Journal of Physics Special Topics
An undergraduate physics journal

P4 7 Baby, you're a firework

M'Barki W., Tambyrajah, M., Spanswick, W., Ali, H.

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

November 18, 2026

Abstract

Inspired by the Katy Perry Song "Firework", we consider what would happen if the metals in a 70 kg human were used to create a firework. We do this by using the elemental mass for the metals to form the "stars", then create a casing and burst charge independently to form an aerial firework shell of total mass 20 kg. This firework would require an initial velocity of 120 ms^{-1} to propel it to a height of 400 m. Finally, we plotted the progression of the firework stars after the explosion.

Introduction

In this paper, we take Katy Perry's "Firework" song literally by constructing a firework aerial shell based on the metal mass composition of a 70 kg human. Given drag and gravity, we explore the trajectory of the firework shell and plot the trajectories of the stars within the shell during the bursting firework display.

Results

Firework material from human body - In this analysis, the only elements we considered were typical compounds used in commercial fireworks [1], and are essential elements in the human bodies present at sufficient quantities [2, 3]. The masses are shown in Table 1. The elemental masses are converted to their equivalent pyrotechnic forms using equation 1 [4],

$$m_{\text{compound}} = m_{\text{element}} \frac{M_{\text{compound}}}{M_{\text{element}}}, \qquad (1)$$

where m and M represent the relevant masses and molar masses respectively. Therefore, the resulting mass of the pyrotechnic material from a 70 kg human is $m_{\text{pyro}} = 3.3$ kg.

Element	Body mass (g)	Form	Firework mass (g)
Calcium	1000	$CaCO_3$	2500
Potassium	140	KNO_3	363
Sodium	100	$NaNO_3$	370
Magnesium	19	Mg	19
Iron	4.2	Fe	4.2
Copper	0.072	Cu	0.072

Table 1: Metallic elements present in a 70 kg human body, their assumed pyrotechnic forms and corresponding mass [3].

Total firework shell mass - For the full mass of the firework shell, we also need to consider the burst fuel and the casing. A firework requires fuel to generate the burst that creates the firework display. We use the limit provided by [5], which states that the burst charge should not exceed 25% of the total chemical composition (burst charge and effects). Mathematically,

$$\frac{m_{\text{burst}}}{m_{\text{burst}} + m_{\text{pyro}}} \leq 0.25 \qquad (2)$$

which gives an upper limit of $m_{\text{burst}} = 1.1$ kg. This will maximise the size of the firework display for our human firework shell. This is not to

be confused with lift charge, which is not part of the shell. Most of the mass of our chosen aerial shell [6] is within the casing, consisting $\sim 78\%$ of the total mass. Therefore, $m_{\text{casing}} = 16$ kg, giving a total shell mass of ~ 20 kg.

Launching the firework - Here we calculate the required launch energy for our firework to reach the typical height of an aerial shell of given radius. Our spherical shell has a uniform density, $\rho = 1000$ kg m^{-3} [7], giving a radius of 0.17 m. When the shell is launched vertically it will experience gravitational and drag forces. Assuming quadratic drag, the equation of motion is

$$m\frac{dv}{dt} = -mg - \frac{1}{2}\rho_{\text{air}} C_d A v^2 \,, \tag{3}$$

where $\rho_{\text{air}} = 1.2$ kg,m^{-3} is the air density, $g = 9.81$ m s^{-2} is the gravitational field strength [8], $C_d = 0.45$ is the drag coefficient for a sphere [9], and A is the frontal cross-sectional area, πr^2. Letting $b = \frac{\rho_{\text{air}} C_d A}{2m}$ and using the chain rule, $\frac{dv}{dt} = v\frac{dv}{dy}$, equation 3 becomes

$$mv\frac{dv}{dy} = -mg - mbv^2 \,. \tag{4}$$

Rearranging, we can integrate with respect to height and velocity from the launch to the peak height, h, and obtain the initial velocity, v_0,

$$h = \frac{1}{2b}\ln\left(\frac{bv_0^2 + g}{g}\right) \rightarrow v_0 = \sqrt{\frac{ge^{2bh} - g}{b}} \,. \tag{5}$$

For a radius of 0.17 m, we approximate a peak height of $h \approx 400$ m from [10]. Substituting in values, we obtain $v_0 = 120$m s^{-1}. Using $m = 20$ kg, this gives a kinetic energy of 140 kJ. To calculate the lift charge mass, we assume an efficiency of 10% for our gunpowder [11]. As gun powder has a specific energy of 3 MJ kg^{-1}, this kinetic energy would require a lift charge mass of $m_{\text{lift}} = 470$ g [12].

Firework display - For our firework display, we resolve the drag and gravity from equation 3 into their x and y directions and obtain the plot in Figure 1. We use a different value for b, assuming a star radius of 1 cm [13].

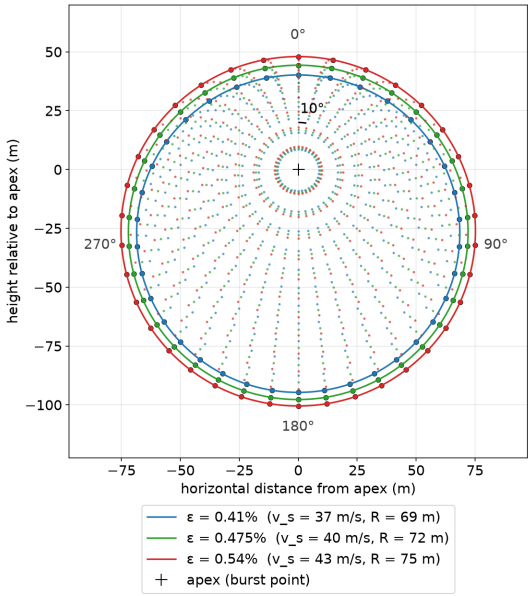


Figure 1: Path of 36 stars separated by 10° during the initial burst, plotted for 3 s in increments of 0.25 s from the apex point. The blue, green and red dots show different paths given the kinetic energy efficiency provided by the burst fuel. v_s refers to the initial velocity of the star.

Discussion and Conclusion

We found that a firework shell with the equivalent metal mass composition of a 70 kg human produces a 20 kg firework shell. We base our maximum height on other fireworks of similar radii, h = 400 m, giving a launch velocity, $v_0 =$ 120 m/s. We assume ideal weather conditions, constant air density along the flight path, and ignore the shell material in the air resistance calculation, though this is likely negligible. For our post-burst displacement plot, we take the individual firework stars to have equivalent size, giving a symmetrical display. The diameter of the burst is 144 ± 6 m (Figure 1), with the uncertainty only coming from the kinetic energy efficiency of the explosion. Considering the largest constituents of the firework, calcium shall produce orange, sodium yellow, potassium lilac and magnesium white [1]. We think the overall colour would be mainly yellow and orange, and this shall be explored in our next paper.

References

[1] Kosanke, B. *et al.*(2013). Pyrotechnic reference series no. 4 pyrotechnic chemistry. https://www.jpyro.co.uk/wp-content/uploads/bk2022h.pdf

[2] Zoroddu, M. A., Aaseth, J. *et al.* (2019). The essential metals for humans: A brief overview. Journal of Inorganic Biochemistry, 195, 120–129. https://doi.org/10.1016/j.jinorgbio.2019.03.013

[3] CRC Handbook of Chemistry and Physics. (n.d.). Chemical Composition of the Human Body.https://bionumbers.hms.harvard.edu/files/CRC

[4] Libretexts. (2013). 4.3: Formulas and their meaning. *Chemistry LibreTexts.* https://chem.libretexts.org/Bookshelves/General_Chemistry/Chem1_(Lower)/04%3A_The_Basics_of_Chemistry/4.03%3A_Formulas_and_Their_Meaning

[5] United States Consumer Product Safety Commission. (2018). Final rule: Amendments to fireworks regulations (p. 2). https://www.cpsc.gov/s3fs-public/Final%20Rule%20-%20Amendments%20to%20Fireworks%20Regulations%20-%20September%2026%202018%20%281%29.pdf

[6] Koch, E. *et al.* (2012). Metal–fluorocarbon pyrolants. XV: Combustion of two ytterbium–halocarbon formulations. Journal of Pyrotechnics, 31(31), 3–33. https://www.jpyro.co.uk/wp-content/uploads/J31_FULL_s6t6.pdf

[7] Poor, K. *et al.* (1997). US States Patent. https://patentimages.storage.googleapis.com/40/c7/6b/3bb43c2c4c8537/US5627338.pdf?ct=1793634962775

[8] Tipler, P. A. (2008) *Physics for Scientists and Engineers.* 6th ed. New York: W.H. Freemen and Company.

[9] Davis, L. (2019). Body orientation during a skydive. *Pressbooks.* https://openoregon.pressoks.pub/bodyphysics/chapter/drag-force/

[10] Kosanke, B. *et al.* (n.d.). Report of Aerial Shell Burst Height Measurements. https://www.jpyro.co.uk/wp-content/uploads/K02_001_free.pdf?ct=1793786319043

[11] United States Army. (1975). AMCP 706-270 engineering design propellant actuated devices. *EverySpec LLC.* https://everyspec.com/ARMY/ARMY-General/AMCP_706-270_SEP1975_53506/

[12] Elert, G. (2019). Glenn Elert. *The Physics Hypertextbook.* https://physics.info/energy-chemical/

[13] Muneno, Y. *et al.* (2006). Explosive composition for fireworks and method for manufacturing the same. https://patentimages.storage.googleapis.com/2a/a3/bb/368cbd30101a64/US6982014.pdf