



Efficient Characterization Methods for Structural Dynamics

Sandia-Goodyear Cooperative Research and Development Agreement (CRADA) 1640.03

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SD CRADA History



- More than 10-years of Structural Dynamics partnership between Sandia and Goodyear
 - July 1994 to May 1998; CRADA 1185, Computational Simulation and Verification Technologies for Tire Dynamics
 - Aug. 1998 to Dec. 2002; CRADA 1516, Efficient Characterization Methods for Structural Dynamics
 - Nov. 2002 to Nov. 2011; CRADA 1640.03, Efficient Characterization Methods for Structural Dynamics
- Goodyear T-VET contacts:
 - Tim Richards (1994–1996)
 - Rick Scavuzzo (1997–2000)
 - Mark Selover (2000–2002)
 - Eddy Pan (2003–date)

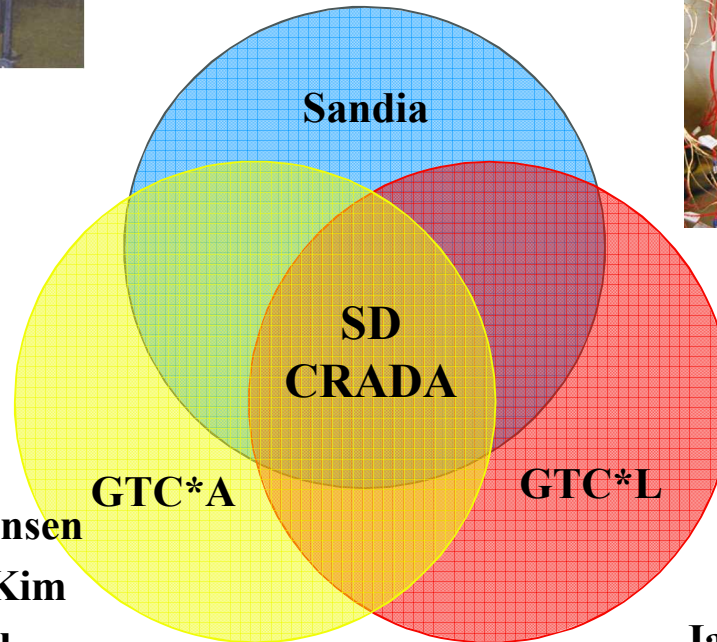
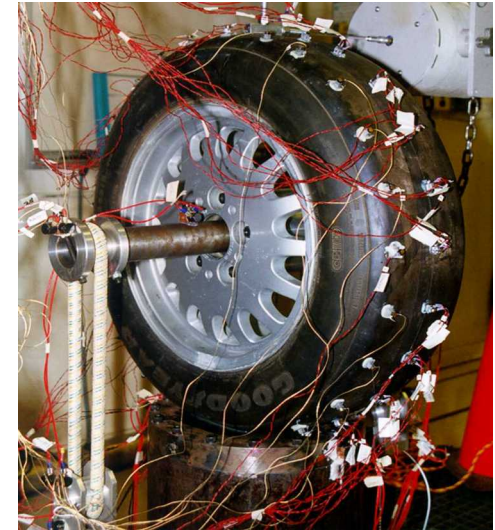
SD CRADA Project Team



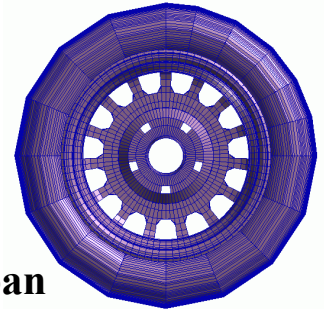
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Tom Carne
Clark Dohrmann
Curt Nelson



David Johansen
Seungbo Kim
YW Luk
Xianwei Meng
Eddy Pan

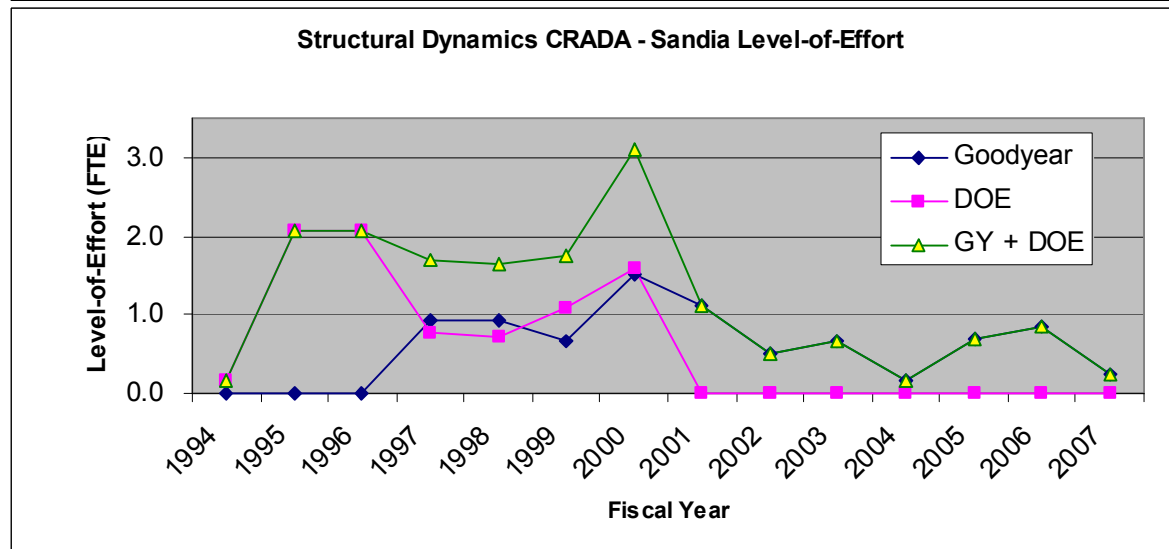
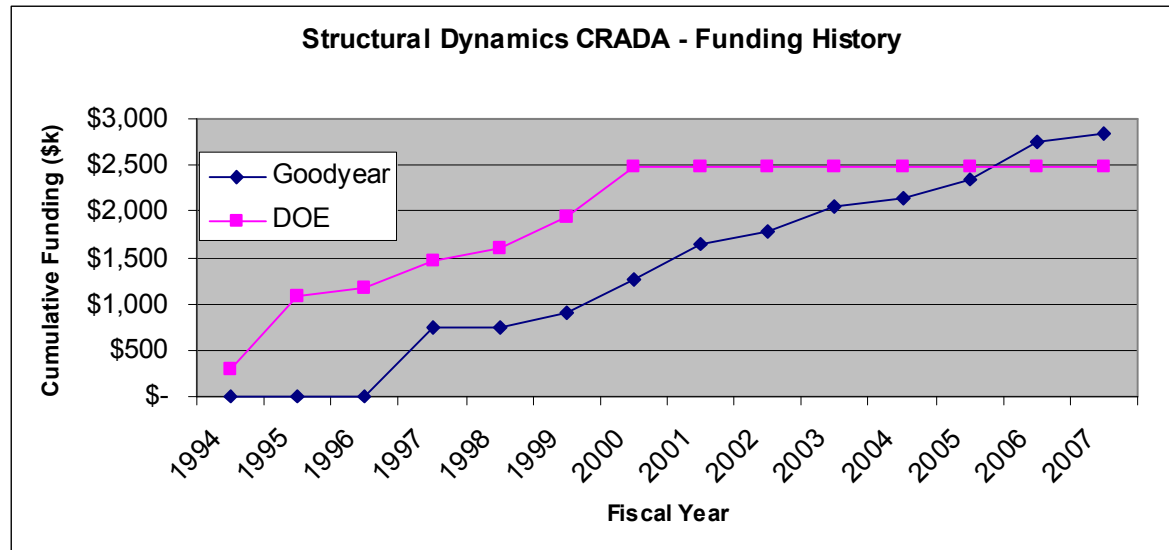


Bau Doan
Doris Maus
Jacques Schouten
Christophe Thiry
Frederic Wullens

SD CRADA — Sandia Financial History



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What Problem We are Trying to Solve



- Goodyear manufactures and sells products (tires) that are useful only as a subsystem in an overall system (vehicle)
 - success depends on the overall system, not just our subsystem
 - need a robust capability for modeling/testing/evaluating tires...
...but that is not enough!
 - need to develop an efficient modeling capability for vehicles to ensure that the tires and vehicle work properly together
 - Goodyear does not want to become a vehicle modeling expert
 - limited time and money
 - even the vehicle manufacturers cannot create analytical models of their vehicles with enough fidelity for evaluating tire designs Need to 150 Hz (ride), 500 Hz (noise)
 - do not need the amount of information such an analytical model would provide
 - interested in the response at only a few key locations (driver-to-vehicle contact points) due to inputs at the 4 wheel attachments (spindles)
 - create a test-based model of the vehicle to serve as the boundary condition for analytical models of the tires/wheels

SD CRADA Objectives



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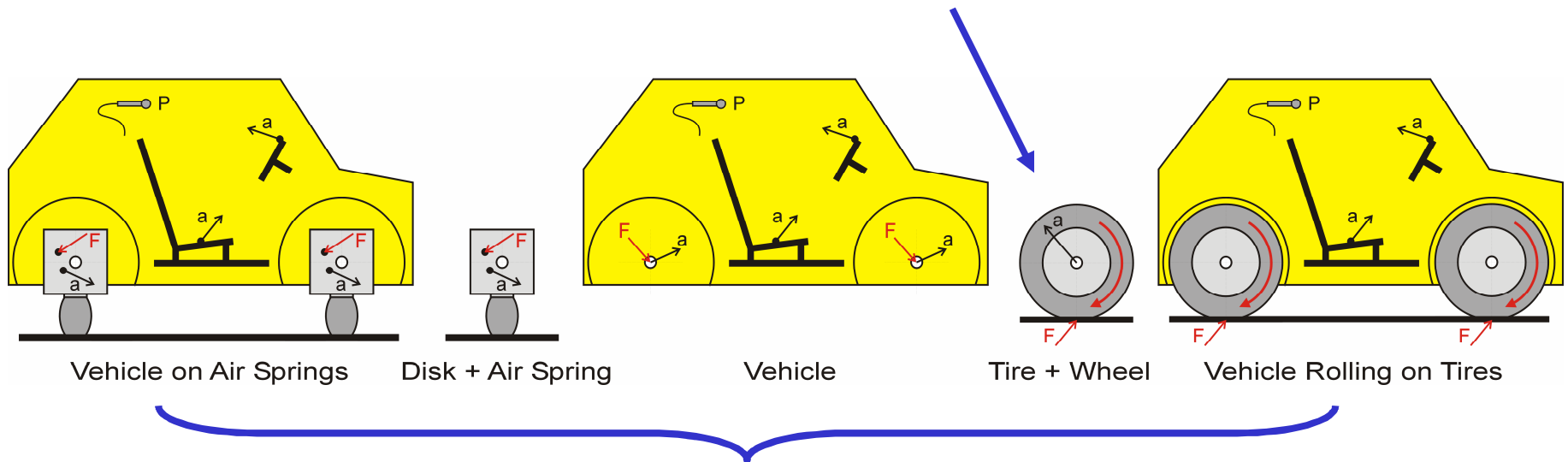
- (Goodyear) Reduce tire design cycle time and quickly achieve NVH targets in Replacement and OE programs
 - Enhance and improve current design guideline process
 - Improve NVH performance by evaluating vehicle influences on tire NVH performance
 - Optimize tire performance based on specific vehicle sensitivity
- (Sandia) Improved capabilities for modeling and testing complex structures
 - Develop new test and analysis techniques
 - validate techniques on systems that see immediate, extensive usage; most Sandia systems have never been used in their full range of operating environments
 - Develop test-based approach to quickly calculate accurate models (boundary conditions) for complex systems

SD CRADA – 2 Major Topic Areas



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- Model the Noise, Vibration, and Harshness (NVH) Response of Tires
 - develop predictive, linear, analytical models (finite element) suitable for construction tuning in the tire design process



- Vehicle Response Modeling / Vehicle Characterization
 - develop an efficient modeling capability for combined vehicle+tire systems
 - a tire is “good” only if it works well when attached to a vehicle
 - using an admittance approach

Introduction to Admittance Modeling



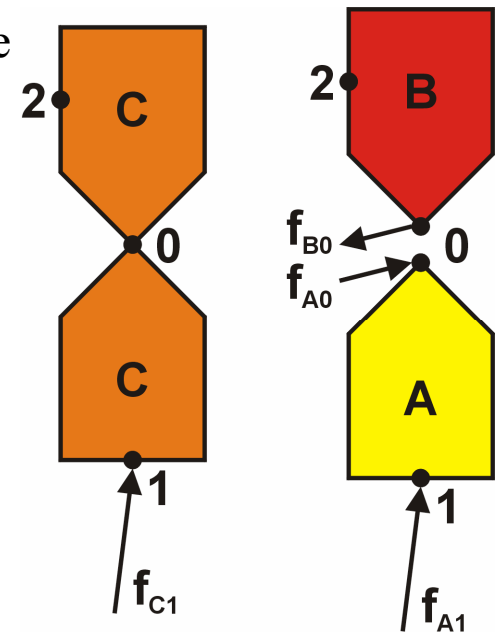
- Admittance approach is a “building block” technique that has a wide range of applicability
 - couples subsystems to predict the combined structural response of an entire system (or can extract a subsystem from the system)
 - subsystem models can be obtained from any source
 - provides a link between the experimental and analytical worlds
 - develop models using the most effective technique

A = add-on system (tire + wheel)
 B = base system (vehicle)
 C = combined system, complete system
 0 = connection point (spindle)
 1 = input location (road)
 2 = response location (seat, steering wheel)

Use force equilibrium and compatibility at the connection point to derive relationships between system C and subsystems A and B

Admittance:

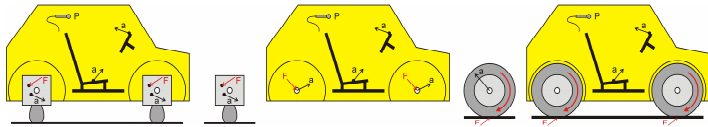
$$H_{C12} = \frac{a_{C1}}{f_{C2}} = \frac{\text{acceleration at point 1 on structure C}}{\text{force at point 2 on structure C}}$$



CRADA Effort

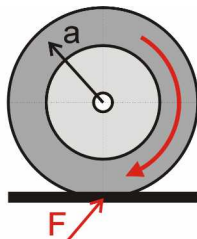


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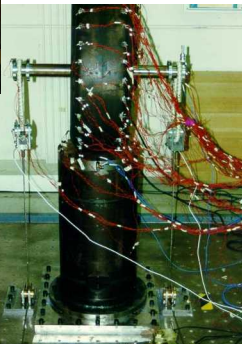
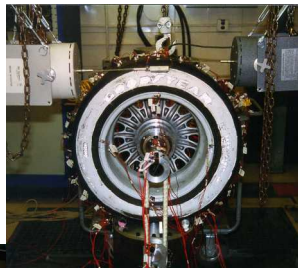


Tire/Wheel Modeling

- FE models of free, parked, and rolling tires
 - material properties
 - high/low strain (2-stage modeling)
 - strain softening and time-dependence (for rolling tire)
 - reduction of FE models to modal models
 - success due to close coupling between analytical and experimental efforts
- Develop test rigs for **validation** of tire/**wheel** models
- **Input forces on rolling tires**
 - tire rolling over a cleat
 - blocked-force technique / fixed-spindle testing
- Tire construction sensitivity (“4-corner” tire builds)
 - soft/stiff sidewall, soft/stiff treadband



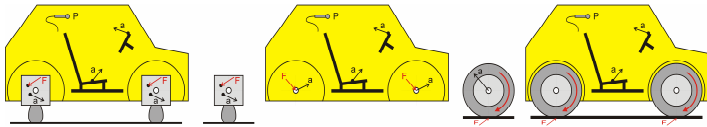
Tire + Wheel



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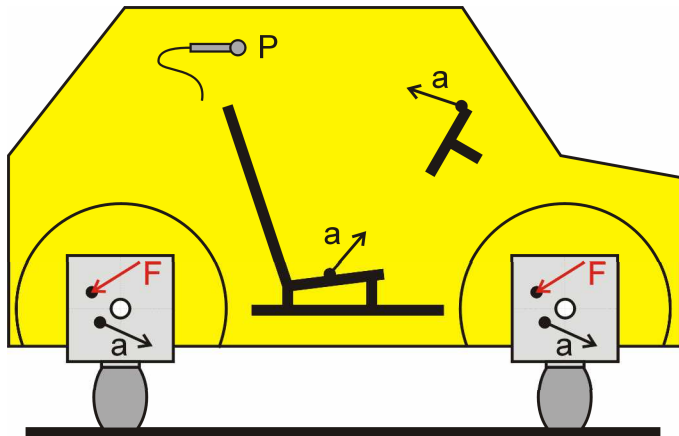


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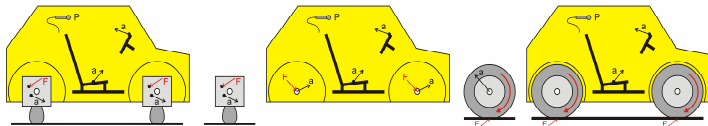
Vehicle Testing

- Develop test techniques and procedures
 - sensor and input force locations/directions
 - measurement accuracy, data quality checking
 - dither
- Hardware design
 - rigid disks, air springs



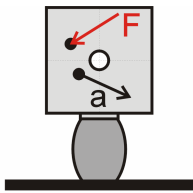
Vehicle on Air Springs



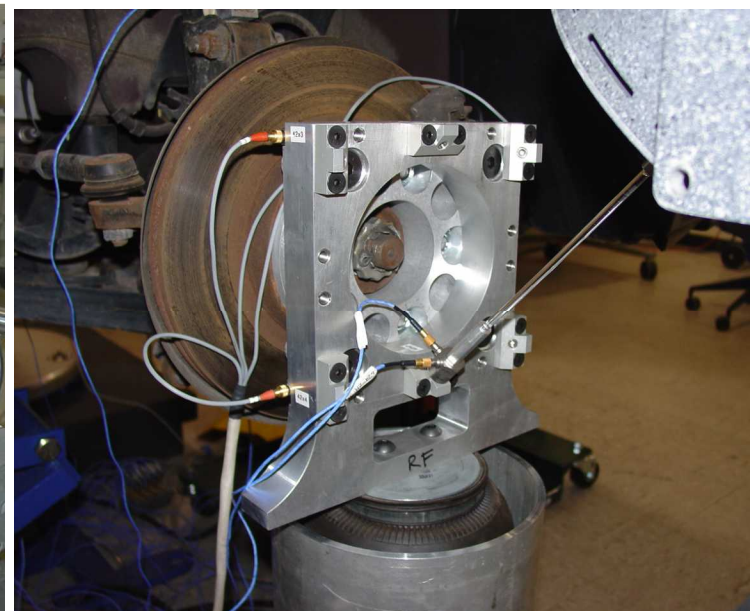


Air Springs and Rigid Disks

- Develop technique to measure air spring damping and stiffness properties
 - frequency dependence of damping
- Disk design
 - stiffness, mass properties, force/accel locations



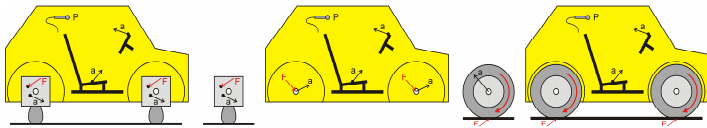
Disk + Air Spring



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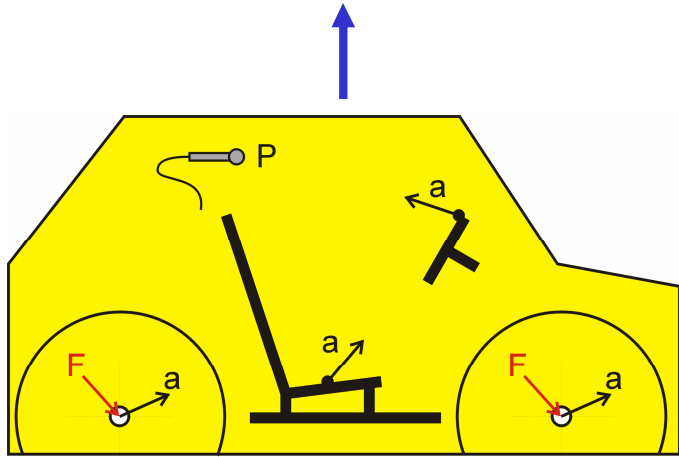


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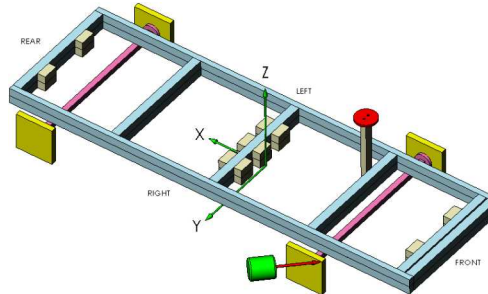
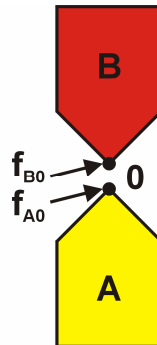
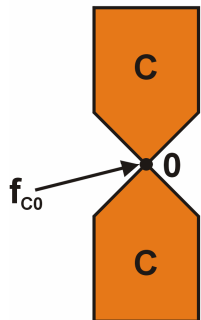
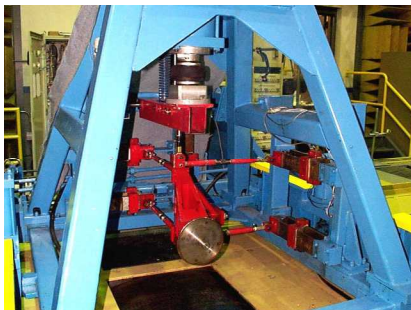


Vehicle Model

- Admittance technique
 - admittance theory and code; data processing
- Test-based model of vehicle floating free in space
 - force/moment inputs at spindles; responses at spindles and other “special” locations
- Develop library of production vehicles
 - prototype vehicle available for only a short time
 - identify trends in customer metrics
 - identify trends in model year differences



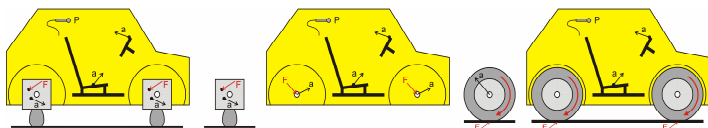
Vehicle



CRADA Effort

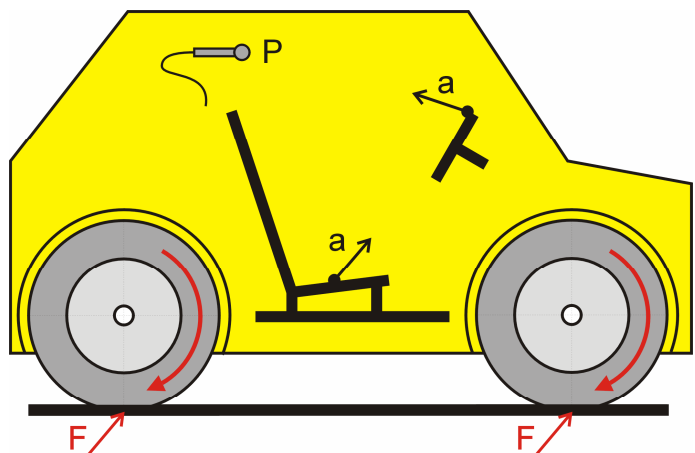


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Complete Model of Vehicle on Tires

- Use admittance theory to attach analytical tire/wheel models to test-based vehicle model
 - vehicle can be parked or rolling
 - evaluate how well a tire works with the vehicle
- Validation



Vehicle Rolling on Tires





Tire/Wheel Modeling

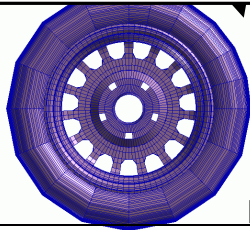
Vehicle Modeling

Testing & Validation

Finished

Ongoing

Future



Free Tire FE Models

Two-Stage Approach

Parked Tire FE Models

Modal Model Reductions (GTMM)

Empirical Modal Models for Rolling

Blocked-Force Input

Cleat Force Input

Rolling Tire FE Model

Admittance Theory

Admit Test Techniques

Admittance Code

Code Verification

Vehicle Dither

Excitation (dir, ampl)

Vehicle BCs

Wheel-Car Attachment

Admit with Fit FRFs

Modal Rig

Tire Patch Rig

Suspension Rig

El Burro

Seismic Mass Rig

Rolling Tire Rig

Blocked-Force Rigs

Blocked-Force Approach

Excitation Type & Level

Admittance Test Validation

Parked Tire Validation

Lab Validation

Road Validation

Vehicle Class-Specific Issues

Technology Development Map (Apr. 2007)



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Tire/Wheel Modeling

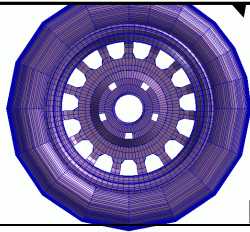
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Customer Testimonials



- BMW Feedback
 - TVET*L presented BMW with overview of vehicle characterization activities on BMW X5
 - BMW was genuinely surprised and impressed by level of technology
 - BMW volunteered that **NO other tire company** had, or was developing, this expertise/capability
 - Impressed by our technology strategy and leadership initiative
 - Some insights on tire/vehicle interaction TVET observed never seen before by BMW — again getting their attention
- OE customers show interest in using tire-vehicle analysis technology to reduce cycle time
 - BMW joint project is in progress — 2-year loan of a 345 to Goodyear
 - Joint project with Toyota is being proposed