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A1_4 Defenestration

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Abstract

This article investigates a frequent trope in space based fiction of removing an enemy by ejecting them out the airlock, or of a person being dragged out to space due to damage to the spacecraft's hull. We find that the force exerted on the person isn't very large for a hole the size of a door, but it may be sufficient to eject the person if the hole was around 2m x 4m, and if the air is resupplied to the room at the rate that it is emitted.

Introduction

A common occurrence in space based films and TV shows is for an airlock to be opened in order to eject a person or creature from a spaceship, or for a hole to be blown into the side of the ship causing a person to be sucked out. In this article we will investigate the force exerted on a person standing in a room when an airlock/hole is opened into outer space. A schematic of the problem is shown in figure 1 below.

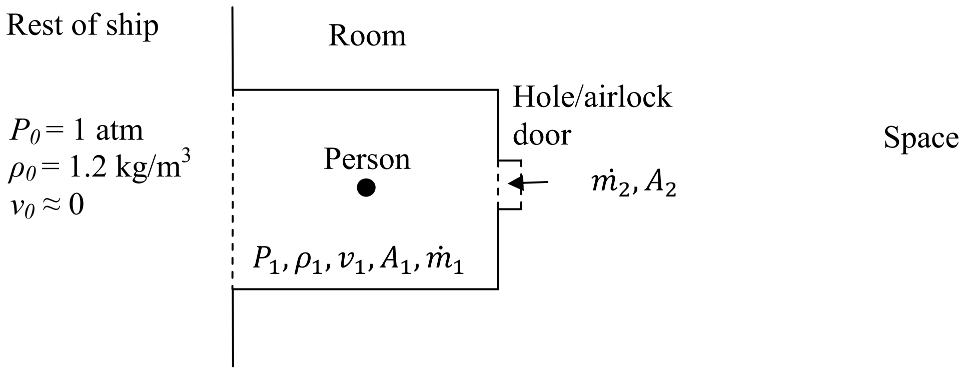

Figure 1 showing a top down schematic of the situation where *P* is the pressure, *ρ* is the density of air, *v* is the velocity, *A* is the cross-sectional area of the room/hole, and $\dot{m}$ is the mass flow rate

In the proceeding analysis we will model the system as if there is no wall between the ship and the room that the person is in; if the room is sealed off from the rest of the ship this will still produce a rough approximation for the initial force exerted on the person, although this force will very rapidly drop.

Theory

We will take the pressure in the spaceship to be 1 atm and the temperature to be 20°C, this means P_0 = 101.3 kPa and T_0 = 293 K. Using the ideal gas law,

$$P = \rho RT, \tag{1}$$

where R = 287 J kg^{-1} K^{-1} is the specific gas constant for air [1], and the density of air, ρ_0, is 1.2 kg m^{-3}. We will assume that the rest of the ship is large enough that P_0 and ρ_0 remain constant and v_0 remains close to zero. In our model we will take the size of the hole, A_2, to be roughly that of a door (1m x 2m). Since the pressure in space is approximately zero, the velocity of the air through the hole will be large and choked flow will occur. The equation for the mass flow rate in compressible isentropic flow, assuming the system is in a steady state and is inviscid, is given by [2]:

$$\dot{m} = \frac{AP_0}{\sqrt{T_0}}\sqrt{\frac{\gamma}{R}}M\left(1 + \frac{\gamma - 1}{2}M^2\right)^{-\frac{\gamma+1}{2(\gamma-1)}}, \tag{2}$$

where γ is the specific heat ratio and M is the mach number. Air is mostly diatomic so γ = 1.4. The maximum flow rate occurs when M=1, this is called choked flow. Therefore

$$\dot{m}_2 = \frac{A_2 P_0}{\sqrt{T_0}}\sqrt{\frac{\gamma}{R}}\left(\frac{\gamma + 1}{2}\right)^{-\frac{\gamma+1}{2(\gamma-1)}} = 480\ kg\ s^{-1}. \tag{3}$$

We will take the cross sectional area of the room to be 4m x 4m so A_1 = 16 m^2. We know from conservation of mass that

$$\dot{m}_2 = \dot{m}_1 = \rho_1 A_1 v_1, \tag{4}$$

therefore, using Eq.(2) to find the mass flow rate inside the room and equating it to $\dot{m}_2$, we get

$$6610 M_1 (1 + 0.2 M_1^2)^{-3} = 480. \tag{5}$$

This has solutions of M_1 = 0.073 or M_1 = 3.7, but the flow in the room will be subsonic, since the flow at the hole will be at the speed of sound and the flow upstream is close to zero, so M_1 = 0.073. By definition $M_1 = v_1 / C_s$, where C_s is the speed of sound, and $C_s^2 = \gamma P_1 / \rho_1$. Since the situation isn't isothermal we will find C_s by using Bernoulli's equation for compressible flow [3] inside the room, eliminate P_1, ρ_1, and v_1 by using the above relations, and equate it to the solution to Bernoulli's equation upstream:

$$\frac{\gamma}{\gamma + 1}\frac{P_1}{\rho_1} + \frac{v_1^2}{2} = \frac{C_S^2}{\gamma + 1} + \frac{M_1^2 C_S^2}{2} \approx \frac{\gamma}{\gamma + 1}\frac{P_0}{\rho_0} = 4.9 \times 10^4. \tag{6}$$

Therefore C_s = 342 m s^{-1} which results in v_1 = 25 m s^{-1}. To find the force the air exerts on the person we will find the drag:

$$F_D = \frac{1}{2}\rho_1 v_1^2 C_D A_p = \frac{1}{2}\frac{\dot{m}_2}{A_1} v_1 C_D A_p, \tag{7}$$

where we have used Eq.(4) to eliminate ρ_1, C_D = 1.1 is the coefficient of drag for a person [4], and A_p is the cross-sectional area of a person which we will take to be 0.4m x 1.8m ≈ 0.72 m^2. This results in a force of 300 N.

Conclusion

This force is approximately half the force exerted by gravity so the person would likely get knocked off their feet. However, once they are on the ground their cross-section will drop to roughly a sixth of when they were upright and their drag coefficient will also drop, so the force will fall to approximately a tenth and the person would not get dragged into space. If the room was sealed from the rest of the ship the same initial force would occur, but for a 4m x 4m x 4m room the total mass of air would be 80kg, and since the initial mass flow rate is 480 kg s^{-1} the force will very quickly drop; this means that if the person is human, and not wearing a space suit, the lack of air is the problem and not the threat of being dragged out to space.

The force is strongly dependant on the size of the hole into space because, as seen from Eq.(3), $\dot{m}_2$ is proportional to A_2, and $\dot{m}_2$ is related to v_1 through Eq.(4); as a rough estimate, if the area was increased by a factor of 4, so that the hole is 2m x 4m, the force would increase by a factor of 16. This leads to a force when the person is flat on the ground of around 500N, which means they will be dragged out if the coefficient of friction between them and the ground is less than around 0.7, which is reasonable.

In conclusion, a door sized hole would not cause a person to be ejected from the spacecraft, but it could occur if the hole was large enough and provided the air in the room was replenished fast enough.

References

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[3] http://adg.stanford.edu/aero/FUNDAMENTALS/bernoulli.html accessed 24/11/12.
[4] http://www.engineeringtoolbox.com/drag-coefficient-d_627.html accessed 13/11/12.