2026
SMART PROTOTYPES
SUMMIT

Multi-scale Wet Tire Dynamics: Modeling and Validation in a VI-grade Simulator

Ing. Marco Sbrosi

R&D – Head of Tyre Modelling & Driving Simulator, Pirelli Tyre

Matteo Romano

PhD Candidate, University of Naples Federico II, MegaRide

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RESEARCH FRAMEWORK

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

MEGARIDE
APPLIED VEHICLE RESEARCH

Multi-scale Wet Tire Dynamics: Modeling and Validation in a VI-grade Simulator

PhD Candidate — Matteo Romano

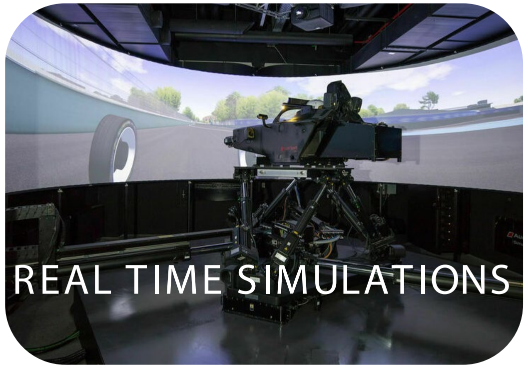
Advisors — Prof. Flavio Farroni
Ing. Marco Sbrosi
Ing. Andrea Sammartino
Ing. Filippo Bassetto

COMPANY OVERVIEW

MEGARIDE®
APPLIED VEHICLE RESEARCH
an official UniNa spinoff company

UniNa Vehicle Dynamics research group

13	30	5	4
Motorsport Categories	Racing Teams	Car-makers	Tire-makers



WHERE WE LEFT

2025 ZERO PROTOTYPES SUMMIT

Advanced tire modeling approach for vehicle behavior validation on low-friction surfaces

- Testing: Tire and vehicle level approaches.
- Modeling: Wet multi-physical tire parametrization.
- Validation: Good agreement with experimental results.

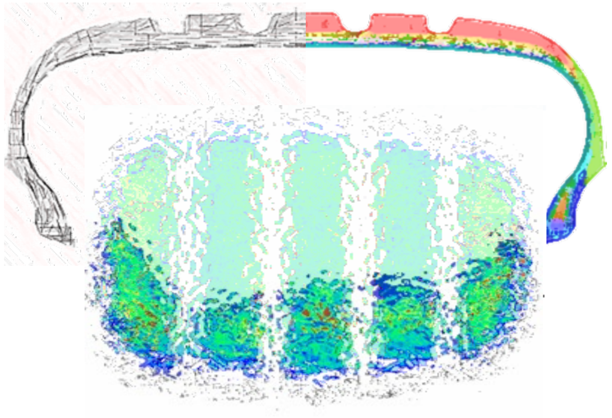
2026 SMART PROTOTYPES SUMMIT

Multi-scale Wet Tire Dynamics: Modeling and Validation in a VI-grade Simulator

- Testing: Real-world testing (straight and bend aquaplaning).
- Modeling: Physical hydrodynamics equations added to Pirelli proprietary model.
- Validation: Highly realistic behavior confirmed.

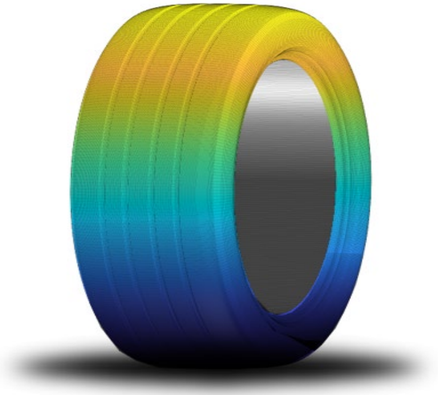
PIRELLI VIRTUALIZATION ENVIRONMENT

Design



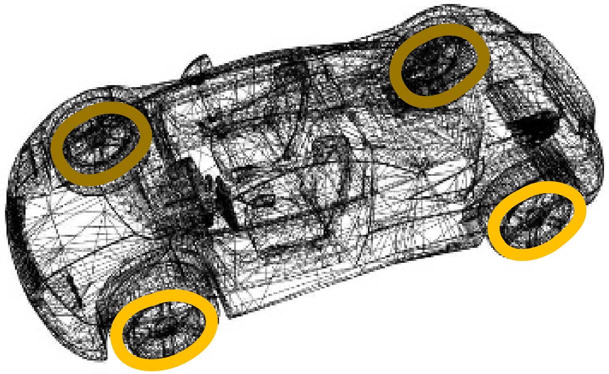
High-Fidelity
FEM models

Tire Simulation



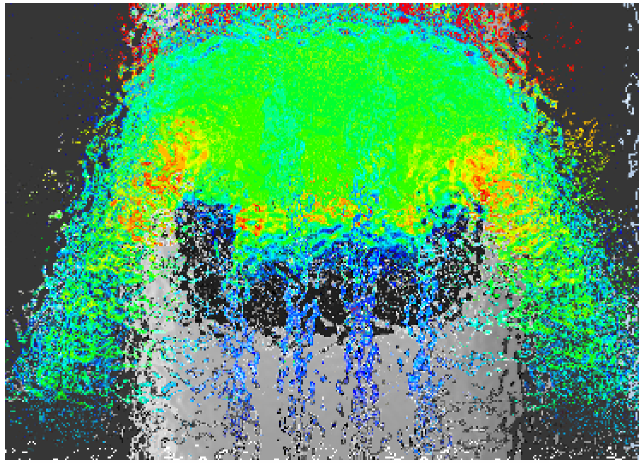
Proprietary
Physics-Based Formulation

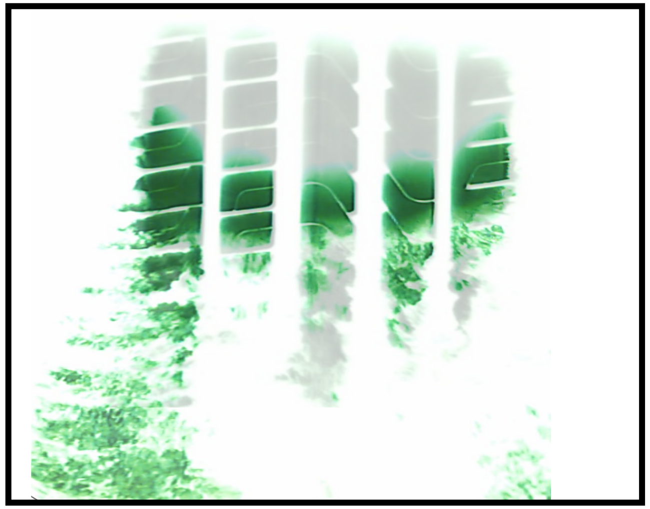
Vehicle Simulation



Vehicle level
Real-Time model integration DiL

extedend the capabilities of RealTime virtual tyre testing by means of advanced multiscale physics modelling





From FEM Insight to Real-Time Capability

Extracting Physical Mechanisms

High-fidelity simulations reveal key physical behaviors like hydrodynamic lift and tread-water interaction.

Experimental Validation

Controlled experiments validate and calibrate the models to ensure accuracy and robustness across conditions.

Reduced-Order Model Development

Validated physics are reformulated into simplified models optimized for stable real-time vehicle simulations.

Driving-in-the-Loop Integration

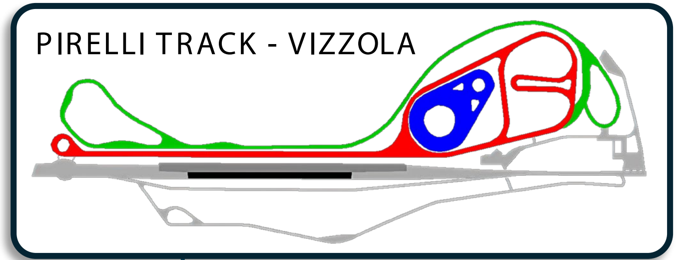
The tyre model is implemented within a VI-grade driving-in-the-loop environment to simulate realistic driving conditions.

REAL CASE STUDY: AQUAPLANING TESTS

TEST FACILITY & EQUIPMENT

Outdoor wet performance testing at Pirelli Vizzola proving ground.

Instrumented vehicle.

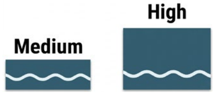


TESTING SCENARIOS

Two scenarios evaluated:

- Straight aquaplaning;
- Bend aquaplaning.

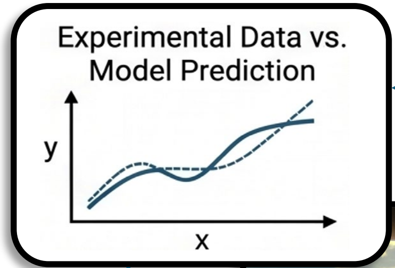
Two water film thickness values.



DATA & VALIDATION

Controlled and repeatable test conditions.

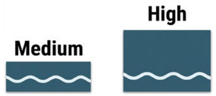
Experimental data used for model validation through driving simulator.



REAL CASE STUDY: AQUAPLANING TESTS

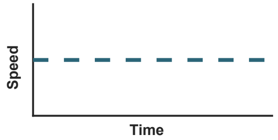
TEST METHODOLOGY – STRAIGHT AQUAPLANING

Water depth



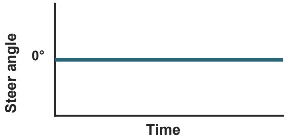
Fixed water depth

Entry speed



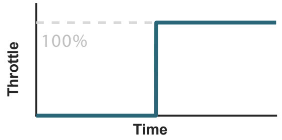
Same as outdoor

Steering

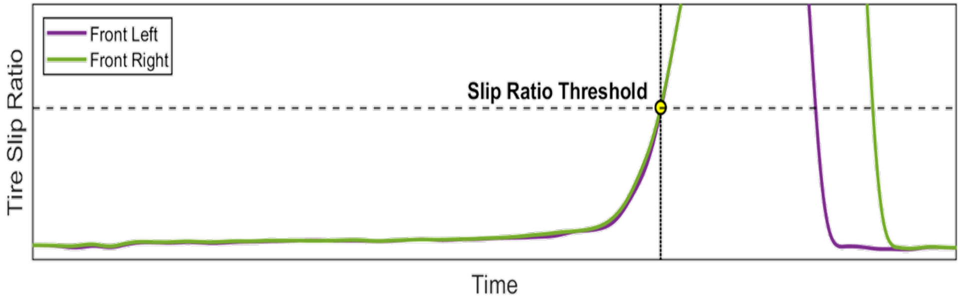


Fixed 0°

Throttle

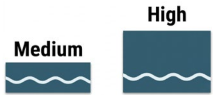


Step to full throttle inside basin



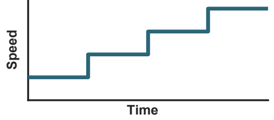
TEST METHODOLOGY– BEND AQUAPLANING

Water depth



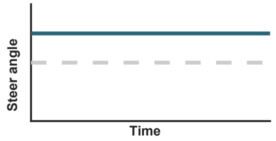
Fixed water depth

Speed



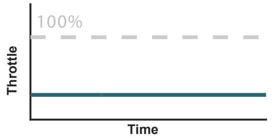
Progressive speed increase

Steering

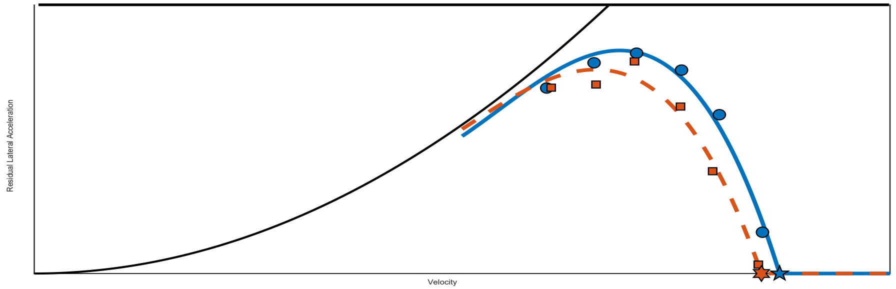


Constant steering input

Throttle



Constant throttle demand



WET TIRE-ROAD INTERACTION

WHY WATER CHANGES TIRE BEHAVIOR

THERMAL BEHAVIOR IMPACT

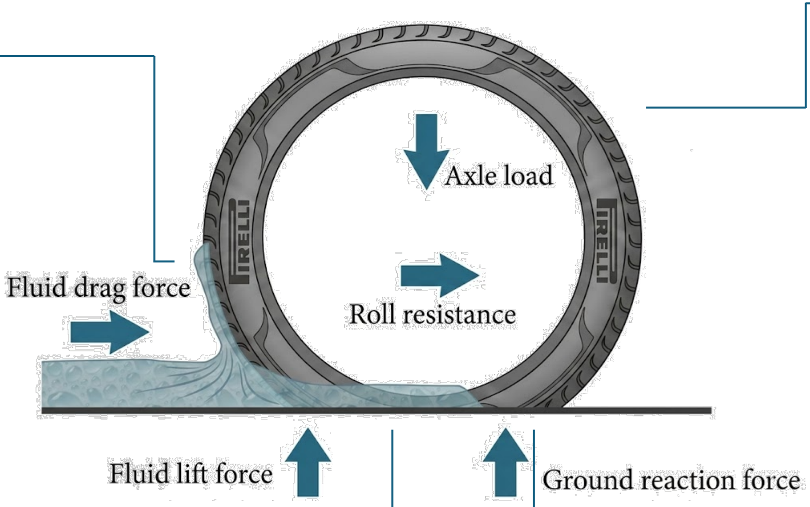
- enhanced heat removal
- tire works at lower temperature

LUBRICATION REGIME

- boundary lubrication
- elasto-hydrodynamic lubrication
- full hydroplaning

PHYSICAL CONTACT ALTERATION

- fills road cavities
- reduces effective roughness



Multi-physical phenomena

Temperature Balance:
- lower grip
- higher stiffness

Hydrodynamic Forces:
- lift and drag forces
- higher rolling moment

Path Clearing Effect:
- lower WFT for rear tires
- modified vehicle balance

Wet Contact:
- lower adhesion
- lower road roughness

WET TIRE-ROAD INTERACTION

FROM MULTI-PHYSICS TO MODELING STRATEGY

WET TIRE DYNAMICS: MULTI-PHYSICAL NATURE

Water presence introduces multiple interacting phenomena that influence tire behavior.

- HYDRODYNAMIC EFFECTS
- PATH CLEARING EFFECTS
- LOCAL CONTACT INTERACTION
- THERMAL EFFECTS

MODELING STRATEGY

THERMAL EFFECTS

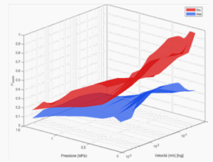
thermoRIDE

Thermal and wet effects decoupling using thermoRIDE

HYDRODYNAMICS

Physics based model of macro and path clearing effects

MICRO-CONTACT



Currently under research

OUTCOME

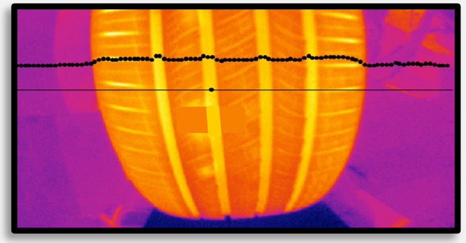
A physics-based and modular wet tire model for accurate vehicle behavior prediction

EXPERIMENTAL CHARACTERIZATION

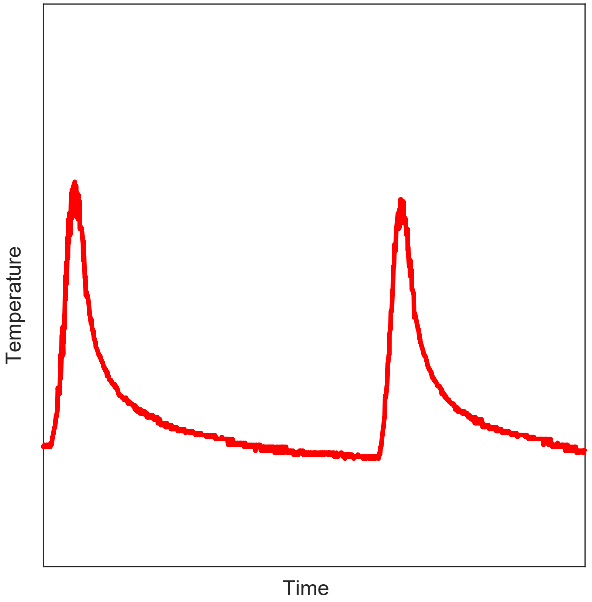
DRY BASELINE

TEST SETUP

Flat trac dry testing

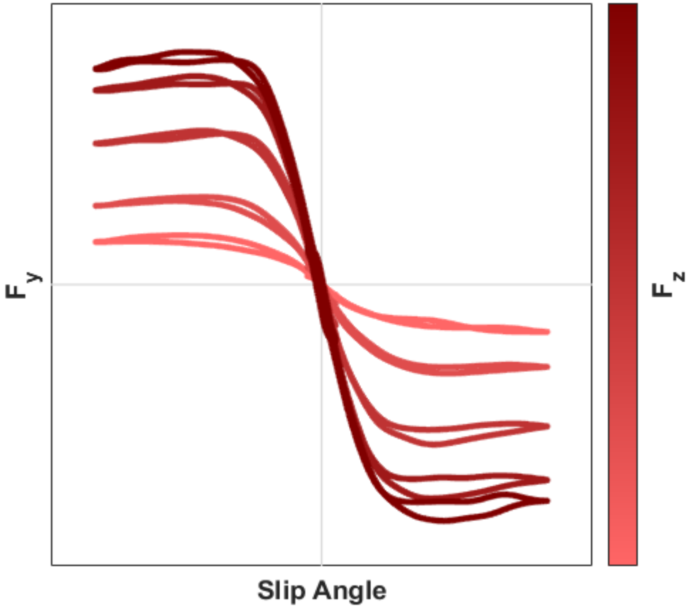


THERMAL RESPONSE



Complete thermal characterization in dry conditions

INTERACTION CURVES



Characterization of forces and load dependency in dry conditions

Dry testing provides the baseline needed to decouple thermal effects in wet conditions.

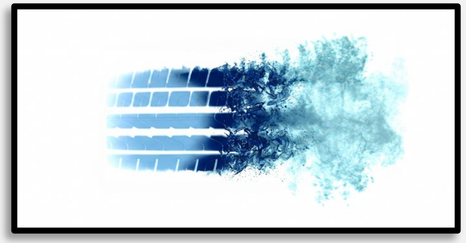
EXPERIMENTAL CHARACTERIZATION

WATER-INDUCED EFFECT IDENTIFICATION

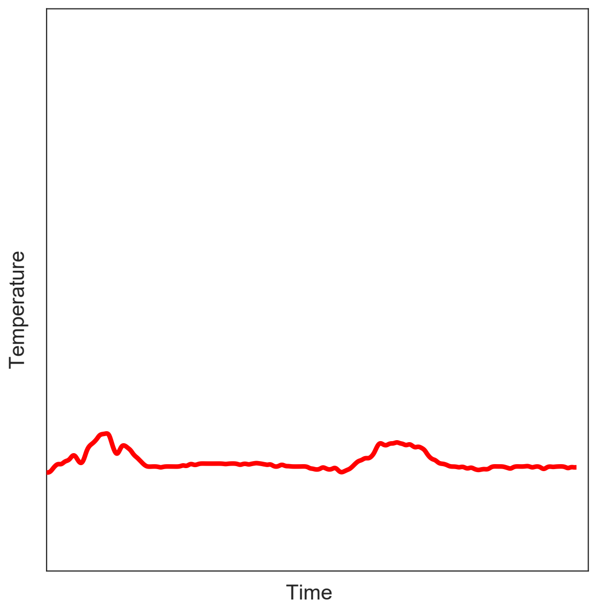
TEST SETUP

Flat trac wet testing:

- Controllable WFT
- Repeatable conditions

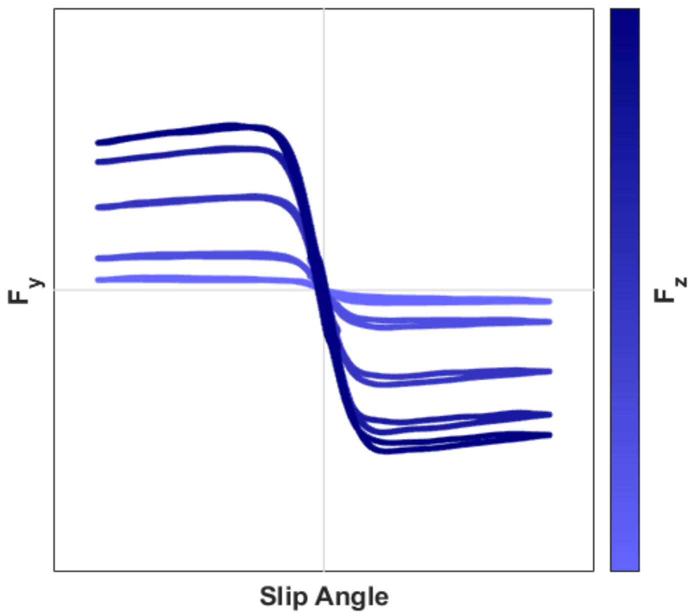


THERMAL RESPONSE



Complete thermal characterization in wet conditions

INTERACTION CURVES



Identification of forces and load dependency in wet conditions

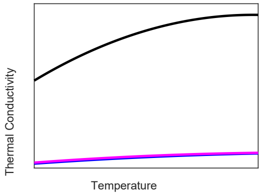
Wet testing enables identification of water-induced force reduction and thermal behavior.

THERMAL CHARACTERIZATION

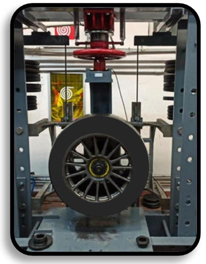
TIRE DIGITALIZATION

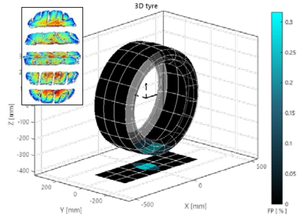
2025 ZERO PROTOTYPES SUMMIT | From activities presented at ZPS 2025

Thermal characterization



Structural characterization

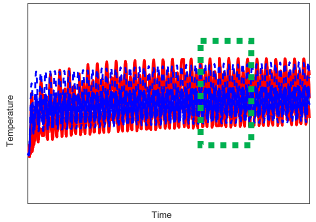




thermoRIDE

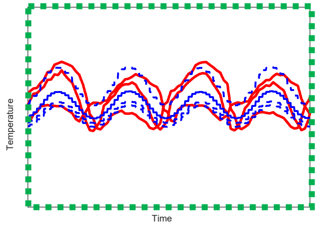
non-destructive thermal and structural properties characterization

MODEL - DRY CALIBRATION



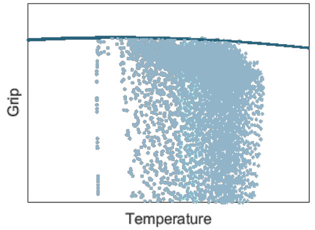
calibration towards flat trac dry data

thermoRIDE



inner layers temperature estimation, linked to tire dynamic behavior

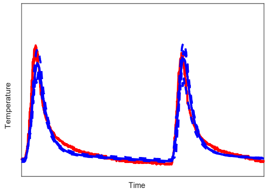
adheRIDE



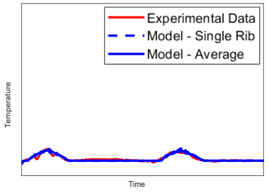
identification of grip and stiffness dependence on temperature and inflation pressure

MODEL - WET CALIBRATION

FLAT TRAC DRY DATA

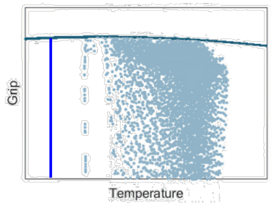


FLAT TRAC WET DATA

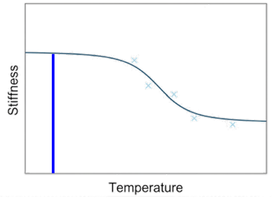


calibration refinement of thermal model towards flat trac wet data

GRIP



STIFFNESS



- low temperature on tire dynamics in wet conditions were estimated
- thermodynamic effect was separated from performance drop due to interaction with water

THERMAL EFFECTS

THERMAL SIMULATION

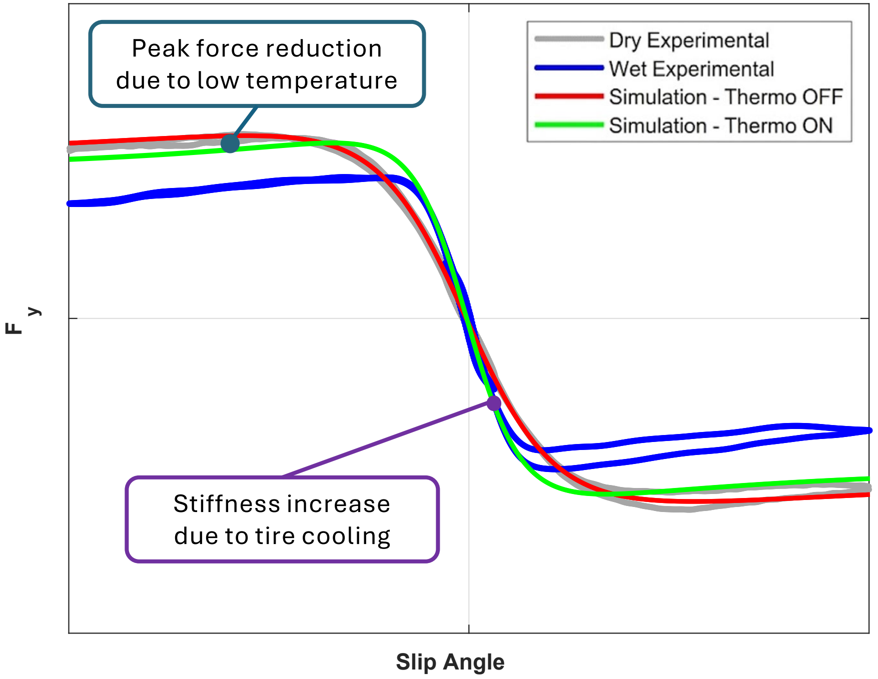
Same operating conditions as Flat-Trac tests

Fixed nominal F_z, water film thickness and speed

Grip & stiffness vs temperature curves identified

thermoRIDE adheRIDE

INTERACTION CURVES



KEY RESULTS

Thermal effects significantly increase stiffness

Improved agreement with experimental data

Remaining discrepancies linked to interaction with water

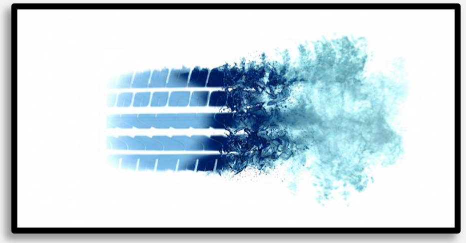
EXPERIMENTAL CHARACTERIZATION

WATER-INDUCED EFFECT IDENTIFICATION

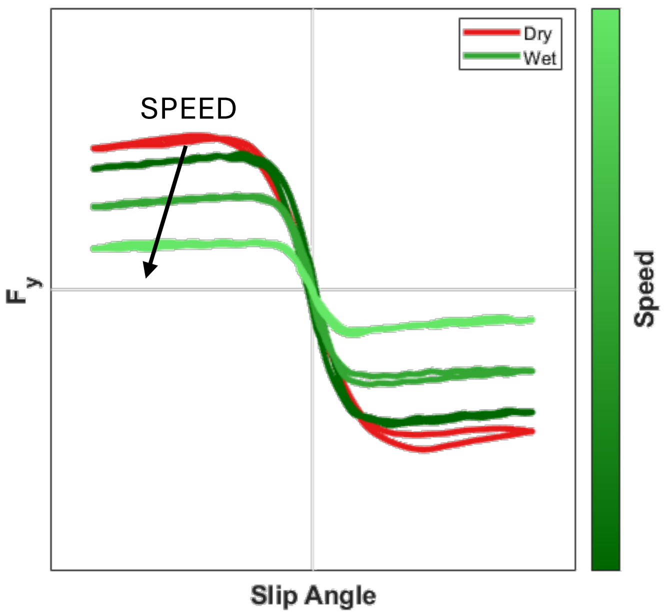
TEST SETUP

Flat trac wet testing:

- Controllable WFT
- Repeatable conditions

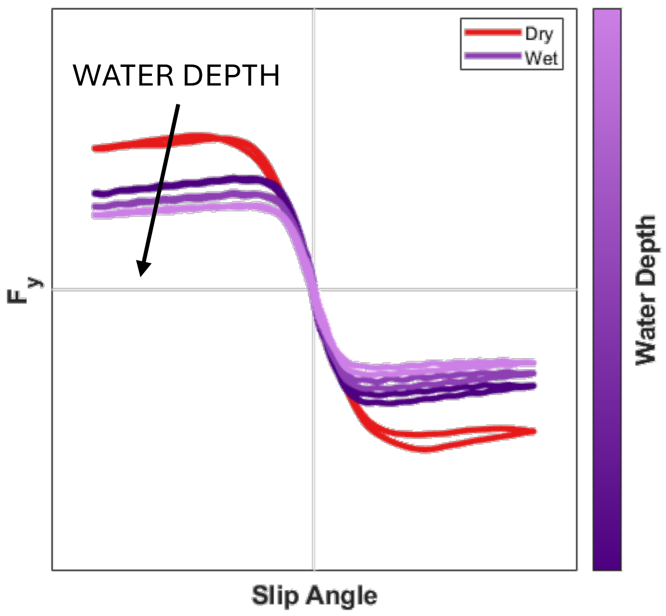


INTERACTION CURVES



Speed effect on interaction forces at fixed WFT and vertical load

INTERACTION CURVES



Water depth effect on interaction forces at fixed speed and vertical load

Water film thickness and speed drive the reduction of available tire forces in wet conditions.

WET TIRE-ROAD INTERACTION

MODELING OF WATER-INDUCED HYDRODYNAMICS

MODEL INPUTS

- Water film thickness
- Speed
- Vertical load
- Tire geometry

PHYSICS-BASED HYDRODYNAMIC MODEL

MODEL OUTPUTS

- Lift Force: vertical load reduction due to water.
- Drag Force: water resistance.
- Rolling Moment: asymmetric water distribution effect.

MODEL RESPONSE – HYDRODYNAMIC EFFECTS

SIMULATION CONDITIONS

Same operating conditions as Flat-Trac tests

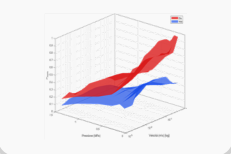
Fixed nominal F_z

Fixed water film thickness

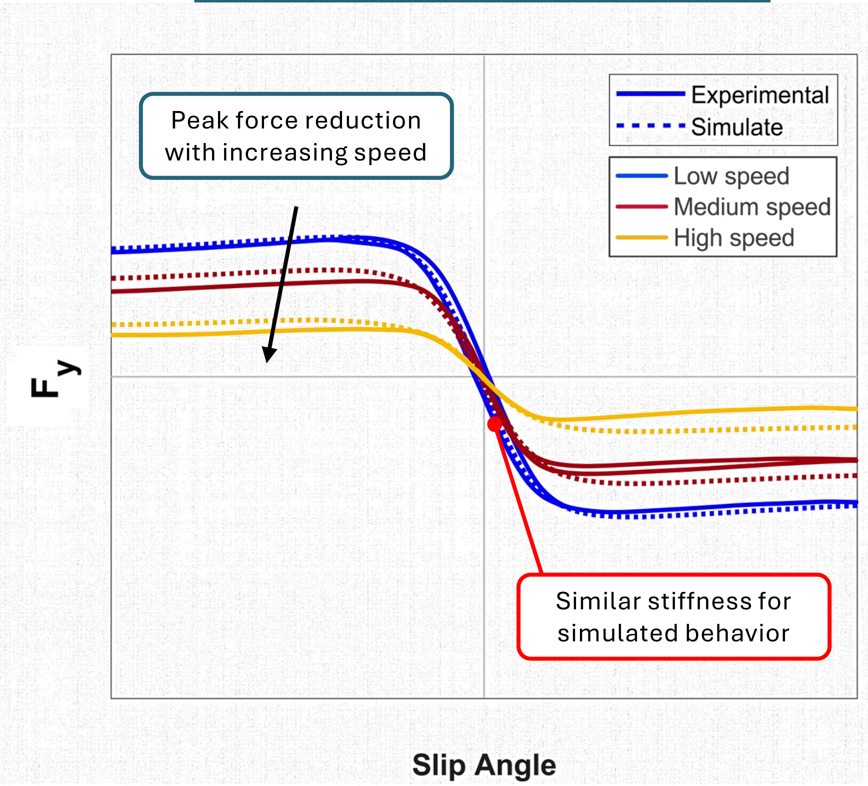
Increasing speed

HYDRODYNAMICS

MICRO-CONTACT



INTERACTION CURVES



KEY RESULTS

- Model captures the main trends of experimental data
- Grip loss is partially driven by hydrodynamic lift
- Simulated grip is higher than experimental → missing local effects

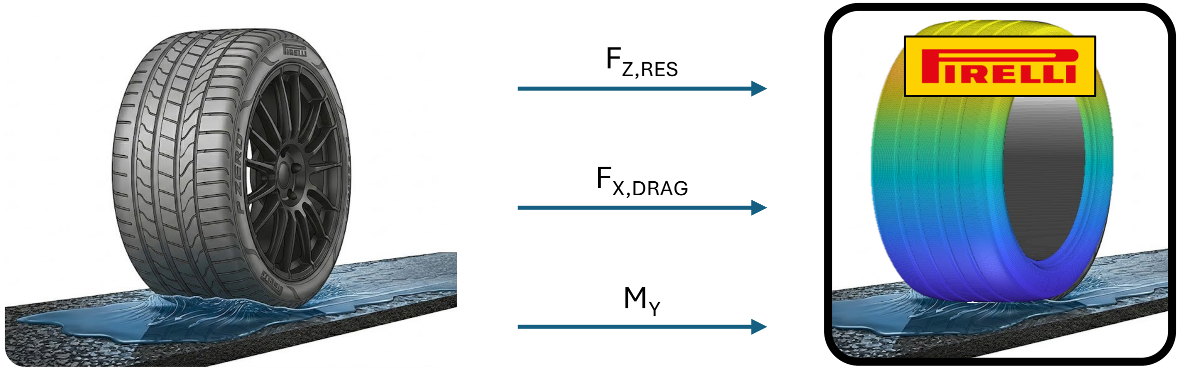
NEXT STEP

Include wet local contact effects on tire dynamics

FROM WET TIRE PHYSICS TO VEHICLE SIMULATION

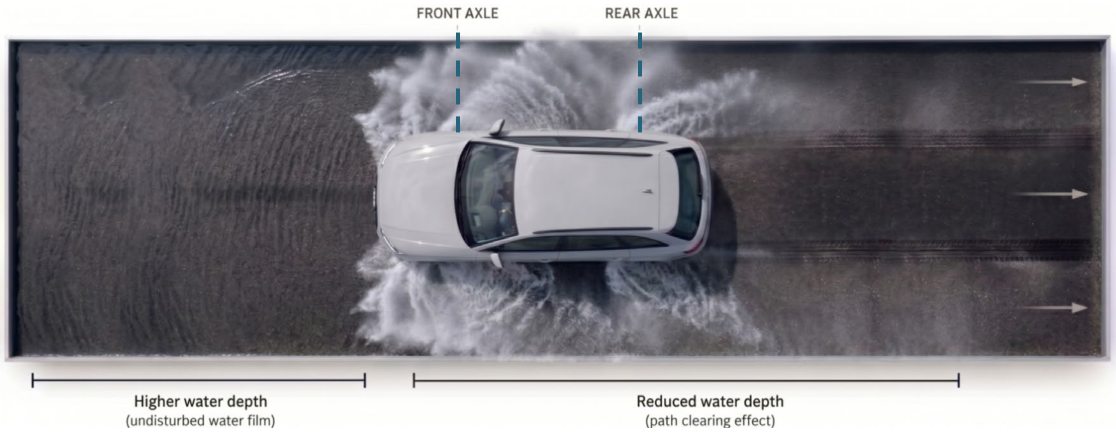
1 WET MODEL OUTPUTS

- Residual vertical load replaces nominal load in tire-road forces computation
- Hydrodynamic drag force is included in the longitudinal force balance
- Water-induced rolling moment contributes to rolling resistance



2 COUPLING WITH VEHICLE SIMULATION

- Model computes modified longitudinal and lateral forces based on water film thickness and vehicle speed.
- Path clearing effect reduces rear axle water depth depending on vehicle geometry, speed and motion



FROM WET TIRE PHYSICS TO VEHICLE SIMULATION

③ VEHICLE SIMULATION IN AQUAPLANING CONDITIONS

SCENARIOS REPRODUCED IN VI-CRT

- Straight aquaplaning
- Bend aquaplaning

Performed at medium and high water film thickness

VEHICLE & TIRE SETUP

- Same vehicle setup as outdoor tests
- Same tire set and inflation pressure
- Same maneuvers

MODEL VALIDATION

- ✔ Compare simulation with outdoor data
- ✔ Validate aquaplaning onset (straight & bend)
- ✔ Assess vehicle dynamics consistency in extreme wet
- ✔ Ensure simulator realism for DiL applications

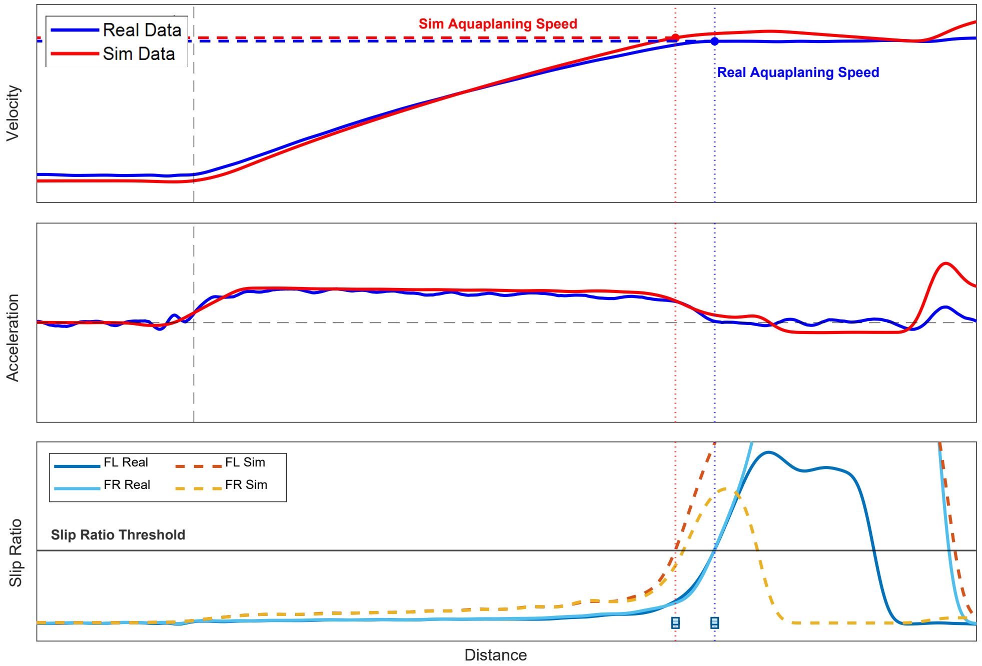
REFERENCE DATA: outdoor aquaplaning tests performed at Vizzola Pirelli proving ground with instrumented vehicle.

MODEL VALIDATION

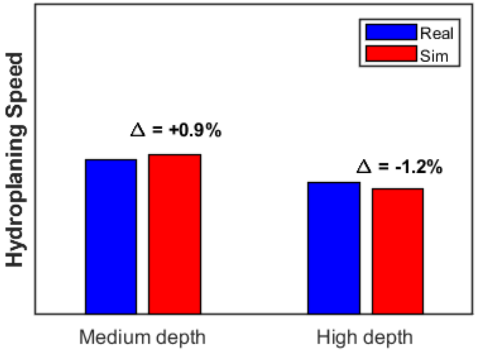
④ SIMULATION RESULTS – STRAIGHT AQUAPLANING

HIGH WATER DEPTH

- Accurate prediction of critical hydroplaning speed
- Consistent longitudinal acceleration drop and wheel slip evolution during full hydroplaning onset



Simulated Maneuver



Hydroplaning speed

Strong correlation between simulation and outdoor data at:

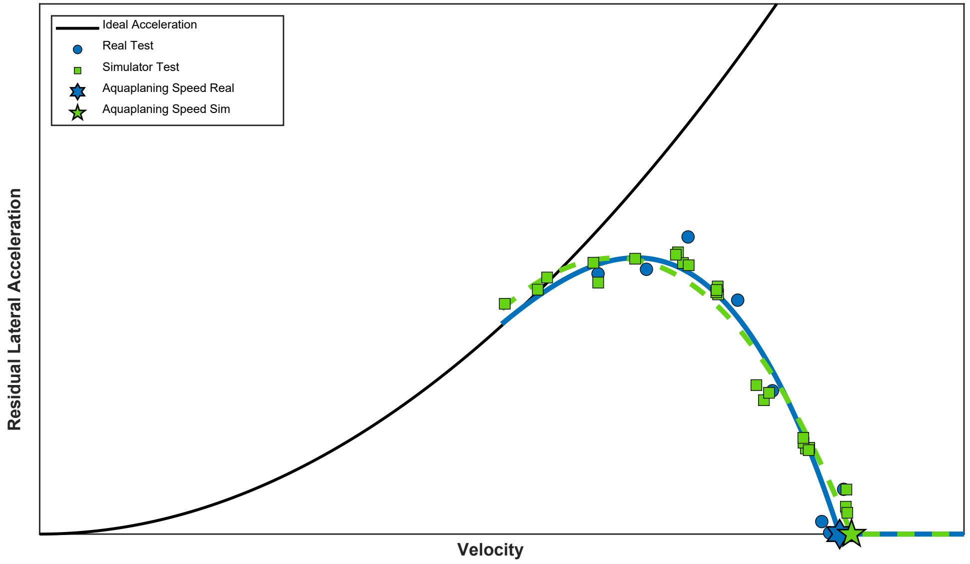
- Medium water depth
- High water depth

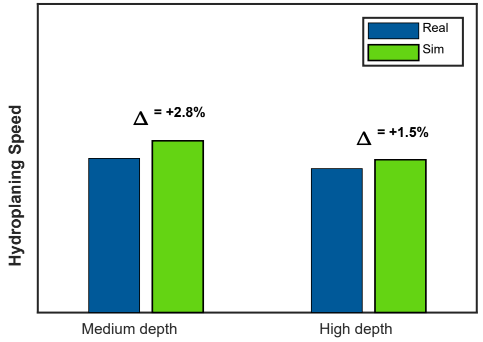
MODEL VALIDATION

⑤ SIMULATION RESULTS – BEND AQUAPLANING

HIGH WATER DEPTH

- Robust prediction of hydroplaning threshold maintained under severe wet bending conditions
- Residual lateral acceleration trend confirms realistic lateral force degradation





Hydroplaning speed

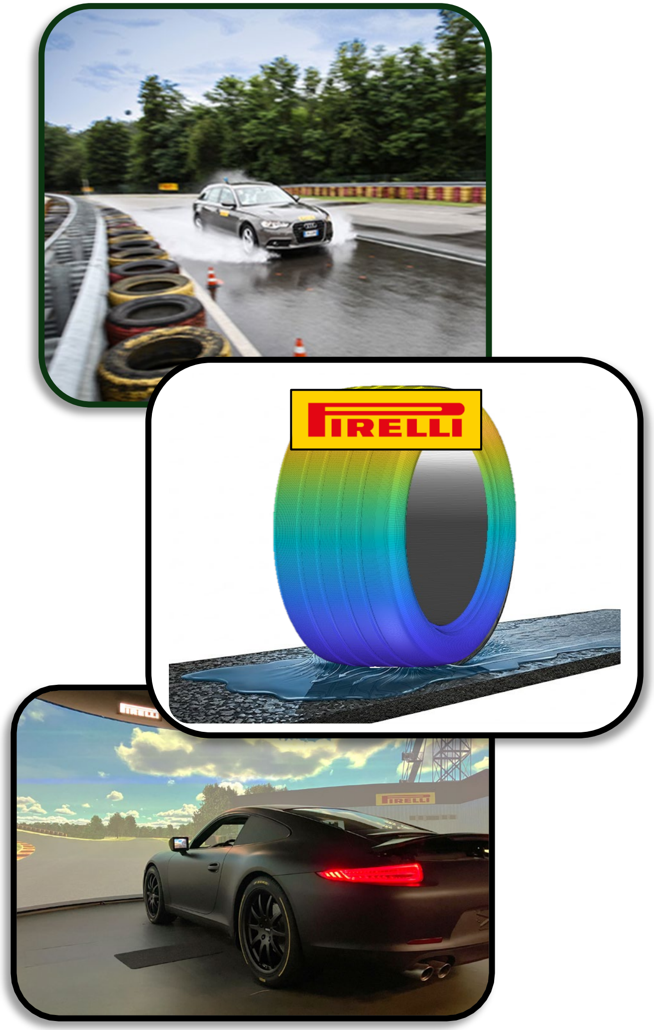
Strong correlation between simulation and outdoor data at:

- Medium water depth
- High water depth

CONCLUSIONS AND FUTURE DEVELOPMENTS

In the present work:

- A physics-based wet tire module was developed and integrated into Pirelli Tyre Model framework introducing hydrodynamic lift, drag and water-induced rolling moment into the tire-road interaction framework;
- The model was integrated at the driving simulator including path clearing effects (rear axle) to reproduce aquaplaning conditions;
- Validation against straight and bend aquaplaning tests at Vizzola showed strong correlation with outdoor vehicle behavior, confirming realistic wet dynamics reproduction.



Future developments during the PhD research activity:

- Extend the framework toward a hybrid predictive wet model, combining global hydrodynamics with local wet-contact effects to improve robustness, transferability and real-time applicability.

THANK YOU

Marco Sbrosi, PhD
R&D – Head of Tyre Modelling & Driving Simulator

Pirelli Tyre S.p.A.
Viale Piero e Alberto Pirelli, 25 - 20126 Milano (MI)
marco.sbrosi@pirelli.com
www.pirelli.com

MEGARIDE APPLIED VEHICLE RESEARCH
Università degli Studi di Napoli Federico II

Matteo Romano
PhD Candidate

University of Naples Federico II - MegaRide
Via Claudio, 21 - 80125 Napoli (NA)
matteo.romano@unina.it
info@megaride.eu