MEGARIDE
APPLIED VEHICLE RESEARCH

tire technology EXPO 2020

PROMETEON

PHYSICAL MODELS FOR TRUCK TIRE/ROAD CHARACTERIZATION AND THERMAL ANALYSIS

Eng. Andrea Sammartino
Modelling and Validation at MegaRide

MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

WE WILL TALK ABOUT…

- Objective evaluation of tire performance during test sessions
- Vehicle performance analysis during races and track tests
- Pacejka's Magic Formula tire model parameters identification
- Tire thermal and viscoelastic characterization
- Real time physical thermal model
- Advanced grip/temperature analysis
- Future scenarios

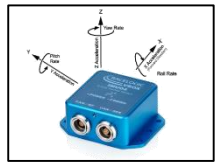
MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

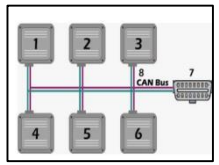
Tire Performance Objectivation

S-Motion

IMU



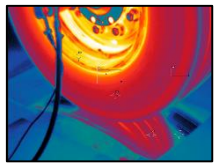
CAN



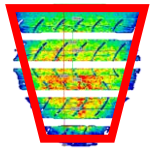
Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

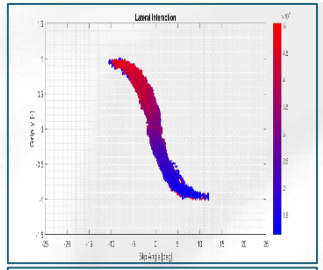


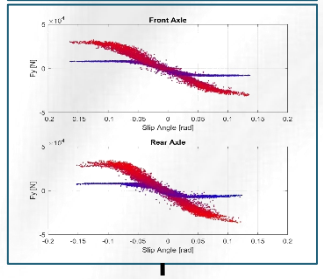
Footprints Test



Forces Estimator

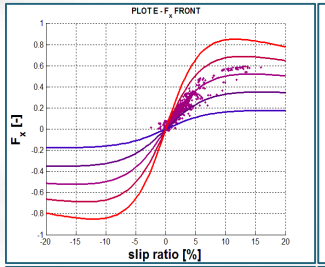
TRICK4TRUCK

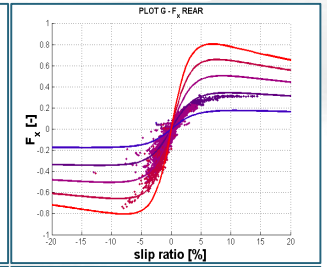


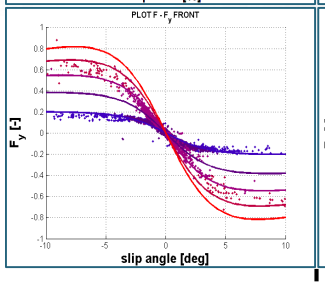


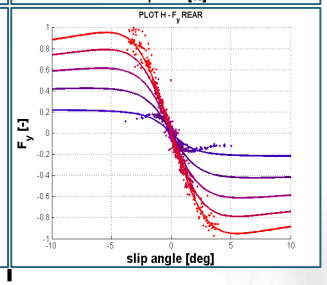
MF Identifier

TRIP-ID



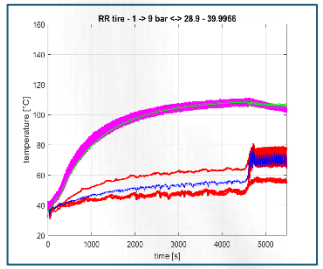






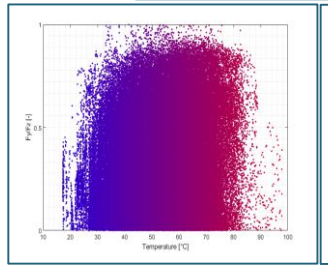
Thermal Model

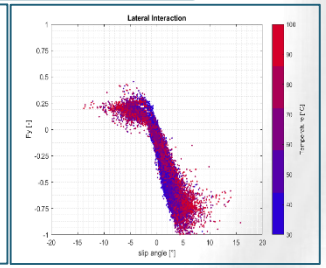
thermoRIDE



MF-Evo

adheRIDE



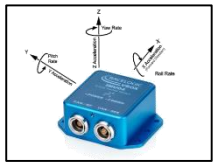


MEGARIDE
APPLIED VEHICLE RESEARCH

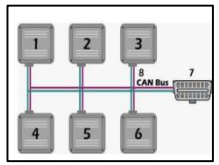
PROMETEON

Tire Performance Objectivation

S-Motion



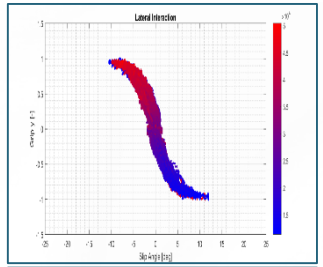
IMU

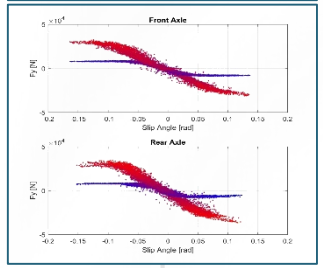


CAN

Forces Estimator

TRICK4TRUCK





MF Identifier

TRIP-ID

Thermal Model

thermoRIDE

MF-Evo

adheRIDE

Diffusivity Test

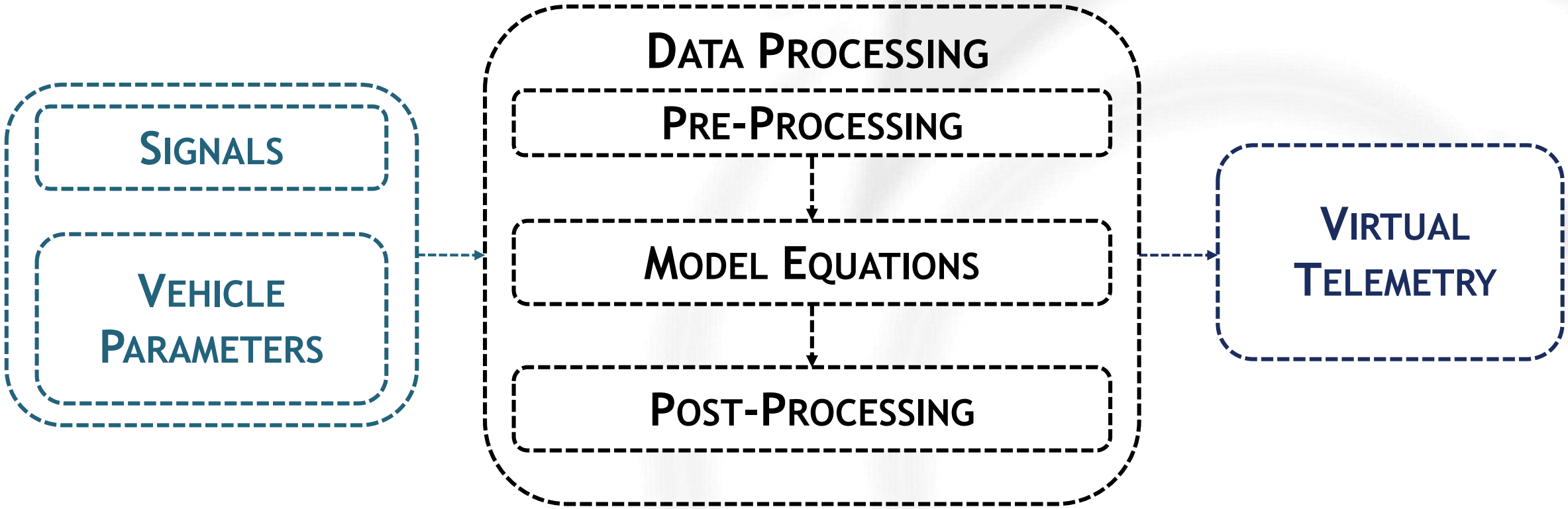
SEL Test

Footprints Test

Tire Thermal and Viscoelastic Characterization

TRICK4TRUCK TOOL

OPERATING SCHEME



TRICK4TRUCK TOOL

TEST PROCEDURE

Iveco Stralis 500 My 2011

- Inertial Characteristics
- Geometric Dimensions
- Suspensions Kinematics
- Aerodynamics

→ VEHICLE PARAMETERS →

TRICK4TRUCK

TRICK4TRUCK TOOL

TEST PROCEDURE

Iveco Stralis 500 My 2011

Kistler S-Motion

- Inertial Characteristics
- Geometric Dimensions
- Suspensions Kinematics
- Aerodynamics

→ VEHICLE PARAMETERS

- Longitudinal Velocity
- Lateral Velocity
- Sideslip Angle
- Yawrate

→ SIGNALS

→ TRICK4TRUCK

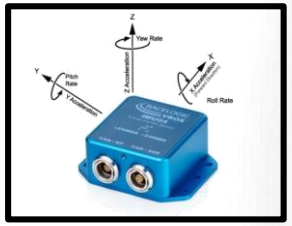
TRICK4TRUCK TOOL

TEST PROCEDURE

Iveco Stralis 500 My 2011

Kistler S-Motion

IMU (Racelogic V-Box)



- Inertial Characteristics
- Geometric Dimensions
- Suspensions Kinematics
- Aerodynamics

→ VEHICLE PARAMETERS

- Longitudinal Velocity
- Lateral Velocity
- Sideslip Angle
- Yawrate

- Longitudinal Acceleration
- Lateral Acceleration

→ SIGNALS

→ TRICK4TRUCK

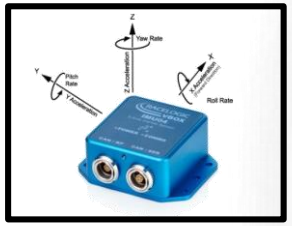
TRICK4TRUCK TOOL

TEST PROCEDURE

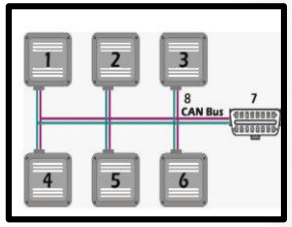
Iveco Stralis 500 My 2011

Kistler S-Motion

IMU (Racelogic V-Box)



CAN Bus



- Inertial Characteristics
- Geometric Dimensions
- Suspensions Kinematics
- Aerodynamics

→ VEHICLE PARAMETERS

- Longitudinal Velocity
- Lateral Velocity
- Sideslip Angle
- Yawrate

- Longitudinal Acceleration
- Lateral Acceleration

→ SIGNALS

- Wheel Angular Speed
- Steering Angle

→ TRICK4TRUCK

TRICK4TRUCK TOOL

DATA PROCESSING

PRE-PROCESSING

- Acquired **Data Analysis:**
  - Transfer to CG
  - Conventions Adaptation
  - Reference systems

TRICK4TRUCK TOOL

DATA PROCESSING

PRE-PROCESSING

- Acquired **Data Analysis:**
  - Transfer to CG
  - Conventions Adaptation
  - Reference systems
- Static and Dynamic **Offsets Identification Procedure**

TRICK4TRUCK TOOL

DATA PROCESSING

PRE-PROCESSING

- Acquired **Data Analysis:**
  - Transfer to CG
  - Conventions Adaptation
  - Reference systems
- Static and Dynamic **Offsets Identification Procedure**
- **Data Filtering**

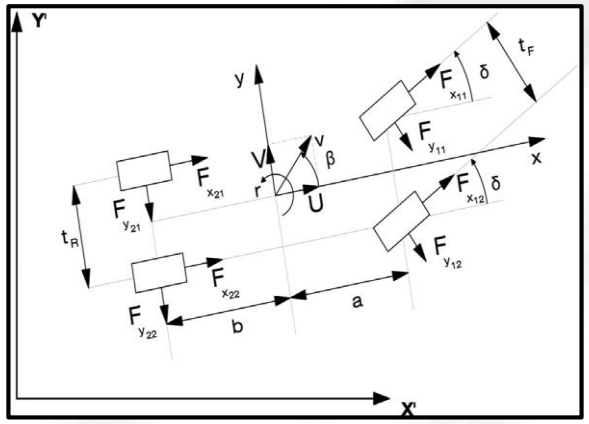
TRICK4TRUCK TOOL

DATA PROCESSING

PRE-PROCESSING

- Acquired **Data Analysis:**
  - Transfer to CG
  - Conventions Adaptation
  - Reference systems
- Static and Dynamic **Offsets Identification Procedure**
- **Data Filtering**

MODEL EQUATIONS



- Vehicle Model with **8 D.O.F.**:
  - **3 D.O.F.** for rigid body motion (longitudinal, lateral, yaw)
  - **4 D.O.F.** for wheels rotation
  - **1 D.O.F.** for steering

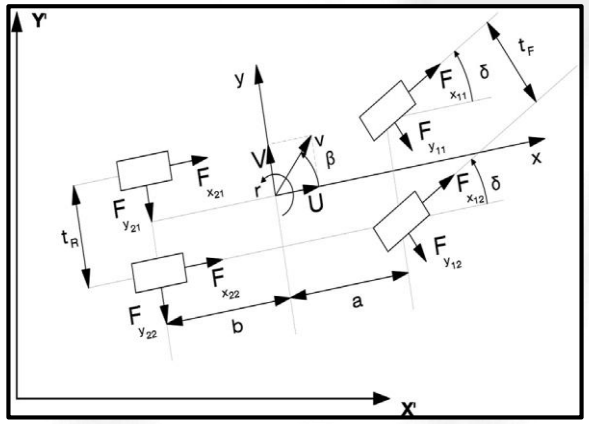
TRICK4TRUCK TOOL

DATA PROCESSING

PRE-PROCESSING

- Acquired **Data Analysis:**
  - Transfer to CG
  - Conventions Adaptation
  - Reference systems
- Static and Dynamic **Offsets Identification Procedure**
- **Data Filtering**

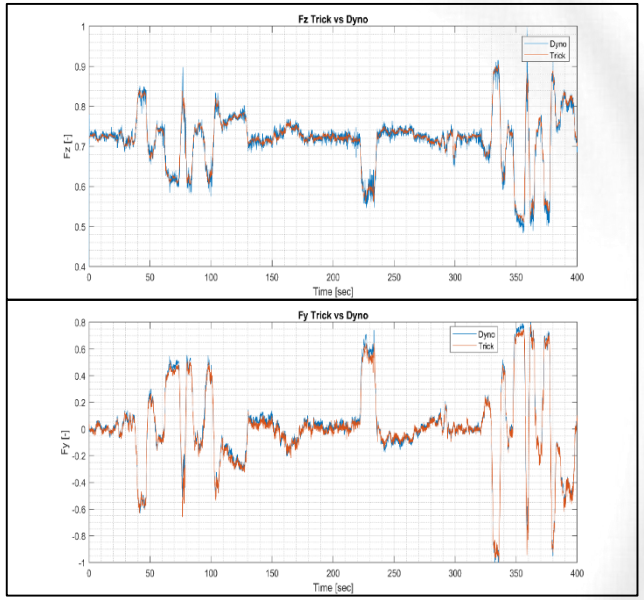
MODEL EQUATIONS



- Vehicle Model with **8 D.O.F.**:
  - **3 D.O.F.** for rigid body motion (longitudinal, lateral, yaw)
  - **4 D.O.F.** for wheels rotation
  - **1 D.O.F.** for steering

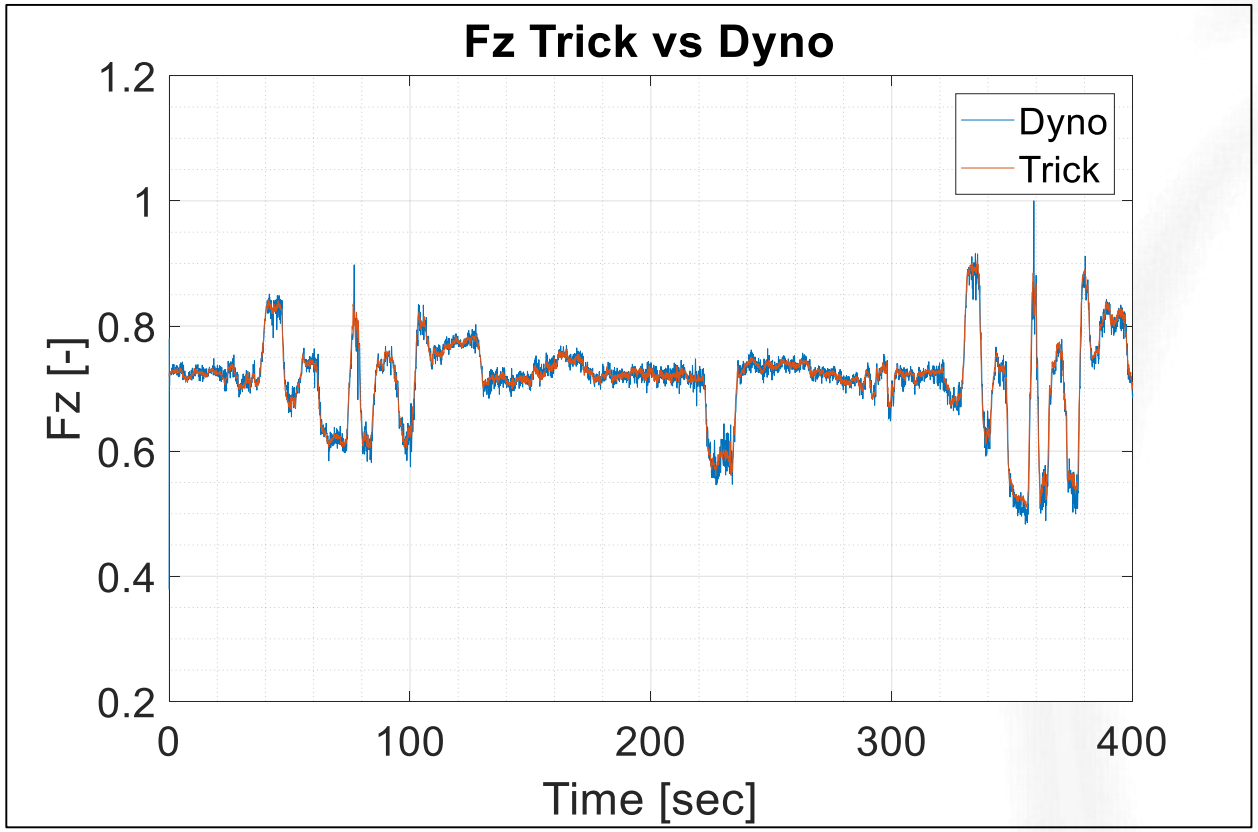
POST-PROCESSING

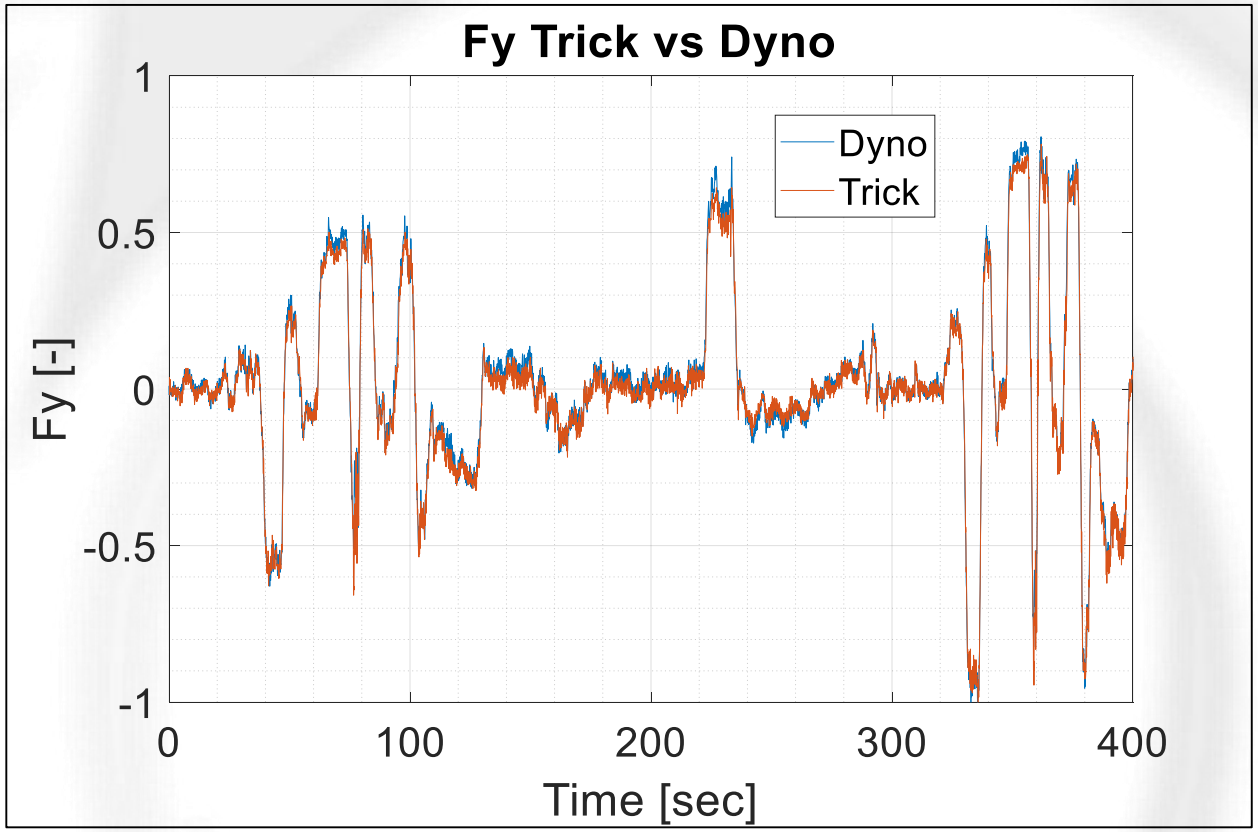
- Forces measured by a **dyno-hub** have been used to validate TRICK4TRUCK estimation



TRICK4TRUCK TOOL

VIRTUAL TELEMETRY - VALIDATION

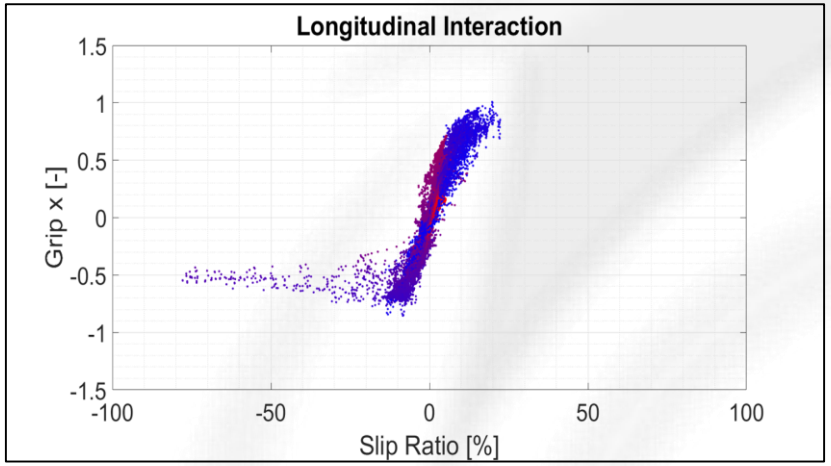


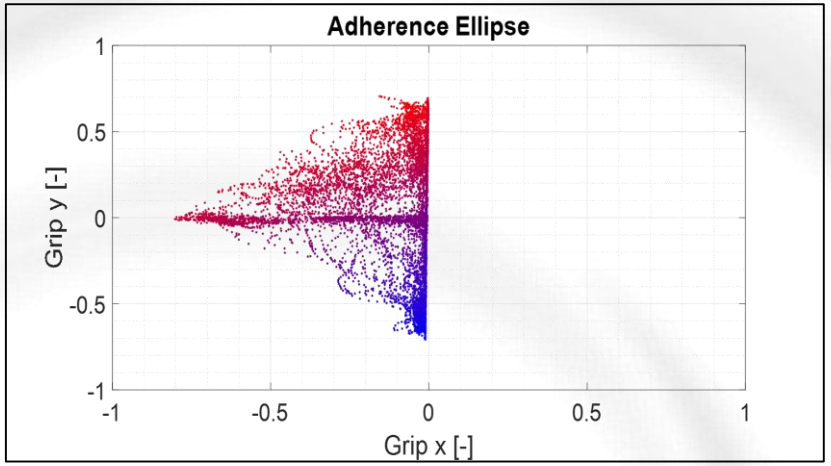


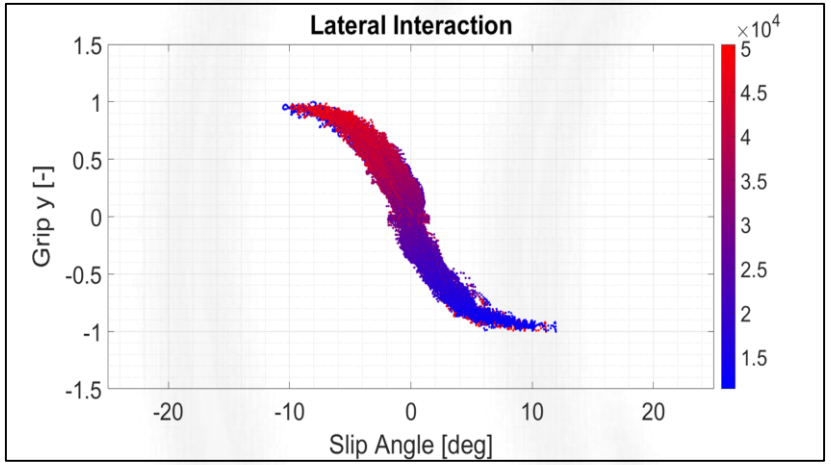
TRICK4TRUCK TOOL

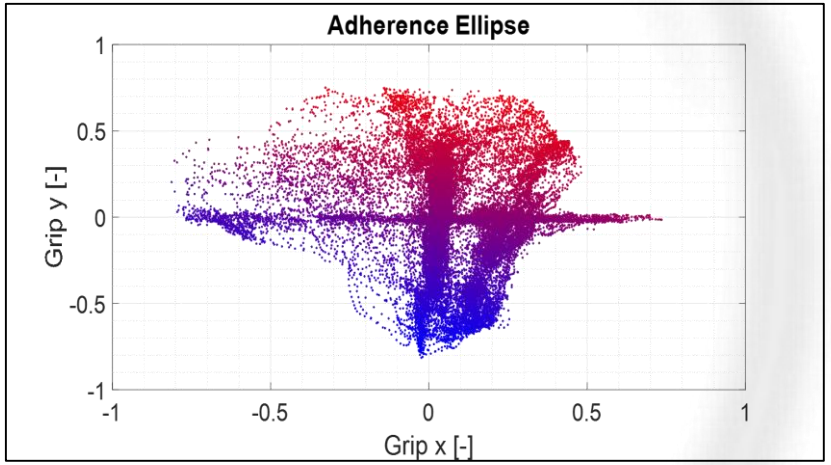
VIRTUAL TELEMETRY – TIRE CHARACTERIZATION

- the estimated forces (coloured according to vertical load) allow a good understanding of the shape of the curve, making possible the **identification of the maximum grip value**





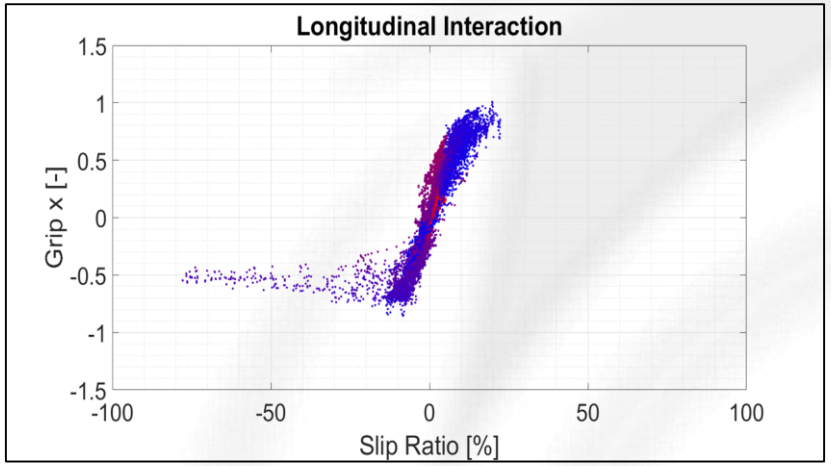


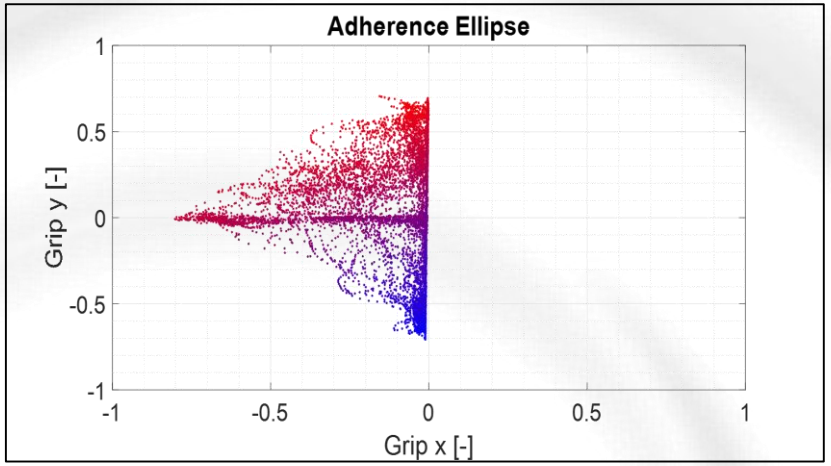


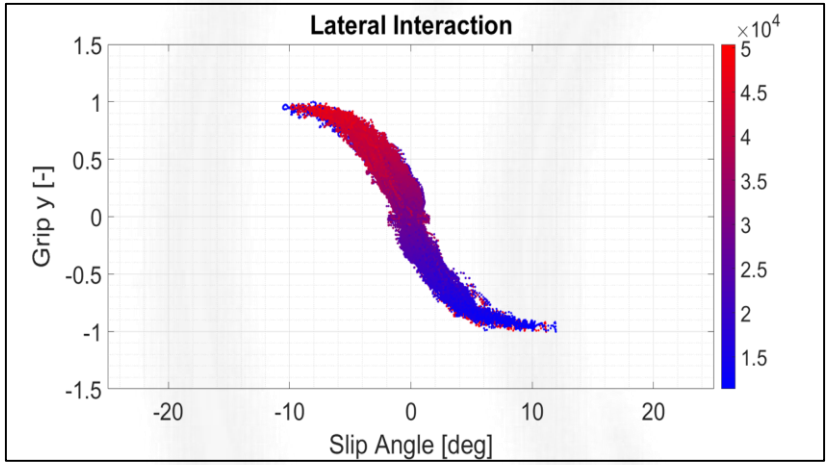
TRICK4TRUCK TOOL

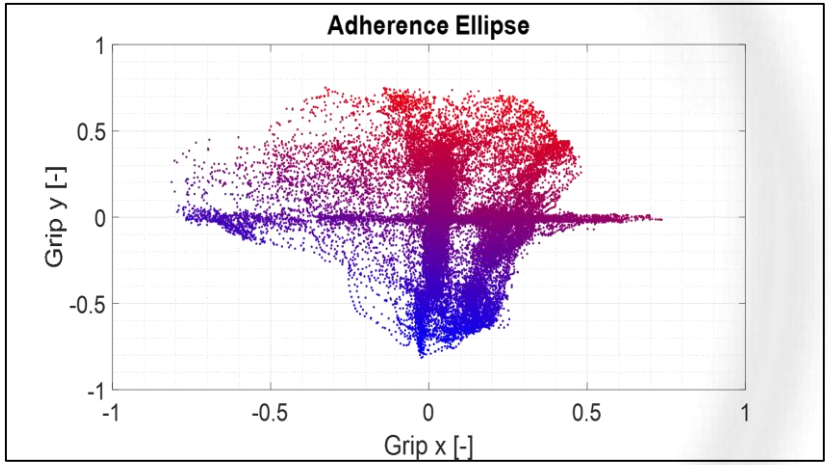
VIRTUAL TELEMETRY – TIRE CHARACTERIZATION

- the estimated forces (coloured according to vertical load) allow a good understanding of the shape of the curve, making possible the **identification of the maximum grip value**
- the model reproduces with a good level of detail **tire's behavior** both in the case of right turning, left turning, traction and braking phase









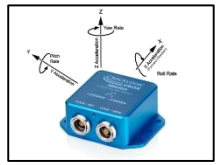
MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

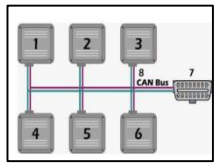
Tire Performance Objectivation

S-Motion

IMU



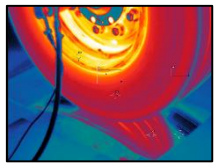
CAN



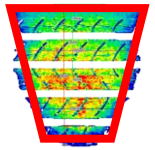
Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

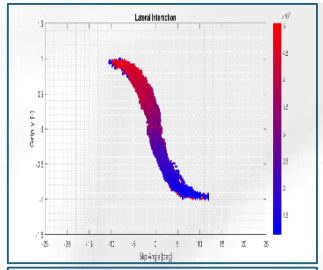


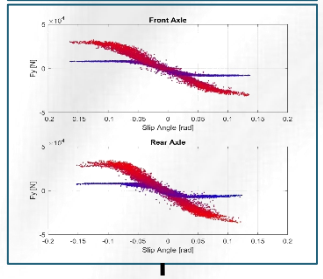
Footprints Test



Forces Estimator

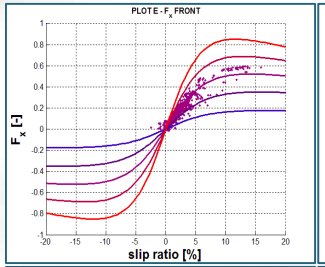
TRICK4TRUCK

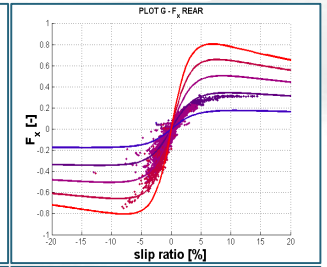


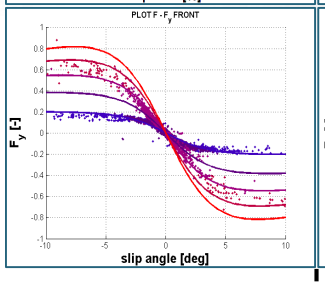


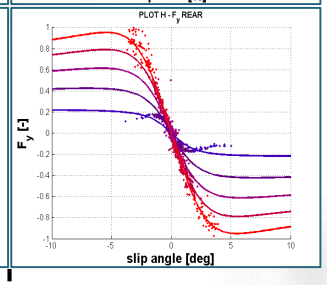
MF Identifier

TRIP-ID



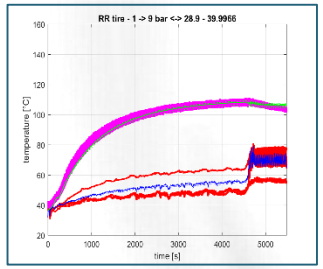






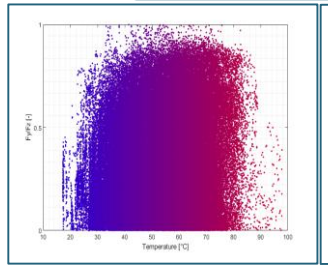
Thermal Model

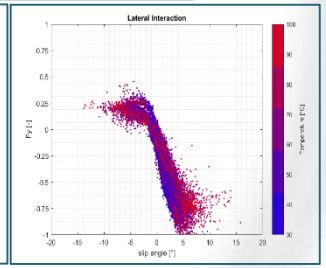
thermoRIDE



MF-Evo

adheRIDE





MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

Tire Performance Objectivation

S-Motion

IMU

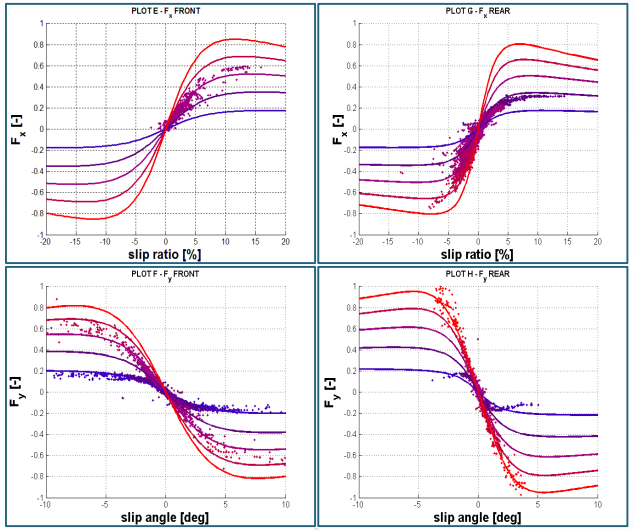
CAN

Forces Estimator

TRICK4TRUCK

MF Identifier

TRIP-ID



Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

Footprints Test

Thermal Model

thermoRIDE

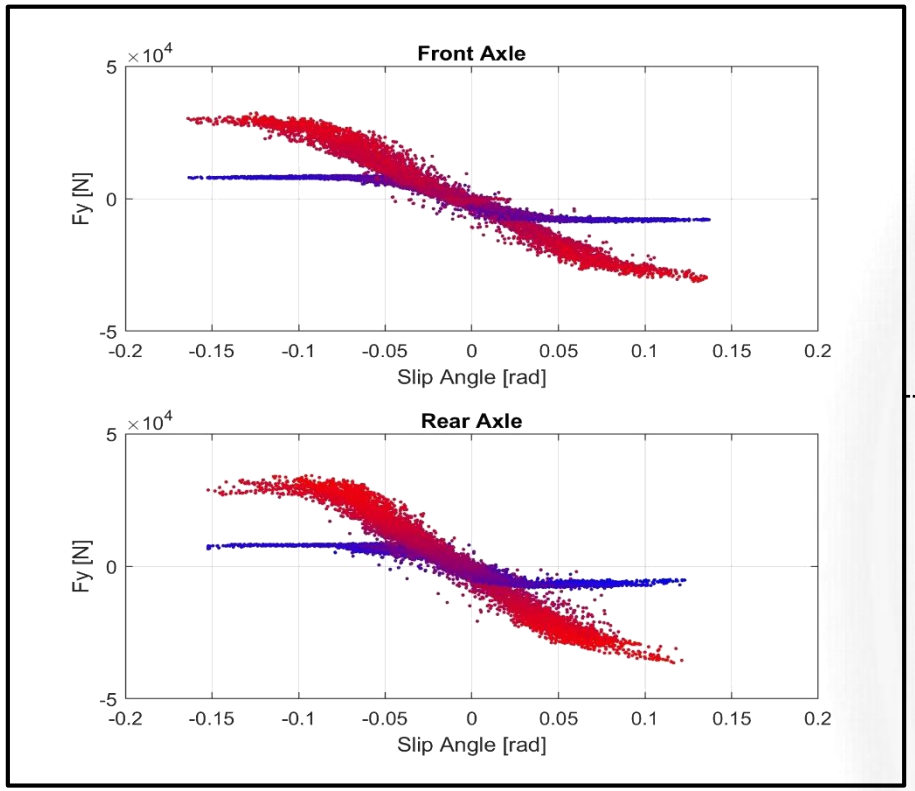
MF-Evo

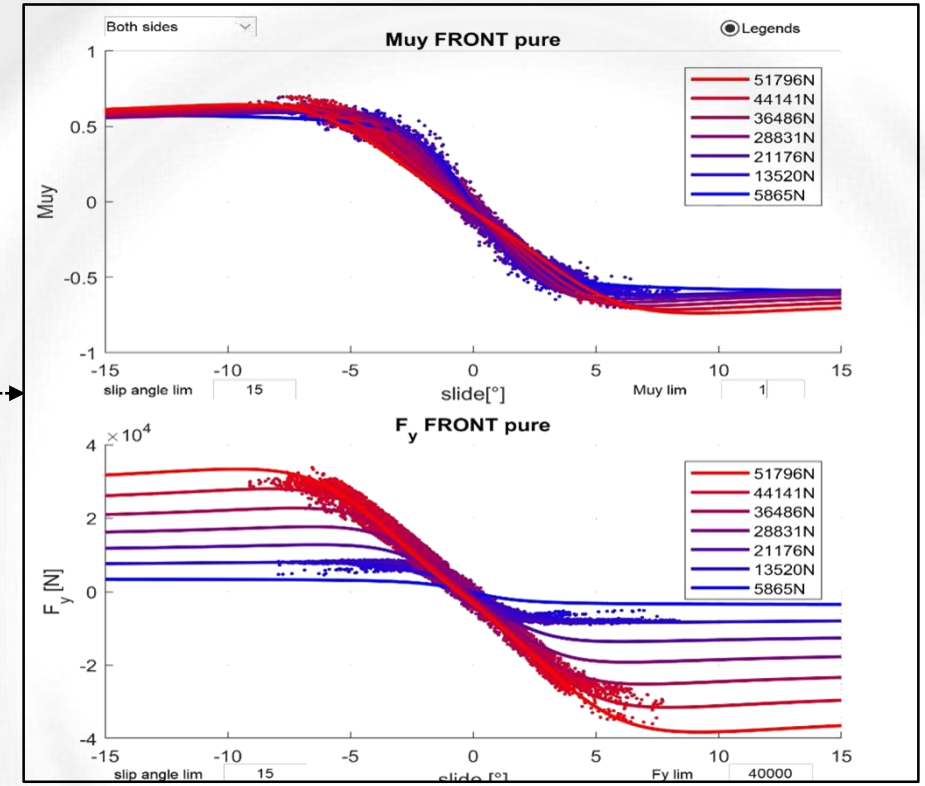
adheRIDE

TRIP-ID TOOL

MAGIC FORMULA IDENTIFIER

Thanks to **TRIP-ID** (Tire-Road Interaction Parameters Identification) tool it has been possible to identify the truck's tire MF parameters.





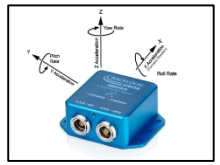
MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

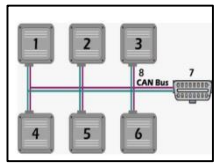
Tire Performance Objectivation

S-Motion

IMU



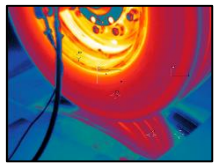
CAN



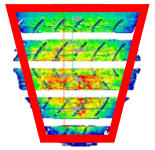
Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

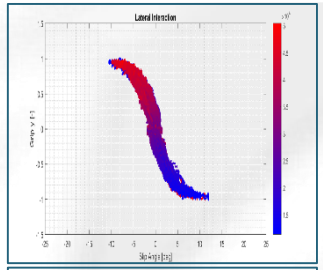


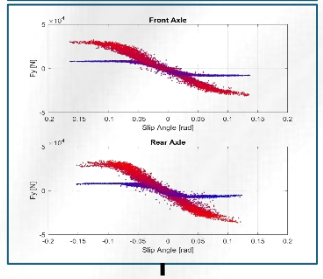
Footprints Test



Forces Estimator

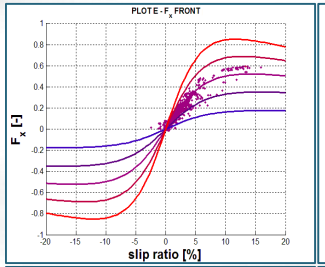
TRICK4TRUCK

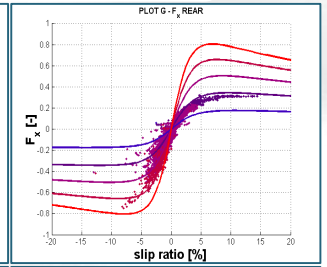


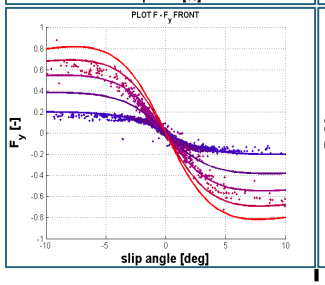


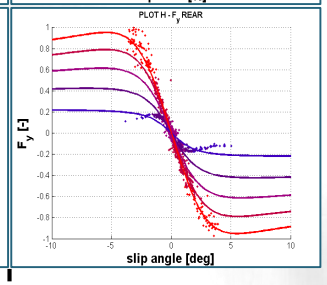
MF Identifier

TRIP-ID



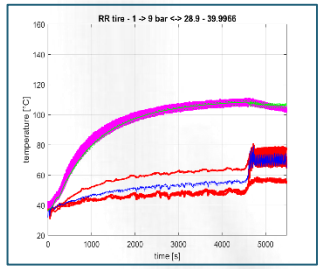






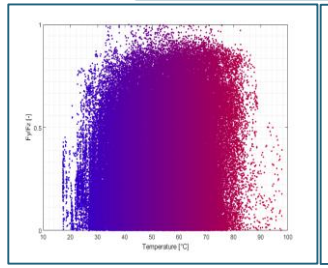
Thermal Model

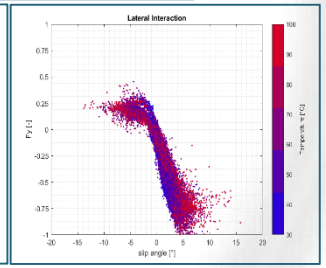
thermoRIDE



MF-Evo

adheRIDE





MEGARIDE
APPLIED VEHICLE RESEARCH

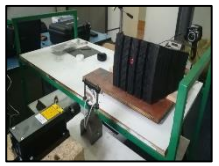
PROMETEON

Tire Performance Objectivation

S-Motion

IMU

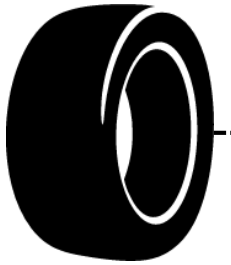
CAN



Diffusivity Test

SEL Test

Footprints Test



Tire Thermal and Viscoelastic Characterization

Forces Estimator

TRICK4TRUCK

MF Identifier

TRIP-ID

Thermal Model

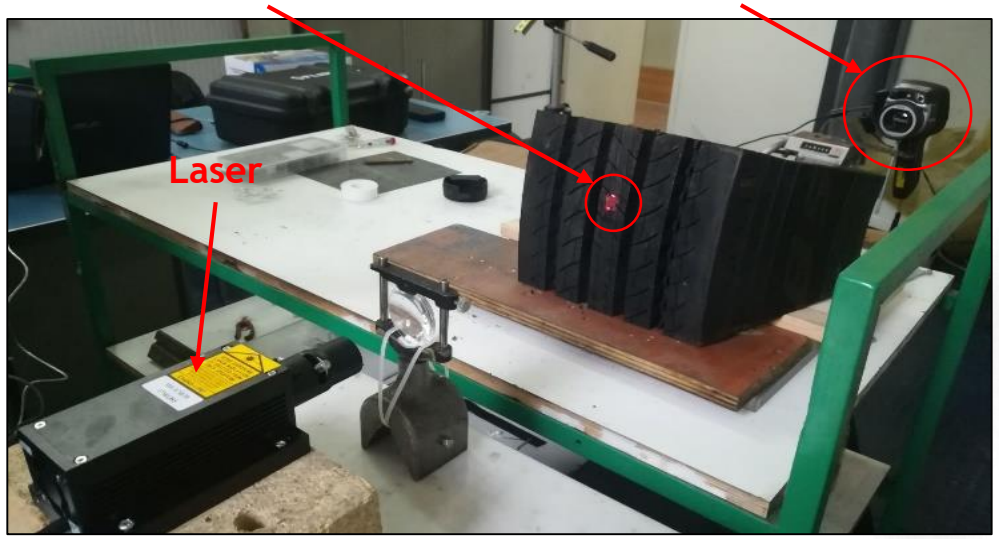
thermoRIDE

MF-Evo

adheRIDE

Diffusivity Test

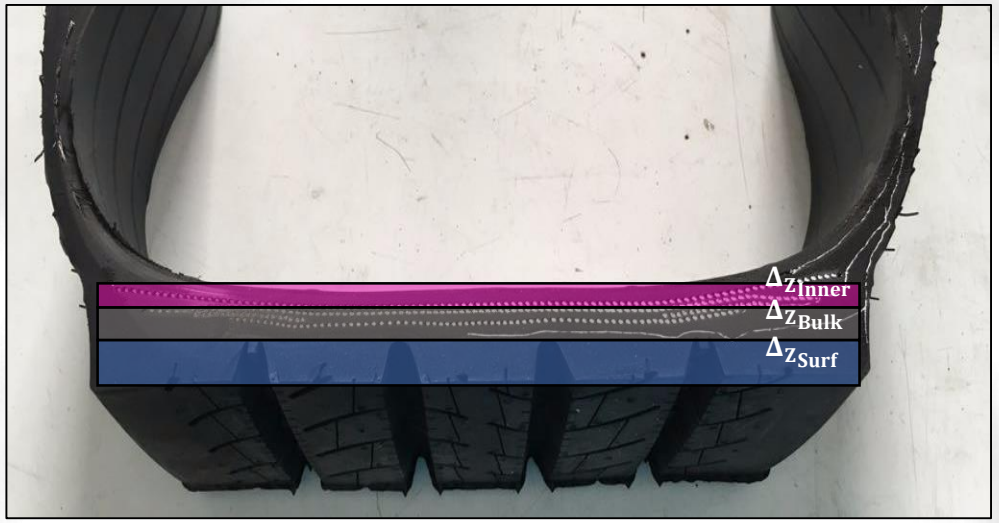
Thermo Racing Tire Lab



Belt + Inner

Tread

Whole Section



For each mass of the layer of interest, the density, the specific heat and thermal conductivity as function of temperature are evaluated by means of an iterative identification procedure, according to the Fourier's diffusivity's law:

$$\vec{\mathbf{q}} = -\mathbf{k} * \overrightarrow{\nabla \mathbf{T}}$$

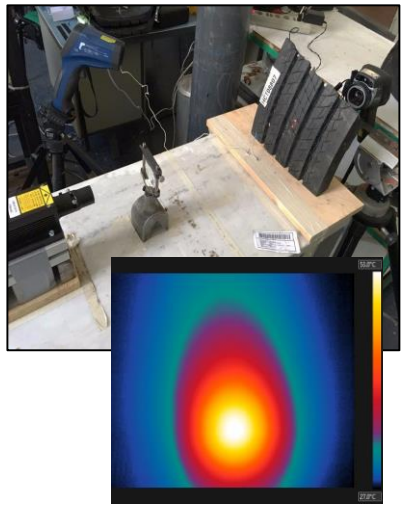
MEGARIDE
APPLIED VEHICLE RESEARCH

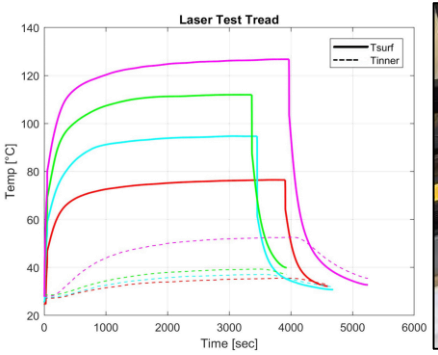
PROMETEON

Diffusivity Test

Thermo Racing Tire Lab

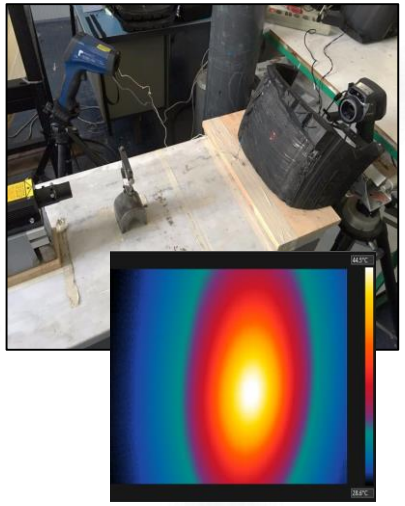
Tread

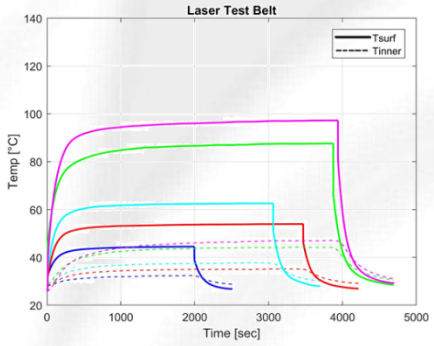




Power (W)	Surface T Max (°C)	Inner T Max (°C)
1.0	76.5	35.5
1.5	94.7	37.0
2.0	112.0	39.3
2.4	126.8	52.6

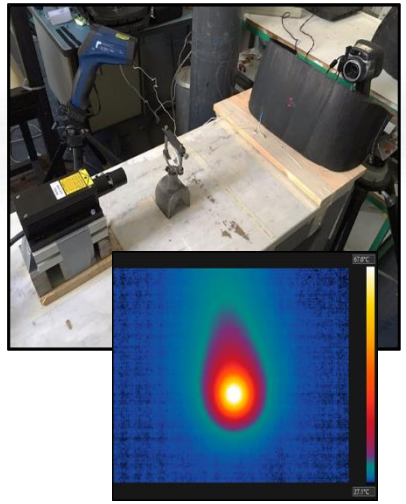
Bulk

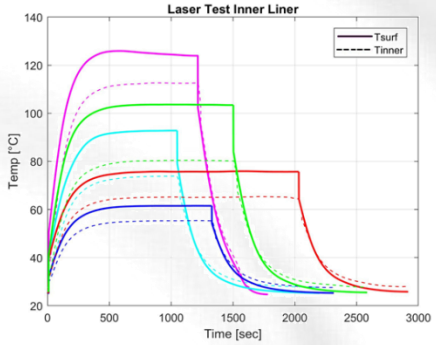




Power (W)	Surface T Max (°C)	Inner T Max (°C)
1.0	44.5	32.4
1.5	54.0	35.2
2.0	62.6	37.7
3.5	87.6	44.3
4.5	97.3	47.0

Inner Liner

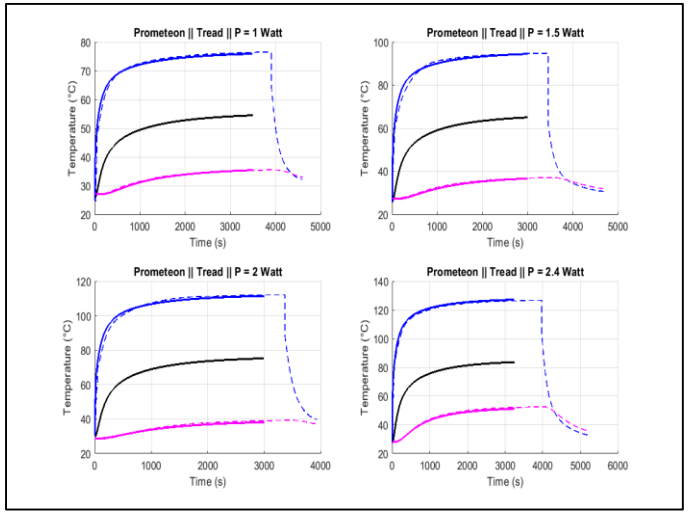


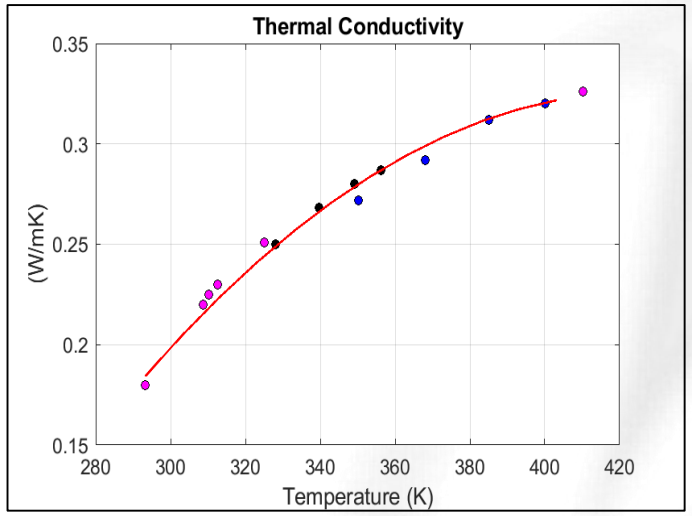


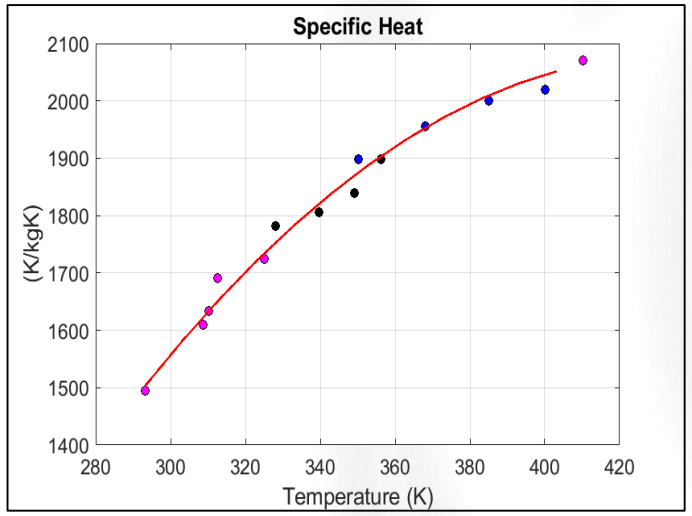
Power (W)	Surface T Max (°C)	Inner T Max (°C)
0.5	61.5	55.4
0.75	75.9	65.4
1.0	92,8	74.0
1.25	103.6	80.5
2.4	126.0	112.6

Diffusivity Test

Parmeters Identification





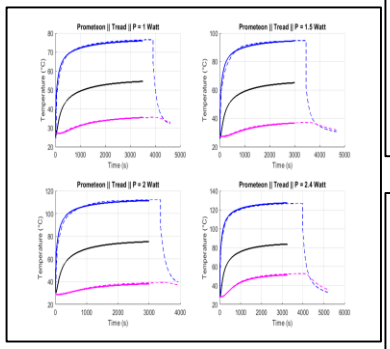


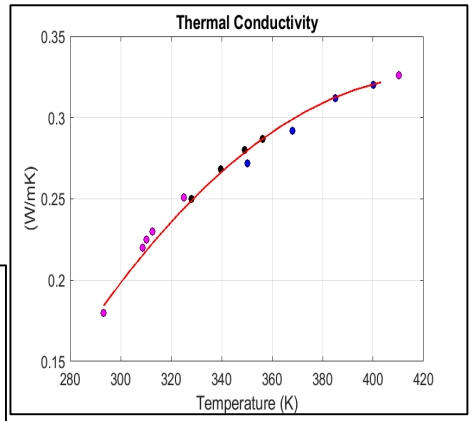
- The procedure stops as the estimated temperatures (solid line) are in agreement with the experimental data (dotted line).
- The experimental points obtained have been fitted with quadratic law

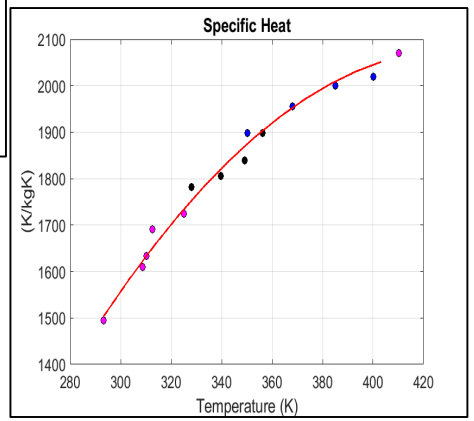
Diffusivity Test

Parmeters Identification

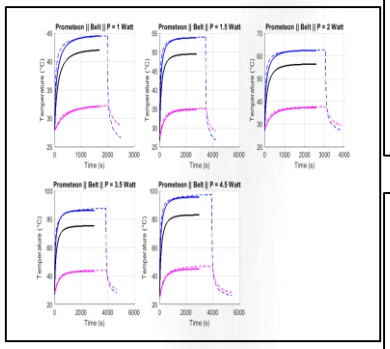
Tread

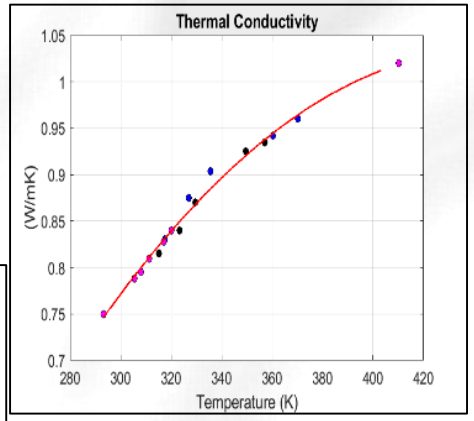


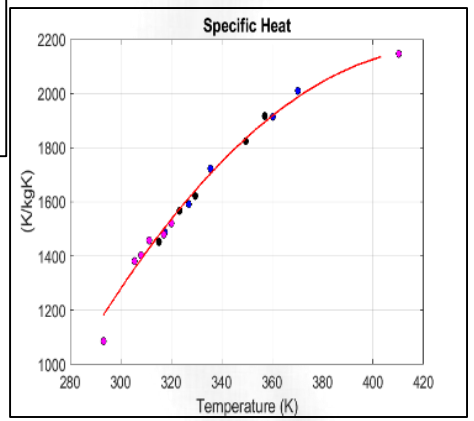




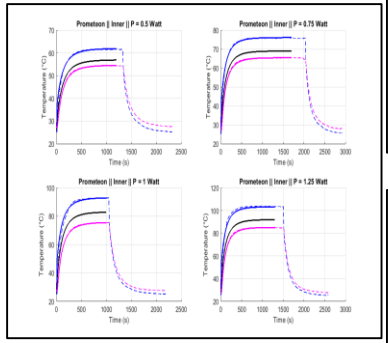
Bulk

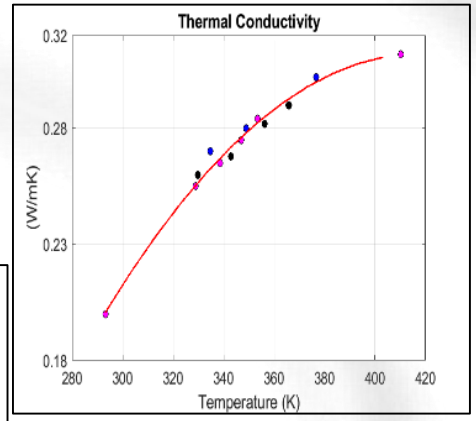


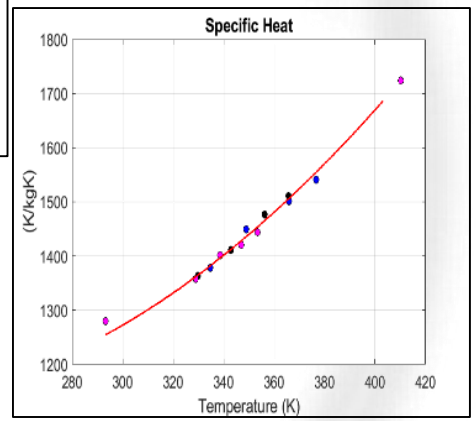




Inner Liner







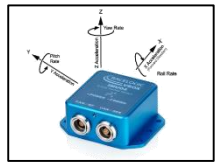
MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

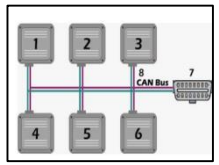
Tire Performance Objectivation

S-Motion

IMU



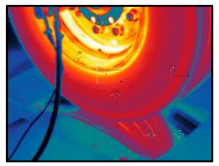
CAN



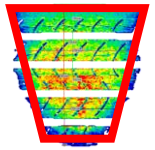
Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

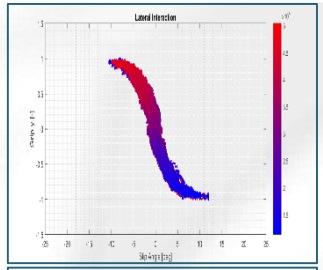


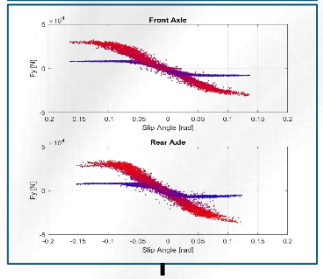
Footprints Test



Forces Estimator

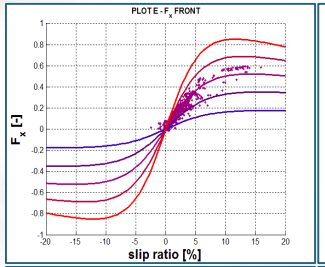
TRICK4TRUCK

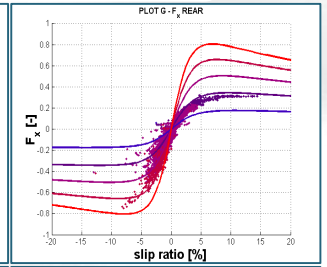


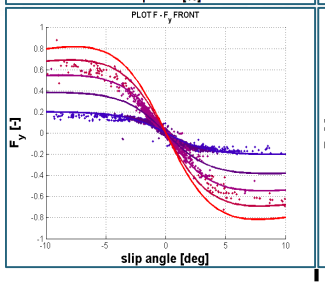


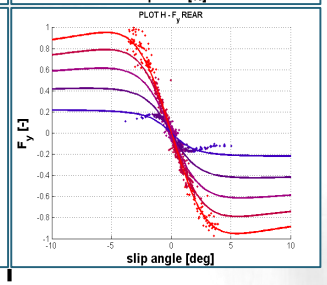
MF Identifier

TRIP-ID



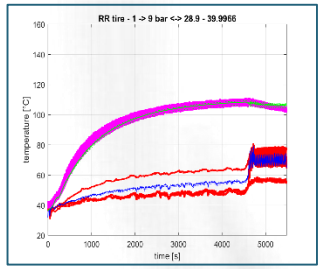






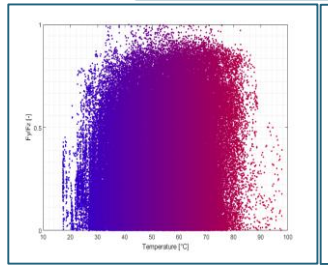
Thermal Model

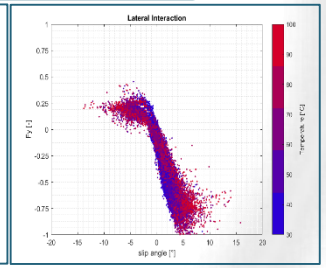
thermoRIDE



MF-Evo

adheRIDE





MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

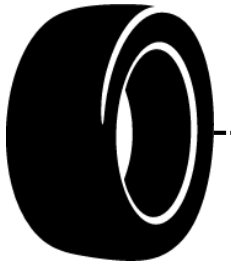
Tire Performance Objectivation

S-Motion

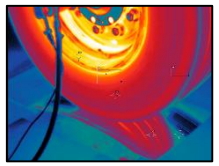
IMU

CAN

Diffusivity Test



Tire Thermal and Viscoelastic Characterization



SEL Test

Footprints Test

Forces Estimator

MF Identifier

Thermal Model

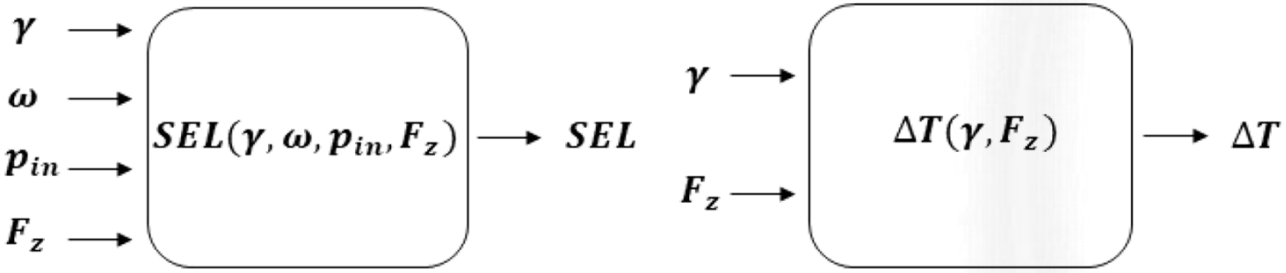
MF-Evo

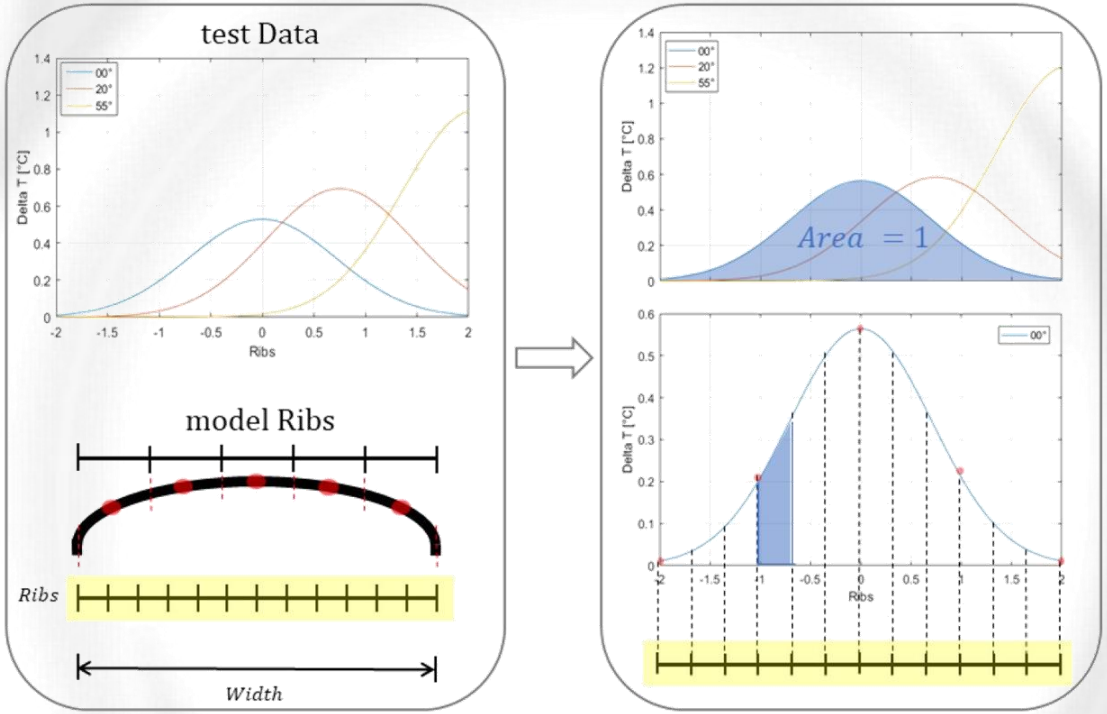
SEL Test

Strain Energy Loss Characterization

The Strain Energy Loss (SEL) is defined as the energy generated by the tire because of cyclic deformations and is due to a super-position of several phenomena: intra-plies friction, friction inside singular plies, non-linear viscoelastic behavior of all rubbery components, etc.

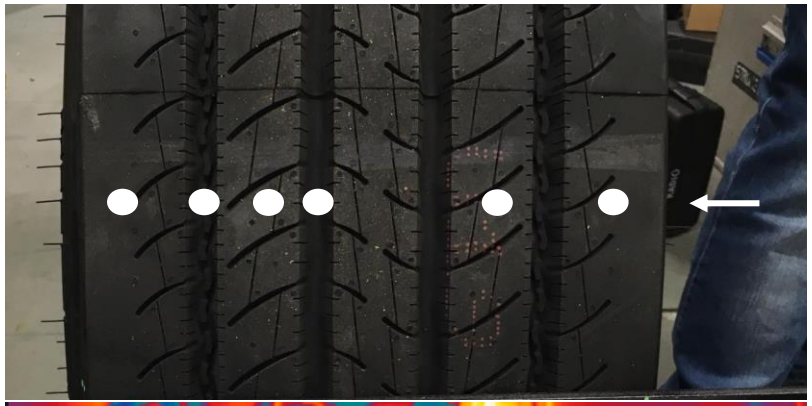
$$SEL = f(\vec{F}, \omega, \gamma, p_{in\_air})$$

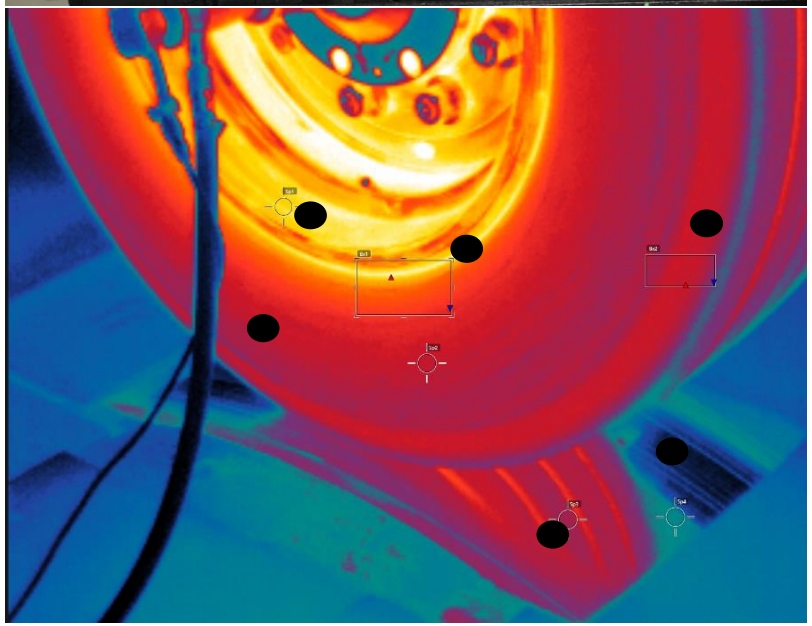


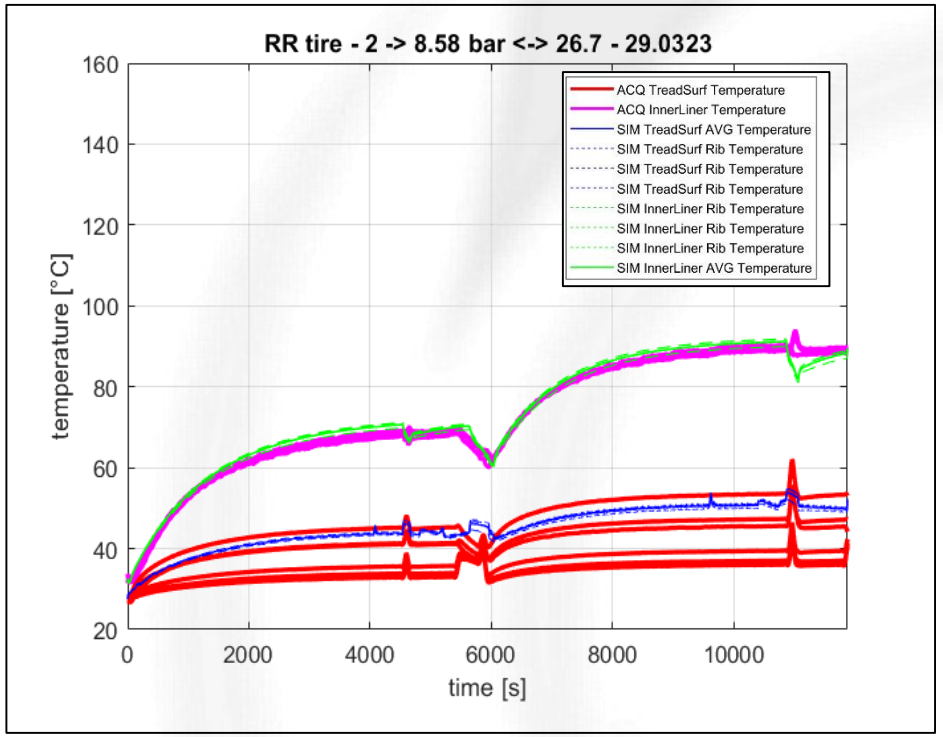


SEL TEST

STRAIN ENERGY LOSS CHARACTERIZATION







The test procedure involved the acquisition of temperatures in several points of interest, shown in the images on the left.

SEL's law identification process has led to the results shown in the figure, with good correlation with the experimental data.

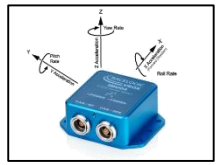
MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

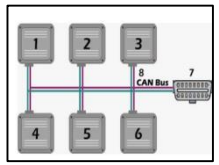
Tire Performance Objectivation

S-Motion

IMU



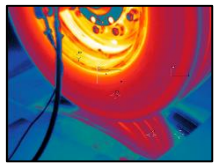
CAN



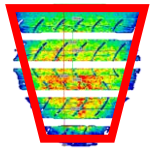
Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

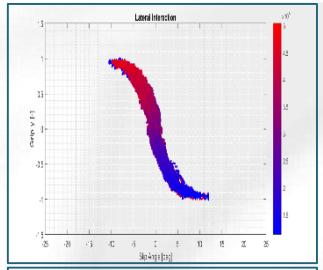


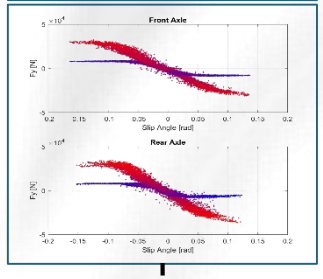
Footprints Test



Forces Estimator

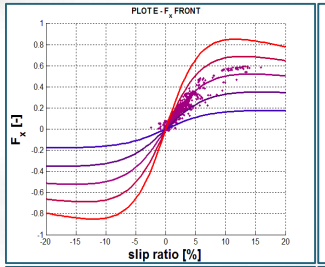
TRICK4TRUCK

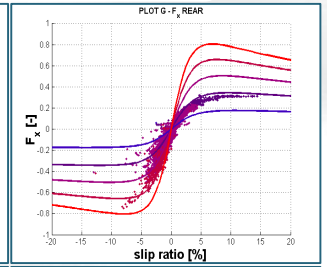


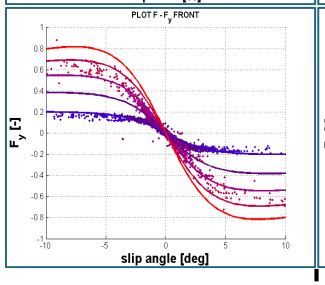


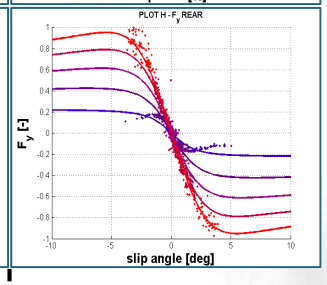
MF Identifier

TRIP-ID



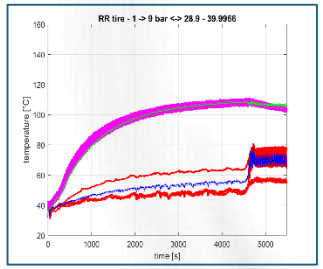






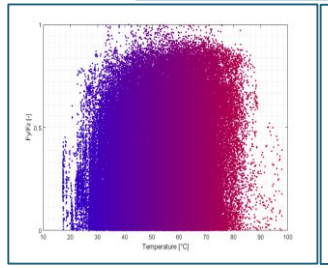
Thermal Model

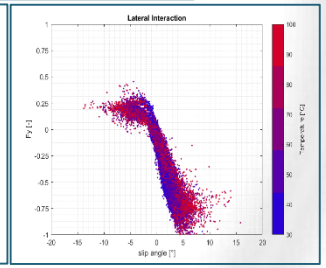
thermoRIDE



MF-Evo

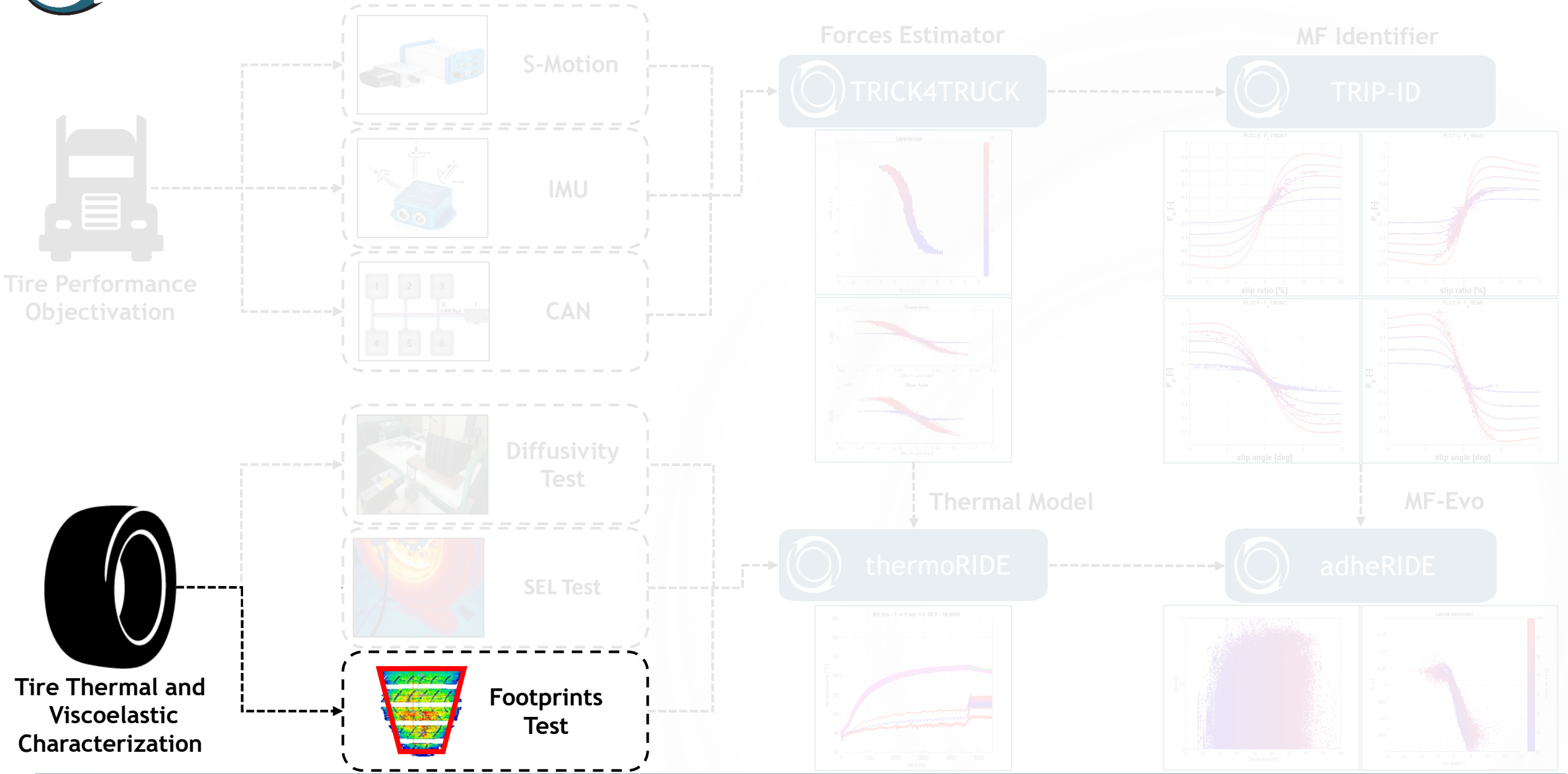
adheRIDE





MEGARIDE
APPLIED VEHICLE RESEARCH

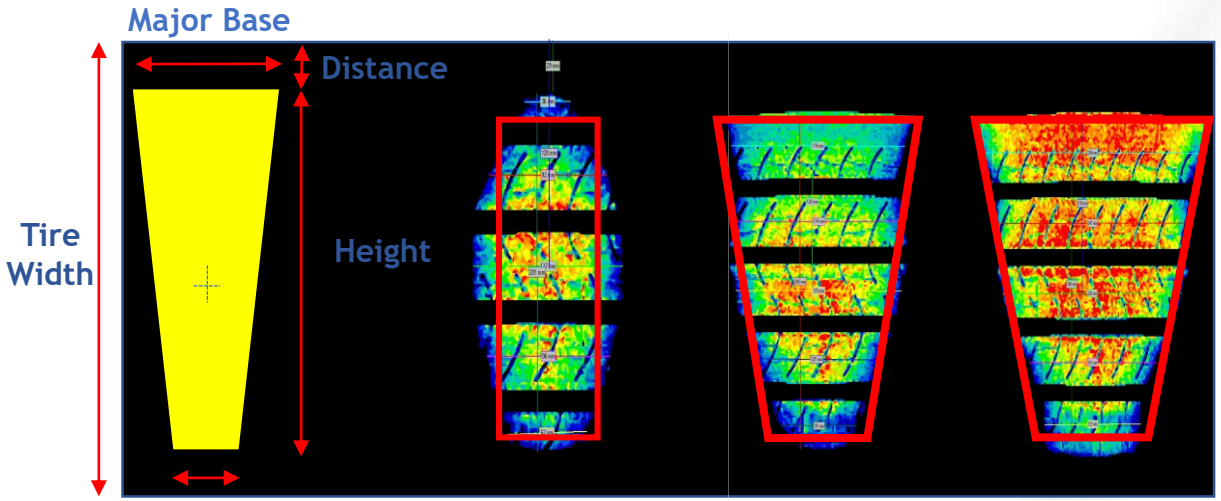
PROMETEON



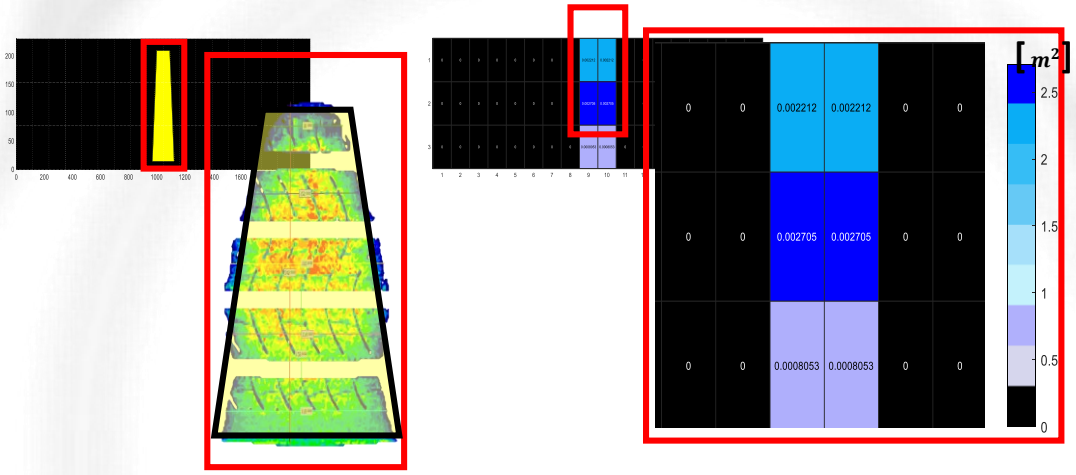
FOOTPRINTS TEST

FOOTPRINTS PARAMETERIZATION

The contact patch is concerned with a simplified representation.The shape of the footprint changes with the inclination angle value, it is a rectangle when the IA value is equal to 0 and it is a trapezoid if the IA value is different from 0.
The tire is discretized in a certain number of cells and the area maps show the contact patch distribution on each of that.



IA [deg] : 0	IA [deg] : -3	IA [deg] : -6
Fz [N] : 10000	Fz [N] : 25000	Fz [N] : 45000
Pi [bar] : 9	Pi [bar] : 9	Pi [bar] : 9



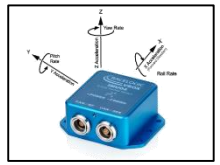
MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

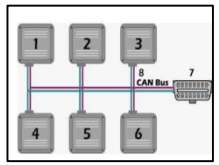
Tire Performance Objectivation

S-Motion

IMU



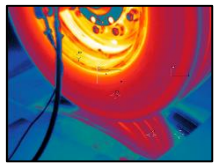
CAN



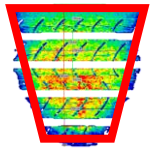
Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

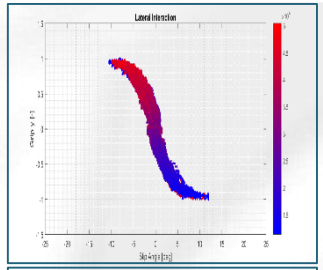


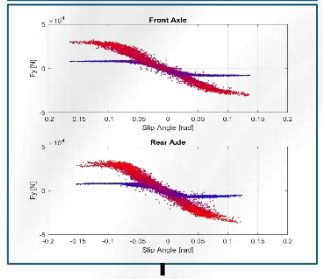
Footprints Test



Forces Estimator

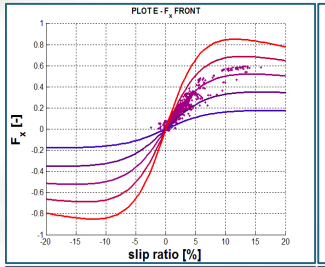
TRICK4TRUCK

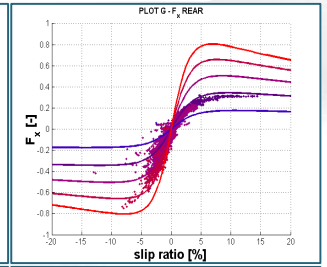


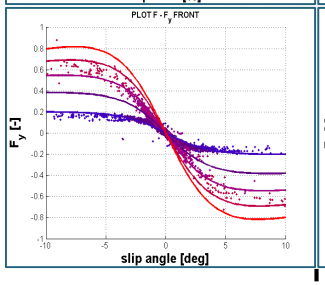


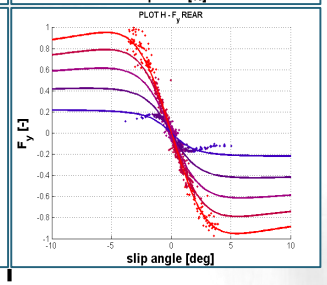
MF Identifier

TRIP-ID



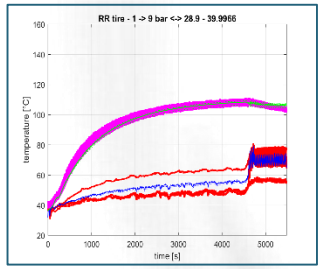






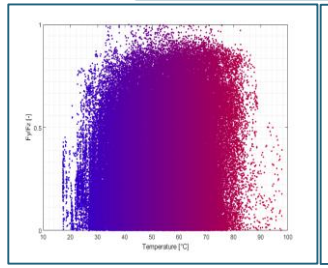
Thermal Model

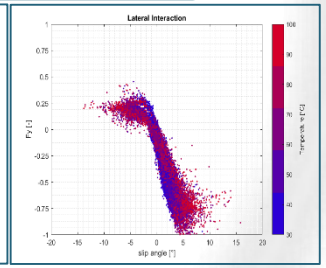
thermoRIDE



MF-Evo

adheRIDE





MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

Tire Performance Objectivation

S-Motion

IMU

CAN

Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

Footprints Test

Forces Estimator

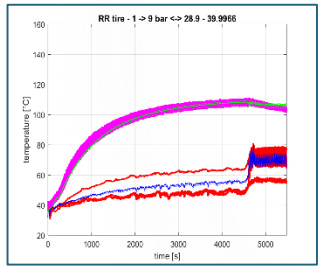
TRICK4TRUCK

MF Identifier

TRIP-ID

Thermal Model

thermoRIDE



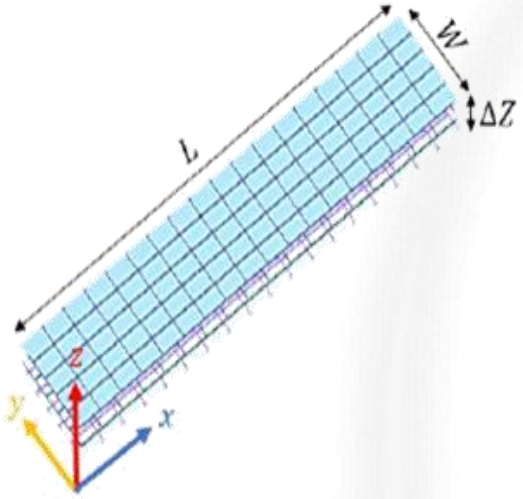
MF-Evo

adheRIDE

THERMORIDE

THERMAL MODEL DESCRIPTION

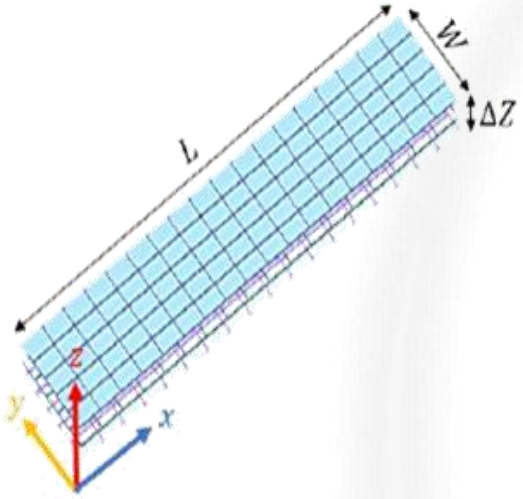
thermoRIDE thermodynamic model is based on the use of the Fourier's diffusivity equation applied to a three dimensional domain.

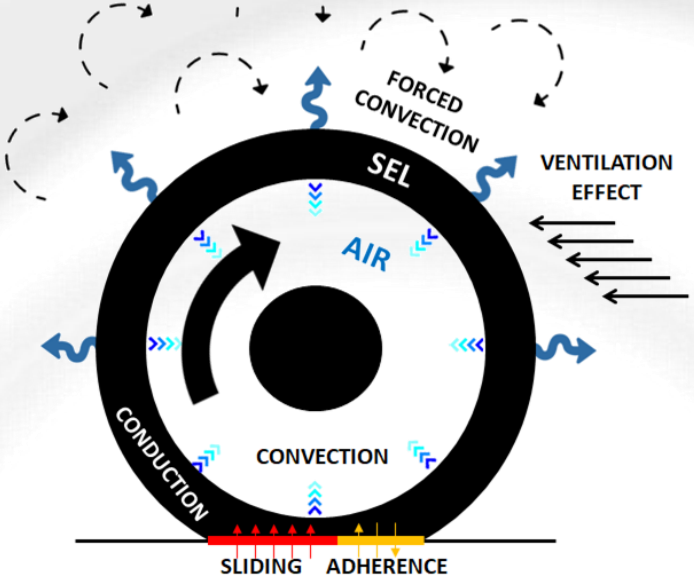


THERMORIDE

THERMAL MODEL DESCRIPTION

thermoRIDE thermodynamic model is based on the use of the Fourier's diffusivity equation applied to a three dimensional domain.





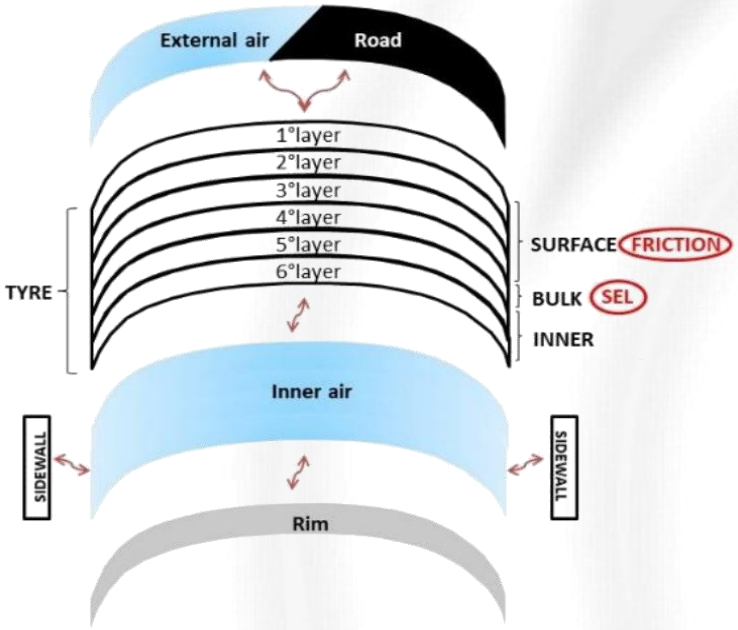
The model considered takes into account of the tire's heat exchange with the external environment:

- **Heat exchange with road**
- **Heat exchange with external air**
- **FP (Friction Power)**
- **SEL (Strain Energy Loss)**
- **Heat exchange with internal air**

THERMORIDE

THERMAL MODEL DESCRIPTION

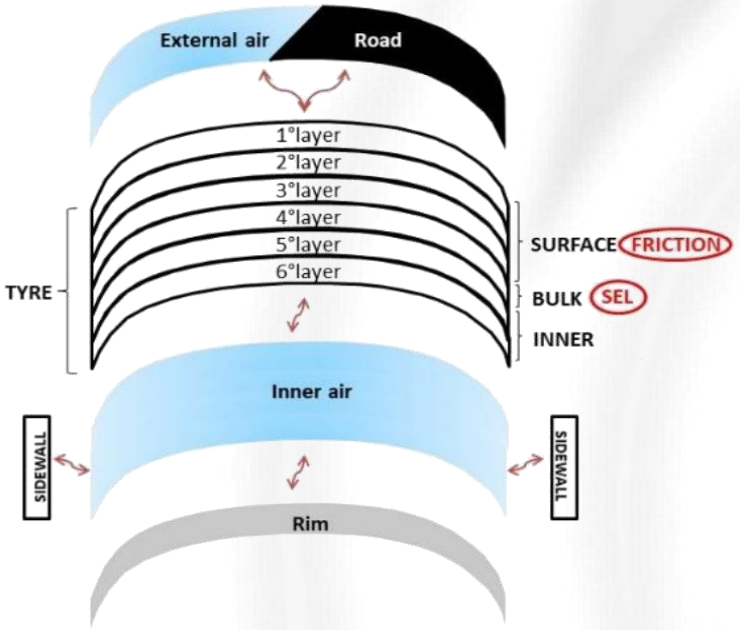
The default tire discretization along the radial and lateral directions is illustrated in the figures below.



THERMORIDE

THERMAL MODEL DESCRIPTION

The default tire discretization along the radial and lateral directions is illustrated in the figures below.



- **TreadSurface:** the most external part of the tread
- **TreadCore:** strictly connected to tire grip and stiffness
- **TreadBase:** its temperature is linked to tire stiffness
- **Belt:** it gives a big contribution to the SEL
- **Plies:** it is another important contributor to SEL
- **InnerLiner:** it is the layer in contact with the inner air

THERMORIDE

TRACK THERMAL TESTS DESCRIPTION

To feed the thermal model, a specific track session with an instrumented truck has been carried out.
Test sessions have been carried out on an overloaded trailer and the instruments used are shown in the image below:

- **Kistler Dyno-Hub** on trailer's right rear wheel
- **Kistler S-Motion**

THERMORIDE

TRACK THERMAL TESTS DESCRIPTION

To feed the thermal model, a specific track session with an instrumented truck has been carried out.
Test sessions have been carried out on an overloaded trailer and the instruments used are shown in the image below:

- **Kistler Dyno-Hub** on trailer's right rear wheel
- **Kistler S-Motion**

Tests carried out are listed below:

- **Test1_80km/h**
- **Test2_90km/h**
- **Test3_100km/h**
- **Test4_110km/h**

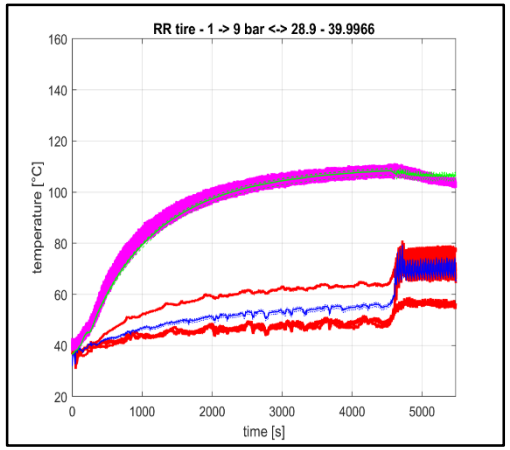
All tests have been performed according to the following scheme:

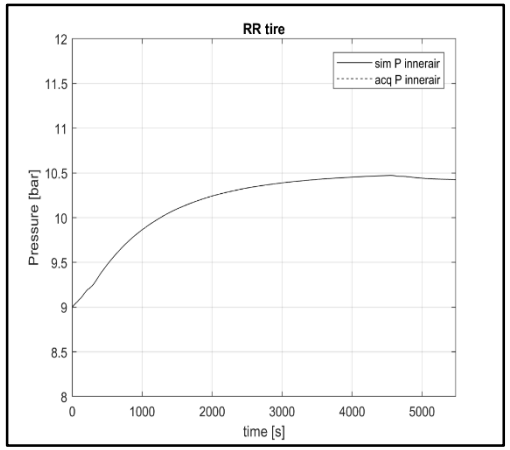
- **75 minutes** on Nardò Ring at constant speed
- **15 minutes** dynamic square

THERMORIDE

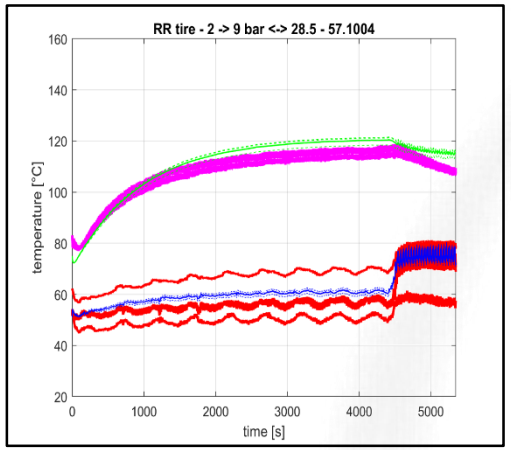
RESULTS

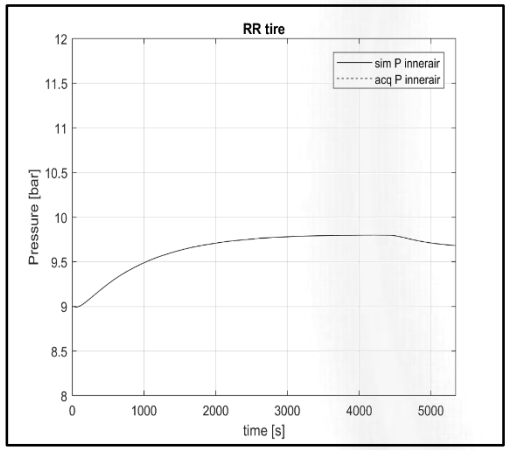
80 KM/H



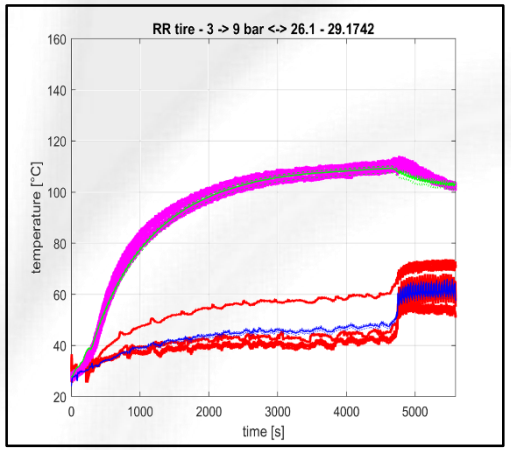


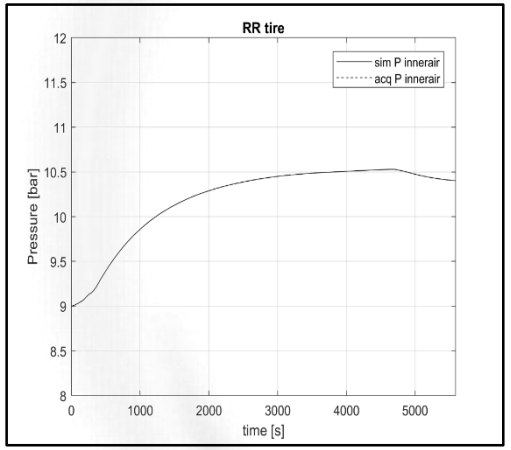
90 KM/H



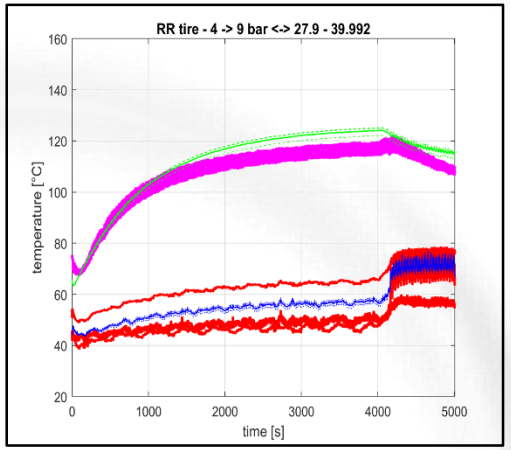


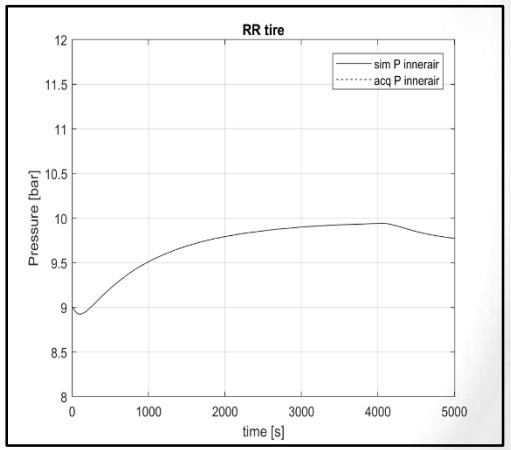
100 KM/H





110 KM/H





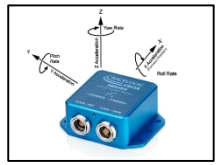
MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

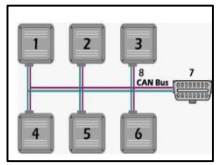
Tire Performance Objectivation

S-Motion

IMU



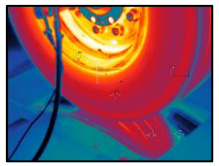
CAN



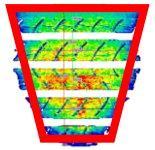
Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

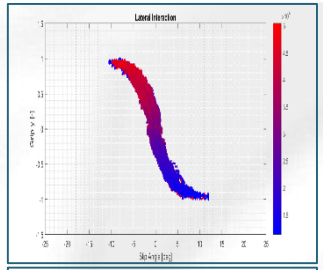


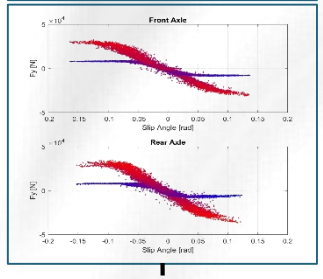
Footprints Test



Forces Estimator

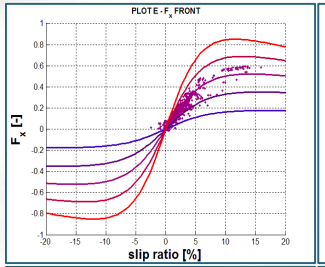
TRICK4TRUCK

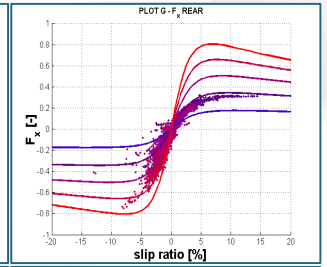


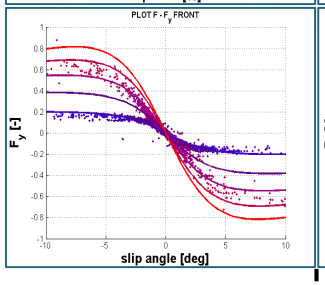


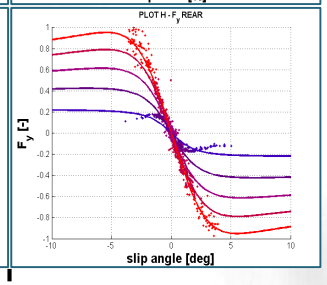
MF Identifier

TRIP-ID



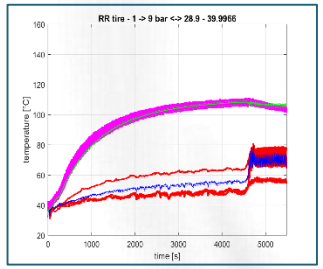






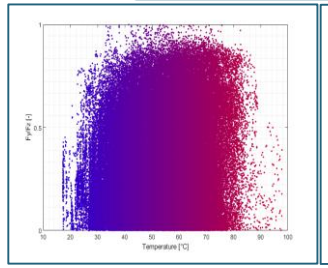
Thermal Model

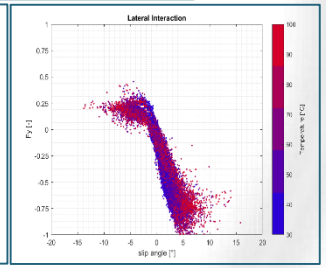
thermoRIDE



MF-Evo

adheRIDE





MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

Tire Performance Objectivation

S-Motion

IMU

CAN

Forces Estimator

TRICK4TRUCK

MF Identifier

TRIP-ID

Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

Footprints Test

Thermal Model

thermoRIDE

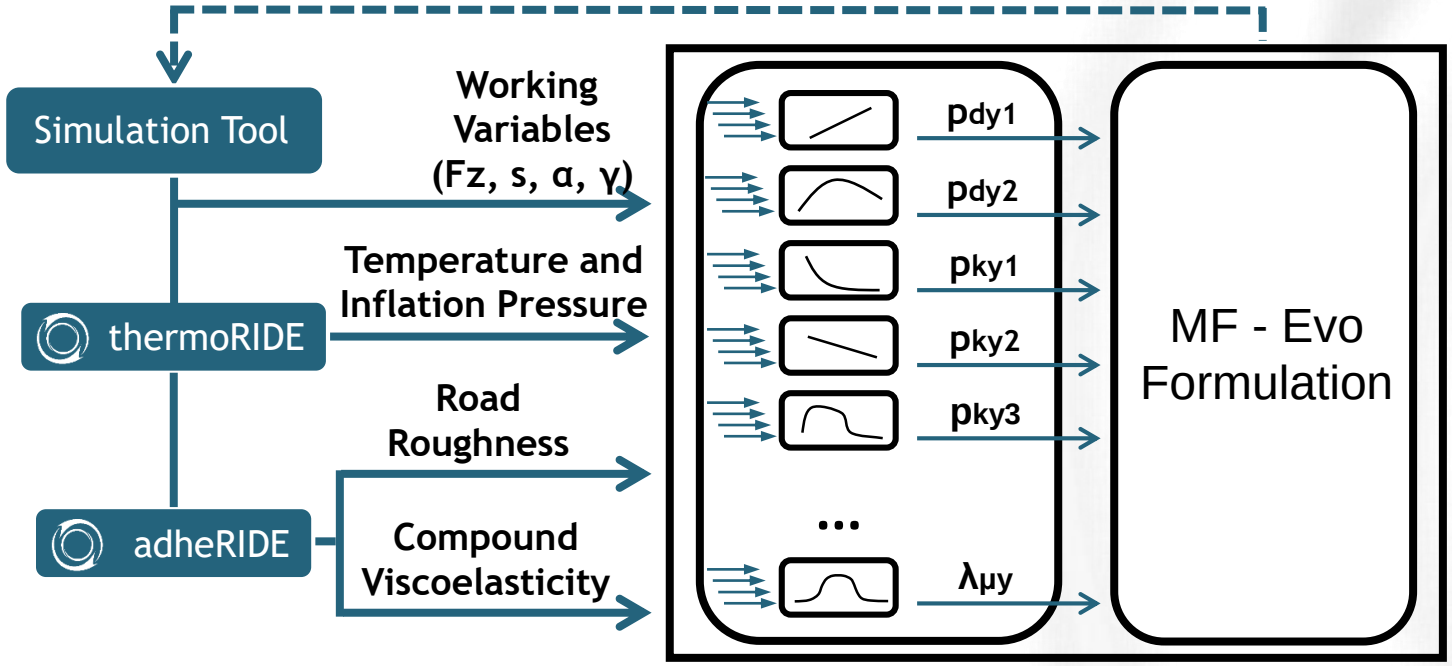
MF-Evo

adheRIDE

adheRIDE

Advanced Grip/Stiffness Analysis

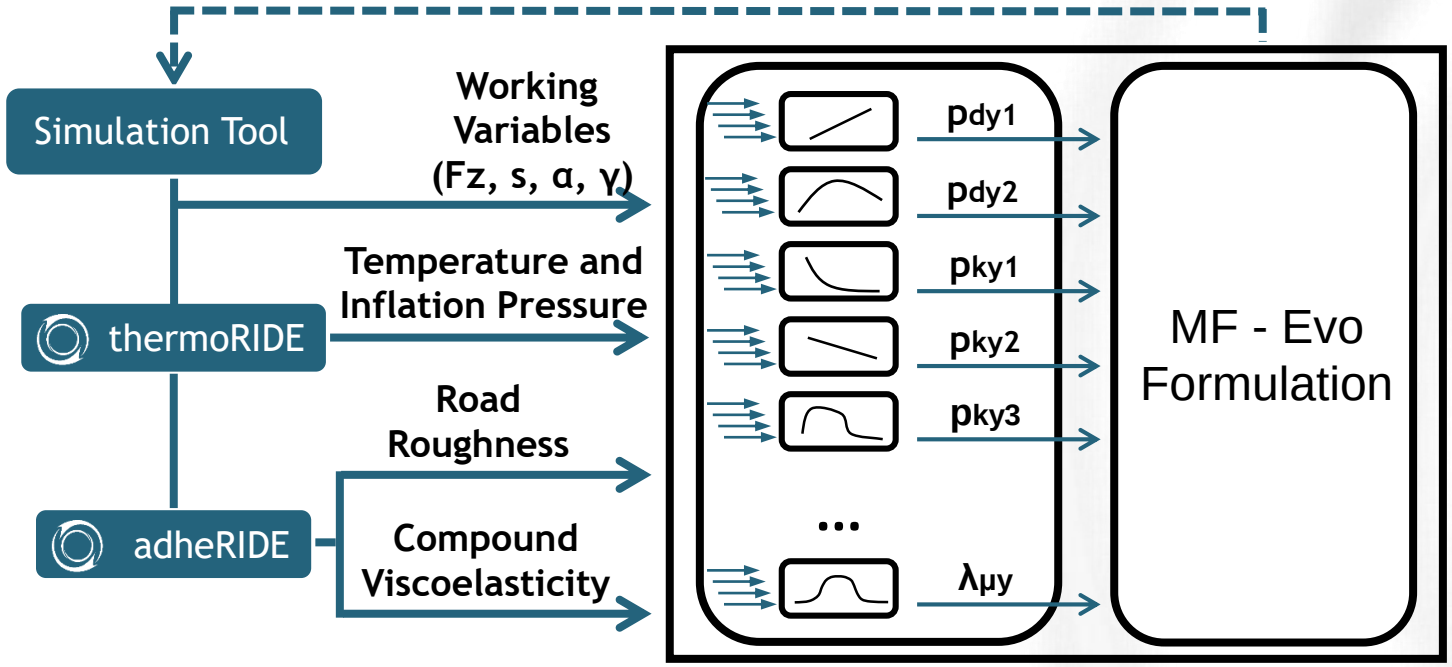
- an innovative Pacejka's Magic Formula extending the physical sensitivity of the tire model
- the MF-Evo formulation allows to feed the simulation loop taking into account the **temperature/inflation pressure/friction phenomea**

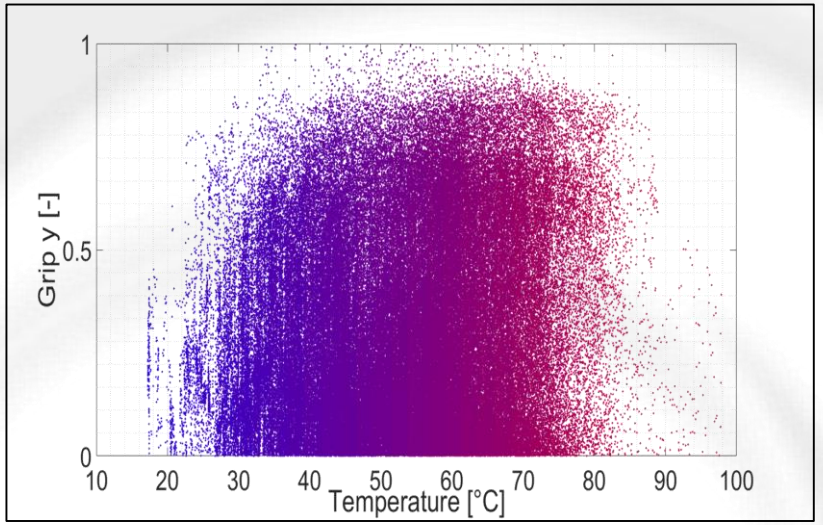


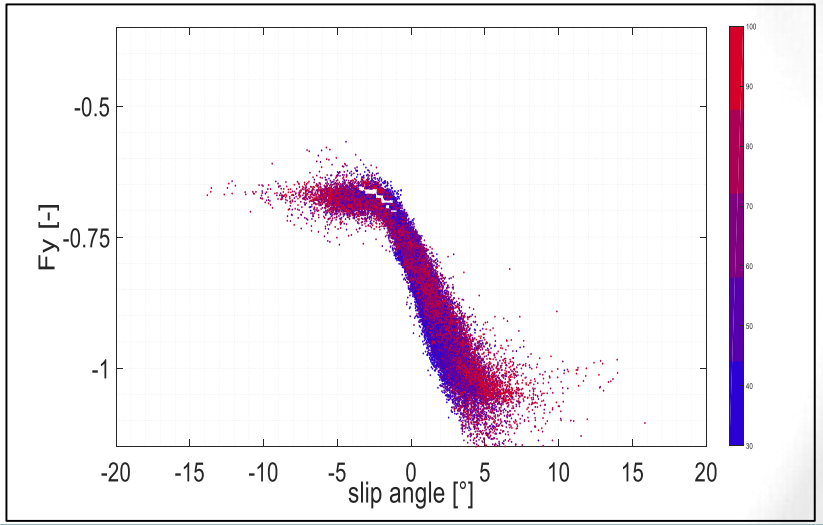
adheRIDE

Advanced Grip/Stiffness Analysis

- an innovative Pacejka's Magic Formula extending the physical sensitivity of the tire model
- the MF-Evo formulation allows to feed the simulation loop taking into account the **temperature/inflation pressure/friction phenomea**







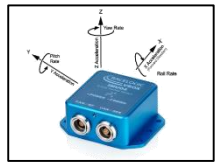
MEGARIDE
APPLIED VEHICLE RESEARCH

PROMETEON

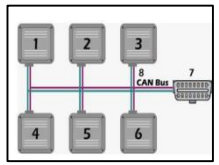
Tire Performance Objectivation

S-Motion

IMU



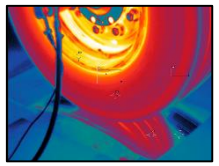
CAN



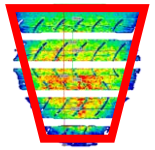
Tire Thermal and Viscoelastic Characterization

Diffusivity Test

SEL Test

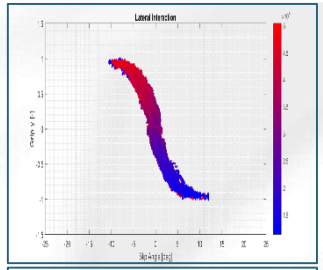


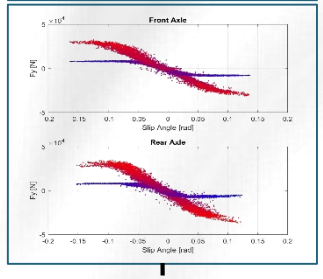
Footprints Test



Forces Estimator

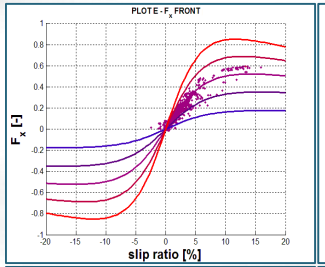
TRICK4TRUCK

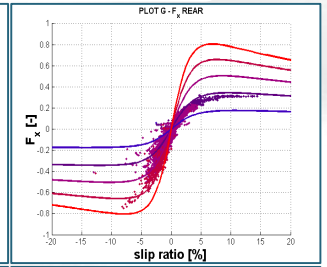


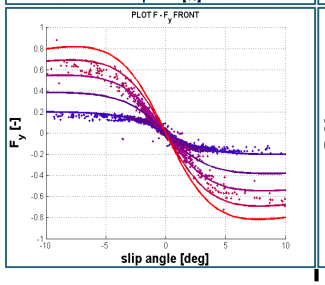


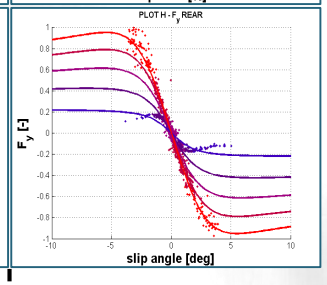
MF Identifier

TRIP-ID



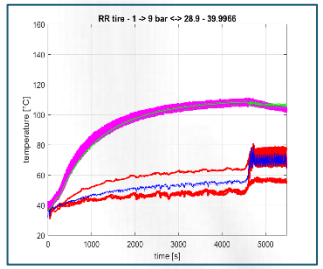






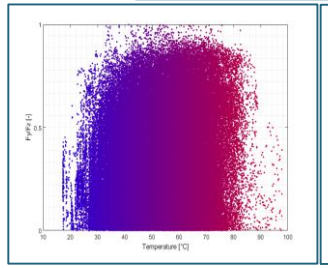
Thermal Model

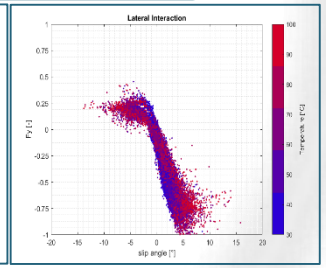
thermoRIDE



MF-Evo

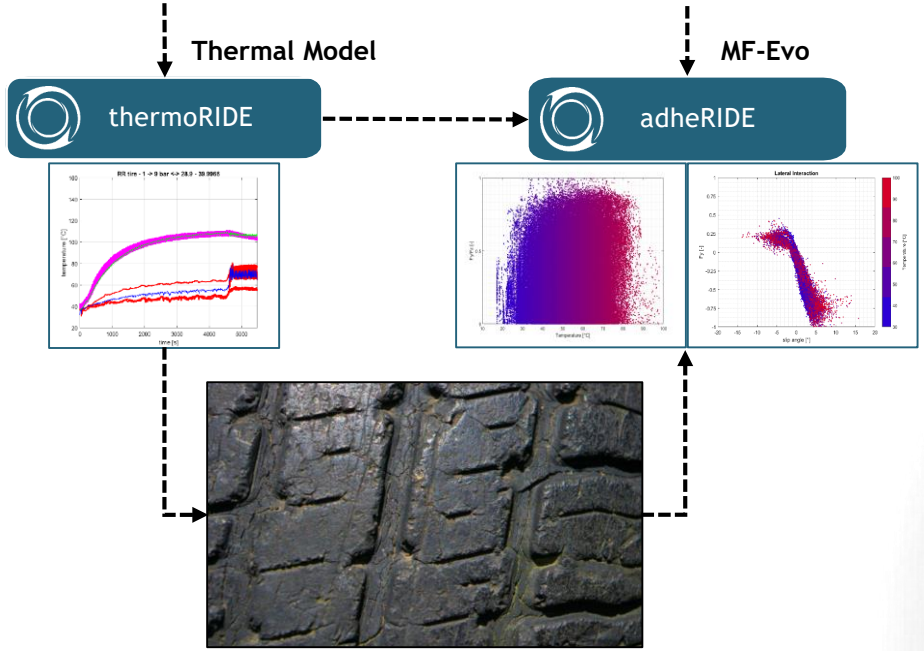
adheRIDE





What's Next...

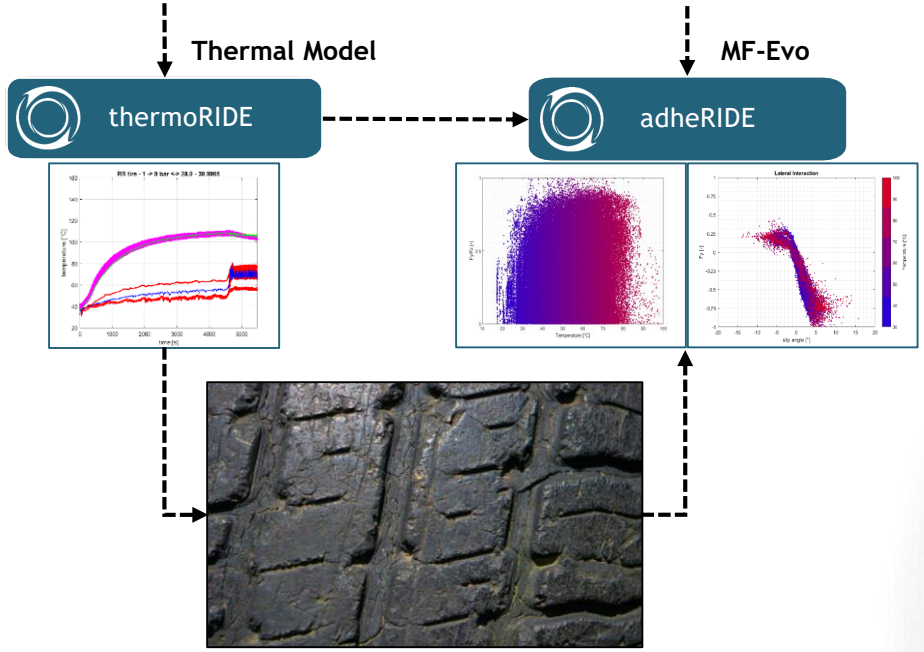
Future Scenarios



- development of a specific truck tire wear model
- MF-Evo formulation sensitive to wear

What's Next...

Future Scenarios



- development of a specific truck tire wear model
- MF-Evo formulation sensitive to wear

- Specific snow track sessions for TRICK4TRUCK tool and thermoRIDE validation

MEGARIDE

andrea.sammartino@megaride.eu

Via Claudio 21, 80125 NAPOLI
DII – Dipartimento di Ingegneria Industriale Università degli Studi di Napoli "Federico II"

megaride_vehicle_dynamics

MegaRide - appliedvehicledynamics

www.megaride.eu