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P4_6 What a Drag!

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Abstract

Transporting bicycles via a roof rack can often be convenient and easy, especially if you have a small car or do not wish to modify the car's frame. However, this method is also thought to be the least fuel efficient due to the extra drag that the bikes create. Our analysis of the extra fuel per mile needed to transport two bikes via a roof rack for both petrol and diesel vehicles showed that there is a strong dependence on the speed at which the vehicles are travelling.

Introduction

Roof racks are a common method used to transport bikes via a car. In this method the bikes are secured onto the car stood upright. Compared to other methods of securing bikes to the outside of a car, such as a boot rack, this creates extra drag which the car needs to overcome. Resulting in the car having to burn more fuel, relative to other configurations, in order to gain the required energy.

Theory

To analyse how much extra fuel is used by both petrol and diesel cars using the roof rack, we took an example of a car transporting two bikes based on an adult mountain bike, since these usually require transporting to a venue rather then being used for commuting.

The drag force is given by equation (1) [1].

$$F_D = \frac{1}{2} C_d \rho v^2 A \tag{1}$$

Where C_d is the coefficient of drag, ρ is the density of air which was assumed to be 1kg/m^3 for the analysis, v is the velocity of the car and A is the frontal area.

Since we are examining the extra fuel required, we need the difference in drag between the roof rack and the boot rack case. Since the only difference in frontal area is the bikes themselves, this means that the extra drag is just from the surface area of the bikes.

If force and speed are constant then the extra work per distance required from the roof mounted bikes is just the drag force from the bikes, as shown in equation (2)[1].

$$\frac{\Delta W}{s} = F_D \tag{2}$$

Where $\Delta W/s$ is the extra work per distance travelled and F_D is the drag force from the bikes.

In order to convert this energy into an amount of fuel, we need to know the amount of energy per litre that the fuel contains, E_L, however, due to dissipating effects in the engine and power transmission, there is an efficiency factor needed in order to account for these, η. Along with including conversion factors for miles and meters, 1609 meters/mile, as well as for miles per hour into meters per second, 2.237 mph/m/s, we find an expression for the extra fuel per mile as an expression of the car's velocity, equation (3).

$$\frac{litre}{mile} = \frac{1609}{2\eta E_L} C_d \rho \left(\frac{v}{2.237}\right)^2 A \tag{3}$$

Results and Discussion

To find an estimate for the frontal area of a bike we took values from an example bike [2] such as stem length and handlebar width, as well as taking some standard values such as stem diameter [3]. Breaking the frontal area up into rectangular segments for the handlebars, stem, wheel and cranks produced a frontal area of approximately 0.36m^2 for one bike, therefore, in our situation, $A = 0.72\text{m}^2$. C_d is assumed to be close to a cylinder's, 1.2 [4], due to the bike components. η is 0.18 for a petrol car and 0.24 for a diesel [5]. E_L is 32.6MJ/L for petrol and 35.9MJ/L for diesel [6].

Using these values it is possible to find an estimate for the extra fuel that is used at different speeds, figure (1).

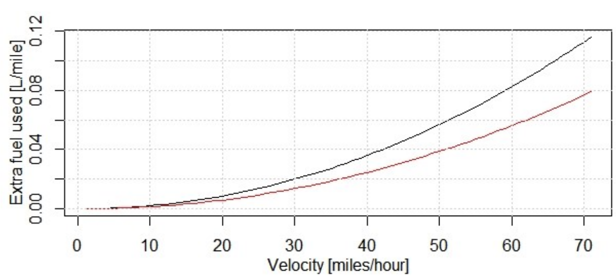

Figure 1: Graph of the extra fuel used per mile for petrol (black) and diesel (red) cars transporting two bikes. Produced using the R language and Rstudio software.

Since the expression is dependent on v^2, the amount of extra fuel burnt varies greatly between low speeds and the legal limit of 70mph, where the extra fuel used reaches approximately 0.12L/mile for petrol and 0.08L/mile for diesel. This suggests that the size of the impact of using a roof rack compared to other methods is highly dependent on how long you are travelling at high speeds while on the journey. However, it also confirms that the use of a roof rack always uses extra fuel. Diesel cars use less extra fuel then petrol cars do, this is due to their slightly higher efficiency and greater amount of energy per litre.

Conclusion

We have demonstrated the effects of using a roof rack to transport two bikes for a petrol and a diesel car, with the amount of extra fuel needed, figure (1), being dependent on the speed the car is travelling at. Figure (1) shows that at low enough speeds, the extra fuel used could be negligible, however, this is not true for the higher speeds calculated. Since car efficiencies vary, our figures are general estimates, further work could examine the effects of differing parameters, such as car efficiency, different types of bikes or different methods of transportation.

References

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