

# Car Suspension and Handling

Fourth Edition



Donald Bastow  
Geoffrey Howard  
John P. Whitehead

# Contents

Preface to the Fourth Edition .....	xi	
Preface to the First Edition .....	xiii	
Notation .....	xv	
<b>Chapter 1</b>	<b>Introduction .....</b> 1	
1.1	Scope and Layout of the Book .....	1
1.2	The Function of the Suspension System .....	3
1.3	Suspension Geometry .....	9
1.4	Kinematics and Compliance (K&C) .....	17
1.5	Vehicle Dynamics .....	18
1.6	References .....	19
<b>Chapter 2</b>	<b>Disturbances and Sensitivity .....</b> 23	
2.1	Road Irregularities .....	23
2.2	Influence of Wheel Size .....	25
2.3	Subjective Assessment of Ride .....	25
2.4	Human Sensitivity to Vibration .....	27
2.5	Measurement Standards for Vibration .....	30
2.6	Influence of Noise on Assessment of Ride Comfort .....	34
2.7	Influence of Phase of Differential Vibration on Assessment of Ride Comfort .....	35
2.8	References .....	36
<b>Chapter 3</b>	<b>The Wheel and Tire .....</b> 39	
3.1	Introduction .....	39
3.2	The Wheel Rim .....	39
3.3	Tire Size Designation .....	43
3.4	Tire Construction Types .....	45
3.5	Tire Properties with Reference to Vehicle Braking .....	51
3.6	Tire Properties with Reference to Vehicle Cornering .....	54
3.7	Rolling Resistance .....	69
3.8	Tire Uniformity .....	72
3.9	Aspect Ratios .....	76

3.10	Tire Selection and Air Chamber Geometry .....	77
3.11	References .....	81
Chapter 4	Steering .....	83
4.1	Dynamic Function of the Steering System .....	83
4.2	Steering Angles: Effects of Tire Slip Angles and Steering and Suspension Kinematics .....	84
4.3	Relative Positions of Front- and Rear-Wheel Tracks .....	89
4.4	Understeer and Oversteer .....	89
4.5	Directional Stability .....	92
4.6	Torque in the Steering System .....	94
4.7	Steering Torque Effects Due to Steering Geometry .....	95
4.8	The Steering Column .....	99
4.9	Steering Gear .....	101
4.10	Constant Velocity (CV) Driveshaft Joints .....	104
4.11	Torque Steer Effects .....	108
4.12	Front-Wheel Steering Oscillations—Shimmy .....	110
4.13	Power Assistance .....	114
4.14	Electric Power Steering .....	119
4.15	Rear-Wheel Steering Systems .....	121
4.16	References .....	124
Chapter 5	Suspension Systems and Their Effects .....	127
5.1	An Introduction to Suspension Design .....	127
5.2	Suspension Systems in Common Use .....	129
5.3	Spring Function and Theory .....	129
5.4	Energy Storage Capacities .....	131
5.5	Spring Natural Frequencies .....	133
5.6	Leaf Springs .....	135
5.7	Torsion Bars and Coil Springs .....	137
5.8	Coil Spring Rates .....	139
5.9	Wishbone Suspensions—Effect on Wheel Rates .....	140
5.10	Gas Springs .....	142
5.11	Ride Height Control .....	144
5.12	Bump and Rebound Stops .....	146
5.13	Interaction of Front and Rear Suspensions to Single Applied Disturbances .....	150
5.14	Effect of Regularly Repeated Disturbances .....	153
5.15	Suspension Roll-Center Height Determination .....	154
5.16	Suspension Geometry for Anti-Dive and Anti-Squat .....	158

	5.17 Compliance—Effect on Road Noise and Harshness .....	162
	5.18 References .....	163
<b>Chapter 6</b>	<b>Dampers .....</b>	<b>165</b>
6.1	Types of Damping .....	165
6.2	Damping Effects on Vehicle Ride Spectra .....	166
6.3	Damping Characteristics .....	168
6.4	Measurement of Damper Characteristics .....	173
6.5	Hydraulic Dampers .....	174
6.6	Types of Hydraulic Dampers .....	175
6.7	Lever-Arm Dampers .....	176
6.8	Telescopic Dampers .....	176
6.9	Other Arrangements—Hydropneumatic .....	183
6.10	Critical Damping Coefficients .....	184
6.11	References .....	185
<b>Chapter 7</b>	<b>Front Suspensions .....</b>	<b>187</b>
7.1	Front Beam Axle—Reasons for Decline in Use .....	187
7.2	Independent Suspensions .....	188
7.3	Significant Obsolete Systems .....	189
7.4	Recent Independent Suspension Systems .....	193
7.5	Double Steering-Pivot Front Suspensions .....	199
7.6	Friction in Strut and Link Type Suspensions .....	199
7.7	References .....	201
<b>Chapter 8</b>	<b>Rear Suspensions .....</b>	<b>203</b>
8.1	Classification of Types .....	203
8.2	Live Rear Axles .....	204
8.3	De Dion Axles .....	207
8.4	Dead Rear Axles for Front-Wheel Drive Vehicles .....	209
8.5	Twist-Beam Rear Axles for Front-Wheel Drive Vehicles .....	211
8.6	Independent Rear Suspension Systems— Swing Axles .....	215
8.7	Independent Rear Suspension Systems— Trailing and Semi-Trailing Arms .....	217
8.8	Independent Rear Suspension Systems—Wishbones .....	223
8.9	Independent Rear Suspension Systems—Multi-Link, and Strut and Link .....	224
8.10	References .....	228

Chapter 9	Drive Layouts and Their Effects .....	231
9.1	Drive Layouts .....	231
9.2	Background to Front-Wheel Drive .....	232
9.3	Front-Drive Versus Rear-Drive Arguments .....	234
9.4	Modern Design Priorities .....	235
9.5	Mass Distribution .....	236
9.6	Dynamic Characteristics .....	239
9.7	Four-Wheel Drive .....	242
9.8	References .....	243
Chapter 10	Advanced Suspension Systems .....	245
10.1	Ride and Handling Limitations .....	245
10.2	Background to Advanced Suspensions .....	246
10.3	Interconnected Suspensions .....	254
10.4	Self-Leveling Suspensions .....	263
10.5	Adaptive Damping .....	266
10.6	Active Attitude Control .....	269
10.7	Fully Active Suspension Systems .....	273
10.8	Slow Active Suspension Systems .....	275
10.9	Electronic Stability Aids .....	277
10.10	References .....	279
Chapter 11	Computer Aided Engineering (CAE) for Suspension .....	283
11.1	Computer Use in Suspension Design and Engineering .....	283
11.2	Structural Engineering .....	284
11.3	Computer Aided Engineering for Suspension Kinematics and Compliance (K&C) .....	285
11.4	Computer Aided Engineering for Vehicle Dynamics .....	286
11.5	Computer Aided Engineering for Noise Analysis and Refinement Prediction .....	290
11.6	References .....	291
Appendix 1	Disturbances and Structural Durability .....	293
A1.1	Designing and Developing for Durability .....	293
A1.2	Special Surfaces .....	294
A1.3	Durability Cycles .....	296
A1.4	Laboratory Test Methods .....	297
A1.5	Road Load Data .....	297

A1.6	Powertrain Durability .....	299
A1.7	References .....	299
Appendix 2	More on Tires .....	301
A2.1	Introduction .....	301
A2.2	Pneumatic Tires .....	301
A2.3	Tubeless Tires .....	302
A2.4	Rubber Compounds .....	303
A2.5	Tread Patterns .....	306
A2.6	Extended Mobility Systems .....	309
A2.7	Non-Dimensional Tire Data .....	315
A2.8	References .....	318
Appendix 3	Steering Calculations and Worked Examples .....	319
A3.1	Steering Ball Joints .....	319
A3.2	Ball Pin Shank Fitting .....	319
A3.3	Ball Joints—Provision of Friction .....	322
A3.4	Steering Angles of Inner and Outer Front Wheels .....	324
A3.5	Different Inner and Outer Wheel Lock Angles .....	326
A3.6	Calculations for Independent Suspension Systems— Worked Examples .....	328
A3.7	Torque Steer Components .....	335
A3.8	Inertia Torques Affecting Steering .....	336
A3.9	Steering Geometry Errors, Bump, and Rebound .....	338
A3.10	Incorrect Relative Lengths of Cross-Steering Tube and Linkage Arms .....	342
A3.11	Incorrect Alignment of Steering Tube and Linkage .....	343
A3.12	Inertia Torques Due to Fore and Aft Links— Worked Examples .....	345
A3.13	Effect of Weight Transference in Cornering .....	354
A3.14	Sideways Forces—Effect of Influences Other than Lateral Acceleration .....	355
A3.15	Cornering Behavior—Worked Examples .....	357
A3.16	References .....	362
Appendix 4	Suspension Calculations and Worked Examples .....	363
A4.1	Basic Suspension System .....	363
A4.2	Vibrations of Basic System—Approximate Frequencies .....	364
A4.3	True Frequency, Sprung Mass .....	364

A4.4	True Frequency, Unsprung Mass .....	366
A4.5	Spring/Mass Systems—Worked Examples .....	367
A4.6	Effect of Viscous Damping on Natural Frequency— Critical Damping .....	370
A4.7	Effect of Damping on Forced Vibration Amplitudes .....	371
A4.8	Critical Damping—Worked Examples .....	375
A4.9	Relative Pitch and Bounce Frequencies— $k^2/ab$ Ratio .....	382
A4.10	Effect of $k^2/ab$ Ratio on Pitching Tendency .....	383
A4.11	$k^2/ab$ Ratio and Pitch Frequency .....	384
A4.12	$k^2/ab$ Ratio about the Vertical Axis—Effect on Transient Behavior .....	386
A4.13	$k^2/ab$ Ratio about the Vertical Axis—Desirable Value .....	389
A4.14	Pitch Excitation—Coupled Suspensions .....	389
A4.15	Attitude Changes Due to Braking .....	390
A4.16	Attitude Changes Due to Traction .....	394
A4.17	Attitude Changes—Inboard Brakes and Independent Suspension at the Drive End .....	395
A4.18	Percentage Anti-Dive and Anti-Squat—Calculation Requirements .....	397
A4.19	Anti-Pitch Rate of Car Suspension—Worked Examples .....	398
A4.20	Anti-Roll Rates .....	407
A4.21	Roll Angles in Cornering .....	408
A4.22	Moment of Inertia in Roll—Worked Examples .....	412
A4.23	Mass Distribution Front and Rear .....	422
A4.24	References .....	423
	Index .....	425
	About the Authors .....	453

Indeed, multi-link suspensions are generally only used in both front and rear in sedans. Only a few models of compact cars have a multi-link suspension and that only in the rear (Volkswagen Golf with more than 120 horsepower, Ford Focus).

5. Double Wishbone Suspension. McLaren MP4-12C double wishbone suspension system. The dual triangle design provides superior ride comfort, dynamics and handling. However, its manufacturing cost is high. This is why it is generally only standard on top-of-the-range models such as Mercedes E-Class and S, BMW 5 and 7 series, and Audi A4.

1 Suspension and Handling Basic Suspension and Setup Principles.

2 Basic Principles of Tuning The three major elements of handling :

1. Grip Level Determines the maximum possible cornering speeds / G-levels
2. Balance Understeer / oversteer
3. Controllability How hard is it to drive?
4. Balance front-to-rear handling and tire temperatures using swaybars, shocks, camber, etc., if possible.
5. If car oversteers (understeers) entering and understeers (oversteers) exiting corner, lower (raise) all pressures.
6. If #5 only occurs late (early) in race or session, start with lower (higher) pressures.
7. Modify above for individual handling (and wear) needs: i.e, raise or lower front or rear pressures knowing that lower pressure works better at lighter loads and that higher pressure works better at higher loads.