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The Virtual Tire

Program and Abstracts

August 30th – September 3rd, 2021

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Schedule at a Glance

Time	Monday August 30	Tuesday August 31	Wednesday September 1	Thursday September 2	Friday September 3
8:00 AM	Conference Opening	Techical Session #3 Student Papers #2	Business Meeting	Techical Session #6 Tire-Road Interaction	Techical Session #8 Tire & Vehicle System
8:05 AM					
8:10 AM					
8:15 AM	Keynote Address Mike Anderson General Motors				
8:20 AM					
8:25 AM					
8:30 AM					
8:35 AM			Distinguished Achievement Award		
8:40 AM					
8:45 AM					
8:50 AM					
8:55 AM					
9:00 AM		Break			
9:05 AM					
9:10 AM					
9:15 AM	Break	Plenary Lecture Christian Oertel Bradenburg University	Break		
9:20 AM					
9:25 AM				Break	Break
9:30 AM	Techical Session #1 Emerging Technologies		Panel Discussion "Virtual Tire Submissions: Challenges from the Automotive Industry"		
9:35 AM					
9:40 AM				Plenary Lecture Mike Stackpole Stackpole Engineering Services	Techical Session #8 Tire & Vehicle System (continued)
9:45 AM					
9:50 AM					
9:55 AM					
10:00 AM					
10:05 AM					
10:10 AM					
10:15 AM		Break			
10:20 AM					
10:25 AM					
10:30 AM		Techical Session #4 Virtual Design	Break		Break
10:35 AM				Break	
10:40 AM					
10:45 AM	Break		Techical Session #5 Predictive Technologies		Panel Discussion "The Next Chapter in Tire Model Technology"
10:50 AM				Techical Session #7 Tire Wear	
10:55 AM					
11:00 AM	Techical Session #2 Student Papers #1				
11:05 AM					
11:10 AM					
11:15 AM					
11:20 AM					
11:25 AM					
11:30 AM					
11:35 AM					
11:40 AM					2022 Announcement
11:45 AM					
11:50 AM					
11:55 AM					Close of Conference
12:00 PM					
12:05 PM		Break		Break	Break
12:10 PM		COOPER TIRES Sponsor Breakout Session		TMSI Sponsor Breakout Session	SMITHERS INNOVATE WITH CONFIDENCE Sponsor Breakout Session
12:15 PM	Break				
12:20 PM	LINK Sponsor Breakout Session		Break		
12:25 PM			Endurica Get Durability Right Sponsor Breakout Session		
12:30 PM					
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1:30 PM					

Key
Business Meeting Items
Invited Speakers / Panels
Technical Session
Sponsor Breakout Session
40th Milestone Videos

Day 1 – Monday, August 30th, 2021 – All Times Eastern Time Zone

8:00 AM	**Conference Opening**		**Matthew Schroeder** *2021 Conference Program Chair*
8:15 AM	**Keynote Address**	The Move to Virtual	**Mike Anderson -** General Motors *Executive Director Global Virtual Design, Development, & Validation*
9:15 AM	Break – 40th Milestone Videos		
	Session 1: Emerging Technologies		**Corissa Lee**, *Exponent*
9:30 AM	1.1	Modal Coupling Analysis of Tire-Rim Assembly	**Tan Li** *Maxxis Technology Center*
9:55 AM	1.2	Design and Optimization of Tire Traction During Lateral and Longitudinal Dynamics Using Fuzzy Logic for Autonomous Vehicles	**Dileepan Anandan, Kaushik Kumar** *Hyundai Mobis* **Pruthvi Krishnamurthy** *Ashok Leyland*
10:20 AM	1.3	An Algorithm for Estimating Tread Depth for Intelligent Tire Solutions	**Tom Sams** *Bridgestone Americas*
10:45 AM	Break – 40th Milestone Videos		
	Session 2: Student Papers #1		**Matthew Schroeder**, *Cooper Tire*
11:00 AM	2.1	Tire Multiphysical Modelling for the Analysis of Thermal and Wear Sensitivity on Vehicle Objective Dynamics and Racing Performances	**Antonio Maiorano** *Università degli Studi di Napoli Federico II*
11:25 AM	2.2	Analysis of Off-Road Tire Cornering Characteristics Using Advanced Analytical Techniques	**Fatemeh Gheshlaghi** *Ontario Tech University*
11:50 AM	2.3	Experimental Friction Analysis Through Innovative Compound-Substrate Contact Modelling for Automotive Applications	**Vincenzo M. Arricale** *Università degli Studi di Napoli Federico II*

Day 2 – Tuesday, August 31st, 2021 – All Times Eastern Time Zone

	Session 3: Student Papers #2		**Matthew Schroeder**, *Cooper Tire*
8:00 AM	3.1	Exponential Decay of Contact-Patch Friction Steering Moment with Rolling Speed	**Jai Prakash** *Politecnico Di Milano*
8:30 AM	3.2	VESevo, An Innovative Device For Non-Destructive And Smart Viscoelastic Characterization of Tire Compounds	**Antonio Maiorano** *Università degli Studi di Napoli Federico II*
9:00 AM	Break – 40th Milestone Videos		
9:15 AM	**Plenary Lecture**	Virtual Tires: Requirements, Fields of Application and Ways of Implementation	**Christian Oertel** Brandenburg University***, Professor of Applied Sciences, Mechatronics***
10:15 AM	Break – 40th Milestone Videos		
	Session 4: Virtual Design		**Xianwei Meng**, *Goodyear*
10:30 AM	4.1	FTire - Engineering a Virtual Tire	**Joachim Stallmann** *Cosin Scientific Software AG* **Bhaskar Chaturvedi, Swaroop Sharma** *Continental Reifen Deutschland*
10:55 AM	4.2	adheLAB: Advanced Calibration Tool for a Real-Time MF-Based Multiphysical Model	**Martina Natiello** *MegaRide*
11:20 AM	4.3	Evaluation of Virtual Tire	**Yi Li** *Global Center for Automotive Performance Simulation*
11:45 AM	4.4	Modeling and Simulation for Virtual Tire Development	**Tom Ebbott, Evan Cogansparger** *Goodyear*

Day 3 – Wednesday, September 1st, 2021 – All Times Eastern Time Zone

8:00 AM	The Tire Society Annual Business Meeting	**Will Mars** *President of The Tire Society*
8:35 AM	Presentation of the Distinguished Achievement Award	**Jerry Potts** *Past-President of The Tire Society*
9:15 AM	Break – 40th Milestone Videos	
9:30 AM	**Live Panel Discussion** Virtual Tire Submissions: Challenges from the Automotive Industry	**Tom Ebbott** (Moderator), *Goodyear* **Greg Bunting**, *General Motors* **Guenter Leister**, *TWMS Consulting* **Jan Prins**, *Jaguar Land Rover* **Madhu Rao**, *Tesla* **Mario Weinberger**, *BMW*
10:30 AM	Break – 40th Milestone Videos	
	Session 5: Predictive Technologies	**Qian Li**, *Cooper Tire*
10:45 AM	5.1 Tire Durability Prediction Using Three-Element Layered Mesh for Cord-Rubber Composites	**Pooya Behroozinia** *Maxxis Technology Center*
11:10 AM	5.2 Incremental, Critical Plane Analysis and Experimental Verification for TBR Tyre Bead Endurance Applications	**Vidit Bansal** *CEAT Tyres*
11:35 AM	5.3 A Microsphere based Rubber Curing Model for Tire Production Simulation	**Thomas Berger** *Technische Universität Dresden*
12:00 PM	5.4 A Model for Predicting Residual Casing Life of a Tire Following an Impact Event	**Tom Ebbott & Gobi Gobinath** *Goodyear*

Day 4 – Thursday, September 2nd, 2021 – All Times Eastern Time Zone

	Session 6: Tire-Road Interaction	**Eric Pierce**, *Smithers*
8:00 AM	6.1 A Comprehensive Model for Characterizing Rubber Wet Friction	**Jonathan Watson** *Maxxis Technology Center*
8:30 AM	6.2 Experimental Investigation of the Influence of Snow Density, Temperature and Moisture on the Friction Behavior of Tire Tread Blocks	**Michael Hindemith** *Institut for Dynamic and Vibrations Research*
9:00 AM	6.3 "Target Tracking" Capture, Visualization and Quantification of the Tire Tread Movement Under Dynamic Conditions	**Dr. Lin Kung** *TMSI LLC*
9:25 AM	Break – 40th Milestone Videos	
9:40 AM	**Plenary Lecture** The Evolution of Engineering Tools and the Virtual World in Motorsports: A Personal Story	**Mike Stackpole** Stackpole Engineering Services *Founder & President*
10:40 AM	Break – 40th Milestone Videos	
	Session 7: Tire Wear	**Gobi Gobinath**, *Goodyear*
10:55 AM	7.1 Evaluating Tire Tread Wear and its Dependence on Tire Working Conditions by Using the Finite Element Method and Archard's Wear Theory	**Heron J. Dionisio** *Prometeon Tyre Group*
11:20 AM	7.2 On-Road Vehicle Measurements of Tire Wear Particle Emissions and Approach for Emission Prediction	**Toni Feißel** *Technische Universität Ilmenau*
11:45 AM	7.3 Active and Semi-Active Suspension Systems for Minimising Tyre Wear in Articulated Vehicles	**Georgios Papaioannou** *KTH Royal Institute of Technology*

Day 5 – Friday, September 3rd, 2021 – All Times Eastern Time Zone

		Session 8: Tire & Vehicle System	**Jerry Pospiech,** *ACS Inc.*
8:00 AM	8.1	"Mobility Ring" - A New Concept for Recovery of Mobility After a Tire Breakdown	**Prof. Dr. Günter Leister** *TWMS Consulting*
8:30 AM	8.2	Evaluation of Driving Simulator Technology for Ride & Comfort using a Physical Tire Model	**Francesco Calabrese** *Fraunhofer ITWM* **Javier Catalan** *Applus+ IDIADA*
9:00 AM	8.3	Parking Specific Parameterization Method for FTire	**Dominic Neumann** *BMW Group*
9:25 AM		Break – 40th Milestone Videos	
9:40 AM	8.4	Virtual Modeling of Steering Rack Loads Using Force and Moment Data	**Bo Lin** *Ford Motor Company*
10:05 AM	8.5	Methods for Improving Correlation Between Indoor Tire Test Data and Full Vehicle Simulation and Testing	**Marco Furlan** *Calspan Corporation*
10:30 AM		Break – 40th Milestone Videos	
10:45 AM		**Live Panel Discussion** The Next Chapter in Tire Model Technology	**Mike Stackpole** (Moderator), *Stackpole Engineering Services* **Flavio Farroni**, *MegaRide* **Axel Gallrein**, *Fraunhofer ITWM* **Michael Gipser**, *Cosin Scientific Software* **Christian Oertel**, *Brandenburg University* **Willem Versteden**, *Siemens*
11:45 AM		Announcement of the 2022 Annual Meeting and Conference	**Gobi Gobinath** *2022 Conference Program Chair*
12:00 PM		Close of Conference	**Matthew Schroeder** *Conference Program Chairman*

Please join our sponsors at exclusive breakout sessions following the conference each day!

Sponsor Breakout Sessions Schedule

Monday	Tuesday	Wednesday	Thursday	Friday
LINK	Cooper Tires	Endurica	TMSI	Smithers

About The Tire Society

The Tire Society was established to disseminate knowledge and to stimulate development in the science and technology of tires. This is pursued through technical meetings and publication of the journal, Tire Science and Technology. The Society is a not-for-profit Ohio corporation managed by a duly elected Executive Board of tire industry professionals who serve on a volunteer basis.

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	Lin Kung	*TMSI LLC*	North Canton, OH
	Bob Pelle	*The Goodyear Tire & Rubber Company*	Akron, OH
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	Gregory Smith	*General Motors*	Detroit, MI

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Many members volunteered their time to put together the 40th Annual Meeting and Conference.

CONFERENCE COMMITTEE:

2021 Program Chair:	Matthew J. Schroeder	*Cooper Tire & Rubber Company*
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2023 Program Chair:	Ric Mousseau	*General Motors*
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Gobi Gobinath	*The Goodyear Tire & Rubber Company*
Corissa Lee	*Exponent*
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Yaswanth Siramdasu (C)	*Hankook Tire & Technology*
Tan Li (C, S)	*Maxxis Technology Center*
James Valerio (C, S)	*Hankook Tire & Technology*
Qian Li (S)	*Cooper Tire & Rubber Company*

* C – Conference Judge, S – Student Paper Judge

The Tire Society also thanks the many contributions from our partners at Allen Press! In particular, we wish to thank Chris Lapine and Terry Leatherman for their tireless commitment to assisting us in our goal of disseminating knowledge in the science and technology of tires.

In addition to the Journal Editor, the associate editors volunteer time to contribute to the peer review process associated with publishing manuscripts in the Tire Science & Technology Journal:

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The 41st Annual Meeting and Conference
September 12th & 13th, 2022

Conference Theme: **New Horizons in Tire Evaluation**

Program Chair:	Gobi Gobinath	*The Goodyear Tire & Rubber Company*
Co-Chair:	Ric Mousseau	*General Motors*

The Conference Committee would appreciate your assistance and suggestions.

A call for papers will be issued to attendees of the conference and will be available online.

Visit www.tiresociety.org for updates.

Keynote Address

Mike Anderson – General Motors
Executive Director Global Virtual Design, Development, & Validation

Title of Talk: ***The Move to Virtual***

Mike Anderson is currently the Executive Director of Global Virtual Design, Development & Validation at General Motors. In this role, he and his team are responsible for the computer-aided engineering (CAE) of every component, sub-system, and integration area of all current & future GM vehicles. He has held numerous positions during his 30 years at GM, including Executive Director of Global Transmission & Electrification Hardware, Executive Director of Global Engine Hardware, Global Chief Engineer and Program Manager of Four-cylinder Gas Engines, and Director of Engine Development & Validation. He is currently president-elect of FISITA, and a member of the Exascale Computing Project Industry Council. He holds a patent on engine variable valve lift control and has published on various powertrain technologies. He has also been an instructor on powertrain design & integration at the University of Michigan & the SAE Spark Ignition Engine Technology Engineering Academy. Anderson earned his Bachelor of Science degree in Mechanical Engineering from Purdue University, and a Master of Science degree in Mechanical Engineering from the University of Michigan.

Plenary Lectures

Christian Oertel – Brandenburg University

Professor of Applied Sciences, Mechatronics

Title of Talk: ***Virtual Tires: Requirements, Fields of Application and Ways of Implementation***

Dr. -Ing. Christian Oertel is a Professor at TH Brandenburg University of Applied Sciences, Mechatronics. He leads research and development teams in various industry and government sponsored research and development programs in collaboration with commercial software companies like T-Systems and IAT in Berlin. His areas of research include; tire mechanics including the development of the tire model family RMOD-K, vehicle system dynamics including tire models and full vehicle multibody simulations, tire testing and the tire property lab at TH Brandenburg, and virtual tire modelling including the development of a finite element and database based system. He earned his PhD at the Technical University of Berlin.

Mike Stackpole – Stackpole Engineering Services

Founder & President

Title of Talk: ***The Evolution of Engineering Tools and the Virtual World in Motorsports: A Personal Story***

Michael Stackpole is the Founder and President of Stackpole Engineering Services based in North Canton, Ohio. He obtained his Master of Engineering Degree from the University of Akron in Akron, Ohio. Early in his career, he worked in various vehicle dynamics and tire modeling technical roles at both The Goodyear Tire & Rubber Company and Bridgestone/Firestone. There he developed expertise in the areas of tire/vehicle simulation development, tire testing and custom tire modeling. He established Stackpole Engineering Services over 20 years ago to further this expertise, providing engineering software solutions, tire testing, tire modeling and engineering services in support of OEM Vehicle and Tire Manufacturers and Professional Race Programs across the globe. With more than 30 years of career highlights on his resume, he has experienced first-hand the evolution of engineer tools and the virtual world throughout the sport of auto racing in Formula 1, NASCAR, SportsCar and IndyCar.

Live Panel Discussion

Virtual Tire Submissions: Challenges from the Automotive Industry

This panel discussion features users of virtual tire submissions from the automotive industry. In this panel, they will discuss topics such as:

- What are the drivers for virtual development? What is the virtual tire's contribution to that effort?
- What are the unmet needs in virtual tire submissions for current vehicle development?
- What will be the future requirements for virtual tire submissions?

Tom Ebbott
Moderator
R&D Fellow
The Goodyear Tire & Rubber Company

Greg Bunting
Global Technical Manager
General Motors

Dr. Günter Leister
CEO
TWMS Consulting

Jan Prins
Technical Specialist
Wheels and Tyres
Jaguar Land Rover

Madhu Rao
Senior Engineer
Chassis Engineering
Tesla

Mario Weinberger
Specialist - Tire Development Process
BMW Group

Live Panel Discussion

The Next Chapter in Tire Model Technology

This panel discussion features developers of tire model technologies. In this session, they will discuss the cutting-edge technology being developed for modeling tire behavior for vehicle simulations. The topics for this discussion may include:

- Tire Thermal Modeling
- Tire Wear Modeling
- Tire Wet Modeling
- Tire NVH Modeling
- Snow / Soft Soil Modeling

Mike Stackpole
Moderator
Founder and President
Stackpole Engineering Services

Flavio Farroni
CEO & co-founder
MegaRide

Axel Gallrein
Tire Simulation Division MF
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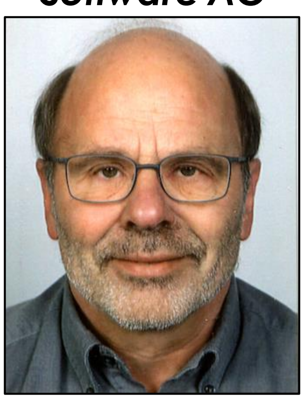

Christian Oertel
Professor of Applied Sciences, Mechatronics
Brandenburg University

Willem Versteden
Product Manager Simcenter Tire
Siemens Digital Industries Software

Modal Coupling Analysis of Tire-Rim Assembly

Tan Li[1,2]
Joe Shan[2]
Christopher Lu[2]

Tire modes have a significant effect on vehicle ride, vibration, and noise performance. They are important for identifying NVH issues and performing vehicle simulations. Rim is an important component in the vibration transfer path and may have significant influence on the tire modal behavior. In this study, a 195/65R15 slick tire is used to demonstrate the modal testing and simulation of the tire-rim assembly.

Tire mode shapes (CnWm where n indicates circumferential order and m indicates width order) include series of tire balloon mode (W1), drift mode (W2), sidewall bouncing mode (W3), lateral bending mode (W4), crown bending mode (W5), and sidewall shear mode (W6). Rim mode shapes are categorized into flanges in-phase (Fn IP) mode series and flanges out-of-phase (Fn OP) mode series.

Both simulation and measurement show that tire modes can strongly couple with rim modes when their natural frequencies and deformation shapes are close, resulting in significant vibration transfer and structure-borne noise. For example, at ~200–400 Hz: C1W6 (sidewall steer) tire mode may couple with F1 (first circumferential order) rim mode; C2W6 (sidewall warp) tire mode may couple with F2 (second circumferential order) rim mode. In addition, aluminum rim typically shows higher coupling frequencies and lower vibration amplitudes than steel rim.

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Design and Optimization of Tire Traction During Lateral and Longitudinal Dynamics Using Fuzzy Logic for Autonomous Vehicles

Dileepan Anandan[1,2]
Kaushik Kumar[2]
Pruthvi Krishnamurthy[3]

In future, Autonomous Vehicles will be in a growing trend to achieve 100% accuracy in maintaining safety and performance, i.e. advanced technology like fuzzy logic needs to be implemented in the design phase. In this paper, we are going to use advanced fuzzy logic control to precisely optimize the required tire traction with respect to tire friction parameters (Slip Angle and Slip Ratio) during longitudinal (Acceleration and Braking) and lateral (Cornering) Dynamics. We have considered the Slip ratio and Slip angle as input. Lateral Force, Longitudinal Force, and Self Aligning Moment are calculated as required output for an autonomous driving condition. This will help in maintaining the use of tire performance at various stages of autonomous vehicle operation. Longitudinal and lateral dynamics calculations are carried out using the Pacejka tire model with some tire empirical values.

Keywords: Autonomous, Self-Aligning Moment, Fuzzy Logic, Lateral Force, Longitudinal Force, Slip Angle, and Slip Ratio.

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An Algorithm for Estimating Tread Depth for Intelligent Tire Solutions

Tom Sams[1]

Tread depth sensing has become a focal point for intelligent and smart tire concepts. It is one of the most important measurements in that it is a major safety concern when the tire is worn past the treadwear indicator. As autonomous vehicles become more widespread, tire tread depth sensing will become a necessity as there will no longer be a driver to visually inspect or measure the tire tread depth. Even when there is a driver present, a large percentage of drivers do not know when their tires need to be replaced.

An algorithm for estimating tread depth from only contained air and ambient temperature measurements has been developed. These measurements can be made with conventional TPMS. The algorithm is based on the physics of tire cool-down, where the tire mass is directly proportional to the thermal time constant. A series of drum tests were performed, which demonstrated the ability of this algorithm to estimate tread depth with less than 5% error for a PSR tire. The algorithm becomes much more accurate for larger tires such as those used for TBR applications. This algorithm can work for any tire, with only a few basic parameters needed such as size and original tread depth.

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Tire Multiphysical Modelling for The Analysis of Thermal and Wear Sensitivity on Vehicle Objective Dynamics and Racing Performance

Andrea Sammartino[1,3]
Damiano Capra[2]
Flavio Farroni[3]
Antonio Maiorano[3]
Aleksandr Sakhnevych[3]

The handling behavior of a vehicle is deeply linked to the phenomena occurring within the tire-road interaction, affecting the vehicle performance and safety potential. Among the tire dynamic models, Pacejka's Magic Formula (MF) tire model is undoubtedly one of the most widely adopted tire models for both offline optimization routines and online real-time simulation environment in the automotive field. The original MF formulation does not take into account of the tire thermodynamics and wear effects, clearly affecting the tire and therefore the vehicle dynamics, to be necessary especially for high level applications, such as motorsport competitions.

Exploiting a multiphysical calibrated tire model, consisting in an evolved version of the standard MF model (MF-evo), and a properly parametrized vehicle model, validated throughout experimental outdoor data, the current work extends the study on the vehicle behavior's variations induced by thermodynamic and wear conditions, defining a series of advanced metrics to analyze and to correctly interpret the results. Particular attention is addressed toward the possibility to highlight how under-oversteering behavior of a car changes according to different thermodynamic states of tires; to achieve this, a commercial software has been used to perform a series of objective steady-state maneuvers and long runs employing the virtual driver, exploiting the logic of a lap time optimizer.

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Analysis of Off-Road Tire Cornering Characteristics Using Advanced Analytical Techniques

Fatemeh Gheshlaghi[1,2]
Zeinab El-Sayegh[2]
Moustafa El-Gindy[2]
Fredrik Oijer[3]
Inge Johansson[3]

This paper focuses on analyzing the cornering characteristics of an off-road truck tire running under several operating conditions over different soils. The Finite Element Analysis (FEA) technique is used to model the 315/80R22.5 truck tire, while the Smoothed-Particle Hydrodynamics (SPH) technique is used to model the soil. Tire and soil models are validated using experimental data and published measurements. The tire-soil interaction is investigated under different tire conditions such as longitudinal speed, inflation pressure, vertical load, and slip angle; in addition to various soil characteristics such as cohesion, internal friction angle, and rut depth. Cornering force, self-aligning moment, and overturning moment are studied in this paper as the fundamental cornering parameters that affect truck lateral stability and control. The Genetic Algorithm (GA) technique is used to develop a relationship between the cornering parameters and operating conditions. The GA equations will later be implemented into a full vehicle model to evaluate the full vehicle performance.

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Experimental Friction Analysis Through Innovative Compound-Substrate Contact Modelling for Automotive Applications

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The knowledge of the tire viscoelastic properties, deeply affecting the tire dynamic behavior, is a particularly crucial topic for tire manufacturers to achieve the objective of friction performance and to govern the degradation mechanism during the tire life cycle.

To this purpose a friction model, called Gr.E.T.A. (Grip Estimation for Tyre Applications), aiming to predict the friction coefficient at different possible operating conditions, in terms of temperature, pressure and relative velocity, arising at the contact patch tire-road interface, is proposed. The Gr.E.T.A. model requires both the roughness parameters, associated with micro- and macro-scale of the road profile, and the viscoelastic properties of tire compound, function of temperature and excitation frequency in order to mathematically describe the contact phenomena between the rubber surface and the substrate counter face. The compound characterization has been achieved employing a non-destructive methodology VESevo, capable of estimating the viscoelastic Storage Modulus and Loss Factor, whereas the road profile characteristics have been optically acquired and synthetized.

To validate the model outputs, a specific experimental campaign has been conducted employing an evolved version of the British Pendulum bench with different tire road profiles and compound specimens.

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Exponential Decay of Contact-Patch Friction Steering Moment with Rolling Speed

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Steering torque is a very important quantity for the driver feeling. In fact, it gives the driver an idea of the road adherence condition while driving the vehicle. Several models are available in literature to simulate shear forces at the contact patch, most of them are based on semi-empirical tire models that account for tire slip and slip angles. They have good reliability when speed is medium and high. At very low speed, like in parking maneuvers, these models suffer from both reliability and numerical issues. This paper presents a model to compute the steering moment due to contact-patch friction at any longitudinal speed including pivot steering condition. In particular, it supplements the pivot steering model with a novel exponential decay of moment model to simulate various rolling speeds of the wheel. The decay rate of steering moment found to be dependent on contact-patch geometry and rolling speed. The steering moment obtained with the proposed model can be combined with self-aligning moment obtained from the slip based empirical models to obtain the net steering moment.

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VESevo, An Innovative Device for Non-Destructive and Smart Viscoelastic Characterization of Tire Compounds

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Viscoelastic properties of tires compound play a fundamental role in the vehicle dynamics affecting both the vehicle performances and the safety according to different working conditions depending on road roughness and temperature.

The knowledge of these properties is usually carried out by means Dynamic Mechanical Analysis (DMA) on compound samples suitable for laboratory conditions, which can be specifically produced for the test or extracted from the tire, causing its destruction.

In this scenario, the Applied Mechanics research group of the Department of Industrial Engineering at the Federico II has developed an innovative device, called VESevo, capable of providing a smart and non-destructive characterization of the viscoelastic properties of tires tread compound. The patented technology of the VESevo allows the characterization of the Storage Modulus and the Loss Factor thanks to the build-in high-accuracy sensors, which enable the user to carry out many measurements at different conditions and directly in-situ.

The possibility to obtain the compounds viscoelastic response by means of a totally non-destructive and non-invasive procedure, opens scenarios of interest in a very broad panorama of applications ranging from the monitoring of the material performance during its whole lifecycle, to the quantitative analysis of products quality and repeatability of production processes.

In this work, the authors present the VESevo technology comparing the results to the ones obtained with the standard Dynamic Mechanical Analysis technique.

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FTire - Engineering a Virtual Tire

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The automotive industry is facing unprecedented challenges due to the reduction in development time of new vehicles and tires. To achieve this goal the industry increasingly relies on virtual prototyping in the development process. An accurate representation of the tire is critical to ensure the validity of the developed virtual prototypes. This is especially true for extremely dynamic simulation maneuvers where the tire is subjected to complex operating conditions. FTire is a highly accurate physics-based, 3D nonlinear, real-time capable tire simulation model that is ideally suited for advanced vehicle dynamics simulations. FTire is the industry-leading physics-based tire model that takes the role of the tires digital twin.

Finite Element (FE) tire models are widely used in tire industry for tire design and development. Although FE tire models can provide extremely high detailed insight into the tire behavior the usefulness of these models in vehicle dynamic simulation environment is limited due to the extremely long solving time. The paper presents recent activities to facilitate, unify, and automate data transfer from FE models to FTire. These new tools do not only support the rapid development of new tire designs, but also establish a method of providing a highly accurate virtual tire for the wider automotive industry during the very early pre-production tire development stage.

This virtual tire, expressed in terms of a ready-to-run FTire data set, can then be used as digital twin of the tire for all kinds of dynamics assessments, including real-time HiL and driving simulator applications.

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adheLAB: Advanced Calibration Tool for a Real-Time MF-Based Multiphysical Model

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In an increasing number of vehicle dynamics applications, from virtual prototyping and on-board control systems to real-time simulations, a tire-road interaction model is essential to obtain reliable results in reality's representation.

In the recent years, an advanced multiphysical tire model, called adheRIDE, has been developed to take advantage of the accuracy and quite low computational cost offered by the tire Magic Formula dynamic model, also including the effects due to tire thermal and wear conditions, compound viscoelastic properties, and road roughness characteristics, employing auxiliary multiphysical formulations, modifying the parameters of the original MF model in runtime.

The necessity to parametrize the advanced MF model has led in the development of an interactive tool adheLAB, able to identify the miscellaneous model parameters on experimental data acquirable in outdoor or indoor testing sessions. The adheLAB tool is presented highlighting the methodological steps and the smart features introduced. The goodness of the model parameterization and the potential of the adheLAB methodology is validated on a real case-study, employing the experimental data acquired in outdoor handling session with a motorsport partner.

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Evaluation of Virtual Tire

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The virtual tire as a key component accelerating the vehicle development needs to be evaluated at the sub-system level before plugging it into the full-vehicle system. The current study focuses on establishing a framework for systematic evaluation of tire model (virtual tire), assuming the model already can pass the code verification. This broad topic is divided into three parts.

1) quantitatively define the applicable domain of a virtual tire;

2) validate a model as a black-box within its applicable domain merely through testing the input-output relation against physical measurement. The challenge comes up when model prediction deviates from measurement. Because neither measurement is ideal, nor simulation reflects every aspect of the real world. What effort should be made to reduce the discrepancy;

3) how to deal with the situation when the parameter identification process leads to non-unique sets of model parameters resulting in similar model performance.

The proposed evaluation scheme was applied to industry-wise widely used commercial virtual tires such as MF-Tyre and FTire. Each subject is discussed in detail with specific examples from the knowledge base of GCAPS who provides competitive tire modeling services for vehicle companies for years. Many pieces of evidence point us to a famous aphorism, "all models are wrong, but some are useful," which applies to the virtual tire as well.

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Modeling and Simulation for Virtual Tire Development

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Many transformations are currently taking place in the automotive industry. One example is the transition of the product development process from one heavily reliant on the building and testing of prototypes to one that is heavily reliant on modeling and simulation.

Finite element modeling and other types of structural models have been used for decades to provide design direction and reduce the number of prototype build and test cycles. Capabilities to predict many tire performances have been developed and published over the years, including tire durability, rolling resistance, treadwear, force and moment, noise, and others. These capabilities largely target objective measures of tire performance, such as those that can easily be measured in a laboratory. The performances that have evaded quantitative prediction are those that require a test driver's evaluation with prototype tires tested on a vehicle. Subjective ride and handling are the main performances that have required the building and testing of prototypes as the only reliable method of evaluation. With the advent of the modern generation of vehicle simulators, the driver-in-the-loop subjective performance evaluations can now also be accomplished ahead of building and testing physical prototypes.

This presentation will provide a look at a tire development process that utilizes finite element analysis and other predictive methods for many tire performances, together with the use of vehicle simulators, for the evaluation of subjective response. This combination will provide a total virtual development platform to meet the requirements of the OE or replacement markets and will provide more mature tire designs prior to building and testing physical prototypes.

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Tire Durability Prediction Using Three-Element Layered Mesh for Cord-Rubber Composites

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Cord-rubber composites are used in tire structures due to their superior strength in high-cycle fatigue applications. A durability analysis can be conducted on a tire, to predict the time for crack initiation in rubber to occur in various regions of the tire. In this study, the cord-rubber composites were modeled in tire structures by embedding rebar elements for the cords within continuum rubber elements using ABAQUS.

Mesh refinement within the thickness direction is critical with the method described, due to the fact shear strain between reinforced layers has a significant effect on predicted rubber durability. This study highlights the importance of mesh refinement in the thickness direction in order to improve the fatigue life prediction in tire structures. A new three-element layered cord-rubber composite mesh is developed to predict crack initiation in tires.

This study describes the method by which the crack initiation can be predicted. The results of the simulation will be compared with and without the three-element layered composite mesh. The simulations utilized EnduricaDT for prediction of time to crack initiation. Validation of the predictions will be presented by comparing simulation results to measured tire durability results. Moreover, the effects of different factors such as higher normal loads on the tire durability are presented. In conclusion, it is shown how the fatigue life prediction in tire structures is improved using this methodology.

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Incremental, Critical Plane Analysis and Experimental Verification for TBR Tyre Bead Endurance Applications

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Rubber near internal steel cord endings is prone to failure, especially at the turn up region for TBR tyres, as seen in tyre failure reports from the field. Failures at this region have been measured experimentally using a multi-step Bead Endurance test. The failures have also been analyzed using incremental critical plane analysis. This simulation method provides an estimate of the life of the tyre at the design stage. The simulation has been applied to determine the growth of the most critical crack using ABAQUS and Endurica DT for a 11.00R20 TBR tyre and a 10.00R20 TBR tyre operating at 830 kPa and loading up to 200% of rated load. The applied load and DT protocol used is based on the Bead Endurance tyre testing protocol. The results of the Endurica DT simulation are compared with scalar invariant theory (i.e., strain energy density) for the two designs. The results are also compared with the actual testing results as obtained from the Bead Endurance test to ensure the validity of the developed simulation process. The simulation method gave greater than 90% correlation with the actual Bead Endurance test results and is now in use as part of New Product Development cycle.

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A Micro-sphere Based Rubber Curing Model for Tire Production Simulation

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In this contribution, a constitutive model for rubber is presented, which describes the material in its unvulcanized and vulcanized state as well as during its phase change. The model is based on the micro-sphere approach to represent the macroscopic behavior by a finite number of microscopic polymer chains.

When the uncured rubber is exposed to large temperature, the polymer chains build up crosslinks with each other and the material changes from soft visco-plastic to stiffer visco-elastic behavior. The state of cure over time at different temperatures is identified via a moving die rheometer (MDR) test.

Based on this experimental data, a kinetic model is fitted to represent the state of cure in the simulation. The material model changes from an unvulcanized state to a vulcanized state based on the current degree of cure in a thermo-mechanically consistent manner and fulfills the second law of thermodynamics. The curing model framework is suitable to combine any given material models for uncured and cured rubber.

The presented material formulation is applied to an axisymmetric tire production simulation. Therefore, the kinetic state of cure approach is fitted to MDR experimental data. The uncured and cured material model parameters are fitted separately to experiments with a gradient based fitting procedure. The in-moulding and curing process of the tire production is simulated by a finite element approach. Subsequently, the simulated footprint of the tire is compared to experimental results. It can be shown, that the quality of the footprint could be optimized by changing the shape of the green tire solely.

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A Model for Predicting Residual Casing Life of a Tire Following an Impact Event

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By applying recognized engineering methods, including finite element analysis, the role of impact events on the service life of a tire was studied including effects of speed, wear conditions and angles of impact. The approach combines well-known finite element analysis methods to simulate a tire rolling over an obstacle with the calculation of damage at the tire belt edge imparted by the impact event using recognized methods of rubber fatigue analysis.

An equivalent simplified method is developed and used to demonstrate that across a range of impact conditions, some can cause substantial internal damage while other conditions can cause very little damage. The area of investigation is the tire belt edge, so even though significant internal damage may have occurred, it might not be detectable visually or in the normal operation of a vehicle. In some cases, the non-detectable damage is shown to propagate to a point where the tire loses its structural integrity prior to reaching its normal operating life defined by treadwear. This study includes the role of mechanical, temperature and rate effects.

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A Comprehensive Model for Characterizing Rubber Wet Friction

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This research was conducted to study the effect of road surface roughness and water film thickness on the friction coefficient of a rubber compound. The speed, load, and material effect on wet friction will also be investigated.

A friction testing machine is used to capture the friction properties of a cured rubber wheel. The machine uses a large drum wrapped in sandpaper as the road surface. A nozzle delivers water to the road surface at various flow rates. The small rubber wheel is run on top of the road surface at a pre-determined vertical load, speed, and slip rate. The output data includes the friction coefficient and the slip rate.

The water film thickness is roughly estimated by the flow rate and geometry of the nozzle; at a drum speed of 50 km/h, the water film thickness is between 0.0096 mm (200 cc/min) and 0.144 mm (3000 cc/min). Various sandpaper grits are analyzed for surface roughness characteristics and the size of asperities is compared to the estimated water film thickness. Using established models, the friction coefficient is analyzed against the water depth to study the critical film thickness indicating saturation. The surface roughness effect on the friction coefficient is then studied and an attempt will be made to include the surface roughness parameter into the wet friction model. The surface roughness effect on two separate rubber compounds will be studied in addition to analyzing the effects of changes to the test load and speed.

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Experimental Investigation of the Influence of Snow Density, Temperature, and Moisture on the Friction Behavior of Tire Tread Blocks

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In nature, the mechanical properties of snow change due to the influence of the weather, which has a significant influence on the snow traction of tire tread blocks and affect the results of winter tire test. However, laboratory testing allows for a high degree of reproducibility and stability of these influences: We investigate the friction behavior of tire tread blocks on snow road surfaces on a linear rolling test rig RepTiL (Reproducible Tread Block Mechanics in Lab) [1].

The experiments with siped and unsiped samples resulted in a clear discrimination of tire tread performance between high (~30%) and low slip (<10%) conditions: Under high slip, especially on bad snow conditions (low density, high temperature and high moisture), the siped (winter) tire tread clearly outperforms the unsiped (all-season) tire treads. In low slip rolling conditions the difference between treads is not as clear. Under certain conditions, in particular on hard snow the unsiped (all-season) stiffer tread blocks can provide 5% higher traction.

In transfer to vehicle testing in winter conditions, we deduce that the ranking of a tire test with a reference tire is only a momentary snapshot of vehicle and environmental parameters, thus slip conditions as well as snow surface parameters (density, temperature, moisture) have to be monitored well.

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"Target Tracking" Capture, Visualization and Quantification of the Tire Tread Movement Under Dynamic Conditions

Dr. Lin Kung[1]
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Tire footprint has been studied for quite some time by researchers because of its impact on both tire and vehicle performance. Both static and dynamic footprint measurements have been developed with various sensing methods such as mechanical probes, contact paper, contact pressure mat, and optical images. Dynamic footprint image can render insight into the inner working of tire tread during contact with road surface.

The need to visualize tread movement within footprint has been a goal for many to further enhance understanding for improved tire performance. This paper presents an optical system to capture moving footprint image and track multiple points on the tread surface. The displacement of these tracked points under controlled loading, rolling and torque conditions were digitized and analyzed. The potential applications of the system are to be addressed.

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Evaluating Tire Tread Wear and its Dependence on Tire Working Conditions by Using the Finite Element Method and Archard's Wear Theory

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The tire industry still spends a considerable amount of resources for indoor and outdoor tests during the product development stage. Virtual tests can make this step faster, saving both money and time. Considering lifespan and mileage are important issues especially for truck tire consumers, virtual wear analyses give valuable information that help engineers to improve their products.

This study aims to exemplify a way to predict tread band wear using the finite element method approach and Archard's wear theory. Besides this, it shows the importance of following the vehicle revision plan as it has an impact on how long the set of tires will last. Tread wear simulation is implemented through user subroutine and adaptive meshing technique, while friction energy is calculated using a steady-state analysis at selected working conditions. Data collected from outdoor experiments provide the necessary information to check and validate the analysis.

The impact of the lack of an appropriate vehicle maintenance on tire wear is evaluated by changing some boundary conditions of the model such as load, inner pressure, camber and toe angles. The simulation results show good agreement with the information found in the literature.

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On-Road Vehicle Measurements of Tire Wear Particle Emissions and Approach for Emission Prediction

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Airborne particulate matter has long been associated with negative environmental and health impacts. Tire wear, in the form of particulate matter and microplastic emissions, could also lead to a potential hazard to human health and the ecosystem. To develop countermeasures reducing the tire wear, it is necessary to identify and classify all relevant influencing parameters. The presented study introduce a test vehicle, which enables the sampling and measurement of tire-induced emissions under different operating conditions. For this purpose, requirements of an efficient tire particle sampling system and the development process required for this are presented. The sampling setup ensures the separation of brake and tire wear emissions and includes measurement devices for particle number and mass as well as numerous driving dynamics parameters. Based on on-road tests, correlations between the driving dynamic load and the resulting particle emissions are analyzed. In addition, the tire wear mass is determined and compared with the gravimetric measurement of the emitted particle mass (PM_{10}). Based on the obtained data, model approaches for the estimation of emissions and tire wear are derived. Additionally, these models are implemented into a full-vehicle simulation to predict tire wear and particle emissions for other test environments.

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Active and Semi-Active Suspension Systems for Minimising Tyre Wear in Articulated Vehicles

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Electric and hybrid propulsion systems for articulated vehicles have been getting more attention, with manufacturers heading towards the electrification of heavy vehicles. This is motivated by the goal to decrease the particle emissions from the exhaust of conventional propulsion systems. However, the more environmentally friendly fully electric or hybrid articulated vehicles are expected to have increased non-exhaust pollution related sources compared to a conventional articulated vehicle. A fact that could potentially cancel the benefits of removing the exhaust, due to their significantly increased mass. One of the main sources of non-exhaust pollution is the tyre wear and can jeopardize the benefits of electrification in ground transport systems. Therefore, research has to be conducted towards this direction, and this is where this works lies.

Inner (tyre structure and shape) and external (suspension configuration, speed, road surface, etc.) factors are mainly affecting wear. This work focuses on suspension systems and more specifically on the ability of active and semi-active suspensions to decrease tyre wear in an articulated vehicle. In this direction, an articulated vehicle model, which has incorporated the tread in its modelling, is built to study its tyre wear during cornering over a class C road. The model is employed with passive, active (Hinf and PID controllers being employed), and semi-active suspensions (SH-2) aiming to investigate the induced levels of wear. Additionally, the suspension systems are also compared with regards to other vehicle performance aspects, i.e., driver's comfort and stability.

Important conclusions are extracted regarding tyre wear on articulated vehicles and the results aim to secure the benefits of electrification in heavy vehicles.

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"Mobility Ring" - A New Concept for Recovery of Mobility After a Tire Breakdown

Günter Leister[1]

A new mobility system, which can be mounted directly between the damaged tire and the wheel is presented which enables fast recovery of mobility for the customer. The mobility ring system consists of two resp. three parts, a ring divided optionally into two parts and a carrier cross. The ring is mounted on the defect wheel via the carrier cross and the ring resp. the ring parts can then be attached.

This new mobility system, which can be mounted directly on the defective wheel and enables fast mobility to the customers has a lot of advantages:

- Direct and fast mounting on the defective wheel
- In 5-10 minutes you can leave the dangerous situation
- No transport of the defective wheel in the vehicle interior
- Assembly over several inch sizes possible with one part.
- Speed limit 80 km/h
- Kilometer range: recommended to the next patrol station or change station
- Small pack size
- Weight reduction compared to emergency wheel and runflat tire
- WLTP advantages compared to runflat tire

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Evaluation of Driving Simulator Technology for Ride & Comfort using a Physical Tire Model

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An important component of the vehicle development process is the subjective evaluation by test drivers. In this phase, a professional driver subjectively assesses various key performance indicators of the prototype variants in a multi-attribute sense in order to choose the best candidates for the definition of the final product. The current challenge is to perform large parts of these subjective assessments at a driving simulator in a virtual environment in order to reduce the need of physical prototypes, reducing cost and turnaround time [1]. In the handling domain, it has been already demonstrated that a physical tire model like CDTire is fundamental for the achievement of this goal [2].

In this article, the authors would like to focus more on the ride and comfort domain. The physical tire model CDTire - in combination with a validated VI-CarRealTime vehicle model and the virtual proving ground from Applus+ IDIADA - are the key ingredients that allow a professional driver to perceive more realistic sensations and thus to asses a vehicle and tire setup variation over an extended attribute range.

To demonstrate this, the various phases of off-line model validation against measurements and virtual testing at the Applus+ IDIADA driving simulator are described in depth and analyzed. The results, as well as the advantages of this methodology for the subjective assessment are then discussed.

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Parking-Specific Parameterization Method for FTire

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Virtual steering system layout in the early development phase requires adequate tire models to predict realistic steering rack forces. An accurate representation of parking is particularly important as the largest steering rack forces occur during this maneuver.

Physical tire models are mainly parameterized for rolling conditions. Since the tire has different mechanics in non-rolling conditions, this paper introduces a new parameterization procedure for the physical tire model FTire, focused on the parking maneuver.

To this end, an additional full vehicle measurement setup is used to understand the tire motions, forces and moments during the parking maneuver. It is also shown that a tire model based on a standard parameterization procedure results in speed-dependent parking moment deviations of up to 18 % when compared to component measurements.

Thus, new measurement methods are developed to help parameterize the tire model specifically for this maneuver. A linear friction tester is used to determine the friction interaction between tire and road at the relevant relative velocities. In addition, measurements are performed on a tire stiffness test rig, in which translatory and rotatory movements are overlaid. Further, the contact patch shape, ground pressure distribution and tire outer contour are digitalized and added into the model.

A tire model based on the new parking specific parameterization is then compared to the standard tire modeling approach and component measurements as well as the full vehicle measurements. In conclusion, improvements of up to 12 % for drilling torque, up to 15 % for the longitudinal force, a more realistic lateral stiffness and improvements of up to 6 % when simulating the steering rack force can be stated.

After the results are evaluated and interpreted, recommendations for future developments of this parameterization procedure and an extension of the virtual tire model are discussed.

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Virtual Modeling of Steering Rack Loads Using Force and Moment Data

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Over the last two decades, the Electric Power Assisted Steering (EPAS) system has been gradually replacing Hydraulic Power Assisted Steering (HPAS) systems in vehicles ranging from small cars and SUVs to Class 2 trucks. With EPAS, an accurate rack load prediction is necessary in the early stages of vehicle development for the sizing of mechanical and electrical components. This is very important to ensure the system design meets safety standards, functional requirements, and system reliability; however, it is challenging to predict the rack load when the prototype vehicle is not yet available.

In order to address this challenge, the authors have developed a method of predicting the rack load without a prototype vehicle by sweeping a tire through virtual suspension geometry using the Tire Force and Motion Machine (TFM) at Link, where the TFM measures 3 forces and 3 moments while the tire is under load on a friction surface. The forces and moments measured from the TFM are analyzed through the suspension kinematics solver to produce the rack load, as if it was measured from the tie rod of the physical vehicle.

In this study, the method of generating motion commands for the TFM machine and the kinematic analyses on the measured forces and moments are presented. The method is validated with several vehicle tests, and a new concept of deploying tire characterization schemes for suspension design optimization is presented.

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Methods for Improving Correlation between Indoor Tire Test Data and Full Vehicle Simulation and Testing

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Indoor laboratory testing of tires plays a critical role in the development of both new tires and vehicles. While data from such testing help guide design decisions and support the creation of mathematical tire models, the correlation between indoor test data and full-vehicle proving ground results can be unpredictable and uncertain. With an increased reliance on CAE to predict vehicle handling, stability, durability and ride attributes, correlation issues can lead to program delays and higher costs.

This paper explores common causes for correlation issues and methods to improve correlation. This includes the effects of indoor testing methodology, data processing and modelling approaches, as well as proving ground test methods and instrumentation. Primary factors such as road surface, tire temperature and wear, as well as secondary factors such as transient tire response and enveloping behaviors are analyzed and compared.

The results show that improvements in correlation can be achieved through modest changes to the indoor testing approach. New approaches in modelling and simulation technology have also been identified to further enhance the correlation.

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