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A4 10 It's Dragging

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Abstract

Elevated ambient temperatures can enhance Formula 1 car performance because the reduction in air density outweighs the accompanying increase in viscosity. This study models these effects using Sutherland's law for viscosity and ideal-gas scaling for density over a 10 °C to 35 °C range at sea level, where viscosity rises by ≈ 6.8% and density decreases by ≈ 8.1%. Drag scalings with an 80:20 form-to-friction split yield a ≈ 7.6% total drag reduction at fixed speed, implying comparable savings in required power and energy per unit distance.

Introduction

Formula 1 (F1) performance is strongly coupled to aerodynamics. Teams refer to "hot" tracks as "low-power" conditions because warmer air creates thermal management challenges for the power unit and brakes, while also altering the car's aerodynamic performance. Separately, this less-dense air also reduces aerodynamic drag, which aids straight-line speed [1]. However, higher temperature also increases air viscosity, which can raise skin-friction drag. Here, we quantify both effects and estimate the net change in energy required per distance for a typical F1 running condition.

Decomposition of Drag

The total drag on a car is the sum of pressure drag D_p and skin-friction drag D_f, expressed as

$$D = D_p + D_f. \tag{1}$$

Pressure drag scales with dynamic pressure,

$$D_p \propto \frac{1}{2}\rho V^2 C_D A, \tag{2}$$

where ρ is air density, V is velocity, C_D is the drag coefficient, and A is the reference area. Skin-friction drag scales with ρC_f over the wetted area, and for a turbulent boundary layer on a smooth surface, the engineering correlation

$$C_f \propto Re^{-1/5} \tag{3}$$

applies, where $Re = \rho V L/\mu$ is the Reynolds number, and L is the length scale. Thus,

$$D_f \propto \rho C_f \propto \rho(\rho V L/\mu)^{-1/5} \propto \rho^{4/5}\mu^{1/5} \tag{4}$$

at fixed speed V and length scale L [2].

Thermophysical Properties

Air properties relevant to drag are dynamic viscosity $\mu(T)$ and density $\rho(T)$. The viscosity of an ideal gas follows Sutherland's law,

$$\mu(T) = \mu_{ref}\left(\frac{T}{T_{ref}}\right)^{3/2}\frac{T_{ref}+S}{T+S}, \tag{5}$$

where μ_{ref} is the viscosity at the reference temperature, T_{ref}, and Sutherland temperature S is 110 K, capturing the increase of μ_{ref} with temperature [3]. Under near-constant pressure and for dry air, density obeys the ideal-gas scaling $\rho \propto 1/T$ (humidity effects introduce small corrections but are neglected here). These relations set the Reynolds number and therefore influence both drag and overall vehicle aerodynamics.

Method

We consider two representative ambient conditions at sea level and constant pressure: a "cool" case at $T_1 = 10\,^\circ\mathrm{C} = 283\,\mathrm{K}$ [4] and a "hot" case at $T_2 = 35\,^\circ\mathrm{C} = 308\,\mathrm{K}$ [5]. We assume the vehicle speed V, reference area A, and drag coefficients remain fixed between these conditions to isolate the effect of fluid properties. The air viscosity $\mu(T)$ is obtained using Equation (5), and the density ratio follows the ideal-gas scaling $\rho_2/\rho_1 \approx T_1/T_2$ at fixed pressure.

We propagate these property changes into the drag components using the scalings

$$D_p \propto \rho, \qquad D_f \propto \rho^{4/5}\mu^{1/5},$$

appropriate for form drag and turbulent skin-friction drag at fixed speed and geometry. Finally, assuming a typical 80:20 split between form drag D_p and skin-friction drag D_f for a bluff road vehicle, we form a weighted total-drag ratio. Because energy per distance at fixed speed is proportional to drag, the same ratio gives the change in energy per lap segment.

Results

The viscosity, Equation [5], increases by about 6.8% between $10\,^\circ\mathrm{C}$ and $35\,^\circ\mathrm{C}$, giving $\mu_2/\mu_1 \approx 1.068$.

The ideal-gas density ratio is $\rho_2/\rho_1 \approx 283/308 \approx 0.919$ (an 8.1% decrease). Using the drag scalings, the skin-friction component changes by

$$\left(\frac{\rho_2}{\rho_1}\right)^{4/5}\left(\frac{\mu_2}{\mu_1}\right)^{1/5} \approx 0.947,$$

while the form-drag component scales directly with density, $D_{p,2}/D_{p,1} \approx 0.919$.

Applying the 80:20 weighting gives the total-drag ratio of 0.924, corresponding to roughly 7.6% less total drag, in the hotter $35\,^\circ\mathrm{C}$ condition compared with $10\,^\circ\mathrm{C}$, all else being equal.

Discussion

Viscosity vs density. Air viscosity increases with temperature, enhancing friction drag, while density decreases more strongly, reducing both drag components; the net outcome is a lower total drag and energy expenditure per distance in hotter air at fixed speed. For a representative 70:30 form–friction partition, the total-drag ratio is about 0.93, indicating a reduction of roughly 7.3%.

Applicability to Formula 1. In F1 applications, drag partition depends on track, setup, and downforce targets; bluff-body studies suggest form drag usually dominates, so this first-order treatment isolates fluid-property effects and excludes setup-dependent factors such as cooling-flow drag. In hot conditions, enlarged cooling exits would increase form drag and partly offset the predicted 7.6% reduction in total drag.

Using an 80:20 form–friction split as a baseline, sensitivity tests show that moderate changes in this partition do not materially alter the conclusion; for a 70:30 split, the total-drag ratio remains about 0.93. Interpreted in terms of straight-line performance, a drag-reduction factor of about 0.92 implies an increase in theoretical top speed of roughly 2–3% at constant power. This corresponds to an on-track gain of several km/h over a 320 km/h baseline, which is competitive in a racing context.

Conclusion

Across a representative $10\,^\circ\mathrm{C}$ to $35\,^\circ\mathrm{C}$ ambient temperature range at sea level, air viscosity increases by $\approx 6.8\%$, while density decreases by $\approx 8.1\%$. Using standard turbulent-flow scalings, this results in an $\approx 7.6\%$ reduction in total aerodynamic drag for a F1 car at fixed speed, translating to comparable energy savings per lap. The physical intuition is straightforward: hotter, thinner air lowers dynamic pressure sufficiently to offset the modest increase in skin-friction drag from higher viscosity.

References

[1] https://tinyurl.com/mercamgf1 [Accessed 03 November 2025]

[2] https://by.genie.uottawa.ca/~mcg3341/DragOfRoadVehicles.pdf Page 14 [Accessed 03 November 2025]

[3] https://www.cfd-online.com/Wiki/Sutherland%27s_law [Accessed 03 November 2025]

[4] https://tinyurl.com/j3kxvfcv [Accessed 03 November 2025]

[5] https://tinyurl.com/4yt99x2t [Accessed 03 November 2025]