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P1_2 Icarus and the Ice Palace

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Abstract

In the 2002 James Bond spy film *Die Another Day*, Icarus, an orbital mirror satellite capable of focusing the energy from solar radiation onto a small area on the Earth's surface, is used to melt an ice palace 1000 tons in mass in <1 hour. The feasibility of this is investigated, modelling Icarus first as a concave mirror and second as a solar powered light-beam device. It is concluded that for Icarus to complete such a feat, its mirror or solar panel area would need to be > 1.2×10^5m^2; larger than any satellite in orbit at present but constructing a satellite this size is not physically impossible.

Introduction

In the 2002 James Bond spy film *Die Another Day*, Icarus (a new orbital mirror satellite capable of focusing the electromagnetic radiation from the Sun onto the Earth's surface) is used to melt an ice palace. At first instance, Icarus is seen reflecting the sunlight down onto the Earth's surface in order to allow crop development throughout the whole year. Later in the film, the satellite appears to store solar energy and then releases it as a beam of light, thereby concentrating it onto the surface.

This paper investigates the possibility of harnessing the power of the Sun via two methods; a satellite consisting of mirror panels (in a concave shape) and a satellite consisting of solar panels and a 'light-beam device.' The model represented here assumes Icarus to be capable of melting an ice structure akin to that featured in the film in a similar time frame, thus giving an approximate measure of the power required. From this, the area of the satellite can be calculated and therefore a comment on its practicality can be made.

Model 1: Icarus as a Mirror

In this model the ray approximation is used (assuming the mirrors in question act as one perfectly reflecting mirror), resulting in all the energy arriving from the mirror reaching the surface of the Earth at a single focal point, *f*. It is also assumed that the satellite is in a geostationary orbit about the Earth, such that the light can be reflected onto the same point on Earth for an extended period of time. This puts Icarus at approximately 35,900km from the Earth's surface from using Kepler's laws for orbital motion [1]. This gives a radius of curvature, *r*, for Icarus of 71,800km ($r = 2f$) [1]. The hypothetical mirror is assumed to be highly reflective and any absorption coefficient that would physically exist is thought to be negligible. The flux of solar energy as a function of distance from the Sun is given by,

$$F = \frac{L}{4\pi R^2}, \qquad (1)$$

where L is the luminosity of the Sun (3.9×10^{26}W) [1] and R is the distance from the Sun to the Earth. Substituting R in as 1AU (1.5×10^{11}m) [1], and neglecting the extra distance to the satellite from the Earth ($f \ll R$), the flux of solar energy striking the mirror is found to be 1380Wm^{-2}. The structure featured in the film was inspired by an Ice Hotel in the village of Jukkasjärvi, Sweden [2], and the mass m of ice used to construct this hotel was approximately 907,000kg (1000 short tons) [3]. This value has been assumed in further calculations. Using the equation for latent heat of fusion,

$$Q_f = mL_f, \qquad (2)$$

where Q_f is the energy required to change state from a solid to a liquid and L_f (334kJ kg^{-1}) [1] is the latent heat of fusion for ice, the energy needed to melt the palace is approximately 3.03x10^{11}J (assuming the ice palace melts at 0˚C)

The energy required to raise the temperature of the ice from -5°C to 0°C should also be taken into account (-5°C is the temperature of the Ice Hotel in Jukkasjärvi [3]), and it is found using $Q = mc\Delta T$, where c is the specific heat capacity of ice (2.05kJ kg^{-1} K^{-1}) [1] and ΔT is the temperature change (5°C). The reader will find that this calculation gives an energy $\approx Q_f/100$, and thus this process can be neglected.

Multiplying the solar energy flux (calculated in equation (1)) by the mirror area, A_m, of the proposed satellite, the power it can deliver is determined. It is then assumed that the entire ice palace melts in approximately t = 1 hour (estimated from the film). An atmospheric absorption coefficient μ must be considered to account for cloud albedo, atmospheric absorption and scattering effects. Rearranging this expression ($Q = FtA\mu$) and equating it to equation (2) gives,

$$A_m = \frac{mL_f}{Ft\mu}\,. \qquad (3)$$

Assuming that μ=0.5 [4] the satellite mirror would have to be ≈1.2x10^{5}m^2 to deliver the required power. The mirror is approximated as a two-dimensional circle due to the large radius of curvature – giving a mirror radius of 197m.

Model 2: Icarus as a Solar Power Generator

Icarus may be modelled instead as a construct of solar panels designed to absorb solar radiation and convert its power into electrical energy for use as a light beam (the technical construction of which will not be considered here). If the area of solar panel is denoted by A_{sp} and $A_{sp} = A_m$, equation (3) can then be used to calculate the time required for such a device to melt the ice palace, having considered an efficiency of conversion of solar power to electrical power, E_c= 0.31 [5], and an efficiency of conversion of electrical power into light E_L=0.30 (modelled on a $C0_2$ laser as this laser provides a comparably high efficiency [7]), this gives a total melting time of t = 10.6hours.

Conclusion

The International Space Station boasts a module length, Truss length, and Solar Array length of 51m, 109m, and 73m respectively, [6]. Comparison of the required mirror radius of 197m for Icarus with these dimensions makes its design, construction and assembly constraints apparent.

Several crude assumptions have been made which over-simplify the problem. For example, the effect of solar radiation pressure on the orbital trajectory of the satellite and diffraction effects have not been considered, as well as whether this mirror could function with 100% reflectivity.

The second model may be improved by investigating a means of converting electrical power stored by a solar panel arrangement; potentially giving a highly concentrated light source. Including these points in the calculations would further improve the accuracy of the model.

From these conclusions whilst Icarus is theoretically possible to construct, it would be challenging to engineer and launch into orbit.

References

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