

An Introduction to Race Car Engineering

Table of Contents

| | <u>Page</u> |
|---|-------------------|
| Chapter 1 – Some Basic Truths | 1/1 to 1/4 |
| <ul style="list-style-type: none"> • Basic concepts and truths leading to the successful study and understanding of vehicle dynamics | |

The Tire Chapters

| | |
|--|--------------------|
| Chapter 2 – Tires: Part One - Design and Performance Parameters | 2/1 to 2/28 |
|--|--------------------|

| | |
|--|------|
| • A First Look at the Contact Patch | 2/3 |
| • A Tire Construction Primer | 2/6 |
| o Tire Design | 2/6 |
| o Tire Types | 2/6 |
| o Tire Construction | 2/6 |
| o Tread Compound | 2/9 |
| o Aspect Ratio..... | 2/11 |
| o Tire Design Concepts..... | 2/12 |
| • Lateral and Longitudinal Forces | 2/14 |
| o Conventional Friction Forces..... | 2/14 |
| o Hysteresis..... | 2/14 |
| o Molecular Bonding | 2/15 |
| • Coefficient of Friction and its Related Forces..... | 2/15 |
| o Lateral Acceleration..... | 2/16 |
| o Centripetal Versus Centrifugal..... | 2/16 |
| o Lateral Force | 2/17 |
| • Terms, Definitions and Explanations | 2/17 |
| o Tire Shear..... | 2/18 |
| o Sidewall Shear Displacement..... | 2/18 |
| o Tread Shear Displacement | 2/18 |
| o Tread Shear Angle | 2/18 |
| o Sidewall Shear Angle..... | 2/19 |
| o Total Shear Angle | 2/19 |
| o Slip..... | 2/19 |
| o Slip Angle | 2/20 |
| o Trailing Edge Slip Percentage..... | 2/20 |
| o Lateral Shear Forces Versus Lateral Acceleration | 2/20 |
| o Tread Shear Angle | 2/20 |
| o Tread Particles | 2/21 |
| o Tread Shear Displacement | 2/22 |
| o Percentage of Shear Displacement..... | 2/22 |
| o Shear Angle..... | 2/23 |
| o Shear Displacement | 2/23 |
| o Tread Cantilever Displacement Angle..... | 2/23 |
| o Sidewall Shear/Deflection | 2/24 |
| o Sidewall Shear Displacement..... | 2/24 |
| o Maximum Tread Shear Angle Versus Maximum Tread Shear Force | 2/24 |
| o Measuring Tread and Sidewall Shear | 2/24 |
| • The Turning Process | 2/26 |
| o Tread Forces | 2/26 |
| o Path | 2/26 |
| o Shear Angle Versus Heat Generation | 2/27 |

| | |
|--------------------------------|------|
| ○ Speed Coefficient..... | 2/28 |
| ○ Track Surface Friction | 2/28 |
| ○ Tire Path..... | 2/28 |
| ○ Car Path | 2/28 |

Chapter 3 – Tires: Part Two

– A Race Engineer’s Look at Tire Performance 3/1 to 3/33

| | |
|--|-------|
| • The Bottom Line – it all begins and ends at the four contact patches | 3/1 |
| • Yaw – The First Look | 3/2 |
| ○ Action and Reaction Forces | 3/2 |
| ○ Rate of Load Transfer | 3/4 |
| ○ Lateral Acceleration versus Yaw | 3/5 |
| ○ Definitions | 3/5 |
| • Race Tire Parameters | 3/6 |
| ○ Slope | 3/6 |
| ○ Vertical versus Normal Load | 3/8 |
| ○ Decreasing Coefficient..... | 3/8 |
| • Slip and Regrip..... | 3/9 |
| ○ Trailing Edge Slip..... | 3/9 |
| ○ Contact Patch Slip..... | 3/10 |
| ○ Regrip | 3/10 |
| ○ Longitudinal Forces | 3/10 |
| • Longitudinal Shear – Inline Braking and Acceleration | 3/11 |
| ○ Tread..... | 3/11 |
| ○ Shear Ratio..... | 3/11 |
| ○ Longitudinal Slip | 3/11 |
| ○ Spring Buffer | 3/12 |
| ○ Vertical Load on the Sidewall Cords | 3/12 |
| • Camber Forces | 3/14 |
| ○ Two Camber Components | 3/14 |
| ○ Non-Vertical Resultant Elastic Forces | 3/14 |
| ○ Counteracting Centrifugal Forces | 3/115 |
| ○ The Inner Workings of Camber | 3/15 |
| ○ Camber and Surface Irregularities | 3/17 |
| • Aligning Moments – Caster Torque and Pneumatic Trail..... | 3/17 |
| ○ The Contact Patch – Lateral Acceleration | 3/17 |
| ○ Caster Torque (Moment)..... | 3/19 |
| ○ Pneumatic Torque (Tread Moment)..... | 3/19 |
| • Further Definitions | 3/20 |
| ○ Pneumatic Torque – Carcass (Sidewall and Belt)..... | 3/20 |
| ○ Combined Pneumatic Aligning Torque | 3/20 |
| ○ Camber Aligning Forces | 3/20 |
| ○ Tire Pressure and Aligning Forces..... | 3/20 |
| ○ Vertical Load and Pneumatic Aligning Forces | 3/20 |
| ○ Aligning Torque and Its Effect on the Steering Wheel | 3/20 |
| ○ Tire Heating | 3/20 |
| • Energy Loss..... | 3/21 |
| ○ Tread Momentum Loss – Tire Drag and Tire Rolling Resistance | 3/21 |
| ○ Rolling Resistance Factors..... | 3/21 |
| ○ Rolling Resistance Coefficient..... | 3/22 |
| ○ Simulation Formulas | 3/22 |
| ○ On Track Testing | 3/23 |
| ○ Shear Drag and Energy Loss..... | 3/24 |
| ○ Shear HP Loss..... | 3/27 |

| | |
|--|------|
| ○ Track and Skid Pad Testing | 3/29 |
| ○ Heat Factors and Air Pressure Versus Acceleration Forces | 3/33 |
| ○ The Big Three | 3/33 |
| ▪ Heat | 3/33 |
| ▪ Normal Load | 3/33 |
| ▪ PSI | 3/33 |

Chapter 4 – Part Three – A First Look at Tire Data..... 4/1 to 4/37

| | |
|---|------|
| • Testing and the Race Engineer | 4/1 |
| • Team Generated Test Analysis | 4/1 |
| • Tire Temperature Measurement | 4/2 |
| • Heat Generation | 4/2 |
| • Load Tire Radius..... | 4/9 |
| • Test Data from the Tire Manufacturers | 4/14 |
| • Tire Test Data..... | 4/15 |
| • Force Versus Load | 4/15 |
| • Aligning Force/Torque..... | 4/30 |
| • Rolling Radius..... | 4/35 |

The Kinematic Chapters

Chapter 5 - WinGeo3 – Wm. C. Mitchell Software

– A Basic Introduction..... 5/1 to 5/25

| | |
|--|-----|
| • The WinGeo3 Demo | 5/3 |
| • Loading WinGeo3..... | 5/4 |
| • Working with the Advanced Demo..... | 5/4 |
| • Left Mouse Click – Right Mouse Click | 5/4 |
| • Single Point Co-ordinates..... | 5/5 |
| • Two Point Co-ordinates | 5/6 |
| • An Overview of the Related WinGeo3 Demo Menus..... | 5/7 |

Chapter 6 – Independent Suspension – A Kinematic Overview 6/1 to 6/60

| | |
|---|------|
| • A Quick WinGeo3 Review | 6/1 |
| • Track | 6/3 |
| • Wheelbase | 6/6 |
| • Backspacing | 6/6 |
| • Offset..... | 6/6 |
| • Uprights and Spindles | 6/7 |
| ○ Kingpin Axis and Inclination Angle | 6/7 |
| ○ Design: Kingpin, Scrub and Caster..... | 6/7 |
| ○ Build: Caster Angle and Trail | 6/8 |
| ○ Kingpin Offset | 6/10 |
| ○ Stock Car Spindles..... | 6/11 |
| • Camber..... | 6/12 |
| ○ Camber Gain..... | 6/12 |
| ○ Bump Camber Change..... | 6/12 |
| ○ Roll Camber Gain | 6/14 |
| ○ Instant Center Location Effects on Camber During Roll | 6/14 |
| ○ Steering Iterations and Camber Change..... | 6/14 |

- Looking at Camber Change..... 6/16
 - Single Ride Calculations..... 6/16
 - Single Roll Calculations 6/16
 - Single Steer Calculations 6/16
 - Combined Calculations 6/16
 - Changing Camber Angle 6/18
- Caster or Side View Kingpin Offset..... 6/20
 - Caster Adjustment 6/20
 - Caster Design..... 6/20
 - The Shopping Cart Effect 6/20
- Aligning Torque 6/24
- Camber Gain due to Caster 6/24
- Caster Jacking – Caster Load Transfer..... 6/26
- Caster Split..... 6/27
- Caster Jacking Combined with Roll and/or Ride 6/27
- Wheel Rates, Aligning Torque and Weight (Load) Jacking..... 6/28
- Camber and Caster Effects 6/28
- Caster Gain..... 6/29
- Scrub 6/36
- Bump Scrub..... 6/36
- Roll Scrub 6/37
- Relative Lateral Movement Versus Scrub..... 6/38
- The Bottom Lines of Scrub 6/38
- Further Examples of Scrub..... 6/38
- Instant Centers..... 6/40
 - Front View Instant Center..... 6/40
 - Side View Instant Center 6/41
 - Swing Arm..... 6/41
 - Instant Axis 6/42
 - Kinematic Motion 6/45
 - Geometric (Jacking/Anti) Forces 6/45
- The Centers (Kinematic, Spring and Geometric) 6/46
 - Front and Rear View Kinematic Roll Center (KRC)..... 6/46
 - Front and Rear Springing (Elastic) Roll Center (SRC)..... 6/46
 - Front and Rear Geometric (Jacking/Anti) Center 6/46
 - Datum Roll Center 6/45
- Looking at the Kinematic Roll Center 6/47
 - Kinematic Roll Center 6/47
 - Instant Center Predetermined Placement 6/48
- The Datum Roll Center – (Actual Roll Center)..... 6/50
- The Two Primary Longitudinal Roll Axes..... 6/54
- Center of Gravity – CG 6/55
 - The Other Centers of Gravity..... 6/55
 - Mass Centroid 6/55
 - Mass Centroid Axis 6/55
 - Polar Moment of Inertia..... 6/56
- Front View Jacking/Anti Roll Center..... 6/56
 - Geometric Jacking/Anti Force Kinematics 6/56
- Side View Longitudinal Jacking Center..... 6/57
 - Anti Dive – Using Outboard Brakes 6/57
 - A-Arm Co-ordinates Versus Anti Dive Forces 6/60

Chapter 7 – Steering Geometry – Kinematics and Definitions.....7/1

- The Five Toes..... 7/1
 - Static Toe Out 7/1
 - Toe Span 7/2
 - Heavily Laden Wheel 7/3
- Steering Speed - Drag Link System 7/3
- Steering Speed – Rack and Pinion 7/3
- Net/Resultant (Dynamic Toe) 7/3
- Bump Steer..... 7/4
- Roll Steer..... 7/4
- Steering Input 7/5
- Steering Box Ratio 7/5
- Steering Input – Rack and Pinion..... 7/5
- Steering Input – Drag Link..... 7/6
- Ride and Roll Steer 7/7
- Bump Steer Geometry – Front View..... 7/9
- Bump Steer Geometry – Side View 7/9
- Combining Bump and Roll Steer Geometry 7/9
- Bump and Roll Steer Adjustment..... 7/10
 - Vertical Co-ordinate Change 7/10
 - Lateral Co-ordinate Change 7/11
 - Fore/Aft Co-ordinate Change..... 7/11
- Change the Static Toe Setting 7/16
- Ackerman Steer..... 7/18
 - Determining Amount of Ackerman Steer 7/20
 - Why Ackerman 7/20
 - Changing Suspension Co-ordinates 7/21
 - Steered Path, Shear Path and Actual Path..... 7/25
- The Turn Radius..... 7/26
- High Speed Turns..... 7/26
- Action and Reaction – A Fundamental Point..... 7/29
 - Primary and Secondary Action and Reaction Forces..... 7/29
- Yaw Observation..... 7/31
- Tracking – Oversteer/Loose Condition at Speed..... 7/31
- Yaw Center Illustrations..... 7/33
- Yaw Centers..... 7/35
- Developing Yaw..... 7/35
- Tires – Drag and Shear..... 7/36
- Yaw Equilibrium..... 7/36
- Yaw 7/36
- Oversteer 7/37
- Understeer 7/38

Chapter 8 – Live Axle – Rear Suspension Kinematics8/1

- Primary and Secondary Live Axle Kinematic Control..... 8/2
- Side View Instant Centers (Single Plane) 8/3
- Something to Think About..... 8/3
- Rear View Instant Centers..... 8/5
- Rear View Axle Motion 8/5
- Kinematic Chassis Motion in Roll About a Live Axle..... 8/7
- The Horizontal Pivot Point..... 8/7

- Combined Chassis and Axle Motion 8/9
- Datum Live Axle Roll Center 8/9
- Track Bar Scrub Kinematics 8/10
- Scrub as the Result of Roll 8/11
- Scrub as the Result of One Wheel Bump 8/12
- Scrub Due to Track Bar Geometry 8/14
- Track Bar Geometry/Kinematic Factors 8/14
- Live Axle Ride, Bump and Roll Kinematics 8/15
 - Ride 8.15
 - One Wheel Bump/Droop 8/15
 - Two Wheel Bump 8/15
 - Pure Roll 8/16
 - Offset Roll 8/16
 - Roll Forces 8/16
- Watts Links Lateral Control 8/17
- Rear Live Axle Roll and Bump Steer 8/19
- Spring Loaded Control Arms 8/21
- Pinion Angle Change 8/21
- Cambered Live Axle Rear End Housing 8/23
- Bump Camber 8/23
- Stagger Camber 8/24
- Toe Camber 8/24
- The Front and Rear Datum Roll Center and the Resultant Roll Axis 8/27
- Anti Squat Kinematics 8/29
- Decoupled Torque Arm and Telescoping Third Link 8/31
- Wheel and Axle Housing Lateral Offset 8/31

Chapter 9 – Truck Arm – Rear Suspension Kinematics.....9/1

Chapter 10 – Springs and Motion Ratios10/1

- The Coil Spring 10/1
- The Spring’s Job 10/1
- Types of Springs 10/1
- Spring Quality 10/1
- Basic Spring Rate Formula 10/3
- Testing the Spring Rate 10/4
- Sag, Free Height and Loaded Height 10/7
- Compliance and Torsional Rigidity 10/8
- Searching for the Elusive Rate Change 10/9
 - Rate Overlap 10/9
 - Free Height Inconsistencies 10/9
 - Compliance and Torsional Rigidity 10/9
 - Combined Rate Changes..... 10/9
 - Kinematic Deflection Problems 10/9
 - Preload Length Versus Load Rate 10/10
- Motion Ratios..... 10/10
 - Motion Ratio 10/10
 - Wheel Rate..... 10/11
 - Motion Ratios – The Simple Answer..... 10/11
 - Primary Motion Ratio 10/11
 - Instant Center Motion Ratio..... 10/12
 - Combined Primary and Instant Center Motion Ratios 10/12

- Spring Angle Motion Ratios 10/12
- Determining Wheel Travel Versus Spring Deflection 10/13
- The Other Team 10/13
- Bell Crank and Push Rod Independent Suspension..... 10/14
- Coil Over Independent Suspension 10/21
 - Coil Over Independent Systems..... 10/22
- Stock Car Independent Suspension 10/25
- Live Axle Motion Ratios..... 10/29
 - Motion Ratios in Ride – Side View 10/29
 - Live Axle – Springs on Top of Live Axle..... 10/29
 - Live Axle Motion Ratios in Roll..... 10/29
 - Live Axle – Springs Mounted Ahead or Behind the Axle Housing 10/29
- Asymmetrical Chassis 10/33
- Symmetrical Chassis 10/36

Chapter 11 – Anti Roll Bars and Motion Ratios 11/1 to 11/20

- Anti Roll Bars 11/1
 - Right Wheel Bump 11/1
 - Right/Left Movement..... 11/1
 - Angular Rate Versus Linear Rate 11/1
 - Shear Modulus (G) Versus Tensile Modulus (E)..... 11/1
- Angular Rate – Tube 11/2
- Angular Rate – Solid Bar 11/2
- Solid Versus Hollow Torque Tubes/Torsion Bars 11/3
- Actual Anti Roll Bar Rates..... 11/3
- The Bottom Line 11/4
- The U Anti Roll Bar 11/4
- GT Anti Roll Bars 11/9
- T Bars..... 11/12
- Monoshocks 11/14
- Howe Bar 11/15

Chapter 12 - Tires as Springs 12/1 to 12/13

- Pneumatic Tires..... 12/1
- Tire Performance Changes Due to a Change in Tire Pressure 12/1
- Tire Spring Rates..... 12/1
- Definitions..... 12/1
- Hub Center Rate 12/2
- Combined Rate/Wheel Rate 12/2
- Vertical Load/Wheel Load..... 12/2
- Tire Squish Versus Wheel Rate 12/2
- Approximate Wheel Rate Calculations 12/2
- Tire Data 12/6
 - Contact Patch Load Rate and Tire Spring Rate..... 12/6

Chapter 13 – Static Loads Mass Centers of Gravity 13/1 to 13/15

- Static Loads..... 13/1
- Static Corner Load Calculator #1 13/1
 - Changing Static Corner Loads 13/1

- Static Corner Load Calculator #2..... 13/3
- Static Corner Load Calculator #3..... 13/3
- Center of Gravity..... 13/4
- The Three Mass Centers of Gravity 13/4
- Total Center of Mass 13/4
- Sprung Mass Center of Gravity..... 13/4
- Unsprung Centers of Gravity 13/4
- Total Mass X and Y Co-ordinates..... 13/4
- The Sprung Mass x and y Co-ordinates 13/6
- Formula for Finding Corner Percentages 13/7
- Total Mass Center of Gravity Height (CG_Z) 13/9
- Measuring Procedures for Center of Gravity Heights (CG_Z) 13/11
- Unsprung Mass Center of Gravity Height (CG_{USZ})..... 13/14

The Dynamics Chapters

Chapter 14 – Load Transfer 101 – The First Basic Look 14/1 to 14/58

- Kinetic Center Co-ordinates..... 14/3
- Lateral Load Transfer Versus Chassis Performance 14/3
- Gravitational Forces 14/4
- Modeling Chassis Performance..... 14/5
- Elements of Chassis Performance 14/7
- The Initial or Shop Set Up..... 14/7
- The Closed Loop..... 14/7
- **The Load Transfer Model – Wan31A** 14/8
- Wan31A – The Quick Overview..... 14/9
 - Wan31A Cars..... 14/9
 - The Colored Cells 14/9
- Chassis A1..... 14/10
 - Springs A1.1 14/10
 - Roll Bars A1.2 14/11
 - Shock A1.3 14/11
 - Initial Conditions 14/11
 - Other Loads A3..... 14/12
- Anti/Jacking A4 14/12
 - Independent A4.1..... 14/ 12
 - Track Bar A4.2 14/12
 - Acceleration A4.3 14/13
 - Brake A4.4..... 14/13
 - Total Antis A4.5 14/13
- Inertial Forces and CG Location A5 14/13
- Solutions A6..... 14/14
 - Loads A6.1..... 14/14
 - Motions A6.2 14/14
 - Bias 14/15
 - Chassis 14/15
 - Ride..... 14/15
- Wan31A Layout..... 14/16
- The Symmetrical 14/18
- Checking for Asymmetries..... 14/18
- Wan31A A Static Set Up Precursor 14/19
 - First Order Static Relationships 14/19

| | | |
|---|--|-------|
| o | Changing Static Corner Load..... | 14/20 |
| • | Basic Static Calculations..... | 14/24 |
| o | Load..... | 14/24 |
| o | A6.3 Ride..... | 14/24 |
| o | A2 Initial Conditions..... | 14/24 |
| o | Bias – Load-Split Calculator..... | 14/25 |
| o | Pad Load Calculator..... | 14/25 |
| o | A1 Chassis – Springs..... | 14/26 |
| o | A1 Chassis – Tire Radius and Radius Changes..... | 14/28 |
| o | A1 Chassis – Roll Bars..... | 14/28 |
| o | A1 Chassis – Shocks..... | 14/29 |
| o | A3 other Loads..... | 14/30 |
| • | Basic Dynamics Calculations..... | 14/31 |
| o | Symmetrical Chassis..... | 14/31 |
| o | A5 Initial Forces..... | 14/31 |
| o | A1 Chassis – Rebalanced Spring Changes and Load Transfer..... | 14/32 |
| • | A Quick Load Transfer Review..... | 14/34 |
| o | A5 Inertial Forces – Longitudinal Acceleration..... | 14/36 |
| o | A5 Inertial Forces – Banking..... | 14/37 |
| o | A5 Inertial Forces – Spring Pairs and Roll Rates..... | 14/37 |
| o | A4 Anti/Jacking..... | 14/39 |
| o | A4 Anti/Jacking – Independent Suspension..... | 14/39 |
| o | A4.2 Anti/Jacking – Track Bar/Live Axle..... | 14/42 |
| o | A4.3 Anti/Jacking – Inline Acceleration..... | 14/42 |
| o | A4 Anti/Jacking – Brake..... | 14/43 |
| • | Combined Inertial Forces..... | 14/44 |
| o | A5 Combined Inertial Forces – Anti Roll Bars..... | 14/44 |
| o | A5 Combined Inertial Forces – Spring Pairs and Preload..... | 14/46 |
| o | A5 Combined Inertial Forces – Dynamic Tire Radius Changes..... | 14/47 |
| o | A5 Combined Inertial Forces – Spring Splits With and Without Rebalancing the Preload..... | 14/48 |
| o | A5 Combined Inertial Forces – Spring Changes that also Change the Roll Rate..... | 14/5 |
| o | A5 Combined Inertial Forces – Single Spring Changes..... | 14/50 |
| o | A5 Combined Inertial Forces – Single Spring Preload Change..... | 14/51 |
| • | Static General Truths..... | 14/53 |
| o | Static Preload..... | 14/53 |
| o | Static Bias..... | 14/53 |
| o | Static (Spring Rate)..... | 14/54 |
| o | Static (Motion Ratio)..... | 14/54 |
| o | Static (Tire Radius)..... | 14/55 |
| o | Static (Anti Roll Bar)..... | 14/55 |
| o | Static (Damper)..... | 14/55 |
| o | Static (Fuel)..... | 14/55 |
| o | Static (Banking)..... | 14/56 |
| • | Dynamic Basic Truths..... | 14/56 |
| o | Dynamic (Inertial Load Transfer)..... | 14/56 |
| o | Dynamic (Track)..... | 14/56 |
| o | Dynamic (Wheelbase)..... | 14/56 |
| o | Dynamic (Spring Pairs)..... | 14/57 |
| o | Dynamic (Single Spring Change)..... | 14/57 |
| o | Dynamic (Anti/Jacking)..... | 14/57 |
| o | Dynamic (Anti Roll Bar)..... | 14/57 |

- Dynamic (Aero)..... 14/58
- Additional Pink Cells 14/58

Chapter 15 – A Mathematical Look at Vehicle Dynamics..... 15/1 to 15/67

- This 67 page chapter presents and thoroughly explains all of the equations and algorithms used to develop the Wan31 vehicle dynamics software. It does so in a carefully design sequential order that will allow the user to not only understand the basics of dynamic simulation but also lays the groundwork for the user to begin expanding the software to fit his/her unique software needs.

Chapter 16 – Load Transfer – Asymmetrical Load Transfer 16/1 to 16/46

- Corner Entry..... 16/1
- Corner Apex..... 16/1
- Corner Exit..... 16/2
- Data Acquisition..... 16/2
- Wan31A – Short Track Stock Car..... 16/3
 - Ride Height and Balance 16/3
 - Wedge and Balance 16/4
 - Spring Changes 16/5
- Load Transfer Through the Ten Cornering Phases (Springs)..... 16/6
 - Phase One – Corner Entry..... 16/7
 - Phase Two – Corner Entry..... 16/9
 - Making Changes 16/10
- CG Height Examples – Load Transfer Changes 16/12
- Changing the Static Wedge Percentage..... 16/12
- Set Up Scenarios 16/15
 - Phase Three Corner Entry 16/15
 - Changes..... 16/16
 - Phase Four – Corner Entry..... 16/17
- Anti and Jacking Forces – The First Four Cornering Phases Revisited 16/18
- A Pure Lateral Acceleration Side Bar 16/19
- The Four Cornering Phases with Anti and Jacking Forces 16/20
- Oval Track Asymmetries 16/22
- Balancing the Braking..... 16/24
- Shocks and Their Effects on Corner Balance..... 16/25
 - A Brief Shock Precursor 16/25
- Types and Rates of Load Transfer 16/26
 - Springs – Force Versus Distance 16/26
 - Anti Roll Bars – Force Versus Distance 16/27
 - Shocks – Forces Versus Distance 16/28
 - Anti/Jacking Forces 16/28
- Shocks 101 16/29
 - Gas Preload/Breakaway 16/29
 - Knee (Transition)..... 16/29
 - Slope 16/29
- Damper Forces and Preload 16/31
- Back to the Cornering Phases - Corner Entry 16/32
- Corner Apex..... 16/36
 - Phase Five..... 16/36
 - Spring Controlled Roll Rate..... 16/37
 - Roll Rate 16/37
 - Front and Rear Jacking Forces with Base Suspension Set Up..... 16/38

- Changing the Front Jacking Forces..... 16/38
- Rear Jacking Forces 16/39
- Changing the Track Bar Angle 16/39
- Phase Six..... 16/39
- Phase Seven 16/40
- Changing Dynamic Load Through Anti Squat Geometry..... 16/41
- Corner Exit..... 16/42
 - Shocks and Phase Seven Load Transfer..... 16/42
 - Change in Shock Travel From Phase Seven to Phase Eight 16/42
 - Phase Nine 16/43
 - Phase Ten..... 16/44
 - Changing the Rear IC Co-ordinates
- Banking 16/45
- Effects of Track Banking – Base Set Up..... 16/45

Chapter 17 – Open Wheel – Inertial and Aerodynamic Loading17/1

- An Ever So Brief Introduction to Aero Maps 17/1
- Downforce, Drag and Pressure Center 17/2
 - Downforce 17/2
 - Pressure Center 17/2
 - Drag 17/2
 - Lift/Drag 17/2
- Wan31A Aerodynamic Maps..... 17/3
- Base Maps..... 17/3
- Drag Versus hp..... 17/3
- Aero Maps..... 17/4
- Changes in Front to Rear Aero Balance..... 17/11
- Wan31A – Open Wheel Chassis 17/12
- Corner Entry..... 17/12
 - Phase One 17/12
 - Low Downforce 17/12
 - Compensating for the New Ride Heights..... 17/13
- Instantaneous Aero Loads 17/13
- Downforce Versus mph..... 17/13
- Aero Balance..... 17/14
- Corner Apex..... 17/15
 - Phase Five..... 17/15
 - Adding Aero Load 17/15
- Corner Exit..... 17/17
 - Phase Nine 17/17
- Wan31C – Supplementary 17/19
 - Wan31C – Short Track 17/19
 - Wan31C – Short Track Fuel Consumption..... 17/19
 - Wan31C – Open Wheel High Downforce 17/19

Chapter 18 – Stagger and Stagger Torque.....18/1 to 18/5

- Tire Stagger..... 18/1
- Locked Rear Ends 18/1
- Stagger Torque..... 18/2
- Stagger and Straight Line Motion 18/3
- Front Stagger..... 18/5

Chapter 19 – Developing the Tire Maps..... 19/1 to 19/23

- Developing the Tire Maps..... 19/1
- Tire Mapping as a Circular Process 19/2
- The Primary Tire Factor – Normal Load Versus Force..... 19/3
- Secondary Tire Factors 19/3
- Temperature 19/3
- Lateral Acceleration 19/4
- Base Line Lateral Testing 19/4
 - Base Line Skid Pad Testing – Developing the Traction Circle..... 19/4
- 100 ft Radius Circle 19/4
 - Initial Set Up..... 19/4
 - Rebalancing the Chassis 19/4
 - Changing the Steer Angle 19/4
 - Calculating the Front and Rear Shear Angle..... 19/4
 - Developing the Individual Corner Loads Versus Tire Coefficient of Friction Factors 19/4
- The Base Lateral Acceleration Procedural Algorithm 19/5
- Temperature and Wear Factors 19/6
- Speed Factor..... 19/5
- Longitudinal Acceleration..... 19/7
 - Base Line Longitudinal Testing 19/7
- The Base Longitudinal Acceleration Algorithm 19/8
- Circuit/Race Track Testing 19/10
- Combined Acceleration..... 19/10
- Best Fit Equations 19/10
- Tested Tire Data 19/12
- The base Tire Calculator 19/13
- Lateral Calculators and Performance Factors..... 19/13
- Longitudinal Acceleration Calculators and Performance Factors 19/15
- On Track Testing..... 19/17
 - Traction Circle 19/17
 - Traction Circle Types 19/20
- Traction Circle Calculator..... 19/21
- Combined Tire Maps..... 19/22

Chapter 20 – Dynamic Simulation Wan31B: Part One 20/1 to 20/26

- First Work Sheet 20/1
 - Inputs 20/1
 - Outputs – Lateral versus Longitudinal..... 20/2
 - Output – Splits Box..... 20/3
 - Input – Thrust Box 20/3
- Second Worksheet - Tires 20/3
- Third Worksheet – Wan31A 20/3
- Using Wan31B 20/4
 - Lateral Acceleration..... 20/4
 - Longitudinal Acceleration Forces – Forward Acceleration 20/7
 - Longitudinal Acceleration Forces – Braking 20/9
- Combined Acceleration Forces 20/10
- Adding the Tire Factors 20/11
- Corner Entry Examples 20/12
- Corner Apex Examples 20/14

- Corner Exit Examples 20/15
- Banking 20/16
- Dynamics and Chassis Set Up Changes – Combining Wan31A and Wan31B 20/18
- Looking at Set Up Changes..... 20/16

Chapter 21 – Dynamic Simulation – Part Two – Formula/Aero..... 21/1 to 21/14

- Mechanical Versus Aerodynamic Balance..... 21/2
- Lateral Acceleration Examples 21/2
- Longitudinal Acceleration – Braking Examples 21/5
- Longitudinal Acceleration – Forward Acceleration Examples 21/6
- Combined Acceleration with Aero Loads – Examples 21/7
 - Corner Entry 21/7
 - Corner Apex – Trail Braking 21/9
 - Corner Apex – Heavy Trail Braking..... 21/11
 - Corner Exit..... 21/11
- Back to the Mechanical Set Up 21/12
- Wan31B Set Up Changes - #1 through #5 21/13
- Homework..... 21/14