Suspension and Handling

Basic Suspension and Setup Principles

Dave Weitzenhof
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?
Basic Principles of Tuning

Major characteristics that affect handling:

• Tire characteristics
• CG height
• Vehicle weight and weight distribution
• Rate-related roll stiffness (over-all and front vs. rear)
  • Controlled by A-R bars, springs, dampers
• Roll center heights and roll axis - contributes to roll stiffnesses
  • Tuned using chassis attitude (pitch & ride height) control
  • Controlled by springs, dampers, motion limiters, but not swaybars
• Aerodynamic downforce (ground effects, wings, etc.)
  • Also affected by chassis attitude and ride height
• Brake characteristics - see “Brake System Basics,” last page
# Items Controlling Grip Level & Handling

<table>
<thead>
<tr>
<th>Tires</th>
<th>Suspension (continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>Spring rates</td>
</tr>
<tr>
<td>Radial</td>
<td>Swaybars</td>
</tr>
<tr>
<td>Bias</td>
<td>Shocks</td>
</tr>
<tr>
<td>Aspect ratio and stiffness</td>
<td>Friction (less suspension friction ⇒ more mechanical grip)</td>
</tr>
<tr>
<td>Size (overall, side-side, and front vs. rear)</td>
<td>Compliance (bushings, etc.)</td>
</tr>
<tr>
<td>Pressure effects (overall and acceleration vs. deceleration)</td>
<td>Ride ht., roll center ht., other alignment settings</td>
</tr>
<tr>
<td>Stagger (used mostly on ovals, can occur unintentionally – check tire diameters)</td>
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</tr>
<tr>
<td>Tread</td>
<td></td>
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<tr>
<td>Pattern</td>
<td></td>
</tr>
<tr>
<td>Compound</td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td></td>
</tr>
<tr>
<td><strong>Suspension</strong></td>
<td><strong>Weight Distribution</strong></td>
</tr>
<tr>
<td>Type</td>
<td>Front to rear</td>
</tr>
<tr>
<td>Struts</td>
<td>CG height</td>
</tr>
<tr>
<td>SLA (unequal length A-arms)</td>
<td>Polar moment</td>
</tr>
<tr>
<td>Trailing arms</td>
<td></td>
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<tr>
<td>Solid axle (Panhard rod, Watts links, etc.)</td>
<td></td>
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<tr>
<td>Other types</td>
<td></td>
</tr>
<tr>
<td><strong>Drive arrangement</strong></td>
<td><strong>Aerodynamic down-force</strong></td>
</tr>
<tr>
<td>Front drive</td>
<td>Wings</td>
</tr>
<tr>
<td>Rear drive</td>
<td>“Tunnels” or &quot;Flat-bottoms&quot;</td>
</tr>
<tr>
<td>All wheel</td>
<td>Spoilers, air dams, and splitters</td>
</tr>
<tr>
<td>Limited slip (spool)</td>
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</tbody>
</table>

Dave Weitzenhof  
E-mail: weitzenhofdavid@bfusa.com
How Rubber and Tire Properties Affect Handling

- **Rubber** friction coefficient ↓ as contact pressure ↑

  Therefore:
- **Tire** friction coefficient ↓ as tire load ↑
- More weight transfer ⇒ less grip
- Uneven tire footprint loading ⇒ less grip
- Deviation from “critical damping” (excess dynamic load variation) ⇒ less grip: i.e., suspension friction, too much damping, too little damping ⇒ less grip

**Everything** that affects handling starts with these principles!
How to Tune Your Handling:
to get more understeer (to get more oversteer)

- More weight in front (rear)
  - May increase (decrease) wheelspin w/o limited slip [Opposite for Front Wheel Drive]
- Soften or lower rear (front)
  - May decrease (increase) wheelspin w/o limited slip [Opposite for Front Wheel Drive]
  - Items involved in stiffening/softening: springs, shocks, swaybars, roll center heights
- Chassis attitude control
  - Increase or lower all spring rates - may need to soften or stiffen swaybars to maintain roll stiffness. Raising all spring rates results in more power oversteer, less trailing-throttle oversteer, and more consistent ride height - ride height affects roll center height and flat-bottom or undertray downforce.
  - Add rebound damping in rear (front) and/or jounce damping in front (rear)
- Wider rear (front) or narrower front (rear) tires
- Wider rear (front) or narrower front (rear) track width
- Change tire pressures: see tire pressure page
- More negative camber in rear (front) – aided by pyrometer readings
- More front or rear toe-in (toe-out) - also affected by amount of “Ackerman”
- Diagonal weight jacking ⇒ different left/right handling
  - Heavy LF & RR, light RF & LR ⇒ more RH understeer, more LH oversteer
- Stiffen everything ⇒ more precise handling, but possibly less mechanical grip
- More (less) limited slip - this mostly affects handling during acceleration
- Stagger on spool or limited slip drive axle - rotates car toward smaller tire
- Aero effects
# Shock Tuning (1)

## Basic adjustments

<table>
<thead>
<tr>
<th>Adjustment</th>
<th>More Compression</th>
<th>More Rebound</th>
<th>More Canister Pressure</th>
<th>Larger Bleed Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Front</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>High-speed</td>
<td>More front unsprung mass control, possible excess suspension loads over bumps or curbs, possible loss of grip over bumps</td>
<td>Less front chassis drop, less trailing-throttle oversteer, possible loss of grip</td>
<td>Better front unsprung mass control, possible loss of front grip over bumps</td>
<td>Less front chassis rise, less power-on understeer, possible loss of grip</td>
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<tr>
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<td>Less front chassis drop, less trailing-throttle oversteer, possible loss of grip</td>
<td>Better front unsprung mass control, possible loss of front grip over bumps</td>
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<td>More front height control, possibly less front grip</td>
</tr>
<tr>
<td>Rear</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-speed</td>
<td>More rear unsprung mass control, possible excess suspension loads over bumps or curbs, possible loss of grip over bumps</td>
<td>Less rear chassis drop, less power-on understeer, possible loss of grip</td>
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**Shock Tuning (2)**

**What other symptoms do you look for?**

- Try to achieve “critical damping” to optimize response and grip ("chassis shock dyno" is useful approximation). Deviation from “critical damping” ⇒ less grip: i.e., suspension friction, too much damping, too little damping ⇒ less grip.

- Low speed bump (bleed) – optimizes platform control and grip.
  - Too much bleed makes the car feel unresponsive and mushy.
  - Too little bleed reduces grip and tire life, and causes the tire to alternate between grip and slip.

- Low speed rebound (bleed) – controls trailing-throttle oversteer and power understeer.
  - More bleed allows increased dynamic ride (roll-center) height.
  - Too little bleed reduces grip and tire life.

- High speed (canister) bump – “support” vs. too harsh on bumps.

- Low speed (canister) bump – “support” vs. too harsh on bumps.

- After car balance has been attained, adjust low-speed bump and low-speed rebound together, both stiffer or softer, to optimize damping for track conditions.

- Higher canister pressure acts similar to reduced bleed.

- For rain – use more bleed and/or lower canister pressure (less low speed control).
Alignment Techniques and Equipment

– If it worked the last time out, measure it ("set-down")!!

• Check alignment before every race or test session
• Check for excessively loose components and match tire diameters side-to-side before checking alignment
• Need to check basic settings (arm lengths, etc.) and caster / bumpsteer only after disassembly or accident
  • Use "sight gage" to zero bumpsteer
  • Set caster using "camber-change" method (caster ≈ 1.4 x camber change for +/-20° steer)
• Don't waste time being too accurate – the following are usually acceptable tolerances for road-racing:
  • Ride height: ± 0.03" with consistent car weight & tire radius, flat reference plane (floor)
  • Toe: ± 0.03" per side
  • Camber: ± 0.1 degree (likely to be readjusted using pyrometer at the track, anyway)
  • Bumpsteer: < 0.02" through normal suspension travel - modify for roll understeer, etc.)
How to Get More from a Test Session

- **BASICS**
  - Plan in advance!!
  - Make one change at a time if possible
  - Make large changes at first
  - Keep a sequential record of *everything you do*, the current tire, weather, and track conditions, *and the results* so that you can review them later!!

- **POSSIBLE TESTING SEQUENCE (MODIFY TO YOUR NEEDS)**
  - Basic aerodynamic balance (high vs. Low speed)
  - Tire pressures (see next page)
  - Spring rates and ride heights
  - Shock valving and settings
  - Camber (use pyrometer)
  - Other (toe, caster, brake bias,...)
  - Repeat (This is an iterative process)

**USE GOOD TIRES!**
Unevenly worn or mismatched tires will give misleading readings, since thinner, worn areas will run cooler than thicker, non-worn areas, and mismatched tire diameters will change weight balance, ride height, temperature distribution, etc.
How to Determine Tire Pressures

1. Ask tire supplier / competitors for nominal starting point if you have no experience with this setup.

2. Make initial changes of about 10% of nominal pressure.

3. Use pyrometer to arrive at nominal settings such that the average of the outer readings is close to the center reading.

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.
**BRAKE SYSTEM BASICS**

- Wheel braking torque requirements (related to car weight, tire type, etc.): Adjust braking capacity using pedal and hydraulic mechanical advantage, pad material, rotor size, etc.
- Balance (hydraulic mechanical advantage front-vs.-rear, balance bar settings, etc.)
- Response linearity (temperature operating range and release characteristics of pad compound)
- System stiffness as related to pedal travel and mechanical advantage
- Rotor configuration
  - Vented (greater long-term cooling capacity, possibly lower mass and heat-sink capacity)
  - Cross-drilled, slotted, etc. (May aid modulation, fade, but causes faster pad wear. Reduces rotor mass and heat-sink capacity; may accelerate rotor cracking.)
  - Floating vs. solid-mount (Less knock-back, vibration, and heat transfer to bearings, but mounting is critical)
- Possible brake problems and solutions:
  - **Instability or Lockup:**
    - Instability related to vehicle attitude control: Modify vehicle attitude with damper settings, ride height or higher spring rates
    - Lockup due to poor modulation characteristics (poor linearity or release characteristics): Try other pad materials or manufacturers
    - Lockup due to improper setup: Check for cross-weighting, rotor problems, etc.
  - **Low Stopping Power:**
    - Fade (good pedal height, but brakes progressively lose stopping power): Add cooling ducts to rotors, change pad material, and/or use larger or vented brakes
    - Low stopping power due to rotor glazing or sequential use of incompatible brake pad compounds: Deglaze, machine, or replace rotors
    - Low stopping power due to low pad coefficient of friction: Use pads with higher coefficient of friction
    - Low stopping power due low mechanical advantage: Use higher lever ratio, smaller master cyls., or larger fluid-area calipers – need enough system stiffness to avoid low pedal
  - **Low Pedal:**
    - Low pedal due to too much system flex: Use stiffer brake lines, calipers, etc. or decrease mechanical advantage
    - Low pedal due to fluid boiling (too hot or water in fluid): Replace brake fluid, add cooling to calipers
    - Low pedal due to fluid foaming (master cylinder vibration): Revise master cylinder reservoirs/mounting or fill reservoirs with fuel-cell foam (beware of loose foam particles)
    - Low pedal due to pad knock-back: Use anti-knock-back springs (may cause excessive drag) or revise/replace caliper seals
    - Low pedal due to taper-worn pads: Machine pads flat or replace
  - **Miscellaneous:**
    - Balance bar problems (binding, out of adjustment): Check binding (lube, check alignment of master cylinder rods, allow sufficient balance-bar angularity) and/or adjust
    - Uneven pad wear due to rotor drag, surface velocity difference, caliper configuration: Revise calipers, taper pad trailing edges, machine pads flat, rotate pads. Inspect pads before each session.
    - Rotor cracking (caused by thermal shock - some pad and rotor types are worse than others): Inspect and replace if cracks are severe.
    - Brake drag with brakes released due to high pad friction at very light contact: Use pads with less drag under light-contact conditions
    - Brake drag with brakes released due to binding caliper pistons: Clean pistons, make sure pads are not excessively tapered