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P3_6 Can an Ion Thruster Prevent ISS Orbital Decay?

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Abstract

We propose the use of an ion thruster to counteract the effect of orbital decay on the International Space Station. Based on ISS altitude data, we calculate the drag force on the station to be 0.07 N. Consequentially, an ion thruster operating at 1 kW and consuming 9 kg of Xe fuel per month is sufficient to counteract this. The feasibility of such a method is considered.

Introduction

Ion thrusters are a form of electric propulsion system that have successfully been used in space missions, such as Deep Space One [1]. They operate by using an exhaust gas (usually Xenon) that is ionized by electron bombardment, and then accelerated between two differing potentials. This acceleration also causes an acceleration in the overall spacecraft in the opposite direction, due to the conservation of linear momentum, thus generating a thrust.

Ion thrusters are characterised by low thrusts and long operating times, compared to traditional chemical rockets where the inverse is true. By attaching an ion thruster to the International Space Station (ISS), a constant low thrust could potentially counteract the force of atmospheric drag, preventing a decay in orbit.

Theory

In order to calculate the thrust required of such a propulsion system, the drag force acting on the system must be known. By using ISS altitude data [2], we see that between the ends of November '16 and March '17 the ISS dropped a total of 3 km in altitude (from 406.6 km to 403.3 km), with no boosts. The rate of orbital decay is variable, as demonstrated in the data. However by using the average over several months of data, a more accurate estimate is made. To calculate the difference in orbital velocities between these two altitudes, we use the equation,

$$v_o = (\frac{GM_E}{R_E + R_o})^{1/2} \tag{1}$$

Where v_o is the orbital velocity, M_E is the mass of Earth, R_E is the radius of the Earth, R_o is the altitude of the orbit and G is the gravitational constant [3]. Note that for simplicity we assume that the ISS is in a perfectly circular orbit. Substituting values into Eq. (1) gives a change in orbital velocity of 1.7 ms^{-1} between November '16 and March '17. By taking the velocity change and dividing by a time of 4 months (10^7 s), we arrive at an acceleration of 1.7×10^{-7} ms^{-2}. Thus, by Newton's 2nd Law, we can use the ISS mass of 4.2×10^5 kg [4] to arrive at a drag force, F_D, of 0.07 N. This is a small force but not unreasonable, given the low particle density at this altitude.

To counteract this drag force, an equal and opposite force of 0.07 N must be generated by the thruster. The equation for rocket thrust [5] is given as

$$F_{\text{thrust}} = \dot{m}v_e, \tag{2}$$

Where $\dot{m}$ indicates mass flow rate, and v_e is the velocity of exhaust particles. We act under the dual assumptions of the system using the minimum power possible, 1 kW [6], and that all power is used in the accelerating grids and ionisation (without delving into the complexities of the system, this is largely true). For this power, there is a corresponding minimum exhaust velocity of 20 kms^{-1} [5]. Thus, for a thrust force of 0.07 N and an exhaust velocity of 20 kms^{-1}, we find a mass flow rate of 3.6×10^{-6} kgs^{-1}. This gives a monthly fuel requirement of roughly 9 kg of Xe in order to constantly maintain this thrust.

Discussion

These results show that for a relatively small amount of Xenon per month and a constant 1 kW of power, an ion thruster would work in combating drag force, preventing orbital decay. Other considerations need to be made however. In the altitude data, we see a slightly different decay rate after each orbital boost. While this is a variable rate, we have simply calculated the force for one (albeit long) period between boosts. A solution to this would be to average decay rate over all the years the ISS has been in orbit and then match the thrust to the corresponding drag force, though that is beyond the scope of this paper.

A second consideration is cost. In order to install such a system, an ion thruster would need to be built and then flown to the ISS, along with a plentiful supply of Xe fuel. The unit would also need to be installed during an EVA (Extravehicular activity), a risky and expensive procedure that requires astronauts to train for months. These considerations would most likely rule out installing such a system when conventional periodic rocket boosts work equally as well.

There is one unmentioned advantage to rocket boosts. During a potential collision, a rocket boost can simultaneously drive the ISS out of the path of the object whilst also increasing altitude. With an ion thruster, a chemical rocket system must still be fitted, as it is unlikely that the thruster could change trajectory in time to avoid collision due to its low thrust compared to chemical rockets.

Conclusions

Over 4 months, the ISS drops in altitude by 3 km, corresponding to a velocity change of -1.7 ms^{-1} which is caused by a drag force of 0.07 N. We find that this force can be counteracted by an ion thruster providing a constant thrust of 0.07 N. For a power of 1 kW, this would require 9 kg of Xe per month. As a comparative factor, the ISS generates 84 kW of energy [4] and Xe could be regularly transported to the station during resupply missions.

We find an ion thruster to be a suitable alternative to preventing orbital decay, although the unnecessary nature of such a project makes it unlikely to be a focus of space agency funding in the future, when conventional rocket boosts serve well.

References

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