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P5_3 "When This Baby Hits 88 Miles Per Hour..."

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Abstract

In this paper we examine the key physical aspects required for a car to ignite Asphalt by driving over the surface, as seen in the highly popular 1985 film "Back to the Future". We calculated the energy transferred through the tyres to the road, and found that the car dissipates around 40 % of the energy required to ignite the road surface. Subsequently, we concluded that to create the fiery visuals as seen in the film the car would have to undergo instantaneous acceleration equivalent to 136 G-force.

Introduction

The highly popular, 1985 film "Back to the future" relies upon the use of time travel for its narrative. In order to travel in time the characters must drive a DMC DeLorean at a speed of 88 mph (39.3 ms^{-1}). As the car reaches this threshold it leaves the current time, leaving two flaming streaks on the road extending from the final contact points.

In this paper we look to calculate whether it is physically possible for tyres to set fire to the road surface whilst travelling at 39.3 ms^{-1}. We will be using the specific scene in which Marty first travels in time, as it allows us to make as little assumptions as possible.

Analysis

From the scene we can see that the initial speed of the car was roughly travelling at 15.6 ms^{-1} before beginning the acceleration to 39.3 ms^{-1}. By using Google Maps we can determine that the distance covered during the acceleration is approximately 120 metres in length. Therefore, our initial parameters can be taken as $v_0 = 15.6$ ms^{-1} and $s = 120$m. Using the equation of motion,

$$v_1^2 = v_0^2 + 2as \tag{1}$$

where 'v_1' is the final velocity, 'v_0' is the initial velocity, 'a' is the acceleration and s is the displacement. Using $v_1 = 39.3$ms^{-1} we can rearrange Eq. (1) to calculate acceleration. Assuming the car accelerates linearly, this acceleration is calculated to be 5.42ms^{-2}.

By equating the forces acting on the car we can calculate the thrust force 'F_T'.

$$F_T = ma + mg\mu \tag{2}$$

Where, 'm' is the mass of the car, 'g' is acceleration due to gravitational forces (9.81 ms^{-2}) and 'μ' is the coefficient of friction between the tyres and the road surface. μ is assumed to be equal to 0.9 [5].

As we are assuming this scenario involves a standard model DeLorean, we can take the mass to be 1233 kg [1]. Inputting the values into Eq. (2) gives, $F = 17570$ N of frictional force acting on the car. Dividing by four gives us the frictional force acting on one individual tyre, this helps us to isolate the system, and gives a force per tyre of $F_{tyre} = 4392$ N.

To calculate the energy dissipated by each tyre we must determine the work done by friction 'W_{tyre}', this energy would be dissipated into the rod surface as heat.

$$W_{tyre} = F_{tyre}s \tag{3}$$

Using Eq. 3, an energy dissipation was calculated as $W_{tyre} = 527$ kJ.

We are going to assume that the road surface is constructed from asphalt, as this material is a common road surface in California, USA, where the film is set. Asphalt ignites at temperatures around 673 K [2]. To determine the required thermal energy that would cause such an ignition we used the equation for heat capacity,

$$Q = m_{road}c\Delta T \tag{4}$$

where 'Q' is the heat energy, 'm_{road}' is the mass of the surface layer of the road, 'c' is the heat capacity of the road surface, given a value of 0.92 $\mathrm{kJkg^{-1}K^{-1}}$, and $\Delta\ T$ is the change in temperature required. As we can assume the road surfaces ambient temperature is around 298 K, the temperature change is roughly 375 K.

To determine the value for m_{road} that will undergo rapid ignition, we can multiply the density by the surface area of the tyre by a small depth of 1 cm. The density was taken as 1180 $\mathrm{kgm^{-3}}$ [2] and the surface are of the tyre is calculated as 0.317 $\mathrm{m^2}$ [3]. Thus, we found that $Q = 1291$ kJ is the required, near instantaneous, energy dissipation to cause an ignition of a tyre-length section of asphalt. Unfortunately, over a distance of 120 m each tyre only dissipates a total of $W_{tyre} = 527$ kJ, which is only around 40 % of the required thermal energy. And thus whilst travelling at 39.3 ms^{-1} the scene in the film is physically inaccurate (and not just with regard to the fire either).

However, if we assume that the ignition is to occur within one whole tyre rotation due to an acceleration that occurs after 39.3 ms^{-1} due to the time travel, we can work out the required speed to cause the ignition.

We subtracted W_{tyre} from the value for Q, we find that $\Delta W = 764$ kJ, this is the change in work done required over a tyre length of around 1.8 m, which is the circumference of the tyre [3]. By substituting the value for ΔW, and with $s =$ 1.8 m into Eq. (3) we can determine the change in force required. This value works out as $\Delta F =$ 424. kN.

By subtracting F_{tyre} from ΔF and substituting this value into Eq. 2, we can solve for 'a'. Therefore we can determine the near instantaneous acceleration required from 39.3 ms^{-1} to cause ignition of the road surface at the tyre contact points. This gives us an instantaneous acceleration of $a = 1354\ \mathrm{ms^{-2}}$, which is equivalent to about a G-force of 138.

Put into context these values would place Marty McFly in very life threatening conditions, as he would experience higher G-forces than any human has undergone in a controlled environment[4] by a factor of approximately three.

References

[1] https://en.wikipedia.org/wiki/DMC_DeLorean [Accessed 10th October 2020]

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[5] http://hpwizard.com/tire-friction-coefficient.html