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A6_2 Safety Concerns over the Hyperloop

W. Schulz, P. Doyle, J. Heaps, E. Minnis

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract

The Hyperloop is a proposal for a new transportation method, involving pods travelling down evacuated tubes in order to decrease journey times and improve efficiency. We explore the potential safety concerns over the system including the sudden increase in air pressure in the tube in an emergency, and also thermal expansion of the tube. It is found that the temperature difference required to cause significant damage is over 236 K, and that the deceleration due to a sudden increase in air pressure is 5 g, a safe value.

Introduction

The Hyperloop is a concept for a new mode of transport, which involves sending pods through a sealed tube in which the air pressure is decreased to a near-vacuum level (approximately 100 Pascals) [1]. This will reduce the air resistance and allows the pods within the tube to travel at a much higher speed, therefore cutting journey times as well as improving the efficiency of long-distance transportation. Although the proposal for transport through de-pressurized tubes has existed since the 18th century (including Robert Goddard's "Vactrain" proposal in 1904) [2], it is not until SpaceX and Tesla CEO Elon Musk announced in 2012 that the concept should be put into practice. A series of competitions is held by SpaceX for engineering teams to build and test prototypes for the Hyperloop over the next few years.

Despite the many advantages of the system, many experts remain critical of the Hyperloop and believe it to be impractical, unsafe and expensive [3]. In this report, we will address the main safety concerns of the system, such as the thermal expansion of the tube and the sudden deceleration of the pod when a sudden increase in air pressure occurs in the tube, possibly due to a major leak or in the unlikely event of a terror attack. For simplicity, we will examine the Hyperloop Alpha concept, which was proposed by Musk and SpaceX, stretching from Los Angeles to San Francisco (a distance of 566.4 km) [1].

Analysis of Thermal Expansion

One aspect to consider is the thermal expansion of the tube, and whether it would be damaged under the resulting strain. To investigate this aspect, we use the Young's Modulus equation [4]:

$$Y = Stress/Strain = (F/A)/(\Delta L/L) \qquad (1)$$

where Y is the Young's Modulus, the ratio between force, F, and area, A, is the stress, and the ratio between the difference in length, ΔL, and length of the tube, L, is the strain. As the tube is made out of steel, $Y = 200\ GN/m^2$, and $F/A = 520\ MN/m^2$ [4], which therefore makes $\Delta L/L = 2.6 \times 10^{-3}$ the breaking strain. This is then inserted into the following equation:

$$\alpha = (\Delta L/L)/\Delta T \tag{2}$$

where α is the coefficient of linear expansion (for Steel, $\alpha = 11 \times 10^{-6}$) and ΔT is the temperature difference. Rearranging the equation, it is found that $\Delta T = 236\ K$, which is a temperature gradient that should not be possible in any climate on Earth. In order to calculate the difference in length according to the respective climates of Los Angeles and San Francisco, Eq. (2) is rearranged to make ΔL the subject, where the temperature differences for the two cities are 20 K and 13 K [5] [6] respectively. The values for ΔL are therefore 125 m and 81 m respectively over the year, which would indicate a need for expansion joints to compensate for the thermal expansion and contraction.

Analysis of Sudden Pressure Increase

The second scenario to consider is the sudden increase in air pressure in the system, should a section of the tube suddenly rupture. The Bernoulli equation is used to calculate the velocity of the pod, should a sudden increase in pressure occur. For simplicity the rearranged version of the Bernoulli equation is shown below [4]:

$$v_2^2 = 2[P_1 + (1/2)\rho v_1^2 - P_2]/\rho \tag{3}$$

where v_1 is the initial velocity, P_1 is the initial pressure, v_2 is the final velocity, P_2 is the final pressure and ρ is the air density. Inserting the values ($v_1 = 311\ ms^{-1}$, $P_1 = 100\ Pa$, $P_2 = 101325\ Pa$ and $\rho = 1.225\ kgm^{-3}$), it is found that $v_2 = 261\ ms^{-1}$. This is a difference of 49 ms^{-1} which, assuming a deceleration time of 1 second, would give a deceleration of 49 ms^{-2}, or approximately 5 g. A series of experiments carried out after WW2 by USAF officer John Stapp revealed that humans can withstand at least 46 g of deceleration [7], which would render 5 g to be a safe deceleration. However, this does not take the force exerted by the explosion, which at close proximity could potentially be fatal.

Conclusion

In conclusion it is found that the thermal expansion of the tube would not cause any significant damage, although expansion joints would be required to accommodate the difference in length over the year. It is also found that a sudden increase in pressure would potentially cause a deceleration of 5 g, a safe figure.

References

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