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A5_3 Sonic the Dead-Hog

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Abstract

In this paper we will be looking at the heat Sonic produces via the friction of spinning up to the speed of sound and the conequences this has on him. Moreover, we will demonstrate that the generated energy per second of 89 kJ leads to a temperature increase of 850 °C per second in Sonic. Lastly, we will briefly cover why he cannot roll at a linear speed of sound due to the limited frictional torque the ground can provide.

Introduction

A blue hedgehog that moves at the speed of sound. A funny sounding concept that became the mascot of SEGA, a video game developer and publisher. This hedgehog is someone many members of our generation grew up with and unlike his plump plumber counterpart, he is incredibly fast. Before Sonic darts off, he spins up on the spot and in this paper we will explore why he cannot move forwards at the speed of sound in addition to the amount of heat this would generate and the temperature change Sonic would need to endure.

To this end, we will compare the frictional torque to the torque generated by Sonic while spinning, followed by calculating the work done by the frictional force on the hedgehog to compute the heat, and temperature change.

Method

To begin, we assume that Sonic is currently spinning/rolling on smooth tarmac (dense asphalt concrete). Additionally, we assume that the outer layer of Sonic, when rolled up, is coated in spines, thus the material making contact with the tarmac is exclusively keratin. We then use these assumptions to calculate the friction force that acts on Sonic. Using the following equation:

$$F_r = \mu_k N \tag{1}$$

where N is the normal force ($N = -mg$) which comes to $\approx$ 350 N [1] and μ_k is the coefficient of kinetic friction which is 0.76 between smooth tarmac and keratin [2]. We find that there is 260 N of force acting on Sonic. Using this information, we find frictional torque using $\tau = F_r r$, where r is Sonic's radius. Standing up, Sonic is exactly one metre tall [1], and in his ball form he is two thirds of that height [3], giving a diameter of 0.67 m and a radius (r) of 0.34 m. Using these numbers, we find that the torque acting counter to the torque generated by Sonic is 89 Nm. Doing a similar calculation where we treat Sonic as a spinning wheel and assume he accelerates to 340 ms^{-1} in one second we find that he exerts a force of 12 kN, which, using the same method as above, means he exerts 4 kNm of torque.

Next we will find the heat Sonic generates through friction. To this end, we will assume that all the kinetic energy lost is converted into heat and that Sonic's acceleration is constant. We make use of the following equation:

$$W = F_r \, d \cos\theta \tag{2}$$

where W is work done, d is distance and F_r is the friction force. Here θ is 180° as at the point of contact with the ground, the friction is acting antiparallel to Sonic's rotation. We are only interested in the magnitude and thus discard the negative sign. We set d equal to Sonic's circumference, which allows us to determine the work done per revolution. Using the diameter from above, we find d to be 2.1 m. Inserting this, and the value for friction calculated earlier into the equation, we find that Sonic generates 560 J per revolution. To find the energy generated per second, we need to determine the amount of revolutions per second. As his linear speed is ≈ 340 ms^{-1} we use the equation relating linear and angular velocity: $\omega = v/r$ and then convert from radians per second to revolutions per second. Using the same r as before, this gives us 160 revolutions per second from which we find that 89 kJ are generated per second.

Lastly, we find temperature change from this process using:

$$Q = m \, c \, \Delta T \tag{3}$$

Rearranging for ΔT and using the specific heat capacity of keratin, 1.5 Jkg^{-1}°C^{-1} [4], we find that Sonic would heat up by 850 °C per second, if we assume a 50/50 split of heat between the tarmac and Sonic.

Analysis

By comparing the torque Sonic outputs to the frictional torque of the tarmac, we can see that only 8.8% of Sonic's torque is useful in propelling him forwards. This demonstrates that, despite spinning fast enough on a surface designed to be used in roads for driving, he would not be able to generate nearly enough grip, so most of his effort would result in slipping. Moreover, the temperature increase Sonic would experience would kill any hedgehog in a fraction of a second. Sonic's power output would be comparable to that of a Ford Fiesta at 120 horsepower [5]. Furthermore, the flash point of keratin is at 230 °C [6], which means that within a quarter of a second, Sonic would spontaneously combust and burst into a ball of flames.

All of the above assumes infinite strength and wear resistance of both the tarmac and Sonic's spines. In reality, tarmac is much stronger and wear resistant than keratin. This means that for Sonic, rolling over tarmac is the equivalent of a human holding their finger against a disc sander.

Conclusion

Overall, Sonic would experience extreme temperature increases, spontaneous combustion and little forwards velocity for all the power he outputs. We believe that Sonic would not survive his attempt at moving at the speed of sound.

References

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[4] Picard and Thomas *Differences in thermal conductivity of tropical and temperate bovid horns* (Ecoscience 6 (2) : 148-158 (1999)) [Accessed 17 October 2022]

[5] `http://tiny.cc/g5e0vz` [Accessed 17 October 2022]

[6] `https://projects.nfstc.org/trace/docs/Trace%20Presentations%20CD-2/Pangerl.pdf` [Accessed 16 October 2022]