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P2 3 Explosive Decompression: Attack on Titan

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Abstract

In this report, we have analysed the flow of fluid from the nape of a titan from the series *Attack on Titan* and the realistic implications that this would result in. By manipulating the Bernoulli and ideal gas equations, we deduced a pressure of $P_1 = 2.5 \times 10^7$ Pa inside the titan which corresponded to an exit velocity of $v_2 \approx 360$ m s^{-1}, faster than the speed of sound in air.

Introduction

In the series *Attack on Titan*, large humanoid titan's roam the world causing havoc on the remains of humanity, only being killed by a cut to their nape. When this happens, a rapid release of steam can be seen. This report aims to analyse the release speed of gas using principles of fluid dynamics, thermodynamics, and gas laws.

Discussion

To analyse the flow of a fluid from one space to another, we look to the Bernoulli equation and compare the pressure (P), height of flow (h), and velocity of flow (v) in two separate frames.

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \qquad (1)$$

Where: P_1 and P_2 are the pressure inside and outside of the titan respectively, ρ is the fluid steam density, v_1 and v_2 are the fluid velocities inside and outside of the titan respectively, g is acceleration due to Earth's gravity, and h_1 and h_2 are the heights at each point, which we will assume to be negligible as the slashes at the titan's nape are always depicted as being horizontal. If we assume that the inside of the titan is in thermal equilibrium, we can state that the gas velocity inside of the titan is $v_1 = 0$. Thus, the Bernoulli equation can be reduced to:

$$P_1 = P_2 + \frac{1}{2}\rho v_2^2 \qquad (2)$$

P_2, pressure outside the titan's body will be equivalent to atmospheric pressure, $P_2 = 101325$ Pa. P_1, the pressure inside the titan, is harder to define as the anatomy of the titan's body is unknown. We make the following assumptions: Steam is produced through metabolic processes and acts like an ideal gas, a titan's body temperature is hot enough to sustain steam and is therefore over 373K, our 'test' titan is average size $h = 15$m. So, to calculate this internal pressure, we use the ideal gas equation:

$$P_1 = \frac{nRT}{V} \qquad (3)$$

Where the gas constant, $R = 8.3145$ J mol^{-1} K^{-1}, temperature, $T > 373$K, number of moles present in the titan, n, and volume of steam within the titan's, V.

Calculations

Firstly, the number of moles of steam within the titan $n = m/M$ where m is the mass of the steam and M is the molar mass of steam ($M \approx 1.8 \times 10^{-2}$ kg mol^{-1}) [1]. The total steam mass in the titan can be found by $m = \rho V$ where ρ is the density of the gas (0.6 kg m^{-3}) [2] and V is volume of gas in the titan respectively. Substituting $n = \frac{\rho V}{M}$:

$$P_1 = \frac{\rho R T}{M} \tag{4}$$

Using the previously defined values, as well as an estimated temperature of $T = 500$K (assumed to account for a titan's high metabolic activity and regeneration abilities), the pressure inside the titan can be estimated as $P_1 \approx 1.4 \times 10^5$ Pa.

Rearranging Equation 2 to be in terms of v, the velocity of the gas released from the titan, we see:

$$v = \sqrt{\frac{2(P_1 - P_2)}{\rho}} \tag{5}$$

Substituting in all previously given values, we find $v \approx 360$ m s^{-1}. At this velocity, steam would travel faster than the speed of sound. Though the show does present these high speeds, it's clear that it's not this magnitude because, there would be some consequences. If we were to use this speed to calculate the mass flow rate of this steam, alongside density (ρ) and area of cut on the titan (A), we use:

$$\dot{m} = \rho \cdot A \cdot v \tag{6}$$

To estimate the area of the cut, A, we can imagine this 15 m tall titan as a "scaled-up" human. If we take an average human as approximately 1.70 m tall [3], with a neck circumference of approx 0.4 m [4], we scale this human by a factor of $\frac{15}{1.70} \approx 8.8$. Imagine the cut in the titan's nape is a "pie slice" of a cylinder with height $h = 8.8\times$ circumference ≈ 3.5 m, radius $r =$ circumference/6 ≈ 0.58 m, and angular size of the slice $\theta = \frac{\pi}{4}$.

$$A = \frac{\theta}{2} r^2 h \tag{7}$$

Evaluating, finds $A = 0.46$ m^2. Now, using Equation 6, we can calculate the mass flow rate of steam as $\dot{m} \approx 100$ kg s^{-1}. Using this value, we can find the force at which the steam exits the titan $F = \dot{m}v \approx 36$ kN. Values calculated suggest that the steam released would result in a high-speed outflow, exceeding the speed of sound. This release speed and force may cause damage to the environment and individuals due temperatures of 500 K.

Conclusion

Steam escaping from a highly pressurized environment at Mach 1 would likely produce shock waves and intense compressional waves, resembling "explosive decompression." However, while the series portrays steam release, it downplays the real-world implications, omitting the high-energy release of such event. Assumptions in these calculations—like high temperatures and the area of the cut—significantly affect results. Though not directly referenced from the *Attack on Titan* universe, they are inferred from the titan's anatomy as depicted in the show [5]. Adjusting values may reduce both P_1 and $\dot{m}$, yielding less impactful outcomes.

References

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