

Contents

Foreword	<u>xv</u>
Preface to the Third Edition	<u>xvii</u>
Preface to Second Edition	<u>xix</u>
Preface to First Edition	<u>xxi</u>
Acknowledgments	<u>xxv</u>

CHAPTER 1

Uncertainty and Sensitivity in Measurements and Calculations in Accident Reconstruction	<u>1</u>
Introduction	<u>1</u>
Upper and Lower Bounds Using a Given Model	<u>4</u>
Differential Variations	<u>6</u>
Statistics of Related Variables	<u>9</u>
Linear Functions	<u>10</u>
Arbitrary Functions (Approximate Method)	<u>11</u>
Finite Differences	<u>13</u>
Monte Carlo Method	<u>16</u>
Design of Experiments	<u>19</u>
The Bayesian Method	<u>23</u>
Application Issues and Other Considerations	<u>31</u>
Other Methods of Evaluating Uncertainty	<u>33</u>

CHAPTER 2

Tire Forces	<u>37</u>
Introduction	<u>37</u>
Rolling Resistance	<u>39</u>
Slip, Longitudinal Force, and Lateral Force	<u>40</u>
Longitudinal Slip	<u>41</u>

Comments, the Coefficient of Friction, and the Frictional Drag Coefficient	<u>45</u>
Longitudinal Tire Force	<u>47</u>
Vehicle Event Data Recorders and Longitudinal Slip	<u>49</u>
Lateral Tire Force	<u>50</u>
Friction Circle and Friction Ellipse	<u>52</u>
Idealized Friction Circle and Idealized Friction Ellipse	<u>53</u>
Friction Circle and Friction Ellipse	<u>55</u>
Modeling Combined Steering and Braking Tire Forces	<u>58</u>
The Bakker-Nyborg-Pacejka Model for Lateral and Longitudinal Tire Forces	<u>58</u>
Modified Nicolas-Comstock Combined Tire Force Model	<u>60</u>
Application Issues	<u>66</u>
Tire Stiffness Values	<u>66</u>
Antilock Braking Systems	<u>69</u>
Light Vehicle (LV) Frictional Drag Coefficients	<u>70</u>
Frictional Drag Coefficients for Heavy Trucks (HT)	<u>72</u>
Hydroplaning	<u>76</u>
Appendix 2A	<u>79</u>
CHAPTER 3	
Straight-Line Motion	<u>83</u>
Introduction	<u>83</u>
Uniform Acceleration and Braking Motion	<u>83</u>
Equations of Constant Acceleration	<u>84</u>
Road Grade and Equivalent Drag Coefficients	<u>87</u>
Vehicle Forward-Motion Performance Equations	<u>87</u>
Stopping Distance	<u>92</u>
Distance from Speed	<u>93</u>
Speed from Distance	<u>93</u>
Application Issues	<u>95</u>
Stopping Distance	<u>95</u>
Two Objects Decelerating While in Contact	<u>98</u>
Motion Around Curves	<u>101</u>
Vehicle Fall Equations	<u>101</u>
Equations of Motion of a Projectile	<u>101</u>
Equations of Motion of a Vehicle Leading to a Fall Including Rotational Inertia	<u>104</u>

CHAPTER 4

Critical Speed from Tire Yaw Marks	<u>111</u>
Introduction	<u>111</u>
Estimation of Speed from Yaw Marks	<u>112</u>
Yaw Marks	<u>115</u>
Radius from Yaw Marks	<u>117</u>
Critical Speed	<u>118</u>
CSF on a Flat Surface	<u>119</u>
Roadway with Superelevation	<u>119</u>
Application Issues	<u>123</u>
Tire Marks in Practice	<u>123</u>
Other Curved Tire Marks	<u>123</u>
Frictional Drag Coefficient, f	<u>124</u>
Driver Control Modes	<u>124</u>
Tire Forces in a Severe Yaw	<u>124</u>
The Critical Speed Formula and Edge Drop-Off (Road-Edge Reentry)	<u>126</u>
Uncertainty of Critical Speed Calculations	<u>126</u>
Estimation of Uncertainty by Differential Variations	<u>126</u>
Accuracy of the Critical Speed Method	<u>127</u>
Statistical Variations	<u>129</u>
Yaw Mark Striations	<u>131</u>
Striation Angles	<u>132</u>
Striation Spacing	<u>135</u>

CHAPTER 5

Reconstruction of Vehicular Rollover Accidents	<u>139</u>
Introduction	<u>139</u>
Rollover Test Methods	<u>141</u>
Documentation of the Accident Site	<u>144</u>
Documentation of the Accident Vehicle	<u>146</u>
Pre-trip Phase	<u>149</u>
Tire Mark Striation	<u>155</u>
Trip Phase	<u>158</u>
Modeling the Trip Phase	<u>159</u>
Complex Vehicle Trip Models	<u>164</u>
Rim Contact	<u>165</u>

Roll Phase	<u>166</u>
Speed Analysis for the Roll Phase	<u>166</u>
Determining the Roll Motion of the Vehicle	<u>170</u>
Generating a Realistic Roll Velocity Curve	<u>173</u>
Example Rollover Reconstruction	<u>174</u>
Vehicle-to-Ground Impact Model	<u>182</u>
Impulse Ratio (μ)	<u>185</u>
Impact Angle (ϕ)	<u>187</u>
CHAPTER 6	
Analysis of Collisions, Impulse-Momentum Theory	<u>189</u>
Introduction	<u>189</u>
Quantitative Concepts	<u>191</u>
Point-Mass Impulse-Momentum Collision Theory	<u>193</u>
Coefficient of Restitution, Frictionless Point-Mass Collisions	<u>199</u>
Collisions Where Sliding Ends before Separation: The Critical Impulse Ratio, μ_0	<u>201</u>
Sideswipe Collisions and Common-Velocity Conditions	<u>201</u>
Controlled Collisions	<u>204</u>
Coefficients of Restitution	<u>206</u>
Stiffness Equivalent Collision Coefficient of Restitution	<u>206</u>
Mass Equivalent Collision Coefficient of Restitution	<u>208</u>
Summary of the Point-Mass Impact Model	<u>209</u>
Planar Impact Mechanics	<u>210</u>
Overview of Planar Impact Mechanics Model	<u>216</u>
Application Issues: Coefficients, Dimensions, and Angles	<u>219</u>
Coefficient of Restitution and Impulse Ratio	<u>219</u>
Distances, Angles, and Point C	<u>221</u>
Work of Impulses and Energy Loss (Crush Energy)	<u>223</u>
RICSAC Collisions	<u>225</u>
Summary of Planar Impact Mechanics Model	<u>229</u>
Application Issues	<u>230</u>
Crashes with Large Mass Disparity between the Vehicles	<u>230</u>
Underride/Override Crashes	<u>233</u>

CHAPTER 7**Event Data Recorders and Crash Reconstruction [237](#)**

Introduction	237
Light Vehicle EDR Data	242
EDR Reported ΔV	242
Recording Delay	244
Incomplete Recording	245
Clipping	245
Effect of ACM Location	246
EDR Reported Precrash Vehicle Speed	247
Heavy Vehicle EDR Data	251
Summary	252

CHAPTER 8**Reconstruction Applications,
Impulse-Momentum Theory [255](#)**

Introduction	255
Point-Mass Collision Applications	256
Rigid Body, PIM Applications: Vehicle Collisions with Rotation	263
Collision Reconstruction Using a Solution of the Planar Impact Equations	264
Reconstructions Using a Spreadsheet Solution of the Planar Impact Equations	266
Optimization Methods for Collision Reconstruction	271
Low-Speed In-Line (Central) Collisions	282
In-Line Impulse-Momentum Impact Model	283
Bumper Pair Stiffness Characterization Method	289
Airbags, Event Data Recorders, and ΔV	302
Crash Data	303
Precrash Data	304

CHAPTER 9**Collisions of Articulated Vehicles,
Impulse-Momentum Theory [311](#)**

Introduction	311
Assumptions for Application of Planar Impact Mechanics to Articulated Vehicles	313

Articulated Vehicle Impact Equations	316
Validation of the Articulated Vehicle Impact Equations Using Experimental Data	323
Appendix 9A: Data Sheets for Example 9.4	345

CHAPTER 10

Crush Energy and ΔV	349
Introduction	349
The CRASH3 Method	350
Crush Stiffness Coefficients Based on Average Crush from Rigid Barrier Tests	361
Application Issues	372
Crush Stiffness Coefficients from Vehicle-to-Vehicle Collisions	372
Damage to One Vehicle Unknown	374
Side Crush Stiffness Coefficients, Two-Vehicle, Front-to-Side Crash Tests	374
Nonlinear Models of Crush	374
Arbitrary Number of Crush Measurements	374

CHAPTER 11

Frontal Vehicle-Pedestrian Collisions	377
Introduction	377
General and Supplementary Information	380
Forward Projection (Type I) Model	380
Hybrid Wrap Model	381
Vehicle-Pedestrian Impact (Type II) Mechanics Model	382
Pedestrian Motion	383
Vehicle Motion	386
Values of Physical Variables	387
Reconstruction (Hybrid) Model	392
Application to a Motorcycle Rider Thrown after Impact	394

CHAPTER 12

Photogrammetry for Accident Reconstruction	399
Introduction	399
Aerial Photography	401

Camera Matching	404
Planar Photogrammetry	405
Three-Dimensional (3D) Photogrammetry	413
Fundamental Information Related to Three-Dimensional (3D) Photogrammetry	414
Mathematical Basis of Three-Dimensional (3D) Photogrammetry	415
Projection Equations	415
Collinearity Equations	417
Coplanarity Equations	418
Multiple Image Considerations	418
Considerations of the Use of Three-Dimensional (3D) Photogrammetry in Practice	418
Summary	428
Appendix 12A: Projective Relation for Planar Photogrammetry	428

CHAPTER 13

Railroad Grade Crossing and Road Intersection Conflicts	433
Introduction	433
Clearing a Crossing or Intersection Using a Sight Triangle	434
Sight Distance for Stopping before a Crossing or Intersection	439
FHWA Grade-Crossing Equations	443
Stopping Distance	444
Stopping Sight Distance	446
Clearing Sight Distance	446
Locomotive Horn Sound Levels at Railroad Grade Crossings	448
Calculation of Horn Sound Levels at a Distance from a Point Source	448
Insertion Loss of Light Vehicles	452

CHAPTER 14

Vehicle Dynamic Simulation	457
Introduction	457
Planar Vehicle Dynamic Simulation	458
Tire Side-Force Stiffness Coefficients	461
Light-Vehicle Side-Force Coefficients	461
Heavy-Vehicle Side-Force Coefficients	462
Sensitivity of the Model to Parameters	462

Examples	<u>463</u>
Appendix 14A: Differential Equations of Planar Vehicular Motion	<u>484</u>
Notation	<u>485</u>
Appendix A: Units and Numbers	<u>487</u>
Appendix B: Glossary	<u>501</u>
References	<u>529</u>
Bibliography	<u>557</u>
About the Authors	<u>559</u>
Index	<u>561</u>