

## ***Aerodynamics Of Road Vehicles***

The detailed presentation of fundamental aerodynamics principles that influence and improve vehicle design have made *Aerodynamics of Road Vehicles* the engineer's "source" for information. This fifth edition features updated and expanded information beyond that which was presented in previous releases. Completely new content covers lateral stability, safety and comfort, wind noise, high performance vehicles, helmets, engine cooling, and computational fluid dynamics. The aerodynamics of passenger cars, commercial vehicles, motorcycles, sports cars, and race cars is dealt with in detail, including. The International Symposium on Dynamics of Vehicles on Roads and Tracks is the leading international gathering of scientists and engineers from academia and industry in the field of ground vehicle dynamics to present and exchange their latest innovations and breakthroughs. Established in Vienna in 1977, the International Association of Vehicle System Dynamics (IAVSD) has since held its biennial symposia throughout Europe and in the USA, Canada, Japan, South Africa and China. The main objectives of IAVSD are to promote the development of the science of vehicle dynamics and to encourage engineering applications of this field of science, to inform scientists and engineers on the current state-of-the-art in the field of vehicle dynamics and to broaden contacts among persons and organisations of the various countries engaged in scientific research and development in the field of vehicle dynamics and related areas. IAVSD 2017, the 25th Symposium of the International Association of Vehicle System Dynamics was hosted by the Centre for Railway Engineering at Central Queensland University, Rockhampton, Australia in August 2017. The symposium focused on the following topics related to road and rail vehicles and trains: dynamics and stability; vibration and comfort; suspension; steering; traction and braking; active safety systems; advanced driver assistance systems; autonomous road and rail vehicles; adhesion and friction; wheel-rail contact; tyre-road interaction; aerodynamics and crosswind; pantograph-catenary dynamics; modelling and simulation; driver-vehicle interaction; field and laboratory testing; vehicle control and mechatronics; performance and optimization; instrumentation and condition monitoring; and environmental considerations. Providing a comprehensive review of the latest innovative developments and practical applications in road and rail vehicle dynamics, the 213 papers now published in these proceedings will contribute greatly to a better understanding of related problems and will serve as a reference for researchers and engineers active in this specialised field.

Aerodynamics has never been more central to the development of cars, commercial vehicles, motorbikes, trains and human powered vehicles, driven by the need for efficiency: reducing carbon dioxide emissions, reducing fuel consumption, increasing range and alleviating problems associated with traffic congestion. Reducing vehicle weight makes it more challenging to ensure that they are stable and handle well over a wide range of environmental conditions. Lighter structures are also more vulnerable to aerodynamically induced vibration. Alongside this, customers demand an environment that is quiet, comfortable and maintains their vision of the world around them in all weathers. These aims must be met by designing

vehicles that engage customers emotionally, promoting the brand values of manufacturers and operators. This can only be done by collaboration between designers and aerodynamicists. Examine the latest developments in vehicle aerodynamic development Explore opportunities to network and share experiences around different areas Focus on future challenges and the engineering knowledge and technology required to resolve them Discuss other areas of development including handling and stability, tyre aerodynamics and modelling, aeroacoustics and fluid structure interaction

Important Factors for Accurate Scale-Resolving Simulations of Automotive Aerodynamics

Multibody Systems Approach to Vehicle Dynamics

From Fluid Mechanics to Vehicle Engineering

External Aerodynamics of Road Vehicles

Volume 2: System Design

Design and Development of Pac Car II

**This volume contains papers presented at the International conference “The Aerodynamics of Heavy Vehicles III: Trucks, Buses and Trains” held in Potsdam, Germany, September 12–17, 2010 by Engineering Conferences International (ECI). Leading scientists and engineers from industry, universities and research laboratories, including truck and high-speed train manufacturers and operators were brought together to discuss computer simulation and experimental techniques to be applied for the design of more efficient trucks, buses and high-speed trains in the future. This conference was the third in the series after Monterey–Pacific Groove in 2002 and Lake Tahoe in 2007. The presentations address different aspects of train aerodynamics (cross wind effects, underbody flow, tunnel aerodynamics and aeroacoustics, experimental techniques), truck aerodynamics (drag reduction, flow control, experimental and computational techniques) as well as computational fluid dynamics and bluff body, wake and jet flows.**

**The first book to summarize the secrets of the rapidly developing field of high-speed vehicle design. From F1 to Indy Car, Drag and Sedan racing, this book provides clear explanations for engineers who want to improve their design skills and enthusiasts who simply want to understand how their favorite race cars go fast. Explains how aerodynamics win races, why downforce is more important than streamlining and drag reduction, designing wings and venturis, plus wind tunnel designs and more.**

**Aerodynamics of Road Vehicles From Fluid Mechanics to Vehicle Engineering Elsevier**

**The Aerodynamics of Road Vehicles**

**Part 1: Engines – Fundamentals**

Encyclopedia of Automotive Engineering

The International Vehicle Aerodynamics Conference

Motor Vehicle Dynamics: Modeling and Simulation

19. Internationales Stuttgarter Symposium

***A comprehensive introduction for students, practising automotive engineers and designers, and anyone with a general interest in the subject. Intended to be affordable by students. Unnecessary details or highly vehicle-specific information has been omitted, but a comprehensive list of references is given, usually with a summary.***

***Train Aerodynamics: Fundamentals and Applications is the first reference to provide a comprehensive overview of train aerodynamics with full scale data results. With the most up-to-date information on recent advances and the possibilities of improvement in railway facilities, this book will benefit railway engineers, train operators, train manufacturers, infrastructure managers and researchers of train aerodynamics. As the subject of train aerodynamics has evolved slowly over the last few decades with train speeds gradually increasing, and as a result of increasing interest in new train types and high-speed lines, this book provides a timely resource on the topic. Examines the fundamentals and the state-of-the-art of train aerodynamics, beginning with experimental, numerical and analytical tools, and then thoroughly discussing the specific approaches in other sections Features the latest developments and progress in computational aerodynamics and experimental facilities Addresses problems relating to train aerodynamics, from the dimensioning of railway structures and trains, to risk analysis related to safety issues and maintenance Discusses basic flow patterns caused by bridges and embankments***

***Multibody Systems Approach to Vehicle Dynamics aims to bridge a gap between the subject of classical vehicle dynamics and the general-purpose computer-based discipline known as multibody systems analysis (MBS). The book begins by describing the emergence of MBS and providing an overview of its role in vehicle design and development. This is followed by separate chapters on the modeling, analysis, and post-processing capabilities of a typical simulation software; the modeling and analysis of the suspension system; tire force and moment generating characteristics and subsequent modeling of these in an MBS simulation;***

**and the modeling and assembly of the rest of the vehicle, including the anti-roll bars and steering systems. The final two chapters deal with the simulation output and interpretation of results, and a review of the use of active systems to modify the dynamics in modern passenger cars. This book intended for a wide audience including not only undergraduate, postgraduate and research students working in this area, but also practicing engineers in industry who require a reference text dealing with the major relevant areas within the discipline. \* Full of practical examples and applications \* Uses industry standard ADAMS software based applications \* Accompanied by downloadable ADAMS models and data sets available from the companion website that enable readers to explore the material in the book \* Guides readers from modelling suspension movement through to full vehicle models able to perform handling manoeuvres**

**Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles**

**Handbook of Railway Vehicle Dynamics**

**Aerodynamic Drag Mechanisms of Bluff Bodies and Road Vehicles**

**The aerodynamics of road vehicles - road measurement of drag and comparison with wind tunnel measurements**

**Progress in Vehicle Aerodynamics and Thermal Management**

**The World's Most Fuel Efficient Vehicle**

*Featuring contributions from leading experts, the Road and Off-Road Vehicle System Dynamics Handbook provides comprehensive, authoritative coverage of all the major issues involved in road vehicle dynamic behavior. While the focus is on automobiles, this book also highlights motorcycles, heavy commercial vehicles, and off-road vehicles. The authors cover historical background to state of the art techniques, and with chapters covering airdams, splitters, spoilers, wings, underbodies and myriad miscellaneous devices, Competition Car Aerodynamics 3rd Edition also features in-depth case studies from across the motorsport spectrum to help develop a comprehensive understanding of the subject.*

*For years, engineers have turned to Aerodynamics of Road Vehicles as their 'bible' on this field. The fourth edition continues this tradition. Much of the material has been substantially revised, and new chapters on wind noise and motorcycles have been added. Aerodynamics of Road Vehicles thoroughly covers the fundamental principles that influence vehicle*

*performance, handling, safety and comfort.*

*An excellent introduction to the topic for the novice or student and a useful refresher and reference for the expert, the book focuses on:*

- *The fundamentals of fluid dynamics as related to vehicle aerodynamics*
- *Specific experimental results*
- *Design strategies, showing how existing individual results can be applied to specific problems*
- *Development techniques, as related to different types of wind tunnels, on-road tests and numerical methods.*

*The aerodynamics of passenger cars, commercial vehicles, sports and race cars, and motorcycles are dealt with in detail. Related fields that are influenced by aerodynamics are also covered, including the effects of aerodynamics on fuel economy, directional stability, engine cooling, and passenger comfort.*

*Contents include:*

- *Introduction to Automobile Aerodynamics (including a section on its history)*
- *Some Fundamentals of Fluid Mechanics*
- *Performance of Cars and Light Trucks*
- *Aerodynamics Drag of Passenger Cars*
- *Directional Stability*
- *Function, Safety, and Comfort*
- *Wind Noise*
- *High-Performance Vehicles*
- *Commercial Vehicles*
- *Motorcycles*
- *Engine Cooling*
- *Heating, Ventilating, and Air Conditioning of Passenger Cars*
- *Wind Tunnels*
- *Measurement and Test Techniques*
- *Computational Fluid Dynamics*

*Aerodynamics of Road Vehicles is an indispensable book for vehicle engineers, designers, researchers, and those working in government regulatory agencies. It is also an excellent introduction for students, and an insightful look for the enthusiast at*

*why vehicles behave as they do. The book covers aerodynamic principles of: Passenger cars; Commercial vehicles; Sports and race car; Motorcycles. By reading this book, vehicle engineers and designers will be able to: Apply general rules to solve your own design problems; Develop test techniques and design strategies to maximise aerodynamic effectiveness. Car enthusiasts will gain an understanding of: Why vehicles behave as they do; The factors affecting vehicle performance, handling, safety, and comfort. Students will learn: The fundamentals of aerodynamics and its application in the 'real-world' of vehicle design; How to apply specific experimental results as general rules to solve design problems./P*

*11th FKFS Conference, Stuttgart, September 26-27, 2017*

*The Science of Vehicle Dynamics*

*Proceedings of the 15th IFToMM World Congress on Mechanism and Machine Science*

*Road and Off-Road Vehicle System Dynamics Handbook*

*Competition Car Aerodynamics 3rd Edition*

*A Survey of Published Literature*

**An introduction to ground vehicle aerodynamics, that will be of particular interest to automotive engineering students, vehicle body engineers/designers/profilers, passenger car engineers/ designers/rendering specialists, wind tunnel testing engineers, computational aerodynamicists, and race car designers. It treats, in particular, drag reduction methods and provides a significant insight into the computational approach to the aerodynamic design of ground vehicles.**

**Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles evaluates various technologies and methods that could improve the fuel economy of medium- and heavy-duty vehicles, such as tractor-trailers, transit buses, and work trucks. The book also recommends approaches that federal agencies could use to regulate these vehicles' fuel consumption. Currently there are no fuel consumption standards for such vehicles, which account for about 26 percent of the transportation fuel used in the U.S. The miles-per-gallon measure used to regulate the fuel economy of passenger cars. is not appropriate for medium- and heavy-duty vehicles, which are designed above all to carry loads efficiently. Instead, any regulation of medium- and heavy-duty vehicles should use a metric that reflects the efficiency with which a vehicle moves goods or passengers, such as gallons per ton-mile, a unit that reflects the amount of fuel a vehicle would use to carry a ton of goods one mile. This is called load-specific fuel**

consumption (LSFC). The book estimates the improvements that various technologies could achieve over the next decade in seven vehicle types. For example, using advanced diesel engines in tractor-trailers could lower their fuel consumption by up to 20 percent by 2020, and improved aerodynamics could yield an 11 percent reduction. Hybrid powertrains could lower the fuel consumption of vehicles that stop frequently, such as garbage trucks and transit buses, by as much 35 percent in the same time frame.

In einer sich rasant verändernden Welt sieht sich die Automobilindustrie fast täglich mit neuen Herausforderungen konfrontiert: Der problematischer werdende Ruf des Dieselmotors, verunsicherte Verbraucher durch die in der Berichterstattung vermischte Thematik der Stickoxid- und Feinstaubemissionen, zunehmende Konkurrenz bei Elektroantrieben durch neue Wettbewerber, die immer schwieriger werdende öffentlichkeitswirksame Darstellung, dass ein großer Unterschied zwischen Prototypen, Kleinserien und einer wirklichen Großserienproduktion besteht. Dazu kommen noch die Fragen, wann die mit viel finanziellem Einsatz entwickelten alternativen Antriebsformen tatsächlich einen Return of Invest erbringen, wer die notwendige Ladeinfrastruktur für eine Massenmarkttauglichkeit der Elektromobilität bauen und finanzieren wird und wie sich das alles auf die Arbeitsplätze auswirken wird. Für die Automobilindustrie ist es jetzt wichtiger denn je, sich den Herausforderungen aktiv zu stellen und innovative Lösungen unter Beibehaltung des hohen Qualitätsanspruchs der OEMs in Serie zu bringen. Die Hauptthemen sind hierbei, die Elektromobilität mit höheren Energiedichten und niedrigeren Kosten der Batterien voranzutreiben und eine wirklich ausreichende standardisierte und zukunftsichere Ladeinfrastruktur darzustellen, aber auch den Entwicklungspfad zum schadstofffreien und CO<sub>2</sub>-neutralen Verbrennungsmotor konsequent weiter zu gehen. Auch das automatisierte Fahren kann hier hilfreich sein, weil das Fahrzeugverhalten dann - im wahrsten Sinne des Wortes - kalkulierbarer wird. Dabei ist es für die etablierten Automobilhersteller strukturell nicht immer einfach, mit der rasanten Veränderungsgeschwindigkeit mitzuhalten. Hier haben Start-ups einen großen Vorteil: Ihre Organisationsstruktur erlaubt es, frische, unkonventionelle Ideen zügig umzusetzen und sehr flexibel zu reagieren. Schon heute werden Start-ups gezielt gefördert, um neue

*Lösungen im Bereich von Komfort, Sicherheit, Effizienz und neuen Kundenschnittstellen zu finden. Neue Lösungsansätze, gepaart mit Investitionskraft und Erfahrungen, bieten neue Chancen auf dem Weg der Elektromobilität, der Zukunft des Verbrennungsmotors und ganz allgemein für das Auto der Zukunft.*

*A Comparison of Cars and Their Models in Wind Tunnels*

*The Aerodynamics of Heavy Vehicles: Trucks, Buses, and Trains*

*Trucks, Buses and Trains*

*Theory of Ground Vehicles*

*Aerodynamics of Road Vehicles*

*Race Car Aerodynamics*

This textbook covers handling and performance of both road and race cars. Mathematical models of vehicles are developed always paying attention to state the relevant assumptions and to provide explanations for each step. This innovative approach provides a deep, yet simple, analysis of the dynamics of vehicles. The reader will soon achieve a clear understanding of the subject, which will be of great help both in dealing with the challenges of designing and testing new vehicles and in tackling new research topics. The book deals with several relevant topics in vehicle dynamics that are not discussed elsewhere and this new edition includes thoroughly revised chapters, with new developments, and many worked exercises. Praise for the previous edition: Great book! It has changed drastically our approach on many topics. We are now using part of its theory on a daily basis to constantly improve ride and handling performances. --- Antonino Pizzuto, Head of Chassis Development Group at Hyundai Motor Europe Technical Center Astonishingly good! Everything is described in a very compelling and complete way. Some parts use a different approach than other books. ---

Andrea Quintarelli, Automotive Engineer

The book presents latest information about new car developments, new or improved testing techniques and new or improved calculation procedures. Presenters are from industry and academia.

This work serves as a reference concerning the automotive chassis, i.e. everything that is inside a vehicle except the engine and the body. It is the result of a decade of work mostly done by the FIAT group, who supplied material, together with other automotive companies, and sponsored the work. The first volume deals with the design of automotive components and the second volume treats the various aspects of the design of a vehicle as a system.

An Introduction

Designing for Speed

The Aerodynamics of Road Vehicles - a Survey of Published Literature

Fundamentals and Applications

## Road Vehicle Aerodynamics

### Handling, Braking, and Ride of Road and Race Cars

Aerodynamics of Road Vehicles details the aerodynamics of passenger cars, commercial vehicles, sports cars, and race cars; their external flow field; as well as their internal flow field. The book, after giving an introduction to automobile aerodynamics and some fundamentals of fluid mechanics, covers topics such as the performance and aerodynamics of different kinds of vehicles, as well as test techniques for their aerodynamics. The book also covers other concepts related to automobiles such as cooling systems and ventilations for vehicles. The text is recommended for mechanical engineers and physicists in the automobile industry who would like to understand more about aerodynamics of motor vehicles and its importance on the field of road safety and automobile production.

This book gathers the proceedings of the 15th IFToMM World Congress, which was held in Krakow, Poland, from June 30 to July 4, 2019. Having been organized every four years since 1965, the Congress represents the world's largest scientific event on mechanism and machine science (MMS). The contributions cover an extremely diverse range of topics, including biomechanical engineering, computational kinematics, design methodologies, dynamics of machinery, multibody dynamics, gearing and transmissions, history of MMS, linkage and mechanical controls, robotics and mechatronics, micro-mechanisms, reliability of machines and mechanisms, rotor dynamics, standardization of terminology, sustainable energy systems, transportation machinery, tribology and vibration. Selected by means of a rigorous international peer-review process, they highlight numerous exciting advances and ideas that will spur novel research directions and foster new multidisciplinary collaborations.

The book starts with an historical overview of road vehicles. The first part deals with the forces exchanged between the vehicle and the road and the vehicle and the air with the aim of supplying the physical facts and the relevant mathematical models about the forces which dominate the dynamics of the vehicle. The second part deals with the dynamic behaviour of the vehicle in normal driving conditions with some extensions towards conditions encountered in high-speed racing driving. Contents: Short Historical Notes on Motor Vehicles Forces Acting between Road and Wheel Road Vehicle Aerodynamics Longitudinal Dynamics Handling of a Rigid Vehicle Motor Vehicle on Elastic Suspensions Road Accidents Readership: Mechanical engineers. keywords: Motor Vehicle Dynamics; Motor Vehicle Handling; Motor Vehicle Comfort; Motor Vehicle Stability; Motor Vehicle Simulation; Motor Vehicle Aerodynamics; Motor Vehicle Suspensions; Tires; Road Accidents; Vehicle-Driver Interaction "... the author provides an interesting and comprehensive treatment of a very complicated subject ... it would be a good addition to the bookshelf of any engineer with an interest in vehicle dynamics or general automotive technology." Applied Mechanics Reviews

Dynamics of Vehicles on Roads and Tracks

Theory and Applications of Aerodynamics for Ground Vehicles

Results Obtained by Numerical Simulation

Proceedings of the 25th International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD 2017),

14-18 August 2017, Rockhampton, Queensland, Australia

Road Vehicle Aerodynamic Design

*These Proceedings contain the papers and oral discussions presented at the Symposium on AERODYNAMIC DRAG MECHANISMS of Bluff Bodies and Road Vehides held at the General Motors Research Laboratories in Warren, Michigan, on September 27 and 28, 1976. This international, invitational Symposium was the twentieth in an annual series, each one having been in a different technical discipline. The Symposia provide a forum for areas of science and technology that are of timely interest to the Research Laboratories as well as the technical community at large, and in which personnel of the Laboratories are actively involved. The Symposia furnish an opportunity for the exchange of ideas and current knowledge between participating research specialists from educational, industrial arid governmental institutions and serve to stimulate future research activity. The present world-wide energy situation makes it highly desirable to reduce the force required to move road vehicles through the atmosphere. A significant amount of the total energy consumed for transportation is expended in overcoming the aerodynamic resistance to motion of these vehicles. Reductions in this aerodynamic drag can therefore have a large impact on ground transportation energy requirements. Although aerodynamic development work on road vehides has been performed for many years, it has not been widely reported or accompanied by much basic research.*

*Understanding the dynamics of railway vehicles, and indeed of the entire vehicle-track system, is critical to ensuring safe and economical operation of modern railways. As the challenges of higher speed and higher loads with very high levels of safety require ever more innovative engineering solutions, better understanding of the technical issues a*

*The goal of the PAC-Car project, a joint undertaking of ETH Zurich and ist partners, was to build a vehicle powered by a hydrogen fuel cell system that uses as little fuel as possible. PAC-Car II set a new world record in fuel efficient driving (the equivalent of 5,385 km per liter of gasoline) during the Shell Eco-marathon in Ladoux (France) on June 26, 2005. This book, addressed to graduate students, engineering professors and others interested in fuel economy contests, is the frst to summarize the issues involved when designing and constructing a vehicle for fuel economy competitions. It describes the adventure of developing the PAC-Car II and others some specifc technical advice for anyone who wants to design an ultra-lightweight land vehicle, whatever its energy source. PAC-Car was a joint project of ETH Zurich and partners from academia and industry. The goal was to build a vehicle powered by a fuel cell system that uses as little fuel as possible. PAC-Car II set a new world record in fuel efficient driving (5,385 km per liter of petrol equivalent) during the Shell Eco-marathon in Ladoux (France) on June 26, 2005. This book is the first to summarize the design and construction issues of a vehicle for fuel economy contests. It deals with the adventure of developing this world-record vehicle and provides some specific technical tips. It will help anyone who is*

*designing an ultra lightweight land vehicle, whatever its source of energy (thermal engine, human power, solar panels), and/or those who are interested in fuel cell applications. The book addresses graduate students and teachers of engineering disciplines as well as other people interested in fuel economy contests. Content: fuel economy competitions, design phase of a fuel economy vehicle, tires, vehicle behavior, aerodynamics, vehicle body structure, wheels, front axle and steering system, powertrain, fuel cell system, driving strategy, conclusion and outlook.*

*Application of the Phoenix Code*

*The Aerodynamics of Heavy Vehicles III*

*The Automotive Chassis*

*Aerodynamics of Road Vehicles, Fifth Edition*

*Automobil- und Motorentechnik*

*Automotive Aerodynamics*

This book includes the carefully edited contributions to the United Engineering Foundation Conference: The Aerodynamics of Heavy Vehicles: Trucks, Buses and Trains held in Monterey, California from December 2-6, 2002. This conference brought together 90 leading engineering researchers discussing the aerodynamic drag of heavy vehicles. The book topics include a comparison of computational fluid dynamics calculations using both steady and unsteady Reynolds-averaged Navier-Stokes, large-eddy simulation, and hybrid turbulence models and experimental data obtained from wind tunnel experiments. Advanced experimental techniques including three-dimensional particle image velocimetry are presented as well, along with their use in evaluating drag reduction devices.

The automobile is an icon of modern technology because it includes most aspects of modern engineering, and it offers an exciting approach to engineering education. Of course there are many existing books on introductory fluid/aero dynamics but the majority of these are too long, focussed on aerospace and don't adequately cover the basics. Therefore, there is room and a need for a concise, introductory textbook in this area. Automotive Aerodynamics fulfils this need and is an introductory textbook intended as a first course in the complex field of aero/fluid mechanics for engineering students. It introduces basic concepts and fluid properties, and covers fluid dynamic equations. Examples of automotive aerodynamics are included and the principles of computational fluid dynamics are introduced. This text also includes topics such as aeroacoustics and heat transfer which are important to engineering students and are closely related to the main topic of aero/fluid mechanics. This textbook contains complex mathematics, which not only serve as the foundation for future studies but also provide a road map for the present text. As the chapters evolve, focus is placed on more applicable examples, which can be solved in class using elementary algebra. The approach taken is designed to make the mathematics more approachable and easier to understand. Key features: Concise textbook which provides an introduction to fluid mechanics and aerodynamics, with automotive applications Written by a leading author in the field who has experience working with motor sports teams in industry Explains basic concepts and equations before progressing to cover more advanced topics Covers internal and external flows for automotive applications Covers emerging areas of aeroacoustics and heat transfer Automotive Aerodynamics is a must-have textbook for undergraduate and graduate students in automotive and mechanical engineering, and is also a

concise reference for engineers in industry.

This text provides a comprehensive introduction to road vehicle aerodynamic design for students, engineers and designers working in the automotive field

Road Measurement of Drag and Comparison with Wind Tunnel Measurements

Advances in Mechanism and Machine Science

Train Aerodynamics

***Road transports are responsible for almost 18 % of the greenhouse gas emission in Europe and are today the leading cause of air pollution in cities. Aerodynamic resistance has a significant effect on fuel consumption and hence the emission of vehicles. For electric vehicles, emissions are not affected by the aerodynamics as such but instead have a significant effect on the effective range of the vehicle. In 2017, a new measurement procedure was introduced, Worldwide Harmonized Light Vehicles Test Procedure (WLTP), for measuring emissions, fuel consumption, and range. This procedure includes a new test cycle with increased average driving speed compared to the former procedure, which thereby increases the importance of the aerodynamic resistance, as it drastically increases with speed. A second effect is that the exact car configuration sold to the customer needs to be certified in terms of fuel consumption and emissions. The result is that every possible combination of optional extras, which might affect the aerodynamic resistance, needs to be aerodynamically analyzed and possibly improved. From 2021, the European Commission will introduce stricter emission regulations for new passenger cars, with the fleet-wide average lowered to 95 grams CO<sub>2</sub>/km, which puts an even higher demand on achieving efficient aerodynamics. Virtual development of the aerodynamics of road vehicles is today used to a great extent, using Computational Fluid Dynamics, as it enables faster and cheaper development. However, achieving high accuracy for the prediction of the flow field and aerodynamic forces is challenging, especially given the complexity of both the vehicle geometry in itself and the surrounding flow field. Even for a simplified generic bluff body, accurately predicting the flow field and aerodynamic forces is a challenge. The main reason for this challenge of achieving results with high accuracy is the prediction of the complex behavior of turbulence. Scale-resolving simulation (SRS) methods, such as Large Eddy Simulation (LES), where most of the turbulent structures are resolved has in many studies shown high accuracy but unfortunately to a very high computational cost. It is primarily the small turbulent structures within the near-wall region that requires a fine resolution in both space (the mesh) and in time. This fine resolution is the reason for the very high computational cost and makes LES unfeasible for practical use in industrial aerodynamic development at present and in the near future. By modeling the turbulent structures within the near-wall region using a Reynolds-Averaged Navier-Stokes (RANS) model, and resolving the turbulence outside the region with a LES model, a coarser resolution is possible to use, resulting in significantly lower computational cost. Which used RANS model is of high importance, and especially how much turbulent***

***viscosity the model generates, as too high values can result in suppression of the resolved turbulence. The transitioning between the RANS and LES regions have a significant effect on the results. Faster transition enables more resolved turbulence, favorable for higher accuracy, but needs to be balanced with sufficient shielding of the RANS region. If resolving the turbulence occurs within the near-wall region, and the mesh is not sufficiently fine, it can result in poor accuracy. By increasing the time-step size and disregarding best-practice guides, the computational cost can be significantly reduced. The accuracy is reasonably insensitive to the larger time step sizes until a certain degree, thereby enabling computationally cheaper SRS to achieve high accuracy of aerodynamic predictions needed to meet present and future emission regulations.***

***An updated edition of the classic reference on the dynamics of road and off-road vehicles As we enter a new millennium, the vehicle industry faces greater challenges than ever before as it strives to meet the increasing demand for safer, environmentally friendlier, more energy efficient, and lower emissions products. Theory of Ground Vehicles, Third Edition gives aspiring and practicing engineers a fundamental understanding of the critical factors affecting the performance, handling, and ride essential to the development and design of ground vehicles that meet these requirements. As in previous editions, this book focuses on applying engineering principles to the analysis of vehicle behavior. A large number of practical examples and problems are included throughout to help readers bridge the gap between theory and practice. Covering a wide range of topics concerning the dynamics of road and off-road vehicles, this Third Edition is filled with up-to-date information, including: \* The Magic Formula for characterizing pneumatic tire behavior from test data for vehicle handling simulations \* Computer-aided methods for performance and design evaluation of off-road vehicles, based on the author's own research \* Updated data on road vehicle transmissions and operating fuel economy \* Fundamentals of road vehicle stability control \* Optimization of the performance of four-wheel-drive off-road vehicles and experimental substantiation, based on the author's own investigations \* A new theory on skid-steering of tracked vehicles, developed by the author.***