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P4_12 Last line of defence

Brewster. N, Adams. N, Smith. J, Kerr. T

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

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Abstract

The last line of defence against enemy missiles is a Close-In Weapon System. This paper investigates a current system – Goalkeeper, a 7 barrelled Gatling gun – and a future system (using lasers) to determine whether a missile can travel fast enough to beat them. It is found that Mach 3.2 may be fast enough to beat a Goalkeeper system; however future laser systems are found to have no such limits with much greater engagement distances.

Introduction

Warships have several lines of defence against incoming missiles; first eliminate the source, if that fails anti-missile missiles are launched to intercept; finally if the threat has still not been eliminated, the last line of defence is a Close-in Weapon System (CIWS). This article investigates whether a missile can travel fast enough to beat any CIWS's.

Goalkeeper

Goalkeeper is a system that is currently installed on many international warships. It consists of a 7 barrel 30mm Gatling gun capable of firing 4200 rounds per minute [1]. The high fire rate guarantees that enough rounds impact and detonate the warhead or completely obliterate the missile. The maximum magazine size is 1200 rounds of MPDS (Missile Piercing Discarding Sabot) ammunition. Targets can be tracked within a 2-7km range with a lower threshold of target speeds of 150ms^{-1}; they are then engaged from within 2km [1].

The turret is fully automated with no user input so can very quickly identify, acquire and eliminate targets. During sea trials against a Mach 2 sea skimming missile the time from detection to elimination of the threat was 5.5 seconds with engagement beginning at 1500m and ending with kill by 300m [1]. Taking the speed of sound at sea level to be 761mph (or 340ms^{-1}) [2] and the engagement range as 1200m (1500–300m), the engagement of the missile lasted 1.8s (using $d = vt$, where d is distance, v is velocity and t is time).

Beating the Goalkeeper

In order to find the speed required to beat this system more information is needed. Since the radar on top of the system detects over a 360° range, detection can occur at any time and location. The turret can rotate at a rate of 100° per second [3]; therefore a worst case scenario is when the target is a full 180° away from the initial orientation, meaning it takes 1.8 seconds to acquire the target. This can be assumed to take place during the tracking phase, so does not affect the firing time. In order for this not to be the case, the missile must travel 5km (from identification at 7km away to point of engagement at 2km) in less than 1.8s, which means a speed of 2.8kms^{-1} or Mach 8.2. This is currently beyond the capabilities of in-service missiles.

Using the engagement time from sea trials, 1.8s, a missile would have to be travelling at 1.1kms^{-1} or Mach 3.2. This is not beyond the capability of current anti-ship missiles; however only a few missiles can achieve this.

The Future

The next generation of CIWS's are likely to use lasers. The Airborne Laser (ABL) program uses a "megawatt class laser" that heats up the missiles skin, weakening it and causing failure due to high speed flight stress [4]. The Advanced Tactical Laser is a similar program looking to mount these systems on ships. Since the exact power is not quoted, for the purposes of this paper it will be assumed to be 1MW. In addition, the composition and structure of most in-production missiles is classified, so the skin is assumed to be made from lightweight metal such as aluminium. Taking the Tomahawk cruise missile as an example, the diameter of the outer shell is 0.52m [5]. From this the skin is estimated to be no more than 2-3cm, to allow sufficient room for the warhead, guidance system and propulsion. Using this, it is possible to calculate how much a section of the surface will heat up as a result of the laser radiation. This is done by considering a cylindrical volume of surface area *A*, equal to that of the laser beam, and depth *d*, the thickness of the shell. Assuming little or no dispersion of the laser beam, the spot size is estimated to have a diameter of 10mm. Using this to generate a volume and the density of aluminium ($2700kgm^{-3}$)[6], a mass of 6.4g is obtained for this section of the missile. Equation (1) is then used to find out how much aluminium heats up.

$$\Delta T = \frac{Q}{mc}, \qquad (1)$$

where ΔT is the change in temperature, Q is the amount of energy supplied, m is the mass of material and c is the specific heat capacity of the material. Using the value of c for aluminium ($938Jkg^{-1}K^{-1}$) gives a change in temperature of $1.75x10^5K$ in one second. The melting point of aluminium is 933K [6], so this would suggest that the surface of the missile would immediately melt. Clearly this is an idealised situation, since the laser spot will increase in diameter with large distances. Equally the energy from the laser will not be contained within the volume considered. Despite this, even when considering a laser beam diameter of 5cm, skin thickness of 10cm and assuming only 25% of the energy transferred heats up this volume, the increase in temperature would still be 503K in 1 second, therefore 2 seconds would be enough to melt the shell and destroy the missile.

Conclusion

Current CIWS's are adequate against the vast majority of missiles. It is potentially possible for a missile travelling faster than Mach 3.2 to defeat a single Goalkeeper system; however there are newer systems available with higher fire rates and shorter engagement times. In addition, there are usually 2 or 3 systems per warship [7] therefore increasing the fire-rate 2 or 3-fold, further decreasing the engagement period.

Laser systems have a much greater potential for missile interception. Even with moderately conservative estimations here, the numbers found suggest that a megawatt class laser would have no problem eliminating an incoming missile. In terms of interception distance, it is worth considering that laser ranging of the Moon with a relatively low power laser is possible [8]. Therefore it is easy to see that a high powered laser could engage over tens of kilometres with no problem. Furthermore, it is noted that lasers are frequently used in manufacturing to cut large sheets of metal with no problem. With these points in mind, it is possible that a laser system would be capable of engaging well beyond the 2km limit of Goalkeeper, with a much shorter engagement time.

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