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P3_4 Elysium: Where'd the Atmosphere Go?

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Abstract

This paper determines whether the Elysium space station, from the 2013 film *Elysium*, could maintain an atmosphere. It was found that Elysium, with a radius of 20 km, would not hold onto its atmosphere unless high wind speeds (183 ms^{-1}, 324 ms^{-1}, and 443 ms^{-1}; for the atmospheric rotations tested) are to be endured by its inhabitants.

Introduction

In the 2013 science fiction film *Elysium* the wealthy population have left Earth, which has become overpopulated, to live on a large rotating ring-shaped space station (called Elysium) which has no roof [1][2]. This paper aims to determine if Elysium could hold onto its atmosphere using only its artificial gravity. It is assumed that the ring rotates such that the inhabitants experience an Earth-like gravitational force at the inner surface, that the atmosphere is isothermal with a moderate temperature of 300 K, and that any friction between the atmosphere and the ring is ignored (as this will occur in a small boundary layer close to the inner surface). Various suggestions have been found on the internet (such as [3]), but nothing appears to give a detailed calculation on the matter.

Theory

In a rotating reference frame, a mass, m, rotating about a point located a distance r away, will feel a centrifugal force, F, acting radially outwards from the centre of the ring, as described by Eq. (1) [4]:

$$F = m\omega^2 r \,, \tag{1}$$

where ω is the mass's angular velocity. This force is what gives the inhabitants an artificial gravity, with the 'gravitational' acceleration, g, given by $g = \omega^2 r$ [4].

If the top of the atmosphere is defined as when $z = h$, where h is the height of a wall around the sides of the ring, and $z = R - r$ is the height above the ring's inner surface (R is the radius of the ring), then the energy a particle requires to escape the ring can be found. It was assumed that the entire atmosphere rotates with the same ω, and that as a particle rises through the atmosphere it remains at the same ω, due to collisions with other particles. The change in potential energy, ΔU, of a particle moving from an arbitrary height to $z = h$, is therefore given by [4]:

$$\Delta U = \int_z^h m\omega^2 (R - z)\, dz \tag{2}$$

Setting Eq. (2) equal to the average kinetic energy of a gas particle, $\frac{3}{2}kT$ [4], (where k is Boltzmann's constant, and T is the temperature of the atmosphere) gives the kinetic energy required to escape. Rearranging for T gives Eq. (3) for T_{lim}, the minimum temperature required for a particle at an arbitrary height, z, to reach height h and hence escape the ring.

$$T_{lim} = \left(\frac{g_0 m}{3k}\right)\left[2(h-z) - \frac{1}{R}(h^2 - z^2)\right] \qquad (3)$$

Where g_0 is the acceleration due to the atmosphere's artificial gravity at $z = 0$.

Discussion

The radius of Elysium is given to be 20 km [2], and the molar mass of air is around 29 gmol^{-1}. Initial tests were taken with a wall height of 1 km (estimated via an image of Elysium [5]), and taking the atmosphere to rotate with the same angular velocity as the ring (so that there are no winds due to differences in angular velocities). In this situation, it was found using Eq. (3) that Elysium would be unlikely to hold onto its atmosphere since, at the surface of the ring, the escape temperature would be $T_{lim} = 22$ K. This is far lower than the atmospheric temperature of 300 K.

Further tests with greater wall heights were performed, along with increasing the atmospheric angular velocity to values greater than that of the ring (assuming that Elysium has a mechanism to drive the atmosphere around at a different angular velocity to the ring). However, the results give little hope for Elysium as shown by Fig. (1).

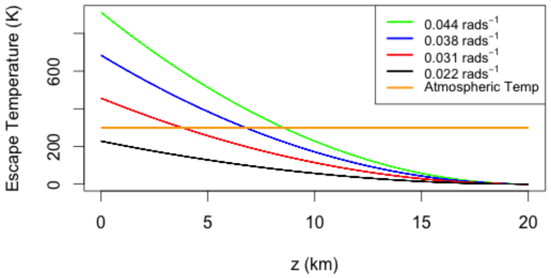

Figure 1: T_{lim} is given with height for various atmospheric angular velocities. $h = 19.999$ km.

The legend in Fig. (1) gives values of ω for the atmosphere, where the black line corresponds to the atmosphere having the same angular velocity as the ring. Fig. (1) shows that when the atmosphere rotates such that $\omega = 0.022$ rads^{-1} (i.e. $g_0 = 1$ g), even with a wall height 1 m shorter than its radius, the entirety of Elysium's atmosphere has enough kinetic energy to escape. When considering greater rotational velocities, Fig. (1) shows that varying amounts of the atmosphere can be held by Elysium. However, wind speeds at $z = 0$ (due to differences in angular velocities) of 183 ms^{-1}, 324 ms^{-1}, and 443 ms^{-1}, corresponding to $\omega = 0.031$ rads^{-1}, 0.038 rads^{-1}, and 0.044 rads^{-1} respectively, occur. The wind speeds, v_w, were calculated via: $v_w = \Delta\omega R$, where $\Delta\omega$ is the difference in angular velocities of the ring and atmosphere.

Conclusion

It was found that an atmosphere is unlikely to be maintained by Elysium, unless wind speeds of the likes of 183 ms^{-1}, 324 ms^{-1}, and 443 ms^{-1} are to be experienced at the surface of the ring. An amount of the atmosphere (the details of which are left to further study) can be maintained if the atmosphere is made to rotate at greater angular velocities than the ring. The result, however, is that great wind speeds would be experienced on the ring surface making life difficult on Elysium.

References

[1] http://tinyurl.com/7bod7t6 (18/10/16)

[2] http://tinyurl.com/h7td7a8 (22/10/16)

[3] http://tinyurl.com/gw439vs (08/11/16)

[4] P. A. Tipler and G. Mosca, *Physics For Scientists and Engineers With Modern Physics* (W. H. Freeman and Company, New York, 2008)

[5] http://tinyurl.com/j3jwk9l (22/10/16)