Executive Summary of AirDensityDrive: F1 Power & Top-Speed Analysis

Aim

To evaluate the impact of air density on engine power output, aerodynamic drag, and top speed for a Formula 1 car under current (2025) and upcoming (2026) power unit regulations.

Scope

- All 24 tracks from the 2024 F1 calendar
- Circuit-specific average temperature and elevation
- Thermodynamic modelling under **choked flow** conditions
- Powertrain and drag force estimation under WOT conditions

Methodology

1. Data Collection – Average elevation and temperature data for each circuit
2. Air Density Calculation – Based on the barometric formula
3. Flow Modelling – Choked flow assumption at intake valve
4. Power Estimation – Using fuel LHV × combustion efficiency + MGU-K power
5. Top Speed Solver – Using numerical root-finding to solve:
$$P_{drag} + P_{rolling} = P_{Available}$$
6. Validation – Comparison against published FIA top-speed data (limited availability))

Key Results

Figure 1 shows that air density typically ranges from 1.1 to 1.2 kg/m^3, with notable outliers at Mexico City, São Paulo, and Las Vegas due to elevation.

Despite using idealized assumptions (e.g., constant Cd, stoichiometric AFR), the model achieves an overall accuracy of 95.48% when compared to available FIA top-speed data as shown in *Figure 2*. All tracks except Singapore fall within a ±10% tolerance band. Some discrepancies (e.g., Monaco, Singapore) stem from real-world limitations like insufficient straight-line distance, DRS use, and fuel mixture tuning are all outside the model's scope. Additionally, teams often run rich mixtures at high RPM for cooling and peak power, especially at altitude, explaining observed overperformance at Mexico City.

Figures 3 and *4* reveal that maximum engine power drops up to 19% at high-altitude circuits due to reduced air density. However, top speeds remain high, reinforcing the dominant role of aerodynamic drag over engine power in those conditions. In 2026, MGU-K output increases from 120 kW to 350 kW, giving hybrid systems a more dominant role. The model predicts significant top-speed gains at low-density tracks in 2026 (*Figure 5*).

Assuming ethanol as the baseline sustainable fuel (used in BTCC and others), comparisons show that despite its lower energy content (26.8 MJ/kg vs. 42.6 MJ/kg for gasoline) and AFR (8.95 vs. 14.13), overall ICE power drops by only ~4 kW under choked flow. The MGU-K increase offsets this completely, leading to higher peak total power and predicted top speeds of up to 390 kph.

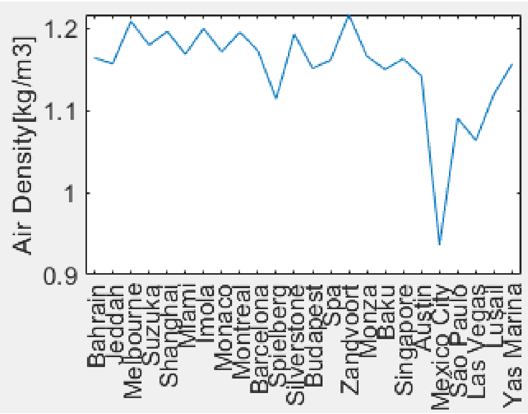

Figure 1. Air Density at each track

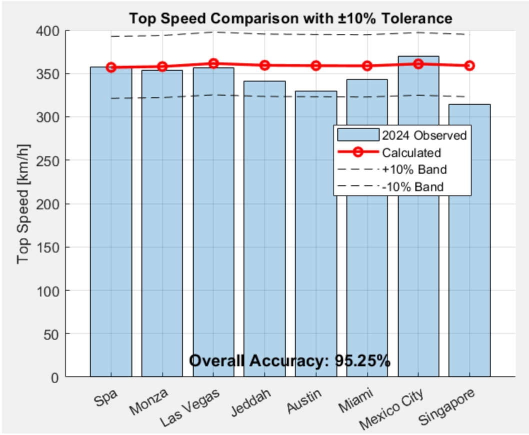

Figure 2. Top Speed Comparison with ± 10% Tolerance

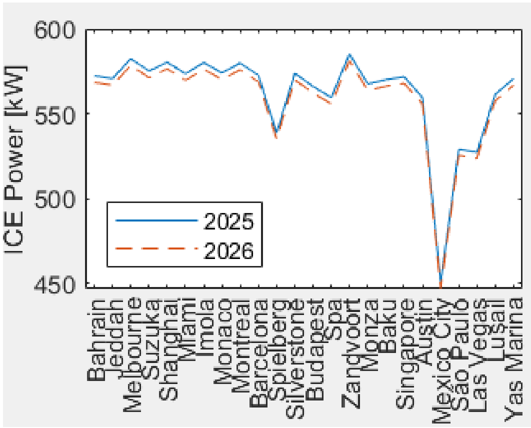

Figure 3. ICE Power results

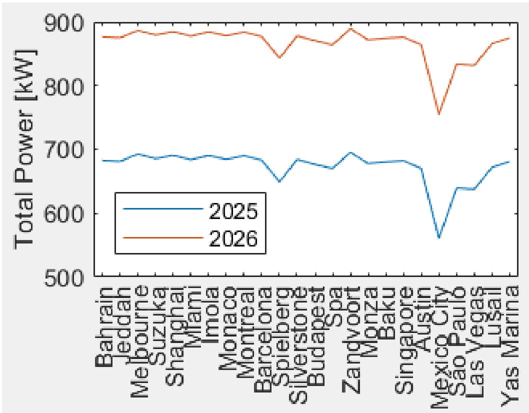

Figure 4. Maximum Total Power results

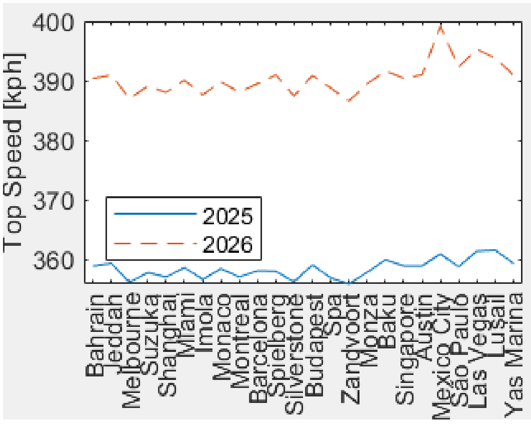

Figure 5. Top Speed results

Next Steps

- Improve validation by sourcing top-speed telemetry for all circuits
- Revisit results post-2025 and 2026 seasons to assess model fidelity
- Investigate straight-entry speeds and DRS zones for circuits with deviations (e.g., Monaco)

Conclusion

This model provides a clear first-order estimate of how air density, engine configuration, and hybrid power strategy affect top speed across the F1 calendar. The insights gained support a deeper understanding of performance trade-offs, informing future work in aerodynamic setup, MGU-K calibration, and energy management.

This study reflects my commitment to building analytical tools and physical insight applicable to performance engineering in top-level motorsport.