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P2_3 Firing from the Gulf

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Abstract

In the 2009 film Transformers: Revenge of the Fallen, a railgun is fired from the Gulf of Suez to the top of the Great Pyramid of Giza in approximately 5 seconds. We consider parabolic motion to calculate the muzzle velocity of the projectile to be 28000 ms^{-1}. We then calculated the acceleration and the necessary force required within the railgun. Finally, the energy required to achieve the desired result was found to be 1.96x$10^9 J$.

Introduction

In Transformers: Revenge of the Fallen, a projectile is fired from a railgun aboard a US Navy Destroyer, which strikes a Transformer climbing The Great Pyramid of Giza.[1] The weapon is fired from "The Gulf", which is assumed to be the Gulf of Suez. The railgun therefore has a horizontal distance of approximately 140 km from its target. The pyramid has a height of 139 m from base to tip [2] and Giza has an elevation of 19 m [3] giving a total elevation of 158 m. Using film footage, the estimated height of the railgun above sea level is 11 m, and the railgun length is 10 m. We also measured a time of 5 seconds for the projectile to reach the target. We used these values to calculate the initial velocity of the projectile when it leaves the railgun, and the acceleration required to achieve this velocity. Using this, we also calculated the force required to produce such an acceleration and the work done by the force on the projectile.

Theory

We assume the air resistance on the projectile to be negligible due to its small surface area. The trajectory will therefore be a parabolic arc under the force of gravity. An object under constant acceleration, a, obeys the following equation of motion:

$$s = ut + \frac{1}{2}at^2, \qquad (1)$$

where s is the displacement, u is the initial velocity and t is the time of flight. By considering the horizontal and vertical components of projectiles flight we calculated the muzzle velocity and angle of launch required to hit the target. The muzzle velocity is the velocity that the projectile would need to be accelerated to by the railgun. A railgun consists of two parallel conducting metal rails with a sliding armature between them. A current is sent down the rails and across the armature, any wire carrying a continuous current will produce a magnetic field, B, in accordance with Ampere's Law [4]. The interaction of the two magnetic fields exerts a magnetic (Lorentz) force, F_m, in the direction perpendicular to the magnetic field

$$F_m = I\vec{l} \wedge \vec{B} = IlB, \qquad (2)$$

where I is the current in the rail and l is the length of the rail. This force propels the armature, and the projectile along the length of the barrel. The projectile begins at rest and if all the energy from the magnetic field is used to deliver a constant acceleration, a_r, on the projectile then the motion inside the barrel can be described by

$$v^2 = 2a_r l = \sqrt{a_r t_r}, \quad (3)$$

Where t_r is the time taken to reach the end of the barrel. We assume that the mass of the armature is negligible and that the force, F, exerted on the projectile, of mass m, given by

$$F = ma_r, \quad (4)$$

Is equal to the magnetic force expressed in equation 2. The energy, E, delivered to the projectile by the magnetic force is then

$$W = F_m l. \quad (5)$$

Results and Discussion

Using equation 1 and its x and y components, where the acceleration of the projectile was 0 ms^{-2} horizontally, due to the previously stated negligible air resistance and -9.81 ms^{-2} vertically The height, time and distances were substituted as stated previously. The angle of launch was therefore calculated to be 0.110^o, and so the velocity to be 28000 ms^{-1}. The projectile is assumed to be the same 11.3 kg tungsten pellet used by the US Navy prototype railgun [5] and would begin at rest at one end of the 10 m long barrel. It is then uniformly accelerated to the muzzle velocity. Using equation 3, this acceleration was found to be $3.92\text{x}10^7$ ms^{-2} in a time of $7.14\text{x}10^{-4}$ s, calculated using equation 3. The current in each rail produced a magnetic field and the interaction of the two B fields exerted a force on the projectile, causing acceleration. This force, calculated using equation 4 was $4.43\text{x}10^9$ N. Assuming 100 % efficiency, the work done by the force was found to be 4430 MJ. In order for the railgun to successfully hit its target 140 km away it would need to receive a minimum of 4430 MJ, as we assumed that all energy used was transfered into the kinetic energy of the projectile. A real life prototype was built by the US Navy uses 32 MJ of energy [5]. Zumwalt-class destroyers have the largest energy output of any destroyer class, at 78 MW [6] which is still much smaller than the required energy for the railgun depicted in the film. The muzzle velocity of the projectile we calculated is more than twice the escape velocity for Earth at 11190 ms^{-1} [7], which is far faster than any current launch platform can achieve.

Conclusion

In summary, the railgun used by the US Navy in the film is far beyond the capabilities of current technology. The energy required to fire a projectile from the Gulf of Suez to the Great Pyramid in 5 seconds is a factor of 100 greater than the current prototype possessed by the US Navy in real life. To further probe the feasibility of the railgun used in the film, more information about the internal magnetic systems, such as the applied current, would need to be known.

References

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