733e6 seconds
Planetary Phase Angle = -60.9°
Hohmann Δv_1 = -0.8605 km/s
Ejection Velocity = 3.2774 km/s
Ejection Angle = 152.3°