Journal of Physics Special Topics
An undergraduate physics journal

P1 3 Engines Like It Hot, But Not Too Hot

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October 20, 2026

Abstract

This paper models the relationship between the air temperature of an Internal Combustion Engine and its power output. In increasing the air temperature from 10°C to 35°C, an 8.1% decrease in peak power was found, consistent with an inverse relationship between the air temperature and power output. A brief comparison is also made between the losses in power and aerodynamic drag caused by increased air temperature.

Introduction

As shown by Pulgam et al. (2025) [1], increased air temperatures decrease the density of air and therefore the drag force it can exert on Formula 1 cars. Less aerodynamic drag has a positive effect on the car's top speed, however the lower air density will also decrease the maximum power output of the engine as a result of there being fewer gas molecules in the combustion chamber. Here, a comparison is made between the effects on the car's top speed caused by these two factors.

Only the Internal Combustion Engine (ICE) of the car is considered, as electric motors are not affected by air density. The power output P of the ICE is derived from the torque exerted on the crankshaft of the engine, such that [2]:

$$P = \tau\omega, \tag{1}$$

where τ is the torque acting on the crankshaft, and ω is the angular frequency of the crankshaft. The torque exerted by one piston is found as [2]:

$$\tau = F_{\perp} d, \tag{2}$$

where $F_{\perp}$ is the perpendicular component of the force applied by the piston, and d is taken as the radius of the crankshaft. The total force exerted on the crankshaft by the piston can be found from [2]:

$$F = PA, \tag{3}$$

where P is the pressure inside the combustion chamber and A is the surface area of the piston head. To find the perpendicular component of this force, it must be multiplied by the sine of the angle between the crankshaft and the bottom of the piston. This angle can be found as a function of time if the angular frequency of the crankshaft is known:

$$\theta = \frac{\omega t}{2}. \tag{4}$$

Modelling Combustion Chamber Pressure

Each cylinder is modelled to utilise the Otto Cycle, which consists of an adiabatic compression, combustion, adiabatic expansion, and exhaust stages [3]. The volume of the cylinder is taken as V_1 when the piston is at the bottom of the cylinder, and V_2 when the piston is at the top of the cylinder. P_1 represents the initial pressure within the cylinder, so the pressure

after adiabatic compression is found as [2]:

$$P_2 = P_1 \left(\frac{V_1}{V_2} \right)^{\gamma}, \tag{5}$$

where γ is the ratio of the specific heats at constant pressure and volume, taken to be 1.36 for an unburned air-fuel mixture at 300 K [4]. The temperature change during adiabatic compression is also found from [2]:

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma - 1}, \tag{6}$$

where T_1 and T_2 are the initial and final temperatures respectively. The temperature after combustion T_3 is then found as [3]:

$$T_3 = T_2 + R\frac{Q}{c_v}, \tag{7}$$

where R is the ratio of the masses of air and fuel in the combustion chamber, Q is the energy released per unit mass of fuel burned, and c_v is the specific heat of the fuel at constant volume. Assuming a slightly lean mixture of gasoline and air, values of $R = 15$ [5], $Q = 46.7$ MJ kg^{-1} [6], and $c_v = 2.22$ kJ kg^{-1} K^{-1} [7] are used.

The maximum pressure achieved P_3 in the combustion chamber ocurrs at T_3, and the Gay-Lussac law can be applied to calculate it [8]:

$$P_3 = P_2 \left(\frac{T_3}{T_2} \right). \tag{8}$$

The transition from maximum compression to minimum compression can be modelled using Eq. (5) and Eq. (6), as it is an adiabatic process.

Estimating Power Loss

Following the Otto Cycle from Eq. (5) to Eq. (8), the force applied to the piston during expansion can be simulated. The starting pressure was taken to be atmospheric pressure, 101,325 Pa [2]. For a Formula 1 car, the ratio between V_1 and V_2 was taken to be 16 [9], and the surface area of a piston head to be 5027 mm^2, on account of their diameter being 80 mm [10]. Calculations used a frequency of 12000 RPM, such that the angular frequency was 400π. Using Eq. (3) and Eq. (4) the perpendicular force exerted by the piston can be found as a function of time for different initial temperatures, as shown by Fig. (1). By increasing the initial temperature

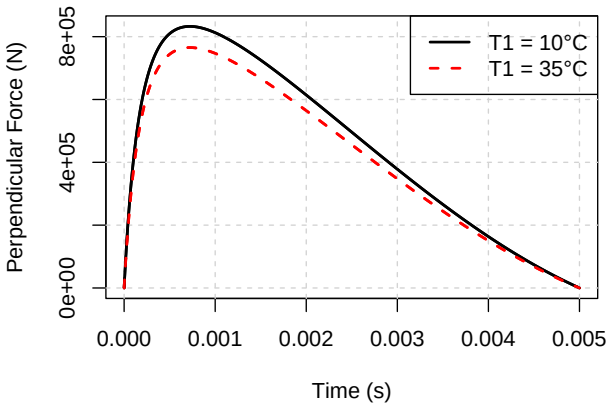

Figure 1: Perpendicular force acting on the crankshaft from a single piston as a function of time at the temperatures considered by Pulgam et al.

from 10°C to 35°C, an 8.1% decrease in the maximum force was found. Eq. (1) and Eq. (2) show that the engine's power is directly proportional to the force applied by the piston, so an 8.1% decrease in output power would also be seen. By combining Eq. (6), Eq. (7) and Eq. (8), it can also be shown that the maximum pressure, and therefore power output, is inversely proportional to the air temperature, as $P_3 \propto (T_1)^{-1}$

Conclusion

By assuming that Formula 1 engines undergo Otto Cycles, it has been shown that the maximum power output of the engines is inversely proportional to the air temperature inside them. The relative decrease in engine power between 10°C and 35°C, at 8.1%, was calculated to be very similar to the relative decrease in drag, which was 7.6% [1]. As these two effects work against each other, further research should be conducted to calculate the overall change of the car's top speed due to higher temperatures.

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