Journal of Physics Special Topics
An undergraduate physics journal

A5_3 Explosive Decompression: Trajectory Troubles

J. MacQuillin, J.F.B.Q. Kerr, J. Musk, I. Priest

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

November 29, 2020

Abstract

In this paper we model the effects of an Explosive Decompression on the orbital trajectory of the International Space Station (ISS). We found that in an ideal decompression, the trajectory of the ISS would remain relatively unchanged, only affecting the altitude of perigee by 8 km.

Introduction

A common occurence in science fiction is a spacecraft experiencing Explosive Decompression (ED). ED refers to the rapid loss of pressure due to a sizable breach in the hull. An instance of this occurs in the film "The Martian" [1]. ED is used by the crew of the Hermes to cause a change in velocity of the craft (Δv), in order to rendezvous with the titular stranded astronaut. In this paper we apply the concept of using ED as a source of thrust for the International Space Station (ISS), specifically to see whether an ED event that drains every module is capable of producing enough Δv to de-orbit the station when fired retrograde.

Method

To simplify the problem we made the following assumptions. Firstly, the air density and pressure on the ISS are that of the Earth's atmosphere at STP. Secondly, the ED leads to a constant thrust vector through the centre of mass of the ISS. Thirdly, the internal gas pressure and density remain constant throughout the ED. Finally, the Δv acts on the ISS instantaneously. To go about calculating whether such an ED could be capable of de-orbiting the ISS we need to calculate the Δv the ED would cause. We first went about defining the velocity at which the atmosphere within the ISS would eject at. This was done using a rearrangement of the Bernoulli Equation [2]. Our rearrangement assumes that the gravitational terms cancel due to micro-gravity, that the pressure outside the ISS is 0 Pa and the gas velocity inside the ISS is 0 ms^{-1}. We then took this simplified form, and rearranged for v, the gas velocity as it leaves the ISS. The rearrangement gives Equation 1.

$$v = \sqrt{\frac{2P}{\rho}} \tag{1}$$

Where P is the pressure of the atmosphere inside the ISS, and ρ is the density of the air inside the ISS. Next, we used the Tsiolkovsky Rocket Equation, Equation 2, to calculate the Δv caused by the ED.

$$\Delta v = v_e \ln \frac{m_0}{m_f} \tag{2}$$

Where v_e is the exhaust velocity, m_0 is the mass including the propellant, and $m_f = m_0 - V\rho$, which is the mass after the propellant has been ejected, where V is the pressurised volume of the ISS. By substituting Equation 1 into v_e and the equation for m_f into Equation 2, we form Equation 3.

$$\Delta v = \sqrt{\frac{2P}{\rho}} \ln\left(\frac{m_0}{m_0 - V\rho}\right) \qquad (3)$$

Once the Δv caused by the ED was calculated, we input this value as a deceleration "burn" into GMAT (NASA's General Mission Analysis Tool) [3]. GMAT performed a simulation of the trajectory travelled by the ISS before and after the ED event, allowing us to determine whether the change in orbit would cause the ISS to de-orbit.

Results

For the calculation of Δv, we used the values: $P = 101325$ Pa, $\rho = 1.225$ kgm^{-3}, $m_0 = 419725$ kg [4] and $V = 932$ m^3 [4]. Plugging these numbers into Equation 3 gave us the value of $\Delta v = 1.108$ ms^{-1}. When we put this value into the simulation as the Δv, it produced Figure 1.

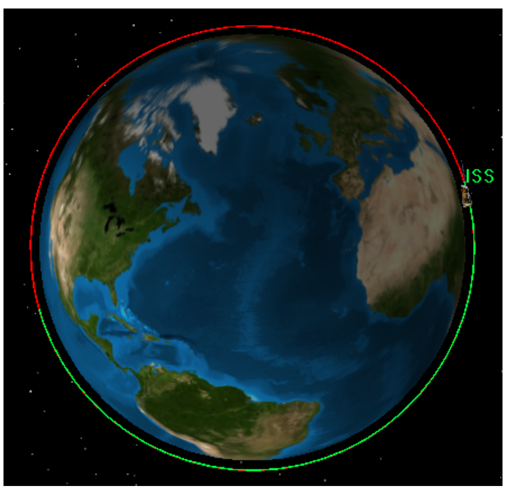

Figure 1: The GMAT visualisation showing the red initial orbit of the ISS, and the green post-ED orbit. The burn occurs at the left of the image.

The post-ED orbit perigee that the simulation stated had an altitude of 400 km, an 8 km reduction from it's original value of 408 km [5].

Conclusion

At the new altitude of perigee, the atmospheric density of Earth is insufficient to provide the drag necessary to complete the de-orbit of the ISS. This shows that given the initial assumptions are valid, the ISS would be safe in its orbit in the event of an ED, though the same cannot be said for the crew. However, some of our assumptions would significantly change the Δv value if they were accounted for. Our second assumption, that the thrust vector acts through the centre of mass, is idealistic, as the majority of the ISS' mass is contained in the Truss structure. The pressurised segment is suspended underneath the Truss, which means that the decompression would likely cause a torque, rather than a linear force. Our third assumption is also unrealistic, as while the decompression is classed as explosive, it would still act over a period of time. This would make the manoeuvre less efficient, causing the perigee to change even less. This also invalidates our final assumption, as it states that the burn happens instantaneously. In conclusion, the value that we calculated is likely a maximum for de-orbiting the ISS with the atmosphere contained within. Therefore, in the event of an Explosive Decompression on the ISS, the station would remain in orbit of the Earth.

References

[1] *The Martian*. 2015. [Online] Directed by Ridley Scott. Hungary: Scott Free Productions [Viewed 3 November 2020]. Available from Netflix.

[2] P.A. Tipler, G. Mosca, *Physics for Scientists and Engineers, 6th Ed* (New York, 2008), Ch. 13, p. 441.

[3] NASA Goddard Space Flight Center, "General Mission Analysis Tool (GMAT)," version R2020a. `http://gmatcentral.org`

[4] `https://www.nasa.gov/feature/facts-and-figures` [Accessed 4 November 2020]

[5] `https://www.heavens-above.com/orbit.aspx?satid=25544` [Accessed 4 November 2020]