



Interplanetary Trajectory Optimization ISP

Lecture 3

Designing an Interplanetary Trajectory



Introduction

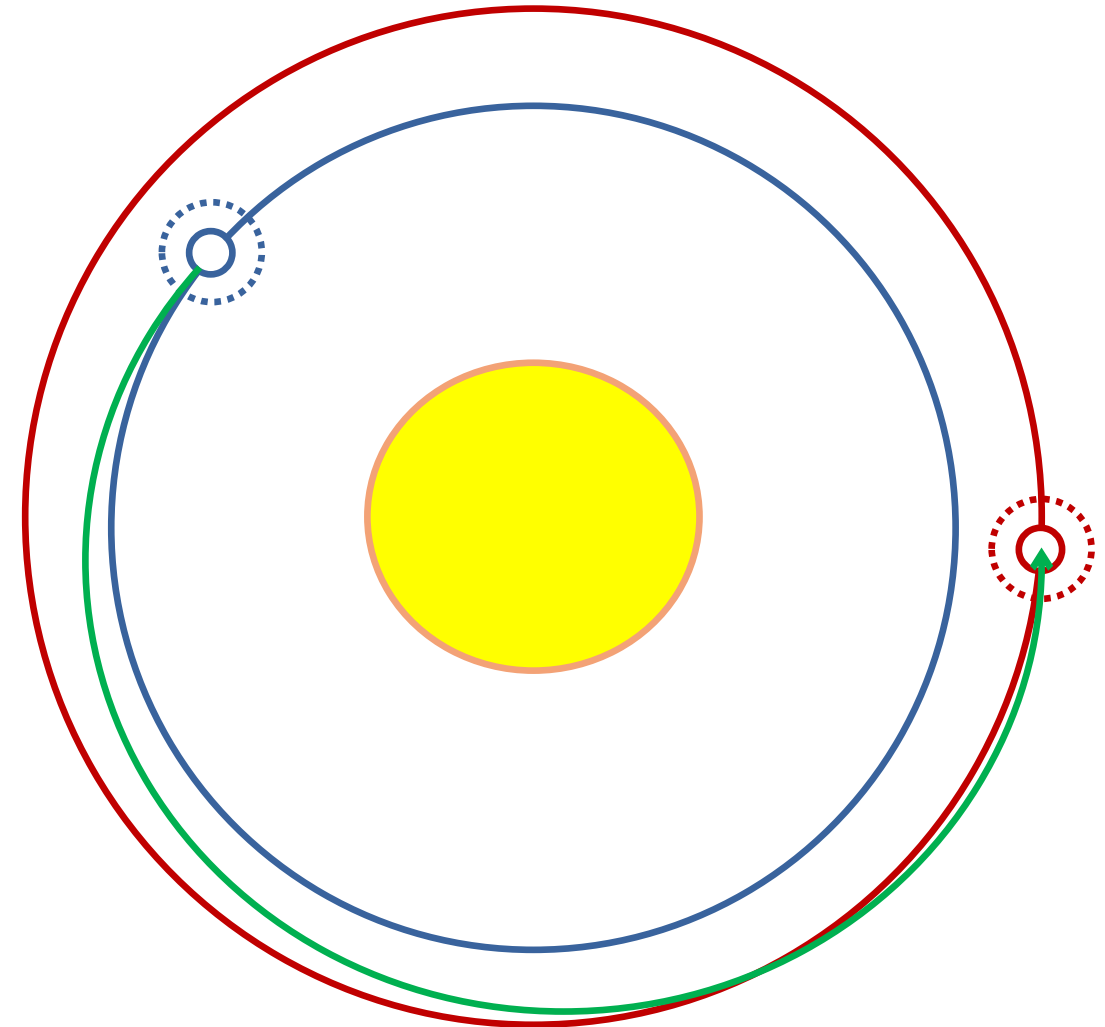


- ◆ Designing an Interplanetary Trajectory combined knowledge of spacecraft & orbital dynamics and optimization theory
- ◆ Selecting an appropriate level of fidelity for your analysis is also crucial
- ◆ A common method is to use an iterative fidelity approach, where detail is added in incrementally

Patched Conic Method

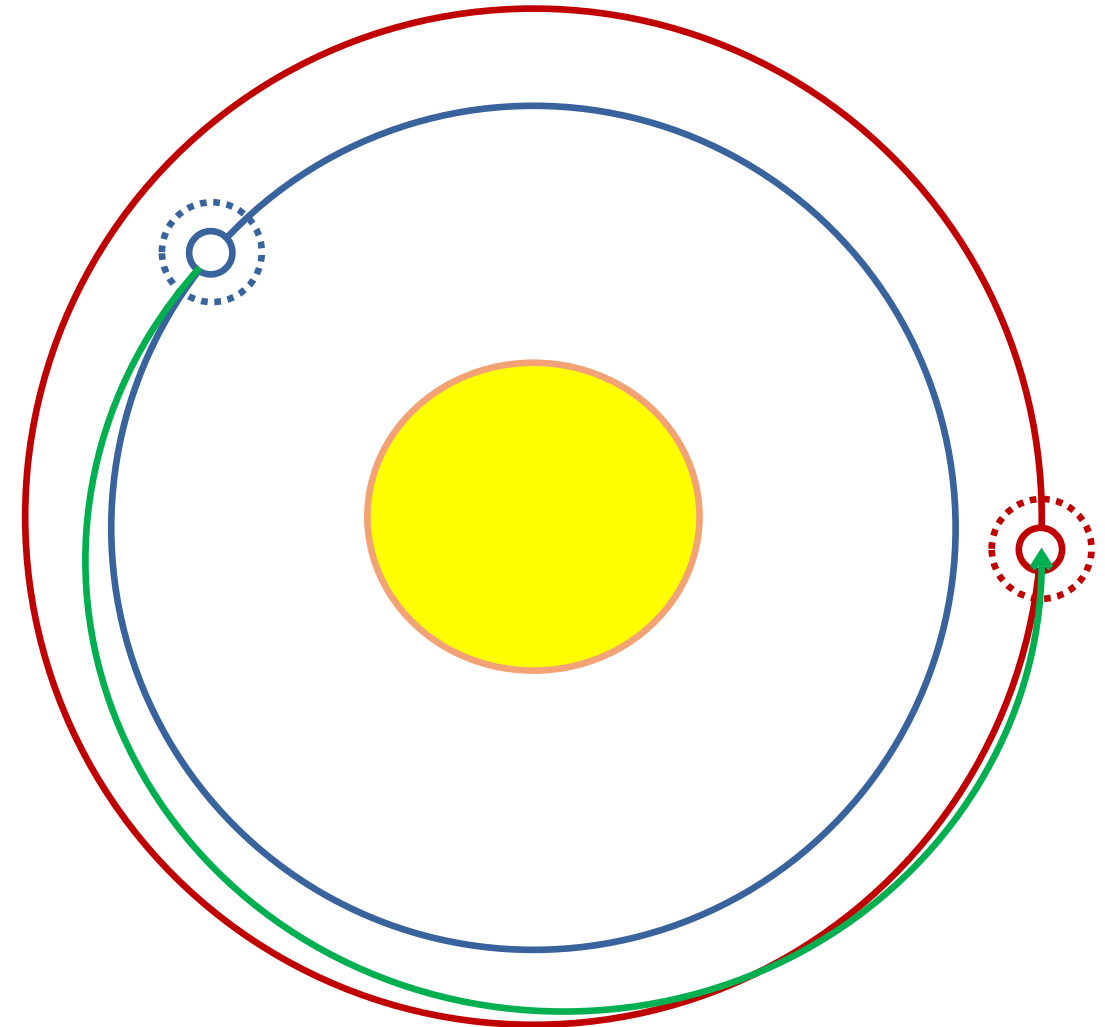


- ◆ [Wikipedia article](#)
- ◆ Designing an interplanetary trajectory is *technically* an n-body optimization
- ◆ We can side-step this issue by only considering a body's gravity if the vehicle is within its [sphere of influence](#) (SOI), which has a radius roughly
- ◆ When inside this radius around a planet or other body, only the gravity of that body is used for trajectory analysis
- ◆ At the edge of the sphere, the Sun's gravity takes over



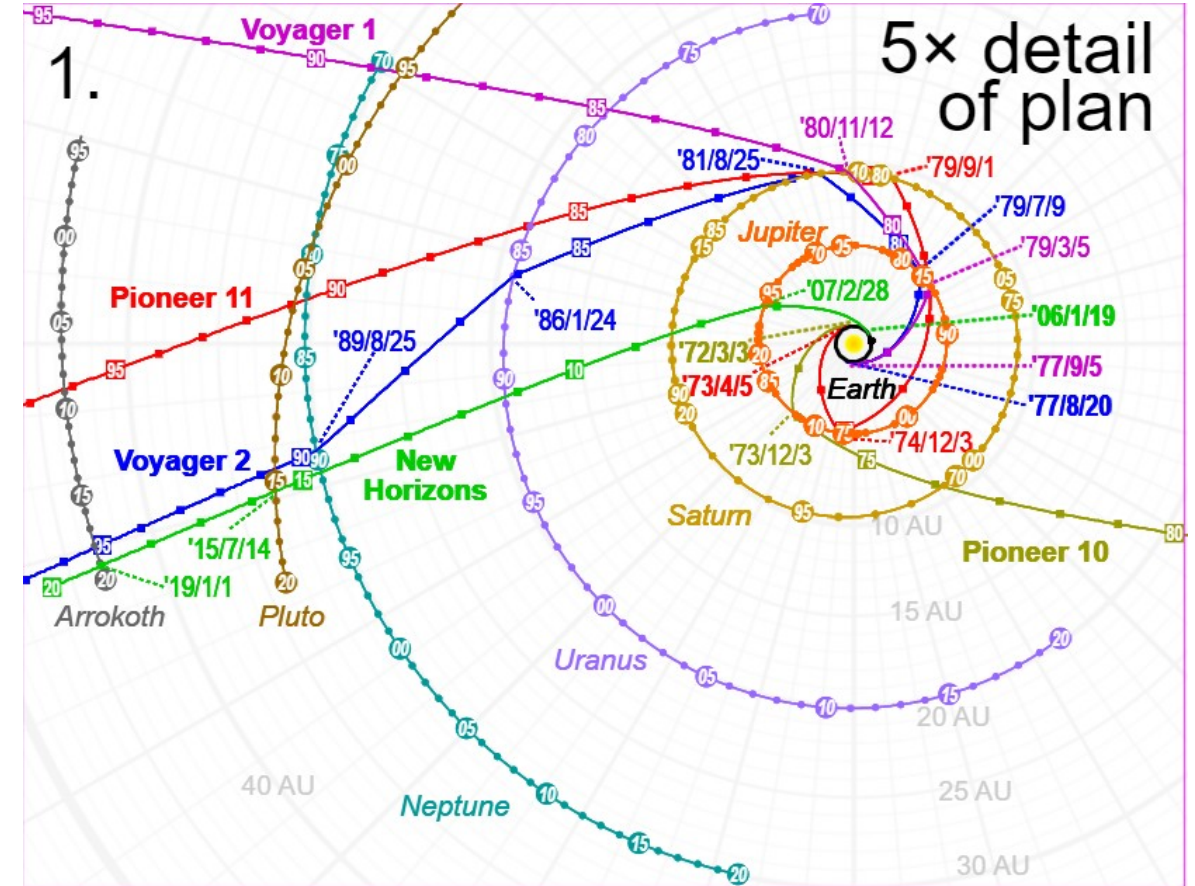
Patched Conic Method

- ◆ Within the first (blue) body's SOI a hyperbolic escape trajectory is used to begin
- ◆ Then when in the Sun's (yellow) SOI an elliptical orbit is used to transfer over to the next body (red)
- ◆ Optimization constraints are used to enforce that the position and velocity of the vehicle is consistent at each interface between one body's SOI and another



Voyager 1 - Trajectory

- ◆ [Wikipedia](#)
- ◆ Voyager Grand Tour
- ◆ Launch
 - ◆ September 5, 1977
 - ◆ [Titan IIIE](#)
 - ◆ Initial orbit aphelion 8.9 [astronomical units](#)
- ◆ Jupiter closest approach
 - ◆ March 5, 1979
 - ◆ 349,000 km from planet center
- ◆ Saturn closest approach
 - ◆ November 12, 1980
 - ◆ 124,000 km from planet center
- ◆ Exit from heliosphere
 - ◆ February 17, 1998
 - ◆ 69 (AU) from the Sun



[Source](#)

Project 1 - Voyager



- ◆ Work with the following assumptions
 - ◆ Voyager starts at its initial energy state (orbit) at the location of Earth at its departure date
 - ◆ Fly-by plane orientation = 0°
- ◆ Create a program to answer the following questions
 1. What argument of periapse in Voyager's initial orbit would make it roughly coincide with Jupiter?
 2. What is the angle of departure from Earth's orbit?
 3. How long is the transit from Earth to Jupiter?
 4. What angle of deflection does the flyby at Jupiter produce?
 5. What is the angle of departure from Jupiter's orbit?
 6. How long is the transit from Jupiter to Saturn?
 7. What angle of deflection does the flyby at Saturn produce?
 8. What is the angle of departure from Saturn's orbit?
 9. How long is the transit from Saturn to the heliosphere edge?
- ◆ Produce a plot of the trajectory

Project 1 – Voyager 1 - Additional



- ◆ Use pykep's trajopt module to compute the trajectory
- ◆ Produce a plot of the trajectory
- ◆ Compare the result with Project 1
- ◆ Why are they different?

Linking Performance and Design

- ◆ Expand the rocket equation to include information about the vehicle performing a mission

- ◆ This can be used in several ways
 - ◆ Knowing PMF and Isp tells you the maximum performance in of a vehicle
 - ◆ Knowing requirements, Isp, PMF can tell you about the masses of the vehicle
- ◆ s are *additive*, such that

Project 2 – Mars Colonization

◆ Work with the following assumptions

◆ Start with a vehicle in Low Earth Orbit (LEO)

- 500 km altitude circular
- Engine Isp = 360 s
- Vehicle Propellant Mass Fraction = 0.8
- Mars stay: [7, 365] d

◆ Use a launch date in 2039

◆ Mars orbit

- 500 km altitude circular

◆ Payload is left behind at Mars

◆ Create a program to answer the following questions

◆ Earth-Mars Transit

- When is the best time to leave Earth?
- How long does the Earth-Mars transit take?
- What is the requirement?

◆ Mars-Earth Transit

- How long of a stay at Mars will bring about another good transit opportunity?
- How long does the Mars-Earth transit take?
- What is the requirement?

◆ Vehicle Design

- What % of your propellant is burned on the outbound leg?
- How much payload can you bring?
- What are the corresponding propellant and structural masses?

◆ Produce a plot of the trajectory

◆ Stretch Goal: Integrated Mission

- ◆ Show difference in mission profile and performance when both the outbound and inbound legs are optimized simultaneously