Journal of Physics Special Topics

A4_9 It's not just Smoke and Mirrors

A. Foden, A. Higgins, C. Sullivan, J. Sallabank

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

Nov 19, 2014.

Abstract
This paper looks at the feasibility of using wires too thin to be resolved by the human eye as a means of making a stage magician float. It is found that for the two configurations tested, stresses of 4.9 GPa and 3.51 GPa would be exerted upon the wire. These are both notably more than the tensile strength of steel, but not so high as to be never be feasible. This doesn't completely rule out wire though, as other combinations of wire and methods of concealment may be used.

Introduction

Magicians commonly levitate as part of a stage show. It is also a common publicity stunt used by many magicians with a variety of secret methods. This being said, people generally jump to the conclusion that hidden wires have been used. In this paper we will look at a specific case in which a stage magician levitates in front of an audience, and we look at the feasibility of using wires that cannot be resolved by the eyes of the audience.

Method

Due to the variance in stage size and audience positioning, we take relatively conservative estimates for distances used. We assume the magician levitates close to the edge of the stage, which is located 5 m in front of the audience. Meaning that the wire must not be able to be resolved at 5 m from the audience.

To work out the thickness the wire has to be, we can use the equation from *Physics for Scientists and Engineers* [1],

$$\sin(\alpha) = 1.22\frac{\lambda}{D} \Rightarrow \alpha \approx 1.22\frac{\lambda}{D}. \quad (1)$$

Where λ is the wavelength we observe at, D is the diameter of the aperture used to observe and α is defined in figure 1. The approximation comes from the small angle approximation $\sin(\theta) \approx \theta$.

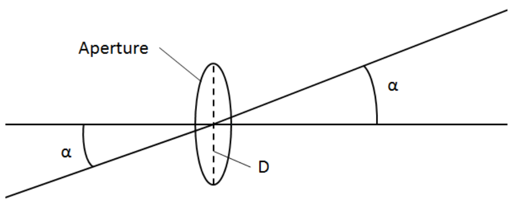

Figure 1: Diagram showing a circular aperture of diameter, D, and the angle, α, at which it can resolve.

Using the diagram in figure 2, and using basic trigonometry, we find the relation

$$d = r\tan(\alpha) = r\tan(1.22\frac{\lambda}{D}) \approx 1.22r\frac{\lambda}{D}. \quad (2)$$

Where d is the diameter the wire needs to be in order to not be resolved, and r is the distance to the stage. The approximation here comes from the small angle approximation $\tan(\theta) \approx \theta$.

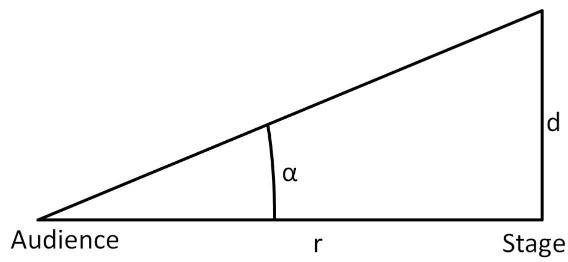

Figure 2: Diagram showing the relative position of the audience and stage. The stage is a distance r from the stage, the angle α is the same as in figure 1, and d is the diameter that can be resolved at a distance r.

For the wire to be feasible, it must not break under the weight, mg (where m is the mass of the magician and g is the acceleration due to gravity), of the magician. This means we need to work out the stress, S, that acts upon the wire, at diameter, d, when lifting the magician.

$$S = \frac{F}{A} = \frac{mg}{\pi R^2} = \frac{mg}{\pi(\frac{d}{2})^2} \approx \frac{mg}{\pi(1.22\frac{r\lambda}{2D})^2}. \quad (3)$$

Here, F is the force due to the weight of the magician, A is the cross-sectional area of the wire and R is the radius of the wire. The wavelength chosen to observe at is 550 nm; This value has been chosen as it is the approximate median of visible wavelengths. The mass used is 70 kg [2]. The distance, r, to the stage was estimated previously to be 5 m, and the diameter, D, of the eye is 8 mm [3]. Using these values we find the stress exerted on the wire to be 4.9 GPa. This result is discussed in the conclusion.

A second scenario, in which two ropes each supporting half the mass of the magician (shown in figure 3), is considered. In this case, we make the following change to equation 3, based on the trigonometry described in figure 3 and the fact each wire supports half the magician's mass:

$$mg \Rightarrow \frac{mg}{2\cos(\theta)}. \tag{4}$$

Where θ is defined in figure 3.

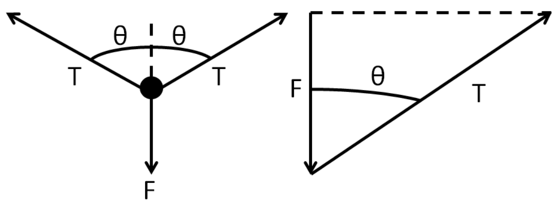

Figure 3: Diagram showing the angle the wires are holding the magician, and a free force diagram to which trigonometry was applied.

Taking θ to be 45°, and keeping the remaining values the same, this reduces the stress in the wire to 3.51 GPa. This result is again discussed in the conclusion.

Conclusion

The values calculated are high. The tensile strength of steel, that is to say, the maximum amount of stress steel can take before breaking is 500 MPa [4], an order of magnitude higher than what was calculated. The tensile strength of a carbon nanotube is between 11 and 63 GPa [5]. This means that, although not really feasible in either of the configurations we tested, it might be possible in future. This paper also doesn't look at other combinations of wire that could be used. And if the audience were further away, thicker wires may be used. Which means the use of wires isn't ruled out by these findings, only in the two circumstances tested. Another suggestion as to how wires may still be used, would be painting wires black and using a black back ground.

References

[1] P. A. Tipler, G Mosca, *Physics For Scientists and Engineers* (W. H Freeman and Co., 2008), sixth edition, p. 1160.

[2] `hypertextbook.com/facts/2003/AlexSchlessingerman.shtml` Last viewed on 19/11/2014

[3] `www.ncbi.nlm.nih.gov/books/NBK381/` Last viewed on 19/11/2014

[4] `http://www.ami.ac.uk/courses/topics/0123_mpm/` Last viewed on 19/11/2014

[5] `http://www.sciencemag.org/content/287/5453/637` Last viewed on 19/11/2014