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P6_10 Hadouken! The Physics of Street Fighter

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Abstract

We examined the possibility of creating a *Street Fighter* style Hadouken fireball by throwing a fuel-soaked dodgeball fast enough that the viscous drag forces ignite the fuel. We found the necessary velocity to ignite gasoline must be greater than $41ms^{-1}$ ($93mph$). We found this to be much greater than the record dodgeball throw.

Introduction

The video game franchise *Street Fighter* features a number of fantasy style attacks; one of the most famous of these is the Hadouken attack [1]. This is in essence a fireball attack, launched from the hands of the player. We examine how this effect could be mimicked by throwing a solid ball coated or soaked in fuel through the air at a velocity sufficient to cause ignition of the fuel.

Calculations

Any object travelling through a viscous media, such as the air, will experience a drag force equal to

$$\boldsymbol{F_D} = -\frac{1}{2} C_D \rho v^2 A \hat{\boldsymbol{v}}, \tag{1}$$

where F_D is the drag force, ρ is the density of the fluid, and C_D, v and A are the drag coefficient, velocity, and cross-sectional area of the object respectively [2]. $\hat{\boldsymbol{v}}$ is a unit vector in the direction of v. The dimensionless drag coefficient depends on the shape of the object, and for a ball is 0.5 [3]. The power P exerted by this force is then

$$P = -\boldsymbol{F_D} \cdot \boldsymbol{v} = \frac{\pi}{4} \rho v^3 r^2. \tag{2}$$

where r is the radius of the ball.

Assuming the ball can be propelled at constant velocity, all of this power goes into heating the ball (and the air around the ball, but we shall neglect this[1]) or creating pressure (sound) waves. The energy contained in sound waves is minimal and will be neglected also [5]. The cooling of the ball will be due mainly to radiative cooling, as is described by Newton's law of cooling [6]:

$$P_r = e\sigma S(T_b^4 - T_a^4), \tag{3}$$

where P_r is the radiative power of heating (or cooling if this value is negative), e is the emissivity of the fuel-soaked ball, S is the surface area of the ball, and T_b and T_a are the temperatures of the ball and the air respectively. σ is the Stefan-Boltzmann constant, $5.67 \times 10^{-8} W m^{-2} K^{-4}$. [6]

At the point where these two powers sum to zero, the temperature will be constant. We require this temperature to be above the autoignition point of our fuel (for gasoline this is $T_I = 280°C$ [7]). We therefore combine Eq. (2) and Eq. (3) to give the following equation for ignition velocity

$$v_I = \sqrt[3]{\frac{16 e\sigma}{\rho}(T_I^4 - T_a^4)}, \tag{4}$$

where we have used $S = 4\pi r^2$ and $T_b = T_I$. The emissivity of rubber, the material we assume our ball is made from, is approximately 0.9 [8]. As the density of air is approximately $1kgm^{-3}$ at standard pressure [9], and we assume an air temperature of $10°C$, this gives $v_I = 41ms^{-1}$ ($93mph$). It is worth noting that at this velocity the temperature would asymptote to the autoignition temperature, and as such it would take an infinite time to ignite. Any velocity above this value would allow the ball to ignite in a finite time.

[1] As the specific heat of the air is much lower than that of the ball [4], the air will absorb much less heat than the ball for the same temperature rise.

Conclusion

The fastest throwers in the sport of dodgeball can only achieve velocities of around $66mph$ [10]. This is much less than the value we have calculated ($93mph$). Even if we assume the player could still throw as fast with a gasoline-soaked dodgeball as with a normal dodgeball, they would not be able to attain this autoignition velocity even momentarily, and as such could certainly not maintain it for any length of time, as would be required for the ball to ignite. It may be interesting for future research to explore mechanical methods of launch.

References

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