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P5_4 Decommissioning the International Space Station

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Abstract

The goal of this paper was to see whether it would be possible to de-orbit the International Space Station by completing a single Hohmann Transfer burn, using only the Progress module engine, reducing its orbital radius so that it experiences higher atmospheric drag. We found that 12,760 kg of fuel would be required to create a burn to achieve this, and therefore not possible with the Progress module in its current capacity.

Introduction

The International Space Station (ISS) is one of the world's greatest scientific feats, having occupied space since late 2000 [1]. In the not-too-distant future, the ISS will have expired it's mission duration and will be decommissioned; the objective of this paper is to see whether it would be possible, using the Progress module, to de-orbit the station so that it is captured by the Earth's atmosphere.

Theory

De-orbiting a spacecraft involves applying an orbital manoeuvre to decrease the spacecraft's orbital radius, so that it falls within the Earth's atmosphere and experiences atmospheric drag, eventually bringing it down. The most energy efficient orbital transfer is called the Hohmann Transfer, which is simply an elliptical transfer where, in this case, the apogee is at the starting radius of the ISS, and the perigee is at the top of the atmosphere, as shown in figure 1. This orbit is achieved by burning the engines in the opposite direction to the motion of travel, to slow down the orbital velocity. The equation for this burn [2] is given by:

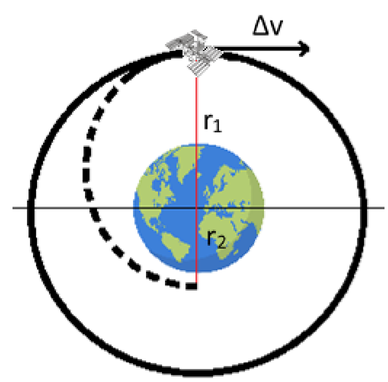

Figure 1: The Hohmann Transfer for the ISS to reduce it's orbital radius to that of the Earth's atmosphere.

$$\Delta v = \sqrt{\frac{GM}{r_1}}\left(\sqrt{\frac{2r_2}{r_1+r_2}}-1\right) \tag{1}$$

where Δv is the change in velocity (delta-v) required to change the orbit, G is the gravitational constant, M is the mass of the Earth, r_1 is the initial radius of the ISS and r_2 is the radius at the top of the atmosphere.

As there is no distinct boundary between the atmosphere and the vacuum of space, we decided to choose 100 km as our goal altitude [3], below which lies 99.99997% of the atmosphere [4].

We then needed to consider the capabilities of the Progress module attached to the ISS [5], which has a fuel capacity of 880 kg, and an average specific impulse of 306 s; the specific impulse is a measure of how effectively an engine uses fuel and is directly proportional to thrust. Both mass and specific impulse are factors that help make up Tsiolkovsky's rocket equation given by:

$$\Delta v = I_{sp} g \ln\left(\frac{m_i}{m_f}\right) \tag{2}$$

where Δv is the delta-v from the transfer, I_{sp} is the specific impulse, g is acceleration due to gravity on Earth, m_i is the mass of the ISS with the necessary fuel and m_f is the mass of the ISS when the fuel is used (given as 419,725 kg) [1]. We wanted to know how much fuel would be required to complete the manoeuvre, so rearranging for m_i gives:

$$m_i = m_f \exp\left(\frac{\Delta v}{I_{sp} g}\right) \tag{3}$$

Calculations

Firstly, we wanted to find how big of a delta-v would be required to complete our desired Hohmann Transfer, so taking the average altitude of the ISS to be 409 km [1], we get $r_1 = r_{Earth}$ + 409 km = 6780 km. Similarly, $r_2 = r_{Earth}$ + 100 km = 6471 km, so substituting those values into equation 1 we get Δv = -89.9 m/s. This answer is negative because the burn is in the opposite direction to the motion of travel, so for the circumstance of utilising the rocket equation here we can take the modulus of Δv.

Now to find the mass of fuel required to complete this delta-v we substitute our Δv value into equation 3, and using the aforementioned values for I_{sp} and m_f, we find that the mass of the ISS with fuel is 432,485 kg, meaning that a fuel mass of 12,760 kg is needed to complete the burn.

Discussion & Conclusion

Evidently this value of 12,760 kg is an enormous amount of fuel, and given that the Progress module in its current state has a capacity of 880 kg of fuel, it is not capable of completing the burn required to send the ISS into the atmosphere in one burn. There are margins of error within our calculations as all of the values we have used are rounded up, as well as the fact that we have taken averages of both the initial orbit radius, and the specific impulse of the Progress engine- both of which vary. We believe that either multiple Progress modules would need to be employed to achieve this de-orbiting manoeuvre, or the Progress engine would need to be modified so that it had a greater specific impulse. It should also be noted that we have assumed that the burn completed by the engine is instantaneous, whereas in reality the burn would take a more considerable length of time. This would not particularly affect the ISS in achieving its desired new altitude of 100 km, however it would not reach that height on the exact opposite side of the Earth as suggested by figure 1. Another factor to consider is that the ISS at its current altitude already experiences some atmospheric drag, so it may take less fuel to complete the transfer than first calculated.

References

[1] `https://www.nasa.gov/feature/facts-and-figures` [Accessed 8 October 2019]

[2] `https://ocw.mit.edu/courses/aeronautics-and-astronautics/16-07-dynamics-fall-2009/lecture-notes/MIT16_07F09_Lec17.pdf` [Accessed 8 October 2019]

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[4] F. K. Lutgens, E. J. Tarbuck, *The Atmosphere*, Prentice Hall, 6th ed, pp 14-17

[5] `http://spaceflight101.com/spacecraft/progress-m/` [Accessed 8 October 2019]