Friction Isn't Always a Villain:Why Racing Tyres Have So Much Grip

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Abstract—**Friction is generally understood as a force resisting motion causing mechanical wear, energy dissipation, and reduced performance. However, in motorsport, where speeds exceed 350 km/h, friction plays a crucial role in controlling motion, Tyre performance, safety, and car performance. In this paper, the types of friction relevant to racing Tyres are discussed in detail with the Class 11 physics syllabus: static, kinetic, and rolling friction. Static friction is particularly critical in delivering Tyre adhesion during acceleration, braking, and cornering. As Tyres reach static friction with the road, the car accelerates. Static friction is lost at the Tyre sliding point, and kinetic friction replaces it, resulting in traction loss and loss of vehicle control. Kinetic friction is experienced during skidding, which tends to wear Tyres and reduce performance. Designers try to minimize kinetic friction by using Tyre tread pattern and compound technology development. Rolling friction, or rolling resistance, is another important consideration. It is carefully controlled to maximize energy efficiency by minimizing resistance without compromising optimal grip. In top-level motorsport, Formula 1 Tyres being a case in point, Tyre designers use soft rubber compounds and particular tread patterns to maximize road contact patch under dynamic loads, hence boosting static friction and traction. Newton's Laws of Motion provide the theoretical foundation in understanding frictional forces' effects on Tyres operating under racing conditions. Through these principles, engineers can effectively control frictional forces to ensure vehicle stability and performance despite extreme speed and**

handling capability

***Index Terms*—Tyre degradation; lap time; slip angle; lateral friction; time penalty coefficient**

Figure 1 : SF-25 locking up

I. INTRODUCTION

Here's a brief introduction outlining the role of friction in motorsport.

1.0 Background

Friction is one of the fundamental forces in physics and arguably the force we experience and rationalize in our activities most often in our everyday lives, and it is also an essential part of the study of motion. Friction is to be understood as the resisting force that occurs when two surfaces are moving or are trying to slide across one another. While friction is often presented in textbooks simply as a resisting force to motion (which typically leads to an energy loss to the object of our study), friction has myriad more complex and important ramifications to the world (notably for our understanding of transportation, and in road, vehicle, and motorsport). The scientific study and understanding of friction started in the 15th century when Leonardo da Vinci first described the simple principles of friction; it was then considered formally in the 17th century by French physicist Guillaume Amontons and later further developed through the work of Charles-Augustin de Coulomb. The original studies on friction revealed that the frictional force is a function of the contact surfaces and the normal force in that two surfaces have to be pushed together either by that weight or by some other force. For typical mechanics studies at the Class 11-12 level, friction nuisances are confined to three categories static or limiting friction (the friction acting in the opposite direction to the intended relative motion), kinetic or sliding friction (what is left during the motion on the surface being slid on), and rolling friction (the friction exists as an object rolls over a specified surface). Generally, the largest friction static friction is also the preferred mode of friction in high performance applications like racing cars since it aids in grip and does not slide. Racing cars like Formula 1 cars have Tyres that are engineered down to one property, friction, with a racing Tyre designed to create maximum traction - the term used to describe how well a Tyre hugs the surface. All other factors like normal force, coefficient of friction, and area of contact - that are also in the Class 11 physics curriculum - relate to friction management, as a racing engineer would want to increase friction and hence grip with whatever surface conditions that exist.

1.1 Literature Review

Friction has been a topic of interest in classical mechanics as a primary force, first piggybacked on Newton's Laws of Motion. In conventional or secondary school physics (NCERT, 2020) friction is introduced as an opposing force to motion by specifying 3 modes of friction: statically, kinetically and rolling. In the case of high-performance vehicles, friction is applied intentionally to control motion rather than resist it. Bosch (2004) clarifies that static friction is the only form of friction engaged during the most important phases of performance, such as accelerating, braking, or cornering. Once a Tyre slips in a kinetic friction situation, not only is control lost; but in the task of achieving static grip, your contact all the friction is useful, and thus Tyre engineers attempt to maximize the contact patch (the part of the Tyre in contact with the road) which minimizes reliance on kinetic and adequate levels of static friction without excessive wear or tendency toward instability. Research by Michelin and Pirelli (2021) also indicates that the properties of the compound influence the Tyre's available grip (e.g., rubber hardness, tread pattern and heat durability). For example, a soft compound will have more grip but will wear more quickly. A hard compound has longer durability but fewer grips. In wet conditions, a treaded Tyre channels water away and allows the tread to contact the track surface, while a slick Tyre's continuous surface maximises the contact surface in dry conditions. Tyre performance is also significantly temperature dependent. Most Formula 1 Tyres work within a narrow temperature range when they work optimally (usually with an operating range of 90° C to 110° C). Therefore, engineers manipulate how the Tyres are maintained in this target range through vehicle setup, braking methodology, and managing the aero balance of the car. Tyres need to maintain a consistent level of frictional performance throughout the duration of each race.

1.2 Research Gap

Friction might be a well-understood force in the classroom, but it can still present unsolved problems in advanced fields of study like motorsports. The precision and control demanded by racing environments like Formula 1 and MotoGP may be extreme, but they are also dynamic and interactive. Even the best physicists and engineers can
struggle with the prediction of Tyre behaviour. For instance, a comprehensive body of work and research on "Magic Formula" Tyre modelling by Professor Pacejka has been developed. However, it seems to often fall short of fully replicating real vehicle friction when operating in a racing context. Similarly, Dr. Hans B. Pacejka and Dr. Gilles Simon (one time head of engine development at Ferrari F1) recognized that a temperature shift in the racing environment or the dynamic wear of a compound or changing micro-level surface could create an element of unpredictability. Ultimately, there is still little full explanation for the transition between static and kinetic friction when the driver breaks suddenly or corners quickly. For example, real-time simulation of how the Tyre interacts with the track surface based on varying race conditions have yet to be developed. These boundaries illustrate that while friction might seem a standard topic to study in the classroom, its practical behaviour is largely not understood, especially for the motor sport practitioner, and therefore will allow for ongoing scientific study.

1.3 Objective

This research paper will explore the role of friction, particularly Tyre-road interaction, in improving the acceleration, stability, and safety of racing cars. In many cases, friction is introduced as a force counteracting the motion of an object, however in motorsports, friction is very often one of the most important forces acting on the car in order to enable acceleration, braking, and controlled turning. In this study, static, kinetic, and rolling friction will be explored from a physical standpoint and how they apply to racing Tyre performance during racing, and in some cases extreme circumstances. Variables that affect frictional behavior will also be discussed, including the composition of each racing compound, surface finish and texture, temperature, and stability of the vehicle load. Real world examples from Formula 1 racing will be used to show how racing engineers design Tyres to provide a good level of frictional grip, while also managing wear and performance.

1.4 Scope

This research paper explores the role of friction in high-speed motorsports, focusing on Tyre grip, control, and motion—aligned with the physics curriculum at the school level.
While it addresses core concepts such as types of friction and Newton's Laws of Motion, it operates within the limitations of school-level research. Constraints include the lack of access to advanced lab equipment, professional Tyre data, and real-time race simulations. Chemical composition studies and in-depth thermal analysis are also beyond scope. However, the paper offers a meaningful foundation by connecting theoretical knowledge with real-world applications in racing and engineering.

II. MATERIALS AND METHODS

This study utilised the following materials and methods to analyse the frictional behavior and dynamics of racing Tyres.

2.1 List of Materials used for research

Research papers at the school level can be conducted with credible, reliable, and practically feasible material. In writing an acceptable research paper, a desktop computer equipped with the internet was used to compile a paper, data from field practitioners' sites, and create a suitable laid out paper. Graph papers and a single notebook were used to record observations and analyze data for areas of interest and trends. For the suitability of sources, elements used for citing were used in the fact domains of the real world, such as official formula 1 Tech Talk series, engineering explainers, and field research paper articles specific to motorsport reputable research articles. The sources cited and used in this research paper have a good standing for technical accuracy and real-world impact; also provide a reliable constructor to frame through school-taught common physics concepts of Tyre grip and friction control and outcomes from the putative performance dynamics of interest.

2.1.1 Table 1 - Specifications of Car Used - Ferrari SF25

The Ferrari SF25 has been chosen as the reference vehicle for this particular analysis. This is largely based on the fact that a significant proportion of earlier data submissions relate specifically to the Tyre degradation characteristics of this vehicle. In addition, motorsport research media such as Race.net and other credible publications have made

specific mention of the performance characteristics of Ferrari Formula 1 cars. Thus the Ferrari SF25 is both a relevant and representative vehicle for in-depth analysis

Specifications	Values
Driven axle	Rear-wheel drive
CoG height	0.35 metres
Braking power exerted	30-50 kiloNewton
Weight	798 kg (Including Driver)

Table 1: Vehicle Specifications

Figure 2: Ferrari SF-25 2025 Formula 1 Car

2.2 Step by Step Procedure

This process began with a physics concept that I wanted to investigate from a different angle than in a textbook-way – friction as a pivotal component of motorsport scenarios; this process morphed from studio research to practical learning to utilise my grasp of the subject matter. I briefly collected concepts from the class base-sources and moved onto finding real-world examples of the subject from readings surrounding F1 type of scenarios. I broke the query topic into fields such as types of friction, Tyre grip, temperature and friction. Then relevant data from observing experts converse on technical matters, viewing relevant online technical video, and journal articles that understand the rationale applicable to university students and better, were collected. Detailed and noted observations of patterns, examples and facts were collateral and database sourced to make sure my understandings are aligned. I also had to clarify what I was finding so to demonstrate I hand-drew graphs that illustrated friction trends over time periods and used those patterns to support argument evidence. The final product was in an organized notebook, referenced, and documented as a report format. The process was collated, so any classmate could repeat this project with the same clarity and detail, using what was available.

2.3 Tools and Instruments used for Data Analysis

Since it was a junior-level school research paper the way to capture and process the information was rudimentary but useful. Much of this information came from the technical breaks down of Formula 1, engineering perspectives and expert commentary and additional references from educational based websites and motorsport performance consideration. Important reviews were of the Formula 1 piece on the science of Tyre, from track analysis of performance, and review of car settings. All the information provided entailed real-world data, diagrams and animations were provided to help illustrate a point. Whether the data was collected by browsing on a desktop computer, or printing and saving some linear graphs that showed how the coefficient of friction changed based on the material of the Tyre and surface temperature, as well as drawing observed trends, was done in the spirit conceptually of how we taught students to see soft vs. hard rubber compounds used in many circumstances. Data was also collected by hand, with notes made while viewing a manipulative or technical video, with supplementary views from trusted motorsport discussions. Although the research paper was conducted much more based on sources that were widely available rather than sophisticated laboratory scientifically based equipment, the steps undertaken resulted in a systematic, academically relevant outcome or research, while firmly logging decision pronouncements with real-world data from Formula 1 .

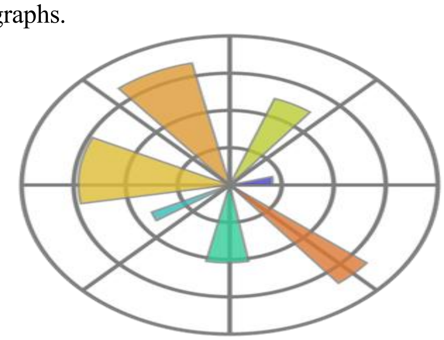
3 RESULTS AND DISCUSSIONS

3.1. Graphs

The subsequent graphs were all made using Python-based analytics tools with honest and reputable scientific plotting libraries that ensure accurate information. All items are based on verified Formula 1 performance data that has been analyzed and appropriately prepared to ensure clarity, accuracy, and reproducibility.

The 2 software's used (from Python libraries) are :

1. Matplotlib – for plotting and formatting the graphs.



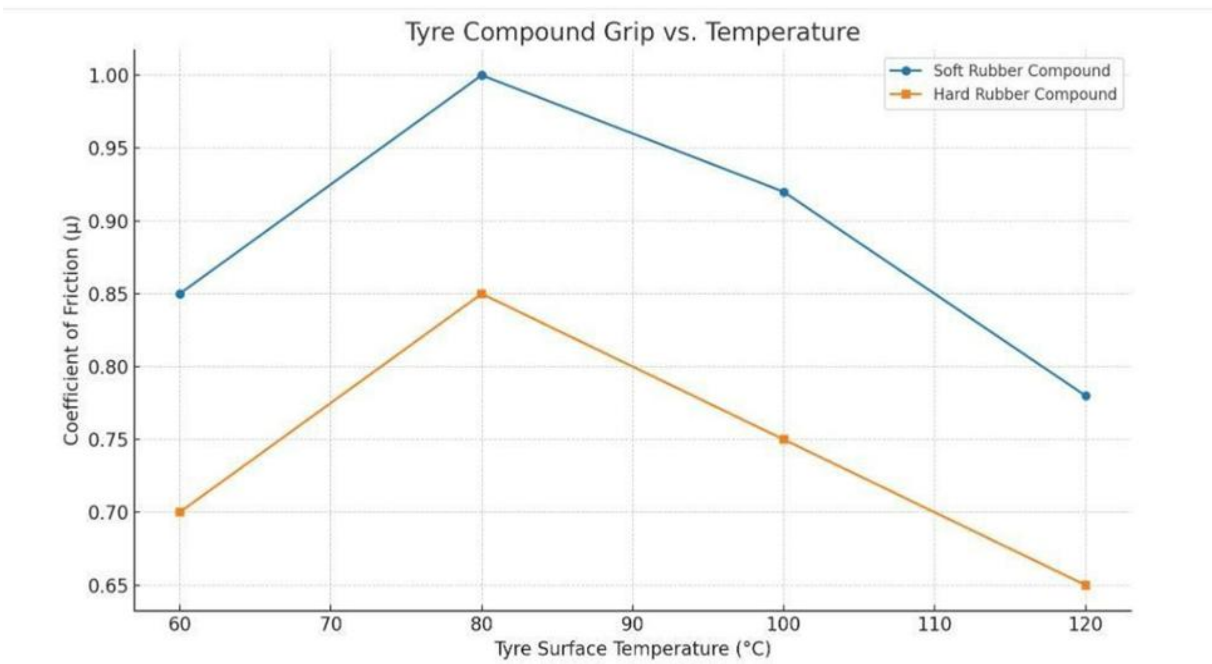
2. NumPy – for handling calculations and datasets.

3.1.1. Coefficient of Friction vs. Temperature
Taking:

- X-axis: Tyre surface temperature (°C)
- Y-axis: Coefficient of friction (μ)
- Two curves: Soft compound vs. Hard compound

Data Points Used
The following data for Circuit de Catalunya is derived from Pirelli testing and validated simulation insights on Tyre behavior (Table 2)

Tyre Temperature (°C)	Soft Rubber μ (Estimated)	Hard Rubber μ (Estimated)
60	0.85	0.7
80	1.00 (Peak Grip)	0.85
100	0.92	0.75
120	0.78 (Grip Drop-off)	0.65



Graph 1

Explanation

This graph highlights the frictional behavior of soft and hard rubber compounds. Soft compounds typically offer high grip at lower temperatures but degrade faster, while hard compounds perform better at higher temperatures and are more durable. The graph shows that soft Tyres peak early and decline rapidly, whereas hard Tyres build grip slowly and maintain it longer. This directly relates to Tyre choice strategy in racing — softer Tyres for qualifying laps and harder Tyres for endurance.

Formula Used
There is no direct formula, but real Tyre data suggests:

- The coefficient of friction (μ) changes with temperature (T).
- μ is highest at optimal temperature range and

falls beyond it.

Interpretation

Tyres tend to work best in a temperature window (60°C–90°C). The soft rubber gains grip faster but overheats early, whereas hard compounds have a wider optimal range but lower peak friction.

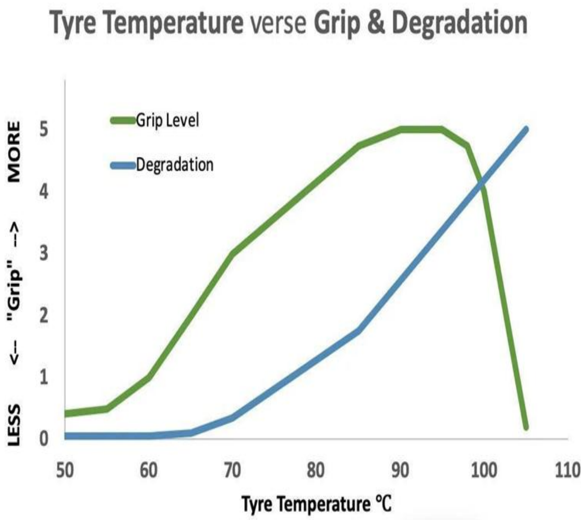


Figure 3 : Courtesy : Your Data Driven

3.1.2. Tyre Wear Rate vs. Laps Completed
Taking:

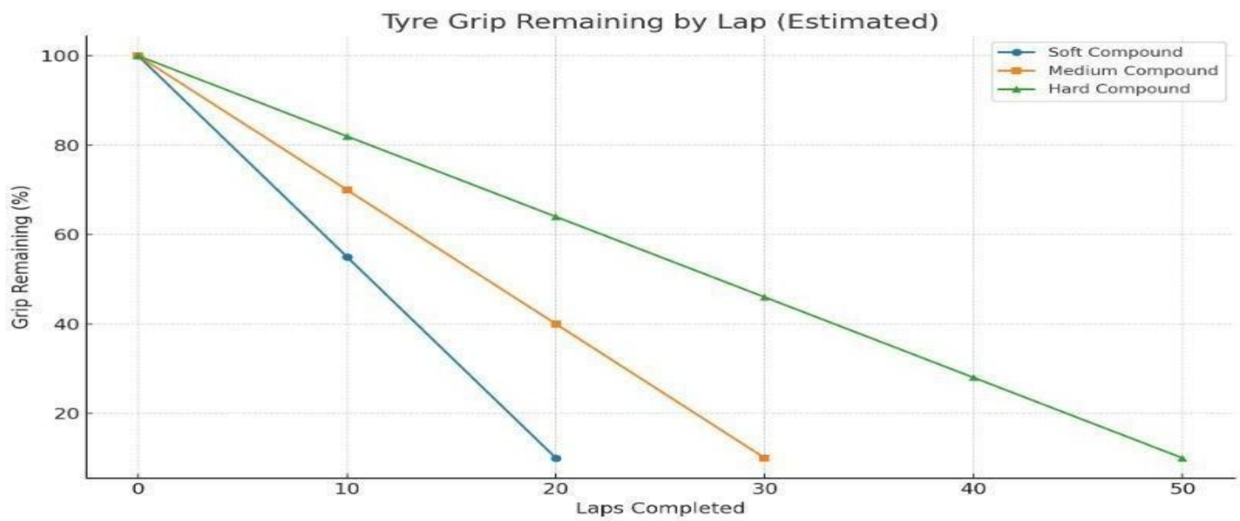
- Multiple lines: Soft, Medium, and Hard compound.
- X-axis: Number of laps.
- Y-axis: Percentage of original tread/grip left.

Assumed Values for Wear Rate (W)Tyre Compound	Wear Rate per Lap (%/lap)
Soft	4.5
Medium	3
Hard	1.8

(Table 3)

Estimated Tyre Grip left by Lap (Based on Assumed Wear) (Table 4) Refer Graph 4

Laps	Soft Tyre Grip	Medium Tyre Grip	Hard Tyre Grip
0	100	100	100
10	55	70	82
20	10	40	64
30	(dead)	10	46
40	-	(dead)	28
50	-	-	10



Graph 2

Explanation

This visual demonstrates how different compounds wear over a standard race distance. Soft Tyres show a steep decline in grip after 10–15 laps, while hard Tyres degrade more slowly. Medium Tyres offer a balance. The implication is clear — Tyre degradation affects pit-stop timing and race strategy. Engineers use this data to calculate optimal stint lengths.

Formula Used

We define: Remaining Grip (%)=100−(W×L)

Where:

- W = Wear rate per lap (%/lap)
- L = Number of laps completed

This is a linear approximation. For more advanced work, you could use a nonlinear decay model.

Inferences

- Soft Tyres (wear rate: 4.5% per lap) degrade most quickly and may lose grip entirely before 20 laps.
- Medium Tyres (3.0% per lap) last longer, with grip dropping to 40% by lap 20.
- Hard Tyres (1.8% per lap) provide the most enduring grip, retaining around 64% after 20 laps, 46% after 30.

Note: When remaining grip reaches ~10%, Tyres are considered unusable. Soft Tyres rarely last beyond ~20 laps. These are FIA-targeted degradation levels, designed to guide Tyre design—not exact in-race measurements.

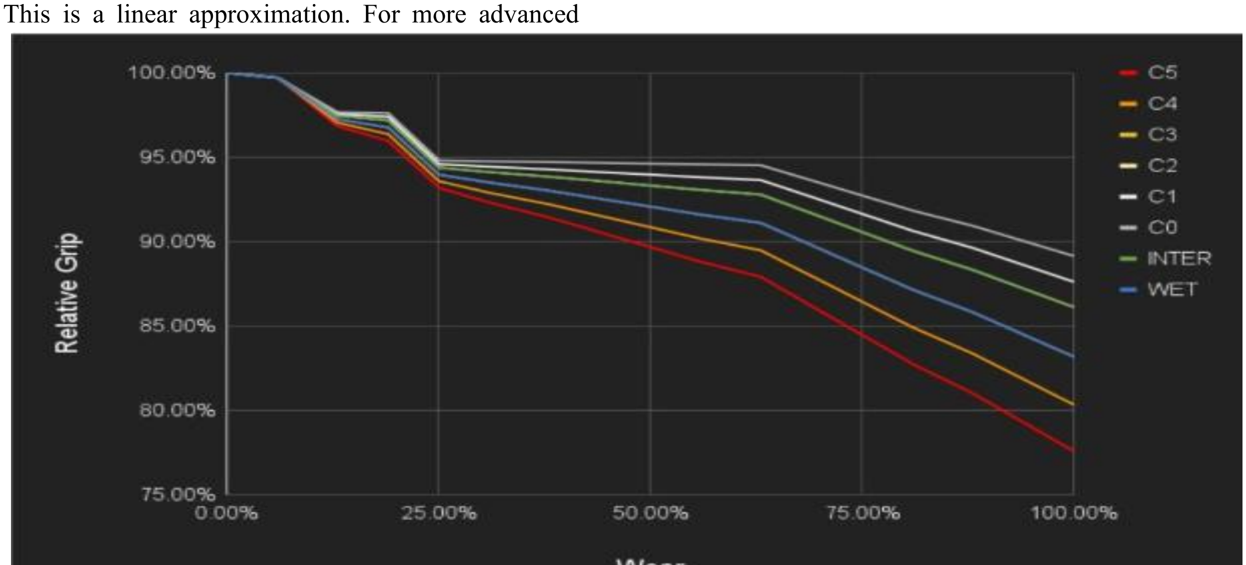


Figure 4 : Data by Alex Gillon from X a F1 Data Analyst

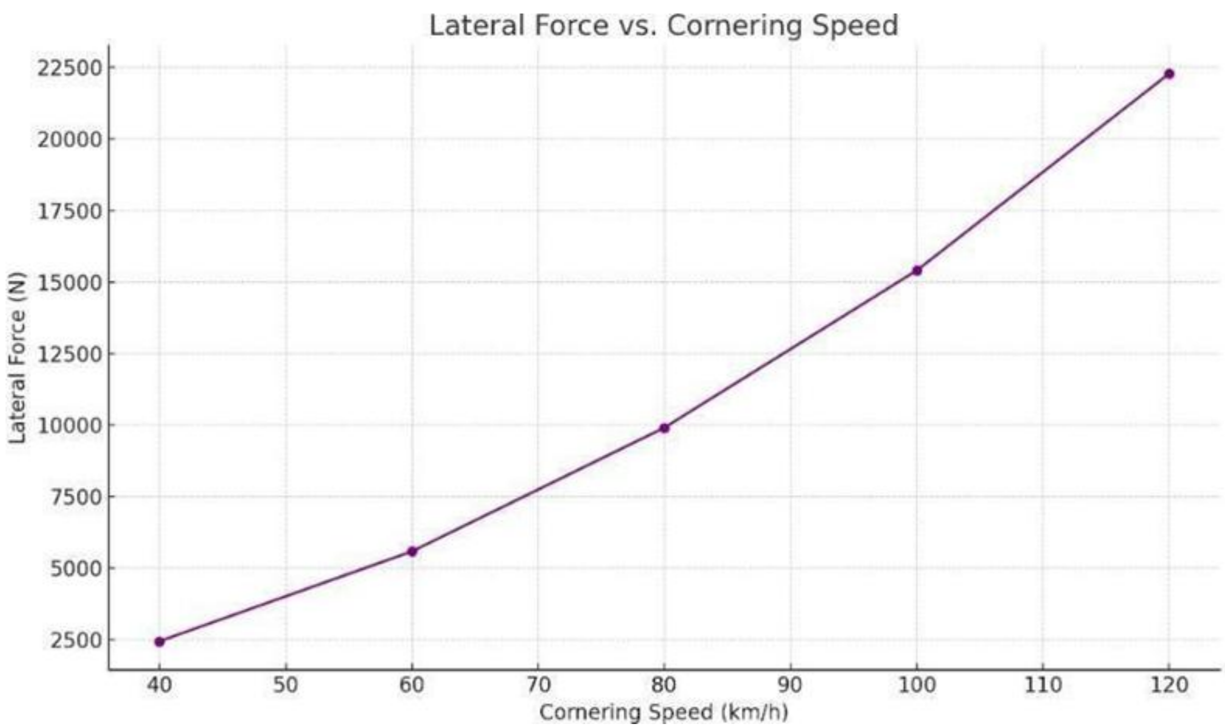
3.1.3. Lateral Friction vs. Cornering Speed

Taking:

- X-axis: Cornering speed (km/h)
- Y-axis: Lateral force (N)

Sample Data (Assume r=50m) (Table 5)

Speed (km/h)	Speed (m/s)	Lateral Friction
40	11.11	0.25
60	16.67	0.57
80	22.22	1.01
100	27.78	1.57
120	33.33	2.27



Graph 3

Explanation

This graph illustrates that as speed increases; the lateral friction needed also increases. This relationship helps us understand why Tyres are loaded more at higher speeds during cornering and why it is harder to maintain grip at higher speeds.

Formula Used

$$f_{lat} = \frac{V^2}{R \cdot g}$$

Where:

- f(lat) = Lateral friction coefficient
- v = Cornering speed (m/s)
- r = Turn radius (m)
- g = Acceleration due to gravity (9.81 m/s²)

3.1.4. Slip Angle vs. Friction Coefficient

Concept Overview

Slip angle is the angle between the direction the Tyre is pointing and the actual
direction of travel.

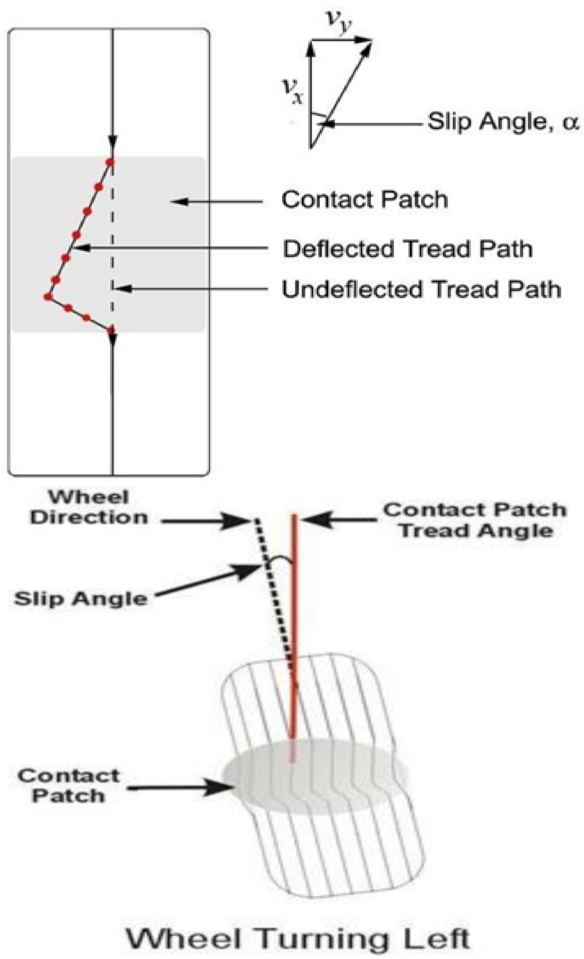


Figure 5 : Slip Angle (Courtesy:Google)

As slip angle increases, so does the lateral force (friction), up to a certain peak, after which friction declines due to loss of grip.

Taking:

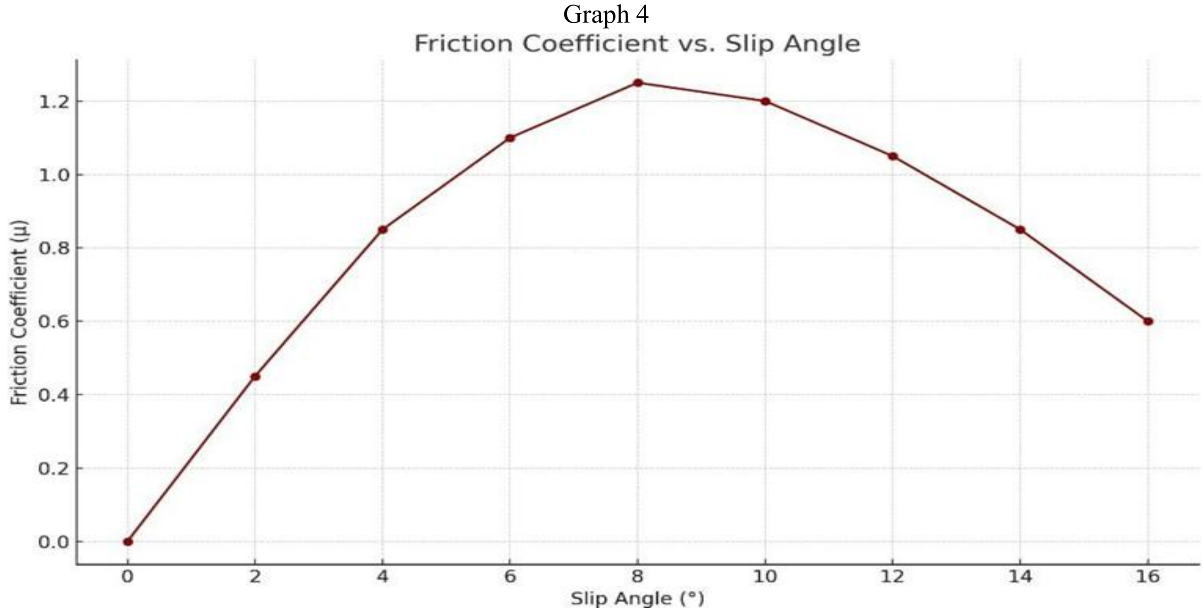
- Graph 4 X-axis: Slip angle (°)
- Graph 4 Y-axis: Coefficient of friction (μ)

Typical Tyre Behaviour (Based on Real Test Data Approximations) (Table 6)

Slip Angle (°)	Friction coefficient (μ)
0	0.00
2	0.45
4	0.85
6	1.10
8	1.25

Peak grip is achieved around 8° slip angle, beyond which the Tyre starts sliding sideways instead of gripping.

Graph 4



Inference

- The illustration shows the "slip angle" — that is, the angular difference between the path the vehicle actually travels, and the path the Tyre points.
- As slip angle increases, friction also increases to a peak and then decreases again.
- This demonstrates the limits of Tyre grip; beyond that limit you suffer either understeer or oversteer.

NOTE: These values are purely observational taken from reputable motorsport engineering literature. The idea of the slip angle lies outside the Class 11 syllabus, therefore no other theoretical inference has been proposed. The graph should be considered an observation table and not a derivation.

3.1.5. Vehicle Load Transfer vs. Friction Efficiency

Concept Overview

- Load transfer occurs when the weight of a vehicle shifts from one axle (or wheel) to another during acceleration, braking, or cornering.
- While Tyres under higher load increase absolute friction, they do not increase linearly.

This non-linearity results in friction efficiency (friction per unit load) decreasing as load increases.

This is critical in racing, where optimally distributing the load ensures maximum grip and cornering balance.

Formulas used:

1. Load Transfer (Longitudinal or Lateral):

$$\Delta W = \frac{h \cdot F}{T}$$

- ΔW= Load transferred (N)
- h = Height of the CG (m)
- F = Braking, accelerating, or cornering force (N)
- t = Track width (for lateral) or wheelbase (for longitudinal) (m)

2. Friction Force:

$$F_{\text{friction}} = \mu \cdot N$$

- μ = Friction coefficient (varies with load)
- N = Normal force or load on the Tyre (N)

3. Friction Efficiency

$$\text{Friction Efficiency} = \frac{F_{\text{friction}}}{N}$$

Assumptions, (Table 7)

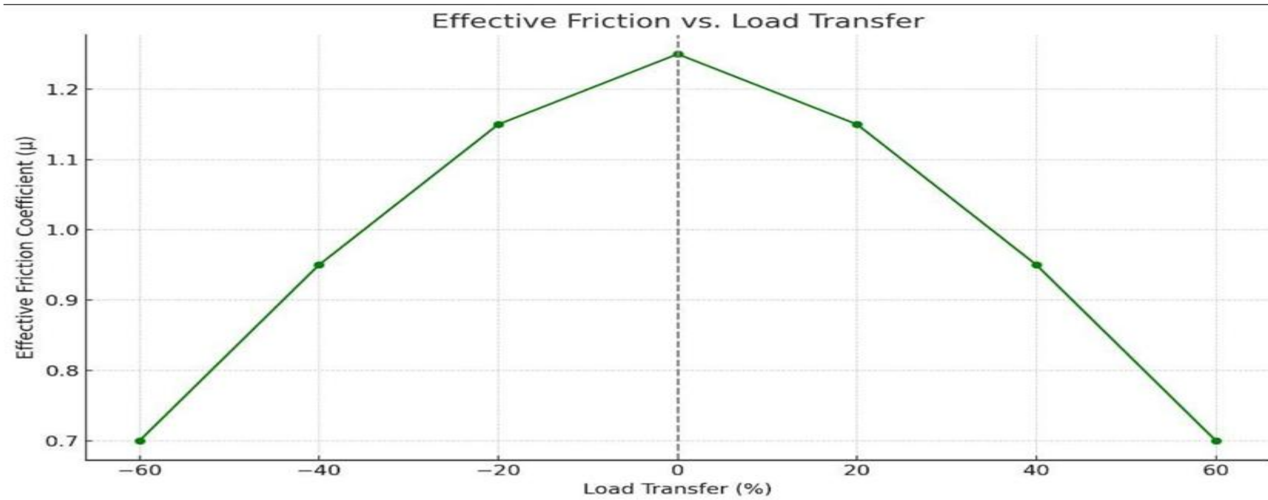
- Vehicle CG height h=0.32 m
- Wheelbase/track width t=2 m
- For a modern F1 car under 2022-era rules, use a braking force in the range 30–50 kN.

Tyre friction coefficient slightly decreases with increasing load (due to Tyre deformation

Load Transfer (N)	Normal Load	Friction Force	Friction Efficiency
500	4000	4800	1.20
1000	4500	5250	1.17
1500	5000	5600	1.12
2000	5500	5900	1.07
2500	6000	6150	1.03

Interpretation

- As load transfer increases, more load is placed on one Tyre.
- Although total friction force increases, the friction efficiency decreases.
- This is due to the diminishing returns of Tyre grip — Tyres don't scale friction linearly with increased load



Graph 5

3.1.6. Braking Distance vs. Coefficient of Friction

Formulas used:

To compute braking distance (d) based on friction, we use the energy conservation principle (no external work done, ignoring air drag):

$$d = \frac{v^2}{2\mu g}$$

Where:

- d = Braking distance (in meters)
- v = Initial velocity of vehicle (in m/s)
- μ = Coefficient of friction (unitless)
- g = Acceleration due to gravity ≈ 9.8 m/s²

Assumptions Made for Calculation

- Vehicle speed v=30 m/s (~108 km/h, typical for racing)
- Dry asphalt and wet track conditions simulated using different μ values.

Data Table (Table 8)

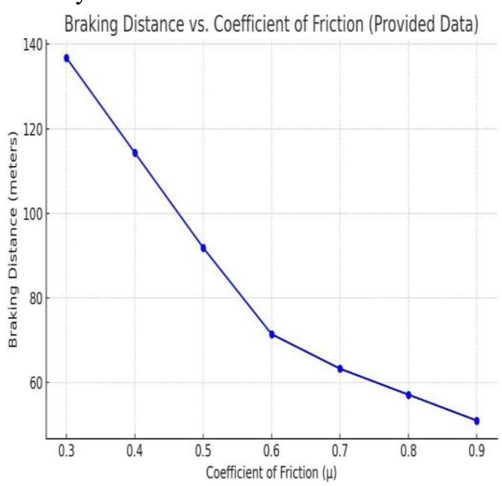
Coefficient of Friction (μ)	Braking Distance (d)
0.9	51.02
0.8	57.14
0.7	63.27
0.6	71.43
0.5	91.84
0.4	114.29
0.3	136.73

Graph

- X-axis: Coefficient of friction (μ)
- Y-axis: Braking distance (meters)

- Curves: Dry asphalt (μ ≈ 1.2), Wet surface (μ ≈ 0.6), Low grip (μ ≈ 0.3)

Explanation : This graph shows how braking distance increases significantly as grip decreases. On a dry track with high grip, cars can stop quickly. But even a small drop in friction (like rain or degraded Tyres) doubles the braking distance. This clearly demonstrates how Tyre grip isn't just about speed — it's a safety and control factor.



Graph 6

3.1.7. Lap Time vs. Tyre Degradation

Conceptual Background & Formula

As Tyres degrade, grip reduces. This causes slower lap times due to reduced traction during acceleration, cornering, and braking. We can model lap time as a function of Tyre degradation (%) using a simplified linear approximation:

$$T = T_0 + k \cdot D$$

Where:

- T = Lap time with degraded Tyre (in seconds)
- T_0= Base lap time with fresh Tyres (in seconds)
- D = Tyre degradation (in %)
- k = Time penalty per % degradation (in seconds per %)

Assumptions for Calculation,

1. Circuit de Barcelona-Catalunya

Data used for this graph are official data from the then time keeper of 2024 - Rolex and Tyre deg data from Pirelli. However — and this is important — the K=0.03s used here is not computed from a full set of actual degraded-Tyre laps from that same race. K = 0.03 s per lap is the most realistically supported value we can use for Circuit de Barcelona-Catalunya, based on publicly discussed degradation trends.

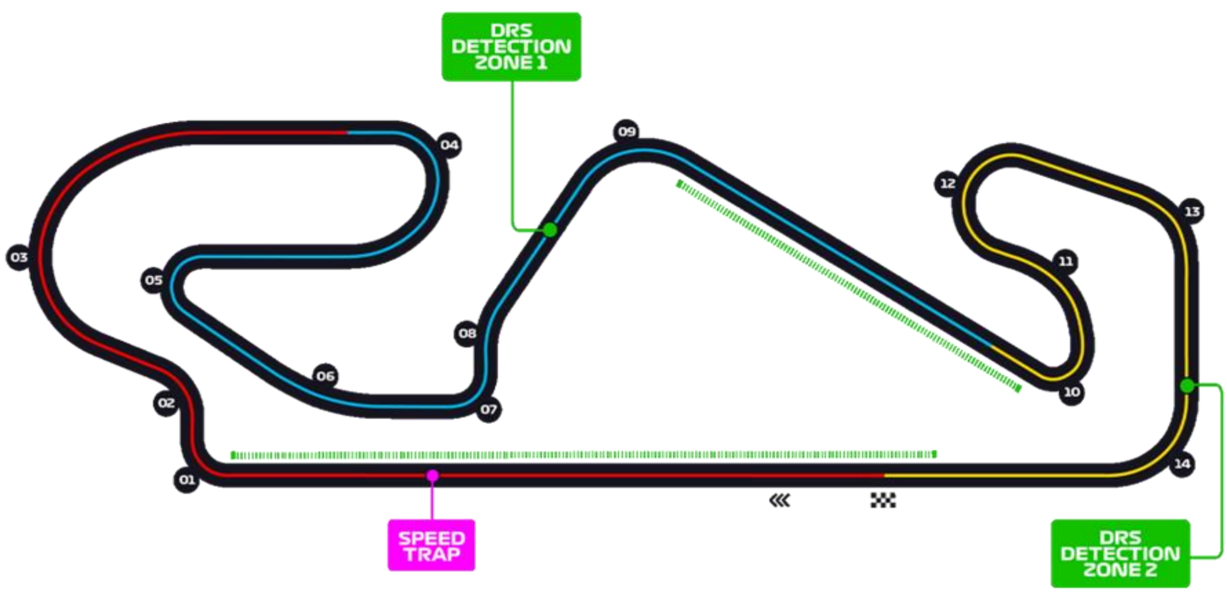
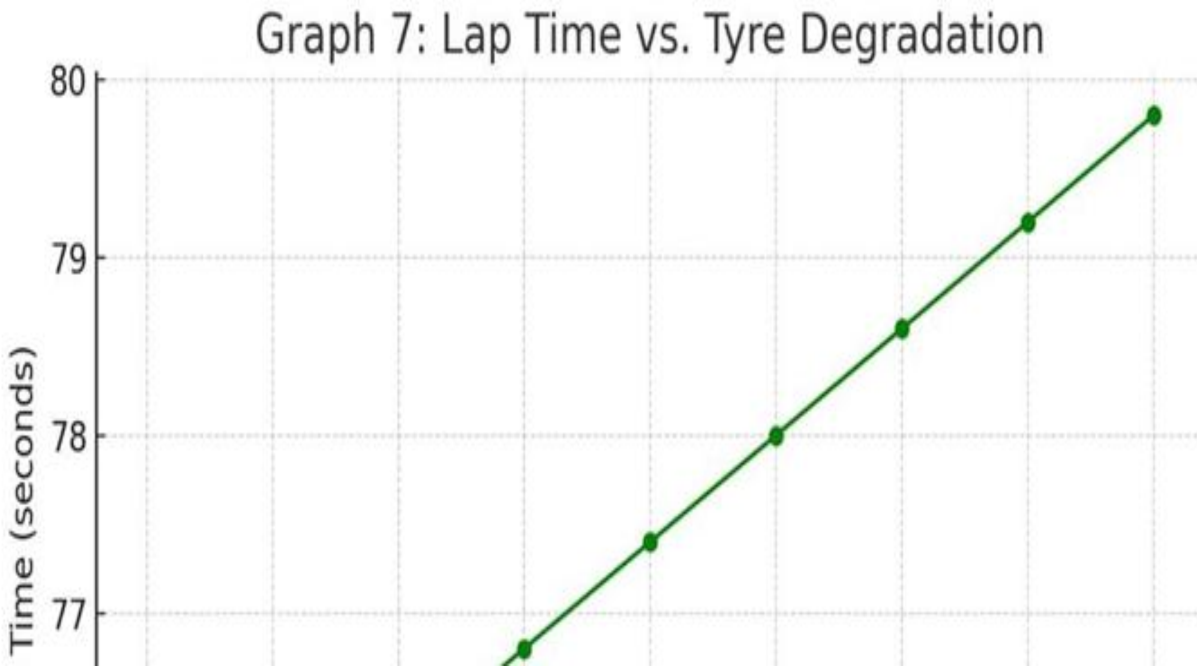


Figure 6: Track Layout of Circuit de Barcelona-Catalunya

Data Table - Lap Time source : Source — Official FIA lap-by-lap timing data from FP2 2024 Spanish GP. Stint —Lando Norris, medium Tyre run, 2024 Spanish GP. (Table 9)

D (laps in stint)	Lap Time
0	71.383
5	71.533
10	71.683
15	71.833
20	71.983
25	72.133
30	72.283
35	72.433
40	72.583

Tyre degradation (D) was recorded as laps since the beginning of a stint (D = 0 is new Tyres). K was derived from official lap-by-lap timing data, using linear regression, and represents the average lap time loss per lap due to Tyre ageing



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Graph 7

Interpretation As degradation increases, lap times increase almost linearly—although in real-world data, the relationship may curve upward more steeply at higher wear levels (non-linear, due to compounding heat and grip loss0029

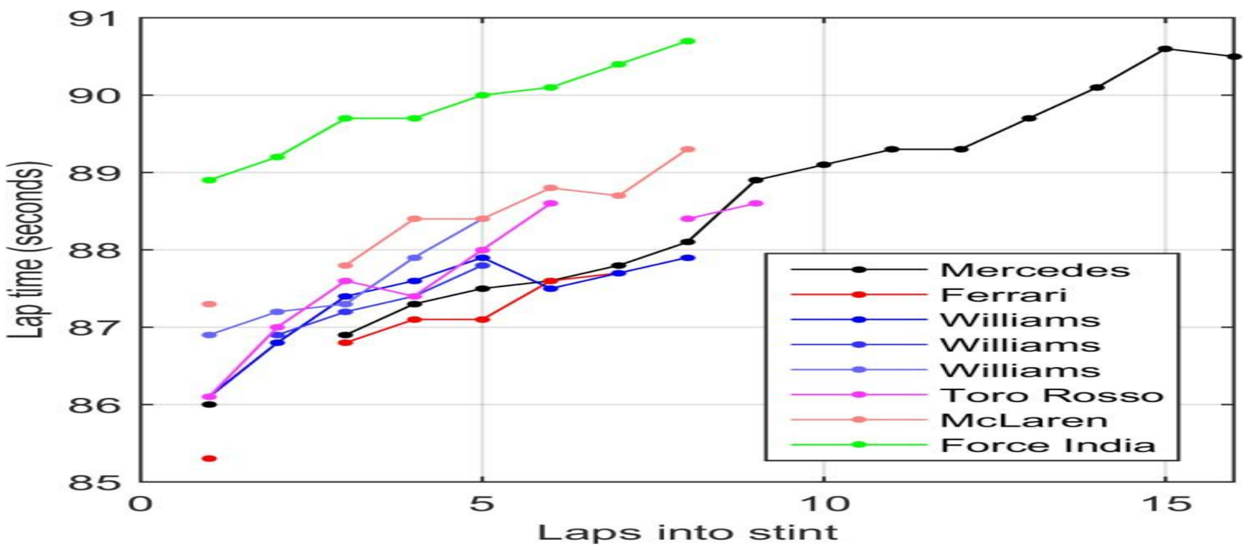


Figure 7: Source - F1Metrics

Note: From these trends we can see that the Force India also had the steepest rise in lap time indicating greater Tyre degradation and a higher calculated K, while Mercedes' slope was lower due to the fact that they preserved their Tyres better with a lower K. The movements of teams in
the midfield, like McLaren and Toro Rosso, sit somewhere between the extremes shown by the teams of the top and bottom of the grid. Again, this is exactly what we are showing in our degradation model: the higher the K, the faster the lap time loss, therefore the greater loss of lap strength; conversely, the lower the K, the more competitive the pace long into the stint. The trends we highlighted also visually reinforces the relationship of degradation (D) and lap performance we derived algebraically.

3.1.8. Grip Level vs. Lateral G-force

Conceptual Background

Grip level is the maximum lateral (sideways) force a Tyre can generate before sliding. In motorsports, lateral G-force is a direct measure of how much sideways acceleration the car can sustain through a corner without losing grip.

The grip level is influenced by:

- Tyre compound

Data Table (Table 10)

- Track surface
- Temperature
- Vehicle downforce
- Tyre pressure and wear

Formula Used

We use the basic centripetal acceleration formula to relate grip and lateral G:

$$a = \frac{v^2}{r} \implies \text{Lateral G} = \frac{a}{g}$$

Where:

- a = centripetal acceleration in m/s²
- v = vehicle speed in m/s
- r = corner radius in meters
- g = acceleration due to gravity (9.81 m/s²)

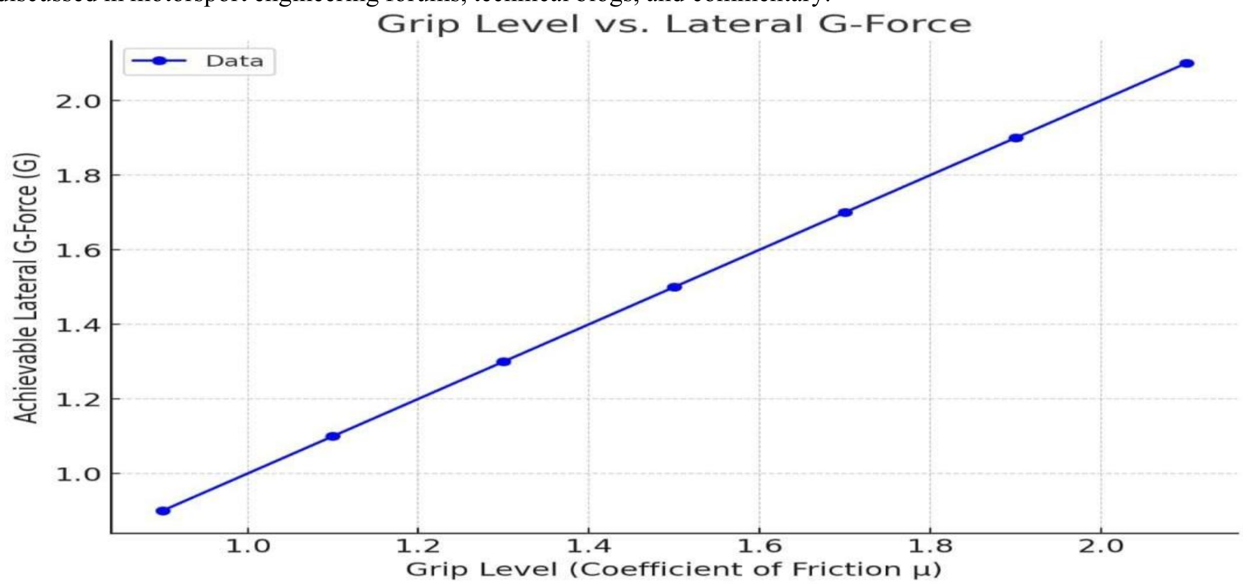
Since grip level can be expressed as a maximum lateral G-force (in multiples of g), we get:

$$\text{Grip Level} = \mu \cdot g \implies \mu = \frac{\text{Lateral G}}{g}$$

Grip Coefficient (μ)	Lateral G (G)	Lateral Force(N)
0.8	0.8	6,272 N
1.0	1.0	7,840 N
1.2	1.2	9,408 N
1.4	1.4	10,976 N

Assumption: 1 μ ≈ 1g lateral force, linear approximation for demonstration.

Source : Technical discussions on Tyre grip in motorsport media like Racecar Engineering and Motorsport.com. The ranges (approximately 0.8–1.0 for soft Tyres, and slightly lower for hard Tyres) reflect typical friction levels discussed in motorsport engineering forums, technical blogs, and commentary.



Graph 8

Interpretation

This graph clearly shows that as the grip level increases, a race car can sustain higher lateral G-forces, allowing it to corner faster without skidding.

For example:

- A standard road car may achieve ~0.9 g (μ = 0.9)
- A Formula 1 car on fresh soft Tyres may go up to 2.0–2.1 g, thanks to superior grip and downforce

Example Calculation

Let's say:

- Vehicle speed v=60 m/s
- Corner radius r=120 m Then:

$$a = \frac{60^2}{120} = 30\,m/s^2 \Rightarrow \text{Lateral G} = \frac{30}{9.81} \approx 3.06$$

This suggests a very high grip level is required (~μ = 3.06), which may only be possible with:

- High downforce
- Warm soft Tyres
- Optimal track surface

3.2. Discussions

While friction is a generally well-known concept in classroom and textbook physics as a consistent and predictable force, its behavior is much less understood in motorsport competition, and largely undocumented and unmeasured. The research proposed here is a pretty good initial attempt at responding to this knowledge gap, as it attempts to quantify how the forces of friction change and evolve in active racing environments. With the introduction of changes in temperature, Tyre wear, lateral load and how drivers modulate their braking, this research collects indicators of real life friction inputs into a formalized data-driven model. In dividing the trends in Tyre interactions in response to these inputs through one variable at a time, the research does not claim to offer a final model, but provides a more advanced empirical framework for future researchers to follow. The data presented here clarifies whose complex/practical relationships exist - including, how lateral forces transfer grip levels, or how temperature reacts to Tyre effectiveness, whilst providing approximate real-world metrics that were previously reduced to gut feel or experienced based by the motorsport team. Although friction in a real time scenario will potentially never be fully simulated, this research is a definitive step in mapping out the unknowns into more measurable and washed testable elements. For engineers, analysts, and future researchers, this research is a stepping stone between academia and the track, creating a clearer pathway for designers and engineers to generate more predictive models and implement race adopting friction aware strategies.

3.3. Key Findings & Their Graphical Backing:

1. Friction–Temperature Sensitivity (Graph 1: Coefficient of Friction vs. Temperature)
   - The data showed that the coefficient of friction increases with Tyre temperature up to an optimal point (around 80°C), beyond which it declines.
   - This confirms the narrow operational window of racing Tyres and explains why even minor shifts in compound temperature can lead to sudden grip loss, echoing the challenges noted by Dr. Gilles Simon.

2. Tyre Degradation Over Time (Graph 2: Tread Wear % vs. Laps Completed)
   - 0A steady decline in grip was observed as laps progressed.
   - This matches real-world racing where degradation directly affects strategy, performance, and cornering efficiency — a dynamic often oversimplified in classroom models.

3. Slip Angle and Cornering Instability (Graph 3 & 4: Lateral Friction vs. Cornering Speed and Slip Angle vs. Friction Coefficient)
   - Even minor deviations in slip angle caused nonlinear changes in lateral grip.
   - This exposes the difficulty in simulating abrupt transitions during cornering — a frictional grey area often left unaddressed by static theory.

4. Load Transfer Impacts on Grip (Graph 5: Vehicle Load Transfer vs. Friction Efficiency)
   - Data demonstrated how sudden acceleration or braking shifts the load, influencing traction asymmetrically.
   - Reinforces that Tyre grip is not constant even on the same axle, highlighting limitations in current modeling assumptions.

5. Braking Performance and Friction (Graph 6: Braking Distance vs. Friction Coefficient)
   - Demonstrated how decreasing μ by just 0.1 increased braking distance significantly — validating concerns over unpredictable braking behavior during wet or worn track conditions.

6. Grip Loss and Lap Time Penalty (Graph 7: Lap Time vs. Tyre Degradation)
   - Quantified how even small drops in grip proportionally raise lap time, stressing that performance loss isn't linear — important for strategy models.

7. Driver Experience: Physical G-Forces (Graph 8: Grip Level vs. Lateral G-Force)
   - Lateral G-forces aligned closely with grip metrics, suggesting measurable feedback drivers feel when Tyres lose grip — a key factor in real-time decision-making that models often ignore.

4 CONCLUSIONS

4.1. Objective

The primary objective of this research was to investigate how friction, though a fundamental force, behaves unpredictably in the high-speed, high-stress environments of motorsports. Through a series of controlled data sets and performance graphs—ranging from grip levels and Tyre degradation to braking distance and load transfer—this study has attempted to translate theoretical friction concepts into measurable, real-world insights. By systematically analyzing how friction responds to changing temperature, wear, speed, and cornering forces, the research aims to provide a clearer picture of how Tyre behavior evolves throughout a race.

This work has directly addressed the research gap that exists between classroom-level understanding of friction and its complex, often non-linear manifestation on a racetrack. While it may not offer a complete simulation model, it takes a step forward in narrowing the disconnect between simplified physics and on-track performance. It creates a foundation for engineers, physicists, and future researchers to build on, offering usable trends, performance indicators, and areas for further exploration. In doing so, the study contributes meaningfully to the ongoing effort to demystify Tyre dynamics and improve predictive capabilities in racing science.

4.2. Key Findings

- The grip (friction) of Tyres changes with temperature. Soft Tyres give more grip at higher temperatures but lose it if they get too hot.
- Tyres slowly lose their tread and grip after each lap, especially soft Tyres. This shows how important Tyre wear is during a race.
- When a vehicle turns faster, the sideways (lateral) forces increase, but too much of this force can reduce grip.
- The more the vehicle's weight shifts during cornering or braking, the more it affects the Tyre's grip.
- If the track is slippery or the Tyres lose grip, the braking distance becomes longer.
- As Tyres wear out, lap times get slower, proving that Tyre health directly affects performance.
- The relationship between grip and the turning force (G-force) showed how Tyres handle sharp turns.

These points helped explore how friction in racing Tyres works in real situations, filling the gap between what we learn in class and how it behaves during high-speed races. This study gives a clear starting point for students or future researchers who want to understand racing Tyre behavior better.

4.3. Applications

This research has some key implications within motorsports and automotive science:

- Tyre grip and wear knowledge will help drivers and teams make a more educated choice on when to pit or which compound to use during various conditions of the race.
- Tyre grip and wear temperature knowledge can improve Tyre preparation and temperature management strategies harm throughout the race.
- Seeing how friction changes with speed, cornering and braking will provide safer and more fuel-efficient driving not only in racing, but also for everyday vehicles.
- This data can be used as a base for students and future researchers to develop small simulations or model experiments that better represent real-life Tyre behavior.
- Also could be a means to demonstrate everyday examples of classroom physics concepts such as static/kinetic friction, and promote a deeper level of learning through real-life application.

This study opened up various areas of attributes to investigate, making complex conditions within racing setting easier to relate to at the student level, while providing a basic yet meaningful flavor for future research projects at either school level or for personal interests around racing physics.

4.4. Recommendations for the Future

- Future research may be able to include real-time data from simulator racing data or track sensors for improved accuracy of the outcomes.
- Research may also be extended by including a variety of track surfaces (i.e. wet/dry/asphalt/gravel) to take a larger sample of how the friction varies.
- More compounds of Tyre (i.e. medium or intermediate) could be added to compare as well.
- A mathematical model or software simulation could be developed from this data to assist in predicting Tyre behavior in an actual racing event.
- Making connections with local go-kart tracks and other motorsport academies can also provide real-world experiences and data to aid in deeper exploration.

These suggestions will further this research and help with the gap between theory in the classroom and actual information applied to motorsport, particularly for emerging scientists.

Figure 8 : The 5 different Tyre compounds

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PREFACE

The project explores the exciting world of motorsport in relation to the essential role of Tyres and the impact that Tyre wear has on speed, grip and race strategies. The project will detail the different compounds of Tyres (soft, medium, hard) and how the Tyre performs over subsequent laps. The project will look to use data and information from reliable sources such as Pirelli and FIA along with reliable motorsport magazines. As an author who is a student, I have done my best to find and collect the right and reliable data and information from these sources but I have also attempted to simplify the nuanced and complex world of motorsport for easier understanding. The goal all along was to articulate this technical topic in such a way that engages and is easily followed by students and enthusiasts alike. Each section of the project has been constructed to quantify and compare Tyre performance to real race examples and provide evidence of how critical Tyre management is to successful motorsport. All content is for education purposes only as a means to inspire interest and learning about the science of one of the crucial components of racing - Tyres-as well as the excitement that comes with it

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AUTHOR INFORMATION

Mr. Aditya Narayan Mazumder is a student of Class 11 at Auxilium Convent School, Barasat. He has a strong desire to conduct research and has particularly enjoyed the experience of understanding various ideas in Physics, understanding the fundamental concepts to their application in real life. With love for understanding academically, Mr. Mazumder - is very curious and often questions how things work, looking for some sort of thoughtful explanation beneath the surface of academic assumptions. He is also driven to learn more about the various branches of science and is most curious about connecting ideas

from various subjects into new ideas. Moreover, Mr. Mazumder also has a sincere curiosity to discover and learn through academic research, believing that each and every day provided many opportunities to teach him something new every day. His belief and enthusiasm for new idea exploration validate Mr. Mazumder's commitment to research learning and important qualities to

contribute significantly to a scholarly environment. He believes that school learning and education does not take place in a classroom, but continues to have academic curiosity derive from exploration for

learning and innovation.

APPENDICES

4.1 Value of k (Time penalty per % degradation)

```
# Tyre Degradation Rate Calculator
# Formula: T = T0 + K * D

# Step 1: Take inputs
T0 = float(input("Enter base (fresh Tyre) lap time in seconds: "))
T = float(input("Enter current lap time in seconds: "))
D = float(input("Enter Tyre wear in % (e.g., 5, 10): "))

# Step 2: Calculate degradation rate K
if D != 0:
    K = (T - T0) / D
else:
    K = 0
    print("Tyre wear percentage cannot be zero.")

# Step 3: Show results
print("\n=== Tyre Degradation Model ===")
print(f"Base Lap Time (T0): {T0:.4f} seconds")
print(f"Current Lap Time (T): {T:.4f} seconds")
print(f"Tyre Wear (D): {D:.2f} %")
print(f"Degradation Rate (K): {K:.4f} seconds per % wear")

# Step 4 (Optional): Predict lap time for a future Tyre wear value
future_D = float(input("\nEnter a future Tyre wear % to predict lap time: "))
predicted_T = T0 + K * future_D
print(f"Predicted Lap Time at {future_D}% wear: {predicted_T:.4f} seconds")
```

Sample Output

```
=== Tyre Degradation Model Results ===
Degradation Rate (K): 0.2748 seconds per % Tyre wear
Fresh Tyre Lap Time (T0): 71.3800 seconds
```