
WAVEY DYNAMICS.

# Advancements of Tyre Science in a Motorsport Context

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# WAVEY DYNAMICS.


Wavey Dynamics core expertise is concentrated around vehicle dynamics and aerodynamics with focus on performance. Our clients are under continuous pressure to innovate and require specialist knowledge to operate at the intensity demanded by their competition.

You may be in a highly competitive championship battle or preparing for one; our depth of skill in aerodynamics and vehicle dynamics allows us to create innovative solutions unavailable to the competition to deliver clear performance advantages.

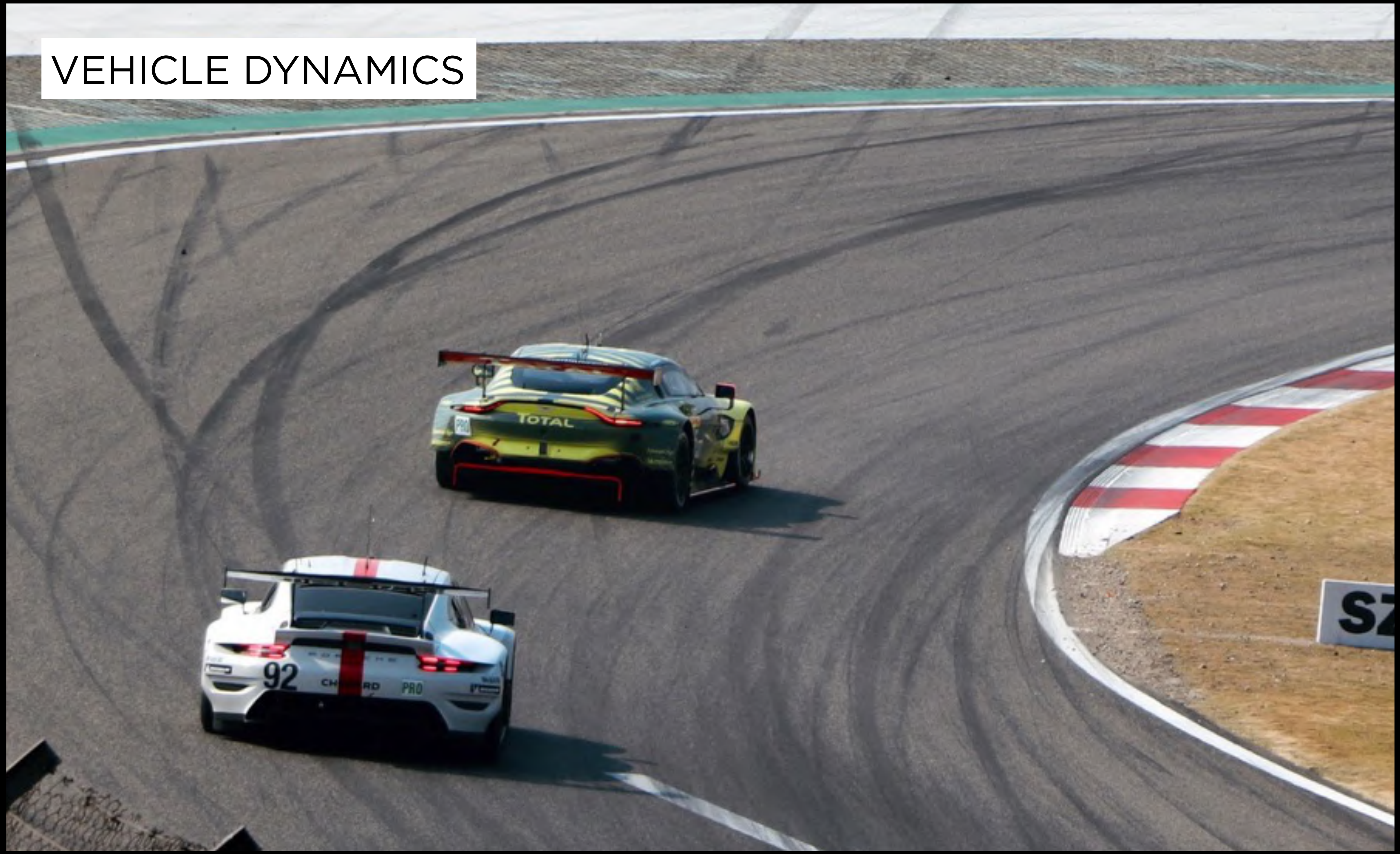
We're favourably placed to offer the following services:

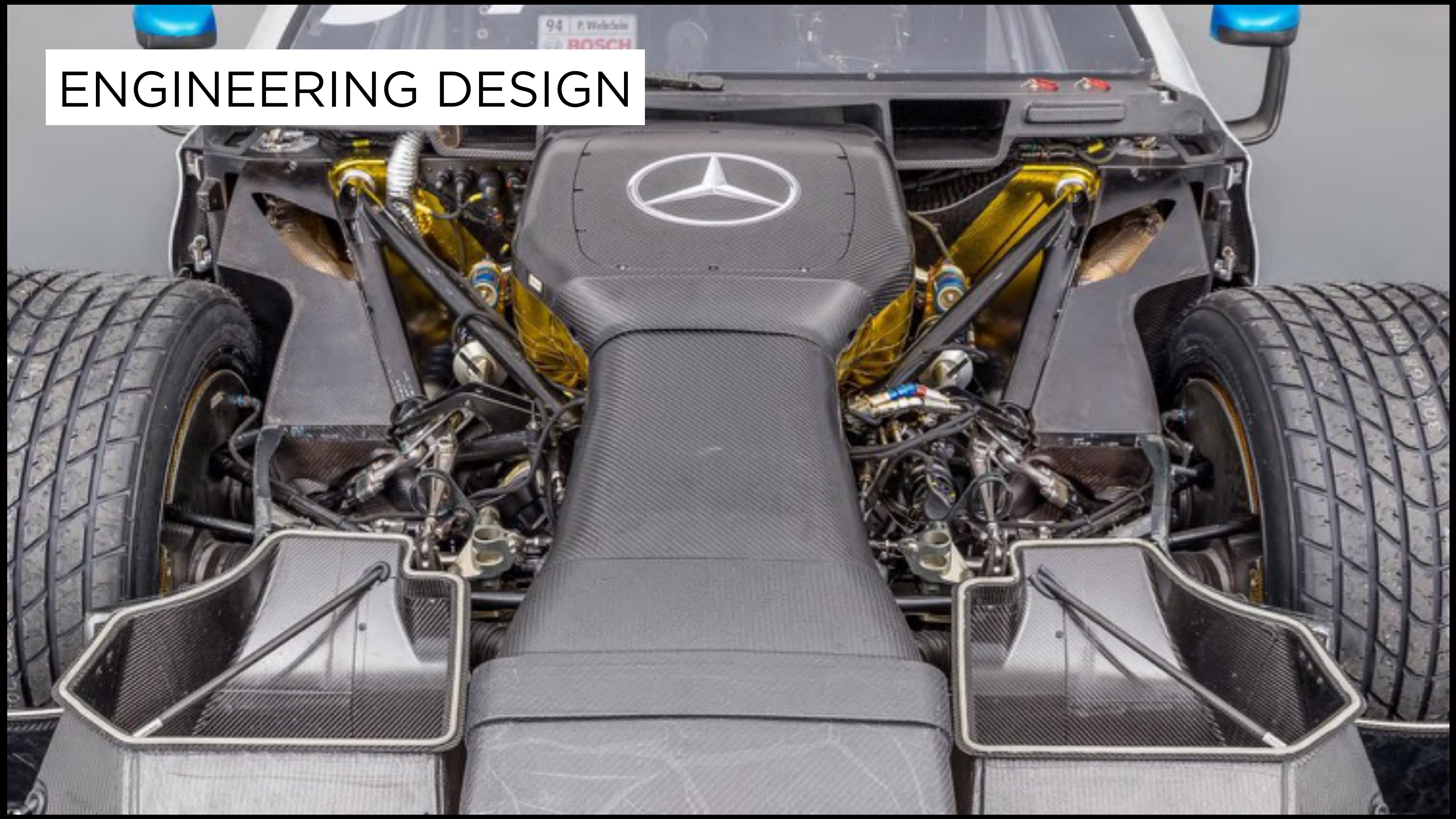
- Vehicle dynamics development
- Aerodynamics development
- Performance & race engineering (Trackside)
- Engineering design

## Exceptional Insight

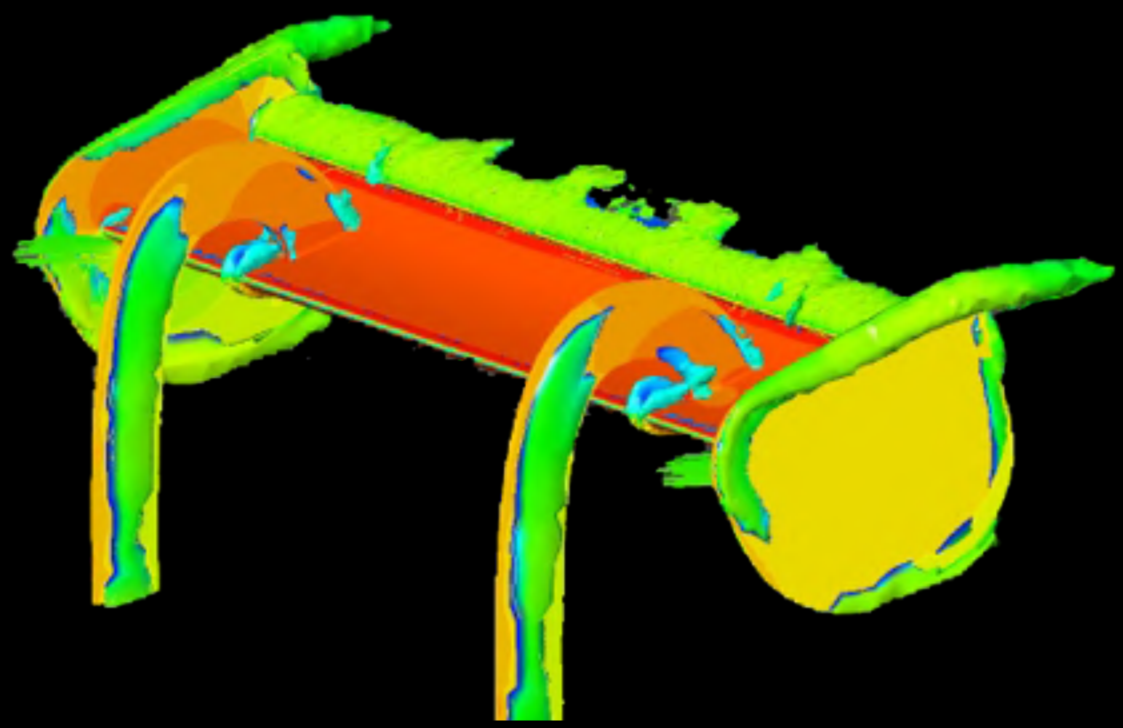
We offer an in-depth understanding of the fundamental physics behind racing, enabling us to implement pragmatic solutions to keep you at the front of the grid

Utilising modern instrumentation, data analysis and simulation tools, **We help to drive a blend between a deep understanding of technology and clear performance outcomes.**


AERODYNAMICS




"ADVANCEMENTS OF TYRE SCIENCE IN A MOTORSPORT CONTEXT"

# CONTEXT

- Why are we interested in tyres?
  - The single most important component.
- Why understanding tyres is important in motorsport
  - BoP and modern motorsport
- Challenges and obstacles in tyre science
  - A highly non-linear component
- Recent developments
  - Modelling tyre properties
  - Measuring tyre properties


# SEMINAR CONTENTS

# 1. INTRODUCTION

*The tyre.*

## RULE #1: THE TYRE IS KING

- The tyre is the only part of the vehicle which is in contact with the track surface - the operating conditions of the tyre are the ultimate dictator of vehicle performance ⟶ <u>What are the best conditions and how do we find them?</u>

- Creating a positive environment for the tyre is of the highest priority.

- A ‘tyre centric’ approach to vehicle dynamics.

## NON-LINEARITY

- The tyre is a highly non-linear component
- Creating mathematical models of tyres is very complex
- In the age of extremely tight performance margins and simulation, this is problematic

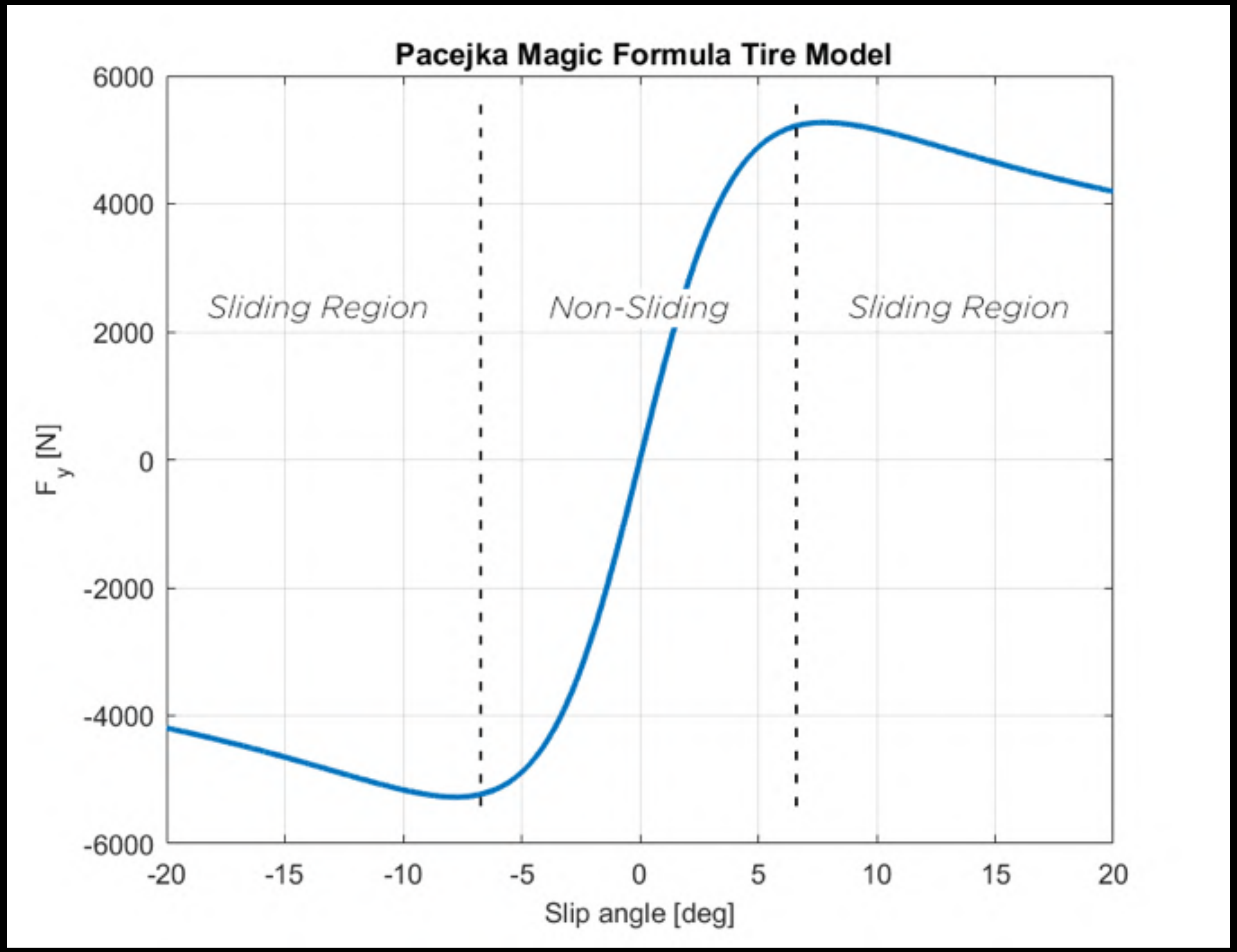



*Figure 1: Lateral force vs. Slip angle graph (Wavey Dynamics)*

## PRIMARY FACTORS INFLUENCING TYRE ADHESION

- Vertical load → Weight transfers, aerodynamics
- Environmental conditions → Moisture, dirt & dust, track micro topology
- Inflation pressure → Contact patch pressure distribution, stiffness
- Wheel camber → Contact patch area
- Compound state → Viscoelastic properties (hysteresis), temperature, wear

# 2. THE TYRE: A VISCOELASTIC MATERIAL

*The properties of viscoelastic materials.*

## VISCOELASTICITY

- Viscoelastic materials demonstrate varying proportions of elasticity and viscosity.
- Energy is stored and dissipated
- The magnitudes of storage and loss dictate the level of hysteresis of the rubber
- When the hysteresis (energy dissipation) is at a maximum, grip is at it's highest.

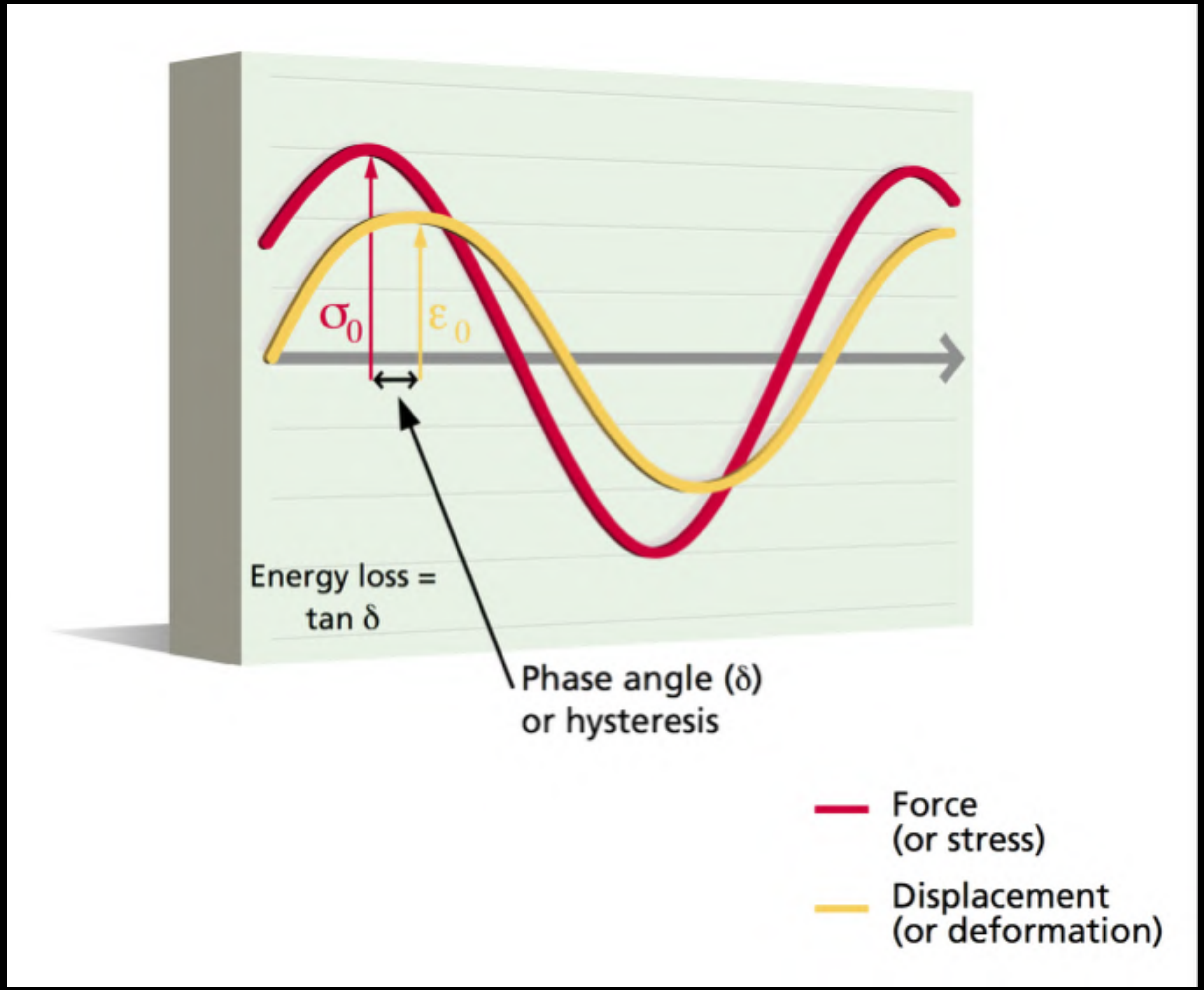



*Figure 2: Displacement always lags behind stress in viscoelastic materials. (1)*

## QUANTIFYING VISCOELASTICITY

Viscoelasticity is quantified through 3 primary parameters:

- **Storage modulus:** A measure of the energy stored during a stress input
- **Loss modulus:** A measure of the energy dissipated during stress input
- **tan $\delta$/Loss factor:** The ratio of loss to storage. This is an indicator of the damping and level of hysteresis within the material.

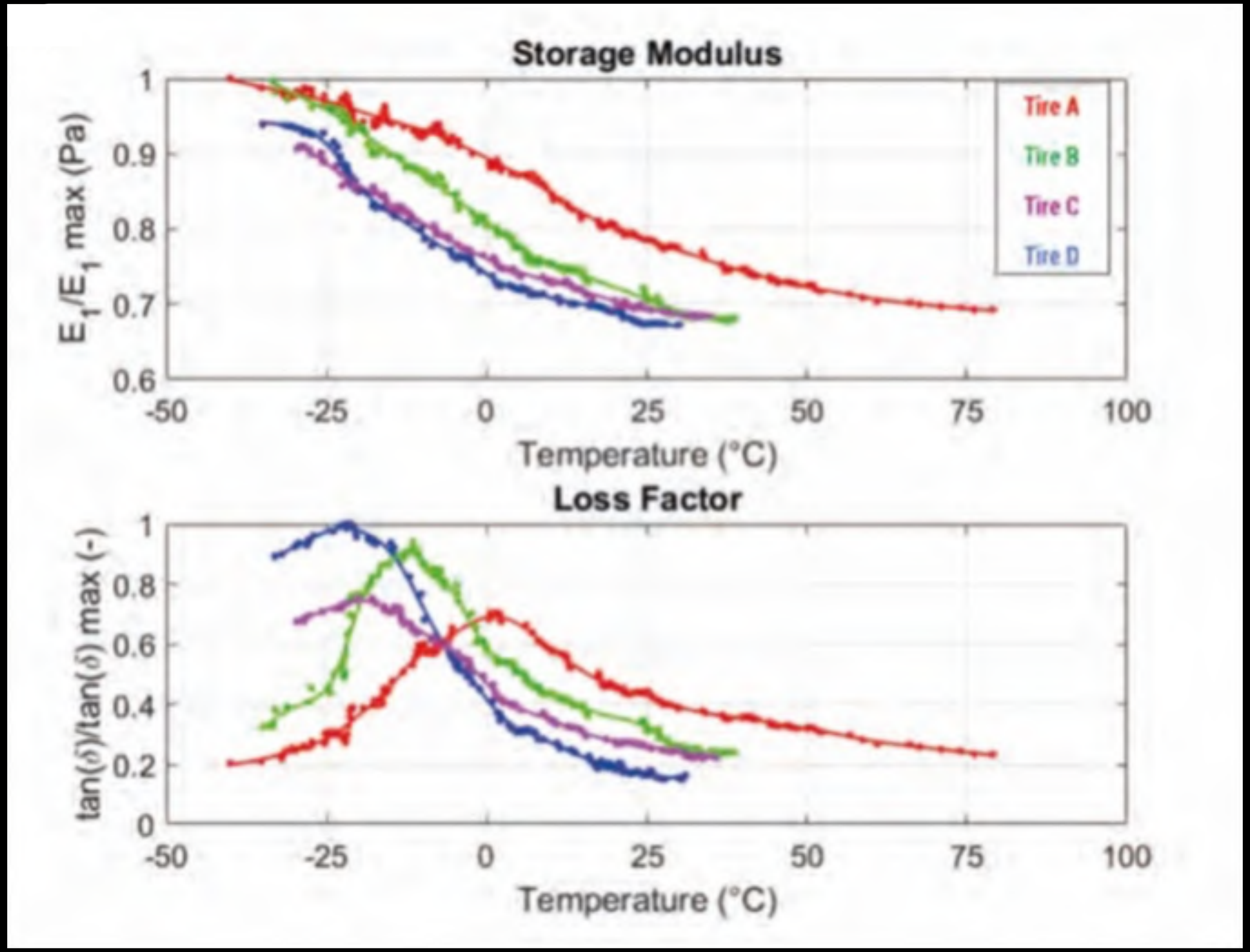



*Figure 3: Storage Modulus & Loss Factor for 4 different tyre compounds supplied by MegaRide (2)*

## TEMPERATURE & FREQUENCY DEPENDANCE

- Viscoelastic behaviour is a factor of temperature and stress frequency
- Heat is generated through energy input into the tyre through:
    - SEL (Strain Energy Loss)
    - Frictional energy
- Stress frequency is defined by road microtopology and sliding velocity.
    - Contributions from mechanical and chemical adhesion mechanisms

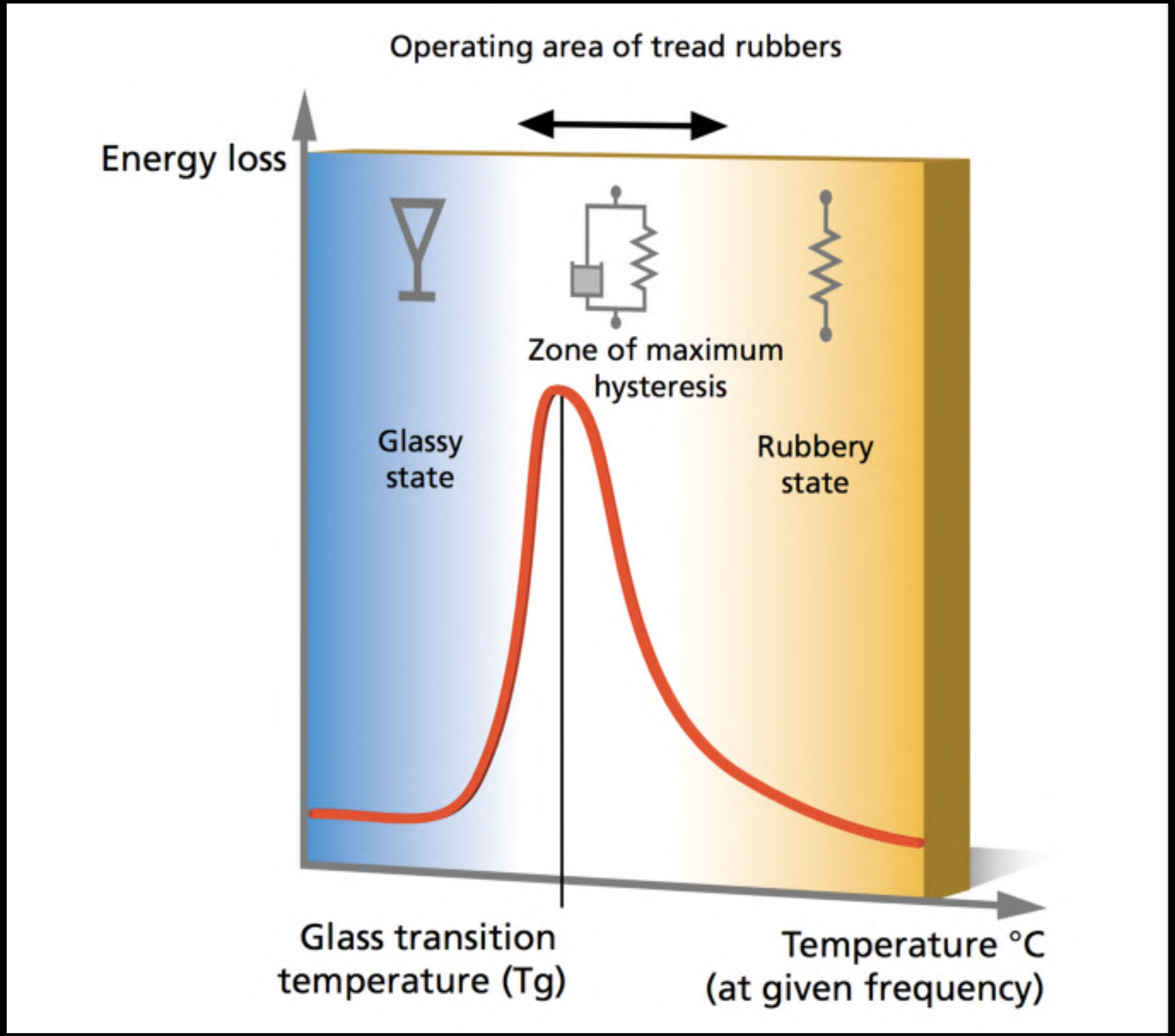



*Figure 4: The glass transition temperature identifies the point of maximum hysteresis. (1)*

# 3. CHARACTERISING THE TYRE-ROAD INTERFACE

*Understanding what's happening at the contact patch.*

## SLIDING ENERGY

- Managing energy input into the tyre over a lap is a very important racecar setup metric

$$Power = Force * Velocity$$

$$P_{SLIDING} = F_{COMBINED} * V_{SLIDING}$$

- Sliding energy is the time integral of power (3).

$$E_{SLIDING} = \int P_{SLIDING} \; dt$$

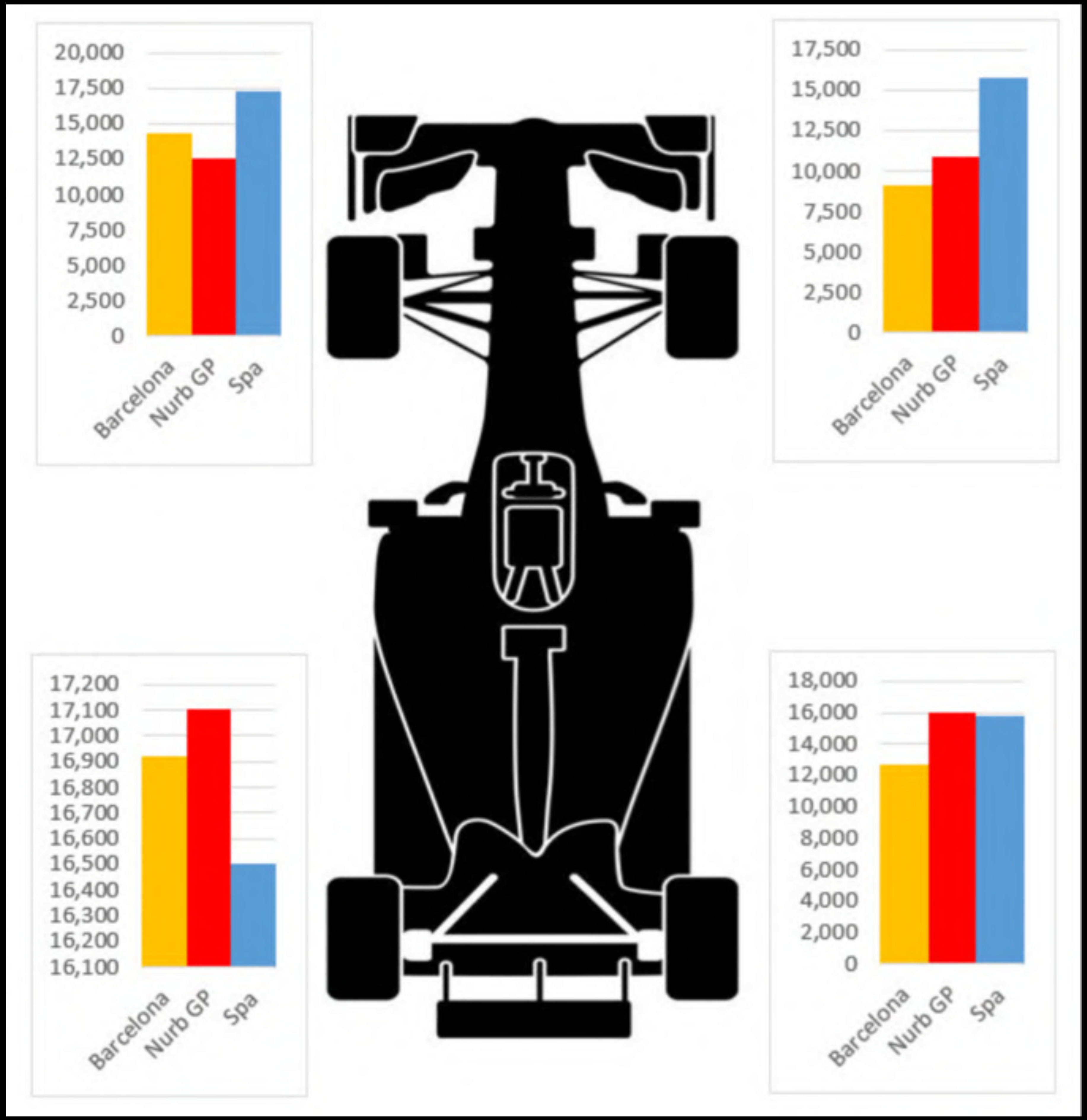



*Figure 5: Sliding energies (kJ) in each tyre for 3 different tracks. (3)*

## HEAT EXCHANGES

- Conduction, convection and radiation into and out of the tyre affect temperature in each of the tyre layers.

- Heat exchanges occur between the tyre and:
  - Track surface
  - Surrounding air (forced convection)
  - Braking components
  - Wheel rim

- This is bi-directional.


*Figure 6: Hot brakes radiate a large amount of heat into the wheels and tyres. (SMP Racing)*

## 3 LAYERS OF THE TYRE

1. **Tread Layer:** In contact with the track surface
2. **Bulk/Core:** The core of the tyre. Temperature of this layer is not possible to measure directly
3. **Inner Liner:** In contact with the gas volume

- The core temperature most strongly correlates with Coefficient of Friction
- The tread layer varies wildly in temperature around the track and doesn't strongly correlate with grip

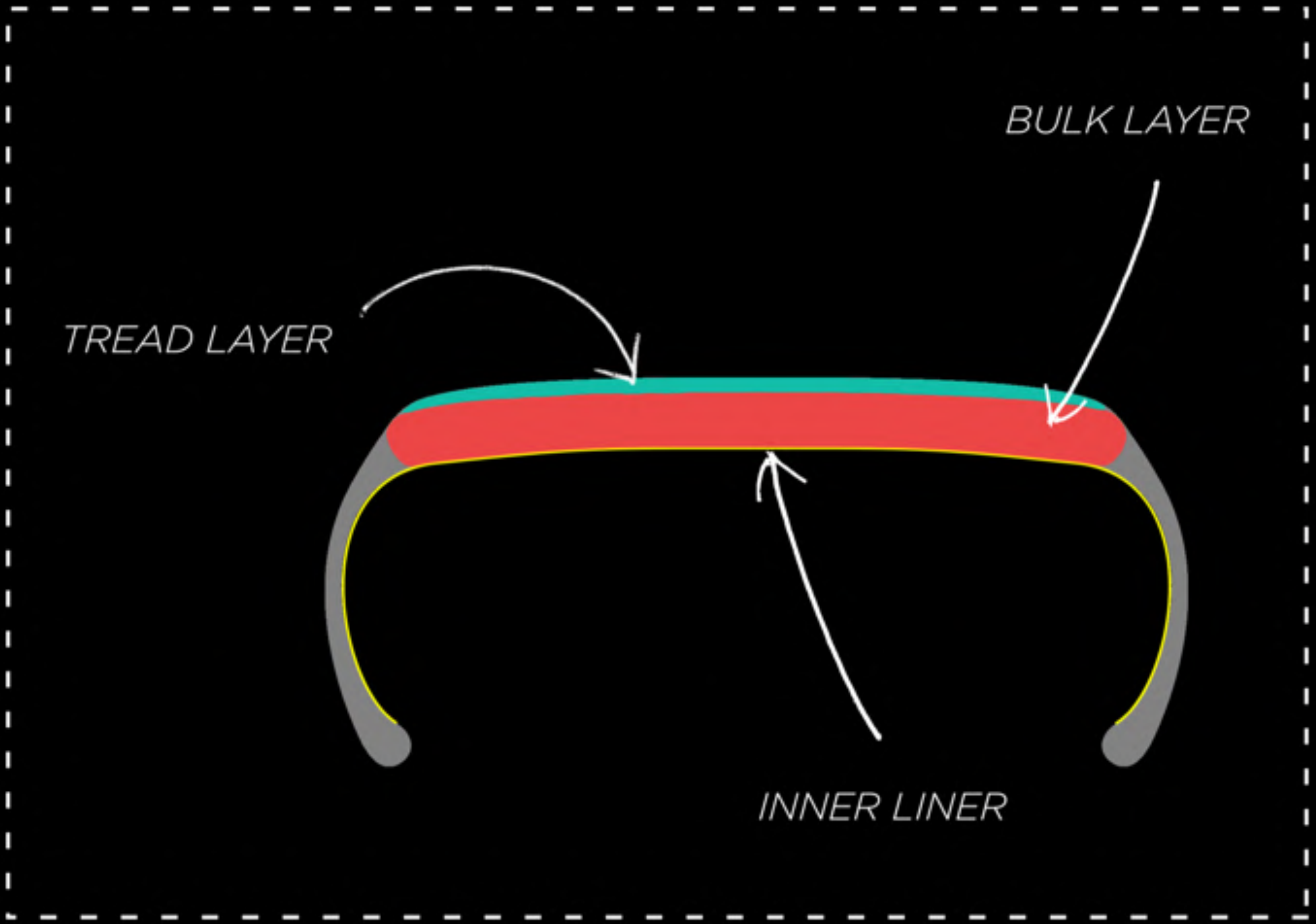



*Figure 7: A Cross section of a racing tyre (Wavey Dynamics)*

## ROAD TOPOLOGY

- Road topology Influences the **stress frequencies** generated by mechanical & chemical adhesion
- The track surface can influence the viscoelastic properties of the tyre by offsetting the point of maximum hysteresis
- Different tracks require different setup approaches

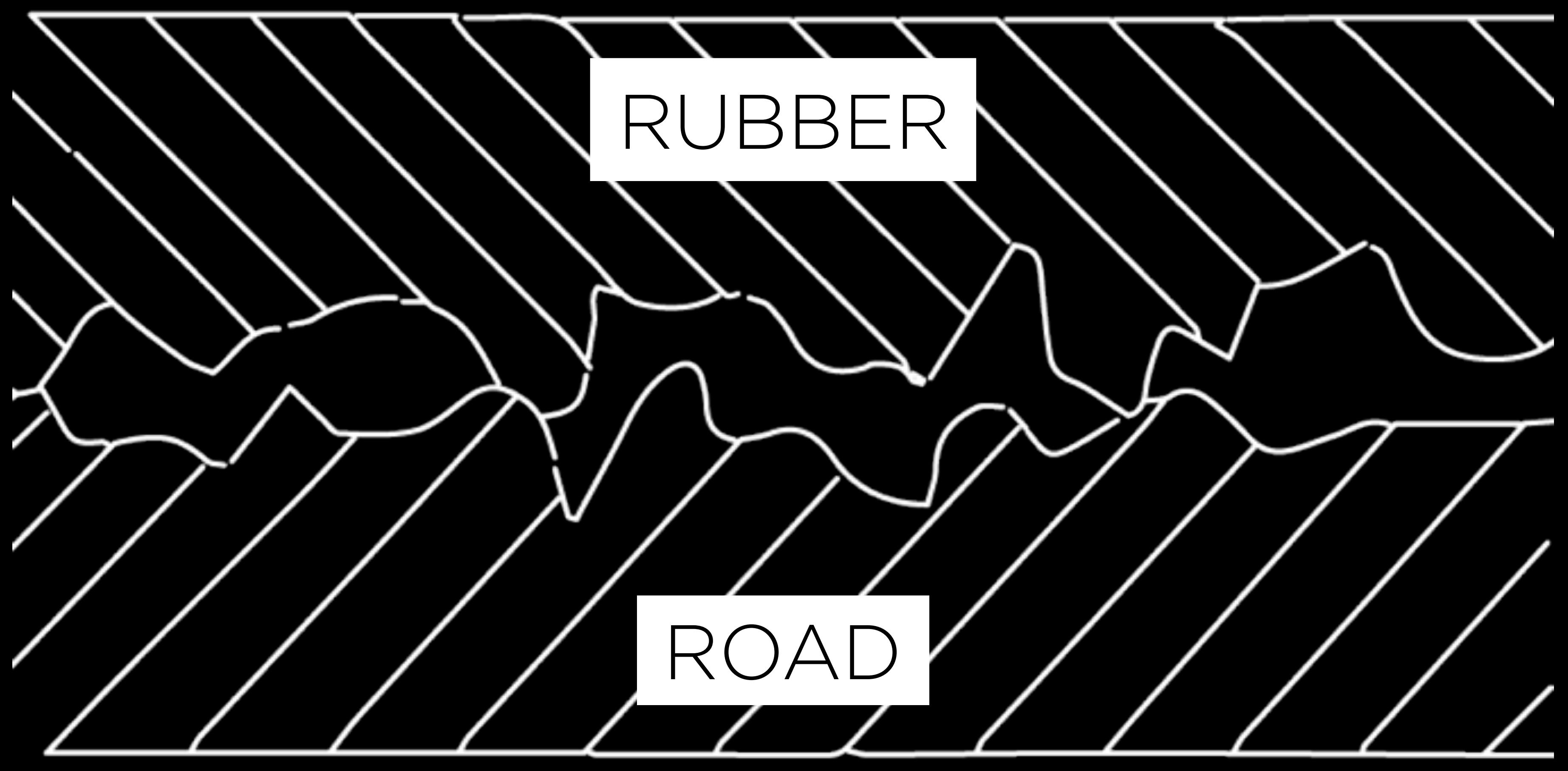



*Figure 8: Microscopic view of the tyre-road interface (4)*

## DEGRADATION

- Chemical and mechanical degradation (wear) influence tyre performance
- The vulcanisation process continues to progress with hot tyres
- Mechanical wear reduces tread volume and decreases the thermal inertia of the tyre volume. It also reduces the SEL

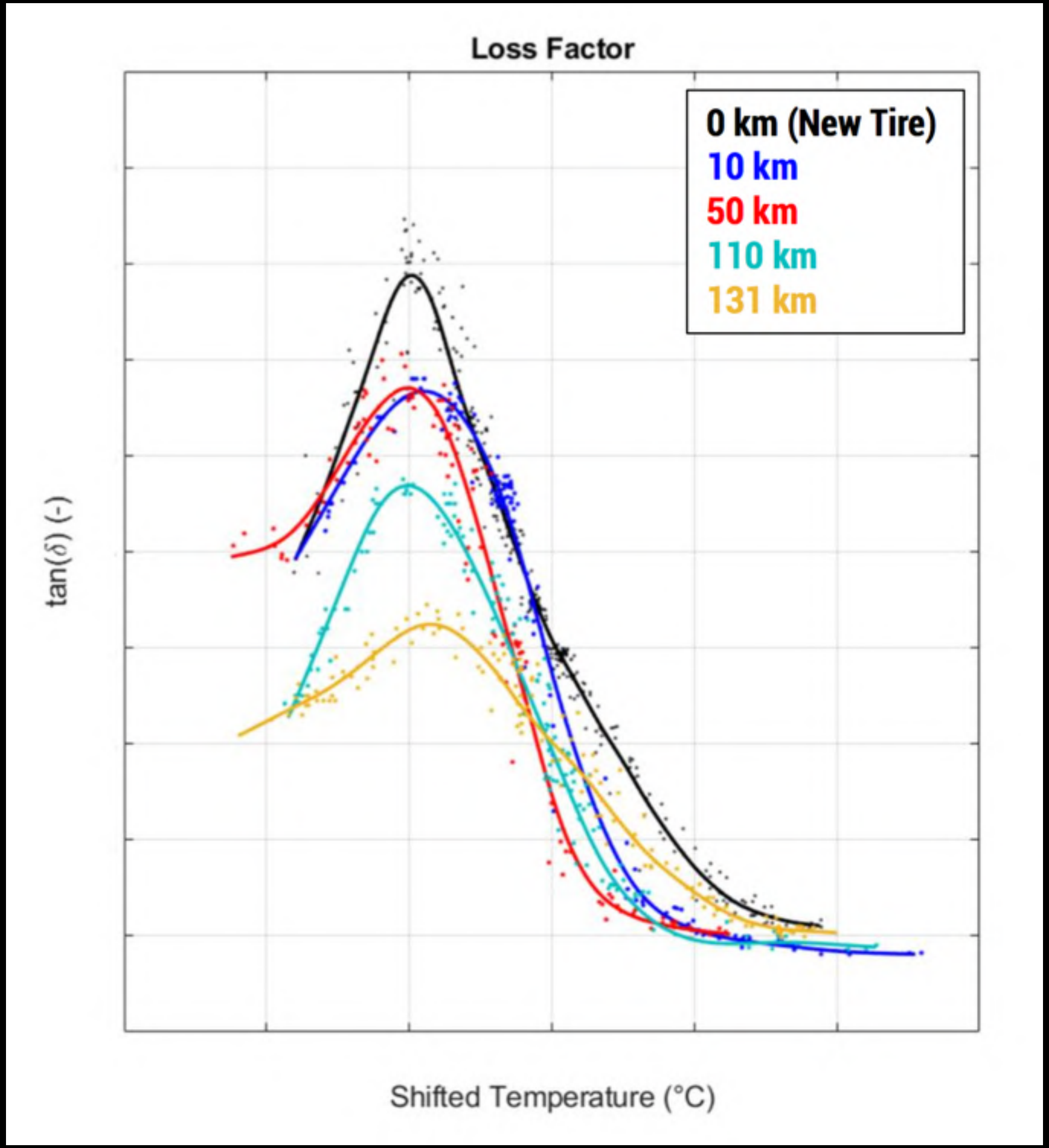



*Figure 9: The degradation process affects viscoelastic properties as documented across 5 measuring points in this data from MegaRide (5)*

# 4. TYRE MODELLING

*Creating & using digital tyre models.*

## HISTORY

- Traditionally, characterising a particular tyre has been done empirically through experience & trial and error

- Empirical models do not account for many of the complex physical phenomena occurring at the tyre-road interface

- With margins of performance becoming tighter and tighter, attention has been focused on developing objective understandings

## HIGH NON-LINEARITY

- Tyres have traditionally been incredibly hard to model objectively as they are very non-linear
- The coefficient of friction of a tyre depends on a whole host of complex, interrelated variables
- The majority of tyre models are developed using the empirical Pacejka 'Magic Formula' model

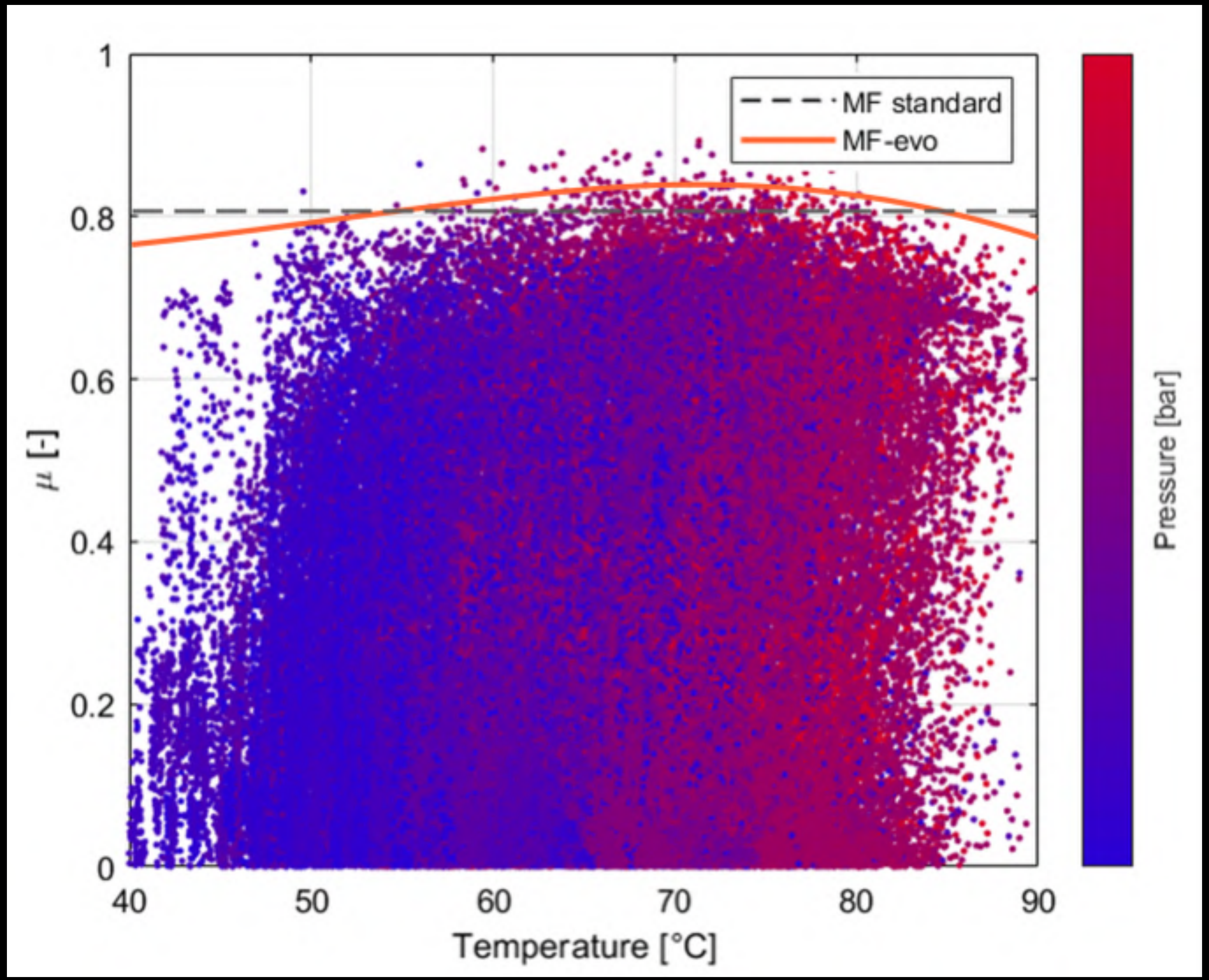



*Figure 10: Coefficient of Friction varies with both temperature and pressure, amongst others, as demonstrated by this data from MegaRide (6)*

## LIMITATIONS

- Traditional models are based on non-physical phenomena
- Don't include many of the complex interactions at the tyre-road interface:
  - Road roughness
  - Temperature generation & exchanges
  - Wear (chemical and mechanical)
- New research has produced exciting advancements in this area.

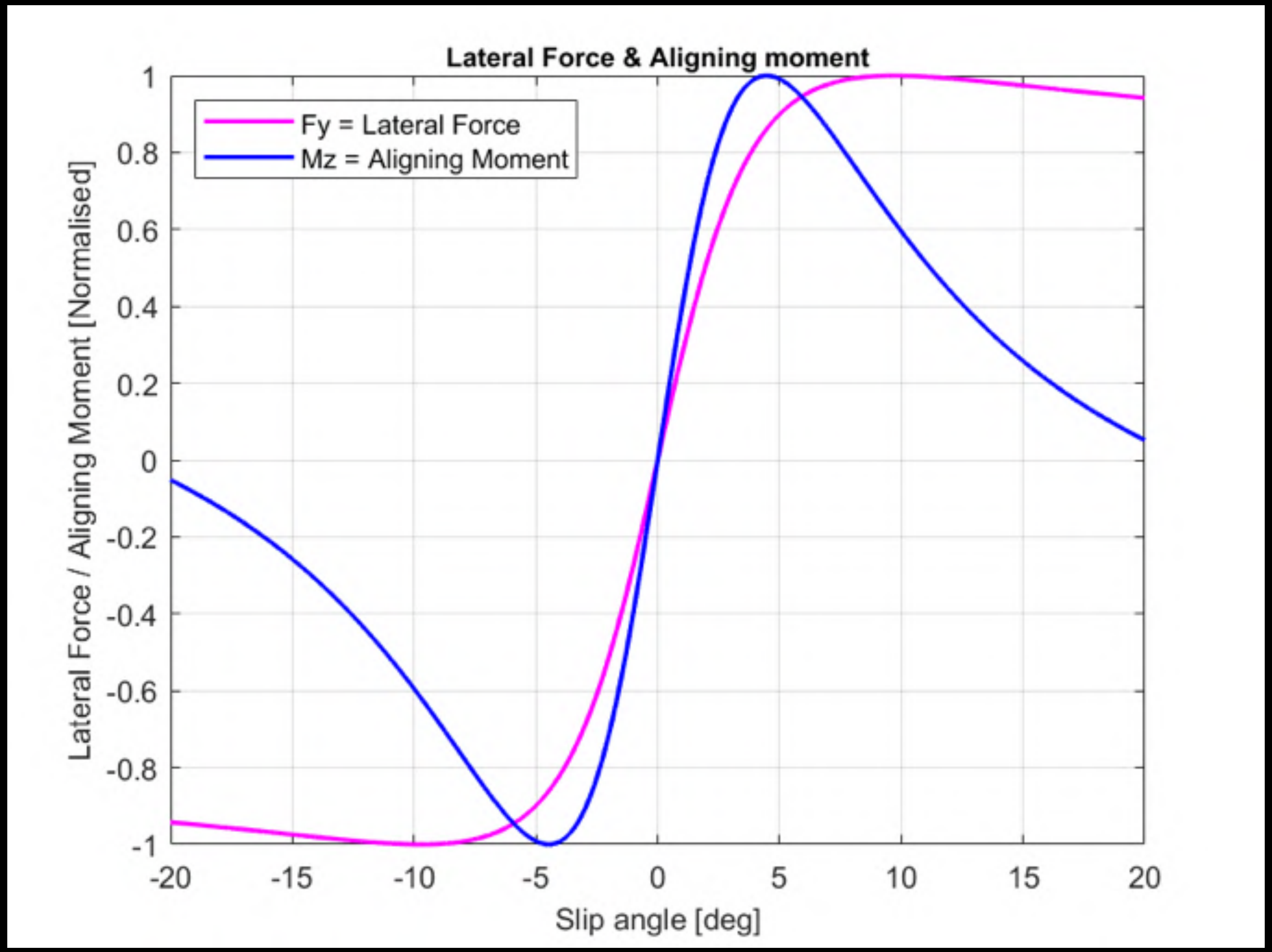



*Figure 11: An outline of the typical relationship between lateral force and aligning moment for a racing tyre (Wavey Dynamics)*

## LEADING THE FIELD

- High level motorsport, such as F1 have been using tyre models bound to physical phenomena for years
- Lots of research going into developing these objective quantifications of tyres in real-time applications
- Certain research groups such as MegaRide are commercialising these mathematical modelling techniques to enable the wider sport to capitalise on their benefits

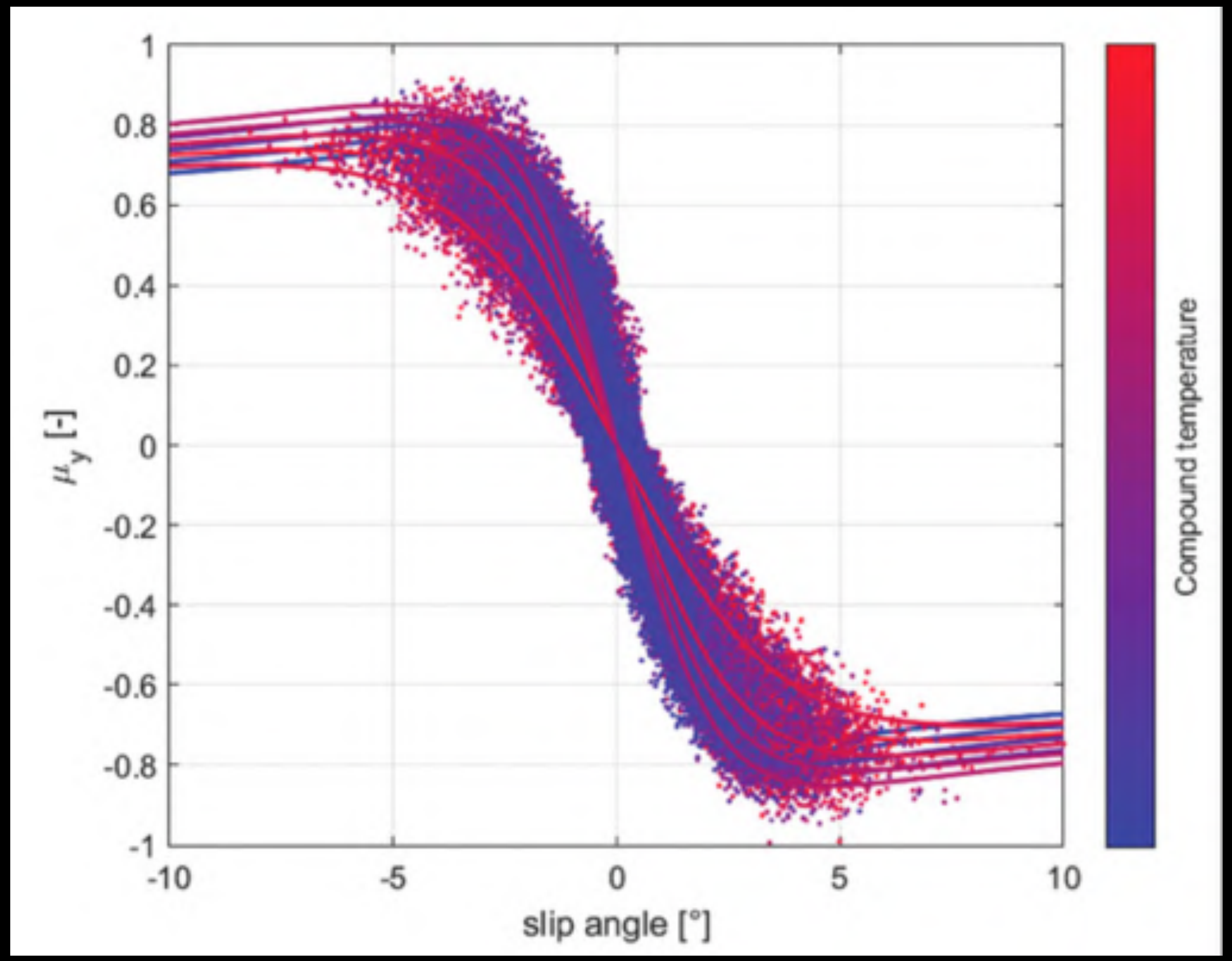
MEGARIDE
APPLIED VEHICLE RESEARCH


*Figure 12: F1 teams have been accurately modelling tyre phenomena for many years, but it has not been available for commercial use. (Vince Mignott)*

## NEW DEVELOPMENTS

Leading research from MegaRide has developed advanced, high fidelity tyre models, which capture, in real-time, the dynamic effects on vehicle performance of:

- Temperature
- Wear (Degradation)
  - Chemical
  - Mechanical



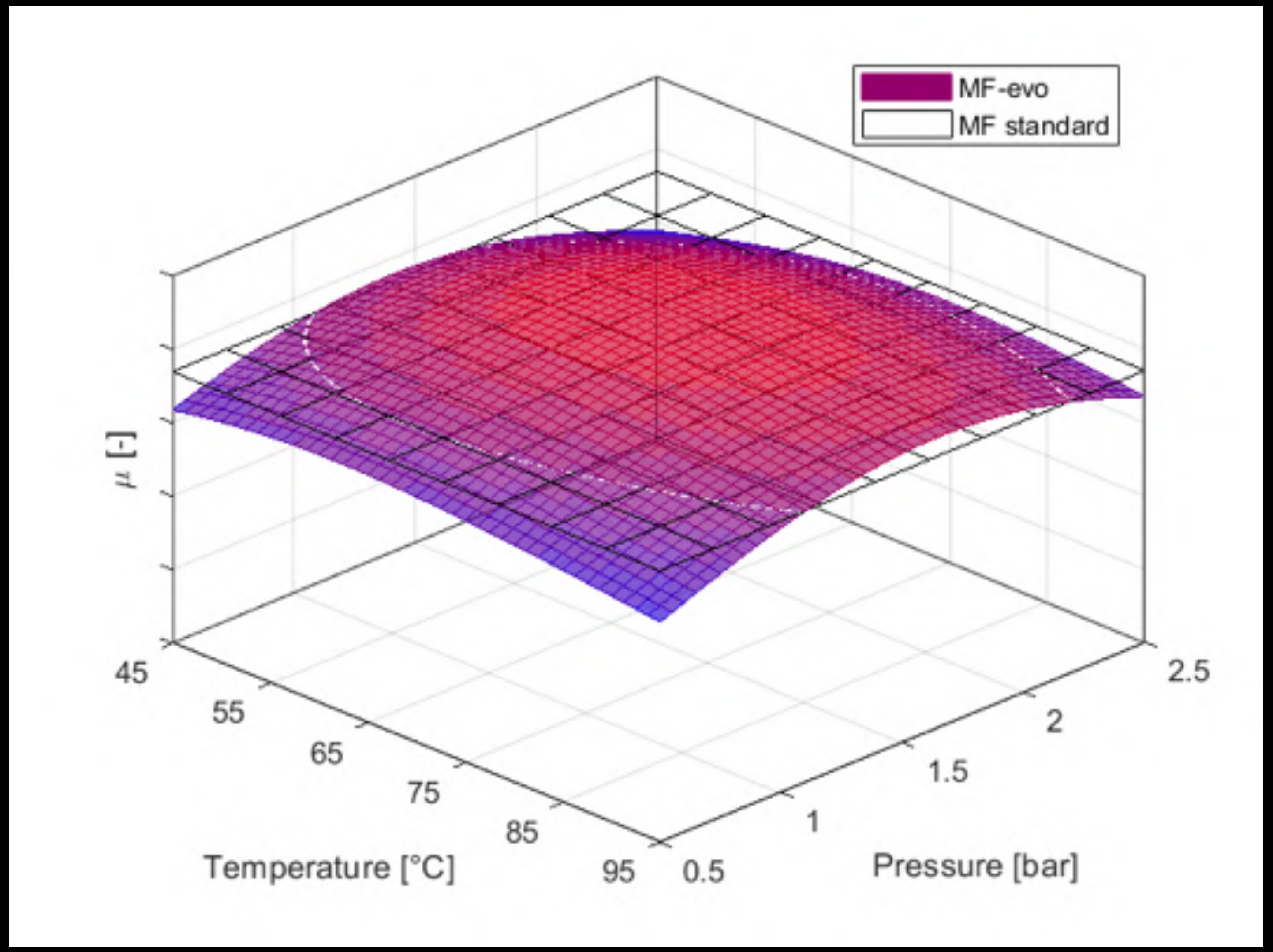




*Figure 13a (top): MegaRide's MF-evo tyre curves overlaid against measured data (6)*

*Figure 13b: (bottom) The MF-evo model developed by MegaRide accurately captures behaviour according to physical phenomena (6)*

USES

Capturing the physical phenomena occurring at the tyre-road interface improves simulation correlation by:

- Modelling thermal evolution of the tyre in all 3 layers
- Predicting tyre pressure evolution
- Predicting the degradation of a tyre over a race distance

These understandings feed into effective vehicle setup

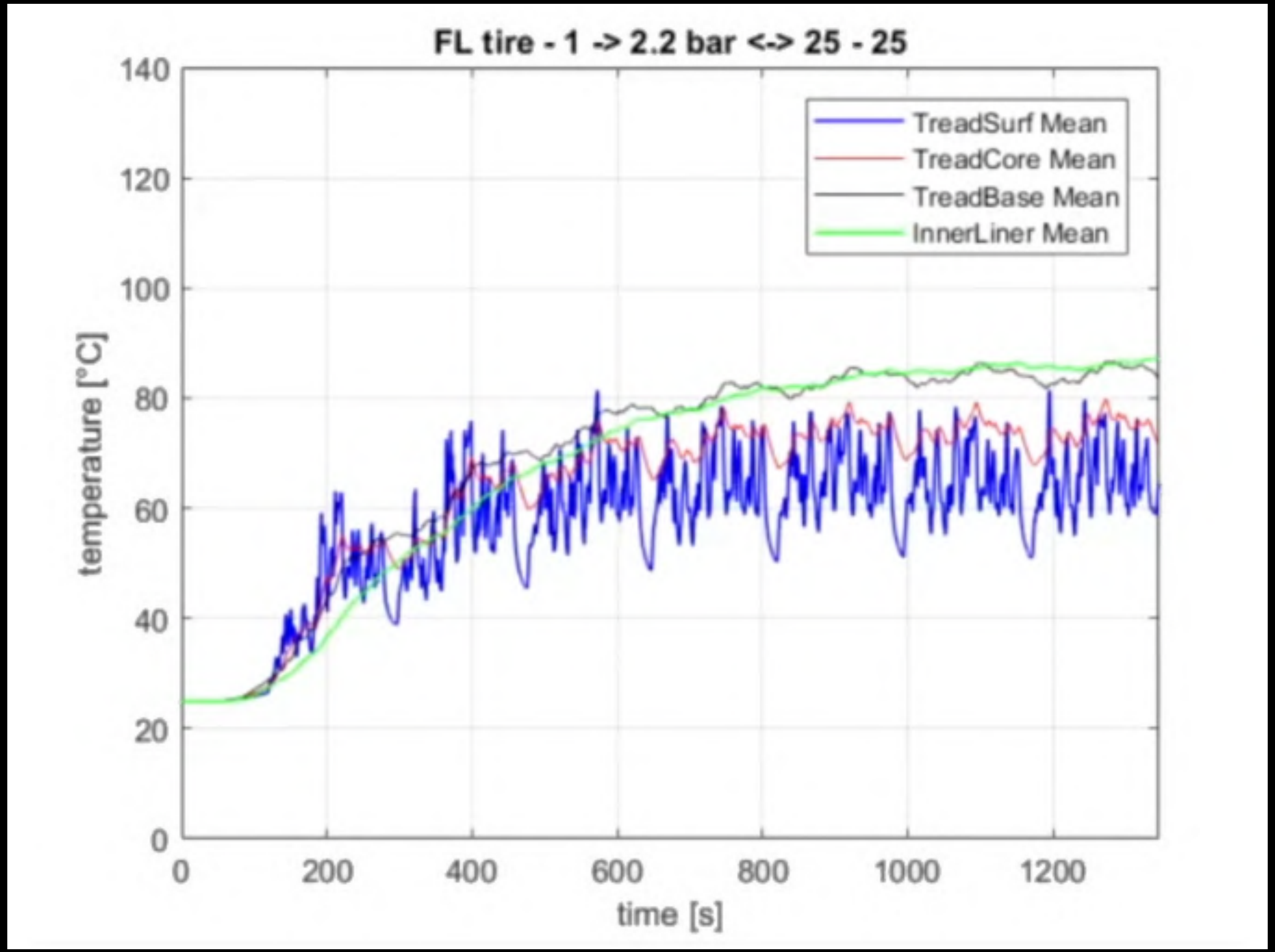



*Figure 14: Data generated by the thermoRIDE tyre model developed by MegaRide captures temperature across the distinct tyre layers. (MegaRide)*

## CORRELATION

- No simulation is 100% accurate
- We must have confidence that they correlate acceptably with the physical world.
- High fidelity tyre models are improving correlation accuracy in offline & DiL simulations
- Improved accuracy in tyre models enables vehicle setups to be reliably evaluated off-track, saving time and resource.

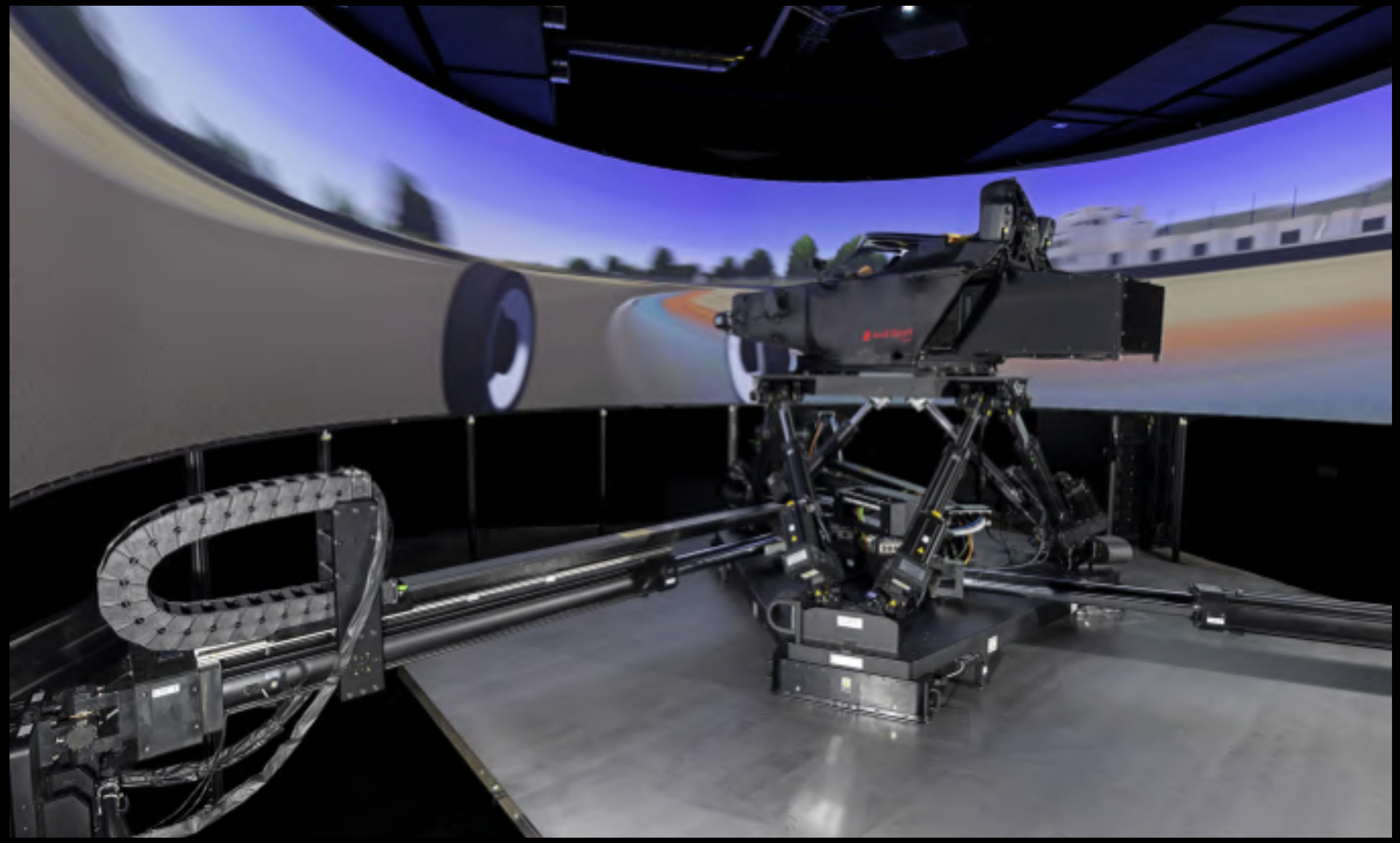
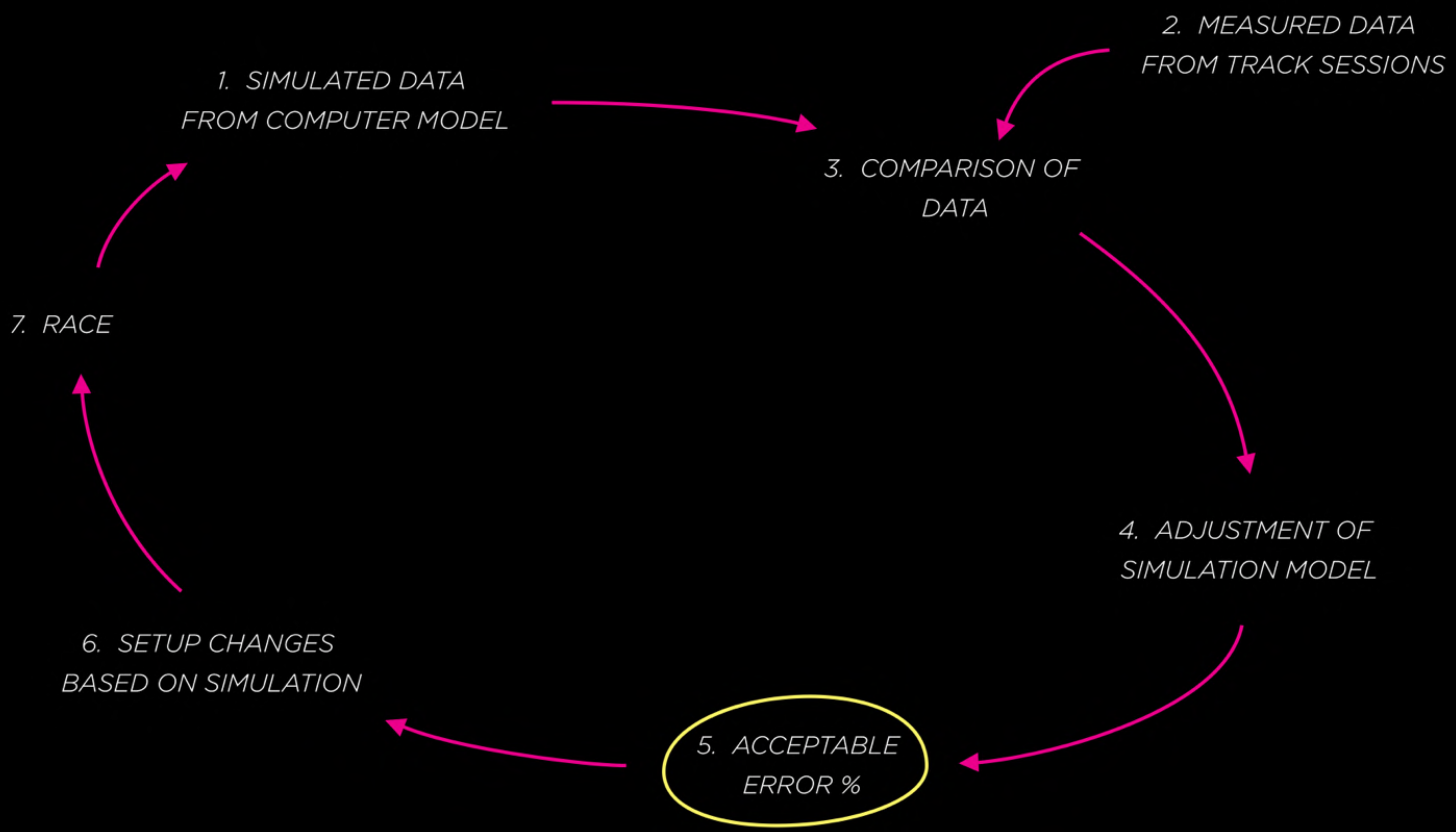


*Figure 15: VI-grade's DiL simulator (VI-grade)*


1. SIMULATED DATA FROM COMPUTER MODEL
2. MEASURED DATA FROM TRACK SESSIONS
3. COMPARISON OF DATA
4. ADJUSTMENT OF SIMULATION MODEL
5. ACCEPTABLE ERROR %
6. SETUP CHANGES BASED ON SIMULATION
7. RACE

## CASE STUDY: A RACE WEEKEND

- Track temperature falls by 25°C between practice and qualifying.
- Cooler tyres will work differently on the track surface and crucially the balance of the vehicle is likely to change.
- Design of Experiment in simulation environment to understand the setup changes required.

| | Practice | Qualifying | |
|---|---|---|---|
| $T_{AIR}$ / $T_{TRACK}$ [°C] | 30/40 | 10/15 | 10/15 |
| Tyre Pressure [Bar] | 1.55 | 1.55 | 1.55 |
| Blanket Temperature [°C] | 40 | 40 | 50 |
| Roll Balance [%] | 40.9 | 40.9 | 40.9 |
| Aero Balance [%] | 46.4 | 46.4 | 43.7 |
| Δ Lap Time [s] | 49.6 | +0.91 | +0.07 |

*Figure 16a: Data generated through a DoE of setup changes with MegaRide's thermal tyre models. (7)*

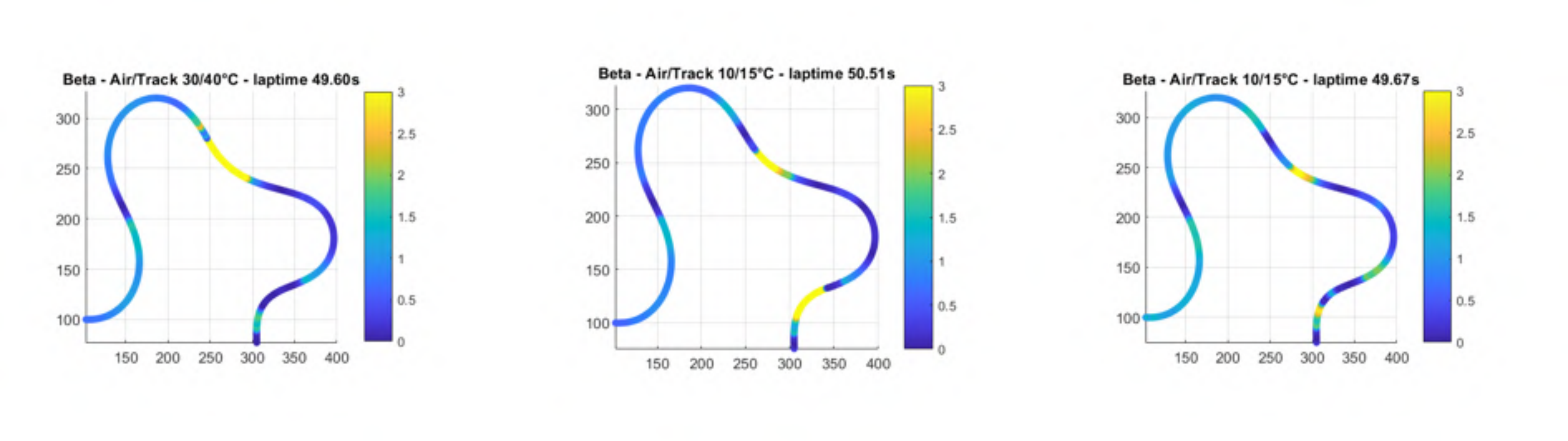



*Figure 16b: Supplementary data from the aforementioned DoE. (7)*

# 5. QUANTIFYING THE TYRE

*Measuring material properties of tyres at the track*

## MECHANICAL ANALYSIS

- Traditionally performed through DMA (Dynamic Mechanical Analysis); a destructive test which destroys the tyre.

- New developments in this field allow viscoelastic analysis using handheld, portable tools.

- The VESevo is a non-destructive test (NDT) tool developed in collaboration with MegaRide which measures the tyre's viscoelastic properties in trackside scenarios.

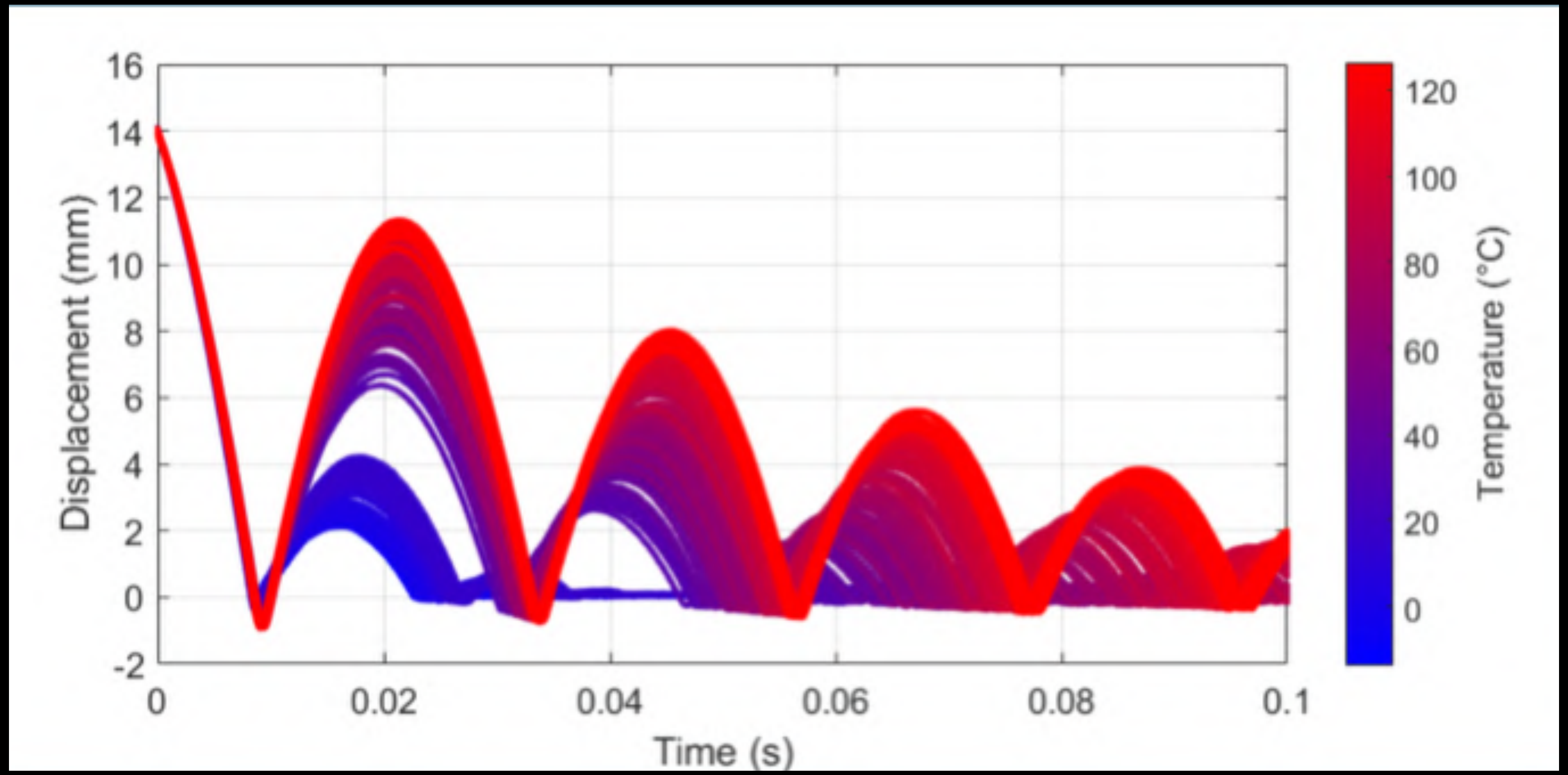



*Figure 17 (top): the VESevo device (8)*

*Figure 18 (bottom): Displacement vs. Time data taken from a tyre over a range of temperatures with the VESevo (5)*

## INFORMATION GAINED

- Measuring storage moduli and loss factors trackside enables us to understand the temperature region in which the tyre is operating at it's peak
- Adjustments can be made to the car to manage energy input and maintain peak temperature
- This can become a key setup input

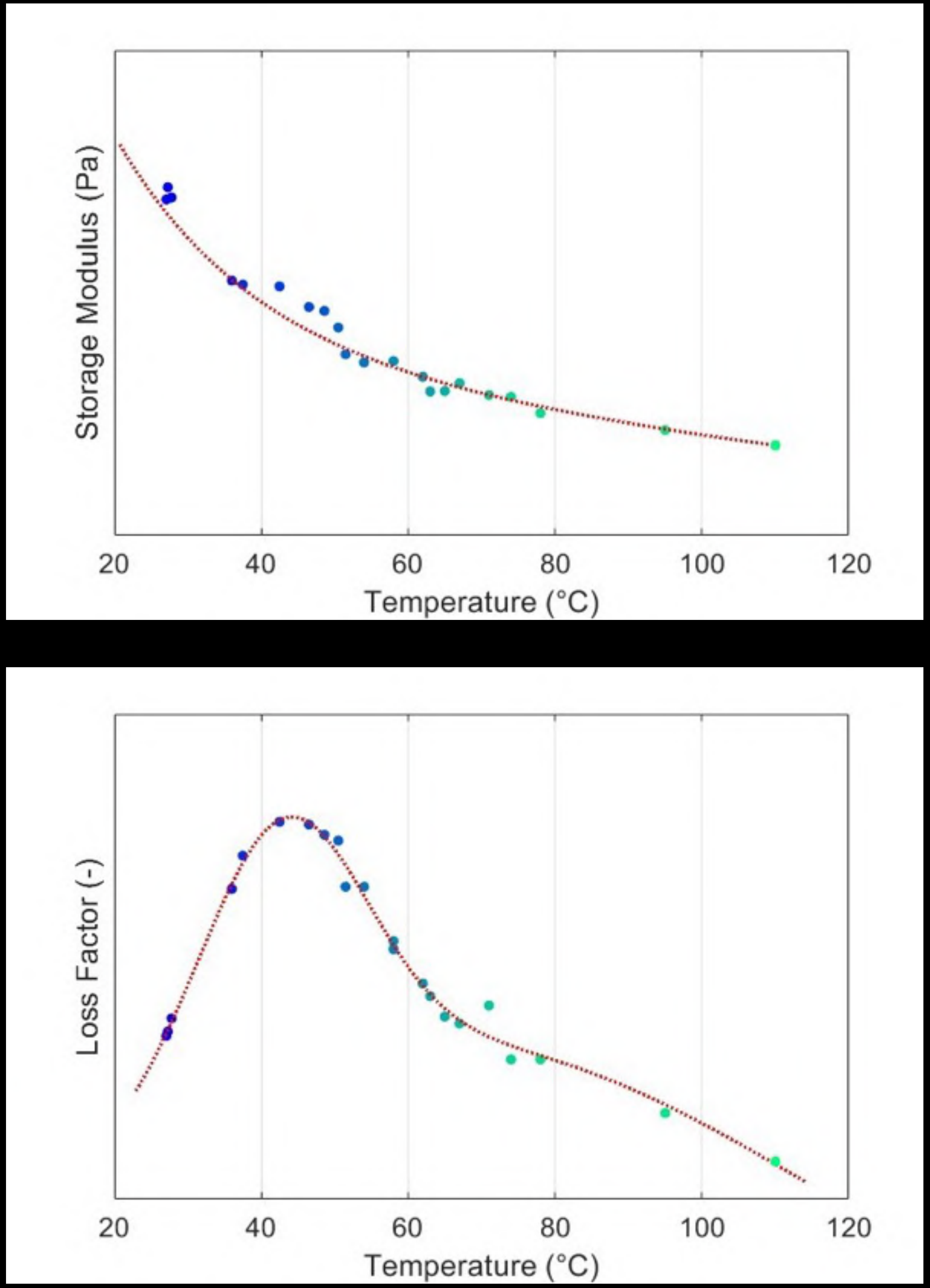



*Figure 19a (top) & Figure 19b (bottom): Storage Modulus & Loss factor measured by the VESevo device over a range of tyre temperatures (8)*

## USING TYRE DATA IN VEHICLE SETUP

- Comparing individual tyres (compounds, brands, quality)
- Understanding F:R tyre use
- Understanding how properties deteriorate over wear life
- Setting tyre blanket/oven temperatures
- Hot/cold tyre pressures

*Figure 20: A GT3 car undergoing some setup changes (R-Motorsport)*

## THE CURING PROCESS

- At higher temperatures, the chemical vulcanisation process continues and causes changes to the compound at molecular level (Sulfur cross-linking)

- Quantifying the effect of the resulting higher storage modulus and a higher hardness is important data

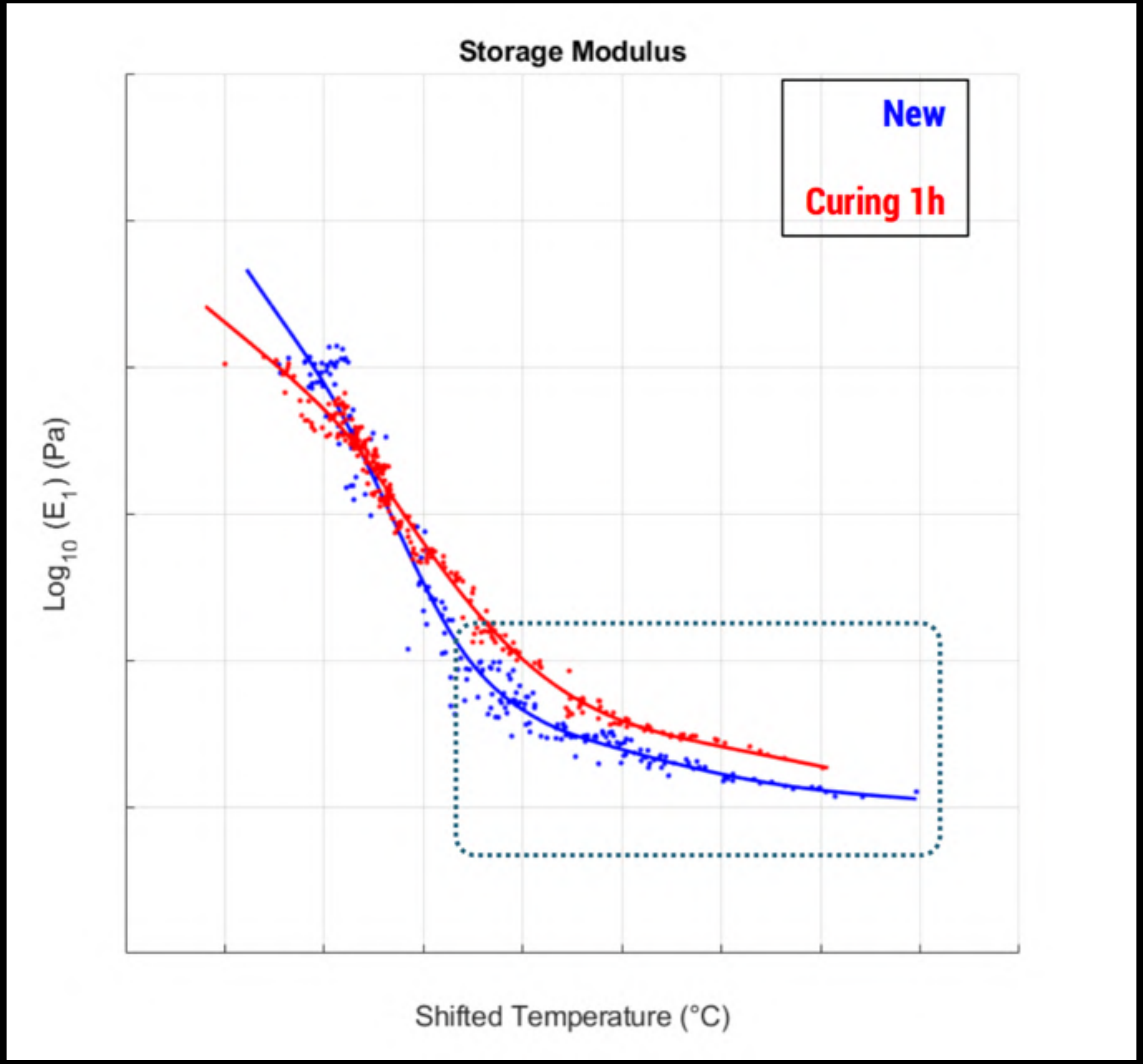



*Figure 21: The VESevo device can be used to measure the effects of curing on a tyre's viscoelastic properties. (5)*

# SUMMARISING

SUMMARISING


## WHAT WE HAVE COVERED

- Key mechanical properties of the viscoelastic tyre
  - Storage & loss
  - hysteresis
- Considerations at the tyre-road interface
  - Influences in tyre performance
- Modern advancements in tyre modelling for simulation
  - High fidelity tyre models (thermal & wear)
  - Input into vehicle setup
- Techniques and benefits of quantifying tyre behaviour at the track
  - Measurement equipment
  - Input into vehicle setup

## PARTNERSHIPS

- At the forefront of these advancements in tyre science is MegaRide, who are a technical partner of Wavey Dynamics.

- Incorporating their high fidelity tyre models and VESevo tool into our work enables us to capture the competitive edge for our clients - extracting the maximum performance from tyres.

- To read more about how their innovations are breaking barriers to F1 technology and how we use them, read our article here.

*END*

## FUNDAMENTALS OF VEHICLE DYNAMICS

- An A-Z of everything you need to learn to begin your journey as an effective vehicle dynamicist.
- If you're a student, motorsport professional, racing team or enthusiast - the course is for you.
- For a course preview, check the link <u>here</u>

Interested? Get in touch!

# WAVEY DYNAMICS.


Wavey Dynamics is a specialist vehicle dynamics and aerodynamics consultancy focused on automotive and motorsport performance development.

Wavey Dynamics has recent projects including:

- CFD Optimisation of a rear wing profile resulting in +20% $C_L$ whilst maintaining $C_D$.
- Design and development of underbody aerodynamics for GT application with focus on rear diffuser performance.
- Development of MATLAB based vehicle dynamics models.
- Vehicle dynamics development of Cup level race car resulting in ~4s lap time improvement at the Nurburgring Nordschleife.
- Design of an aerodynamic splitter with integrated brake cooling ducts. With conjugate heat transfer analysis indicating a circa 30% reduction in peak brake temperatures.
- Trackside & data experience with GT3 & GT4 cars
- Wind tunnel scale model testing.

# LET'S DISCUSS.


- Our website has much more detail on our company, expertise and services offered, along with a collection of technical articles written to summarise a sample of projects we have undertaken.

Please visit waveydynamics.com to learn more.

**Wavey Dynamics Limited.**

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(2) Vehicle Dynamics Research Group, University of Naples Federico II, Italy, "Evaluating Viscoelasticity" , Tire Technology International: 58-61 2021

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(4) Balkwill, J., "Performance Vehicle Dynamics", 17, ISBN: 978-0-12-812693-6

(5) VESEvo., "VESevo Viscoelasticity Evaluation System evolved", https://www.vesevo.eu/wp-content/uploads/2022/03/VESevo_Technology-feb22.pdf, accessed April 2022

(6) Aleksandr Sakhnevych (2021)., "Multiphysical MF-based tyre modelling and parametrisation for vehicle setup and control strategies optimisation", Vehicle System Dynamics, DOI: 10.1080/00423114.2021.1977833

(7) MegaRide., "Multi-physics MF-based simulation platform for temperature, grip and wear prediction"

(8) Megatide,. "VESEvo" https://www.megaride.eu/projects/vesevo/, accessed April 2022