

# Overview

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Most of the problems associated with the safety, economy, and overall quality of road transportation are affected by the characteristics of both roads and vehicles and by the manner in which these two dynamic systems interact. In spite of the complex interaction between roads and vehicles, there has been little interaction and a rather limited flow of information between road and vehicle researchers. At most professional meetings and conferences, the emphasis is usually placed either on roads or on vehicles, but very rarely on both. Moreover, in those conferences that do include both road and vehicle topics in their programs, the road and vehicle presentations take place in separate and often concurrent sessions. In 1990, the first Vehicle-Tire-Pavement Interface Conference was conducted by the Engineering Foundation. In this conference, equal emphasis was placed on the vehicle and the roadway. In 1992, the second Engineering Foundation conference on Vehicle-Road Interaction was held at Santa Barbara, California. This special technical publication has been published as a result of the Vehicle-Road Interaction II Conference in an effort to communicate the current state of the art and future research needs to those involved in studies of vehicles and roads.

The 16 papers published in this volume can be grouped into seven subject areas. These areas are: modeling and simulation of vehicle dynamics and vehicle-road dynamic interaction, laboratory and field tests of vehicle-induced pavement loading, tire characteristics, ride quality and road roughness, advances in vehicle suspension design and control, noise emission due to vehicle-tire-road interaction, and fuel efficiency and rolling resistance.

## **Modeling and Simulation of Vehicle Dynamics and Vehicle-Road Dynamic Interaction**

There are four papers in this section. The first paper, by Verheul et al., presents a general-purpose computer simulation program, called BAMMS, developed from the bond graph model of multibody systems. The features that set BAMMS apart from many other vehicle simulation programs are its flexibility and expandability to a great variety of dynamic systems that can be modeled using bond graphs. Two applications of the program are described; one is the analysis of performance and optimization of design of a racing truck, and the other is the investigation of stability of tractor-trailer combination.

Two other papers in this section deal with computer simulation of the dynamic tire forces of heavy trucks, which constitute a very important element of vehicle-road interaction. The dynamic tire forces of heavy vehicles are the primary cause of pavement damage and have become the subject of many research studies in recent years. However, only a few computer models, of many that have been developed in those studies, have been validated using experimental data. The paper by Cole and Cebon describes a nonlinear three-dimensional model of a heavy vehicle and the results of an experimental validation study. In general, very good agreement was found between measured and calculated tire forces. The three-dimensional model was then compared with a two-dimensional model. The authors concluded that the two-dimensional model is satisfactory for predicting tire forces of typical leaf-sprung, articulated vehicles operating under typical conditions of speed and road roughness. Huhtala et al. used a commercial multibody system analysis software, called ADAMS, to simulate tire forces generated by three-axle and four-axle trucks. The paper provides a thorough analysis of the results of computer simulation. Experimental validation of the truck models is planned for the near future when data from tire force measurements become available.

The fourth paper, authored by Gillespie and Karamihas, uses analytical relationships between truck properties and pavement damage to determine which truck characteristics have the

strongest effect on pavement damage. The truck characteristics studied included truck type, axle loads, number of axles, spacing between axles, suspension type, and tire parameters. Static axle loads were found to have the strongest effect on pavement damage.

### **Laboratory and Field Tests of Vehicle-Induced Pavement Loading**

The two papers published in this section deal with laboratory devices used for accelerated testing of pavement response to vehicle loading. The first paper, by Hugo, focuses on the design of the Texas mobile load simulator, whereas in the other paper, Krarup reports results from tests conducted on the Danish road testing machine. The expected dynamic performance of the Texas simulator was investigated using computer simulation. Two 1:10 scale models of the simulator were then built and tested to augment the design of the full-scale machine.

Krarup's paper can serve primarily as a source of relevant technical data including pavement stress and strain distributions measured under two types of loads, rolling truck tire and falling weight deflectometer. The interpretation and conclusions from the test results are left up to the reader to consider.

### **Tire Characteristics**

This section includes two papers. In the first paper, Gelling describes the tire tread properties and their effect on traction, rolling resistance, and wear. Tire traction, rolling resistance, and wear are known to depend on tire construction and road surface texture characteristics. Gelling shows that these tire properties can also be related, to some extent, to viscoelastic properties of the tread material. In addition, the paper raises an issue of environmental effects of tire properties. Tire recycling and vehicle/tire contribution to the greenhouse effect are two major areas of concern to the tire and automotive industries.

The paper by Navin presents a skid resistance case study conducted on a surface treated with a pavement rejuvenator using a 1991 Lincoln Town Car equipped with an antilock brake system (ABS). The main difficulty in traction tests involving ABS-equipped vehicles is determining when and where the braking actually starts and stops. The testing procedure described by the author should be of interest because it offers an economic alternative to an expensive skid trailer.

### **Ride Quality and Road Roughness**

Ride quality is an important aspect of vehicle-road interaction, not only as a matter of comfort but, more importantly, as a factor affecting driver fatigue and thus traffic safety. Ride quality is a subjective quantity based on a level of comfort perceived by persons traveling over a selected section of road. Since obtaining subjective ratings of ride quality is a rather involved and costly process, highway engineers developed objective measures calculated from road profile and/or vehicle response data to estimate the ride quality. Spangler and Kelly compared five different measures of ride quality that are in common use today, and found the Ride Number to be superior to the other measures in this group. The Ride Number is derived from the road profile measurements, then processed with a digital filter that emphasizes the range of wavelengths to which human subjects have been found to be most sensitive while traveling in highway vehicles.

The paper by Gilmore, while concentrating also on objective evaluation of ride quality, introduces a ride quality measure derived from the dynamics of interaction between a rider and a seat. A new computer program is presented that can be used to simulate the rider-seat interaction. The program can also be employed as a tool in seat and vehicle design. A new feature of the program is that it includes nonlinearities due to geometry or changing kinematic

constraints in the rider-seat-vehicle system. These nonlinearities become increasingly important for ride quality estimation when the road roughness increases and when the vehicle suspension is stiff, which may lead to situations where contact between the seat and the rider is lost or the seat bottoms out.

### **Advances in Vehicle Suspension Design and Control**

The part of a vehicle that has the strongest impact on how the vehicle interacts with the road is the suspension. Vehicle suspension characteristics are crucial for ride quality, handling, and dynamic tire forces. Traditionally, suspension designers have relied on experience, intuition, and subjective measures of a vehicle's ride and handling performance. This was primarily because of the complexity of the vehicle design and due to the lack of adequate analytical or numerical models of vehicle dynamics. In their paper, Alstead and Whitehead outline some of the objective methods developed and used by the Motor Industry Research Association in England in evaluating vehicle ride and handling performance. The authors suggest, however, that in spite of an increase in the use of objective techniques, subjective techniques will continue to play an important part in the development of new suspension designs.

### **Noise Emission Due to Vehicle-Tire-Road Interaction**

The level of noise generated by a vehicle must be considered in two categories—exterior and interior to the vehicle. Concerns about the environmental effects of exterior vehicle noise have been growing rapidly, especially in densely populated areas. These concerns lead to legislation reducing the acceptable level of exterior noise or creating tax advantages to the manufacturers of low-noise vehicles. The implementation of the various legislative actions requires accurate and reliable noise testing procedures, which is the topic of the paper by Wagner. This paper presents the results of several studies conducted by Volkswagen in an effort to develop vehicle noise testing methods. The effects of several test variables such as road surface, type of tire, tire inflation pressure, and temperature are examined. If these variables are not controlled sufficiently, the measurements of exterior noise may vary by 3 dB or more, which constitutes a very significant error. Another very important result reported by Wagner is that, contrary to widespread opinions, tires with good traction characteristics don't necessarily have to be noisy.

The second paper in this section, authored by Voutyras and Thomson, focuses on vehicle interior noise. The primary objectives of the research reported in the paper were to investigate the effects of different road surfaces on vehicle interior noise and to develop a method that would allow for predicting the level of noise generated on different road surfaces based on vehicle noise measured on a single surface. The method, called the road surface weighting functions method, produces results that have been found to be in very good agreement with experimental data.

### **Fuel Efficiency and Rolling Resistance**

Rolling resistance is generally considered to be a characteristic of a tire. However, from a broader perspective, rolling resistance and vehicle fuel consumption depend on characteristics of both vehicle tires and the road surface. In their paper, Gyenes and Mitchell review the results of experimental measurements of the rolling resistance and fuel consumption of cars and trucks using different types of tires and traveling on different road surfaces. Road surface macrotexture and roughness can each increase the fuel consumption of cars by 5% and trucks by 10%. On unpaved roads, this effect is further magnified by 15 to 20%. It is also stated that rolling resistance and thus fuel consumption of trucks can be reduced by the use of higher

inflation pressure and wide single tires in place of dual tires. However, increased tire inflation pressure as well as replacing dual tires with wide single tires causes greater pavement wear.

In the two other papers in this section, the authors discuss the effects of the road surface characteristics, roughness and texture, on the rolling resistance of typical passenger car/tire combinations. In his paper, Delanne presents the results of a very comprehensive study conducted at the Laboratoire Central des Ponts et Chaussées in France involving tests performed in the laboratory, on a test track, and on in-service roads. The results are in good agreement with the results reported by Gyenes and Mitchell earlier in this section. The important question raised in this paper is how the low rolling resistance requirements relate to other vehicle and road characteristics such as traction and noise. The author states that road surfaces that are beneficial for fuel consumption can be detrimental to other road qualities. The paper by Cenek reports on a similar study conducted in New Zealand. It describes the development of the test method for the on-road determination of rolling resistance and the results of application of this method on a variety of roads having widely differing surface texture characteristics.

The papers published in this volume should provide the reader with the latest information and the direction for future research in the area of vehicle-road interaction. I would like to acknowledge sincerely the efforts of the authors, reviewers, ASTM personnel, and the conference organizing committee. Claude Lamure of INRETS, France, served as the conference co-chairman and the following served as members of the organizing committee: Alexander A. Alexandridis, R. B. J. Hoogvelt, Bürckhard Horn, Byron N. Lord, Mark A. Poelman, Ulf Sandberg, Elson B. Spangler, Margaret M. Sullivan, and A. Roger Williams. In addition, J. J. Henry, Charles F. Scheffey, Frank W. Schmidt, and James C. Wambold were the "ex officio" members of the committee. The support of the conference by the Federal Highway Administration is also gratefully acknowledged.

*Bohdan T. Kulakowski*

The Pennsylvania State University,  
Pennsylvania Transportation Institute,  
University Park, PA 16802.  
Conference Chairman and Editor