Journal of Physics Special Topics

P2_10 Laser Powered Elevator

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

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

November 13, 2013

Abstract

The aim of this paper is to analyse how powerful a laser would have to be in order to lift a standard passenger elevator. The lifting force in this case is provided by the radiation pressure alone. We found that the laser beam would need a power of 3.8×10^{12} W to provide sufficient lifting force to accelerate the elevator car upwards at a rate of 1.7ms^{-2}.

Introduction

Photons are the quantised "particles" of light first proposed by Albert Einstein in 1905. These discrete packets of light are said to have no rest mass; they do however possess momentum. Radiation pressure can be thought of as the result of the momentum change from photons being absorbed, emitted or reflected by a surface. This paper will investigate how this pressure could be used to exert the force required to operate a passenger lift.

Theory

We start by looking at the force equation for the elevator car,

$$F_T = -F_G + F_L \qquad (1)$$

where F_T is the total (net) force acting on the elevator car, F_G is the force due to gravity and F_L is the radiation force from the laser. Using Newton's second law and rearranging for the radiation force gives

$$F_L = M_C a + M_C g \qquad (2)$$

where M_C is the mass of the elevator car, a is its upward acceleration and $-g$ is the acceleration due to gravity.

To find F_L we use the equation for the radiation pressure caused by reflection [1]

$$P_{rad} = \frac{2I_L}{c}(\cos\theta)^2 \qquad (3)$$

where P_{rad} is the radiation pressure, I_L is the intensity of the laser, c is the speed of light and ϑ is the orientation of the normal to the reflecting surface relative to the incident radiation. In this case ϑ=0 as we have assumed the reflective surface is on the downward-facing surface of the elevator car, with the laser directly beneath it. Equation (3) is derived using the momentum transfer of photons reflecting off a surface, using the photon momentum $p = E/c$.

F_L can then be found using $P=F/A$. Applying this to equation (3), substituting into equation (2) and rearranging for I_L gives

$$I_L = \frac{cM_C}{2A_R}(a+g) \qquad (4)$$

where A_R is the area of the reflecting surface. The power of the laser beam can be found using the equation $I = W/A$ where I is the intensity, W is the power and A is the cross-sectional area of the beam.

Results

We assume that the total mass of the elevator car is 2200kg (1500kg empty plus 10 passengers of 70kg each). We also assume that that elevator car is cylindrical in shape with a cross-sectional diameter of 2m (due to the fact that laser beams usually have circular cross sections). We then used a figure for the acceleration of the lift of 1.7ms^{-2} (this is the average acceleration of the passenger lifts used for the Taipei 101 building) [2]. These assumptions are the same as those used by Garner et al [3] in their paper on the use of a railgun mass driver to power a passenger lift.

Substituting these values into equation 4 gives a beam intensity I_L of 1.2×10^{12}Wm^{-2}. Assuming that the transmission between the laser and the reflecting surface is lossless for simplicity and that the beam diameter is identical to that of the reflector, the required power from the laser is 3.8×10^{12}W.

If a counterweight was added to the lift, equal to the total mass of the lift and passengers, the F_G term in equation (1) could be ignored. A single laser pointer could then be used to accelerate the lift. We calculate that it would take a 500mW laser pointer approximately 21000 years to accelerate the elevator car to a velocity of 1ms^{-1}.

Discussion

Our calculations show that it is theoretically possible for the radiation pressure of a laser beam to lift an elevator car. The calculated value of intensity is extremely large; it is around 3.6 billion times more intense than sunlight hitting the Earth's surface [4]. The calculated power of the laser is achievable using modern-day lasers, though usually over extremely short time scales (10^{-15}seconds) [5].

Conclusion

Although it is theoretically possible to lift an elevator car using the radiation pressure from a laser beam, the massive intensity and power required make it highly unfeasible as well as extremely dangerous. Radiation pressure may prove a great deal more useful in applications such as long-range spacecraft propulsion [6].

References

[1]J. L, Wright, *Space Sailing* (Gordon and Breach Science Publishers, 1992).
[2]http://www.forbes.com/2007/10/01/elevators-economics-construction-biz-logistics-cx_rm_tvr_1001elevators.html Accessed 13/11/2013
[3]R. Garner, D. Worthy, J. Taylor-Ashley, J. Gregory, *P3_4 A Linear Electromagnetic Mass Driver Powered Elevator,* PST **12**, (2013).
[4]http://earthobservatory.nasa.gov/Features/EnergyBalance/page2.php Accessed 13/11/2013
[5]http://newscenter.lbl.gov/news-releases/2012/07/27/bella-laser-record-power/ Accessed 13/11/2013
[6]http://www.nasa.gov/mission_pages/tdm/solarsail/ Accessed on 13/11/2013