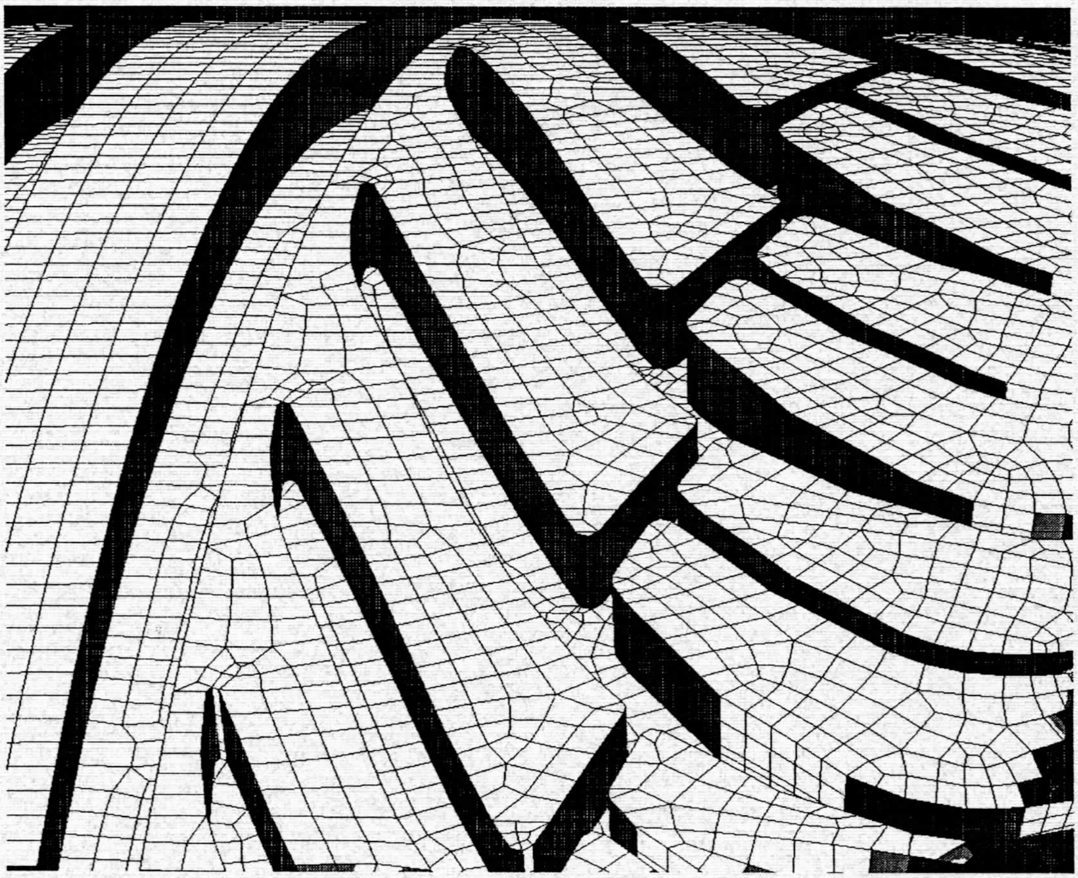
Tire Society 2005

24th Annual Conference on

Tire Science and Technology



September 20-21, 2005
Radisson Hotel, Akron City Centre
Akron, Ohio
www.tiresociety.org

Program and Abstracts

The Tire Society thanks the following sponsors for their support:

ABAQUS, Inc.

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(1) ~~THE~~ EVALUATION OF A ~~TIRE~~ Single POINT RO RES TEST
ML, Pepro, CAMB.

(2) DYNAMIC BEAD UNSEATING OF TIRES.
ML, FEED.

GOT CONDITIONS FROM NHTSA'S ROLLOVER EXPERIENCE FOR FSTDM.

The Tire Society, Inc.

24th Annual Meeting and Conference on
Tire Science and Technology
September 20-21, 2005
Radisson Hotel, Akron City Centre, Akron, Ohio

Overview

Day 1 – Tuesday, September 20

7:15 Registration

8:00 Opening: *Hamid Aboutorabi*, President of the Tire Society

8:15 **Keynote Address**: *Terry Gettys*, President, Michelin Americas Research and Development Corporation

9:00 Program Opening: *Ric Mousseau*, 2005 Tire Society Program Chair

9:05 **Session 1**
Design / Virtual Tire Development
2 presentations

9:55 Break (15 minutes)

10:10 **Session 1 - continues**
Design / Virtual Tire Development
3 presentations

11:25 Tire Society Business Meeting

12:00 Lunch (90 minutes)

1:30 **Session 2**
NVH / Ride
4 presentations

3:10 Break (15 minutes)

3:25 **Session 3**
Military Applications / Testing
4 presentations

6:00 **Dinner**
Speaker: *Dr. David Widauf*, Professor Emeritus, Utah State University

Day 2 – Wednesday, September 21

8:00 **Opening/Announcements**

8:05 **Session 4**
Tire / Vehicle Dynamics
5 presentations

10:10 Break (15 minutes)

10:25 **Session 4 - continues**
Tire / Vehicle Dynamics
2 presentations

11:15 **Plenary Lecture**
Speaker: *Joop Nagtegaal*, Corporate Fellow, ABAQUS, Inc.

12:00 Lunch (90 minutes)

1:30 **Session 5**
Tire / Pavement Interaction
5 presentations

3:35 Break (15 minutes)

3:50 **Session 6**
Materials
4 presentations

5:30 End of Program

Day 1 – Tuesday, September 20

7:15 AM		**Registration**	
8:00 AM		**Opening**	Hamid Aboutorabi, President of the Tire Society
8:15 AM		**Keynote Address**	Terry Gettys, President, Michelin Americas Research and Development Corporation
9:00 AM		**Technical Program Opening**	Ric Mousseau, Program Chair
9:05 AM		**Session 1: Design / Virtual Tire Development**	Steve Vossberg, Session Chair
9:05 AM	1.1	Development of a Non-Pneumatic Wheel	T. B. Rhyne, S. M. Cron
9:30 AM	1.2	Ranking Tires For Heavy Truck Steering Feel Performance Using a Simulation Model	S. L. Haas
9:55 AM		**Break**	
10:10 AM	1.3	Multi-Objective Design Problem of Tire Wear and Visualization of Its Pareto Solutions	M. Koishi, Z. Shida
10:35 AM	1.4	Nonlinear, Finite Deformation, Shell Model Analysis of the Tire Structure	D. Bozdog, W. W. Olson
11:00 AM	1.5	Rim slip and Bead Fitment of Tires: Analysis and Design	C. C. Lee
11:25 AM		**Tire Society Business Meeting**	
12:00 PM		**Lunch**	
1:30 PM		**Session 2: NVH / Ride**	Bob Wheeler, Session Chair
1:30 PM	2.1	In-vehicle Noise Study of the Effect of Four Experimental Design Tires	L. E. Kung, G. J. Kim
1:55 PM	2.2	An Approach to the Prediction of Radiated Tire Noise Using FEM and BEM	I. Shima, V. Q. Doan
2:20 PM	2.3	Reducing Tire-Induced Noise and Vibration	G. M. Hulbert, C. Yilmaz, N. Kikuchi
2:45 PM	2.4	Transient Response Simulation of an Off-Road Motorcycle with Conventional and Multi-Cell Tire Inflation Mechanisms	C. M. Richards, T. W. Summers
3:10 PM		**Break**	
3:25 PM		**Session 3: Military Applications / Testing**	Sally Shoop, Session Chair
3:25 PM	3.1	System and Method for Determining Status of a Tire by Insonification	G. L. Mason, J. A. Evans
3:50 PM	3.2	Evaluation of Low Impact Military Tires	P. D. Ayers, H. Howard, A. Anderson, Q. Li
4:15 PM	3.3	Tactical Military Tire Qualification Testing, SAE J2014	B. Horachek, J. Arnold, H. C. Hodges
4:40 PM	3.4	Lateral Tire Performance on Winter Surfaces	G. E. Phetteplace, S. A. Shoop
5:05 PM		**End**	
6:00 PM		**Dinner**	D. P. Widauf
		The Utah State University Wright Flyer Project	

Day 2 – Wednesday, September 21

8:00 AM		**Opening/Announcements**	
8:05 AM		**Session 4: Tire / Vehicle Dynamics**	Jim McIntyre, Session Chair
8:05 AM	4.1	A New Analytical Tire Model for Cornering Simulation. Part I: Cornering Power and Self-aligning Torque Power	K. Kabe, N. Miyashita
8:30 AM	4.2	A New Analytical Tire Model for Cornering Simulation. Part II: Cornering Force and Self-aligning Torque	N. Miyashita, K. Kabe
8:55 AM	4.3	Two Dimensional Cornering Theory of a Radial Tire	S. N. Kim, I. J. Park, H. H. Gwak, T. Akasaka
9:20 AM	4.4	Load and Inflation Effects on Force and Moment of Passenger Tires Using Explicit Transient Dynamics	H. H. Liu
9:45 AM	4.5	A New Test Procedure for Measuring Tire Forces and Moments at Goodyear	H. Gong, S. Vaduri, R. Kuster, G. Simms
10:10 AM		**Break**	
10:25 AM	4.6	~~The Effect of Gross Over Inflation on Vehicle Handling~~ PRACTICAL EVALUATION of TIRE FORCE & MOMENT DATA	J. A. Popio, R. A Wheeler
10:50 AM	4.7	The Impact of Plus-Sized Wheel/Tire Fitment on Vehicle Stability	J. W. Daws, R. E. Larson, J. C. Brown
11:15 AM		**Plenary Lecture:** An Overview of Analysis Methods for Rolling Tires	J. Nagtegaal
12:00 PM		**Lunch**	
1:30 PM		**Session 5: Tire / Pavement Interaction**	Steve Haas, Session Chair
1:30 PM	5.1	Coupled Solid-Fluid Interaction Approach to Investigate Tire Hydroplaning	J. Isam
1:55 PM	5.2	Coupled Solid-Fluid Interaction Approach to Investigate Tire Viscoplaning	J. Isam
2:20 PM	5.3	Contact Analysis of Tire Tread Rubber on the Flat Surface with Microscopic Roughness	M. Kuwajima, M. Koishi, J. Sugimura
2:45 PM	5.4	Complex Tire-Ground Interaction Simulation: Recent Developments of an Advanced Shell Theory Based Tire Model	D. Bozdog, W. W. Olson
3:10 PM	5.5	Prediction of Tire Performance for Tread Pattern Development	R. Mundl, M. Fischer, W. Strache, K. Wiese, B. Wies, K. Zinken
3:35 PM		**Break**	
3:50 PM		**Session 6: Materials**	Dave Dryden, Session Chair
3:50 PM	6.1	The Behavior of Carbon Black Filled Natural Rubber Under High Strain Rates	S. A. Hussain, M. S. Hoo Fatt
4:15 PM	6.2	Modeling the Amplitude Dependence of Dynamic Stiffness for Filled Rubber with the Bergstrom-Boyce Model	W. V. Mars
4:40 PM	6.3	Effects of Material Properties on the Tire Thermal-Mechanical Characteristics	H. S. Yin, Y. S. Hu, D. L. Chen
5:05 PM	6.4	Evaluation of Tire Endurance With Respect to Shoulder Separation Based on the Material Characterizations and FEA	Y. Wei, Y. S. Hu, H. S. Yin
5:30 PM		**End of Program**	

About The Tire Society…

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

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Paper Number 1.1

Development of a Non-Pneumatic Wheel

Timothy B. Rhyne and Steven M. Cron
Michelin Americas Research & Development Corporation

Since its invention in the late 1800's the pneumatic tire has completely dominated rolling transportation with few exceptions. The pneumatic tire paradigm has easily withstood many challenges in the succeeding 100+ years by various non-pneumatic elastic wheel or spring wheel inventions. Recently, interest in "continued mobility" has provoked a new generation of hybrid solutions that combine a pneumatic tire and a means to provide some limited ability to continue to operate after a loss of inflation pressure.

Some fundamental questions remain. Is there a structural wheel design that could mimic the beneficial properties of the pneumatic tire or even improve them? Could a structural wheel design break some of the fundamental constraints and compromises inherent in pneumatic tire? What new constraints and compromises might arise with such a structural wheel?

This paper presents a structural wheel design that mimics much of the mechanics of a pneumatic tire and takes advantage of some of the improvements that can be made by not having to contain inflation pressure. This structural wheel design is called a Tweel, meaning the integration of the tire and wheel. A deformable ring model, including extension and shear deformation, is used to demonstrate the physics of this wheel design. The model results will be compared to actual measurements made on physical prototypes.

- TIRE WORKS LIKE SPOKES AS CORDS ARE TENSIONED by AIR

Paper Number 1.2

Ranking Tires for Heavy Truck Steering Feel Performance Using a Simulation Model

Steven L. Haas
Michelin Americas Research & Development Corporation

The effects of seven different tire sets on heavy truck steering feel were demonstrated from objective testing. Also, the steering behavior and vehicle dynamics were modeled in order to determine how well the resulting simulations could rank the steering performance of the tire sets relative to the objective results.

The objective testing was performed using a 6x4 tractor with a two-axle semi trailer. Measured data included steering wheel torque, steering wheel angle, and lateral acceleration behavior resulting from on-center type steering tests. In addition, the hydraulic pressure from the power steering system was also measured. The tests consisted of multiple cycles at 0.2 Hz and ± 0.2g. Performance metrics relating to steering feel were calculated based on the interaction between measured parameters.

The same test procedure was also applied using an analytical model of a steering system. The input was steering wheel torque, and outputs included the road wheel angles at the steer axle, which were then fed into a commercial vehicle dynamics model providing the vehicle dynamics behavior along with feedback required for the steering model (e.g. king pin moments). Tire loads and slip angles were also provided by the vehicle dynamics model and used as input to a tire model predicting tire force and moment behavior. Steering performance metrics were subsequently computed and compared to the measured results.

The effects of the different tire sets on steering feel were clearly seen from both the objective and simulation tests. Seven performance metrics were applied in a ranking comparison between measured and modeled results. Correlation of the modeled to measured performance metrics ranged from R^2 values of 0.42 to 0.99 for the seven metrics considered.

F/M Properties significant role

SAE 840069 - On center handling → Norman

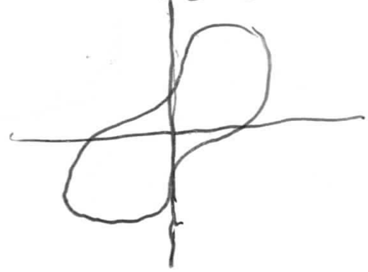
Sinus input 0.2 Hz * using TruckSim

± 0.2g Accel or less
80 KPH

Steering work / cycle

Lissajous pattern
SWA vs. Time
Ay vs. Time
Ay vs SWA

$\text{Work} = \frac{\pi}{180}\int (SWT)\, d\delta$



Paper Number 1.3

Multi-Objective Design Problem of Tire Wear and Visualization of Its Pareto Solutions

Masataka Koishi and Zenichiro Shida
The Yokohama Rubber Co., Ltd.

Since tires carry out many functions and many of them have tradeoffs, it is important to find the combination of design variables that satisfy well-balanced performance in conceptual design stage. To find a good design of tires is to solve the multi-objective design problems. However, due to the lack of suitable solution techniques, such problems are converted into a single-objective problem before solved. Therefore, it is difficult to find the Pareto solutions of multi-objective design problems of tires. Recently, multi-objective evolutionary algorithms are getting popular in many fields to find the Pareto solutions.

In this paper, a design procedure in conceptual design stage to solve multi-objective design problems and its solution visualization are showed. Multi-Objective Genetic Algorithm (MOGA) is employed to find the Pareto solutions of tire performance, which are in multi-dimensional space of objective functions. Response surface method is used to evaluate objective functions in optimization process and can reduce CPU time dramatically. However, it is difficult to see the multi-dimensional information obtained by MOGA. Self-Organizing Map (SOM) proposed by Kohonen can map data from high-dimensional space onto two-dimensional space. Using SOM, design engineers understand easily the relation among Pareto solutions of tire performance and can find good design variables.

Tire tread design is studied to improve uneven wear and wear life for both the front tire and the rear tire of a passenger car. Wear performance is evaluated by FEA. Response surface is obtained by the design of experiments and FEA. Using both MOGA and SOM, we obtain Pareto solutions on a map. We can find some combination of design variables that satisfy well-balanced performance on the map. It helps tire design engineers to make their decision in conceptual design stage.

Paper Number 1.4

Nonlinear, Finite Deformation, Shell Model Analysis of the Tire Structure

Dragos Bozdog and Walter W. Olson
University of Toledo

Shell model development of the tire structure has been limited in past works to small deformations and linearized models. These models have given researchers a limited insight into the static and dynamic properties of the tire. While these models are computationally efficient, they lack the ability to fully represent the tire, which undergoes large deformations as soon as the weight of the vehicle is placed on the structure. In this paper, a nonlinear, large deformation, model is presented. The resulting equations are solved numerically by assuming that the tire is a geometrically simple structure and inflated to a working internal pressure. This shell shape, which is essentially the same as that computed by small deformation, linearized, models, is then placed under increasing planar loads. The result is a shell that is no longer simple but is closely descriptive of tire structures. Finally, the body is rotated with friction at the planar surface. This paper will discuss the analysis that has been conducted to date.

Paper Number 1.5

Rim Slip and Bead Fitment of Tires: Analysis and Design

Ching-Chih Lee
The Goodyear Tire & Rubber Company

A tire slips circumferentially on the rim when subjected to a driving or braking torque greater than the maximum tire-rim frictional torque. The balance of the tire-rim assembly achieved with weight attachment at certain circumferential locations in tire mounting is then lost, and vibration or adverse effects on handling may result when the tire is rolled. Bead fitment refers to the fit between a tire and its rim, and in particular to whether a gap exists between the two.

Rim slip resistance, or the tire-rim frictional torque, is the integral of the product of contact pressure, friction coefficient, and the distance to the wheel center over the entire tire-rim interface. Analytical solutions and finite element analyses were used to study the dependence of the contact pressure distribution on tire design and operating attributes such as mold ring profile, bead bundle construction and diameter, and inflation pressure, etc. Independent design variables were identified to be the distributions of the tire-rim interference, the rubber gauge and modulus, and the stiffness of the bead "foundation." Based on the analyses, general guidelines are established for bead design modification to improve rim slip resistance and mountability, and to reduce the sensitivity to manufacturing variability. An iterative design and analysis procedure is also developed to improve bead fitment.

Any feel for effects on bead unseating

Paper Number 2.1

In-vehicle Noise Study of the Effect of Four Experimental Design Tires

Lin E. Kung
Kumho America Technical Center

Gi Jeon Kim
Kumho Tire Co., Inc.

A test procedure was developed to record and analyze in-vehicle noise near driver's ears. The procedure utilizes a portable dynamic signal analyzer system to acquire time based acoustic signals together with wheel rotational data. The recorded data were then analyzed in both frequency and order spectra for tire NVH.

A research project was coordinated between the two technical centers within the company to investigate two of tire design factors, namely steel reinforcement belt angle and sidewall ply gauge. Two parameters for each design factor were selected. Four sets of the design-experiment tires were then fabricated for each center and were independently evaluated, one by subjective assessments and the other by objective measurements. Comparison between the measured results and the subjective evaluation was made.

- MICRO Phones mounted TO ears
- IR TACHometer on vehicle Drive SHAFT
- several surfaces.
- coast Down 55 - 35 mph

Paper Number 2.2

An approach to the prediction of radiated tire noise using FEM and BEM

Ichiro Shima and Van Q. Doan
Toyo Tire & Rubber Co., Ltd.

Noise radiating from tires is one of the dominant sources which affects interior and exterior vehicle noise. For tires, it is well known that the air pumping noise of grooves, the impact noise of tread blocks and the vibration noise of body are thought of as the three main noise sources.
This paper presents an approach to the prediction of the radiated tire noise by taking those underlying structural and acoustical notions into consideration through modeling both a tire and acoustic field with the finite element method (FEM) and the boundary element method (BEM) appropriately according to those mechanisms. Results of example calculations on a car tire are given and experimental validations are also shown.

Key words: air pumping noise , impact noise , vibration noise, FEM, BEM

Paper Number 2.3

Reducing Tire-Induced Noise and Vibration

Gregory M. Hulbert, Cetin Yilmaz and Noboru Kikuchi
University of Michigan

Tire-induced noise and vibration spans a wide range of frequencies, depending on, among other attributes, tread design, road surface and vehicle speed. Vehicle designers are faced with the daunting task of minimizing this broad frequency spectrum of energy. The design of suspension systems must take into account the need to have a well tuned frequency response.

In this paper, a new approach towards minimizing tire-induced NVH is presented. The methodology is based upon a new perspective of employing anti-resonance, as opposed to damping phenomena, to effectively tune systems for practical performance. The mechanical structure of the system is amenable to cost-effective manufacture and can be packaged in different configurations. We present the fundamental approach towards the design and give several example configurations.

Paper Number 2.4

Transient Response Simulation of an Off-Road Motorcycle with Conventional and Multi-Cell Tire Inflation Mechanisms

Christopher M. Richards
University of Louisville

Thomas Wade Summers
TBDC, LLC

Resistance to complete pneumatic loss due to puncture is the primary purpose for using non-conventional multi-cell tire inflation mechanisms. However, recent subjective testing of one particular multi-cell mechanism also reveals beneficial ride performance characteristics. To gain scientific understanding of this additional benefit, an off-road motorcycle model is developed. Pneumatic stiffness behavior of a conventional inner-tube and the multi-cell inflation mechanism is described by a simplified tire model, which has been shown to accurately predict experimentally measured static stiffness data. Numerically simulated transient response data from the vehicle model is used to evaluate ride performance characteristics when the two mechanisms are used for tire inflation. Data analysis is also performed to reveal why performance improves when the multi-cell mechanism is utilized. The procedure is validated using experimental data collected on a real vehicle under conditions similar to the numerical simulation.

Paper Number 3.1

System and Method for Determining Status of a Tire by Insonification

George L. Mason and James A. Evans
Engineer Research and Development Center

This study introduces a method of insonification through the emplacement of a piezoelectric sensor on the rim of a tire to analyze tire performance. This research seeks to introduce an inexpensive method to evaluate discontinuous deformations of the tire through direct measurements including, insonification, thermal changes, and pressure, as measured internal to the tire.
The proposed effort is of particular importance because the Future Combat Systems are expected operated at high speeds under extreme on and off –road conditions. The current direction of the FCS mandates that the Army must provide proactive R&D work focused on how to evaluate wheel designs for advanced vehicle platforms.

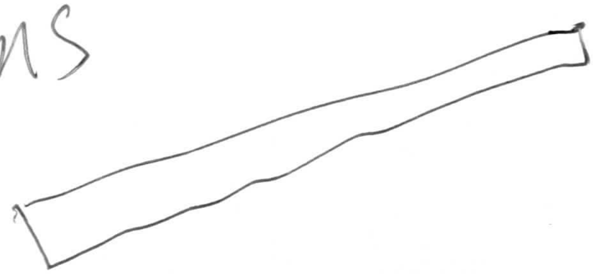
This paper will introduce several recent internal federal patents and commercial patents related to tire sensors. Sensors include piezo-electric, piezo-resistive, lasers, thermal digital camera, potentiometers, and octahedral stress transducers. We introduce in this paper an inexpensive sensor coupled with measurements of the tire while operating on a ridged and deformable surface. Initial analytical methods to include Fourier analysis, wavelets, and Kalman (state space) filters will be used to identify the most appropriate method to calibrate each system with the frequency range emitted internal to the tire.

RAW 30 min ASSUMED EQUILIBRIUM

-DATA FROM PIEZO TO TEMP DATA

• CONTAINED AIR PRESSURE, TEMP

TPMS



Paper Number 3.2

Evaluation of Low Impact Military Tires

Paul D. Ayers
University of Tennessee

Heidi Howard and Alan Anderson
Construction Engineering Research Laboratory (CERL)

Qinghe Li
University of Tennessee

Laboratory and field tests were conducted on three low impact tires (Interco Trxus, Mickey Thompson BAHA Belted HP, Kevlar Dick Cepek F-C) and a standard, currently used military tire (Goodyear Wrangler MT). Laboratory tests include deflection, rutting and plunger tests at pressures ranging from 10 to 30 psi and loads ranging from 600 to 2000 lbs. Footprint area was also measured. Field tests consisted of 1) driving single tires over a plunger at slow speeds and measuring plunger depth, 2) driving the vehicle (modified M1008) in a straight line at various tire pressures and measuring rut depth and disturbed width, 3) driving vehicle (M1097A1) spirals in sand and measuring rut depth and disturbed width, and 4) driving vehicle (modified M1008) spirals over vegetation and measuring disturbed width and vegetative impacts. Although differences between the tire performances exist, this study did not reveal any tires exhibiting consistently lower impact potential than the Goodyear Wrangler MT tire.

Paper Number 3.3

Tactical Military Tire Qualification Testing, SAE J2014

Brett Horachek, Jerry Arnold, and Henry C. Hodges
Nevada Automotive Test Center

Tire wear, failure and capability have come to the forefront of military vehicle logistics. The transport, supply, installation and use rate of tires can cause significant issues not only in the battlefield but also in the support of the troops and movement of all tactical and non tactical equipment and supplies. As a result of the issues found on today's battlefields, the military has placed a renewed emphasis on tire testing in accordance with SAE J2014. This paper discusses the SAE J2014, the development history of the specification, the test specification, the requirements, the procedures and the test conduct. The paper will present tire manufacturers with an insight as to how to prepare tires and the logic for the test.

Tire Noise Level

NATC

- Dimensional
- Traction
- Skid Resistance – Single wheel
- Ride Handling
- mechanical
- Stopping Distance
- Vehicle Evasive maneuver

Paper Number 3.4

Lateral tire performance on winter surfaces

Gary Phetteplace and Sally Shoop
Cold Regions Research and Engineering Laboratory

The Army has approved and funded an Army Technology Objective (ATO) entitled "High Fidelity Ground Platform & Terrain Mechanic Modeling." This ATO is being jointly performed by the Engineer Research and Development Center (ERDC) along with the US Army Tank Automotive Research, Development and Engineering Center (TARDEC) and the Army Research Laboratory (ARL). Two of ERDC laboratories are participating in the ATO: The Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, NH and the Geotechnical and Structures Laboratory (GSL) in Vicksburg MS.

One of CRREL major milestones for the ATO is to extend two-dimensional ground contact models for the TARDEC Real-time Simulator to full three-dimensional functionality by including the lateral forces. Central to that requirement is an understanding of lateral forces on all-seasons terrain. While modeling of vehicle tire lateral force interactions for typical hard paved surfaces is well understood, there is a need to translate that understanding in a consistent manner into off road terrain and low friction surfaces. The experimental work described in this paper is fundamental to gaining the required understanding.

The experimental work, performed with instrumented vehicles, included both lateral and longitudinal traction tests on winter surfaces. The surfaces included ice, packed snow, and unconsolidated snow. The two principal tires tested were an all season LT235/75R15 that has been the subject of many tests on the CRREL instrumented vehicle, and a tire used on the military's HMMWV, size 37X12.50R16.5. For each tire and surface, tests at a minimum of two inflation pressures were conducted. For each surface/tire/inflation variant a minimum of 10 replicate data sets were obtained. This paper will report the results of the tests and the analysis done to date.

CONTRACTED TO NATC

Paper Number 4.1

A New Analytical Tire Model for Cornering Simulation. Part I : Cornering Power and Self-aligning Torque Power.

Kazuyuki Kabe and Naoshi Miyashita
Yokohama Rubber Co., Ltd.

A new analytical tire model for cornering power CP and self-aligning torque power SATP is proposed on the basis of the Fiala model. In a pneumatic tire, the self-deformation by the transmission of force and torque is so large to influence recursively the force and torque generation during cornering. Then CP and SATP have negative feedback loops: As CP and SATP increase, the steering transmission loss by the tire self-deformation also increases to depress further increment of CP and SATP. The present model, the CP/SATP system model, analytically describes the force and torque transmission with feedback loops by taking into account not only *(i) the shear deformation of the tread rubber* and *(ii) the in-plane belt deflection*, but also *(iii) the out-plane sidewall rotation.* As well as other practical systems with a negative feedback loop, the CP and SATP feedback sustain the CP and SATP output level at higher vertical load, and approximates the measured load dependence of CP and SATP with high accuracy. Although the sidewall rotation feedback by SATP has not been considered in the conventional cornering studies, its contribution in recent radial tires is shown to be larger than that of belt deflection by CP.

Paper Number 4.2

A New Analytical Tire Model for Cornering Simulation. Part II : Cornering Force and Self-aligning Torque.

Naoshi Miyashita and Kazuyuki Kabe
Yokohama Rubber Co., Ltd.

An analytical tire model for cornering force CF and self-aligning torque SAT is described on the basis of the Fiala model. CF and SAT come mainly from the shear stress and sliding friction at the tread/road interface. And the CF and SAT variations also change the kinetic conditions for their own generations, that is, the contact pressure distribution, the tread-base shape, and the relative position of the steering axis within contact patch. The present model, the CF/SAT system model, which includes the conditional changes through the CF and SAT feedback loops, approximates the slip-angle dependence of CF and SAT with high accuracy. Least-squares fittings of the measured data with the combined use of the CP/SATP system model and the CF/SAT system model reveals the equivalent part stiffness, the tread friction coefficient, as well as the transient circumferential distribution of contact pressure. The system models may be useful for both the tire production at tire makers and the vehicle dynamics simulation at car makers.

Paper Number 4.3

Two Dimensional Cornering Theory of a Radial Tire

Seok-Nam Kim, In-Jeong Park, Hyun-Hwan Gwak
Hankook Tire Company

Takashi Akasaka
Chuo University

The explication on the cornering characteristics of tire is one of the important subjects for tire performance. Numerous experiments and theoretical approach on the cornering analysis have been studied since one-dimensional theory by E.Fiala. Most of previous works were related with some modification of specific parameters of Fiala's one-dimensional theory. Therefore, some unsolved problems have been remained when a tire is considered as a structural body. For instance, the side force from the Fiala's theory agrees well with experimental result but the SAT (self aligning torque) calculation is far from test data. In addition, slip region on contact area between tire and ground under cornering state cannot be explained because the changes of camber angle, contact pressure distribution and belt distortion are not considered.

In this paper, two-dimensional cornering theory considering the changes of contact pressure distribution under cornering behavior is suggested. Numerical solutions of side force, self aligning torque and slip boundary on contact surface of tire with respect to the slip angle are obtained and show good agreement with experimental results of passenger tire.

Paper Number 4.4

Load and Inflation Effects on Force and Moment of Passenger Tires Using Explicit Transient Dynamics

Hon H. Liu
The Goodyear Tire & Rubber Company

Explicit transient dynamics FEA (ABAQUS) has been used to model a rolling passenger tire (195/75R14) subjected to slip angle sweep of 0 to -1 degree. The computation tracks the rolling and yawing history of the tire on a 3m (10') diameter drum. Various loads and inflation pressures are applied and the computed forces and moments at a slip angle of -1 degree are compared to identify their sensitivities to these varying parameters. The study has found that for the small slip angle used, the lateral force is quite insensitive to inflation and vertical load. On the contrary, the moment is highly dependent on both. The difference in sensitivities is caused by the strong dependence of the moment on footprint size, which is controlled by both tire load and inflation. This analysis is useful in understanding tire cornering characteristics.

Paper Number 4.5

A New Test Procedure for Measuring Tire Forces and Moments at Goodyear

Harry Gong, Sunder Vaduri, Rich Kuster and George Simms
The Goodyear Tire & Rubber Company

Tire forces and moments (F&M) are one of the most important properties of a tire-vehicle system that affect the vehicle handling performance. Accurate and reliable F&M data is therefore critical to the successful application of modeling and simulation technology in vehicle/tire development.

It has been known for many years that test procedures, surface material and equipment greatly affect the measured F&M data. It was reported that in an extreme case 63% difference in measured cornering stiffness was observed between two different machines/procedures [1]. The European consortium TIME of tire & automotive companies developed a test procedure intended to be the standard for measuring tire F&M data for vehicle dynamics modeling & simulations [1]. However, because of the complexity of the test procedure and the resources it required to run the test, it is not widely used by the tire and automotive companies in North America.

Goodyear has developed a general-purpose test procedure that is suitable for measuring tire F&M data that can be used for vehicle handling dynamics simulations as well as for tire handling performance characterization. This paper describes the development and the advantages of this new test procedure. This paper also presents the handling simulation results using tire F&M data from this new test procedure. Comparison of simulation to actual on-vehicle measurements is also included in this paper.

Reference:

[1] *A New Standard for Steady State Cornering Tyre Testing* by Jan Oosten et al, Tire Society Annual Conference, April 2000

120 grit 3M-ITE 15 MINUTES

Vel = 50 KPH

Sweep = 4°/sec

CANNOT RUN MORE THAN 3 CA - SAME TIRE?

REGULATED INFLATION

100, 60, 140, 20, 180% BASE LOAD (VEHICLE APP)

CAMBER 0, -2, +4

-2 TO +12 TO -12 TO +2 @ 4°/sec

10 MIN BREAKIN

DATE TIRE

Paper Number 4.6

The Effect of Gross Over Inflation on Vehicle Handling

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Smithers Scientific Services, Inc.

Experimental tire data is commonly used in vehicle models. Tires have been characterized at several inflation pressures, and the changes in the tire performance were applied to the vehicle model. In this study, analytical, numerical and experimental results are reviewed. The performance of the vehicle is evaluated at various conditions.

Paper Number 4.7

The Impact of Plus-Sized Wheel/Tire Fitment on Vehicle Stability

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Plus-sizing in the tire industry is the growing practice of replacing a vehicle's original equipment wheel size with a larger diameter wheel and replacing the tire with a lower aspect ratio tire of the same diameter. This practice is normally associated with aftermarket sales, but there is a growing trend for vehicle dealerships to fit these larger wheels/tires to new cars. This paper discusses the general practice and its effect vehicle stability. A selection of vehicles taken from the NHTSA New Car Assessment Program's rollover "Star" rating program is used to illustrate the impact of plus sizing on static stability. Some of the dynamic tire effects that could influence vehicle stability are discussed. Dynamic testing using NHTSA's Fish Hook test protocol is used to demonstrate tire and wheel effects on tip-up characteristics. The effect of wheel offset, static stability ratio, tire size and tire behavior under extreme loading on the test vehicle are discussed.

Paper Number 5.1

Coupled solid-Fluid Interaction Approach to Investigate Tire Hydroplaning

Janajreh Isam
The Hashemite University

At certain wet driving conditions, over a road made of a certain surface texture, with a particular rubber tire sculpture, the available horizontal traction force will be dramatically reduced, thus hindering the steering and braking capabilities to the driver . Under these conditions the vehicle is said to be experiencing *hydroplaning*.

The loss of traction is due to an intervening fluid film characterized with a high hydrodynamic pressure which separates part of the tire contact patch from the road surface asperities. During hydroplaning glass pit measurements showed that tire contact batch goes under significant inward deformation and progression loss of contact, and in utmost conditions tire traction is left to the tire side wall.

The observed deformation strongly suggest coupled solid fluid analysis to capture and analyze the hydroplaning phenomena. This work present a weakly coupled fluid solid interaction. The weakly coupling is due to the large degree of freedom of the tire model and the large fluid computational domain size.

The fluid is governed by two phase, incompressible, viscous turbulent flow. The fluid domain is fitted with a multiblock body fitted mesh to easy the mesh deformation. The tire solid model, in the other hand, account for nonlinear rubber materials and the contact between the tire and the road.

This work is a continuation to the previous works of the author (Janajreh et al 2001) were the iterative solid /fluid coupling is added. These procedures allows the tire analyst to verify the effect of the architect as well the construction tire aspects. Two examples will be presented with some corresponding test validations.

Paper Number 5.2

Coupled solid-Fluid Interaction Approach to Investigate Tire Viscoplaning

Janajreh Isam
The HashemiteUniversity

The condition of a tire on a wet road, by in large, is analogous to that of lubrication where the tire tread starts to press on fluid on the road and penetrates through it during the contact time. This phenomenon is referred as viscous hydroplaning (or simply viscoplaning) which rises when a thin fluid film is trapped between the tread block and road asperities whereby hindering contact and minimizing traction.

In our work we intend to present a coupled fluid solid interaction analysis to predict viscoplaning tread block performance. The computational method will be verified analytically on a simple geometry. Our work will model the traction of tread-element as squeeze-film problem. The classical approach is to bring in contact two bodies normally which resisted by the intervening viscous fluid film (Saal, 1936; Moore, 1964, Kienel, 1974; Lee, 1997). This work is a continuation of the efforts of (Brown et al., 1975; Rohde and Oh, 1975; Whickers et al., 1976; Rohde et al., 1976 and Lee 1997 and 2000) who strongly suggested that tread element flexibility plays undeniable role in the fundamental nature of squeeze-film analysis

The sited studies had treated the tread material as linear elastic material (or rigid as in the case of Lee). This work will consider the nonlinear material behavior of the rubber computing hydrostatic pressure that govern by Navier-Stokes fluid equation. Results of the effect of the material, tread geometry, and different operating conditions will be presented to evaluate and demonstrate the sensitivity of the presented method.

Paper Number 5.3

Contact analysis of tire tread rubber on the flat surface with microscopic roughness

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Pavement surface roughness is the major factor affecting the frictional characteristic of tires.

The present paper describes a finite element analysis of the contact mechanics between tire tread rubber and the flat surface with microscopic roughness under partial slip. Rolling/sliding friction of tire tread rubber against abrasive papers, which was assumed to represent microscopic surface roughness of pavement surfaces, was measured at low slip velocities. The experimental results indicate that rolling/sliding frictional characteristics depend on the surface roughness, particularly on asperity peak density of the abrasive papers.

To examine the interfacial phenomena between rubber and the rough surfaces of the abrasive papers, real contact length and partial slip were analyzed under vertical load and tangential force, using two dimensional explicit finite element analysis together with slip velocity dependent frictional coefficients.

FEM results indicate that the total sum of lengths of real contact area and partial slip increase, for finer surfaces, when normal and tangential forces are the same. It is concluded that rolling/sliding friction, at low slip ratio, is affected by ploughing and hysteresis rather than by adhesion.

Paper Number 5.4

Complex Tire-Ground Interaction Simulation: Recent Developments Of An Advanced Shell Theory Based Tire Model

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University of Toledo

The formulation of an advanced shell theory based tire model (ASTBTM) provides the foundation for tire-ground interaction analysis. Micro-mechanics, composite laminate and shell theories are integrated in a consistent tire model solved by a dual symbolic-numeric algorithm. The complex tire-ground interaction is carefully examined by a sensitive numerical procedure and adaptive iteration step. Deformations and stress-strains of the entire tire structure are described as function of vertical, longitudinal, lateral, centrifugal, and friction forces with emphasis on contact interface. The accuracy of solutions is found to be highly depended on mesh size, but consistent over the iterations. The elaborate theoretical model is efficiently balanced by the symbolic computation reduction technique and the system numerical optimization. Finite difference method is used extensively. Simulation provides a step-by-step insight into force generation and macroscopic behavior of the tire. The code developed provides an alternative to existing tire model implementations in vehicle dynamics simulation software.

→ Better way to model a tire !?

* Brewer Tire Report

Paper Number 5.5

Prediction of Tire Performance for Tread Pattern Development

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High cost pressure and shorter product cycles have pushed the development of prediction tools for tire performance. In the present paper a survey will be given on these prediction procedures, which quantify the contributions of the tread pattern to the product performance. Specific focus is put on a user friendly tool surface with an immediately computed performance index as result. These tools offer therefore an efficient alternative to finite element based simulation models of the tire tread pattern only applicable by specialists.

First the way in which the surface geometry of the investigated tread pattern is discretized is described: to simplify algorithmic treatments afterwards the vector defined pattern geometry is mapped onto a pixel grid. The pixels gray values, ranging from black to white are associated to the depth of the pattern negative.

In the following the underlying physical/ mechanical model ideas are described and the algorithmic approaches are sketched. The tire performances under consideration are pattern noise, traction on different surfaces, pattern in plane shear stiffness, straight running behavior, groove sensitivity and uniform flow behavior of the green tire into the patterns negative in the curing mould.

At the end an outlook onto further prediction tools to be developed is given and the related concepts are outlined. The vision of a "total" prediction tool using weighted indices for all relevant pattern performances is developed. Based on a parameterized pattern geometry evolution strategy is applied and an optimal pattern is identified. Using this strategy a virtual development process for the tread pattern geometry fulfilling a set of required target performances will become feasible.

Paper Number 6.1

The Behavior of Carbon Black Filled Natural Rubber Under High Strain Rates

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The strain rates in tires can be well above those obtained from conventional quasi-static tests, which are generally below 1 s^{-1}. This paper illustrates the differences in the deformation and fracture behavior of natural rubber (NR) under high strain rates and what is observed under quasi-static loading. Tensile tests were conducted on an INSTRON electro-mechanical machine to obtain the deformation and failure of unfilled and carbon black filled NR 25, 50, and 75 phr of N550. High-speed tensile tests were then conducted on the same rubber specimens to obtain stress-strain curves at constant strain rates between 10-10^3 s^{-1}. The high-speed experiments were performed on a tensile impact apparatus, which uses a Charpy impact pendulum to impart tensile forces on the ends of the rubber strip. This was achieved by using the hammer to hit a slider bar, which was connected to two copper cables directed around pulleys and attached to sliding grips that hold opposite ends of the specimen. Piezoelectric load cells and linear variable displacement transducers on the grips recorded the load and extension.

The general trend observed from the quasi-static tests on NR is that the strength and stiffness increase with higher amounts of carbon filler, up to a certain value. Beyond this amount, the strength decreases with increasing carbon content while stiffness increases but at a slower rate. The increase of stiffness with percentage of carbon filler has been well-documented, but the decrease in strength with increasing amounts of carbon filler has not been documented as much in the literature. The decrease in tensile strength and fracture strain of NR with increasing carbon filler could be caused by the carbon agglomerates impeding strain crystallization.

The dynamic stress-extension ratio curves indicate that stiffness increases with strain rate but beyond a critical strain rate, the stiffness remains unchanged, i.e., a limiting curve is approached. This limiting curve is associated with the so-called instantaneous response of the material. The instantaneous response curve represents the material's stiffness without any measurable stress relaxation. The increase in stiffness with increasing strain rate is due to progressive absence of stress relaxation. The tensile strength and fracture strain usually increase with increasing strain rate but when the strain rate is beyond the critical value to reach instantaneous curve, both tensile strength and fracture strain decrease with increasing strain rate.

The general shape of the dynamic stress-extension ratio curves is different than those from the quasi-static tests. The initial (low strain) modulus of the dynamic stress-strain curves is very high and then decreases with extension ratio, while that of the static curve is low and increases with extension ratio. Dynamic stress-extension curves do not have the very sharp upturn at break, which is characteristic of NR under quasi-static loading. Since the upturn is associated with strain crystallization, one can assume that strain crystallization is a time-dependent phenomenon and can be suppressed with high rates of loading. In fact a comparison of the quasi-static and dynamic stress-extension ratio curves show that for any given amount of carbon filler, NR can be weaker and less stiff at high strain rates than under quasi-static conditions.

Paper Number 6.2

Modeling the Amplitude Dependence of Dynamic Stiffness for Filled Rubber with the Bergstrom-Boyce Model

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Under steady-state dynamic deformations, the apparent stiffness of rubber's stress-strain response depends strongly on strain amplitude. The effect is associated with the rubber's inelastic response, and is not captured by hyperelastic or linear viscoelastic models. With the aim of incorporating this effect into numerical simulations of tires, a constitutive model due to Bergstrom and Boyce has been evaluated for its ability to capture the effect. The relationship between the model parameters and the predicted dependence of stiffness on strain amplitude is explored. It is shown that the model is able to capture several important features of the response.

Paper Number 6.3

Effects of Material Properties on the Tire Thermal-mechanical Characteristics

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The ever-increasing demands on tire performances presents challenges on tire designer and materials engineers. Furthermore, the requirements of tire performance on tire materials are usually in contrast each other. Therefore, how to select and develop tire materials is a practical problem for tire designers and engineers. This paper presents a simple and effective method to evaluate the effect of tire rubber selection on tire thermal-mechanical characteristics, which play a key role in tire endurance of tire key parts, i.e. belt ends and bead areas. First, different tire shoulder and bead rubbers are designed with different loss tangent and hardness combinations, based on initial finite element analysis. Then parameter study is performed to obtain the local stress-strain cycles in the key areas of interest. These local stress-strain cycles provide the driving forces of thermo-mechanical fatigue and thermal degradation mechanisms. Based on nonlinear viscoelastic theory, the heat generation rates are determined. Then the local temperature fields are calculated by a simplified numerical analysis. From the calculated local temperatures and strain energy, the relative endurance properties of tire key areas can be evaluated, in which the fatigue and aging properties have to be considered. It can be shown that the materials selection and tire part geometric design have substantial impacts on the product endurance. By using the developed procedure, the tire designer can give an initial evaluation on tire rubber selection with relevance to the thermo-mechanical durability.

KEY WORDS: Hysteresis, Thermomechanical, Viscoelastic, Fatigue, Design, Durability

Paper Number 6.4

Evaluation of tire endurance with respect to shoulder separation based on the material characterizations and FEA

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The issue of tire durability attracts more and more attentions in the automotive as well as tire industry sectors. Tire Shoulder Separation-TSR is one of the most often seen problems leading to tire failure and usually causes safety problem of vehicles. The purpose of this present is to probe the causes of premature failure for typical heavy-duty radial tires. Structure and material factors are considered to be the two main factors of high relevance. The mechanism and failure modes are identified for typical heavy-duty radial tires. With respect to structural factors, stress and strain distributions in the area of the tire shoulder are obtained through using the nonlinear FEA. The nonuniformity of the tire belt component caused by manufacturing processes is modeled. In addition to structural modeling techniques, several material characterization techniques are also used to do the cause and effect analysis. Temperature, frequency and strain scan tests are conducted to obtain the dynamical mechanical properties of the rubbers of interest. Parameter study is performed to find the optimum compound combination, based on the minimum local shear strain as well as low heat generation criteria.

Furthermore, interactions among thermal-mechanical-chemical processes will be considered to decide the TSR underling mechanism. It is argued that the tire material arrangement and compound design should be optimized according to the heat generations as well as the stress and strain fields of the tire. Based on these analyses, some countermeasures against TSR by considering materials selection and optimum match for structural design will be provided. Potential improvements to reduce TSR problem will be pointed out.

KEY WORDS: Tire Shoulder Separation-TSR, Failure mode, Heavy-duty radial tires, Thermal-mechanical-chemical analysis.