Research partnership
in technology innovation

Title

Tire wear affecting motorcycle dynamic

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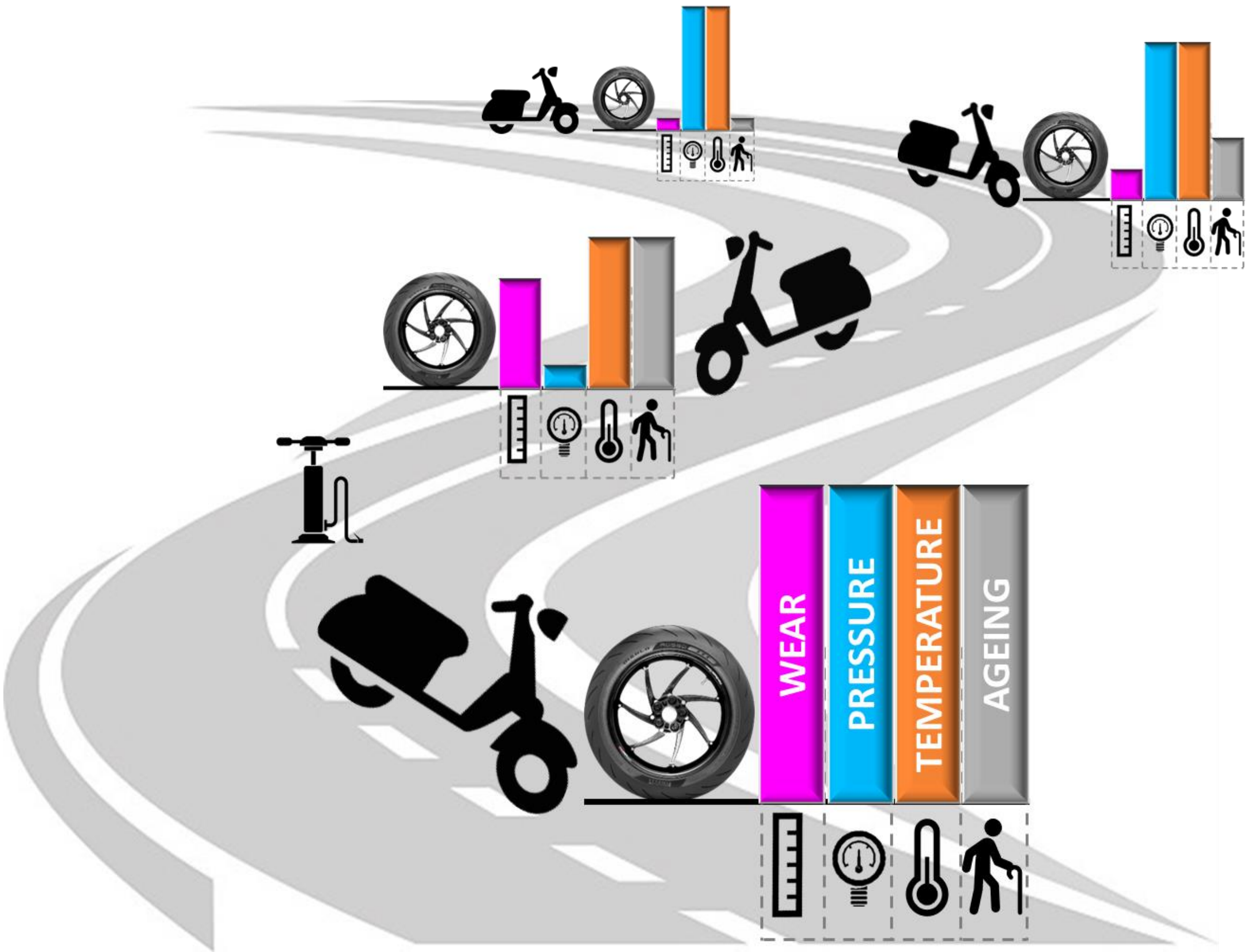
APPLY & INNOVATE TECH WEEKS
Starting Sept. 2020

TIRE OPERATIVE CONDITIONS CHANGE WHILE RIDING



DIFFERENT OPERATIVE CONDITIONS MEANS:

↓

DIFFERENT TIRE BEHAVIOUR

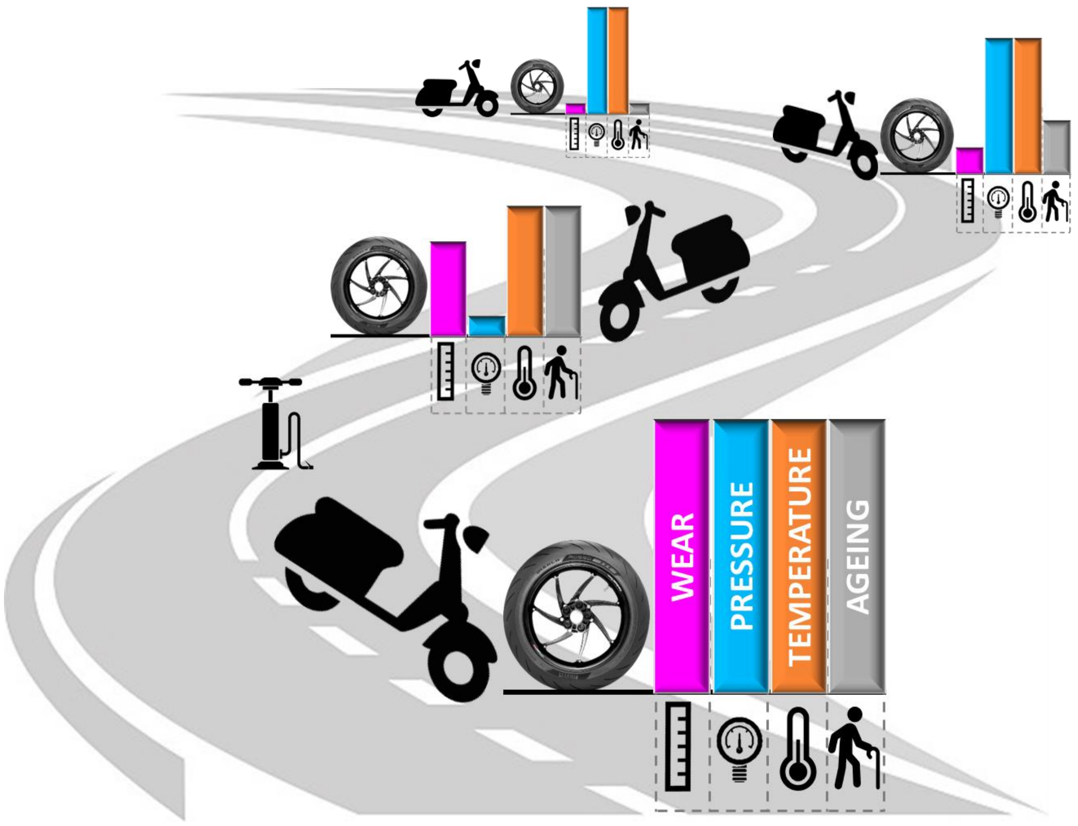
↓

DIFFERENT MOTORCYCLE BEHAVIOUR

Stability

Longitudinal Performance

Handling



MOTORCYCLE BEHAVIOUR SHOULD BE VERIFIED FOR ALL THE PLAUSIBLE TIRE'S OPERATIVE CONDITIONS

WEAR

TARGET

TO INVESTIGATE THE EFFECTS OF TIRE WEAR ON BOTH THE LATERAL AND THE LONGITUDINAL MOTORCYCLE DYNAMIC

↓

TO PROPOSE A PACEJKA MF MODIFICATION INCLUDING THE WEAR DEPENDENCY

OUTLINE

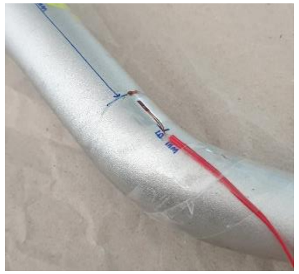
1. INSTRUMENTATION (OUTDOOR TESTS)
2. LONGITUDINAL: OUTDOOR TESTS
3. LONGITUDINAL: INDOOR TESTS
4. LONGITUDINAL: MAGIC FORMULAE MODIFICATION
5. LATERAL: OUTDOOR TESTS
6. LATERAL: SENSITIVITY ANLYSIS THROUGH NUMERICAL SIMULATION
7. CONCLUSIONS

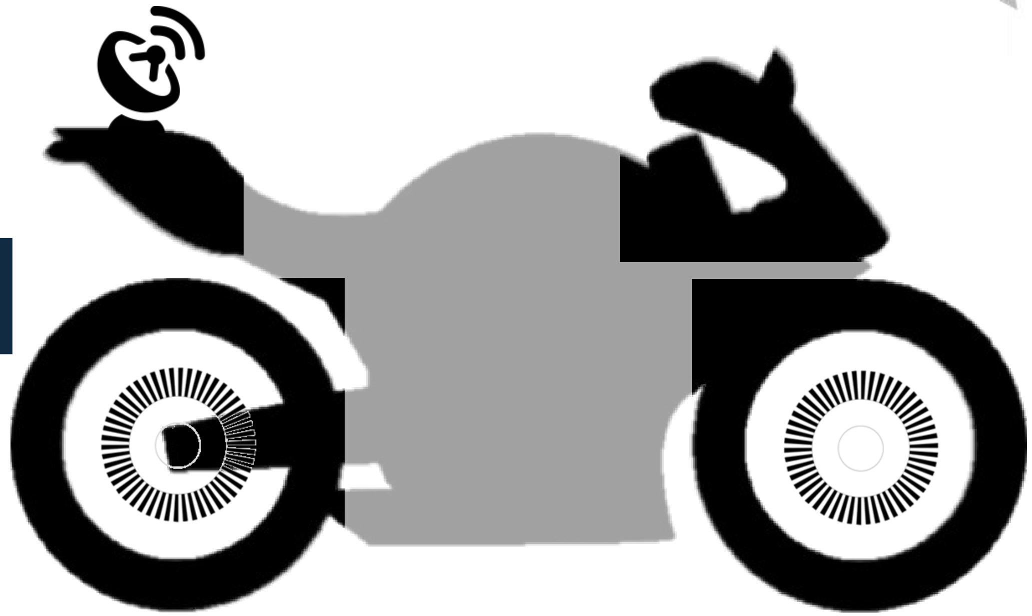
OUTDOOR TESTS

Instrumentation

1 High performance GPS → vehicle speed, longitudinal/lateral acceleration

4 Strain gauges → steerig torque (lateral dynamic)





2 Rear tire encoder → angulare speed

3 Front tire encoder → angular speed

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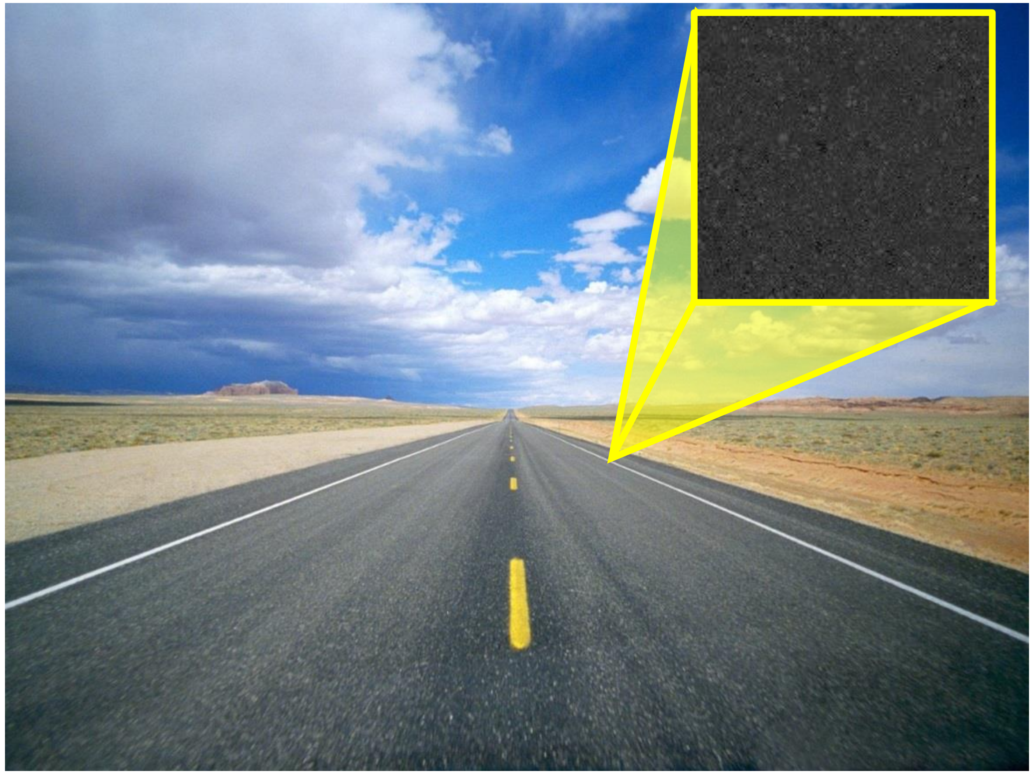
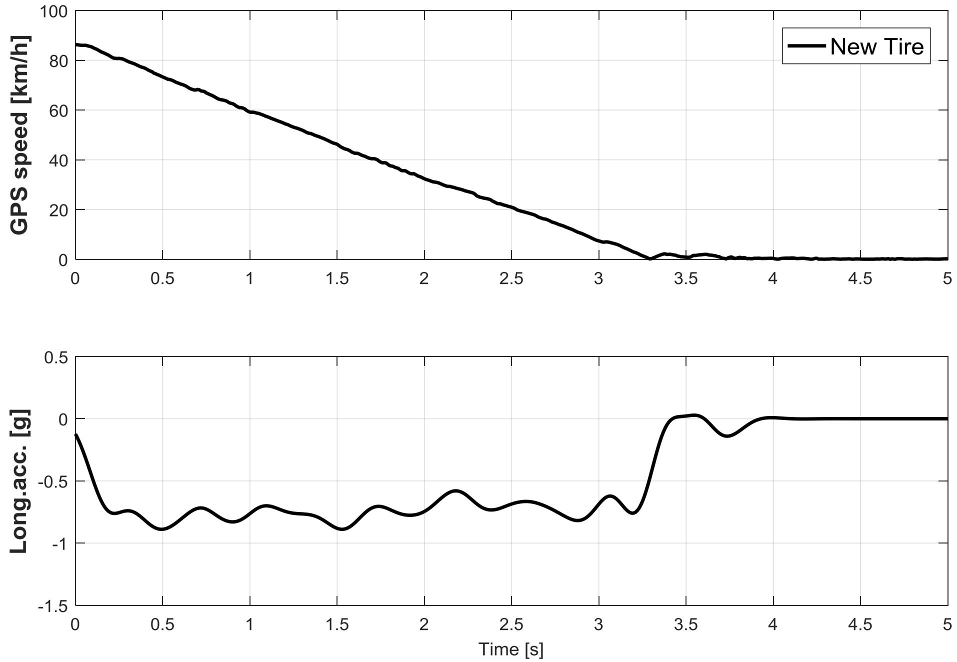
7. CONCLUSIONS

LONG. DYN.: OUTDOOR TEST

Test Scenario&manoeuver

ROAD	MANOEUVER
Straight line road High grip surface (dry tarmac)	FULL BRAKING MANOEUVER. • ABS system status: active • Vehicle speed before braking: constant@85 km/h • 15x test repetitions, at least





LONG. DYN.: OUTDOOR TEST

Test Scenario&manoeuver

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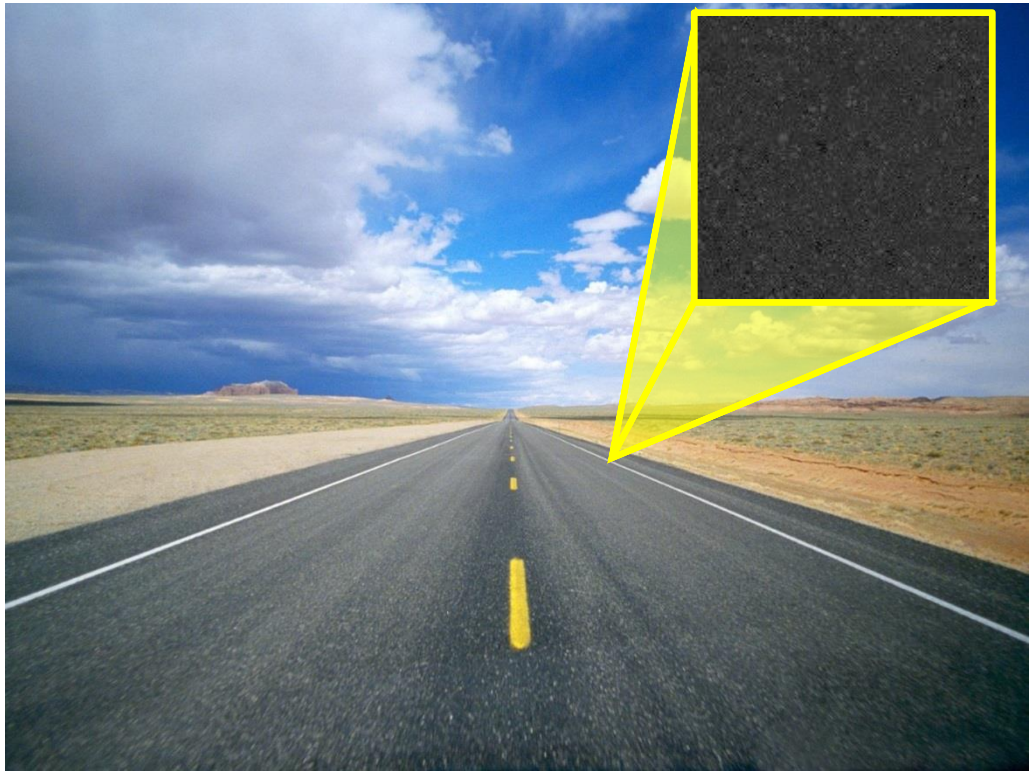

FULL BRAKING MANOEUVER.

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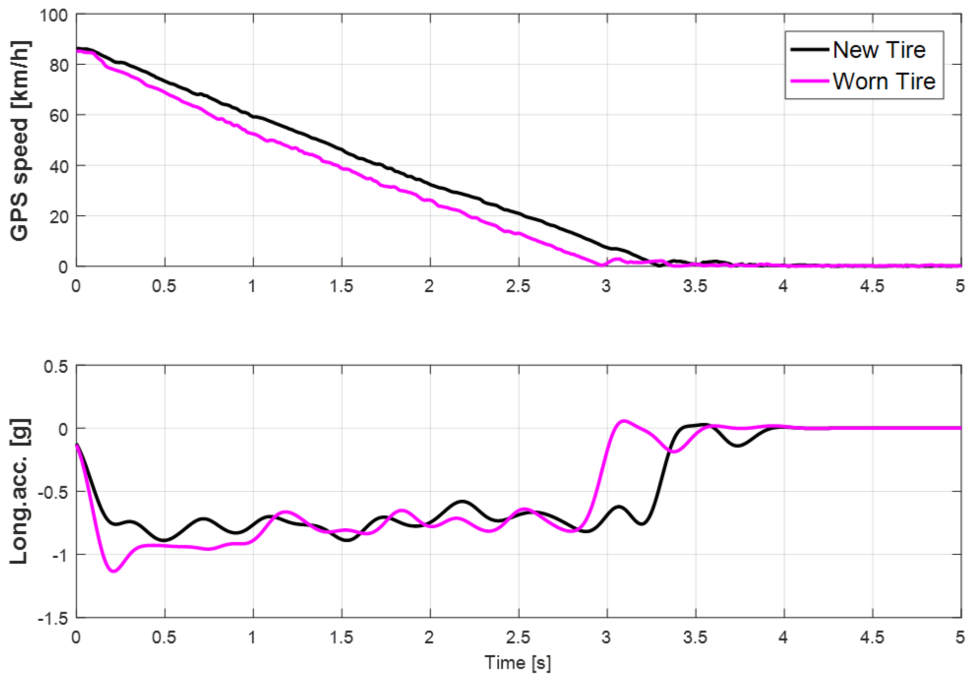
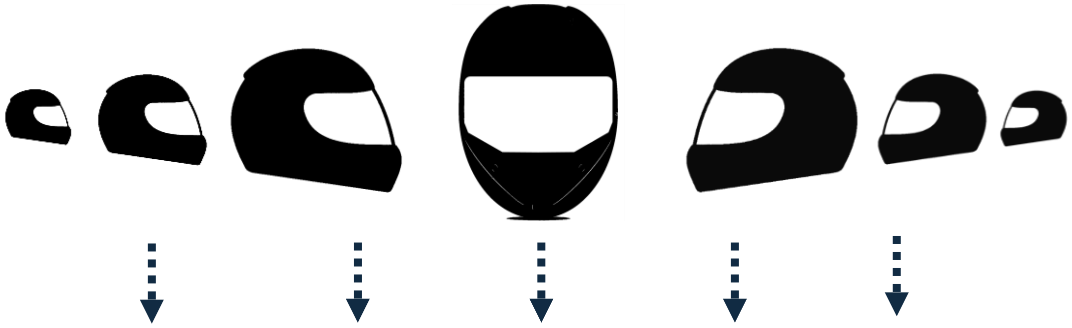


In case of worn tire:

- ❑ lower time to halt (lower braking distance);
- ❑ higher avarage deceleration.

DIFFERENT TIRES MODELS HAVE BEEN TESTED; THE TREND HAS BEEN CONFIRMED

WORN TIRES PERFORM HIGHER BRAKING DECELERATION



RIDERS PERCEPTIONS CONFIRM EXPERIMENTAL EVIDENCE

Why

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7. CONCLUSIONS

Target

To better understand the effects of tire wear on longitudinal dynamic:

NEW TIRE

30% WORN TIRE

70% WORN TIRE

MTS Flat-Trac® III

- ❑ LONGITUDINAL STIFFNESS K_x $(\%wear)$
- ❑ MAXIMUM FRICTION $\mu_{max,x}(\%wear)$

QUASI-STATIC CHARACTERIZATION

- ❑ RELAXATION LENGTH $\sigma_x(\%wear)$

DYNAMIC CHARACTERIZATION

Target

To better comprehend the effects of tire wear on longitudinal dynamic:

MTS Flat-Trac® III

- ❑ **LONGITUDINAL STIFFNESS** $K_x\ (\%wear)$
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QUASI-STATIC CHARACTERIZATION

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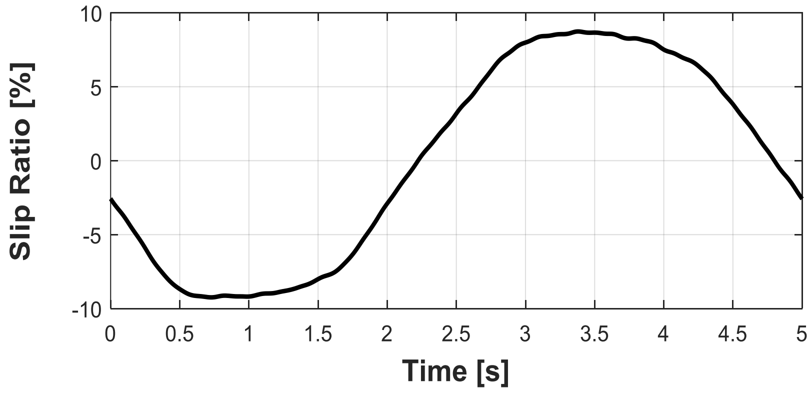
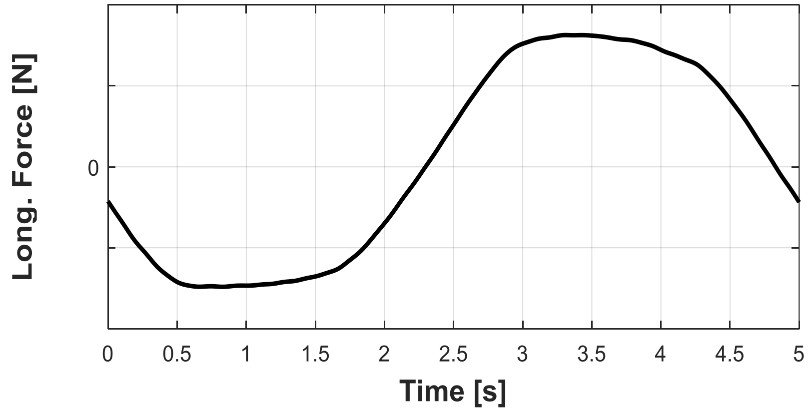
DYNAMIC CHARACTERIZATION

QUASI-STATIC CHARACTERIZATION. PROCEDURE.

- ❑ IMPOSED SLIP RATIO SINUSOIDAL PROFILE WITH A PERIOD OF 5 s (0,2 Hz)
- ❑ MEASURED LONGITUDINAL FORCE





QUASI-STATIC CHARACTERIZATION. PROCEDURE.

- IMPOSED SLIP RATIO SINUSOIDAL PROFILE WITH A PERIOD OF 5 s (0,2 Hz)
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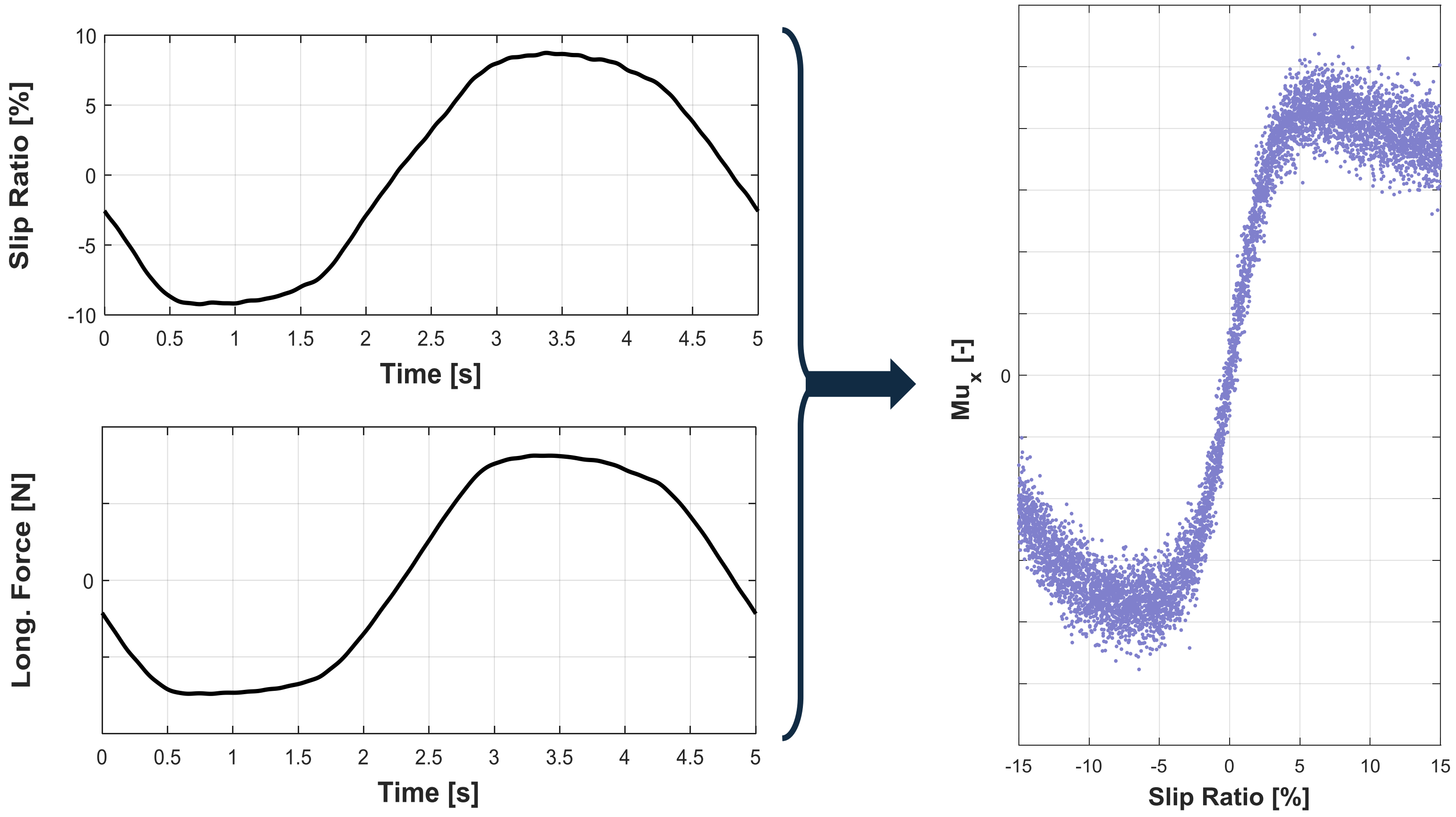
- THE ENGAGED FRICTION COEFFICIENT Mu_X IS COMPUTED AND PLOT VS SLIP RATIO→ A SCATTER PLOT IS ACHIEVED



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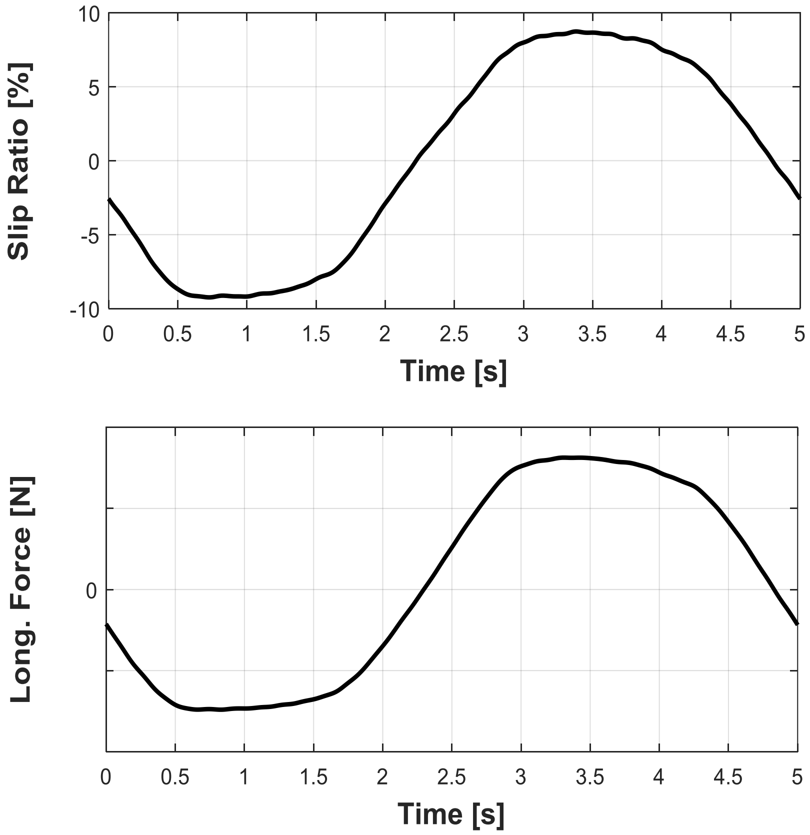
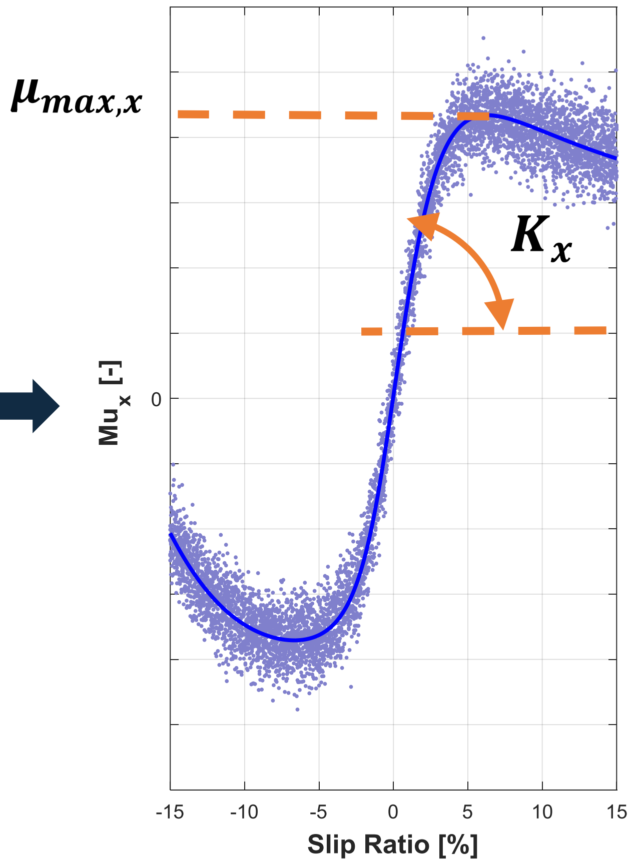
- MEASURED LONGITUDINAL FORCE
- THE ENGAGED FRICTION COEFFICIENT Mu_X IS COMPUTED AND PLOT VS SLIP RATIO→ A SCATTER PLOT IS ACHIEVED
- DATA FITTING THROUGH PACEJKA MAGIC FORMULA: THE LONGITUDINAL STIFFNESS (Kx) AND THE MAXIMM GRIP ($\mu_{max,x}$) CAN BE IDENTIFIED



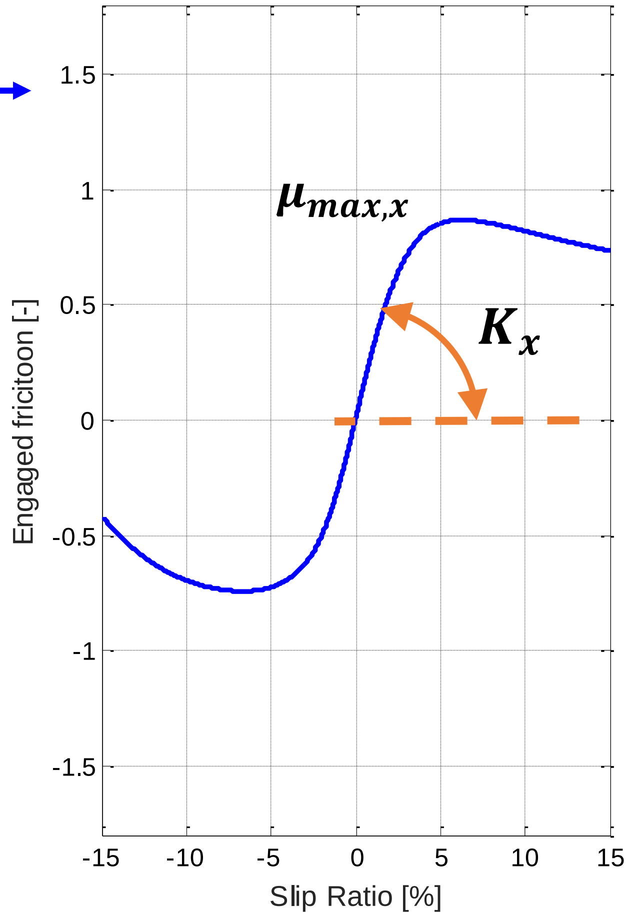


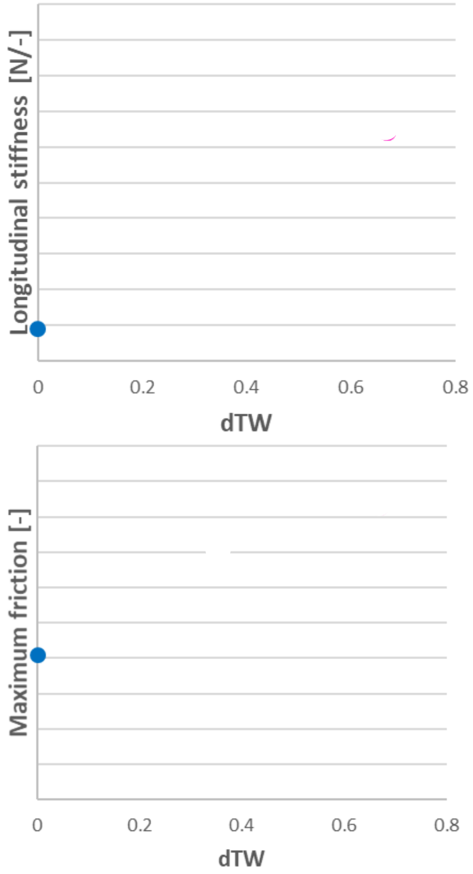
QUASI-STATIC CHARACTERIZATION. NEW and WORN TYRE BEHAVIOUR.

DATA HAVE BEEN PLOT AS A FUNCTION OF THREAD WEAR VARIATION, NAMED dTW:

$$dTW = -(h-h0)/h0$$

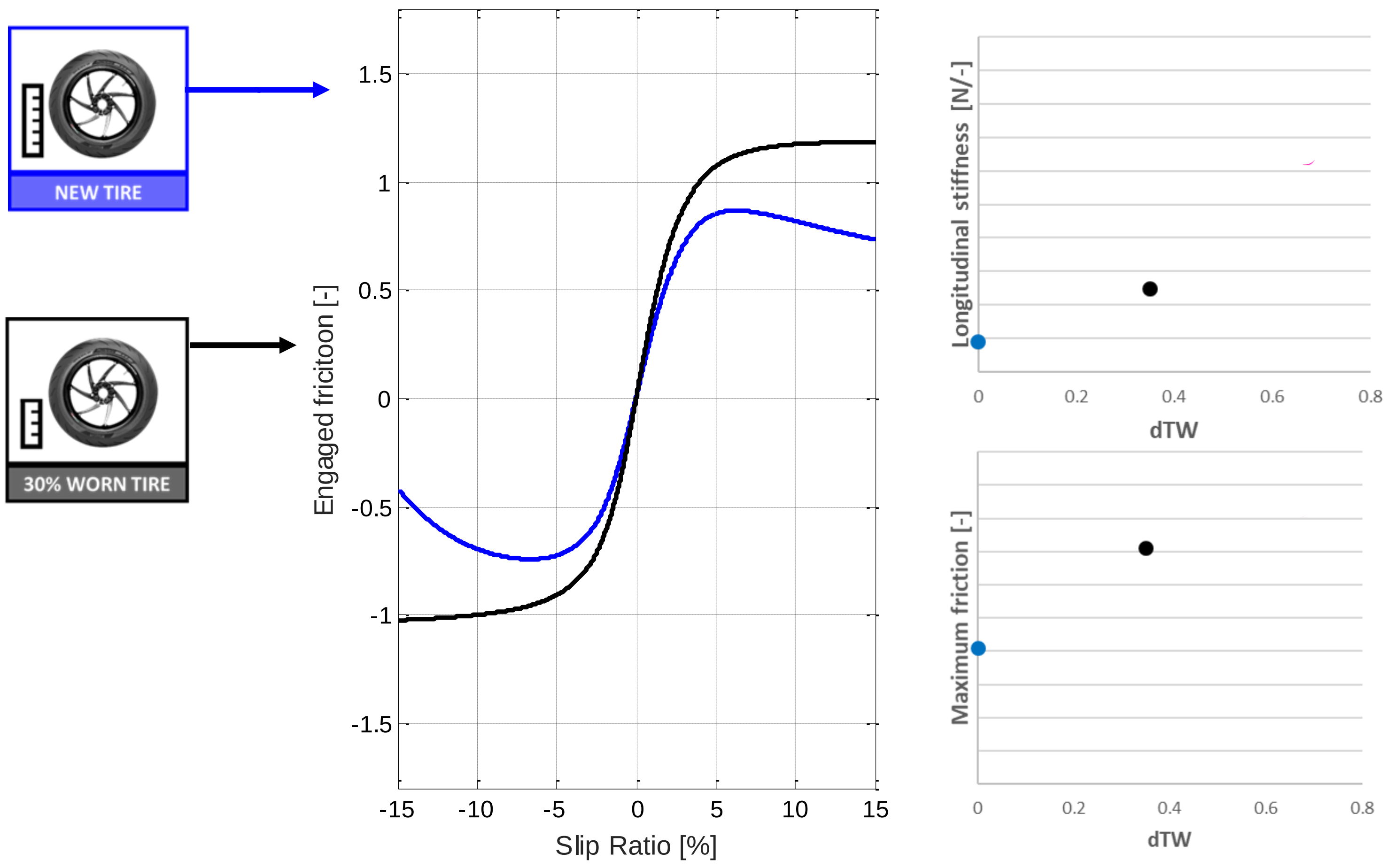
h0: thread height while new tire
h: thread height at a generic wearing condition





QUASI-STATIC CHARACTERIZATION. NEW and WORN TYRE BEHAVIOUR.

REPETITION OF PREVIOUS CHARACTERIZATION FOR SEVERAL WEAR LEVEL



LONG. DYN.: INDOOR TEST

Longitudinal stiffness & Maximum friction

QUASI-STATIC CHARACTERIZATION. NEW and WORN TYRE BEHAVIOUR.

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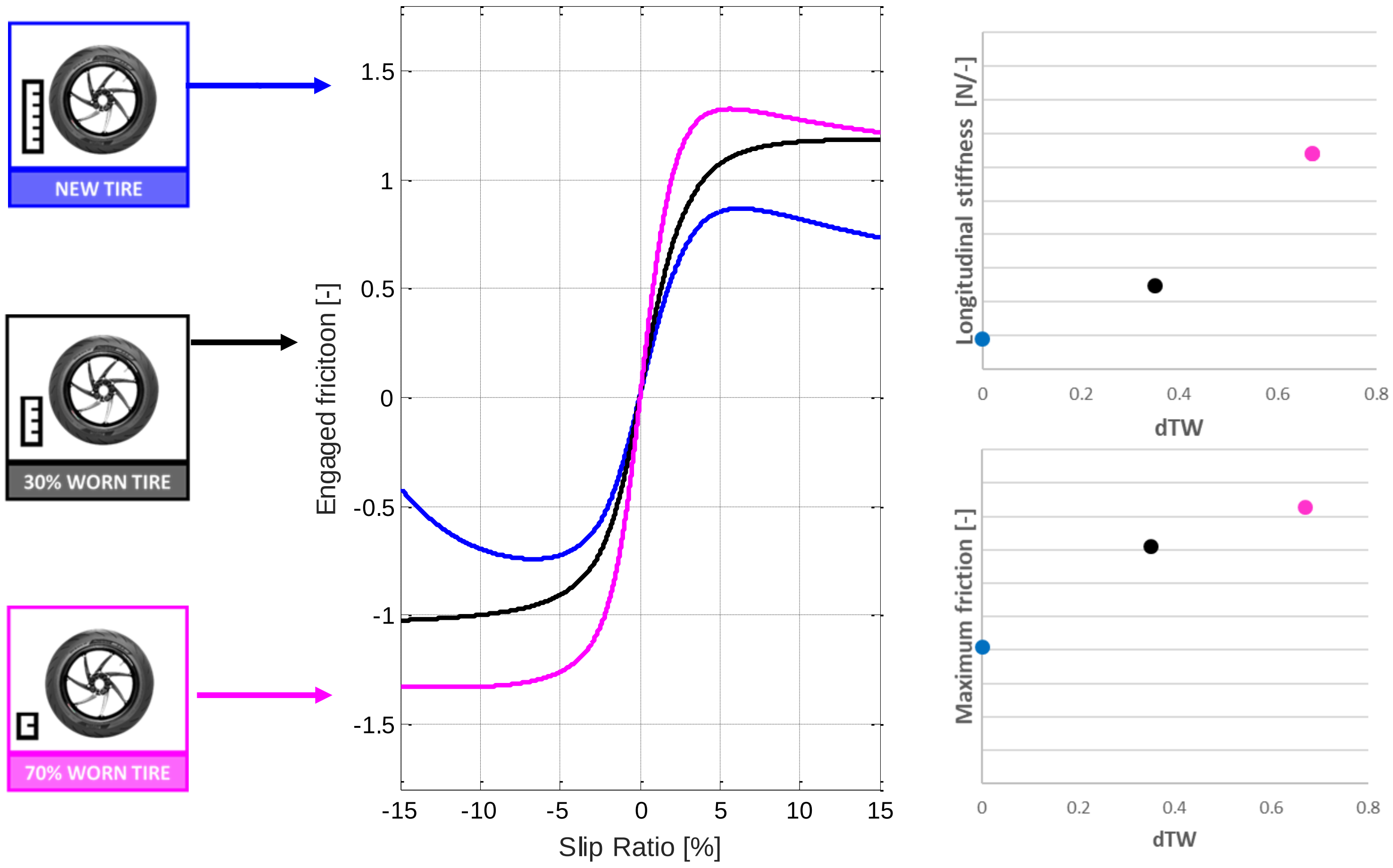
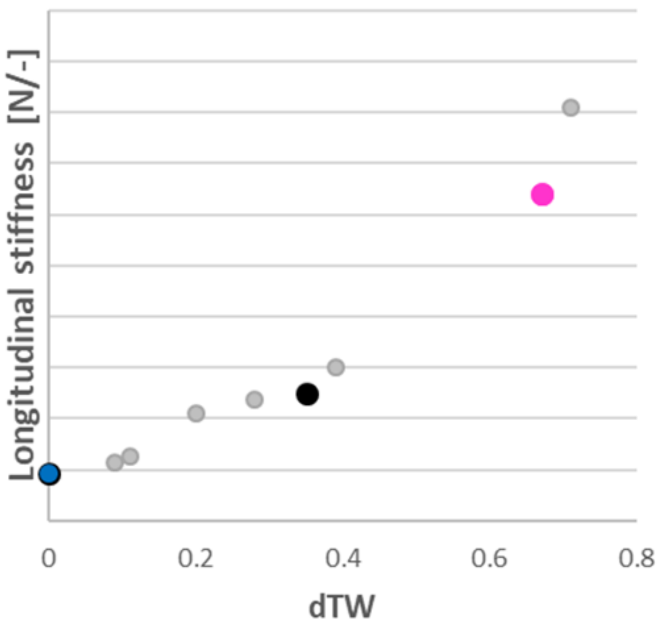


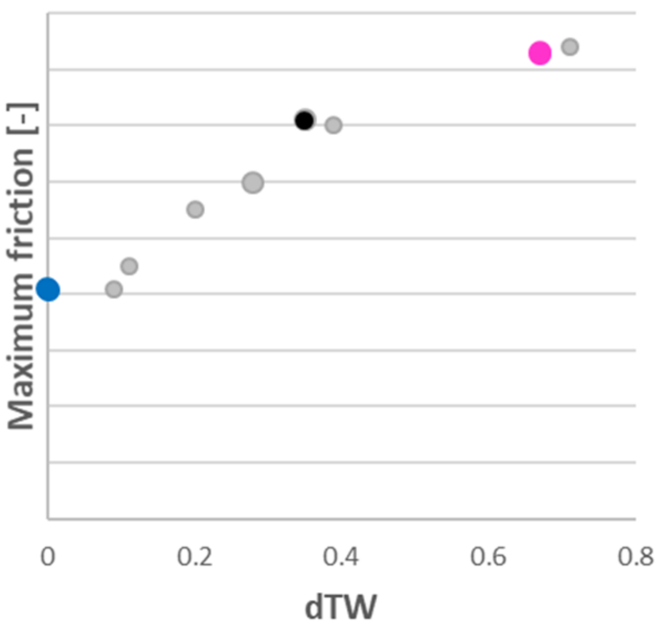
LONG. DYN.: INDOOR TEST

Longitudinal stiffness & Maximum friction

QUASI-STATIC CHARACTERIZATION. NEW and WORN TYRE BEHAVIOUR.

BOTH THE LONGITUDINAL STIFFNESS AND THE MAXIMUM FRICTION COEFFICIENT INCREASE AS THE TIRE WEAR INCREASES





dTW = - (h-h0)/h0

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QUASI-STATIC CHARACTERIZATION

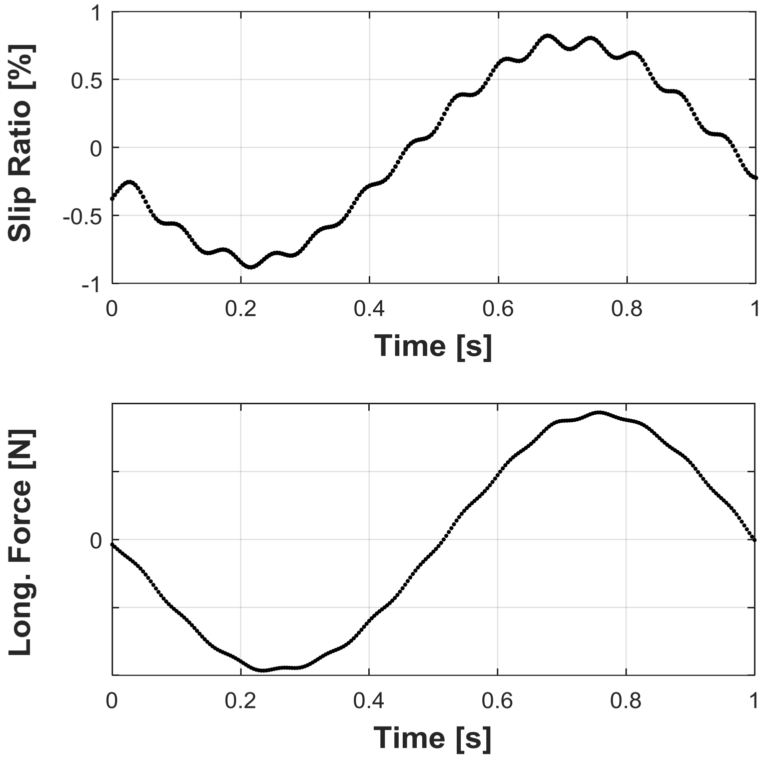
❑ **RELAXATION LENGTH**
$\boldsymbol{\sigma_x(\%wear)}$

DYNAMIC CHARACTERIZATION

DYNAMIC MTS CHARACTERIZATION

RELAXATION LENGHT MEASUREMENT

- ❑IMPOSED SLIP RATIO SINUSOIDAL PROFILE WITH A PERIOD OF 1s (1 Hz)
- ❑GENERATED LONGITUDINAL FORCE SAMPLED AT 250 Hz



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- ❑IMPOSED SLIP RATIO SINUSOIDAL PROFILE WITH A PERIOD OF 1s (1 Hz)
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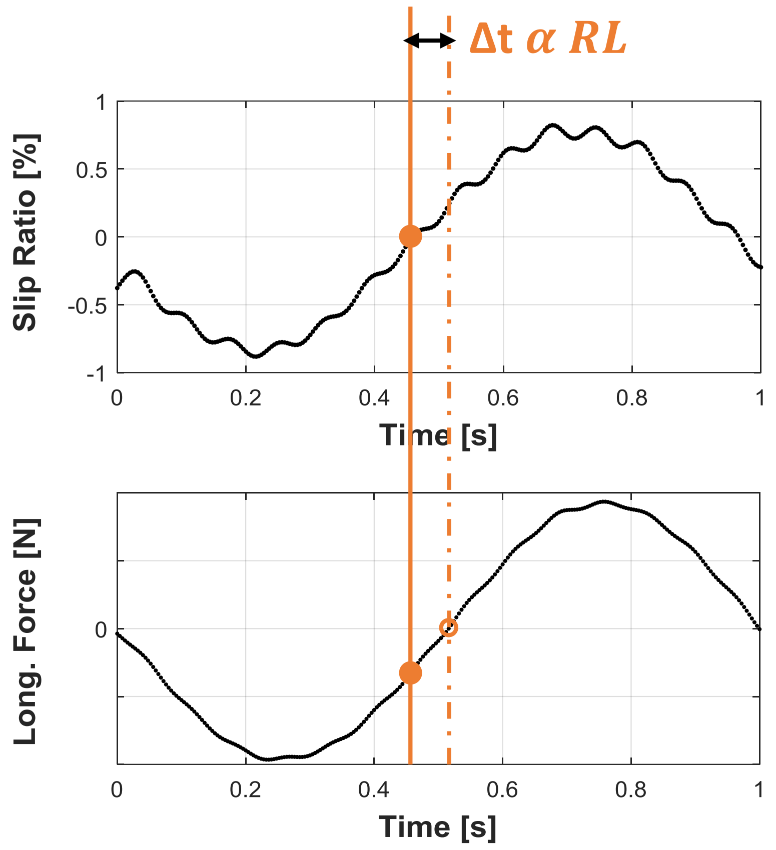
- ❑TIME DELAY BETWEEN SLIP RATIO (INPUT) AND FORCE (OUTPUT) IS MEASURED



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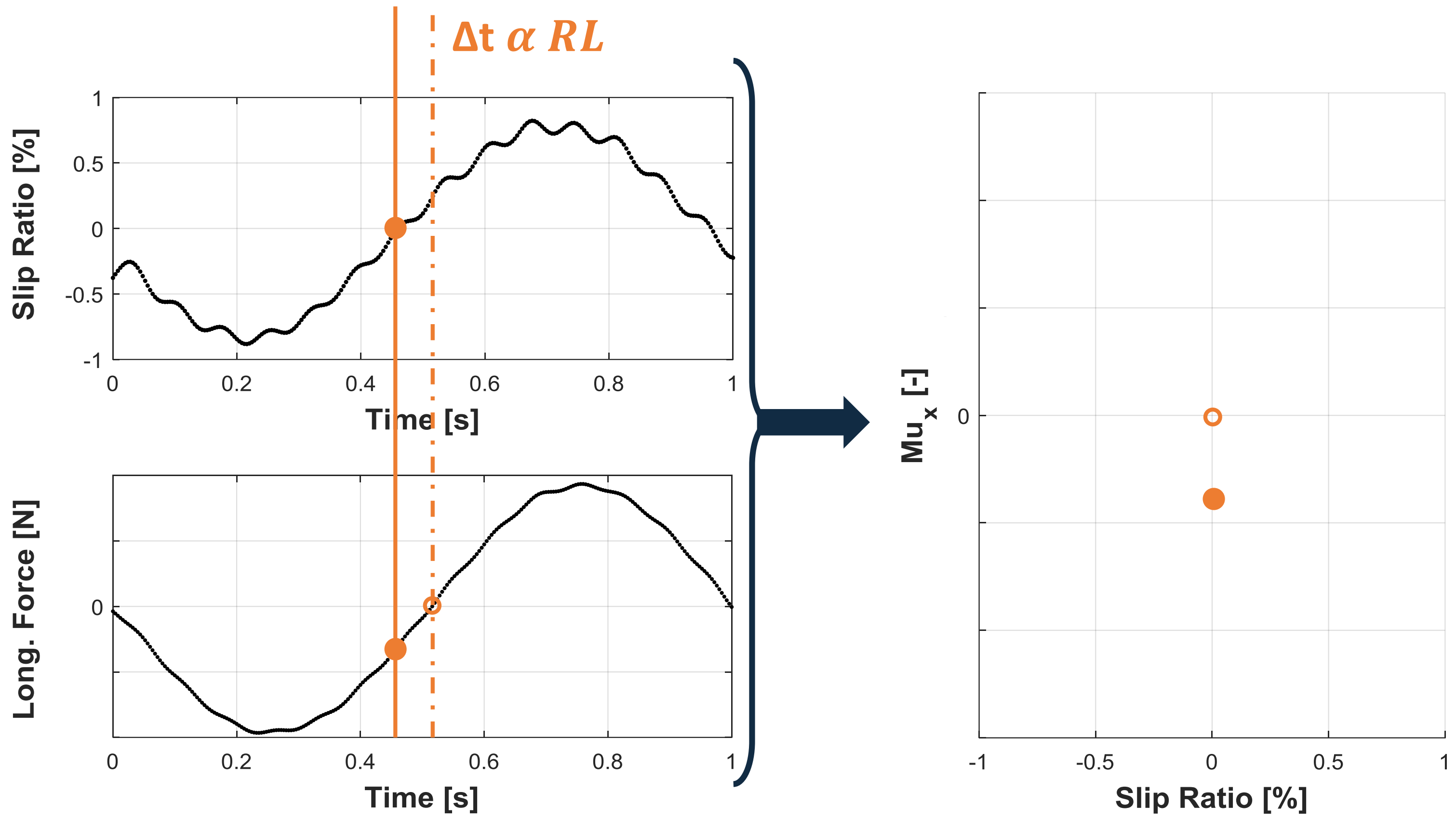

DYNAMIC MTS CHARACTERIZATION

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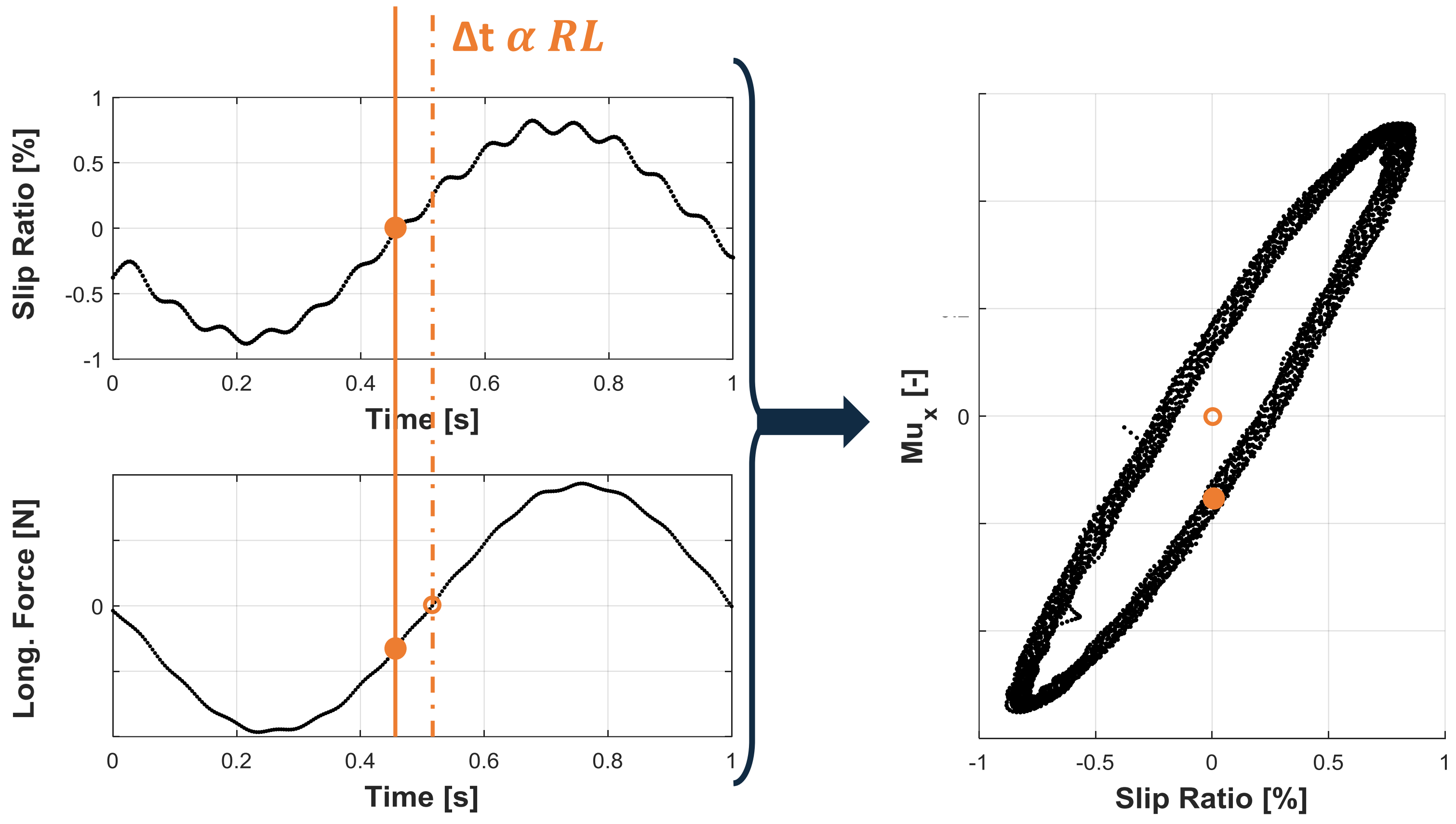
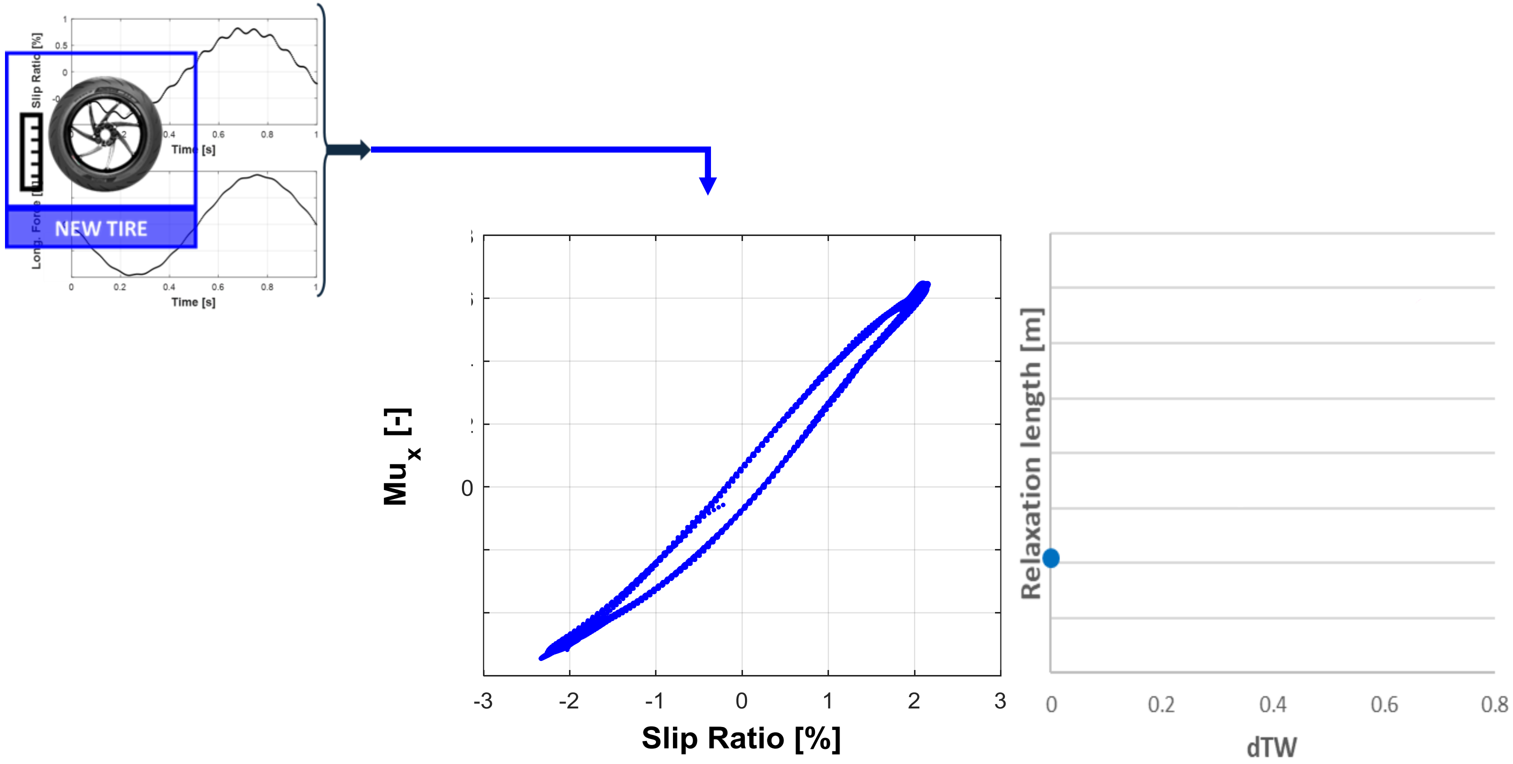
- TIME DELAY BETWEEN SLIP RATIO (INPUT) AND FORCE (OUTPUT) IS MEASURED
- HYSTERETIC BEHAVIOR IS OBSERVED



DYNAMIC MTS CHARACTERIZATION

RELAXATION LENGHT vs WEAR

- ❑ REPETITION OF PREVIOUS CHARACTERIZATION FOR EACH WEAR LEVEL
- ❑ THE SLOPE OF WORN TIRE INCREASES SINCE THE LONGITUDINAL STIFFNESS INCREASES AND IT PRESENTS WIDER HYSTERESIS



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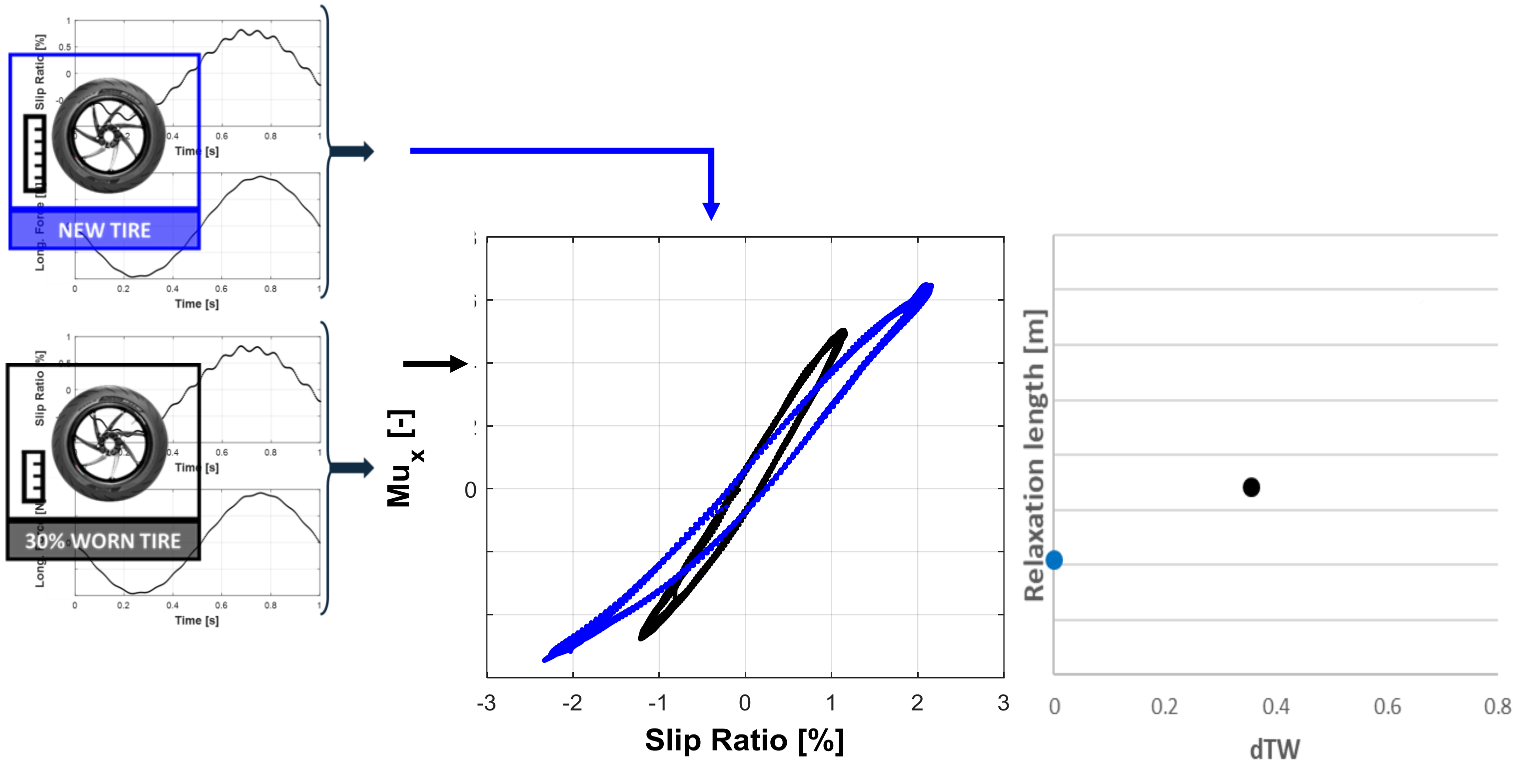

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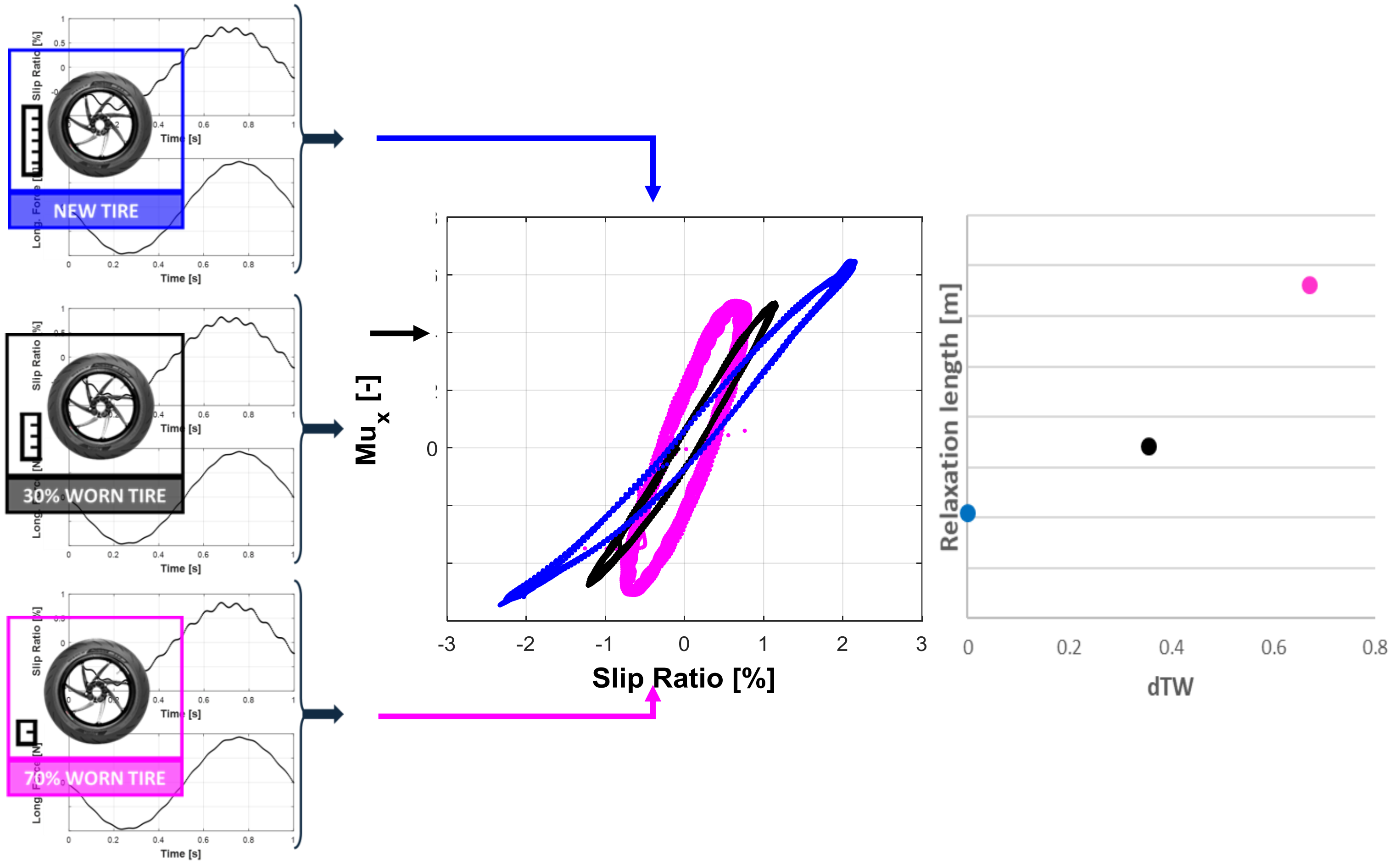
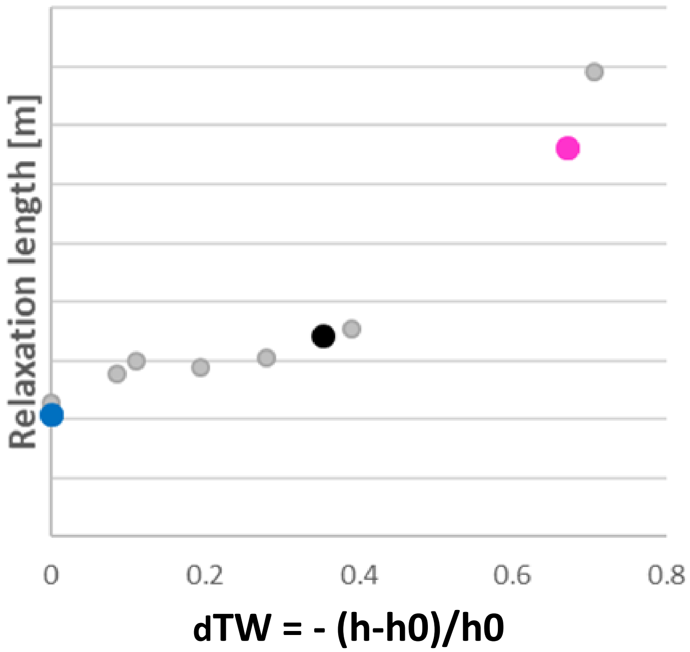


LONG. DYN.: INDOOR TEST

Summary

The proposed results state:

THE RELAXATION LENGTH INCREASES AS THE TIRE WEAR INCREASES.

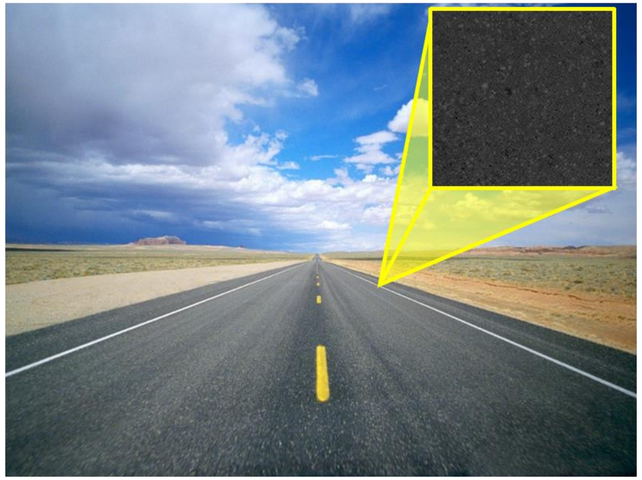


LONG. DYN.: OUTDOOR TEST

Results Explanation

ROAD

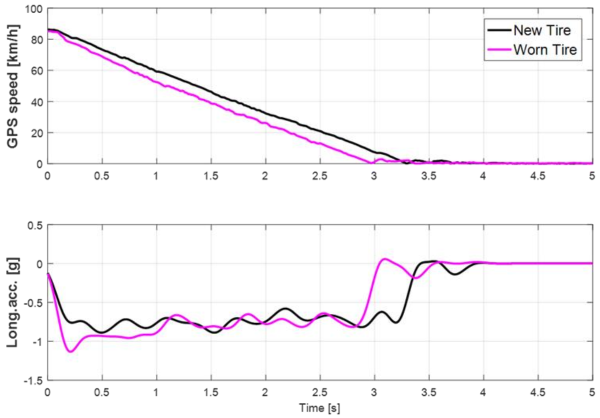
Straight line road
High grip surface (dry tarmac)



MANOEUVER

FULL BRAKING MANOEUVER.

- ABS system status: active
- Vehicle speed before braking: constant@85 km/h
- At least 15 tests repetition



In case of worn tire:

- ❑ lower time to brake;
- ❑ higher avarage deceleration.

THE HIGHER BRAKING PERFORMANCES OBSERVED DURING OUTDOOR TESTS ARE DUE TO HIGHER GRIP

(relaxation length and longitudinal stiffness have no perceivable effects instead)

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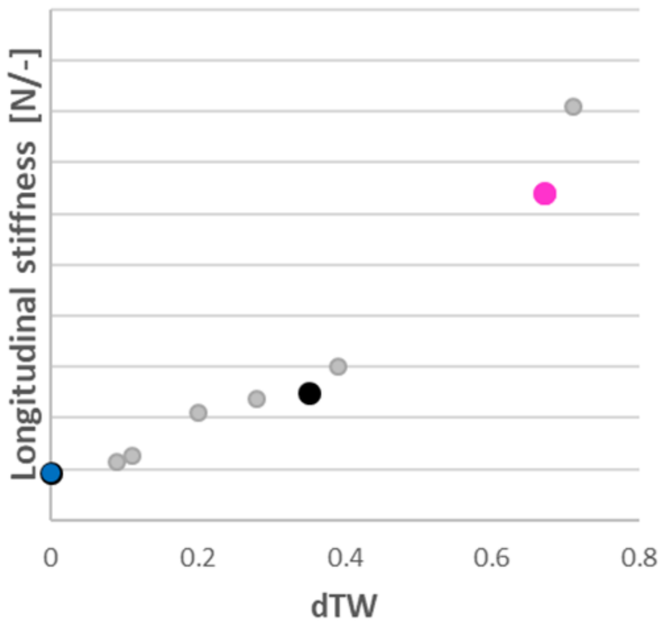
MF MODIFICATION TO INCLUDE WEAR EFFECT

Longitudinal stiffness, relaxation length, maximum friction

TRENDS

Longitudinal stiffness	FITTING EQUATIONS



dTW = - (h-h0)/h0

Pacejka 6.1 MF fitting equation:

$$K_{x\kappa} = F_z\,(p_{kx1} + p_{kx2}df_z)\,\exp(p_{kx3}df_z)\boxed{(1 + p_{px1}dp_i + p_{px2}dp_i^2)}$$

pressure contribute

Modified equation:

$$K_{x\kappa} = F_z\,(p_{kx1} + p_{kx2}df_z)\,\exp(p_{kx3}df_z)(1 + p_{px1}dp_i + p_{px2}dp_i^2)\boxed{(1+ p_{tx1}dTW + p_{tx2}\,dTW^2)}$$

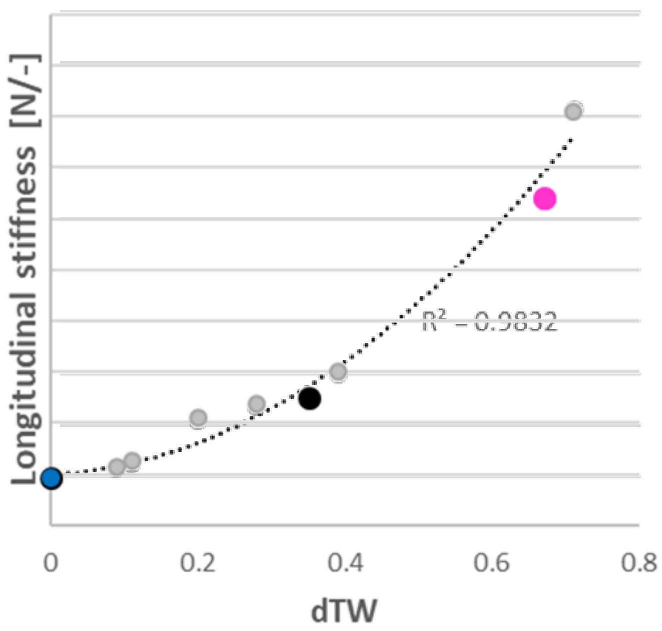
wear contribute

MF MODIFICATION TO INCLUDE WEAR EFFECT

Longitudinal stiffness, relaxation length, maximum friction

TRENDS

Longitudinal stiffness	FITTING EQUATIONS



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Modified equation:

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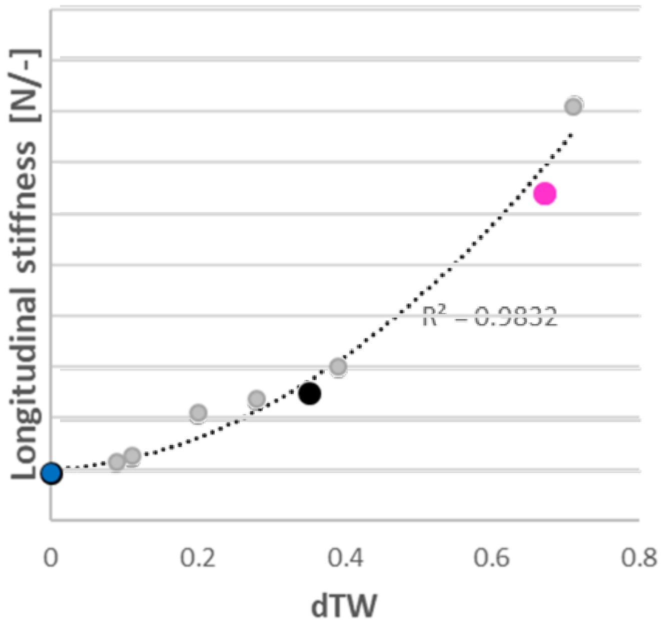
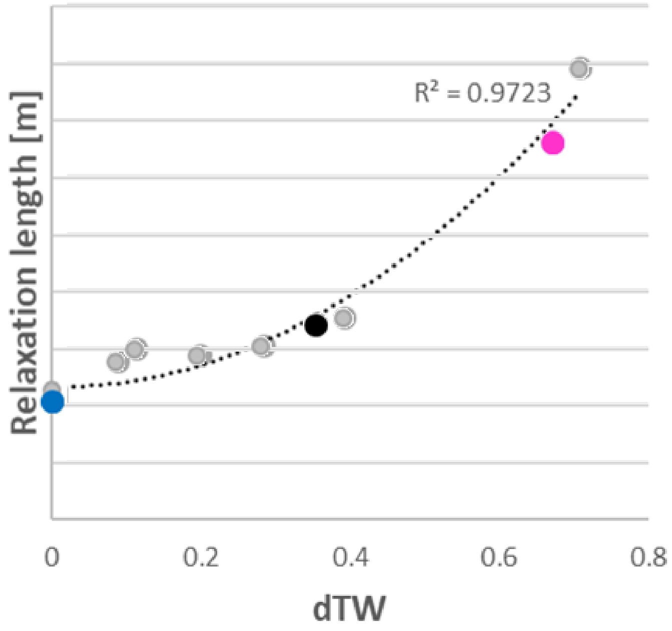
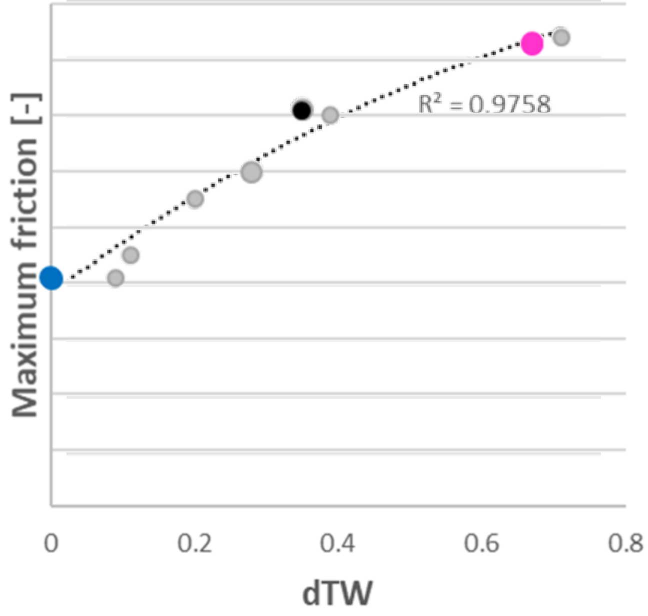
wear contribute

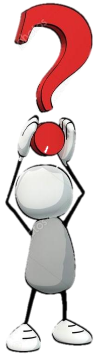
p_{tx1} and p_{tx2} identified coefficients interpolating the longitudinal stiffness VS dTW curve

MF MODIFICATION TO INCLUDE WEAR EFFECT

Longitudinal stiffness, relaxation length, maximum friction

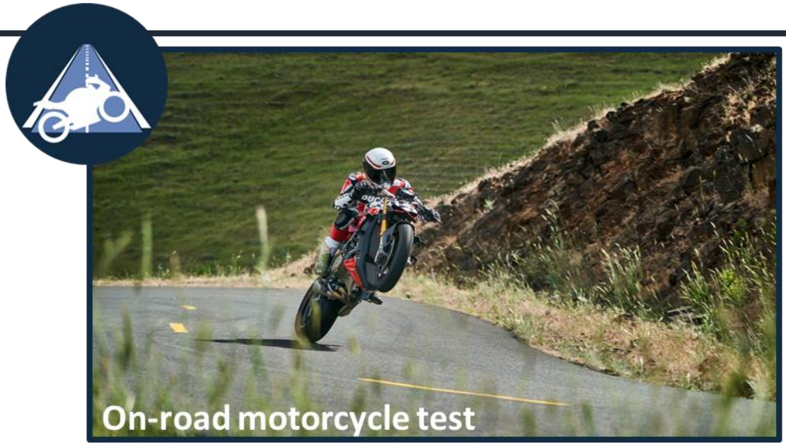
FITTING EQUATIONS

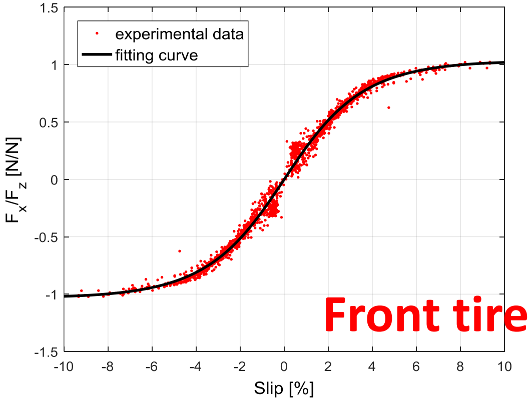
Longitudinal stiffness	Relaxation length	Maximum Friction
		
$K_{x\kappa} = (...)*(1+ p_{tx1}dTW + p_{tx2}dTW^2)$	$c_x = (...)*(1+ p_{cfx4}dTW + p_{cfx5}dTW^2)$	$\mu_x = (...)\ (1+ p_{tx3}dTW + p_{tx4}dTW^2)$

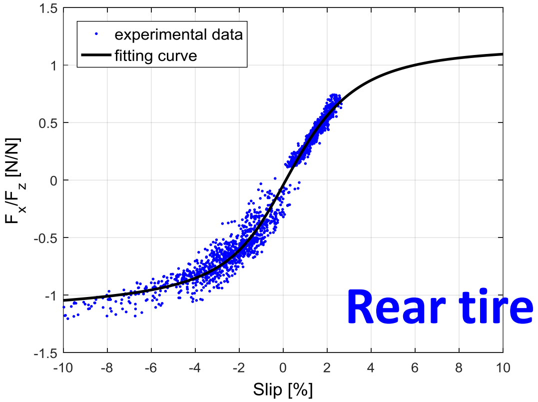


If no indoor tests are available?

ON-ROAD CHARACTERIZATION METHODOLOGY HAS BEEN DEVELOPED







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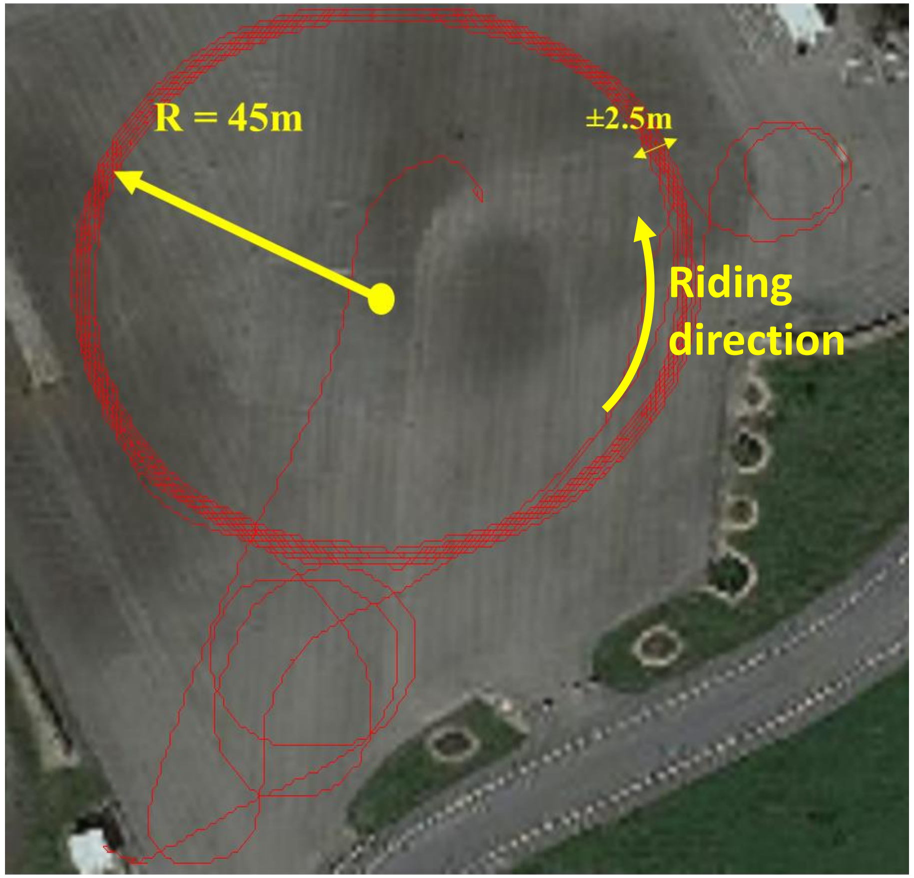
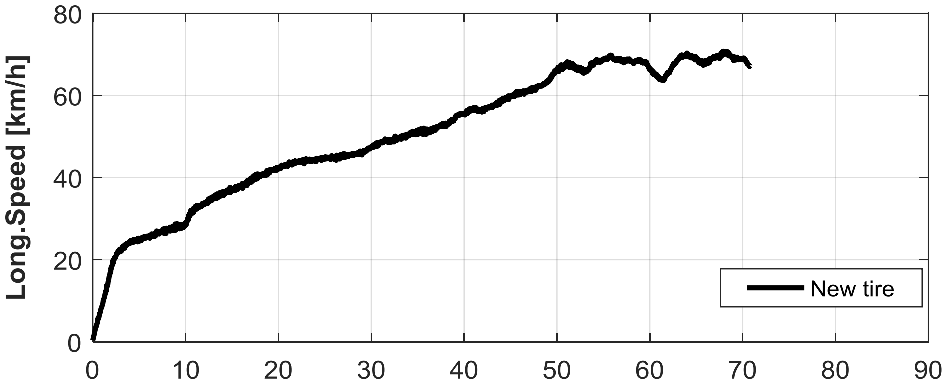
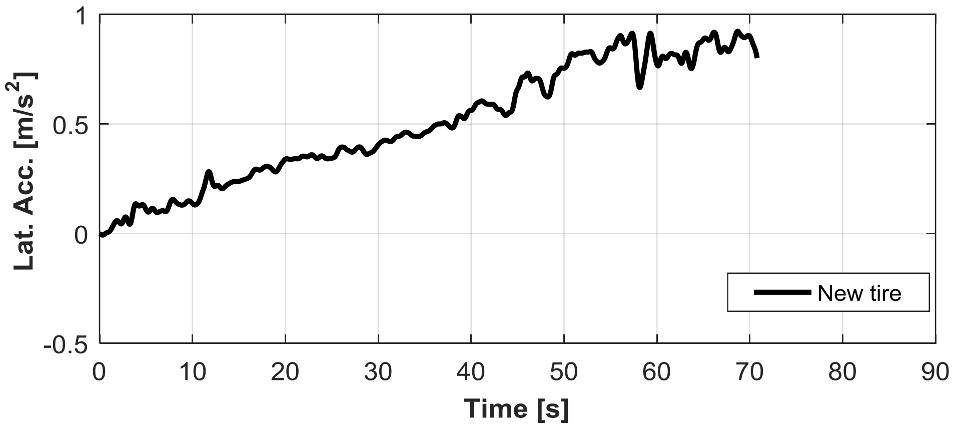
LAT. DYN.: OUTDOOR TEST

Test scenario

ROAD	MANOEUVER
Constant radius turn (45m) executed in CCW High grip surface (dry tarmac)	QUASI STEADY STATE MANOEUVER Slow speed increasing; lat. jerk < 0,1 (m/s²)/s



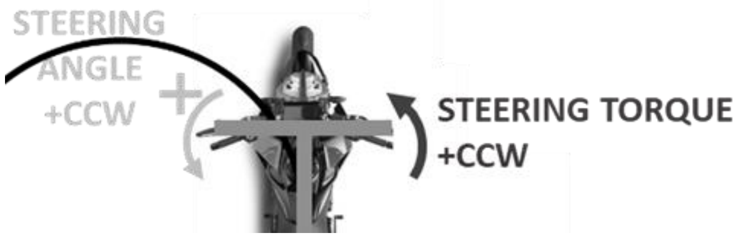




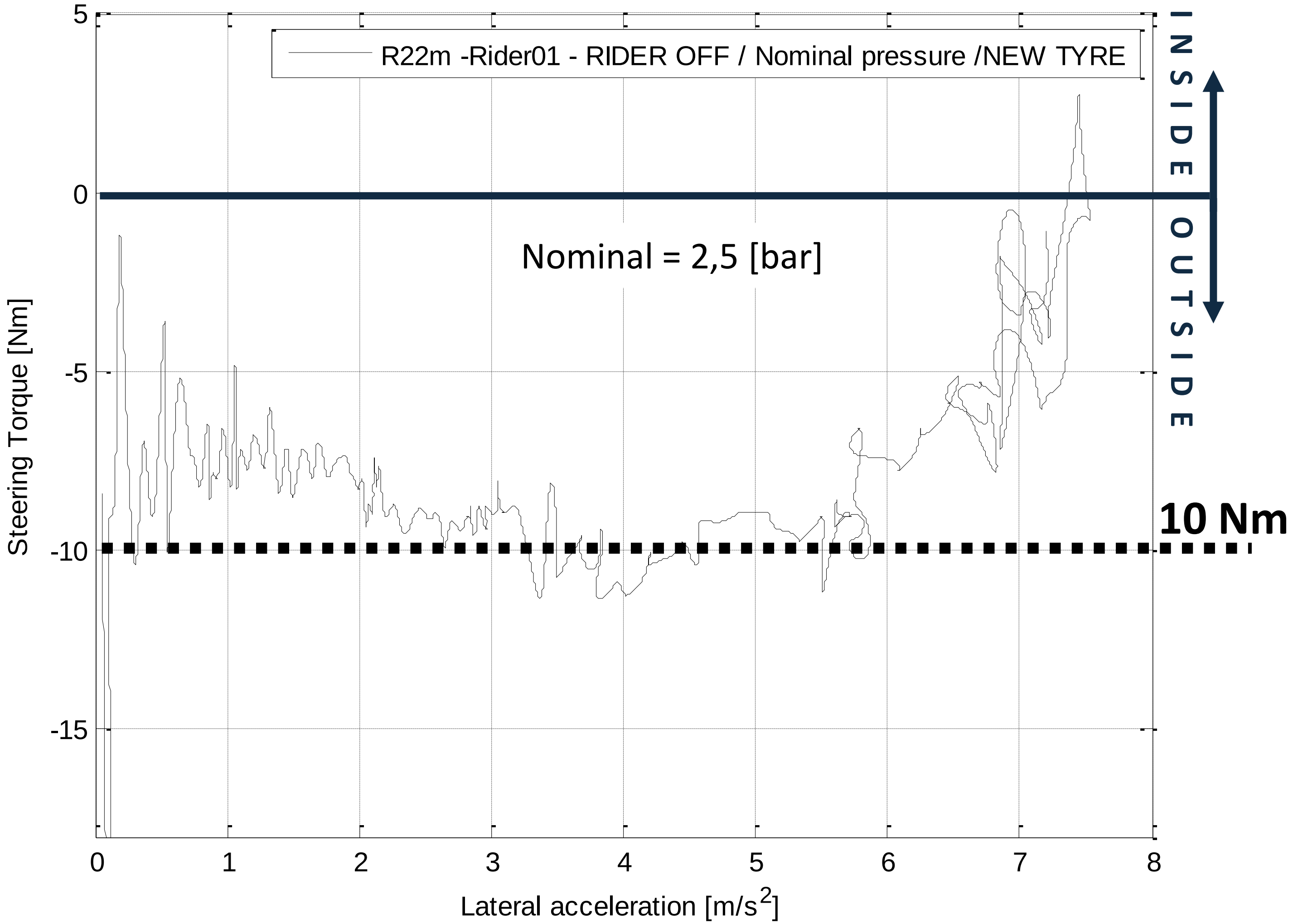
Maneuver and convention

STEERING PAD

- CONSTANT RADIUS:
  R = 45 m
- MOTORCYCLE SPEED:
  FROM 0 TO V_{max}
- QUASI STATIC CONDITION:
  lat. jerk < 0,1 m/s^2/s



Results: steering torque VS lateral acceleration



LAT. DYN.: OUTDOOR TEST

Results

Maneuver and convention

STEERING PAD

- CONSTANT RADIUS:
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- MOTORCYCLE SPEED:
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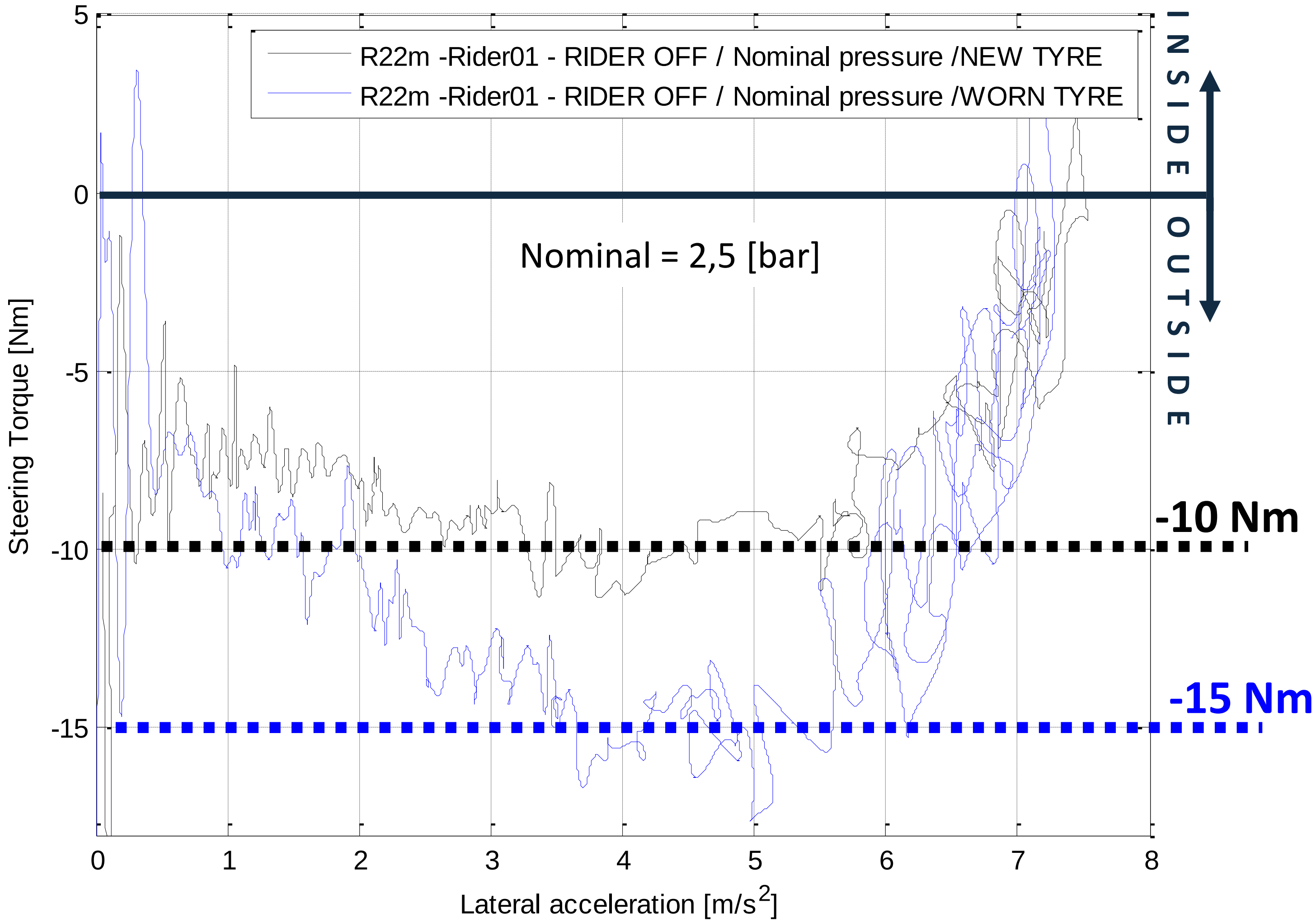

Maneuver and convention

STEERING PAD

- ❑ CONSTANT RADIUS:
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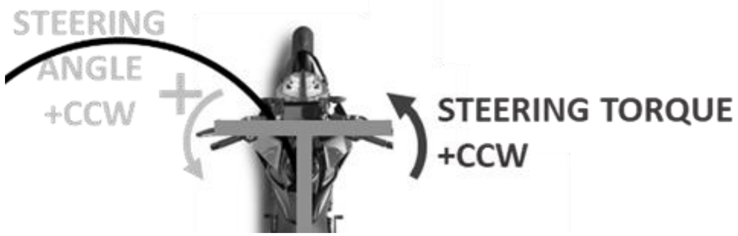
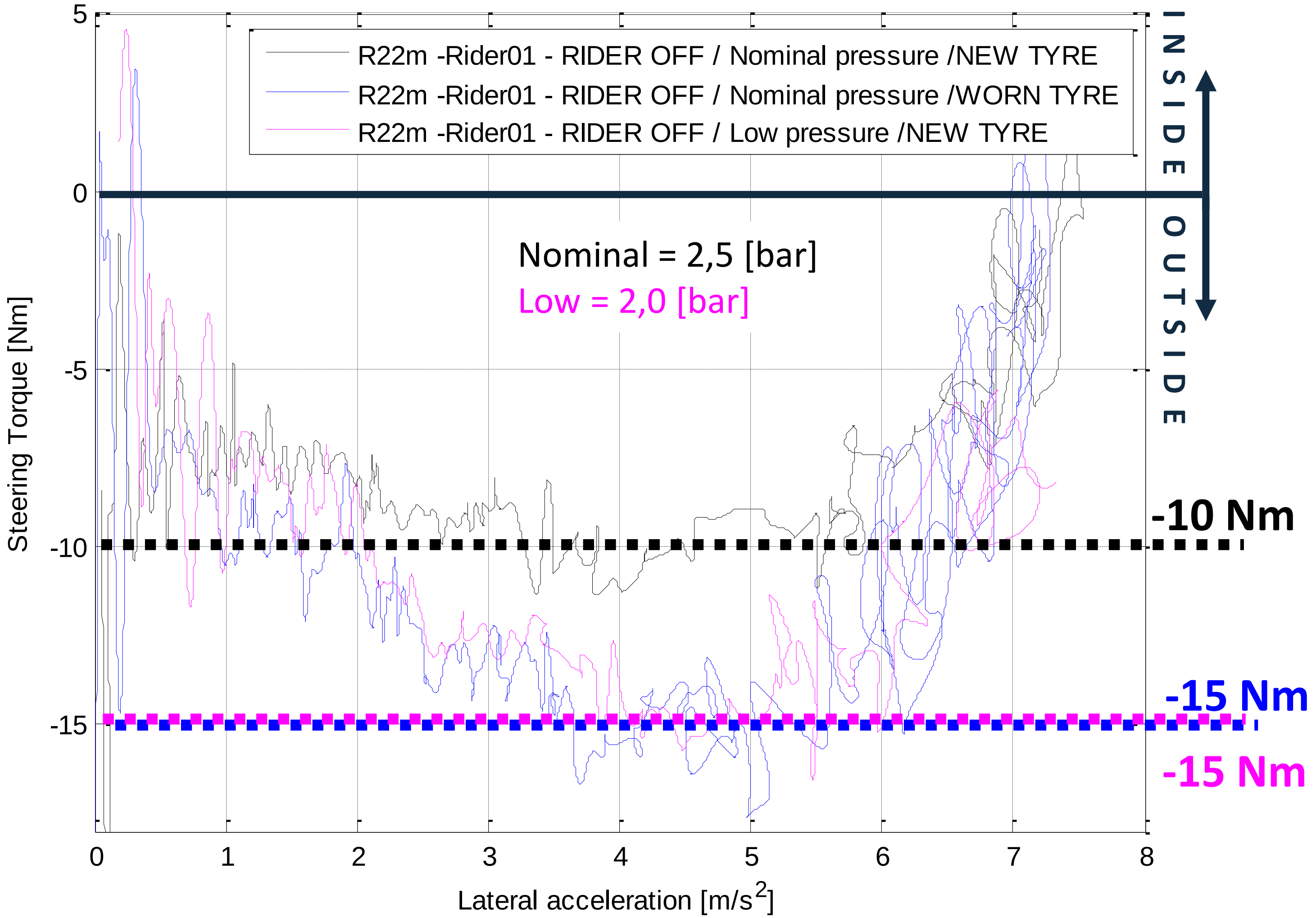
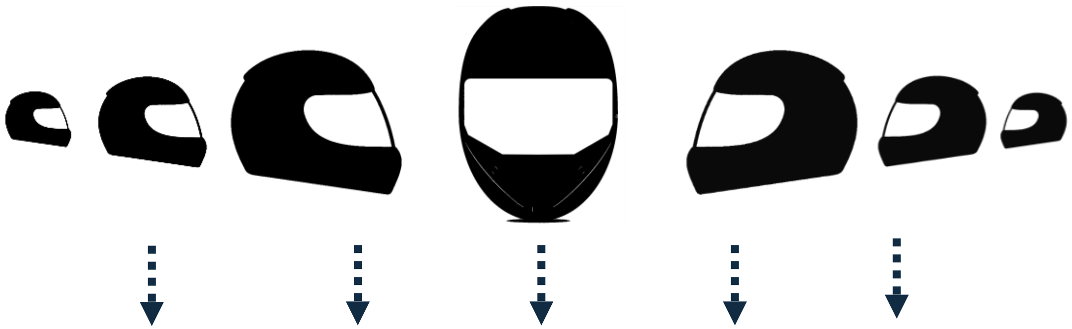


Results: steering torque VS lateral acceleration



Different tires models have been tested.

WORN TIRE IMPLIES HIGHER OUTSIDE STEERING TORQUE.



RIDERS PERCEPTION CONFIRM EXPERIMENTAL EVIDENCE

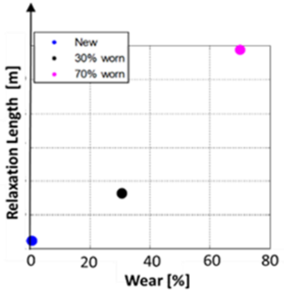
Why

1. INSTRUMENTATION (OUTDOOR TESTS)
2. LONGITUDINAL: OUTDOOR TESTS
3. LONGITUDINAL: INDOOR TESTS
4. LONGITUDINAL: MAGIC FORMULAE MODIFICATION
5. LATERAL: OUTDOOR TESTS
6. LATERAL: SENSITIVITY ANLYSIS THROUGH NUMERICAL SIMULATION
7. CONCLUSIONS

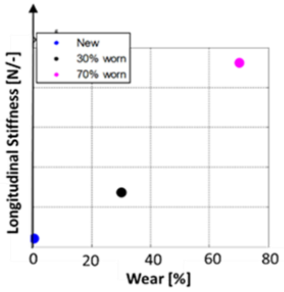
HP:

FROM LONGITUDINAL DYNAMIC CONSIDERATIONS, IF THE WEAR INCREASES (↑)

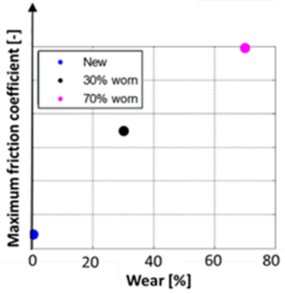
σ_x ↑



K_x ↑



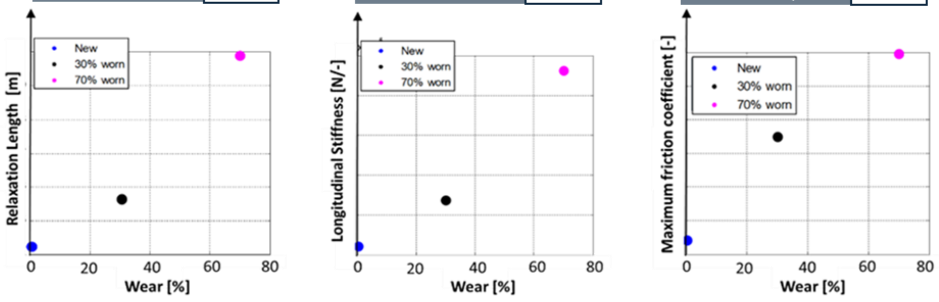
$\mu_{max,x}$ ↑



HP:

FROM LONGITUDINAL DYNAMIC CONSIDERATIONS, IF THE WEAR INCREASES (↑)

σ_x ↑ | K_x ↑ | $\mu_{max,x}$ ↑



IT'S REASONABLE TO ASSUME THAT SOMETHING SIMILAR OCCURS ALSO FOR LATERAL DYNAMIC

HP:

THE TIRE KEY PARAMETERS AFFECTING LATERAL DYNAMICS ARE

Lat. Relaxation Length	σ_y	*Cornering Stiffness*	K_α	*Rolling stiffness*	K_φ	*Max Lat. Friction coeff.*	$\mu_{max,y}$

STEADY-STATE LATERAL DYNAMICS (steering pad)

LAT. DYN.: NUMERICAL ANALYSIS

Assumptions

HP:

THE TIRE KEY PARAMETERS AFFECTING LATERAL DYNAMICS ARE

Lat. Relaxation Length	σ_y	Cornering Stiffness	K_α	Rolling stiffness	K_φ	Max Lat. Friction coeff.	$\mu_{max,y}$

STEADY-STATE LATERAL DYNAMICS (steering pad)

Hypothesis: CORNERING STIFFNESS and ROLLING STIFFNESS variation could affect the increasing of the outside the curve steering torque

IPG MotorcycleMaker

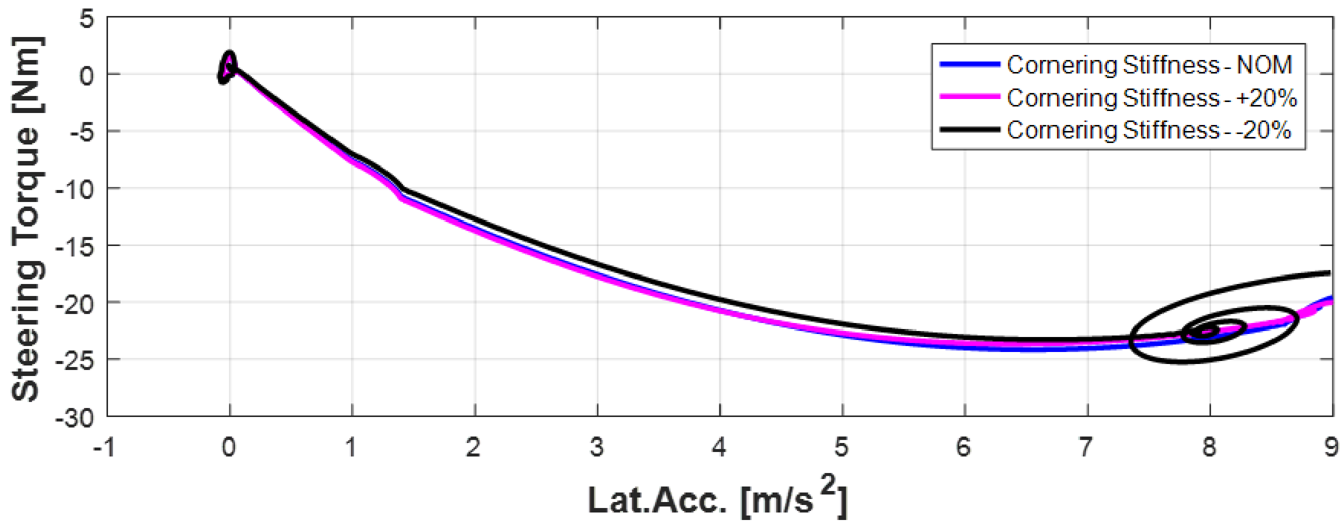
NUMERICAL ANALYSIS:
ROLLING AND THE TIRE CORNERING STIFFNESS SENSITIVITY ANALYSIS HAS BEEN PERFORMED

Steering torque VS lateral acceleration.

SENSITIVITY ANALYSIS ON CORNERING STIFFNESS.

- Nominal value (blue)
- +20% (magenta)
- -20% (black)

THE CORNERING STIFFNESS COEFFICIENT SEEMS NOT TO CAUSE RELEVANT CHANGES IN STEERING TORQUE

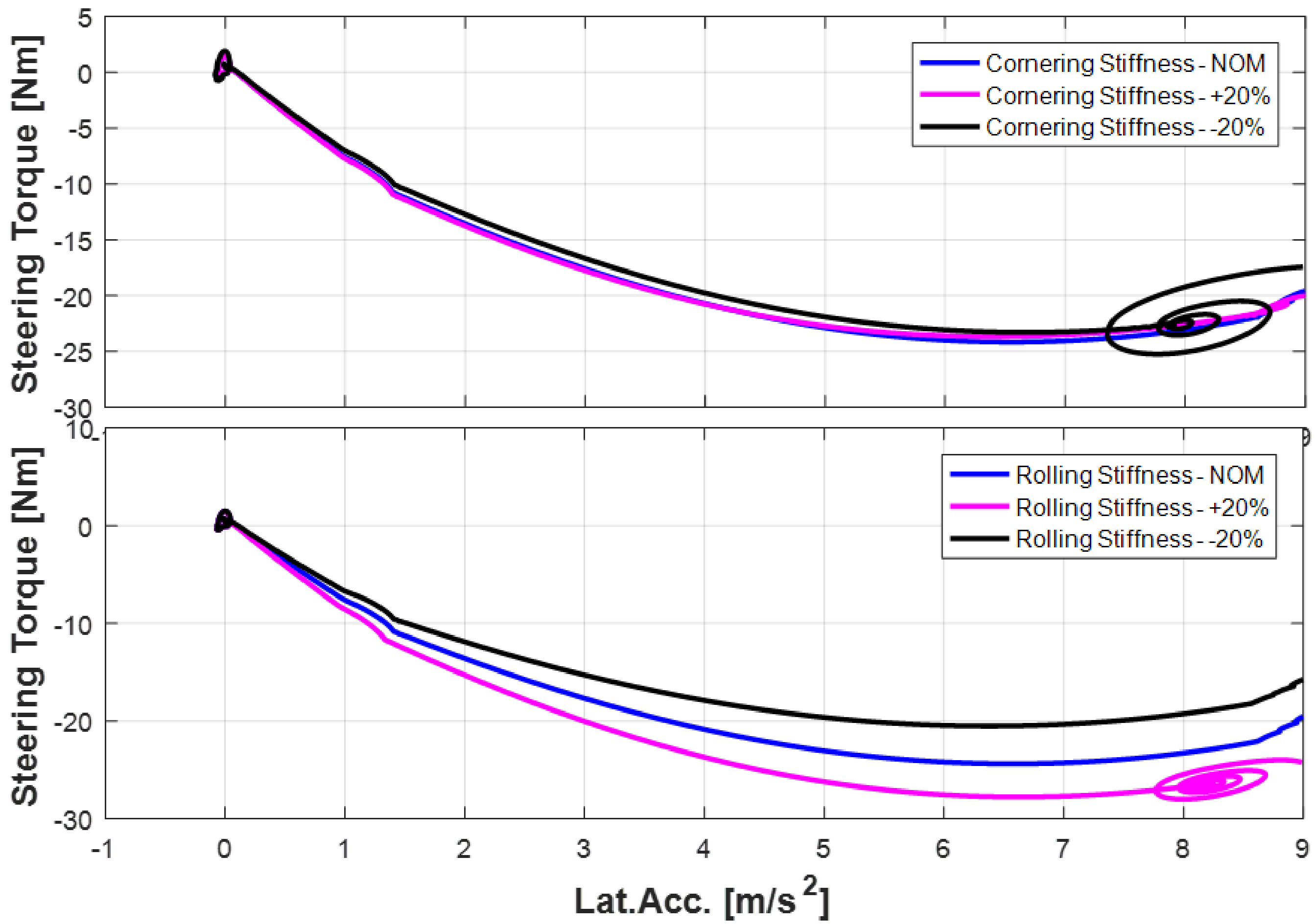


Steering torque VS lateral acceleration.

SENSITIVITY ANALYSIS ON ROLLING STIFFNESS.

- Nominal value (blue)
- +20% (magenta)
- -20% (black)

THE ROLLING STIFFNESS COEFFICIENT AFFECTS THE STEERING TORQUE: THE HIGHER THE ROLLING STIFFNESS , THE HIGHER THE OUTSIDE THE CURVE STEERING TORQUE

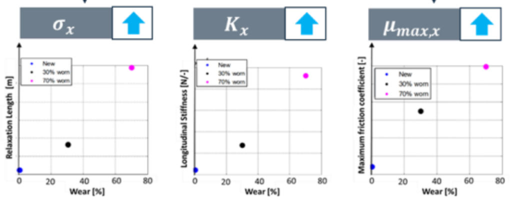


From the numerical sensitivity analysis

AS THE ROLLING STIFFNESS INCREASES, THE OUTSIDE STEERING TORQUE INCREASES

HP:

FROM LONGITUDINAL DYNAMIC CONSIDERATIONS, IF THE WEAR INCREASES (↑)

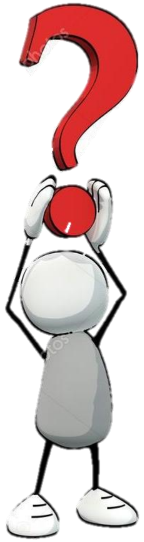


IT'S REASONABLE TO ASSUME THAT SOMETHING SIMILAR OCCURS ALSO FOR LATERAL DYNAMIC

The Hypotesiys done seems to be correct

From the numerical sensitivity analysis

AS THE ROLLING STIFFNESS INCREASES, THE OUTSIDE STEERING TORQUE INCREASES



Why

LAT. DYN.: NUMERICAL ANALYSIS

Wear effect on rolling stiffness

SELF ALIGNING MOMENT

Same turn, same speed, same lateral acceleration

NEW TIRE

Nominal tyre rolling stiffness

Higher tyre rolling stiffness

70% WORN TIRE

LAT. DYN.: NUMERICAL ANALYSIS

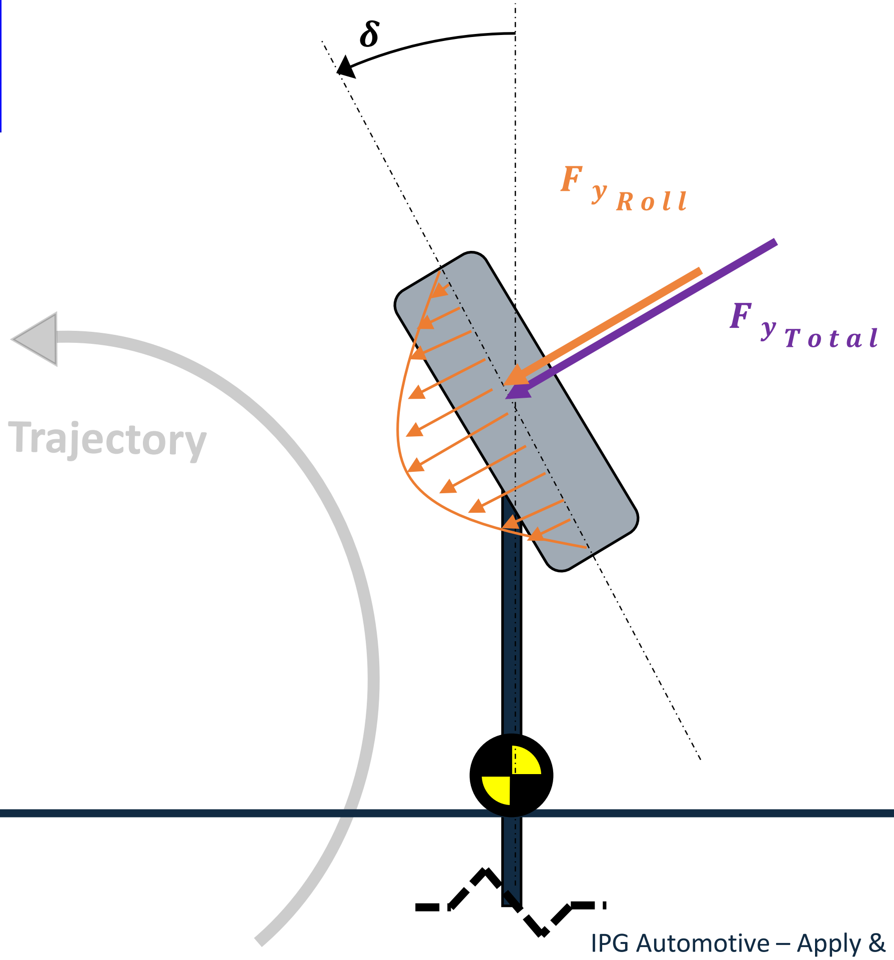
Wear effect on rolling stiffness

SELF ALIGNING MOMENT

Same turn, same speed, same lateral acceleration

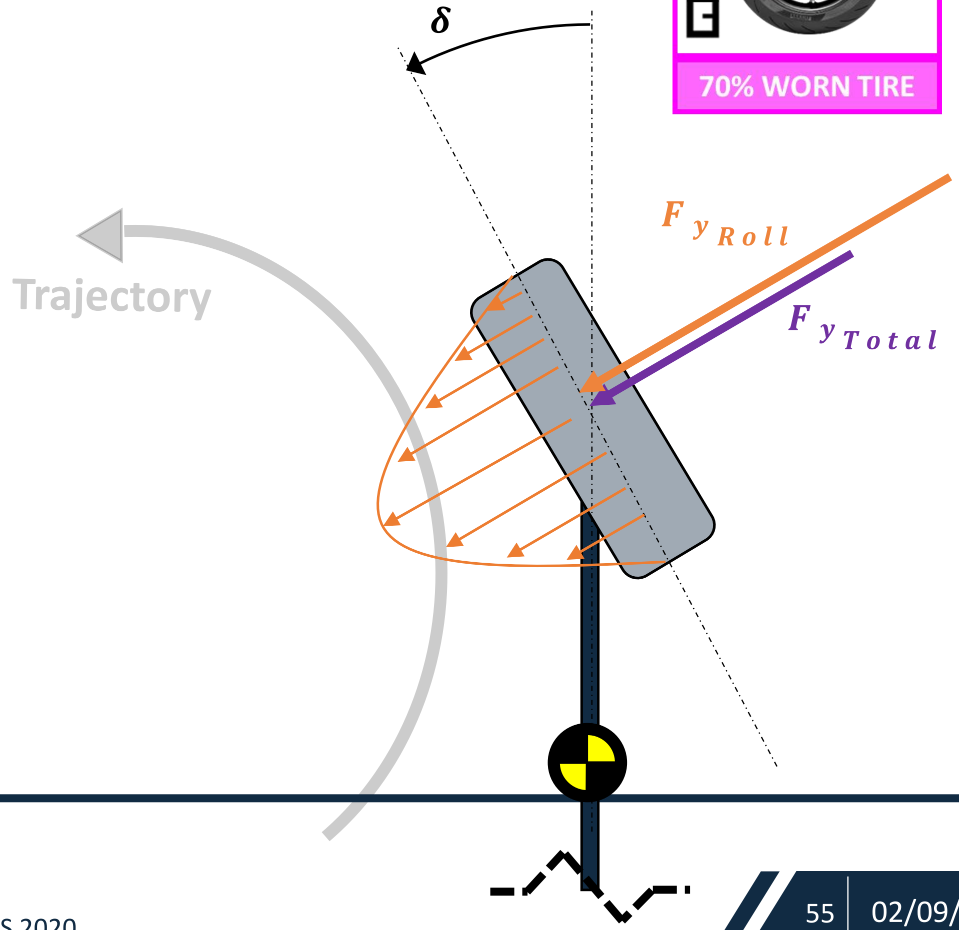
NEW TIRE

Nominal tyre rolling stiffness



Higher tyre rolling stiffness

70% WORN TIRE

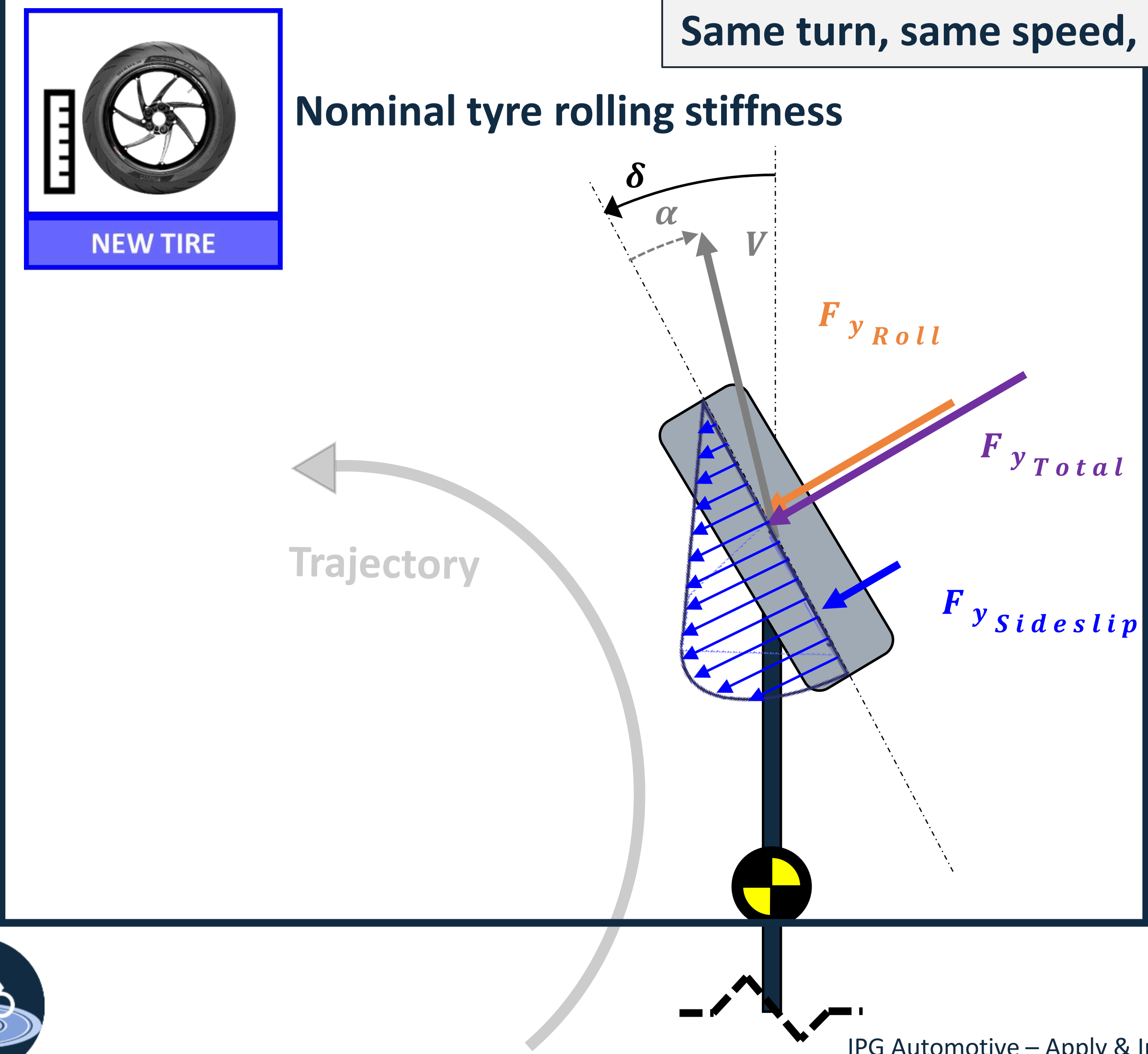


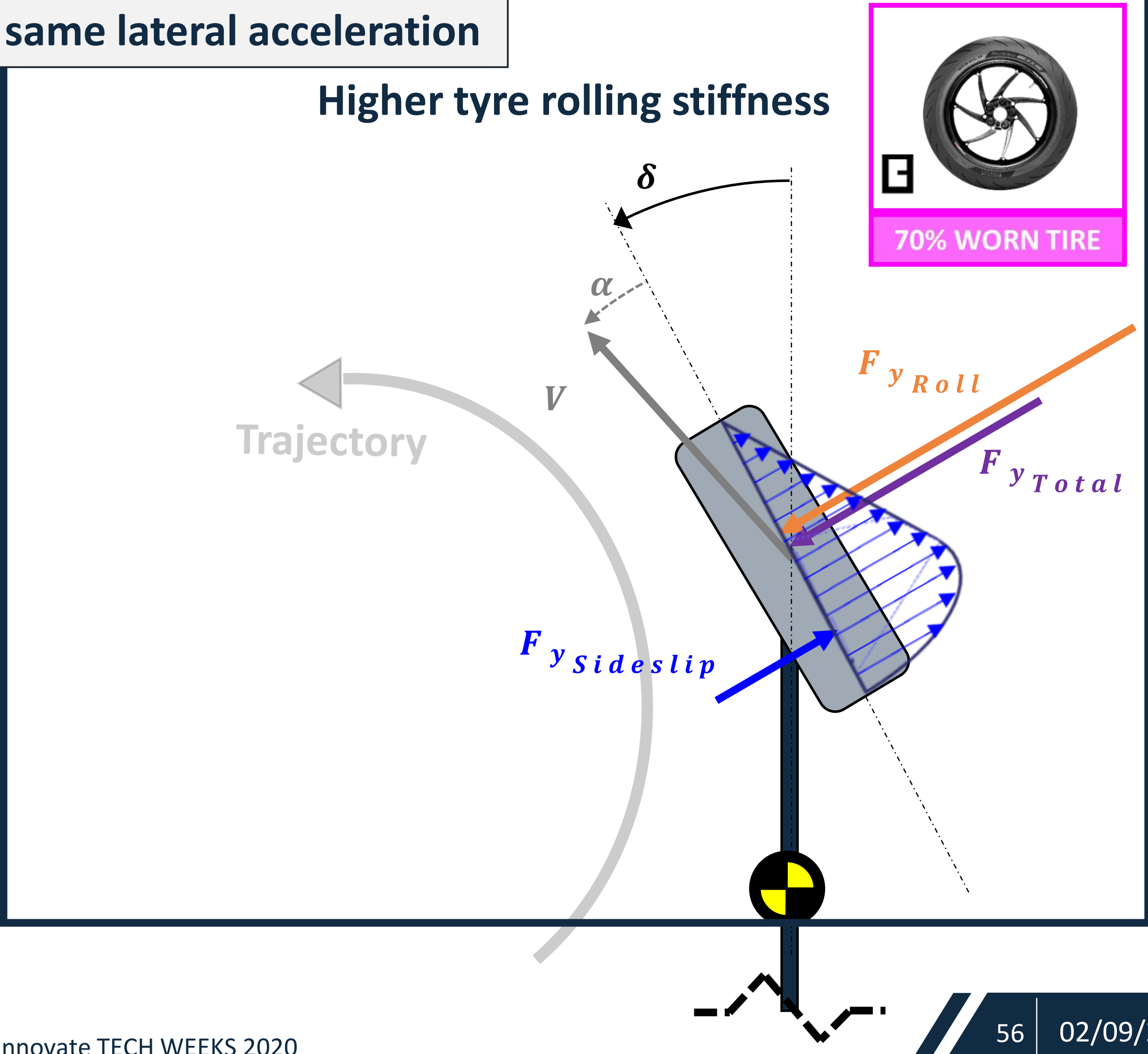
LAT. DYN.: NUMERICAL ANALYSIS

Wear effect on rolling stiffness

SELF ALIGNING MOMENT

Same turn, same speed, same lateral acceleration



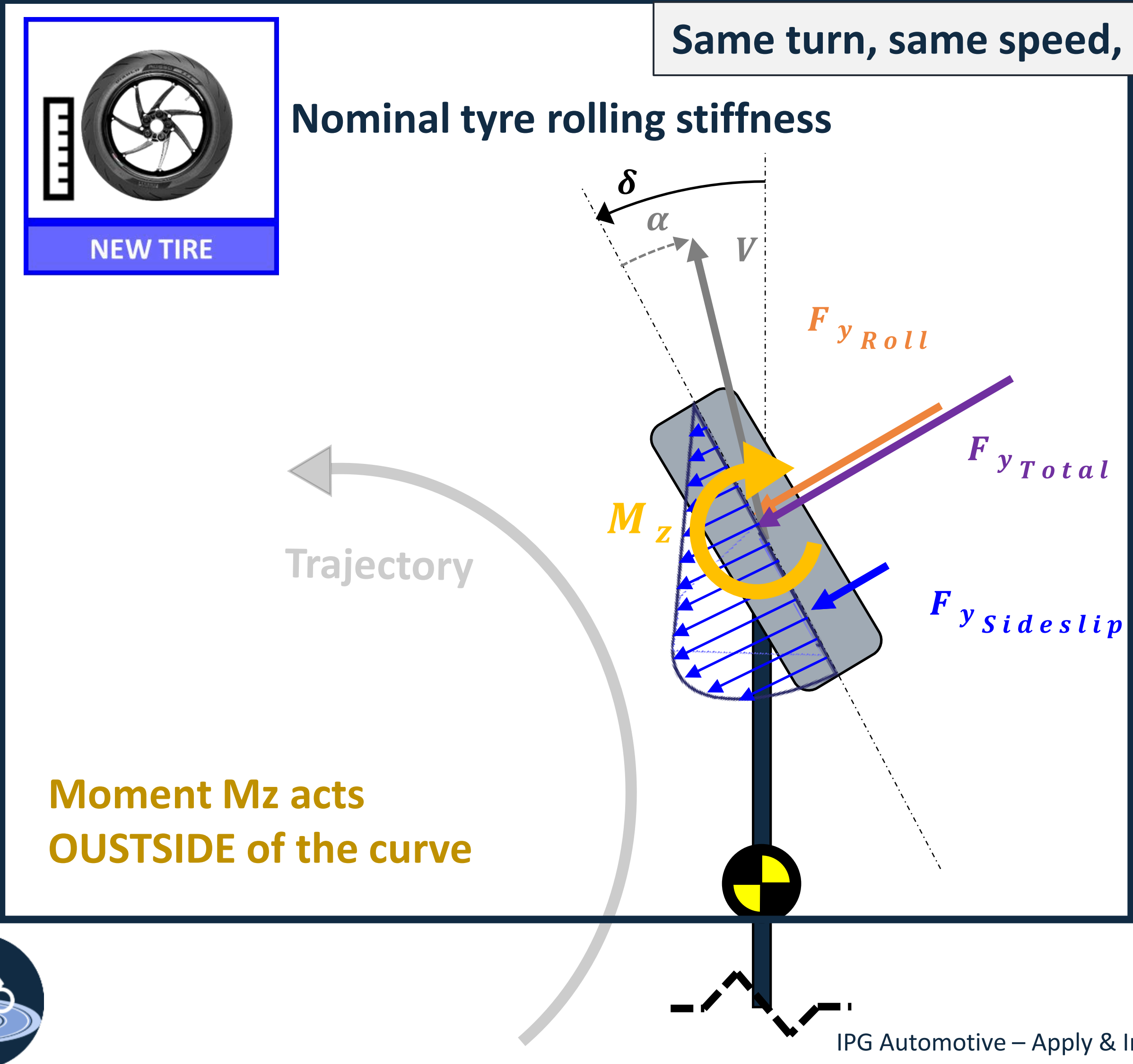


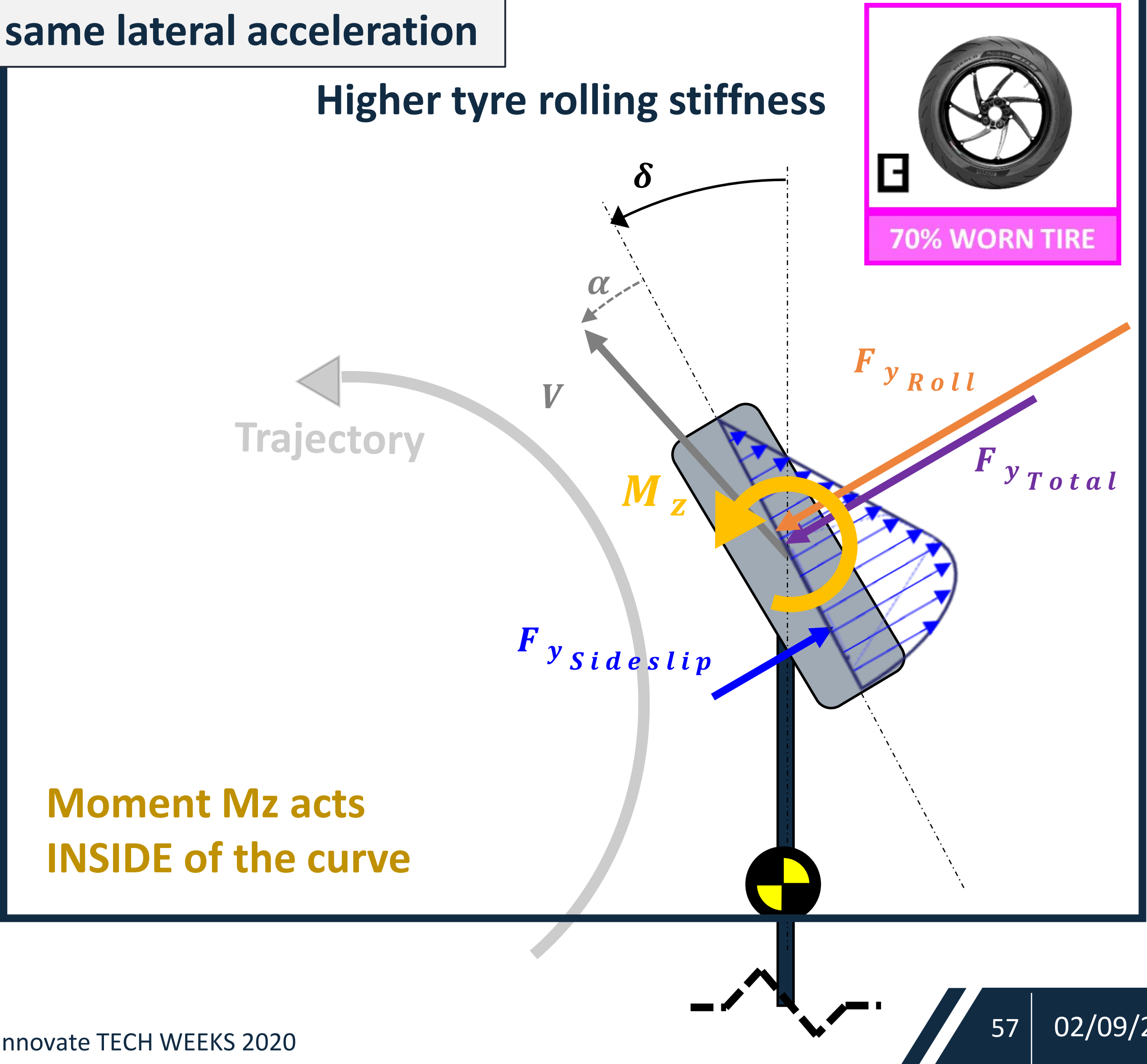
LAT. DYN.: NUMERICAL ANALYSIS

Wear effect on rolling stiffness

SELF ALIGNING MOMENT

Same turn, same speed, same lateral acceleration





Maneuver and convention	Results: steering torque VS lateral acceleration

STEERING PAD

- ❑ CONSTANT RADIUS:
  R = 45 m
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  FROM 0 TO V_{max}
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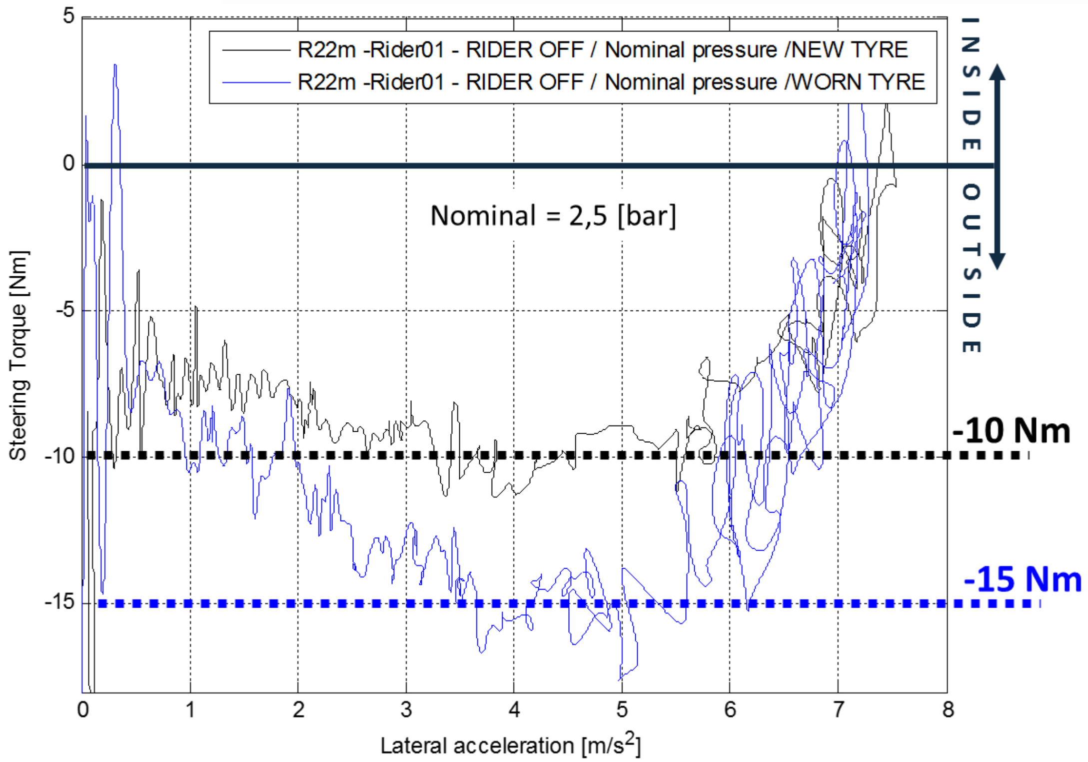

WEAR → HIGHER TIRE ROLLING STIFNESS →
HIGHER OUTSIDE THE CURVE STEERING TORQUE DEMAND NEEDED TO MAINTAIN TRAJECTORY

LAT. DYN.: OUTDOOR TEST

Test scenario

OUTLINE

1. INSTRUMENTATION (OUTDOOR TESTS)
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3. LONGITUDINAL: INDOOR TESTS
4. LONGITUDINAL: MAGIC FORMULAE MODIFICATION
5. LATERAL: OUTDOOR TESTS
6. LATERAL: SENSITIVITY ANLYSIS THROUGH NUMERICAL SIMULATION
7. CONCLUSIONS

GENERAL TARGET:

TO INVESTIGATE THE EFFECTS OF TIRE WEAR ON BOTH THE LATERAL AND THE LONGITUDINAL DYNAMIC; TO PROPOSE A PACEJKA MF MODIFICATION, INCLUDING THE WEAR DEPENDENCY

CONCLUSIONS:

- Increase of wear → increase of tire stiffness, maximum grip, relaxation length
- MF modification has been proposed for longitudinal tire behavior
- Outdoor tests procedure can be used to overcome the lack of the indoor tests and proceed with tire parameter identification, for longitudinal dynamic only
- It has been demonstrated how, both experimentally and numerically, the steering torque is strongly affected by tire rolling stiffness (*the higher the stiffness, the more the outside-the-curve steering torque*)

APPLY & INNOVATE

TECH WEEKS

Starting Sept. 2020

IPG AUTOMOTIVE

Soluzioni ingegneria

SINCE 04

Research partnership in technology innovation

Thank you!