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P1_10 Delta-V Requirements of Spaceflight

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Abstract

The paper calculates the delta-V requirements to launch a spacecraft into Low Earth Orbit and execute Hohmann transfers to the International Space Station orbit and Geosynchronous Orbit. These were found to be 8.03 kms^{-1}, 0.12 kms^{-1} and 3.94 kms^{-1}, respectively. The paper also includes researched values for the delta-V requirements to travel to the Moon and Phobos. The paper aims to highlight the fact that delta-V requirements for manoeuvres beyond Low Earth Orbit are considerably lower than achieving Low Earth Orbit.

Introduction

The past ten years have seen the beginnings of space tourism with the first space tourist, Dennis Tito, spending eight days in space onboard the International Space Station at the cost of £14m [1]. Since this pioneering flight there have been six other space tourists, each paying between $20m and $30m for the privilege to stay onboard the International Space Station [2]. In all cases the tourists have travelled to the International Space Station onboard the Russian Soyuz [2], arranged by the company Space Adventures [3].

The key to launching a spacecraft and manoeuvring a spacecraft in the zero-g environment is to understand the delta-V requirements per action. As these manoeuvres are commonly dictated by the amount of fuel the spacecraft has, it follows that the cost of a mission into space depends somewhat upon the delta-v requirements of said mission. With the recent surge of interest in space tourism by various companies, this paper looks at the delta-V requirements to launch a spacecraft into Low Earth Orbit and to conduct Hohmann transfers to the International Space Station and to Geosynchronous Orbit. The values for the required delta-V's for transfers to the Moon and Phobos are researched.

Theory

To calculate the delta-V required for a Hohmann transfer, the Vis-Viva Integral is used to determine the velocities of the initial circular orbit, elliptical Hohmann transfer orbit and final circular orbit.

$$\Delta v_1 = v_{per} - v_I = \sqrt{\frac{2\mu}{r_1} - \frac{2\mu}{r_1+r_2}} - \sqrt{\frac{\mu}{r_1}} \qquad (1)[4]$$

$$\Delta v_2 = v_{II} - v_{apo} = \sqrt{\frac{\mu}{r_2}} - \sqrt{\frac{2\mu}{r_2} - \frac{2\mu}{r_1+r_2}} \qquad (2)[4]$$

Where Δv_1 and Δv_2 are the required delta-V's to manoeuvre the orbit of the spacecraft into the elliptical Hohmann transfer orbit and the final circular orbit, respectively. v_I and v_{II} are the velocities of the initial and final circular orbits, respectively. v_{per} and v_{apo} are the velocities at periapsis and apoapsis of the elliptical Hohmann transfer orbit, respectively. r_1 and r_2 are the radii of the initial and final circular orbits, respectively. μ is the gravitational parameter of the body being orbited (3.98 x 10^{-8} m^3s^{-2}) [5]. The total delta-V required for the Hohmann transfer is given by

$$\Delta v = \Delta v_1 + \Delta v_2. \qquad (3)$$

Analysis

Using equations (1), (2) and (3) the delta-V requirements were calculated to travel from the radius of the Earth (6370 km): to Low Earth Orbit (200 km), the International Space Station (400 km [6]) and Geosynchronous Orbit (36000 km). These values are shown in table 1 below.

Manoeuvre	$\boldsymbol{r_1}$ (km)	$\boldsymbol{r_2}$ (km)	$\Delta \boldsymbol{v}$ (kms^{-1})
Launch to LEO	6370	6570	8.03
LEO to ISS	6570	6770	0.12
LEO to GEO	6570	42000	3.94

Table 1: Table listing values for r_1, r_2 and the resultant Δv for the Hohmann transfers from launch to Low Earth Orbit (LEO), LEO to the International Space Station (ISS) and LEO to Geosynchronous Orbit (GEO).

Table 1 lists the delta-V requirements for the Hohmann transfer orbits. It was assumed that the initial velocity of the spacecraft on Earth was 0 kms^{-1} and an ideal case was assumed for launch, so atmospheric drag was neglected and only a horizontal velocity component considered. However, when atmospheric drag is taken into account and a vertical launch assumed, the velocity given to the spacecraft due to the Earth's rotation offsets the velocity required to overcome these issues.

Values for orbital transfers to the Moon and Phobos were researched. It was found that a delta-V of 15.2 kms^{-1} is required to travel from the surface of Earth to the lunar surface [7]. Whereas, to travel from the surface of Earth to the surface of Phobos; a delta-V of 14.0 kms^{-1} is required [7]. The oddity that less delta-V is required to travel to Phobos than the Moon can be easily explained by the fact that the gravitational sphere of influence of Phobos is considerably smaller than the Moon's.

Discussion

There are other factors which need considering when planning missions into space, other than the delta-V requirements. Manned missions of a longer duration will require more supplies such as food, water and oxygen. These requirements will obviously increase the mass of the spacecraft and hence the cost of the launch.

Missions, which involve extended travel beyond Low Earth Orbit, will be at risk from prolonged exposure to solar radiation. A form of radiation shield may have to be incorporated, this to would add to the cost of the mission.

Conclusion

Comparing the results in table 1 and the values obtained for a transfer to the Moon and Phobos, it can be deduced that the most costly aspect of space travel, in terms of delta-V, is achieving a Low Earth Orbit about the Earth. Once there it is relatively inexpensive to travel to higher orbit and beyond. Therefore, the space tourism industry could look at the possibility of offering cheaper "flights" from Low Earth Orbit to more distant destinations compared to more costly "flights" from Earth. Alternatively, if a technology were developed which would enable the mass transit of customers from the Earth to Low Earth Orbit, space travel would become a little more affordable. The two values researched for the delta-V requirements to travel to the Moon and Phobos help to illustrate that it is not always obvious which destinations require the least delta-V.

References

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