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A4_5 Solar Propelled Rocket

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Abstract

In this paper we discuss whether it would be feasible to replace the current Soyuz rocket's Earth launch phase, with the radiation pressure from reflected solar radiation. We find that the mirror would need an area 2.05×10^5 km^2 in an ideal situation. This is deemed too large to be practical.

Introduction

Launching objects and people into space is very expensive, in this article we discuss if it would be feasible to replace the first stage of a rocket to reduce cost. The concept we test uses a large mirror - lens system that reflects sunlight directly onto the rocket. Using the radiation pressure produced by this to push the rocket into a geosynchronous position, from which it could then accelerate to orbital velocity.

We evaluate the feasibility of the concept, by finding the mass of the rocket m_2 that would be required to get up to orbital velocity v_{orbit}, from geosynchronous velocity v_2, at the radius of the ISS from the centre of the Earth r_2, with the same payload mass m_p as the Soyuz 2.1a, the rocket that currently resupplies the ISS. We then find the collection area A required to collect enough of the Sun's light for this to be possible.

Mass to Lift

To let this system replace the Soyuz 2.1a we require the mirror to lift the same m_p of 7020 kg [1], and achieve v_{orbit} of 7.67 kms^{-1} [2] to reach the ISS at its altitude of 400 km [2], equivalent to an r_2 of 6778 km. We design the mirror to move only to track the Sun's path through the sky, as it will be large enough that dynamical tracking of the rocket will be difficult. The mirror must therefore also lift the mass of the fuel m_{fuel}, and engine m_e required to accelerate the payload to v_{orbit} after it is launched vertically by solar power. We find the initial required mass including fuel, and engines m_1 by a rearrangement of the Tsiolkovsky rocket equation [3], as a function of mass after acceleration to orbit m$_{orbit}$, substituting a specific impulse I_{sp} of 359 s [4], and gravitational acceleration at the Earth's surface g_0 which is 9.81 ms^{-2} for exhaust velocity

$$m_1 = m_{orbit} e^{(v_{orbit} - v_2)/(I_{sp} g_0)}. \tag{1}$$

Where $v_{1,2}$ are the velocities which keep the mirror directly beneath the rocket at the radius of the Earth r_1 and at orbit radius r_2, and so is given by orbital distance and period

$$v_{1,2} = 2\pi r_{1,2}/(24 \times 60^2). \tag{2}$$

Given that a rocket engine is required to fire the fuel, we find a m_e to m_{fuel} ratio b using values for a 3rd stage Soyuz engine (2335, and 25400 kg respectively).[4]

$$b = m_e/m_{fuel} = 0.0919, \tag{3}$$

and we have that,

$$m_1 = m_p + m_e + m_{fuel}, \tag{4}$$

$$m_{orbit} = m_p + m_{fuel} b, \tag{5}$$

which can be substituted into Eq. (1), the appropriate terms multiplied by m_{fuel}/m_{fuel} and rearranged to find

$$m_{fuel} = m_p \frac{1 - e^{(v_{orbit} - v_2)/(I_{sp} g_0)}}{b e^{(v_{orbit} - v_2)/(I_{sp} g_0)} - b - 1}. \tag{6}$$

Substituting in values into Eq. (6) finds that m_1 is 125×10^3 kg.

Mirror Required

We wish to only make one mirror, that can be used all year round. As such, we place it at the equator where the Sun rises high all year. We assume that a negligible amount of the Sun's light is absorbed by the atmosphere, and that the mirror reflects and focusses all wavelengths perfectly onto the base of the rocket. For simplicity we assume that gravitational acceleration g is constant, and equal to g_0 through the launch phase. We want the Sun to be close to directly overhead and so we set a limit for the launch phase time t of 2 hours, spread around solar noon. From rearranging one of the equations of motion we found that the acceleration a, required to lift the rocket in the required time is given by

$$a = 2(r_2 - r_1)/t^2. \tag{7}$$

Using the Pythagorean theorum to equate the final movement state of the rocket, we require a force F to launch the spacecraft and keep it directly overhead

$$F = \sqrt{(m_1 g + 2m_1 \frac{r_2 - r_1}{t^2})^2 + (m_1 \frac{v_2 - v_1}{t})^2}. \tag{8}$$

Then from the formula for radiation pressure due to luminosity of the Sun [5] L, which is 3.90×10^{26} Js^{-1}, at a distance from the source d equal to 1 AU or 1.496×10^{11} m [3], and where c is equal to 2.998×10^8 ms^{-1} we have

$$F = AL/(3\pi c d^2), \tag{9}$$

Equating and rearranging Eq. (8), and (9) where $v_{1,2}$ are given by Eq. (2) we find the collection area is given by

$$A = \frac{3\pi c d^2 m_1}{L} \sqrt{(g + \frac{2(r_2 - r_1)}{t^2})^2 + (\frac{v_2 - v_1}{t})^2}. \tag{10}$$

Finding that A would be 2.02×10^5 km^2.

Conclusion

We have ignored the absorption of solar radiation by the atmosphere, and assumed the mirror is perfectly reflecting in all wavelengths, neither of which are accurate. When both are taken into account, the size of the already too large to produce mirror would increase. The rocket that would be pushed into orbit would also need a perfectly reflecting mirror on it, as if it did not the radiation focused onto it would quickly heat up the spacecraft and ignite the fuel. This possibility would make the spacecraft very unstable. Because of these reasons the group believes it is very unlikely that anything such as this could be a viable option for lifting a spacecraft of this size.

References

[1] `http://spaceflight101.com/spacecraft/soyuz-ms/` [Accessed 14 November 2017]

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[5] `http://www.am.ub.edu/~robert/Documents/radiation_pressure.pdf` [Accessed 14 November 2017]