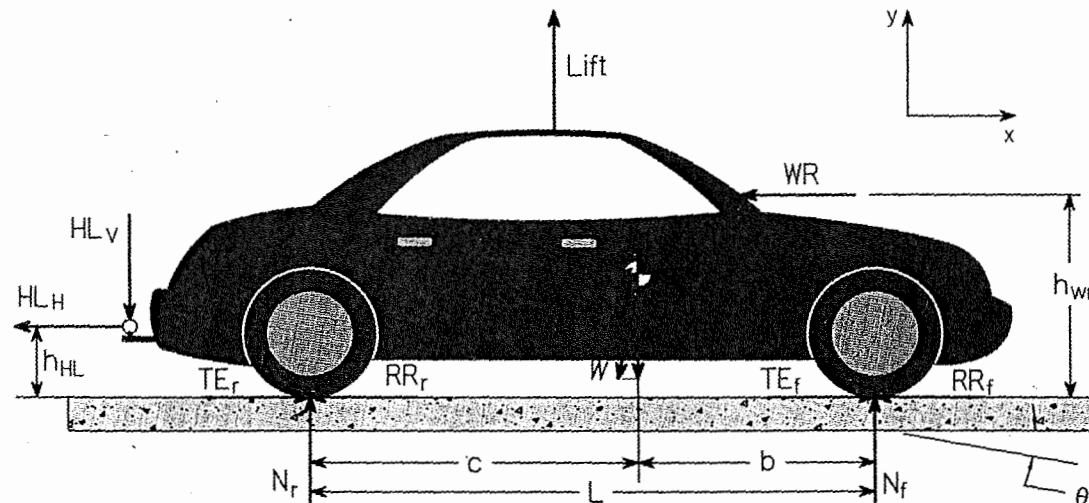


# ...tion to Automotive Powertrains



Craig J. Hoff, Ph.D., P.E.  
Gregory W. Davis, Ph.D., P.E.

powertrain. It is an introductory text on the topic, but it will provide the interested reader with a basis for understanding the fundamentals of automotive engines and automotive transmissions, and more importantly how to select those components to provide the optimum compromise between acceleration performance, gradeability performance and fuel economy performance.

The level of analysis used in the text is not particularly difficult (it is assumed that the reader has a good grasp of engineering mechanics), however the equations derived in the text become the basis for developing computer models that can be used to predict vehicle performance.

## **Acknowledgements**

---

The authors of this book would like to thank and to acknowledge the work and support of many others who have come before us. In particular, we would like to thank Dr. Colin Jordan for his significant contributions to the original notes from which this book was drawn. Finally, we would like to acknowledge the works of others who have made many of the original illustrations in this edition. Unfortunately, we have not yet been able to track down the sources of some of these works. We are working diligently to locate the authors and to replace illustrations as needed. This work is currently a pre-production work intended for educational use.

|                         |   |           |
|-------------------------|---|-----------|
| Table of Contents ..... |   | 5         |
| <b>1</b>                | <b>Automotive Drivetrain Components and Layouts .....</b> | <b>11</b> |
| 1.1                     | Typical Drivetrain Layouts .....                          | 11        |
| 1.1.1                   | Typical Rear Wheel Drive Configuration.....               | 11        |
| 1.1.2                   | Typical Front Wheel Drive Configuration.....              | 14        |
| 1.1.3                   | Rear Wheel Drive with Rear Engine .....                   | 15        |
| 1.1.4                   | Typical Four Wheel Drive Configuration.....               | 16        |
| 1.1.5                   | Drivetrain Packaging .....                                | 17        |
| 1.2                     | Driveline Components .....                                | 18        |
| 1.2.1                   | Clutches.....   | 18        |
| 1.2.2                   | Hydraulic Torque Converter .....                          | 19        |
| 1.2.3                   | Manual Transmission.....                                  | 21        |
| 1.2.4                   | Automatic Transmissions.....                              | 22        |
| 1.2.5                   | Transaxles .....  | 23        |
| 1.2.6                   | Driveshafts .....   | 24        |
| 1.2.7                   | Differentials .....                                       | 25        |
| 1.2.8                   | Rear Axle .....   | 26        |
| 1.3                     | References.....   | 26        |
| <b>Chapter 2 .....</b>  |   | <b>27</b> |
| <b>2</b>                | <b>Road Loads .....</b>                                   | <b>27</b> |
| 2.1                     | Introduction.....   | 27        |
| 2.2                     | Aerodynamic Lift and Drag .....                           | 29        |
| 2.2.1                   | Inviscid Flow: Euler and Bernoulli Equations.....         | 30        |
| 2.2.2                   | Application to an Automobile.....                         | 32        |
| 2.2.3                   | Viscid Flow: Boundary Layers .....                        | 34        |
| 2.2.4                   | Application to an Automobile.....                         | 35        |
| 2.2.5                   | Inviscid Flow over Bodies .....                           | 35        |
| 2.2.6                   | Viscid Flow over Bodies.....                              | 37        |
| 2.2.7                   | Application to an Automobile.....                         | 40        |
| 2.2.8                   | Experimental Techniques.....                              | 40        |
| 2.2.9                   | Application to an Automobile.....                         | 42        |
| 2.2.10                  | Vortex Shedding .....                                     | 46        |
| 2.2.11                  | Application to an Automobile.....                         | 46        |
| 2.2.12                  | Automotive Drag Studies.....                              | 47        |
| 2.2.13                  | Afterbody Drag .....                                      | 48        |
| 2.2.14                  | Wheel and Wheel Wells.....                                | 49        |
| 2.2.15                  | Forebody Effects.....                                     | 50        |
| 2.2.16                  | Underbody Drag.....                                       | 51        |

|          |  |           |
|----------|--|-----------|
| 2.3.2    | Effect of Road Surface.....  | 61        |
| 2.3.3    | Effect of Temperature on Rolling Resistance.....                       | 61        |
| 2.3.4    | Effect of Tire Inflation Pressure .....                                | 62        |
| 2.3.5    | Effect of Tire Speed .....   | 62        |
| 2.3.6    | Effect of Tire Materials.....  | 62        |
| 2.3.7    | Effect of Tire Slip Angle.....   | 63        |
| 2.3.8    | Other Models for Rolling Resistance.....                               | 64        |
| 2.4      | Coast Down Testing.....  | 64        |
| 2.5      | Grade Resistance.....  | 65        |
| 2.6      | The Proving Ground Equation.....                                       | 66        |
| 2.7      | References.....  | 68        |
| <b>3</b> | <b>Power Systems.....</b>  | <b>69</b> |
| 3.1      | Introduction to Internal Combustion Engines and Their Performance..... | 69        |
| 3.1.1    | Spark-ignited (SI) or Gasoline Four-stroke Engines .....               | 69        |
| 3.1.2    | Compression-ignition (DI) or Diesel Four-stroke Engines.....           | 70        |
| 3.2      | Engine Brake Torque and Power .....                                    | 72        |
| 3.2.1    | Brake Power.....   | 73        |
| 3.2.2    | Friction Power (FP).....   | 75        |
| 3.2.3    | Indicated Power (IP) .....   | 75        |
| 3.2.4    | Specific Power .....   | 75        |
| 3.2.5    | Mean Effective Pressure (MEP) .....                                    | 75        |
| 3.3      | Efficiencies .....   | 78        |
| 3.3.1    | Mechanical Efficiency .....  | 78        |
| 3.3.2    | Overall Thermal Efficiency (or Fuel Efficiency).....                   | 78        |
| 3.3.3    | Combustion Efficiency .....  | 80        |
| 3.3.4    | Thermal Efficiency (or Specific Efficiency).....                       | 80        |
| 3.3.5    | Specific Fuel Consumption (SFC).....                                   | 81        |
| 3.3.6    | Volumetric Efficiency.....   | 81        |
| 3.4      | Fuels.....   | 81        |
| 3.4.1    | Octane Rating.....   | 82        |
| 3.4.2    | Decane Rating.....   | 82        |
| 3.4.3    | Determination of Fuel Specific Gravity and Heating Value.....          | 82        |
| 3.5      | Emissions .....  | 82        |
| 3.6      | Other Engine Parameters .....  | 83        |
| 3.6.1    | Mean Piston Speed (S).....   | 83        |
| 3.6.2    | Inlet Air Velocity .....   | 83        |
| 3.7      | Typical Engine Performance Data.....                                   | 83        |
| 3.7.1    | Full Load Performance Comparison of SI and CI Engines .....            | 83        |
| 3.7.2    | SAE Net Versus Gross Performance .....                                 | 86        |

|          |   |            |
|----------|---|------------|
| <b>4</b> | <b>Driveline</b>                                    | <b>93</b>  |
| 4.1      | Introduction  | 93         |
| 4.2      | Driveline   | 96         |
| 4.2.1    | Ideal Driveline                                     | 96         |
| 4.2.2    | Driveline Losses                                    | 99         |
| 4.3      | Tires (Idealized Model)                             | 103        |
| 4.3.1    | N/V Ratio (Idealized Tire)                          | 103        |
| 4.3.2    | Available Tractive Power                            | 108        |
| 4.3.3    | Available Tractive Effort                           | 111        |
| 4.3.4    | Actual Tractive Power and Tractive Effort           | 115        |
| 4.4      | Tires (Better Model)                                | 118        |
| 4.4.1    | Tire Forces and Moments                             | 118        |
| 4.4.2    | Tire Slip   | 119        |
| 4.4.3    | N/V Ratio (Better Model)                            | 122        |
| 4.4.4    | Tractive Effort                                     | 122        |
| 4.4.5    | Example – Effect of Tire Slip                       | 124        |
| 4.4.6    | Slip Angle  | 127        |
| 4.5      | The Friction Ellipse                                | 130        |
| 4.5.1    | Rolling Resistance (Revisited)                      | 134        |
| 4.5.2    | A Final Note on Tires                               | 135        |
| 4.6      | Move-off Elements                                   | 135        |
| 4.7      | References  | 137        |
| <b>5</b> | <b>Gear Ratio Selection</b>                         | <b>139</b> |
| 5.1      | Typical Gear Ratios Selected for Passenger Vehicles | 143        |
| 5.2      | A Procedure for Selecting Gear Ratios               | 149        |
| 5.2.1    | Selection of a top gear N/V ratio                   | 149        |
| 5.2.2    | Determination of Top Gear Ratio and Axle Ratio      | 153        |
| 5.2.3    | Low Gear Ratio Determination                        | 154        |
| 5.2.4    | Selecting Intermediate Gear ratios                  | 159        |
| 5.3      | Example   | 168        |
| 5.3.1    | Select a Top Gear N/V ratio                         | 169        |
| 5.3.2    | Select a top gear ratio                             | 169        |
| 5.3.3    | Select an axle ratio                                | 169        |
| 5.3.4    | Select first gear ratio                             | 170        |
| 5.3.5    | Select intermediate gear ratios                     | 170        |
| 5.3.6    | Evaluate Gear Ratios                                | 172        |
| 5.4      | Homework  | 172        |
| 5.5      | References  | 173        |

# Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

## Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

## Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

## Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

## API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

## LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

## FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

## E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.