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P1_5 Dancing on the ceiling

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Abstract

The possibility of standing and dancing on the ceiling upside down is examined using specially designed shoes with a Venturi tunnel. It is found that for a certain shoe specification as detailed below, both a child and adult would be able to dance on the ceiling with the aid of a leaf blower, blowing through the Venturi tunnel at 23.5 ms^{-1}.

Introduction

Lionel wants to walk and dance upside down, attached to the ceiling as if gravity never existed. The idea of using the Venturi effect was proposed. A Venturi tunnel will be built into his shoes and air will be blown through the tunnel creating a low pressure region which will suck his shoes and feet to the ceiling. The constraint to this method is that at least one foot must always be on the ceiling.

Theory

The Bernoulli principle for a closed pipe at constant height is:

$$P + \frac{1}{2}\rho v^2 = \text{constant} \qquad (1)$$

Where P is the pressure, ρ is the air density, and v is the flow speed.

A fluid must obey mass continuity and therefore must have a constant volume flow rate, I_v:

$$I_v = Av, \qquad (2)$$

where A is the cross sectional area of the pipe in the region with flow speed, v. In terms of v_1 and the two cross sections A_1 and A_2, the flow speed

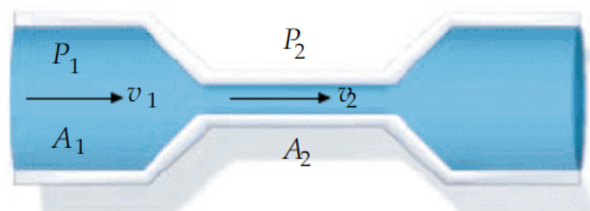

Figure 1: The fluid flow with a constriction in the centre. The flow speed increases in this region to keep a constant volume flow rate, resulting in a drop in pressure. Source: [1]

v_2 is given by:

$$v_2 = \frac{A_1 v_1}{A_2}. \qquad (3)$$

The combination of two cases of Eq (1) for each region of flow and Eq (3) gives,

$$P_2 = P_1 + \frac{1}{2}\rho {v_1}^2 \left(1 - \left(\frac{A_1}{A_2}\right)^2\right). \qquad (4)$$

The force created between the shoes and the ceiling, sometimes referred to as the ground effect in cars (but upside down in this case), is generated by the difference between the low pressure region and atmospheric pressure. The equation for force therefore requires the pressure difference $\Delta P = P_1 - P_2$, see Eq (5).

$$F = \int \Delta P \, dS, \tag{5}$$

where dS is the surface over which the force acts.

Using the fact we need pressure difference and Eq (4), the force is then given by

$$F = \frac{1}{2}\rho {v_1}^2 \left(\left(\frac{A_1}{A_2} \right)^2 - 1 \right) S, \tag{6}$$

for the case where S is a flat surface.

Results and conclusions

The shoes are rectangular in shape and have a Venturi tunnel running through the sole of the shoe. At the front and back there are openings both with dimensions 10 cm by 5 cm giving a cross sectional area of $A_1 = 50$ cm^2; these are the two ends of the tunnel. The centre of the tunnel, where flow is constricted, is cuboid in shape with an opening along the bottom of the shoe to allow contact with the ceiling; the constricted region has a cross sectional area $A_2 = 5$ cm^2 from its height and width of 0.5 cm and 10 cm respectively. Both the ceiling and the bottom of the shoe are assumed to have perfectly flat surfaces and the open section of the Venturi tunnel has the dimensions 10 cm by 25 cm giving a surface area $S = 250$ cm^2 where the pressure drop will interact with the ceiling. All of these measurements are valid as they are close to the dimensions of actual shoes. The density of air, ρ, is taken to be 1.225 kgm^{-3} [2].

Substituting these values into Eq (6) then simplifies the solution to Eq (7) below.

$$F \approx 1.24 \, {v_1}^2. \tag{7}$$

Eq (7) is plotted as the black line in Figure 2. Included on the graph are 4 scenarios showing the air speed required to generate enough force to hold an adult with mass 70 kg and a child with mass 40 kg. The force required for dancing is twice that of standing as when both feet

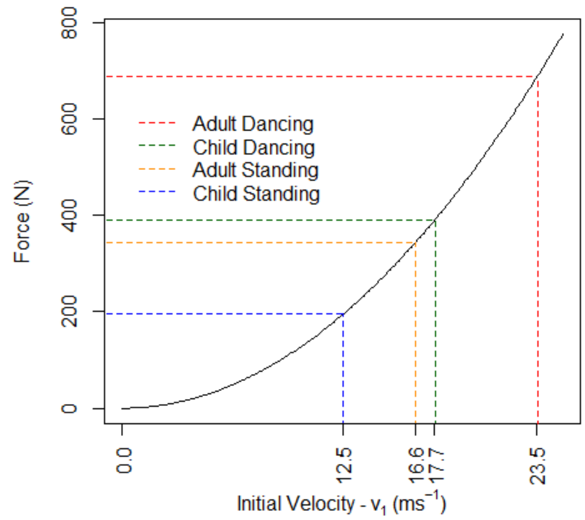

Figure 2: V_1 velocity required in order for the suction force to be enough to hold a range of human weights.

are connected to the ceiling, the force is split equally. The velocity v_1 needed to support a dancing adult and child are 23.5 ms^{-1} and 17.7 ms^{-1} respectively. These results are entirely possible as fast enough fans and particularly leaf blowers can blow air at a rate of up to 110 ms^{-1} [3]. Additionally the shoe dimensions can be manipulated to create lower pressure or a greater surface area, both increasing the generated force.

References

[1] P. A. Tipler, G. Mosca, *Physics for scientists and engineers: with modern physics, sixth edition*, (2008), p. 442

[2] https://www.macinstruments.com/blog/what-is-the-density-of-air-at-stp/ [Accessed 22nd October]

[3] https://www.leafblowersdirect.com/stories/1737-How-to-Measure-Leaf-Blower-Power.html [Accessed 23rd October]