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P4_1 The 'Fat Man'

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Abstract

In this paper we investigated the feasibility of the M42 'Fat Man' by considering the recoil felt on a person when firing the 5.5 kg projectile. It was found that a muzzle velocity of $v_0 = 32.1$ms^{-1} is required to fire the projectile 105 m when air resistance was taken into account. To achieve this muzzle velocity a pressure of $P = 16.1 \times 10^6$ Pa is required in the pneumatic firing system. It was found that the recoil of the system is $p = 188.1$ kgms^{-1}. The M42 'Fat Man' was determined to be a feasible weapon system.

Introduction

The Fallout series of video games is set in a fictional world in which the 'Red Scare', a fanatical fear and paranoia of communism, never faded. The continuation of this paranoia fueled rapid scientific advances on both sides, eventually leading to the creation of an infantry-deployable nuclear weapon; the M42 'Fat Man'. The M42 launches a small nuclear charge (the 'projectile') of mass, m = 5.5 kg to a range of 105 m using a pneumatic system of mass 13.6 kg [1]. We will use this information to evaluate the feasibility of using this weapon system in the real world by calculating the momentum change when the weapon is fired.

Given that we know the maximum range of the pneumatic system, we can calculate the launch velocity using equation (1) below.

$$s = ut + \frac{1}{2}at^2 \tag{1}$$

This equation is used for both the horizontal and vertical components of the velocity, using $a = 0$ ms^{-2} (acceleration), $s = 105$ m (final displacement) and $a = 9.81$ ms^{-2}, $s = 0$ m for the horizontal and vertical components respectively. This leads to a firing velocity of $u = 32.1$ ms^{-1}. We will now consider the effect of drag on the projectile as it moves through the atmosphere. We assumed that the projectile would have the same maximum height, $y_{max} = 26.3$ m, and distance, $x_{max} = 105$ m, from the firing position as calculated without air resistance. With this in mind we need to recalculate the firing velocity required for the projectile to reach its maximum range. This can be done using equations (2) [2], (3) [3], (4) [3], (5) [3] and (6) [3] as shown below.

$$v_t = \sqrt{\frac{2mg}{\rho A C_d}} \tag{2}$$

Where ρ is density.

$$v_{y0} = \left(v_t^2 \left(e^{\frac{2gy_{max}}{v_t^2}} - 1 \right) \right)^{\frac{1}{2}} \tag{3}$$

$$v_{x0} = \left(\frac{v_t^2}{gt} \right) \left(e^{\frac{gx_{max}}{v_t^2}} - 1 \right) \tag{4}$$

$$y = \left(\frac{v_t^2}{2g}\right) \ln\left(\frac{v_0^2 + v_t^2}{v^2 + v_t^2}\right) \tag{5}$$

Where y is vertical distance traveled.

$$v = v_t^2 \frac{v_0 - v_t \tan\left(\frac{tg}{v_t}\right)}{v_t + v_0 \tan\left(\frac{tg}{v_t}\right)} \tag{6}$$

First we need to find the terminal velocity, v_t, of the projectile in air, using equation (2). Here, the terminal velocity contains all the aerodynamic properties of the projectile needed for the other equations. We assume the coefficient of drag is approximately $C_d = 0.5$, just over that of a sphere [4] taking into account to the additional drag effects of the stabilization fins, and assumed a circular cross-section, A, of radius 0.1 m, from what can be seen in-game. The terminal velocity was thus calculated to be 74.9 ms^{-1}.

Then using equation (3) we can calculate the initial vertical velocity to be $v_{y0} = 23.2$ ms^{-1}. By rearranging equations (5) and (6) we can calculate the total time of flight, which is found to be $t = 4.6$ s. With the time of flight calculated; we can now use equation (4) to get the initial horizontal velocity, which is found to be $v_{x0} = 25.1$ ms^{-1}. With both the initial vertical and horizontal velocities; we can calculate, using simple trigonometry, the firing angle to be 42.8 ° with an initial firing velocity of 34.2 ms^{-1}.

We can now calculate the required pressure for the pneumatic system to fire the projectile. First the acceleration, a, during the firing process was found by estimating the length of the firing rail to be 1 m based on visual inspection in-game. This gives $a_{fire} = 584.8$ ms^{-2} assuming constant acceleration over the length.

$$P = \frac{F}{A_{pneu}} \tag{7}$$

We then may calculate the force required to accelerate the charge down the rail. This was found to be 3216.2 N. The internal area of the pneumatic system, A_{pneu} was estimated to be of the order 2×10^{-4} m^2 based on visual inspection in-game. Using equation (7), with the values of F and A stated prior, we find the pressure to be $P = 16.1 \times 10^6$ Pa. We can then calculate the recoil velocity of the weapon system, using the change in momentum, $I = 5.5 \times 34.2$. This was found to be 188.1 kgms^{-1}.

Conclusion

The muzzle velocity without air resistance was calculated to be 32.1 ms^{-1}. With air resistance taken into account the final muzzle velocity is, 34.2 ms^{-1}, this produced a recoil of $p = 188.1$ kgms^{-1}. This recoil can be dealt with assuming that the launcher has some recoil control and the user is stood in a stable position, however this can't be accurately determined as there are no schematics for the weapon. The 16.1×10^6 Pa of pressure used to achieve the acceleration is possible with current compressed gas canisters [5]. Thus the M42 'Fat Man' is possible with modern technology, however specific details on recoil control and the warhead mounted on the projectile will require further research that lies outside the scope of this article.

References

[1] Fallout 4, Bethesda Game Studios, 2015

[2] `https://en.wikipedia.org/wiki/Terminal_velocity`

[3] `https://www.grc.nasa.gov/www/k-12/airplane/flteqs.html`

[4] `https://en.wikipedia.org/wiki/Drag_coefficient`

[5] `http://www.ucl.ac.uk/medicalschool/msa/safety/docs/gascylindersafety.pdf`