SATELLITE LAUNCHING

EEEN 567 - RADAR & SATELLITE ENGINEERING

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Kenya Space Agency Strategic Plan

Kenya Space Agency staff pose for a photo during strategic plan 2020 - 2025 launch.

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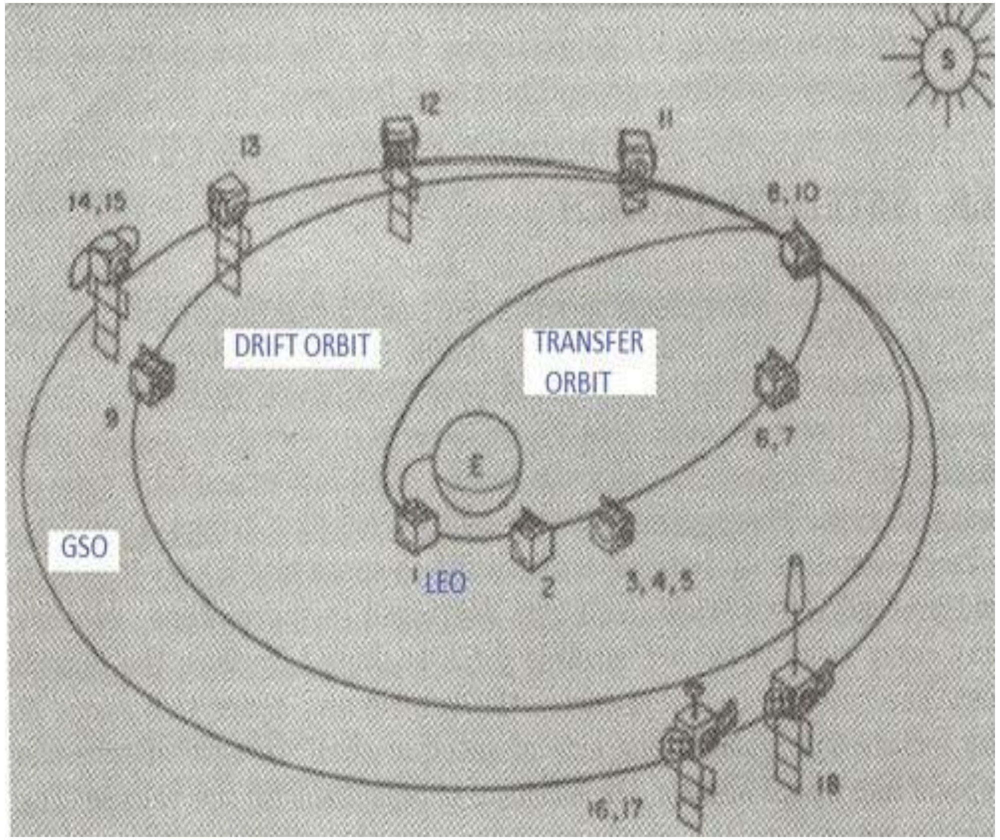
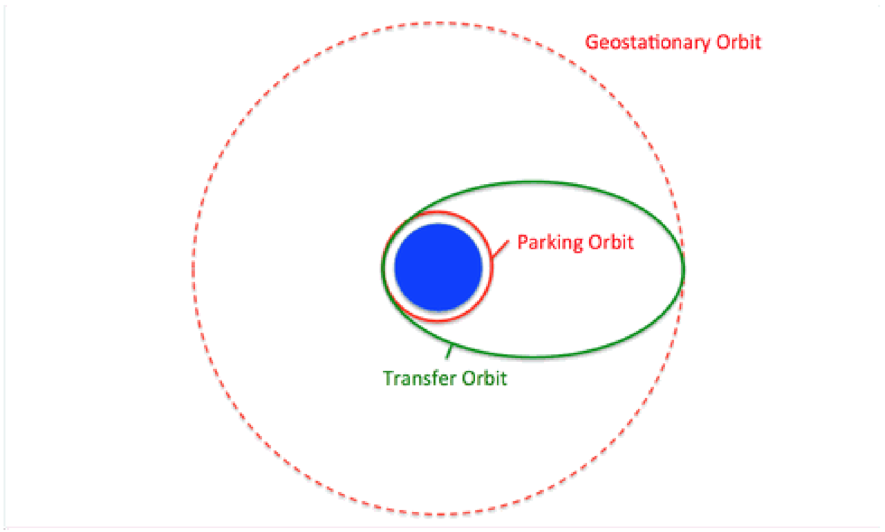
WHAT IS SATELLITE LAUNCHING?

- **Launching a satellite** involves placing it into a specific orbit around Earth or another celestial body.
- **The process requires overcoming Earth's gravity and achieving sufficient velocity to remain in orbit.**
- **Key steps include:**
  1. **Launch:** The satellite is carried by a rocket from the Earth's surface.
  2. **Ascent:** The rocket ascends through the space, often in stages, to reach the desired altitude.
  3. **Orbit insertion:** The satellite is released into its intended orbit, which may involve one or more engine burns.

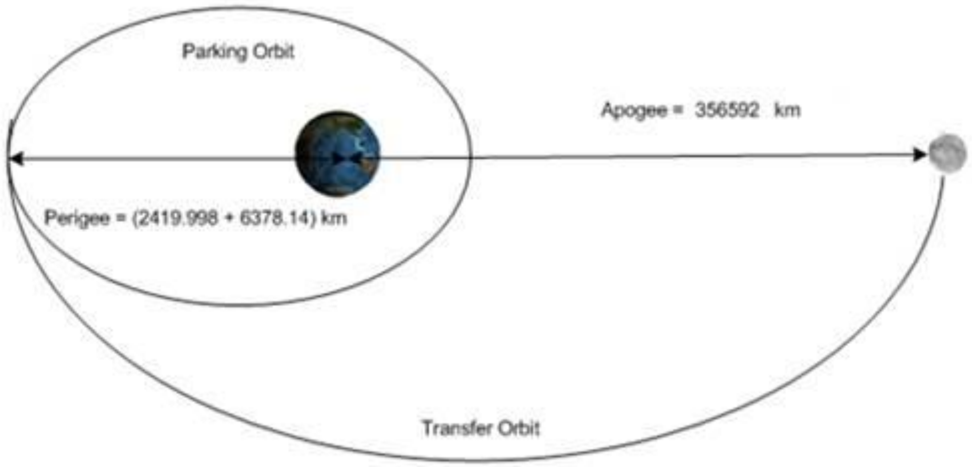


PARKING ORBIT

- **A parking orbit** is a temporary orbit used during the launch of a spacecraft. A launch vehicle boosts into the parking orbit, then coasts for a while, then fires again to enter the final desired trajectory.



- While in parking orbit, the Satellite is checked out and its trajectory measured to determine the velocity and time required to send it to the final orbit or into space is a specific direction.

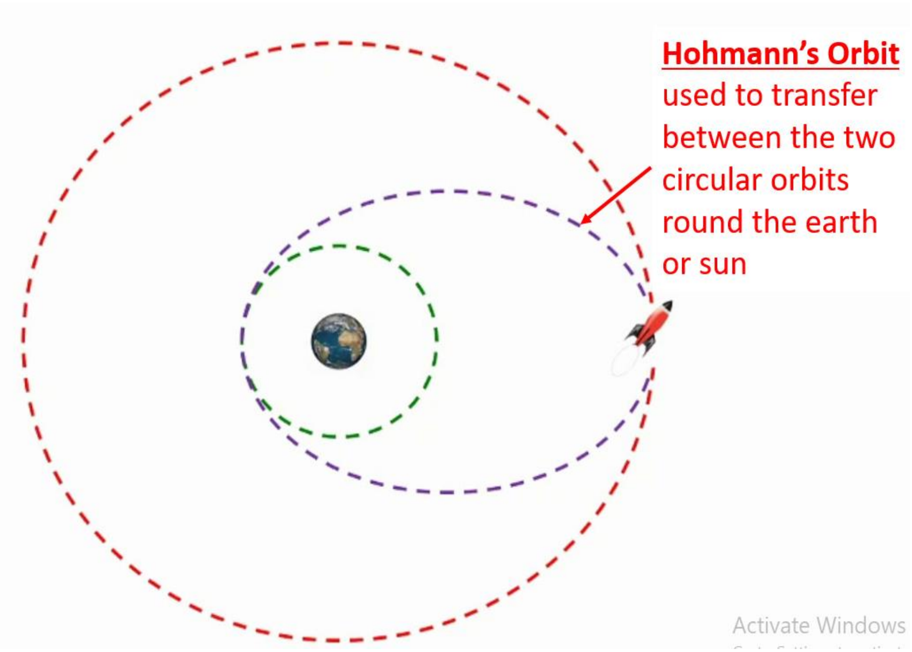


REASONS FOR USING PARKING ORBITS

1. **Parking increases the launch window.** For earth-escape missions, these are often quite short (seconds to minutes) when no parking orbit is used. With a parking orbit, these can often be increased up to several hours.
2. For **non-LEO** missions, the desired location for the final burn may not be in a convenient spot. In particular, for earth-escape missions that want good northern coverage of the trajectory, the correct place for the final burn is often in the southern hemisphere.
3. For **geostationary orbit** missions, the correct spot for the final (or next to final) firing is normally on the equator. It is therefore necessary to hold the satellite in a parking orbit until it is over the equator, then fire again into a geostationary transfer orbit.
4. For **lunar missions**, a parking orbit allowed some checkout while still close to home, before committing to the long lunar trip.
5. Parking is also necessary when the desired orbit has a **high perigee**. In this case the booster launches into an elliptical parking orbit, then coasts until a higher point in the orbit (apogee), then fires again to raise the perigee.

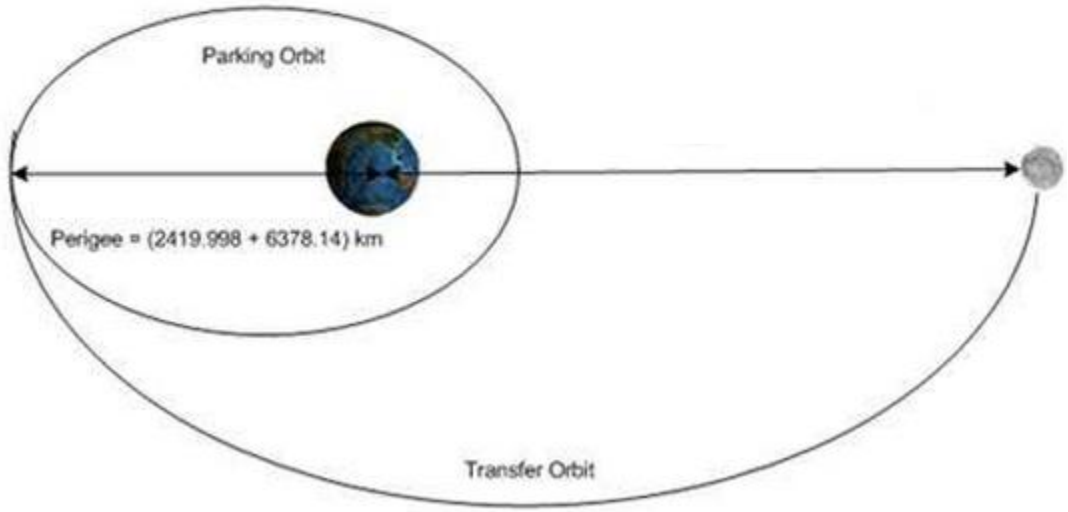
HOHMANN TRANSFER ORBIT

1. The Hohmann transfer orbit is an elliptical orbit used to transfer between two circular orbits of different altitudes, in the same plane.
2. The orbital manoeuvre to perform the Hohmann transfer uses two engine impulses, one to move a spacecraft onto the transfer orbit and a second to move out.
3. The manoeuvre was named after Walter Hohmann, the German scientist who published a description of the orbit in his 1925 book.

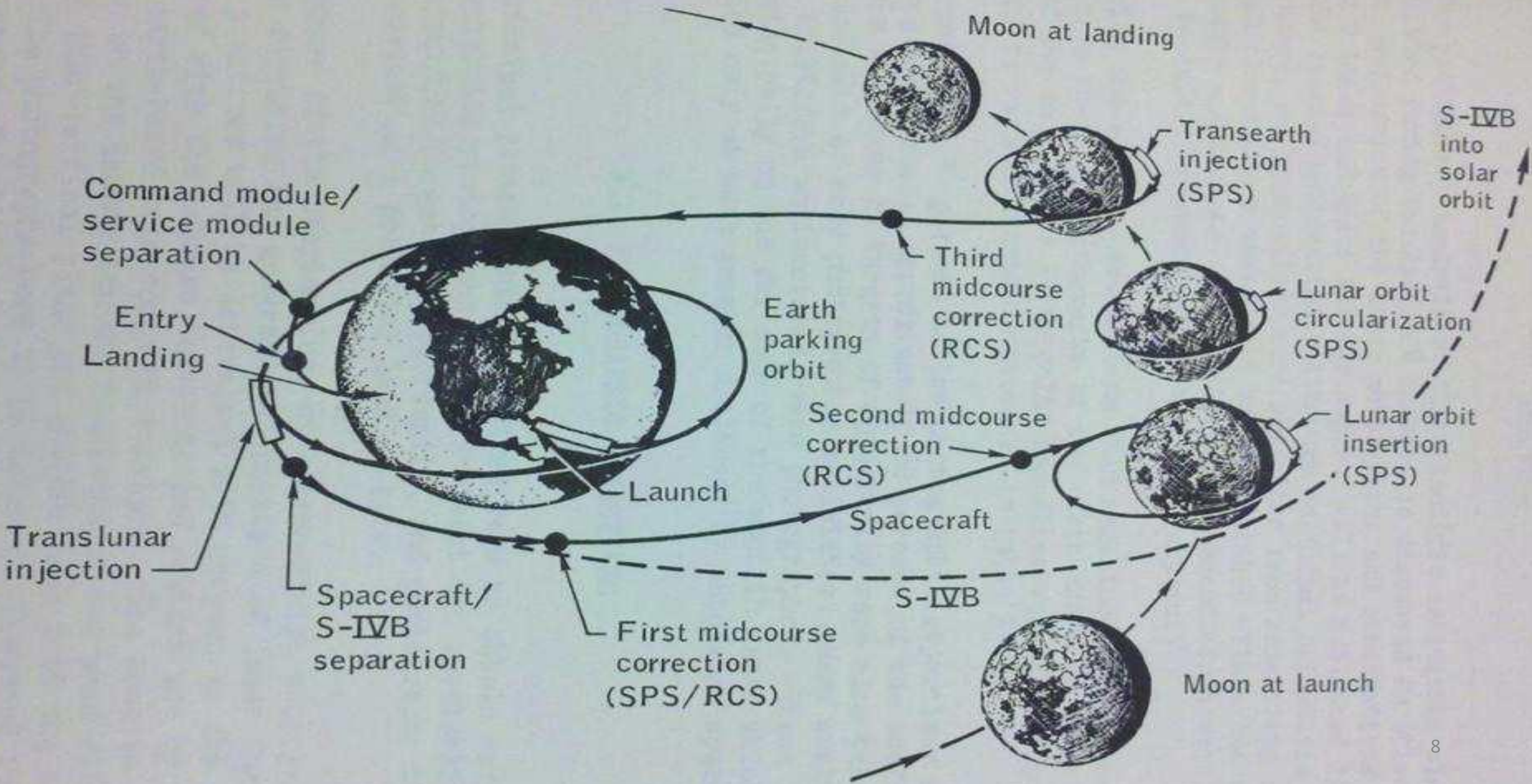


USE OF PARKING ORBITS IN LUNAR MISSIONS

1. The space station is first placed in an elliptical orbit-the parking orbit.
2. The next stage of the journey to the Moon requires firing from parking orbit to transfer orbit.
3. This is accomplished by firing the spacecraft's engine when it reaches its apogee.
4. The goal is to make the apogee of the parking orbit serve as the perigee of the mission orbit.
5. The apogee of the transfer orbit now corresponds to the Moon.

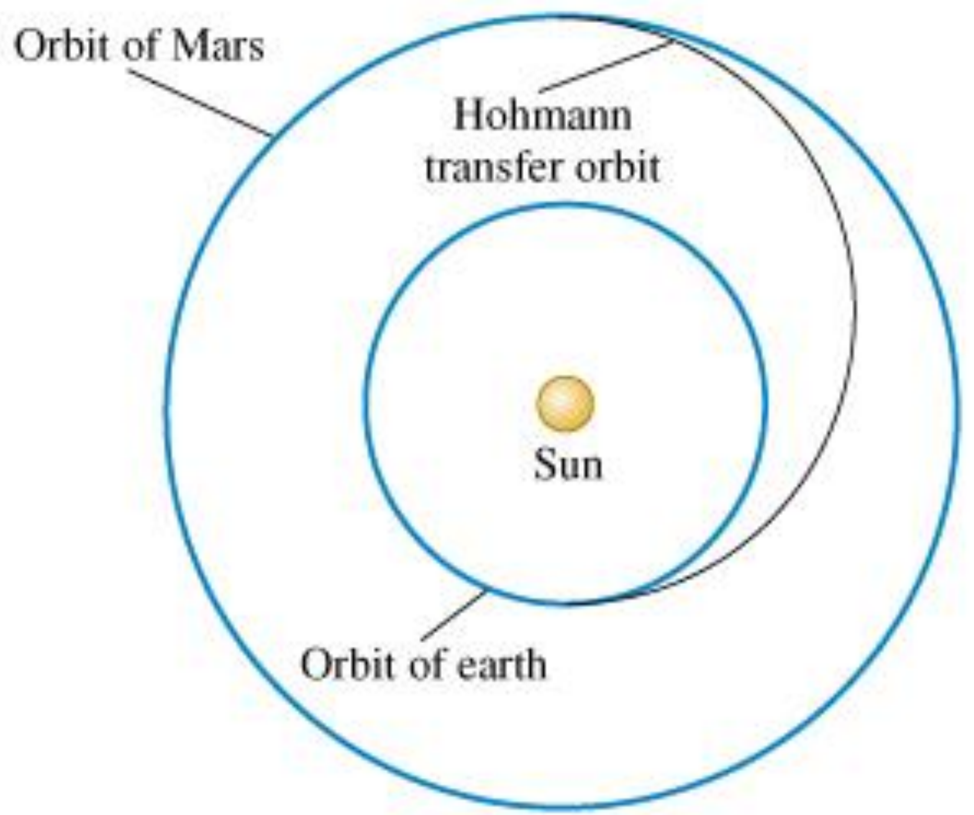


LUNAR MISSION



EARTH TO MARS MISSION

- The most efficient way to send a spacecraft from the earth to mars is by using a **Hohmann transfer orbit**.
- **The Hohmann transfer orbit for mars mission is an elliptical orbit whose perigee and apogee** are tangent to the orbits of the two planets.
- The rockets are fired briefly at the departure planet to put the spacecraft into the transfer orbit; the spacecraft then coasts until it reaches the destination planet.
- The rockets are then fired again to put the spacecraft into the same orbit round the sun as mars.



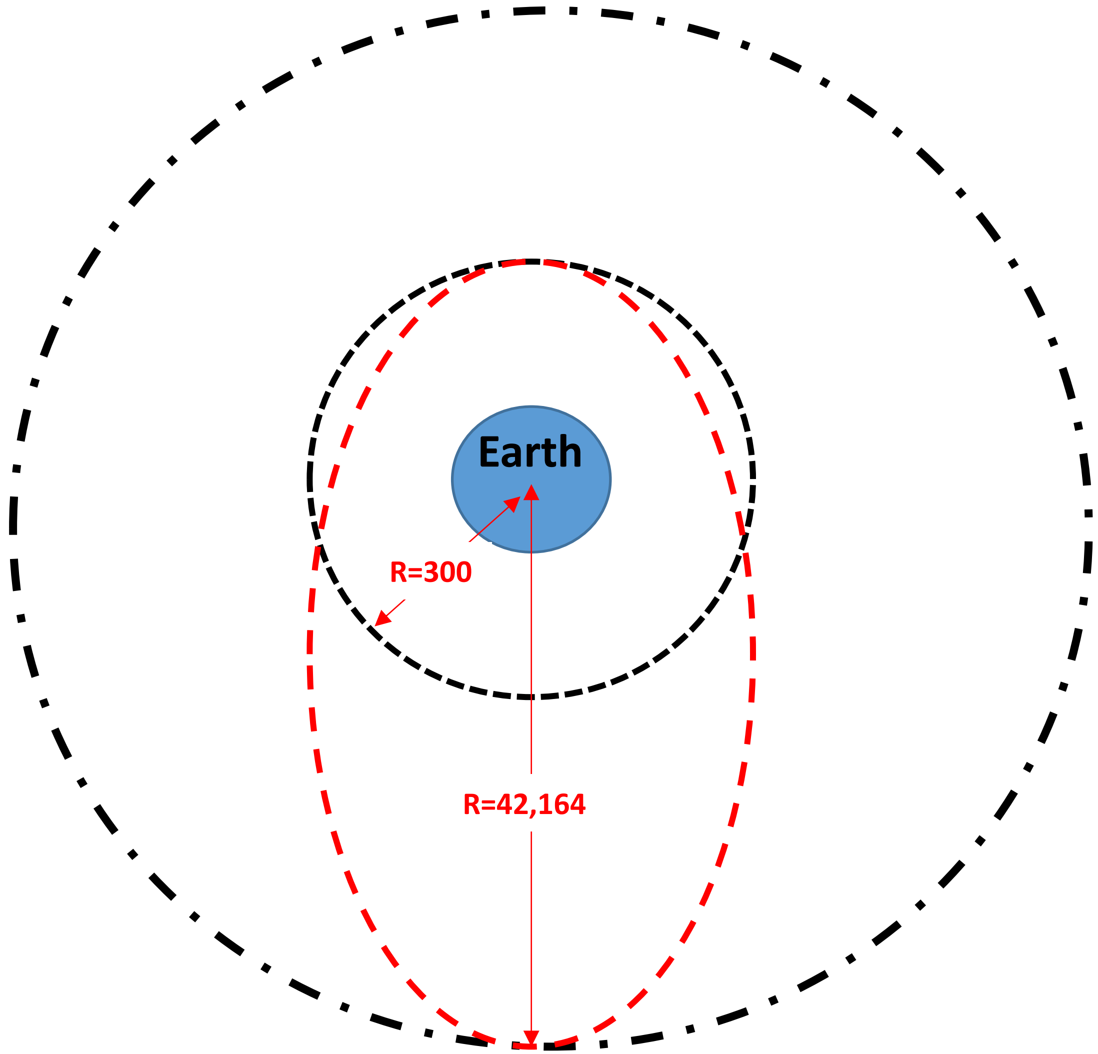
DISADVANTAGES OF USING PARKING ORBITS

The main disadvantage of using parking orbits is the need to use liquid fuel engines as opposed to solid fuel. The reasons are as follows.

1. A rocket needs to coast for a while in the parking orbit, then restart while under zero gravity conditions.
2. But the length of two of the burns (the initial injection burn, and the final burn) typically depend on where in the launch window of the launch occurs.
3. To do this without wasting fuel, a rocket system that can fire, then stop, then start again as needed.
4. This requires a liquid fuel engine since solid fuel rockets cannot be stopped or restarted - once ignited they burn to completion.

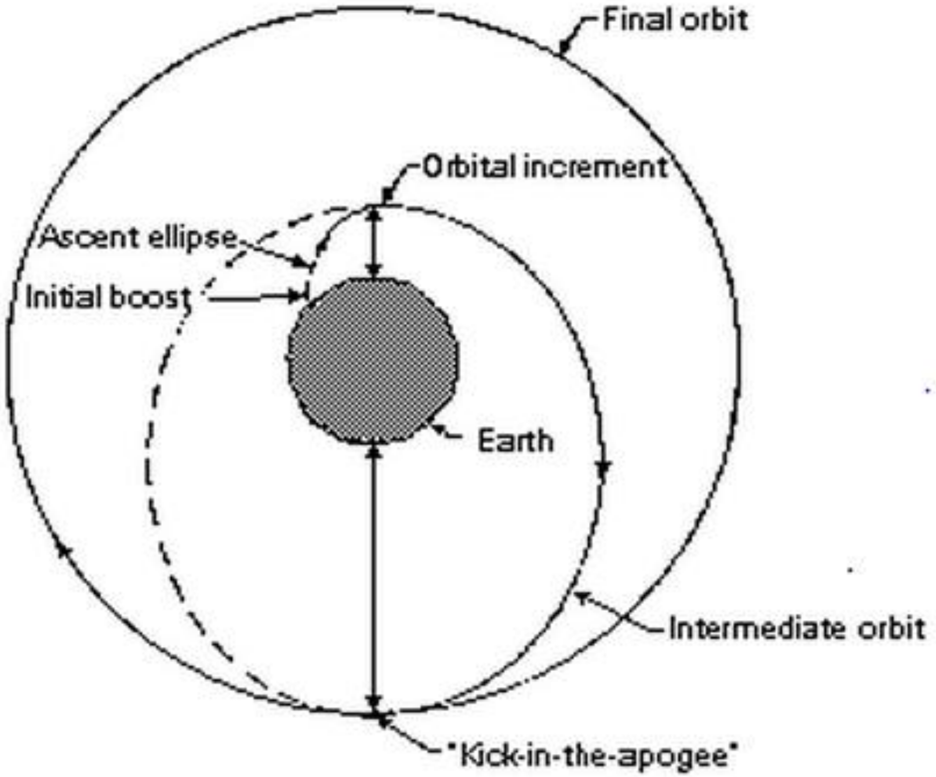
GEOSTATIONARY ORBIT SATELLITE LAUNCHING METHOD 1

1. The satellite is placed in a lower circular orbit at a radius of 300Km
2. The velocity of the satellite is then increased through various propulsion stages changing the orbit into an elliptical orbit with a perigees of 300Kms and an apogee radius of 42,164 Kms.
3. The second velocity increment is then used to make the orbit circular with a radius of 42,164 Kms.
4. This method is used by the Space Transport System (STS).



GEOSTATIONARY ORBIT SATELLITE LAUNCHING METHOD 2

1. The satellite is placed directly into an elliptical lower orbit with a perigee of 300Km and apogee of 42,164 Kms.
2. One velocity increment applied at the apogee pushes the satellite into the geostationary orbit.
3. This method is used by Expendable Launch Vehicle such as Ariane and Delta.



SATELLITE IN CIRCULAR ORBIT

1. Let M be the mass of the earth and m be that of the satellite.
2. If v_s is the velocity of the satellite, h is the height of the satellite and r_e is the radius of the earth then we can write:

$$v_s = \omega(r_e + h)$$

3. If F_1 is the centripetal force on the satellite, then we can write:

$$F_1 = \frac{mv_s^2}{r_e + h} = \frac{m\omega^2(r_e + h)^2}{(r_e + h)} = m\omega^2(r_e + h)$$

4. If the period of the satellite is T, then $\omega = \frac{2\pi}{T}$ and we can write:

$$F_1 = m\left(\frac{2\pi}{T}\right)^2 (r_e + h)$$

5. But the gravitational pull from the earth is given by:

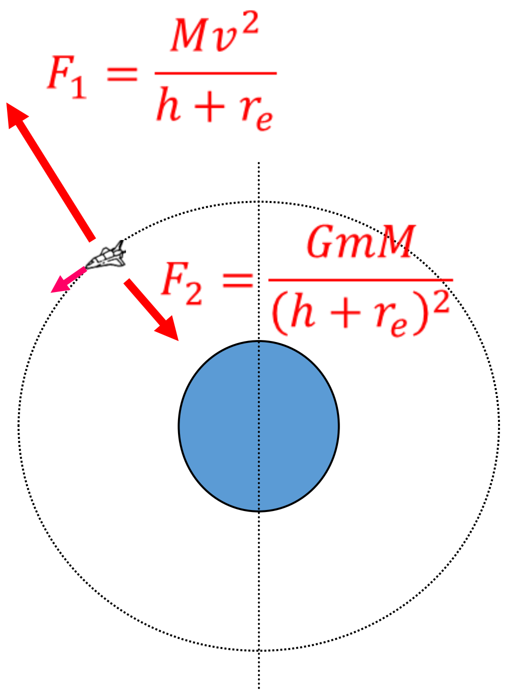
$$F_2 = \frac{GMm}{(r_e + h)^2}$$

6. In equilibrium $F_1 = F_2$

$$m\left(\frac{2\pi}{T}\right)^2 (r_e + h) = \frac{GMm}{(r_e+h)^2}$$

or

$$\left(\frac{2\pi}{T}\right)^2 = \frac{GM}{(r_e+h)^3}$$



For the earth:
$G = 6.672 \times 10^{-11}$ Newton Metre/kg^2
$M = 5.97 \times 10^{24} Kg$
Gravitational Coefficient (or Kepler's Coefficient) is:
$g_0 = GM = 3.9861 \times 10^5$ Km^3/s^2

PERIOD OF SATELLITE IN CIRCULAR ORBIT

$$\left(\frac{2\pi}{T}\right)^2 = \frac{GM}{(r_e+h)^3}$$

- Rearranging the equation and substituting g_o = GM gives:

$$T^2 = \frac{4\pi(r_e + h)^3}{g_0}$$

$$T = \frac{2\pi}{\sqrt{g_o}}(r_e + h)^{3/2}$$

This Confirms Kepler's Second law, i.e

$$R^3 = \frac{\mu}{\omega^2}$$

VELOCITY OF SATELLITE IN CIRCULAR ORBIT

If v_s is the velocity of the satellite, h is the height of the satellite and r_e is the radius of the earth then we can write:

$$v_s = \omega(r_e + h) = \frac{2\pi}{T}(r_e + h)$$

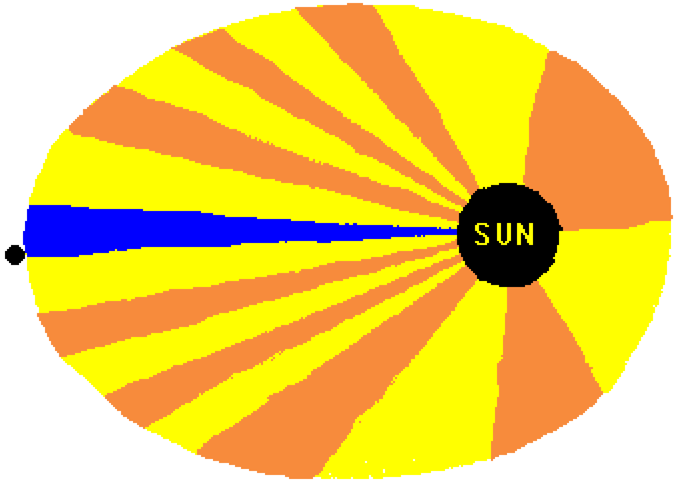
But

$$T = \frac{2\pi}{\sqrt{g_o}}(r_e + h)^{3/2}$$

Therefore

$$v_s = \frac{(r_e+h)}{(r_e+h)^{3/2} / \sqrt{g_o}} = \sqrt{\frac{g_o}{(r_e+h)}}$$

This confirms Kepler's Second law that an increase in radius of the orbit leads to a decrease in the velocity of the satellite.



ESCAPE VELOCITY FOR CIRCULAR ORBIT

1. Escape velocity is the speed at which the kinetic energy plus the gravitational potential energy of an object is zero.
2. It is the speed needed to "break free" from the gravitational attraction of a massive body, without further propulsion.

$$\frac{1}{2}mv_e^2 = \frac{GMm}{r}$$

$$v_e = \sqrt{\frac{2GM}{r}}$$

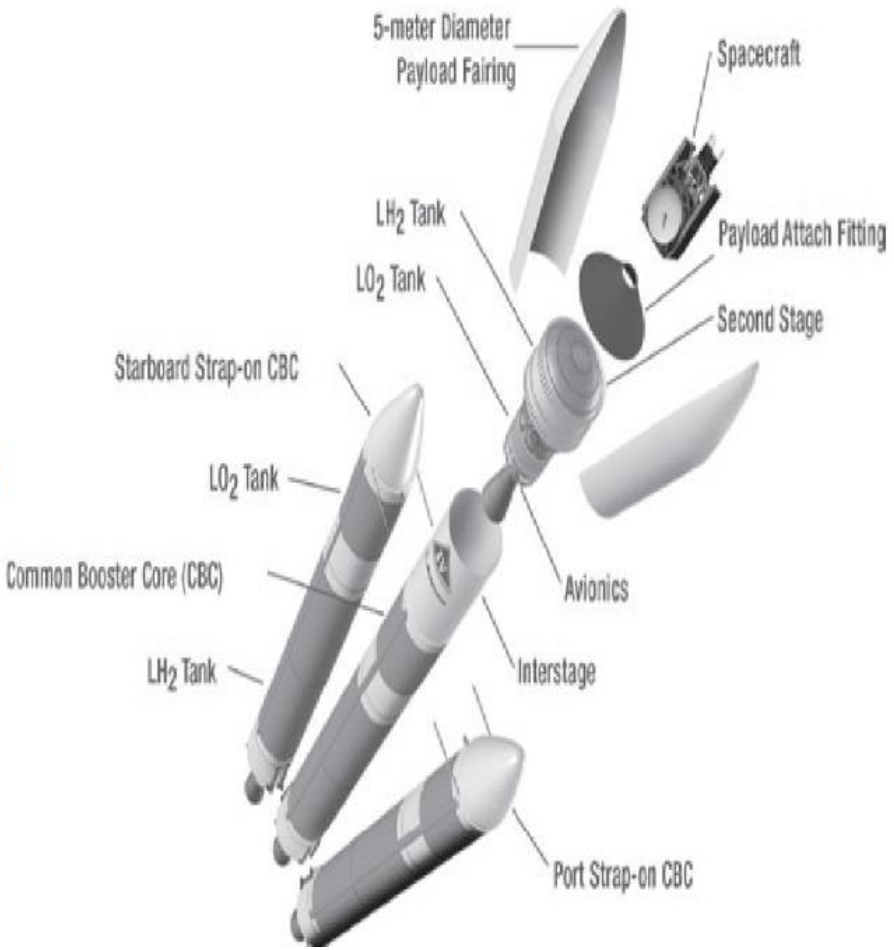
3. The term escape velocity is actually a misnomer, and it is often more accurately referred to as escape speed since the necessary speed is a scalar quantity which is independent of direction

SATELLITE LAUNCH METHODS BASED ON VEHICLES

1. **Expendable Launch Vehicles:** Traditional rockets that are used once and discarded. Examples include Atlas V, Delta IV, and Soyuz.
2. **Reusable Launch Vehicles:** Rockets that can be recovered and flown multiple times, like SpaceX's Falcon 9.
3. **Air Launch to Orbit:** Launching rockets from aircraft at high altitude, used by Virgin Orbit's LauncherOne.

EXPENDABLE LAUNCH VEHICLES (ELVS)

1. **Expendable Launch Vehicles (ELVs)** are rocket systems designed for single-use missions where the various stages are discarded during ascent and cannot be recovered or reused.
2. **ELVs are multi-stage rockets** which operate by sequentially jettisoning empty fuel tanks and spent engines to reduce mass as they ascend, with common configurations including two to four stages that progressively accelerate the payload to orbital velocity.
3. **ELVs main drawback** is extremely high operational costs since entirely new rockets must be manufactured for each launch
4. **ELVs continue to serve vital roles for heavy payloads** and missions where flight heritage outweighs cost considerations.
5. Examples of ELVs are legacy systems like **NASA's Saturn V, Russia's Soyuz, Delta and Europe's Ariane 5.**



REUSABLE LAUNCH VEHICLES (RLVS)

1. **Reusable Launch Vehicles (RLVs) can be recovered**, refurbished, and reflown multiple times rather than being discarded after a single use.
2. **RLVs incorporate advanced technologies** like restartable engines, thermal protection systems, precision guidance and navigation, deployable landing legs, and sophisticated flight control systems that enable controlled descent and landing—either on ground pads, drone ships at sea, or through mid-air capture.
3. **RLVs spread manufacturing costs across numerous missions** while streamlining operations hence are cheaper.
4. **RLVs enable rapid turnaround between missions and support sustainable space operations** by reducing space debris from discarded stages

AIR LAUNCH TO ORBIT

- **In Air Launch to Orbit**, rocket carrying a payload is released from a high-altitude aircraft, typically a modified large cargo or passenger plane, which then ignites its engines to ascend into orbit.
- **The aircraft's carries the rocket to altitudes of 30,000-50,000 feet**, providing several key advantages:
  1. it **avoids the thickest** part of the atmosphere, reducing drag and structural requirements;
  2. **allows launch from virtually any location** with a suitable runway;
  3. enables **more flexible orbital inclinations**;
  4. takes advantage of the aircraft's forward velocity, **resulting in fuel savings and potentially greater payload capacity** compared to traditional ground launches.

Further Reading:
[Preparation of Papers for AIAA Technical Conference`s]