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P1_3 Speed Limit

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Abstract

To be able to go faster than anyone else is a dream held by many people, including the Vesco family, who set the current land speed record for a wheel-driven vehicle in their car The Turbinator. By considering the balance of drive force and drag force on an ideal track, this paper estimates the theoretical top speed of The Turbinator as 486 mph. Then by analysing the new power output of their modified engine, the possibility of exceeding 500 mph was explored. It was found that the new engine with increased horsepower that is being developed would push The Turbinator over 500 mph.

Introduction

At the time of writing, it is just over a decade since Don Vesco set the current land speed record for a wheel-driven vehicle on 18th October 2001 [1]. Driving at the Bonneville Salt Flats, his car The Turbinator set the record at just over 458 mph. At the end of the run, The Turbinator actually reached a speed of 470 mph, still with the capability to accelerate, but for the record it is the fastest speed averaged over a kilometre that is taken. This article examines the factors limiting the top speed attainable by The Turbinator and also considers the feasibility of team Vesco's goal: to exceed 500 mph in a wheel-driven vehicle.

Theoretical Speed Limit

The theoretical top speed of The Turbinator can be calculated quite easily. There are three forces acting on the car: the drive force due to the engine turning the wheels acts in the direction of travel. (The record in consideration is for wheel-driven vehicles only, so the drive force must come from the wheels by definition. There are other cars powered by jet propulsion, for example that travel faster, but are not included in this category.) The drag force F_{drag} due to air resistance and the force due to rolling friction f_r act to impede the motion of the car. The drag force is defined by Equation 1 [2],

$$F_{drag} = \frac{1}{2} C_D \rho A v^2, \quad (1)$$

where C_D is the drag coefficient of The Turbinator, which is taken as 0.2 [2] and v is the car's speed. The density ρ is that of air, 1.29 kgm^{-3} [3], and A is the area of the car perpendicular to the direction of travel, which was found to be 1 m^2. The force due to rolling friction depends on the coefficient of rolling friction, which for tyres on salt flats will be of the order of 0.01 (from comparing with the coefficient for tyres on concrete [3]). Thus f_r will be about three orders of magnitude smaller than F_{drag}, so it is reasonable to assume that the car is running on a perfect frictionless track.

To find the top (or terminal) speed, consider the point where there is no net acceleration on the car as the drive force is equal to F_{drag}, this will occur as the drag force increases as the speed squared. Therefore the right-hand side of Equation 1 may be set equal to the drive force:

$$F_{drive} = \frac{1}{2} C_D \rho A v_T^2. \quad (2)$$

Multiplying through by v converts the left-hand side of Equation 2 to the output power of the engine P, this assumes no transmission loss through the tyres and drive mechanisms.

Rearranging, the terminal velocity v_T may be expressed as:

$$v_T = \left(\frac{2P}{C_D \rho A}\right)^{\frac{1}{3}}. \quad (3)$$

The output power of The Turbinator's engine is 3750 horsepower [1], which is equivalent to 2.8 MW. Substituting this, along with the other parameters outlined above, into Equation 3 gives the theoretical top speed of the Turbinator as 280 ms^{-1} or 623 mph.

Setting the Record

Clearly, the theoretical top speed quoted above is much larger than the speed set during the record attempt in 2001, this is due to a number of factors. The first point to note is that the speed set for the record was averaged over a kilometre, so the car must be able to maintain such a speed over this distance. Another notable factor is that, in the theoretical speed calculated above, any loss in power output due to tyres and transmission through the drive mechanism has been ignored. Given that The Turbinator is a four-wheel drive car, the transmission loss can be approximated as 22% [4], due to extra differentials and power transmission components. In light of this the actual top speed likely from The Turbinator can be estimated by multiplying the previous value by 0.78. This puts the estimated top speed of The Turbinator as 486 mph, which concurs with the speeds it reached towards the end of its run.

Breaking the 500 mph Barrier

The long term goal of team Vesco is to break the 500 mph barrier in a wheel-driven vehicle. The team is currently in the process of modifying The Turbinator's engine so that it is much more powerful at 4400 horsepower (3.23 MW), but will this be enough to achieve their goal?

Assuming first the same conditions used to calculate the theoretical top speed above, this increased power can be substituted into Equation 3 to determine the new terminal velocity. In this case the terminal velocity was calculated to be 293 ms^{-1}, or 653 mph. Again this calculation neglects transmission losses, so a more accurate estimate is obtained by multiplying by 0.78. Thus the estimated top speed using the 4400 horsepower engine would be 509 mph. Thus it would seem that team Vesco could achieve their goal of 500 mph in a wheel powered vehicle.

Conclusions

By considering the terminal velocity of The Turbinator on an ideal track, this paper has calculated its theoretical speed limit as 623 mph. Then after considering transmission losses due to the tyres and drive mechanism, a more accurate estimate of the top speed was determined as 486 mph, which is consistent with The Turbinator's performance at Bonneville Salt Flats. Finally the new power output, given the modifications being made by team Vesco, were analysed and it was found that The Turbinator will have a good chance of breaking the 500 mph barrier at terminal velocity.

References

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