Spacecraft Dynamics Lecture - UUM571 - Project Part 1

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Project Part 1 Overview

- Travel to planet Mars from planet Earth.
- Wait on Mars parking orbit until return window is opened.
- **Stages**:
  - 1) Launch Platform Coordinates Selection
  - 2) Determine Appropriate Launch Date & Time
  - 3) Rocket Launch to Earth Parking Orbit (500km)
  - 4) Conduct Hyperbolic Escape Trajectory Maneuver
  - 5) Apply Hohmann Transfer to Mars
  - 6) Travel to Mars Parking Orbit with Hyperbolic Maneuver
  - 7) Wait Until Return Window is Opened

Launch Location Selection

- Sun-synchronous Earth circular parking orbit is chosen.
- Does not have to be eligible/realistic location.

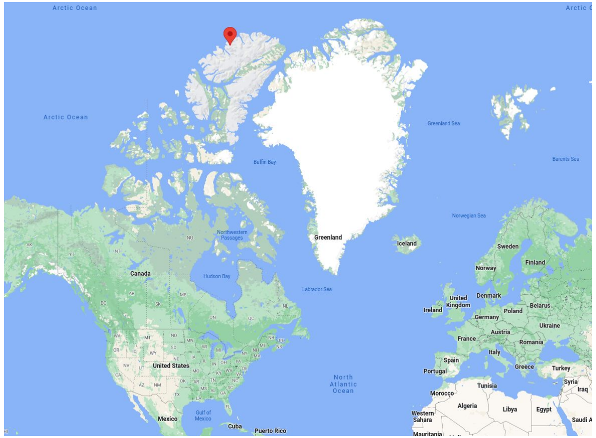
- Azimuth Angle: A = **279.3489 degrees**

- Orbital Inclination: i = **97.401 degrees**
    - average rate of change of the the right ascension:

$$\dot{\Omega} = \frac{2\pi}{365.26 * 24 * 3600}$$

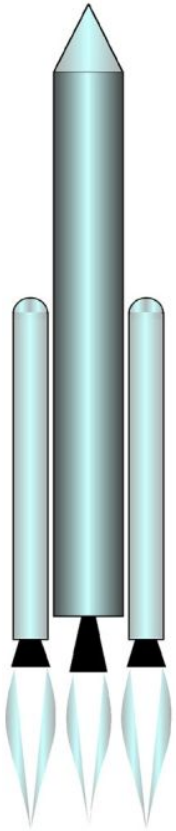
- Latitude Angle: L = **82.499 degrees**

$$cos(i) = cos(\phi)cos(A)$$



Launch Vehicle Design

- **Design Properties:**
  - Launch vehicle rocket will burnout at an altitude of **500 km**.
  - Only one stage rocket is designed.
- **Parameters:**
  - Rocket thrust (constant): **T = 10^6 N**
  - Diameter: **d = 3.7 m**
  - Drag coefficient: **Cd = 0.5**
  - Frontal area of the launch vehicle: **A = 10.75 m^2**
  - Flight path angle: **gamma = 90 degrees**
  - Earth parking orbit spacecraft mass: **m_pl = 6666 kg**
  - Launch vehicle propellant mass: **m_p = 54321 kg**
  - Rocket empty mass: **m_e = 12345 kg**
  - Total Launch Vehicle tandem-stacket mass: **m = 73332 kg**



Rocket Performance

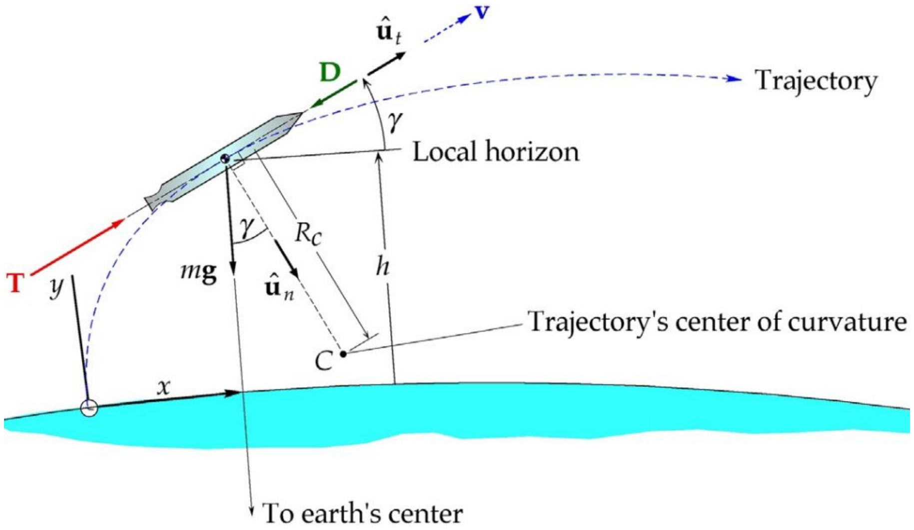
- Changing gravitational acceleration w.r.t. altitude
- Fuel flow rate is considered constant: **m_d = 165.8728 kg/s**
- Experimentally selected specific impulse: **I = 614.548 s**
- Assumed that flight path angle is constant
- Total fuel burning time until reached to

  Earth parking orbit: **t = 327.48588 s**

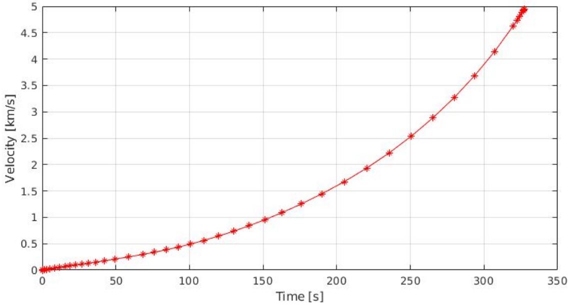
$$t_{burn} = \frac{m_p}{\dot{m}}$$

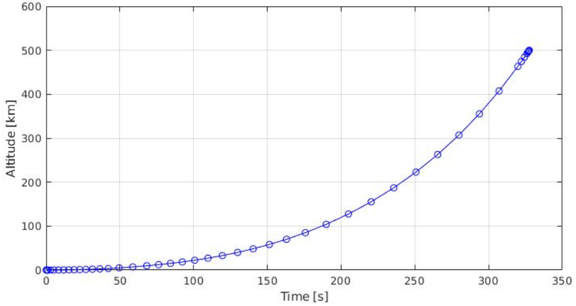
- **5 minutes and 28 seconds**

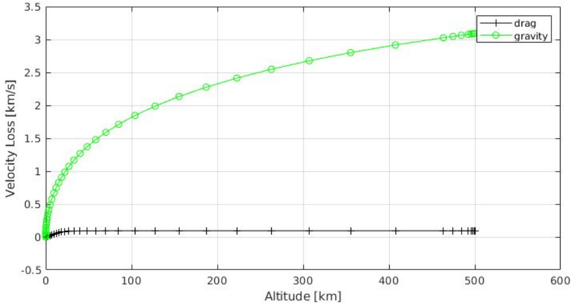
- Spacecraft speed after burnout: **v = 4.95288 km/s**

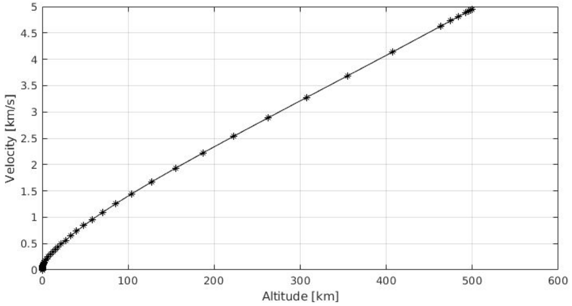


Rocket Performance









- Velocity at Earth circular parking orbit: **v = 7.61258 km/s**
- Spacecraft velocity after rocket burnout: **v = 4.95288 km/s**
- **Delta V = 2.6597 km/s**

Escape Earth SOI

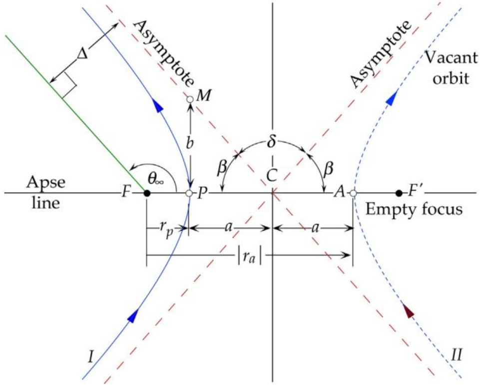
- Specific impulse of spacecraft to make an interplanetary delta-v maneuver: **I = 321 s.**
- Hyperbolic excess speed of the Earth departure hyperbola: **V_∞ = 2.94346 km/s**

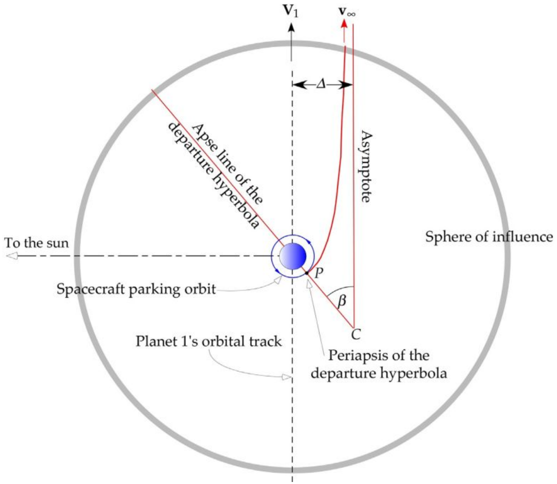
$$\Delta V_{hyperbola} = v_{periapsis} - v_{circular}$$

$$\Delta V_{hyperbola} = v_{circular}\left[\sqrt{2+\left(\frac{v_\infty}{v_{circular}}\right)^2} - 1\right]$$

- **Delta V = 3.54840 km/s**

- Perigee of a departure hyperbola with respect to the Earth velocity vector:
  - **beta = 29.54795 degrees**
- Using an orbit equation for reaching Earth SOI radius:
  - **theta = 148.87471 degrees**
- Total duration of the spacecraft while in hyperbolic trajectory: **t = 273086.80638 s**
- **3 days, 3 hours, 51 minutes, and 27 seconds**





Planetary Ephemeris

- After adding additional **3 days, 3 hours, 56 minutes, and 55 seconds** to the launch date and time, the Hohmann transfer maneuver will be initialized:
    - **Year : 2023**
    - **Month : May**
    - **Day : 10**
    - **Hour : 3 p.m.**
    - **Minute : 8**
    - **Second : 6**

Table 8.1 Planetary orbital elements and their centennial rates

	a (AU) $\dot{a}$ (AU/Cy)	e $\dot{e}$ (1/Cy)	i (°) $\dot{i}$ (°/Cy)	Ω (°) $\dot{\Omega}$ (°/Cy)	ϖ (°) $\dot{\varpi}$ (°/Cy)	L (°) $\dot{L}$ (°/Cy)
Mercury	0.38709927	0.20563593	7.00497902	48.33076593	77.45779628	252.25032350
	0.00000037	0.00001906	−0.00594749	−0.12534081	0.16047689	149,472.67411175
Venus	0.72333566	0.00677672	3.39467605	76.67984255	131.60246718	181.97909950
	0.00000390	−0.00004107	−0.00078890	−0.27769418	0.00268329	58,517.81538729
Earth	1.00000261	0.01671123	−0.00001531	0.0	102.93768193	100.46457166
	0.00000562	−0.00004392	−0.01294668	0.0	0.32327364	35,999.37244981
Mars	1.52371034	0.09339410	1.84969142	49.55953891	−23.94362959	−4.55343205
	0.0001847	0.00007882	−0.00813131	−0.29257343	0.44441088	19,140.30268499
Jupiter	5.20288700	0.04838624	1.30439695	100.47390909	14.72847983	34.39644501
	−0.00011607	−0.00013253	−0.00183714	0.20469106	0.21252668	3034.74612775
Saturn	9.53667594	0.05386179	2.48599187	113.66242448	92.59887831	49.95424423
	−0.00125060	−0.00050991	0.00193609	−0.28867794	−0.41897216	1222.49362201
Uranus	19.18916464	0.04725744	0.77263783	74.01692503	170.95427630	313.23810451
	−0.00196176	−0.00004397	−0.00242939	0.04240589	0.40805281	428.48202785
Neptune	30.06992276	0.00859048	1.77004347	131.78422574	44.96476227	−55.12002969
	0.00026291	0.00005105	0.00035372	−0.00508664	−0.32241464	218.45945325
(Pluto)	39.48211675	0.24882730	17.14001206	110.30393684	224.06891629	238.92903833
	−0.00031596	0.00005170	0.00004818	−0.01183482	−0.04062942	145.20780515

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- Julian day number:

$$J_0 = 367y - INT\left[\frac{7\left[y + INT\left(\frac{m+9}{12}\right)\right]}{4}\right] + INT\left(\frac{275m}{9}\right) + d + 1,721,013.5$$

- Using Kepler's equation to calculate eccentric anomaly E.
- **Mean anomaly**:

$$M = \frac{h + \left(\frac{m}{60}\right) + \left(\frac{s}{3600}\right)}{24}$$

Planetary True Anomaly:

$$tan\left(\frac{\theta}{2}\right) = \sqrt{\frac{1+e}{1-e}}\, tan\left(\frac{E}{2}\right)$$

Hohmann Transfer

Assumptions:

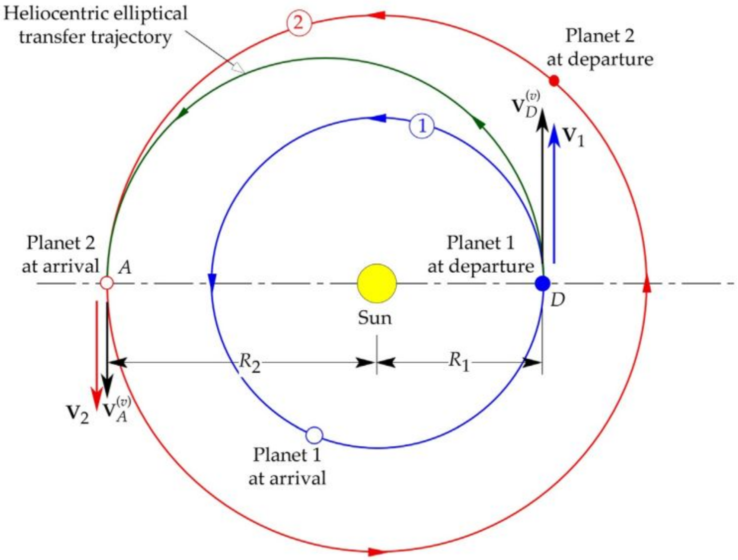
- **inclination** of planetary orbital trajectories of the planets Earth and Mars are assumed to be 0 degrees; so the Earth and Mars have the co-planar orbits.
- solar orbits of the planets Earth and Mars in heliocentric orbital plane are assumed to be **circular orbits**; so the eccentricity of these orbits are equal to 0.
- Solar effects and space **perturbations are neglected**.

- True anomaly difference between planets is **44.32 degrees**.
- The duration of Hohmann transfer:

  t = 22362713.30644 s

- **258 days, 19 hours, 51 minutes, and 53 seconds**
- Spacecraft's heliocentric velocity: **V = 32.72794 km/s**

$$v_{departure} = \sqrt{\mu_{sun} \cdot \left[\frac{2}{R_E} - \frac{1}{a}\right]}$$



Mars Arrival

- The spacecraft **will enter** to the Mars SOI in 2024 year, January, 24th, 10 a.m., 59 min, and 59 sec.
- The speed of the spacecraft after Hohmann transfer **at Mars SOI** location:

$$v_{arrival} = \sqrt{\mu_{sun}\left(\frac{2}{R_M} - \frac{1}{a}\right)} = \boxed{21.48355 km/s}$$

- The speed at Mars **capture orbit** (at Mars SOI radius):

$$v_{mars} = \sqrt{\frac{\mu_{sun}}{R_M}} = \boxed{24.13146 km/s}$$

- The spacecraft **velocity relative to Mars** at periapse of approach hyperbola:

$$v_{perigee}^{mars} = \sqrt{(v_{\infty}^{mars})^2 + \left(\frac{2\mu_{mars}}{r_{mars} + z_{mars}}\right)}$$

- **Delta-V** for stay in mars circular orbit:

$$\Delta V_{arrive} = v_{circular}^{mars} - v_{perigee}^{mars} = \boxed{-2.09018 km/s}$$

Wait for Next Window

- The spacecraft **will enter** to the Mars SOI in 2024 year, January, 24th, 10 a.m., 59 min, and 59 sec.
- Earth and Mars planets **mean angular velocity** (circular orbit assumption):

$$n_E = \frac{V_{earth}}{R_E} = \frac{\sqrt{\frac{\mu_{sun}}{R_E}}}{R_E}$$

- **Initial phase angle** between Earth and Mars:

$$\phi_0 = \pi - (n_M * t_{hohmann}) = \boxed{44.32deg}$$

- **Final phase angle** between Earth and Mars:

$$\phi_f = \phi_0 + (n_M - n_E) * t_{hohmann} = \boxed{-75.09712deg}$$

- **Waiting time**:

$$\boxed{t_{wait} = 39286373.02635s}$$

in other words, **454 days**, **16 hours**, **52 minutes**, and **53 seconds**.

Conclusion

- Codes and simulation are conducted in MATLAB.
- Detailed report is submitted to the Ninova system with all codes and simulations, including LaTEX file.
- Only one reference is used throughout the study:

  "H. Curtis, Orbital mechanics for engineering students. ButterworthHeinemann, 2013"
- Report is 6 pages in IEEE format written in LaTEX.

- To-Do:
  - Detailed readme to be added to the simulation codes.
  - Simulation graphics will be added in the next part of the project.
  - Align with others to make sure that ephemeris and delta-v calculations are correct.