Launchers – Getting to Orbit

Why are Rockets Needed?

The engines and motors previously discussed are needed for:

- Orbital manoeuvring systems
- Orbit raising
- Station keeping
- Launch vehicles

Launching a spacecraft is complicated and requires to anticipate a multitude of different factors.

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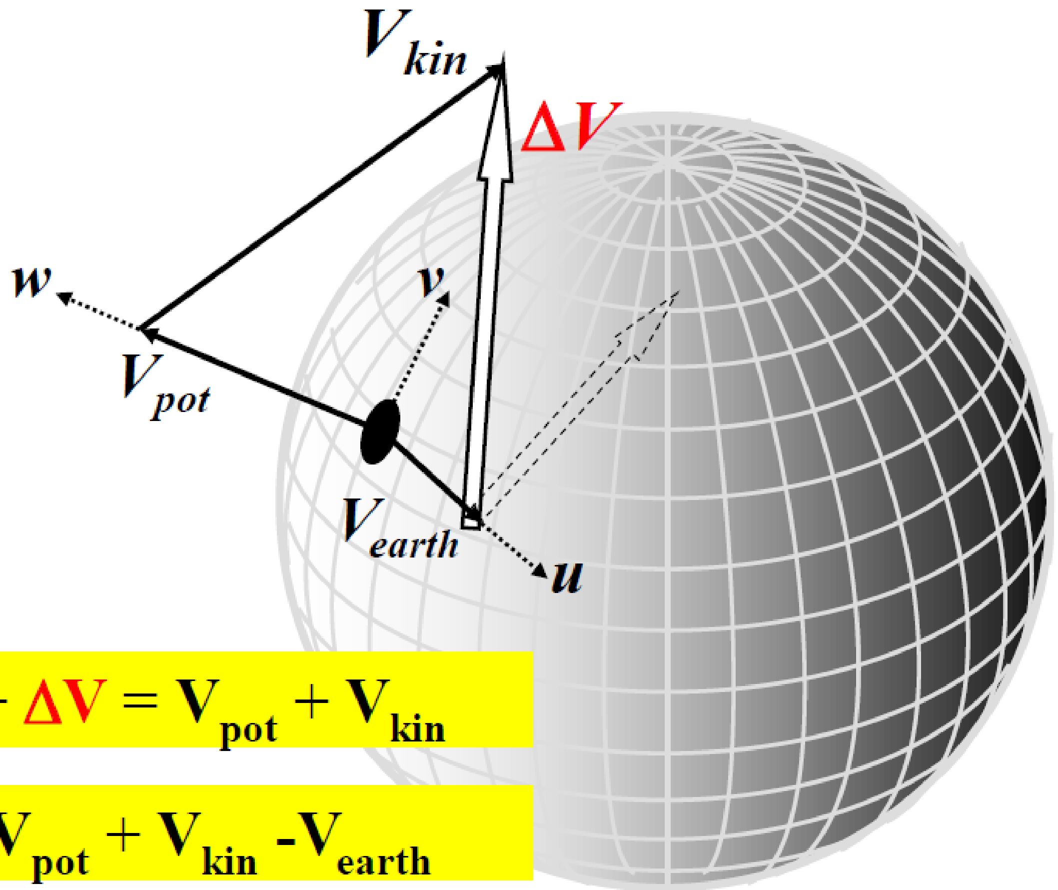
Ascent Velocity Components



$$V_{earth} + \Delta V = V_{pot} + V_{kin}$$

$$\Delta V = V_{pot} + V_{kin} - V_{earth}$$

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Classical Mechanics – Kinetic (KE) and Gravitational Potential Energy (PE)

- Kinetic Energy: it is the energy that a moving body possesses due to its motion. It consists in the work needed for a body with mass to go from rest to a specific velocity.

$$E_k = \frac{mv^2}{2}$$

with E_k the kinetic energy in Joules, m the mass in kg and v the velocity in m/s.

- Gravitational Potential Energy: it is the energy a body with mass has in relation to another body with mass within a gravitational field. When comparing two bodies, one being much more massive than the other, we can write:

$$E_p = mgh$$

with E_p the Potential energy in Joules, m the mass in kg, g the gravitational acceleration in $\frac{m}{s^2}$ and h the height in m.

Potential Energy Applied to Launchers

$$E_p = mg(r)r$$

Taking into account that g decreases with distance from the center of Earth:

$$g(r) = \frac{\mu}{r^2} \text{ (=) } E_p = \frac{m\mu}{r}$$

with r the distance from the center of the Earth in meters, m the mass of the object in kg and μ the gravitational constant for Earth fixed at $4x10^{14}m^3s^{-2}$.

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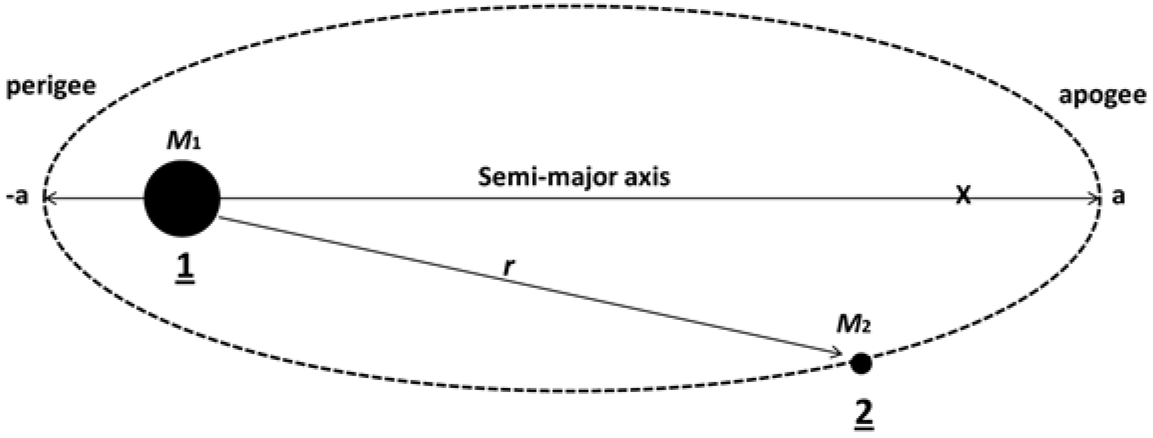
The Vis Viva Equation



The Vis-viva equation or living force equation allows to estimate the necessary velocity increment for a spacecraft or celestial body to achieve specific orbital parameters.

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

with v the orbital velocity in m/s.

Kinetic Energy Applied to Launchers

The launcher needs to build enough kinetic energy to compensate for the potential energy lost to gaining attitude R+h:

$$\frac{mV_{pot}^2}{2} = \frac{m\mu}{R} - \frac{m\mu}{R+h}$$

It also needs enough kinetic energy to maintain a stable orbit so from the Vis-viva equation:

$$V_{kin} = \sqrt{\frac{2\mu}{r} - \frac{\mu}{a}}$$

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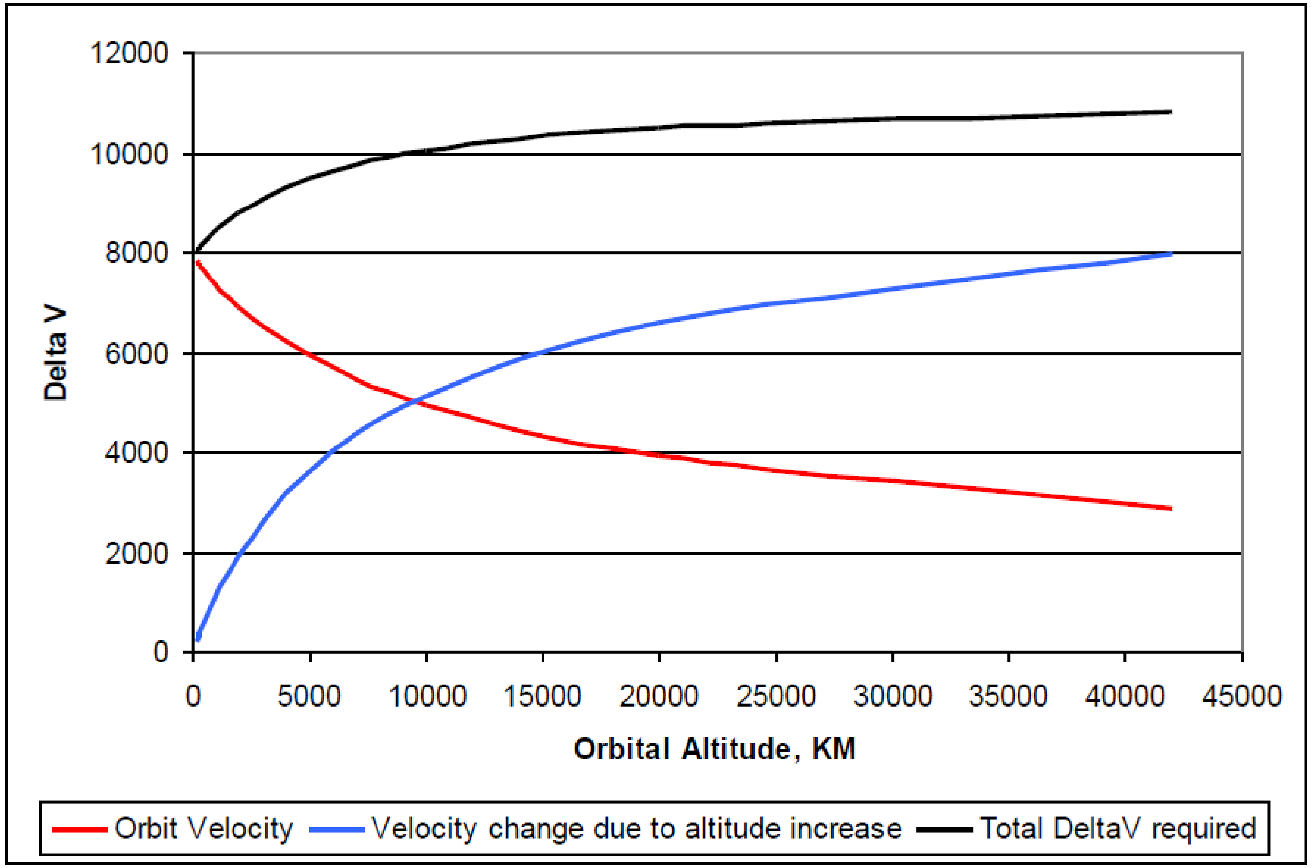
Total Kinetic Energy or Required Velocity Increment



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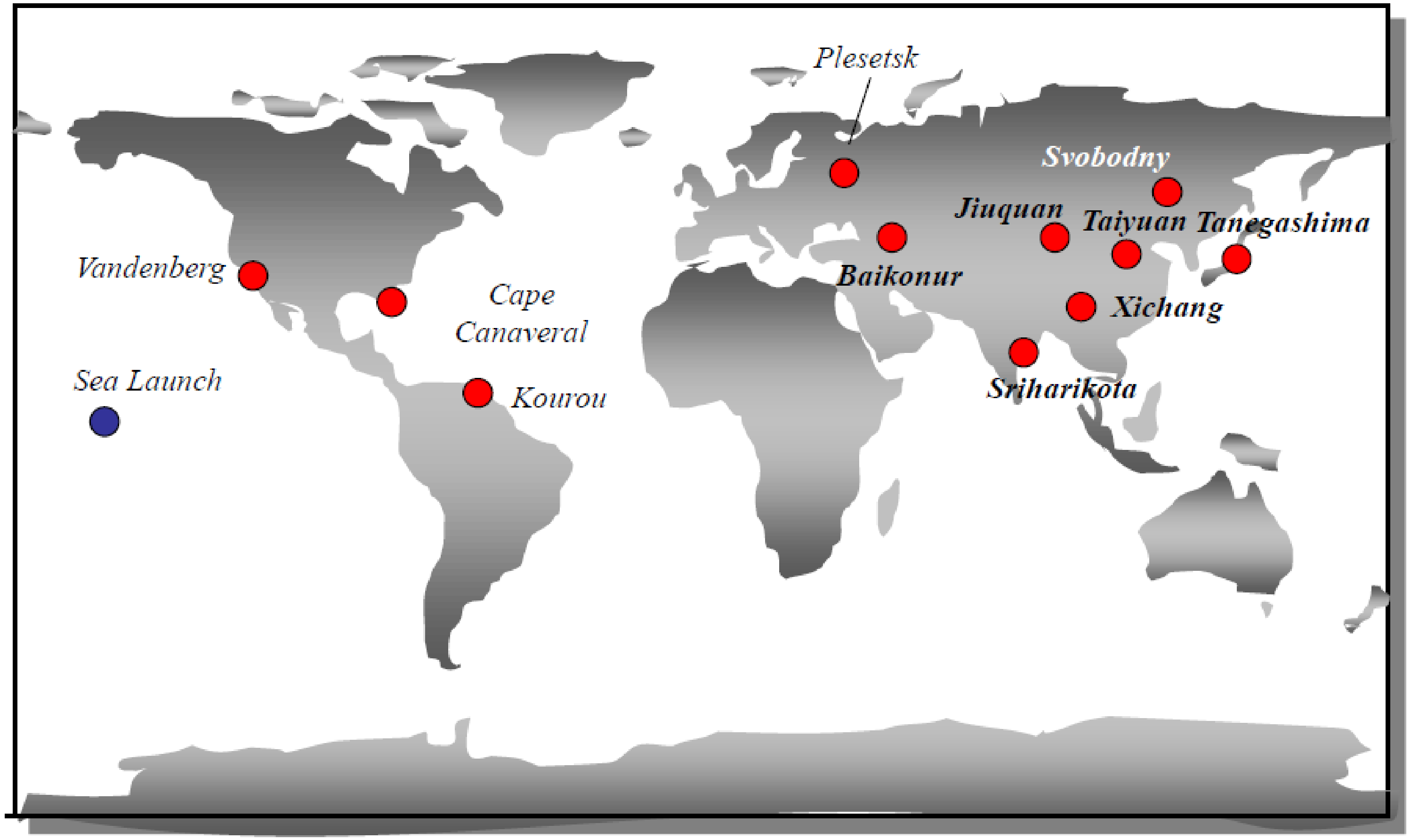
Other Factors

- Gravity: theory assumes instantaneous transfer of energy. However, it takes a finite burn time. The faster the acceleration, the smaller the losses.

- Aerodynamic Drag: at low altitudes atmosphere is dense leading to high drag. Need to compromise with the above.

- Launch site:
  - Use the rotation of the Earth to get a free velocity boost, maximal at the equator.
  - Avoid populous areas.
  - Take into account orbit inclination.

Major Launch Sites



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Reaching Low Earth Orbit

Orbital Velocity	7.7 km/s
Get to Altitude (PE)	1.3 km/s
Gravity Losses	0.7 km/s
Atmospheric Losses (Drag)	0.1 km/s
Earth Rotation (varies)	-0.5 km/s
Total	9.3 km/s