Journal of Physics Special Topics

P2_1 De-orbiting Envisat

K. Raymer, T. Morris, O. Youle, B. Jordan

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

October 9, 2013

Abstract

After losing contact with ESA's Envisat last year, the satellite has become a major addition to the ever increasing amount of space debris orbiting our planet. Due to its size and current orbit altitude, the risk of collision is very high. This paper examines how much fuel would be necessary to de-orbit Envisat to an orbit altitude of approximately 700km, where the time it would take for it to return to Earth would be 25 years. It was found that 143kg of fuel is needed. Whilst this amount is feasible, difficulties arise when considering the cost and complexity.

Introduction

Envisat is the largest civilian Earth observational satellite in space [1]. On 8th April 2012, the European Space Agency's Envisat mission abruptly ended after loss of contact. However, it is still orbiting Earth at an altitude of 790km and it is expected to take about 150 years before it re-enters Earth's atmosphere [2]. The new science fiction thriller *Gravity* highlights this issue. The film depicts the story of two astronauts who are left stranded after fragments from a missile strike on a non-operational satellite causes a cloud of debris to form which creates more collisions; this is known as Kessler Syndrome [3]. The debris collides into their spacecraft, separating them from it [4]. Due to its size and the altitude at which it orbits, Envisat is at a high risk of colliding with other satellites and debris.

This paper attempts to address one way of preventing any future collisions. If Envisat could be slowed down, it would be possible for it to enter an orbit with a lower altitude and natural forces, such as drag, would bring it back into Earth's atmosphere. This paper will investigate what is considered a safe orbit and how feasible it would be to put it there.

Calculating the de-orbit altitude

To begin, it is necessary to calculate what would be considered a safe orbit altitude for Envisat. Currently it is recommended that after a satellite has completed its mission, its orbital lifetime is to take no more than 25 years to return to earth [5]. All missions which were designed after 2007 follow these regulations, however since Envisat began its mission in 2002 no considerations of how to safely remove it were included in its design. The Inter-Agency Space Debris Coordination Committee, IADC, recommends that the altitude at which it would take 25 years to return depends on the *A/m* ratio, where *A* signifies cross sectional area exposed to atmospheric particles causing the drag and *m* is the dry mass (all fluids have been burned or released) of a satellite [5].

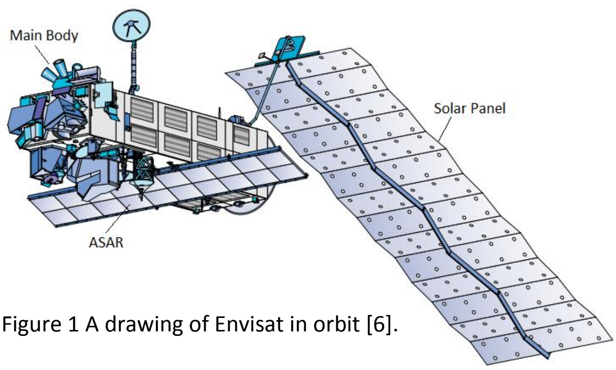

Figure 1 A drawing of Envisat in orbit [6].

To calculate the *A/m* ratio some assumptions need to be made. As the exact orientation and altitude of Envisat is unknown, it is not possible to calculate *A* with accuracy. As shown in figure 1, the cross sectional area is mainly made up of three components: $A = A_{body} + A_{SP} + A_{ASAR}$, where A_{body} is the estimated surface area of the main body, A_{SP} is the estimated area of solar panels and A_{ASAR} is the area of the ASAR instrument indicated in figure 1. Calculations will be made assuming that the maximum possible surface area is exposed; giving the extreme case. Hence, the area is [6]

$$A = (10m \times 4m) + (14m \times 5m) + (1.3m \times 10m) = 123m^2 \quad (1)$$

Envisat had a launch mass of 8211kg [6]. Assuming the fuel tanks are now empty, the dry mass of Envisat is approximately 7892kg. This would give an *A/m* ratio of 0.02m^2/kg. Using this ratio and comparing to the numbers stated in the IADC's guidelines, this approximately relates to an altitude of 700km. Unfortunately, these figures are only a rough estimate due to not knowing exactly the exposed surface area of Envisat or its exact current altitude. Hence the drag force it would actually experience is very difficult to calculate. Also, the effects of solar activity are not considered.

Energy required to de-orbit Envisat

By calculating the total energy of the satellite in its current orbit, r_1, and the orbit at which it needs to be moved to, r_2, it is possible to work out the energy required to move it. The total energy of the satellite is equal to the sum of its kinetic and potential energies.

$$E_{Total} = K + U = \frac{1}{2}mv^2 - \frac{GM_E m}{r}, \quad (2)$$

Newton's second law, $F = ma$, relates the satellite's velocity v to its orbital radius r,

$$\frac{GM_E m}{r^2} = m\frac{v^2}{r}. \quad (3)$$

So substituting $v^2 = \frac{GM_E}{r}$ into the kinetic energy gives a total energy of

$$E_{Total} = -\frac{1}{2}\frac{GM_E m}{r}. \quad (4)$$

where G is the gravitational constant, M_E is the mass of the Earth, m is the mass of Envisat and r is its the orbital radius (radius of the Earth plus $r_1$or r_2) [7].

If $r_1 = 790$km and $r_2 = 700$km then the two total energies for orbits 1 and 2 are -2.19×10^{11}J and -2.22×10^{11}J respectively.

Envisat has four fuel tanks, the contents of which equate to a total mass of 319kg. These fuel tanks contained hydrazine [6] which has a specific energy of 19.5MJ/kg [8]. The energy difference calculated from the two energy totals above is 2.79×10^9J. This approximately equates to 143.1kg of hydrazine.

The amount of fuel necessary is a viable quantity; replacing two tanks (assuming each has a capacity of around 80kg) would be more than enough to de-orbit Envisat to a safer orbit. Issues arise however, when considering how to get this fuel to Envisat. One possible method is to use NASA's Robotic Refuelling Mission, RRM, which is designed to service even non-operational satellites [9].

Conclusions

The quantity of hydrazine needed to de-orbit Envisat seems a reasonable amount. The assumptions made give an upper estimate to the required quantity, so if more time could be spent researching the figures, a more accurate amount could be calculated.

The method of refuelling the satellite is beyond the scope of this report, although possible methods should be considered in the future. So even though a feasible amount of hydrazine is required, the cost and difficulty of getting it to Envisat may be too high.

References

[1]https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat accessed on 05/10/2013

[2] P. B. de Selding, *Envisat to Pose Big Orbital Debris Threat for 150 Years, Experts Say*, *Space News,* 23 July 2010.

[3] A. Gini, *Donald Kessler on Envisat and the Kessler Syndrome*, *Space Safety Magazine*, 25 April 2012.

[4] http://www.imdb.com/title/tt1454468/ accessed on 19/10/2013

[5] *Support to the IADC Space Debris Mitigation Guidelines*, Issue 1, 5 October 2004

[6]https://earth.esa.int/support-docs/pdf/mis_sys.pdf accessed on 19/10/2013

[7] P.Tipler and G.Mosca, *Physics for Scientists and Engineers*, (W.H. Freeman and Company, New York, 2008), 6th ed.

[8]http://en.wikipedia.org/wiki/Energy_density accessed on 06/10/2013

[9]http://www.nasa.gov/mission_pages/station/research/news/rrm_success.html accessed on 19/10/2013