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P4_8 Plasma Windows

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Abstract

The physics behind plasma windows are explored and it is investigated whether they would be applicable on a large scale as a divider between a vacuum and a pressurised hangar. It is found that while possible, it may be difficult due to the large energy needed and the large scale nature of the magnetic field.

Introduction

In science fiction, most notably Star Wars and Star Trek, force fields are employed on the hangars of spaceships allowing ships to fly from the pressurised interior of the ship straight out into the vacuum of space without the need for a mechanical door or airlock system. This paper will model the force field as a plasma window, a volume of hot plasma contained with magnetic fields. Plasma windows were first invented in 1995 by Ady Hershcovitch at the Brookhaven National Laboratory [1]. Plasma windows are used to contain regions of vacuum whilst allowing radiation to pass through. To see how the plasma can contain a vacuum we start with Ampère's law which states that

$$\nabla \times B = \mu_0 j. \qquad (1)$$

If we rearrange this and take the curl with B we get

$$\begin{aligned} j \times B &= \frac{1}{\mu_0}(\nabla \times B) \times B \\ &= \frac{1}{\mu_0}(\mathrm{B} \cdot \nabla)B - \nabla\left(\frac{B^2}{2\mu_0}\right) \qquad (2) \end{aligned}$$

$j{\times}B$ is the force on a plasma and it is the second term in Eqn. 2 we are interested with. The second term is the magnetic pressure

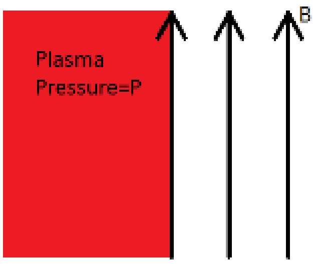

Figure 1. Equilibrium situation in which the pressure of the plasma is equal to $B^2/2\mu_0$

term and at an interface between a plasma and a magnetic field an equilibrium is reached if the pressure of the plasma, P, is

$$P = \frac{B^2}{2\mu_0} \qquad (3)$$

[2]. In this equilibrium situation the plasma cannot move into the field region, see Fig 1.

If we imagine a setup involving 2 parallel magnetic fields either side of a region of plasma then this plasma will be trapped provided the magnetic fields and plasma pressure are given by Eqn. 3. Once the plasma is trapped it can be used to keep regions of normal atmosphere away from regions of vacuum due to its pressure and viscosity (see Fig. 2).

Discussion

We will assume a size for the plasma window of 30m×12m×2m. This is based on the dimensions of the Millennium Falcon and the force field it is seen flying through in Star Wars Episode IV [3]. In order to keep in the air of the hangar bay the plasma will have to have a pressure equal to the hangar bay pressure, which we will assume to be 1

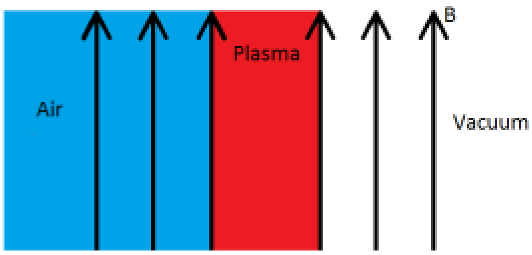

Figure 2. Setup of a plasma window.

atmosphere or 101325 Pa. This will prevent any pressure gradients that would expedite any loss of air to the plasma. Substituting this value into Eqn. 3 gives a required field strength of 0.5 T. If we treat the plasma as an ideal gas then, using the ideal gas law, we have [4]

$$P = \frac{\rho RT}{M}, \tag{4}$$

where P is the gas pressure, T is the temperature, R is the gas constant, 8.31, ρ is the density and M is the molar mass. We know P and R but in order to find T and ρ we need to pick a gas to use as our plasma. We will model the plasma as ionised hydrogen which has an ionisation energy of 13.6eV [5] which corresponds to a temperature of 2.4×10^5 K. Combining this temperature with our value for the pressure and the molar mass of hydrogen, 1.00794, we can get a value for the density of the plasma of 0.05 kg m^{-3}. As the temperature of a gas increases, its viscosity μ increases as shown by Sutherland's formula [6]

$$\mu = \mu_0 \frac{T_0 + C}{T + C}\left(\frac{T}{T_0}\right)^{\frac{3}{2}}, \tag{5}$$

where μ_0 is the viscosity at a known reference temperature T_0, C is Sutherland's constant and T is the temperature of the gas. For hydrogen C=72K, T_0=293.85K and μ_0=8.76μPa·s [7]. This gives a viscosity at 2.4×10^5 K of 3.1×10^4 μPa·s. This value is close to the viscosity of water and is roughly 100 larger than the viscosity of the air in the hangar. Because of this increase in viscosity, any transfer of air in the hangar through the plasma into the vacuum will be extremely difficult at the high temperatures the plasma will be at, thus making any loss of the air in the hangar minimal. Plasma windows have been shown to keep gas at a pressure of 2.7 atmospheres from a vacuum [4] and as diffusion is independent of area this will scale to the hanger plasma window.

From the density of the plasma and the volume of the hangar door the energy taken to initially ionise the plasma can be calculated. The hangar door would contain 36kg of hydrogen using the values of 0.05kgm^{-3} for the density and 720m^3 for the volume of the hangar door. This equated to 2.15×10^{28} atoms, each requiring 2.2×10^{-18} J. This gives the total energy required as 4.7×10^{10} J.

In order to fly a spacecraft through this region of high temperature and ionisation without damaging the craft a magnetic field could be erected around the craft with the same strength as the one in the window to prevent any of the plasma getting close enough to the ship to do damage. However, the interaction of the plasma with the two fields could produce effects that the author has not accounted for.

Conclusion

The magnetic field required to support the plasma window is only 0.5 T which is easily obtained with current technology, however keeping it constant over such a large area may prove difficult. The energy required to initially convert the volume of hydrogen to a plasma is very large but achievable.

References

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Viewed on 22/02/2011 at 23:34

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