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P4_6 A Good Hose Down

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Abstract

This paper investigates the maximum pressure of a fire hydrant a human can withstand before losing control due to the impulse at the hose aperture. The effects of static friction and the maximum grip force are compared, and it is found that an absolute hydrant pressure of 131kPa will cause a human to lose grip of the hose, whereas an absolute pressure of 139kPa is required to cause the handler of the hose to begin to slide backwards.

Introduction

Fire hydrants, commonly found in developed areas of the U.S, are a safety measure designed to ensure ample fire counter measures for the emergency services. This paper attempts to model the maximum pressure of the nozzle of the device at which it is possible to control manually. Considered in our model are the thrust of the water at the exit nozzle, the maximum grip force of a human hand and the effect of static friction between the ground and the individual's feet.

Model

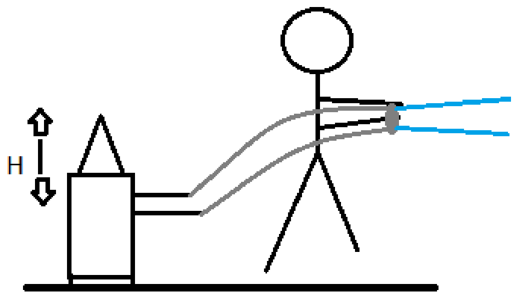

Figure 1: Artistic drawing showing the fire fighter handling the hose outflow a distance H above the hydrant valve.

The model is shown in figure 1 whereby the hydrant is assumed to be fed by an unlimited source of water pressurised to an interior pressure *P*.

Outflow Velocity

The Bernoulli theorem relates the flow velocity, pressure, and height of fluids moving along a streamline path as[1],

$$\frac{P}{\rho} + gZ + \frac{v^2}{2} = B, \tag{1}$$

where P, ρ, Z, and v represent the pressure, water density, height and flow velocity respectively, g is the acceleration due to gravity and B is a constant. It is assumed that the valve is capable of maintaining a pressure P, a height H (assumed as 0.5m in this article) below the hose aperture in the arms of the fire fighter. Since these values are equal along a streamline, we can equate (1) in two instances using the conditions of the above parameters at the hydrant valve, and at the hose opening to find the flow velocity out of the hose v, where P_{at} is the atmospheric pressure.

$$\frac{P_1}{\rho} = \frac{P_{at}}{\rho} + gH + \frac{v^2}{2}. \tag{2}$$

Rearranging for v yields,

$$v = \sqrt{2\left(\frac{P - P_{at}}{\rho} - gH\right)}. \tag{3}$$

Thrust

To determine the amount of force required to hold the nozzle in place, the thrust, F_{th}, produced by the outflowing water at a mass flow rate $\frac{dm}{dt}$, through a hose of cross sectional area, *A* (set as 0.012m^2 corresponding to a 2.5 inch hose radius) , is calculated as,

$$F_{th} = v\frac{dm}{dt} = \rho A v^2. \quad (4)$$

Our fire fighter must be able to supply a force of equal magnitude in the opposite direction to this thrust. The corresponding maximum manageable hydrant pressure is given by equating (4) to the maximum muscle force achievable by the fire fighter, *F,* and rearranging for *P*.

$$P - P_{at} = \frac{1}{2}\frac{F}{A} + \rho g H. \quad (5)$$

Measurements undertaken by Nasa to assess the physical fitness of its crewmembers have identified maximum grip force of male U.S air force personnel as 596N[2]. It is assumed that a fire-fighter handling the hydrant alone will have similar physical capabilities, yielding a maximum hose pressure of 29.7kPa above atmospheric pressure.

Friction

The frictional force F_s coefficient of static friction between a human feet and the ground is given as,

$$F_s = \mu F_N, \quad (6)$$

where F_N is the normal force exerted by a fire fighter of mass *M* (assumed to be 80kg), and μ is the coefficient of static friction. This is equated to the thrust provided by the water outflow from the hose and rearranged for the pressure.

$$P - P_{at} = \frac{\mu M g}{2A} + \rho g H. \quad (7)$$

The soles of a fire fighters boot are typically constructed from vulcanised rubber [3] with a coefficient of static friction of approximately 1 [3]. Substituting the values into (7) yields a maximum allowable nozzle pressure 37.6kPa above atmospheric before the fire fighter is forced to slide backwards. In order to remain stationary, the individual would need to supply a static frictional force equal to hoses thrust in the direction of the water flow i.e. a maximum of 785N for an 80Kg individual using Newton’s second law with μ equal to 1.

Holding on With Help

The Nasa testing process measured maximum static push forces up to 1285N when the test subjects were supported by an object from the rear a distance 80cm from the point at which the force is applied [2]. Substituting this force into (5), it can be shown that by adjusting their hold on the nozzle and receiving support from the rear, the maximum hose pressure achievable increases to 58.4kPa above atmospheric.

Conclusion

By comparing the values obtained for the maximum pressure of the hose considering the friction and maximum grip capabilities of the fire fighter, we see that the individual holding the hose will lose their grip at a pressure approximately 7.9kPa less than the pressure required to force them back. However, in the event the individual is supported from behind, it becomes possible to hold on to the hose up to pressures of 58.4kPa above atmospheric pressure. A typical fire hydrant is capable of providing much higher pressures (up to 350kPa). It may therefore become the topic of another paper to investigate the force of this water as it leaves the outflow hose and diverges.

References

[1] P.A. Tipler and G. Mosca, *Physics for scientists and engineers: with modern physics* (W.H. Freeman and Company, 2008) sixth edition, page 441.

[2] http://msis.jsc.nasa.gov/sections/section04.htm#Figure%204.9.3-8 Accessed 12/11/12

[3] http://www.harvik.com/Firefighter9680.htm Accessed 12/11/12