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Chassis 101

Today's Topics

- Terminology
- Tires
- Suspension Design
- Load Estimations
- Door Prize (For schools attending on-site today)

  HINT: Terminology Awareness

Terminology

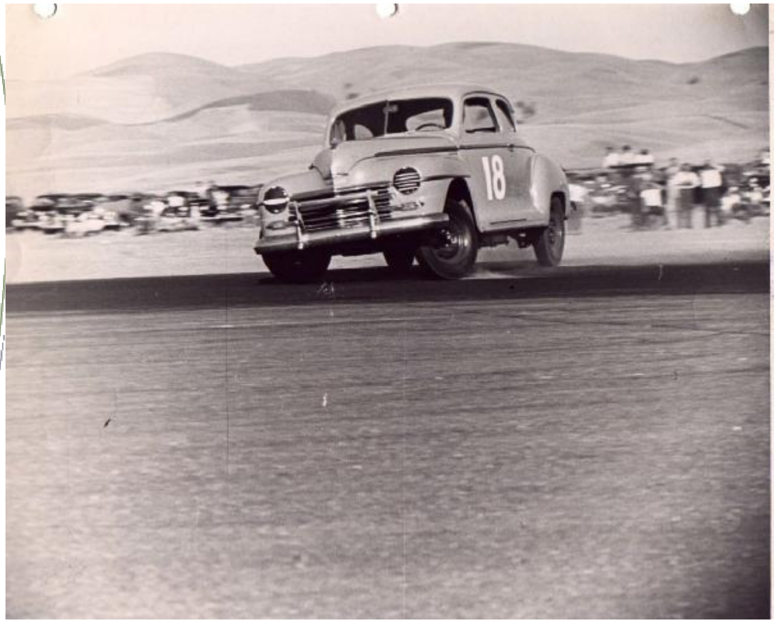
- The design judges in the USA, the UK and Australia have noted that many students are not familiar with standard vehicle dynamics terminology
- This has caused confusion, wasted time, and occasional score reductions during design judging
- You get 45 minutes to state your case in a clear and concise manner
- Read, learn, and know these terms. Cold.

Terminology

Definitions for these common terms can be found in:

- SAE Technical Standard J670e Vehicle Dynamics
- Chassis Design Principles and Analysis and Race Car Vehicle Dynamics (Bill and Doug Milliken)
- "   " to Win series (Carroll Smith)
- Competition Car Suspension (Alan Staniforth)
- Formula 1 Technology (Peter Wright).

Terminology



From RIAM Archives, 1947.

- BALANCE
  - Oversteer
  - Understeer
  - Understeer gradient (in deg/g)

Terminology

- CHASSIS
  - Ultimate tensile strength of materials used in chassis and suspension construction
  - Modulus of elasticity for the same materials
  - The difference between strength and stiffness
  - Torsional rigidity by FEA and by physical measurement
  - Torsional rigidity profile or slope
  - Installed stiffness
  - Bump, droop, roll, heave, warp

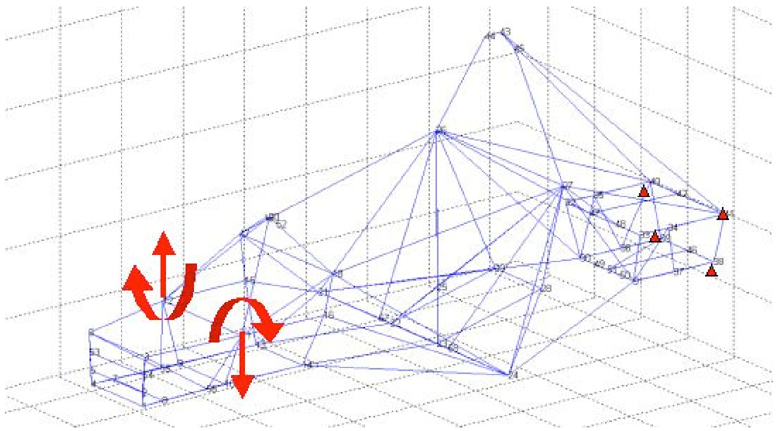


Diagram from rileydynamics.com

Terminology

- SUSPENSION
  - Ride rate
  - Wheel rate
  - Spring rate
  - Motion ratio (installed ratio)
  - Body undamped natural frequency
  - Suspension undamped natural frequency (hop and tramp)
  - The effect of stiction or friction in suspension pivots

Terminology

- MORE SUSPENSION
  - Damping ratio
  - Single tube and twin tube shock absorbers (dampers)
  - Shock absorber bump and droop
  - Shock absorber piston speed
  - Shock absorber nose pressure
  - Shock absorber hysteresis
  - Critical damping

Terminology

- MORE SUSPENSION
  - Roll stiffness
  - Percentage of roll stiffness from springs/anti roll bars
  - Roll stiffness per transverse g. front and rear
  - Static load distribution
  - Lateral load transfer per transverse g.
  - Longitudinal load transfer per g.

Terminology

- MORE SUSPENSION
  - Load transfer due to steering geometry
  - Anti squat and anti dive coefficients and in percentages
  - Advantages and disadvantages of anti squat and anti dive geometry

Terminology

- SUSPENSION GEOMETRY
  - Roll center (definition)
  - Roll center height and lateral location
  - Roll center migration (vertical and lateral)
  - Roll axis
  - Camber
  - Camber change in ride (ride camber coefficient in degrees/inch)
  - Camber change in roll (roll camber coefficient in degrees/degree)
  - Caster
  - Camber change with steer angle due to caster
  - King pin inclination (steering axis)
  - Camber change with steer angle due to king pin inclination

Terminology

- MORE SUSPENSION GEOMETRY
  - Scrub radius (steering offset)
  - Mechanical trail (caster trail)
  - Spindle offset (wheel center to steering axis at spindle height)
  - Toe in and toe out
  - Ackerman, modified Ackerman and anti-Ackerman steering geometry
  - Bump Steer
  - Ride steer
  - Roll steer

Terminology

- MOMENTS
  - Polar moment of inertia
  - Moments of rotational inertia
  - Yaw moment
  - Roll moment
  - Pitch moment

Terminology

- BRAKE SYSTEM
  - Pedal mechanical ratio
  - Hydraulic ratio, front and rear
  - Clamping load front and rear per 100 psi line pressure
  - Coefficient of friction between disc and pad friction material at operating temperature

Terminology

- DRIVE LINE
  - Differential bias ratio
  - Angular capacities of joints used in drive shafts
  - Drive line angles
  - Open differential operation
  - Salisbury or plate differential operation
  - Cam and pawl differential operation
  - Zexel/Gleason differential operation
  - Spool operation

Terminology

- TIRES
  - Coefficient of friction
  - Slip angle
  - Percent slip (slip ratio)
  - Cornering stiffness
  - Camber stiffness
  - Self aligning torque
  - Normal load sensitivity
  - Load transfer sensitivity
  - Pneumatic trail

Tires

From Lucasfilms, Indiana Jones and the Last Crusade, 1989

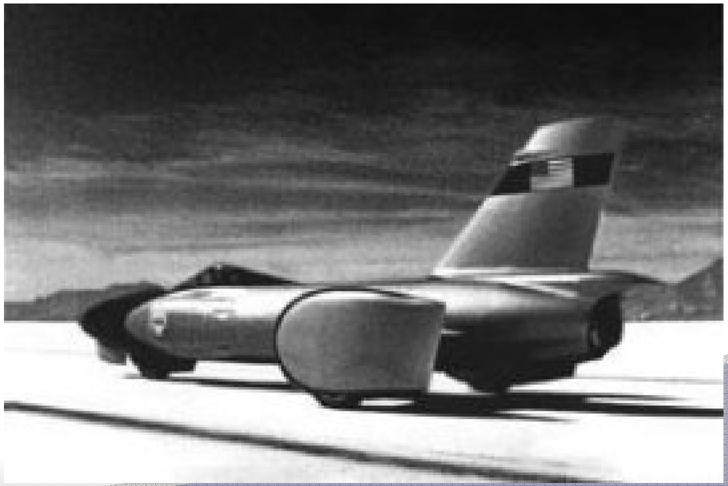
- "Choose wisely."
- Based on your design and performance goals
- Learn all you can about your tire properties
- Follow tire maker's recommendations
  - Tire mounting
    - Some constructions are directional
  - Chassis setup
    - Rim width
    - Wheel alignment
    - Cold inflation pressure
  - New tire break-in
    - Scuffing
    - Heat cycling
  - Post test storage

Tires

From Paul Henri Cahier, 1977

- Historically, dominating race and street vehicles have been designed around their tires.

From S. Lyman, 2005



From Goodyear Tire and Rubber Company, 1965.

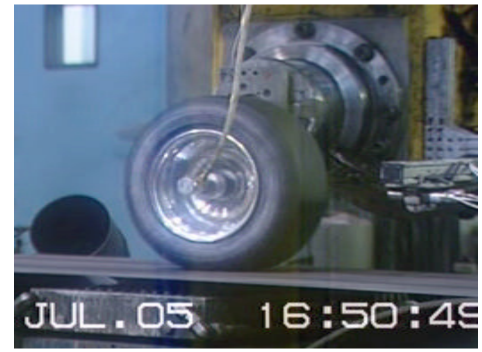
Tire Characteristics

- Tractive Effort vs. % slip
- Lateral Force vs. Normal Load vs. Slip Angle
  - Peak grip vs. limit progressivity and consistency
- Lateral force compliance
- Temperature Sensitivity and Retention
- Steering response
- Wear rate
- Suspension corner design packaging space
- Radial spring rate vs. inflation pressure
- Damping vs. suspension damping

FSAE Tire Test Consortium http://www.millikenresearch.com/fsaettc.html

- SAE Paper 2006-01-3606 (reference)
- If your school is a member, USE THE DATA
- If your school is not a member, seriously consider joining the consortium
- Visit website or contact Doug Milliken for more info

- Elapsed Time, sec
- Roadway Velocity, mph or kph
- Tire Rotational Velocity, rpm
- Slip Angle, deg
- Inclination Angle, deg
- Loaded Radius, in or cm
- Effective Radius, in or cm
- Inflation Pressure, psi or kPa
- Longitudinal Force, lb. or N
- Lateral Force, lb. or N
- Normal Load, lb. or N
- Overturning Moment, lb.-ft. or N-m
- Aligning Torque, lb.-ft. or N-m
- Normalized Longitudinal Force, unitless
- Normalized Lateral Force, unitless
- Road Surface Temperature, °F or °C
- Inside Tire Surface Temperature, °F or °C
- Center Tire Surface Temperature, °F or °C
- Outside Tire Surface Temperature, °F or °C
- Ambient Temperature, °F or °C
- Slip Ratio, unitless



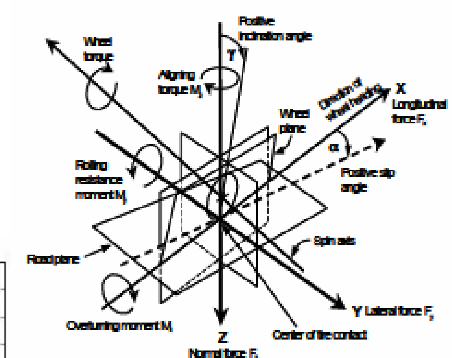
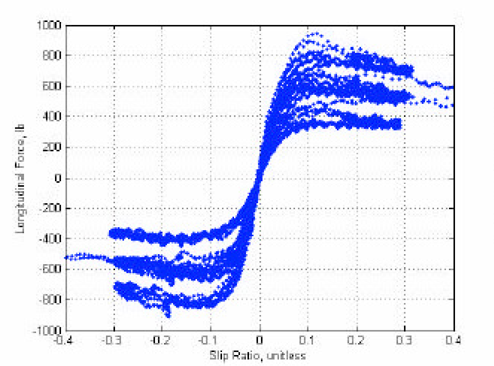
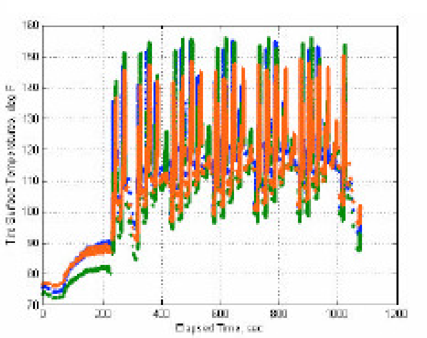
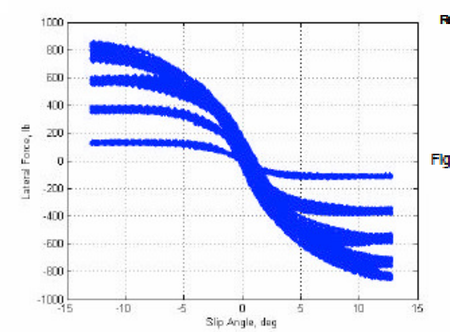


Figure 3: The SAE Tire Axis System

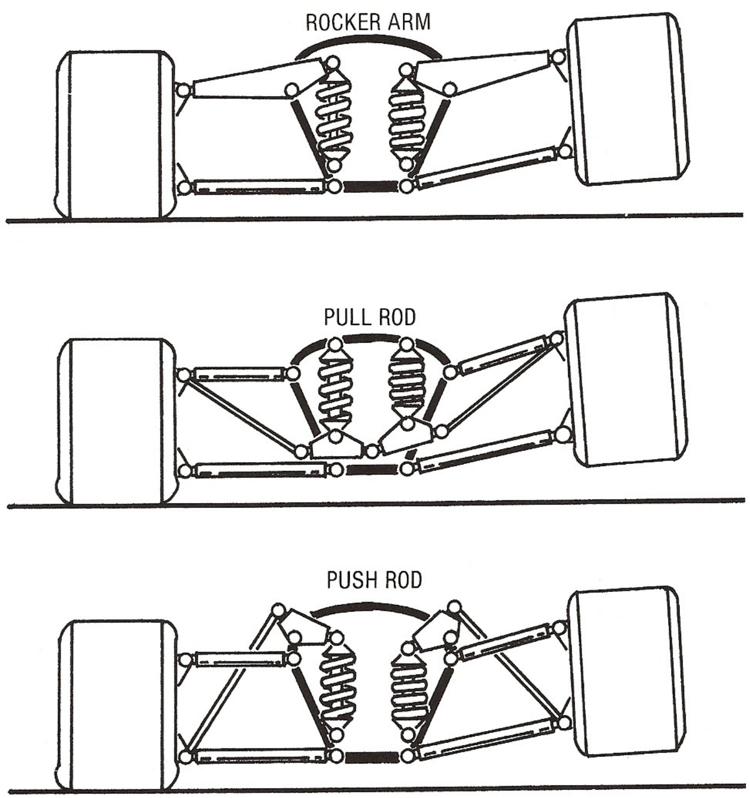


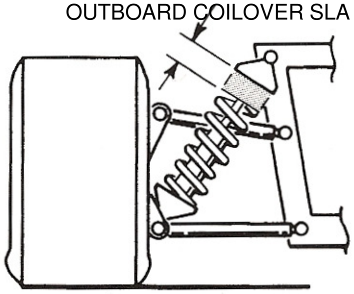




Illustrations and photo from SAE Paper 2006-01-3606

Suspension Design



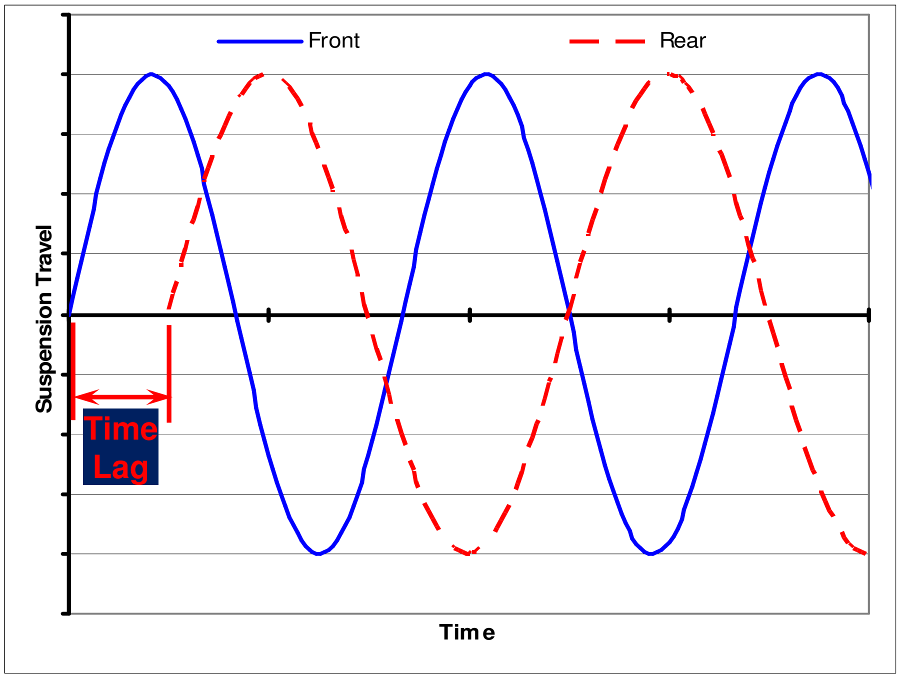


From Paul Van Valkenburgh, Race Car Engineering and Mechanics, 2000

There Are Many Solutions

- "It depends."
- "Everything is a compromise."
  - Suspension 101
    - Ride Frequency/ Balance (Flat Ride)
    - Motion Ratios
    - Ride Friction
    - Suspension Geometry Selection
    - Suspension Layouts- Double A Arm Variations and Compromises
    - Dampers- A Really Quick Look

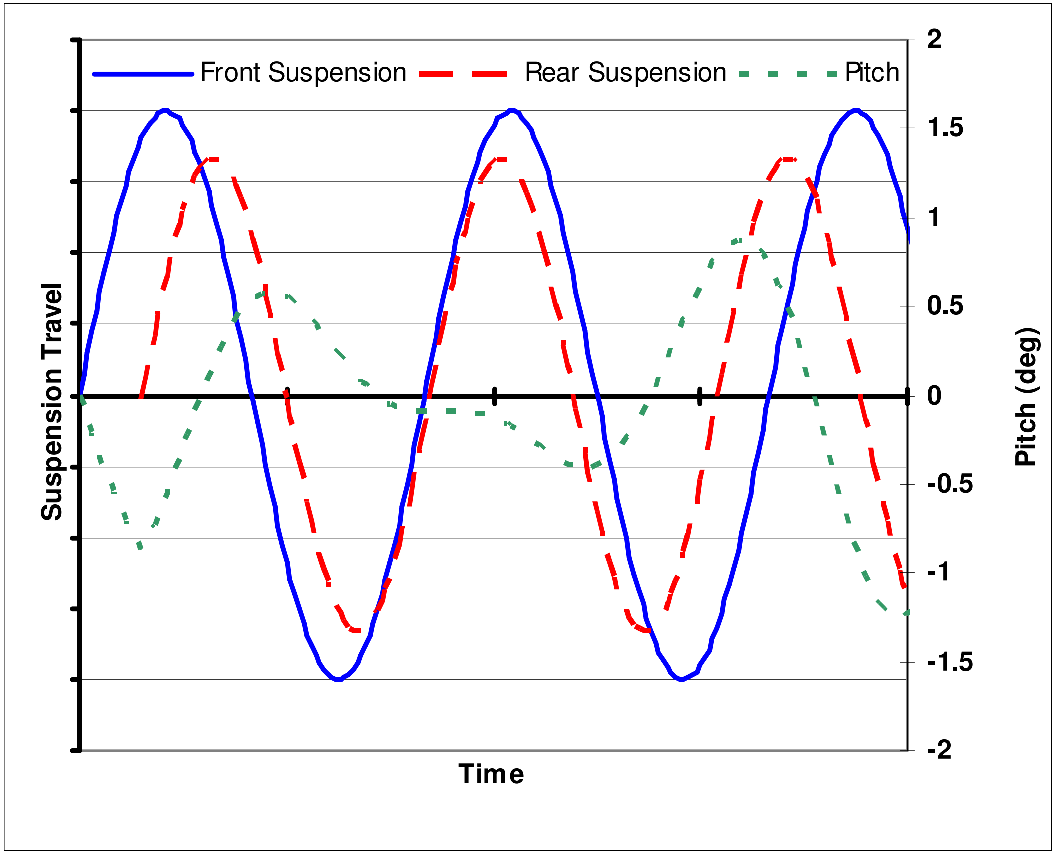
"The thing we had missed was that the excitation at front and rear did not occur simultaneously. The actual case was more like this--



--with the angle of crossing of the two wave lines representing the severity of the pitch."

(From Chassis Design: Principles and Analysis, Milliken & Milliken, SAE 2002)

“By arranging the suspension with the lower frequency in front (by 20% to start) this motion could be changed to--



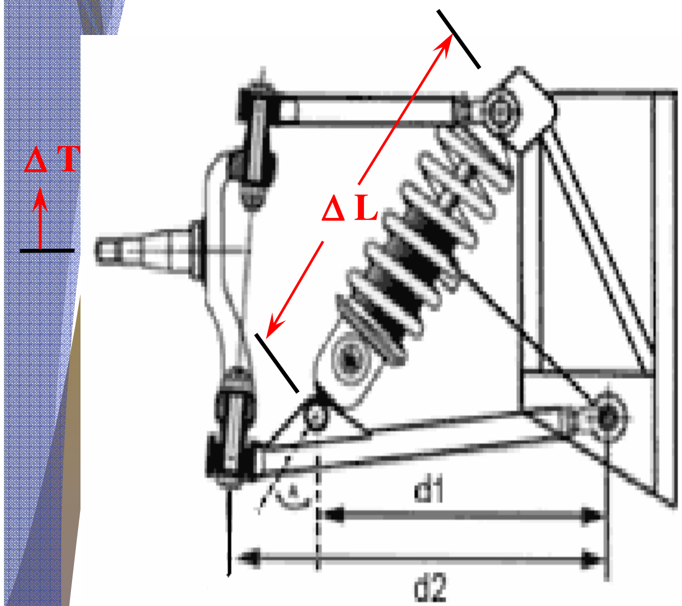
--a much closer approach to a ‘flat’ ride”.

(From Chassis Design: Principles and Analysis, Milliken & Milliken, SAE 2002)

Typical Ride Frequencies

- Passenger car (1.0-1.5 Hz)
- High performance sports car (1.5-2.0 Hz)
- Race cars (1.5-3.0 Hz) depending on course and weather conditions

Does motion ratio affect forces transmitted to the body?



Wheel Rate: 150 lb/in

Motion Ratio: 0.5 ←Not good

Force at wheel for 1” wheel travel = 150 lb

Spring deflection for 1” wheel travel=0.5”

Force at spring for 1” wheel travel = 300 lb

Force at body = Force at wheel / MR

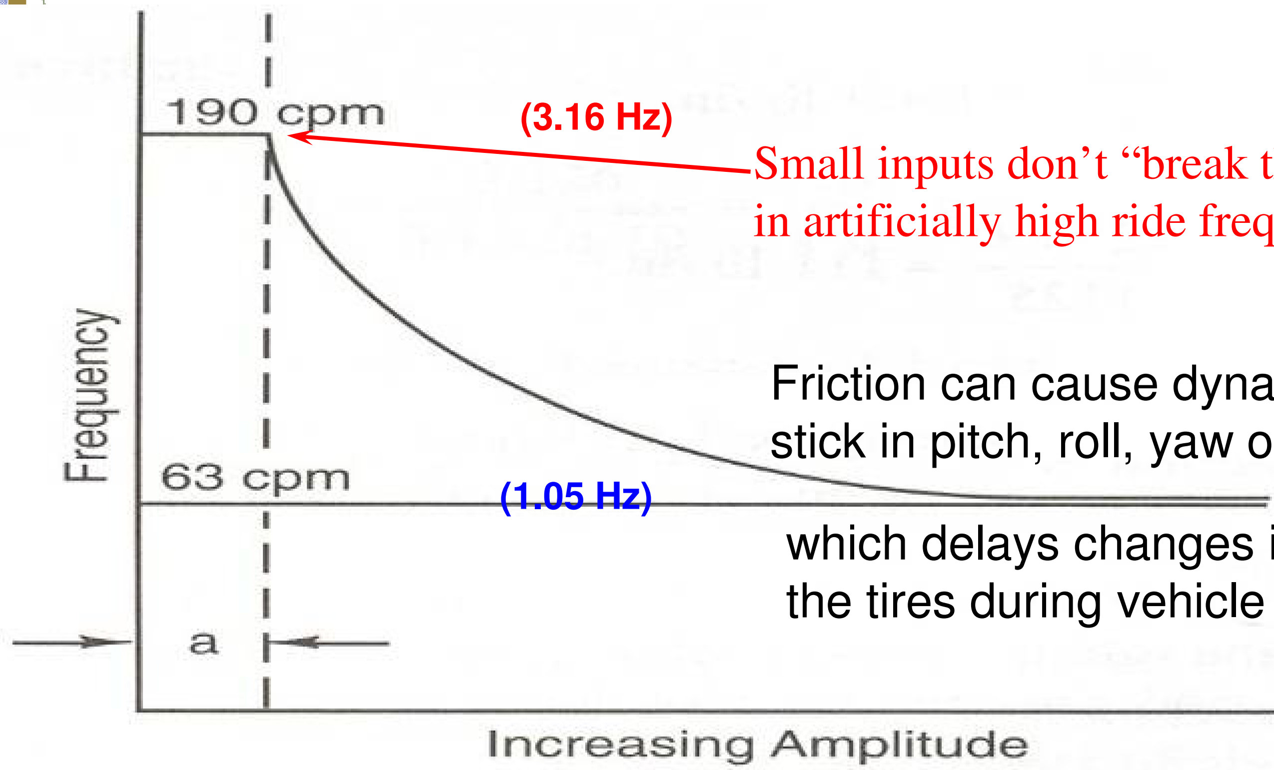
Spring Rate=300 lb / 0.5 = 600 lb/in

Spring Rate= Wheel Rate / MR^2

Does motion ratio affect forces transmitted into the body?

- Motion ratio is spring travel divided by wheel travel.
- The force transmitted to the body is reduced if the motion ratio is increased.

How does ride friction affect frequency?



Small inputs don’t “break through” the friction, resulting in artificially high ride frequency

Friction can cause dynamic vehicle attitude to stick in pitch, roll, yaw or a combination

which delays changes in weight transfer to the tires during vehicle transitions

(From Chassis Design: Principles and Analysis, Milliken & Milliken, SAE 2002)

Ride Summary

- **Flat Ride**
  - Improves handling, acceleration, braking performance
- **Plenty of suspension travel**
  - Allows lower spring rates & ride frequencies
  - Allows progressive jounce bumper engagement
- **Good motion ratio**
  - Reduces loads into vehicle structure
  - Increases shock velocity, facilitates shock tuning
  - 1.00:1 is ideal, 0.60:1 minimum design target
- **Stiff structure (The 5th Spring)**
  - Improves efficiency of chassis and tire tuning
  - Provides more consistent performance on the track
  - Applies to individual attachment compliances, 5:1 minimum design target, 10:1 is ideal
  - Successful SAE designs in the 2000-3000 ft-lbs/deg range (static torsion), 3X for static bending (lbs/in),
- **Low Friction**
  - Permits dampers to provide consistent performance
  - Not masked by coulomb friction (stiction)
  - 40:1 minimum (corner weight to frictional contribution for good SLA suspension

Suspension Layout

- Many contemporary Formula SAE Cars use:
  - Double A arm (pushrod spring/damper actuation)
  - Double A arm (pullrod spring/damper actuation)
  - Double A arm (rocker arm spring/damper actuation)
  - Double A arm (outboard coilover actuation)
  - Parallel A arms
  - Non parallel A arms
  - Equal length A arms
  - Unequal length A arms
  - Solid axle
- There is no right or wrong answer
- Be prepared to “sell” your decision to the design judges.

Suspension Geometry Setup

- Front Suspension 3 views
- Rear Suspension 3 views

Front Suspension Front View

- Start with tire/wheel/hub/brake rotor/brake caliper package.
  - pick ball joint location.
  - pick front view instant center length and height.
  - pick control arm length.
  - pick steering tie rod length and orientation.
  - pick spring/damper location.

FSFV: wheel/hub/brake package

- Ball joint location establishes:
  - King Pin Inclination (KPI): the angle between line through ball joints and line along wheel bearing rotation axis minus 90 degrees.
  - Scrub radius: the distance in the ground plane from the steering axis and the wheel centerline intersections with the ground.
  - Spindle length: the distance from the steer axis to the wheel center.

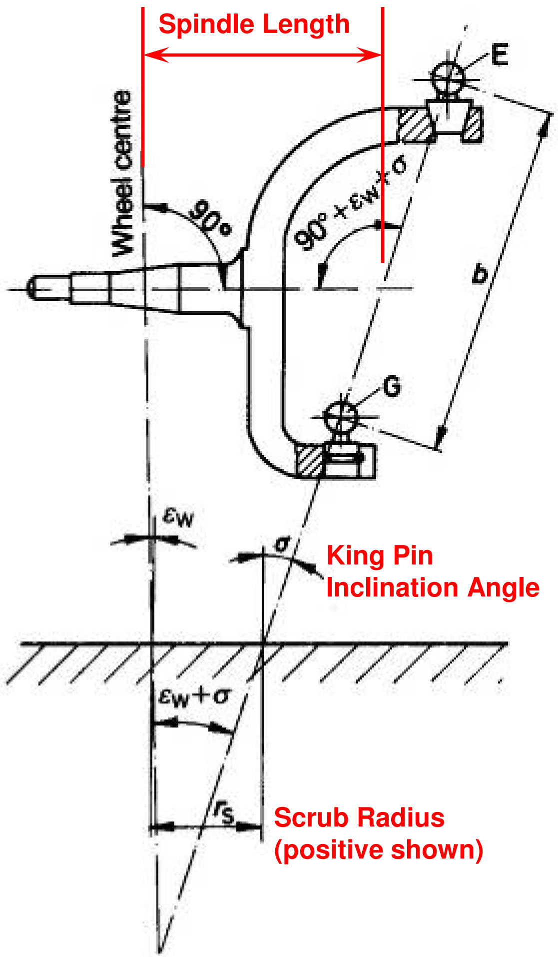


Fig. 3.80 The precise position of the steering axis – also known as kingpin inclination axis – can only be determined if the centre points E and G of the two ball joints are known. The total angle of kingpin inclination and camber ($\sigma + \epsilon_W$) must also be included when dimensioning the steering knuckle as an individual part.

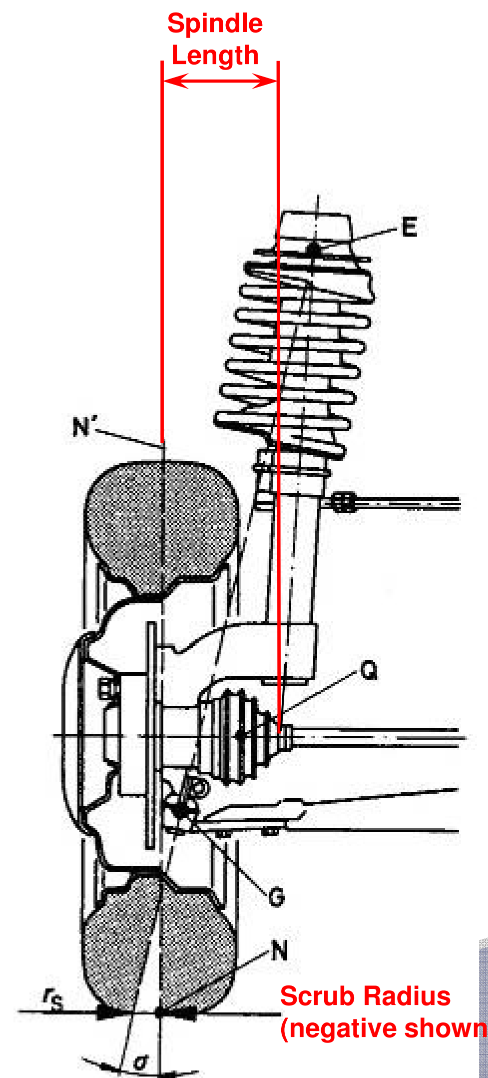


Fig. 3.79 Left front axle of an Audi with negative kingpin offset on the ground r_S = −18 mm and an almost vertical damper unit; the spring was angled to reduce the friction between the piston rod and rod guide. For reasons of space, the CV-joint centre Q had to be shifted inwards; the space for snow chains has to be considered (see Fig. 2.5b and position 10 in Fig. 1.39).

From The Automotive Chassis: Engineering Principles, J. Reimpell & H. Stoll, SAE 1996

FSFV: wheel/hub/brake package

- Scrub radius determines:
  - the sign and magnitude of the forces in the steering that result from braking.
  - a small negative scrub radius is desired.
- Scrub radius influences brake force steer

FSFV: wheel/hub/brake package

- KPI effects returnability and camber in turn.
- KPI is a result of the choice of ball joint location and the choice of scrub radius.

FSFV: wheel/hub/brake package

- KPI effects returnability and camber in turn.
- KPI is a result of the choice of ball joint location and the choice of scrub radius.

FSFV: wheel/hub/brake package

- Spindle length determines the magnitude of the forces in the steering that result from:
  - hitting a bump
  - drive forces on front wheel drive vehicles
- Spindle length is a result of the choice of ball joint location and the choice of scrub radius.

FSFV: wheel/hub/brake package

- Front view instant center is the instantaneous center of rotation of the spindle (knuckle) relative to the body.
- Front view instant center length and height establishes:
  - Instantaneous camber change
  - Roll center height (the instantaneous center of rotation of the body relative to ground)

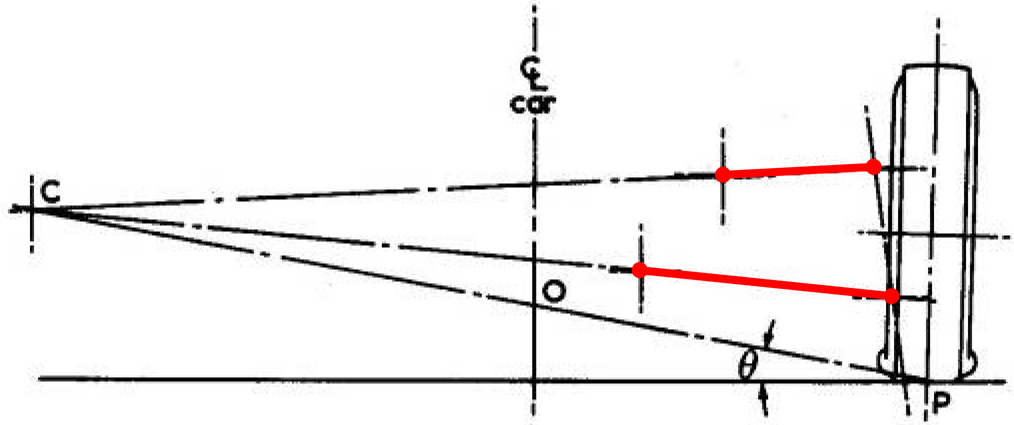


Fig. 5·2 The roll centre derivation for a double wishbone suspension, in this case arranged to give some swing axle effect, is shown

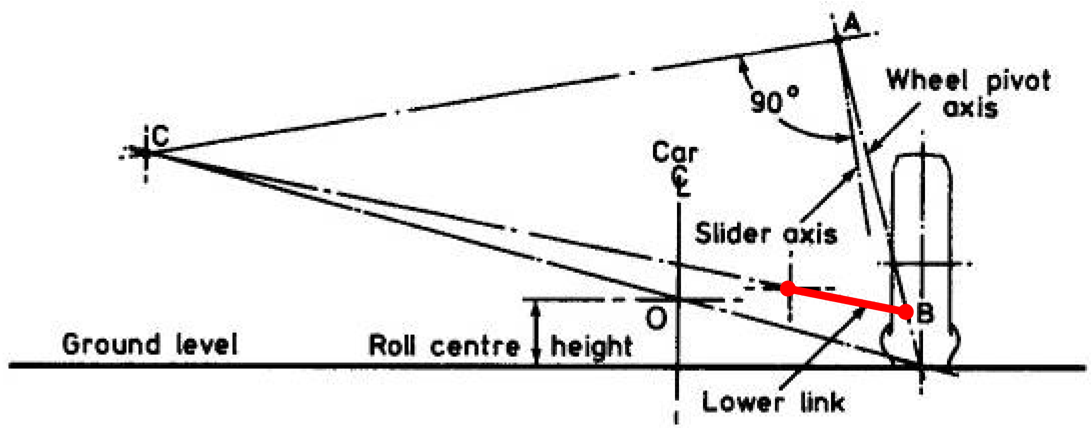


Fig. 5·3 The derivation of the roll centre height for a strut and link type suspension is shown. The 'kingpin' axis is defined by the pivot-attachment point of the slider, *A*, and *B*, the outer end of the lower link. The slider axis could, but more often does not, lie along this axis. *C* is the instantaneous centre of the linkage, the intersection point of the perpendicular to the slider axis from its attachment point and the centre line of the lower link continued

From Car Suspension and Handling 3rd Ed, D. Bastow & G. Howard, SAE 1993

FSFV: wheel/hub/brake package

- The upper control arm length compared to the lower control arm length establishes:
  - Roll center movement relative to the body (vertical and lateral) in both ride and roll.
  - Camber change at higher wheel deflections.

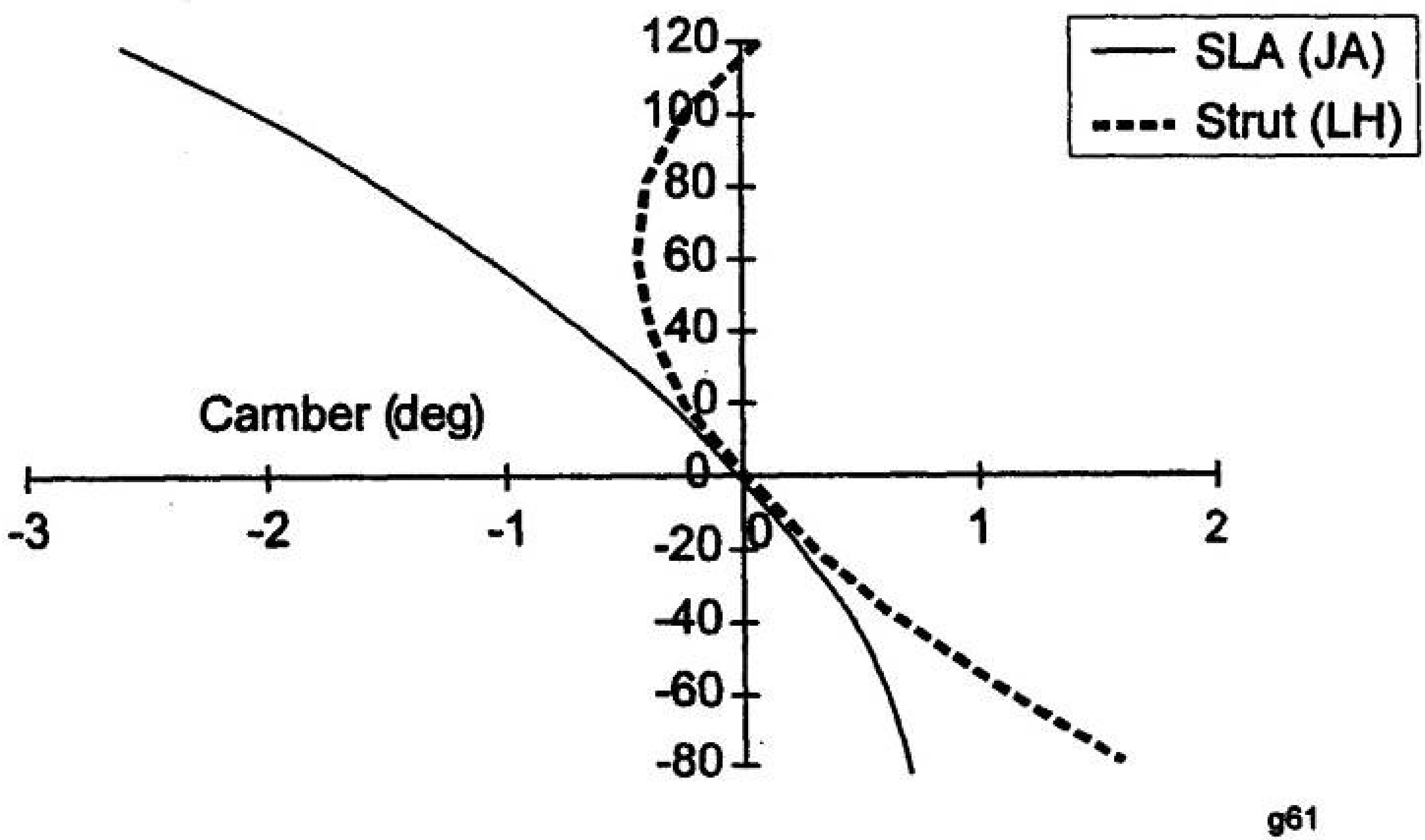


Figure 64 Camber Patterns Of SLA And Strut Suspensions

(From Suspension Geometry and Design, John Heimbecher, DaimlerChrysler Corporation)

FSFV: Roll Center Movement

- Ride and roll motions are coupled when a vehicle has a suspension where the roll center moves laterally when the vehicle rolls.
- The roll center does not move laterally if, in ride, the roll center height moves 1 to 1 with ride (with no tire deflection).

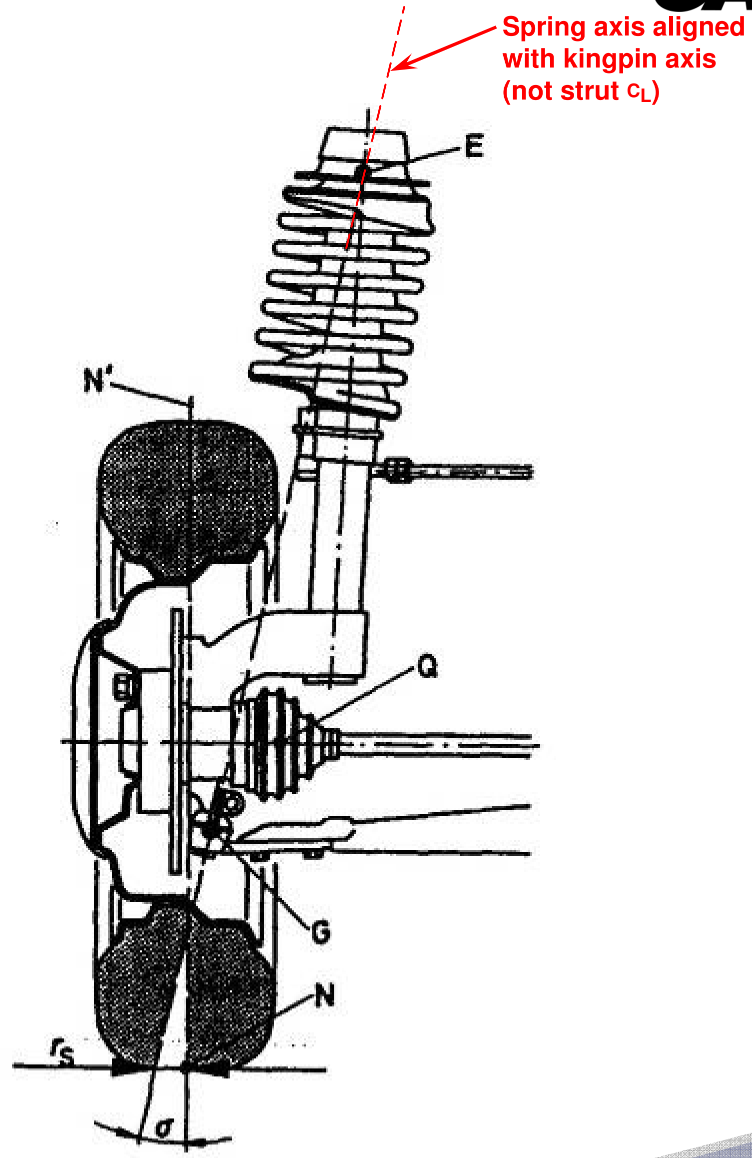
FSFV: wheel/hub/brake package

- The steering tie rod length and orientation (angle) determines the shape (straight, concave in, concave out) and slope of the ride steer curve.

FSFV: wheel/hub/brake package

- The spring location on a SLA suspension determines:
  - the magnitude of the force transmitted to the body when a bump is hit (the force to the body is higher than the force to the wheel)
  - the relationship between spring rate and wheel rate (spring rate will be higher than wheel rate)
  - how much spring force induces c/a pivot loads
- An offset spring on a strut can reduce ride friction by counteracting strut bending (Hyperco gimbal-style spring seat).

Fig. 3.79 Left front axle of an Audi with negative kingpin offset on the ground r_s = –18 mm and an almost vertical damper unit; the spring was angled to reduce the friction between the piston rod and rod guide. For reasons of space, the CV-joint centre Q had to be shifted inwards; the space for snow chains has to be considered (see Fig. 2.5b and position 10 in Fig. 1.39).



From The Automotive Chassis: Engineering Principles, J. Reimpell & H. Stoll, SAE 1996

Front Suspension Side View

- Picking ball joint location and wheel center location relative to steering axis establishes:
  - Caster
  - Caster trail (Mechanical Trail)

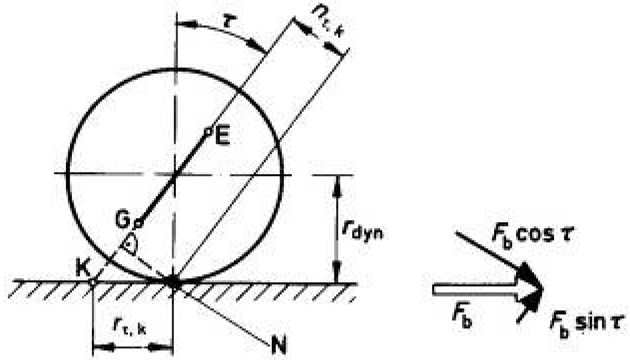


Fig. 3.88 If the extension of the steering axis goes through the ground at point K in front of the wheel centre, the distance arising is the kinematic caster trail $r_{\tau,k}$ (Case 1). A vertical to $\overline{EG}$, drawn through the centre of tyre contact N, when projected onto the xz-plane, gives the lateral force lever $n_{\tau,k}$ (Equation 3.30).

Longitudinal forces which arise, such as the braking force F_b (or the rolling resistance F_R), must be resolved at the centre of tyre contact (or as $F3'_R$ in the wheel centre, Fig. 3.86) by the angle τ.

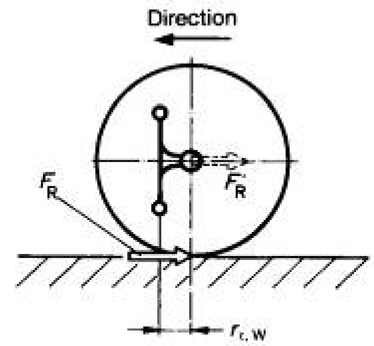


Fig. 3.89 Caster can also be achieved by shifting the wheel centre behind the steering axis (Case 2); if this is vertical, as shown, the (here) positive caster offset is equal to the lever: $r_{\tau,W} = r_{\tau,k} = +n_{\tau,k}$. Rolling resistance forces F_R acting at the centre of tyre contact must be observed as F'_R in the wheel centre.

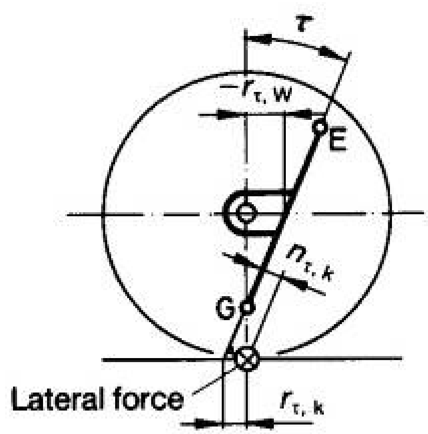


Fig. 3.91 Front axle properties can be improved by a negative caster offset $r_{\tau,W}$; the caster trail $r_{\tau,k}$ on the ground shortens by this amount and the camber alteration when the wheels are turned becomes more favourable.

From The Automotive Chassis: Engineering Principles, J. Reimpell & H. Stoll, SAE 1996

Front Suspension Side View

- Picking the side view instant center location establishes:
- Anti-dive (braking)
- Anti-lift (front drive vehicle acceleration)

Front Suspension Side View

- Anti-dive (braking):
  - Instant center above ground and aft of tire/ground or below ground and forward of tire/ground.
  - Increases effective spring rate when braking.
  - Brake hop if distance from wheel center to instant center is too short.

Front Suspension Plan View

- Picking steer arm length and tie rod attitude establishes:
  - Ackermann
  - recession steer
  - magnitude of forces transmitted to steering

Front Suspension: Other Steering Considerations

- KPI and caster determine:
  - Returnability
    - The steering would not return on a vehicle with zero KPI and zero spindle length
  - camber in turn

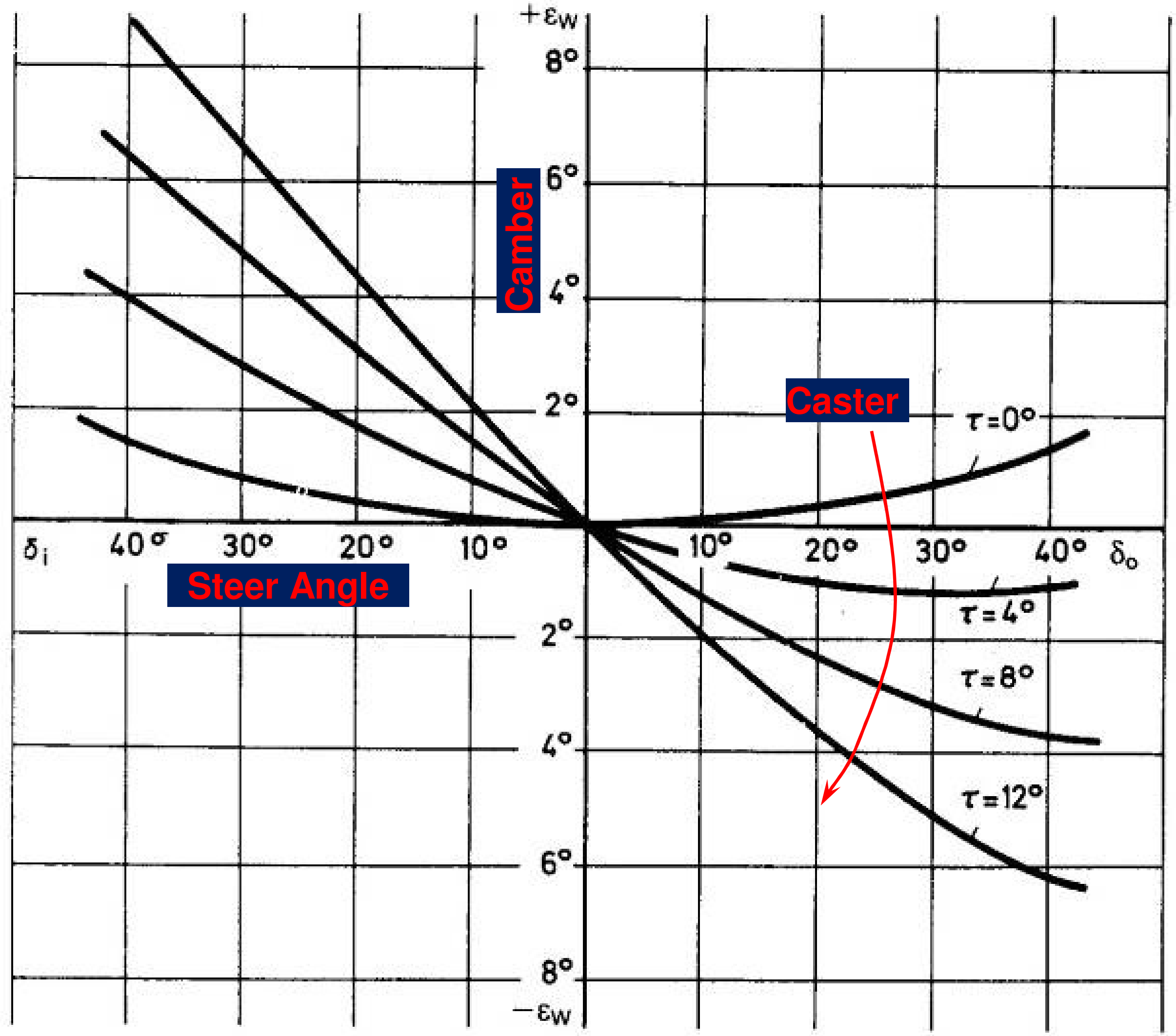


Fig. 3.102 Camber angle $\epsilon_{W,o}$ and $\epsilon_{W,i}$, as a function of the steering angle δ_a (outside of bend) and δ_i (inside of bend). The influence of the various caster angles τ can be clearly seen. Given was: $\sigma_0 = 6°$ and $\epsilon_{W,0} = 0°$

From The Automotive Chassis: Engineering Principles, J. Reimpell & H. Stoll, SAE 1996

Front Suspension: Other Steering Considerations

- Caster and Caster Trail establish how forces build in the steering
  - Caster gives effort as a function of steering wheel angle (Lotus Engineering).
  - Caster Trail gives effort as a function of lateral acceleration (Lotus Engineering).
  - Spindle offset allows picking caster trail independent of caster.

Rear Suspension Rear View

- Start with tire/wheel/hub/brake rotor/brake caliper package.
  - pick ball joint (outer bushing) location
  - pick rear view instant center length and height.
  - pick control arm length.
  - pick steering tie rod length and orientation.
  - pick spring/damper location.

RSRV: wheel/hub/brake package

- Ball joint location establishes:
  - Scrub radius: Scrub radius determines the sign and magnitude of of the forces in the steering that result from braking.
  - Spindle length: Spindle length determines the magnitude of the steer forces that result from hitting a bump and from drive forces. Spindle length is a result of the choice of ball joint (outer bushing) location and the choice of scrub radius.

RSRV: wheel/hub/brake package

- Rear view instant center length and height establishes:
  - Instantaneous camber change
  - Roll center height

RSRV: wheel/hub/brake package

- The upper control arm length compared to the lower control arm length establishes:
  - Roll center movement relative to the body (vertical and lateral) in both ride and roll.
  - Camber change at higher wheel deflections.

RSRV: wheel/hub/brake package

- Some independent rear suspensions have a link that acts like a front suspension steering tie rod. On these suspensions, steering tie rod length and orientation (angle) determines the shape (straight, concave in, concave out) and slope of the ride steer curve.

RSRV: wheel/hub/brake package

- The spring location on a SLA suspension determines:
  - the magnitude of the force transmitted to the body when a bump is hit (the force to the body is higher than the force to the wheel)
  - the relationship between spring rate and wheel rate (spring rate will be higher than wheel rate)
  - how much spring force induces bushing loads
- An offset spring on a strut can reduce ride friction by counteracting strut bending.

Rear Suspension Side View

- Picking outer ball joint/bushing location establishes:
  - Caster
  - Negative caster can be used to get lateral force understeer

Rear Suspension Side View

- Picking side view instant center location establishes:
  - anti-lift (braking)
  - anti-squat (rear wheel vehicle acceleration)
  - Remember, you don't know your anti percentages until you establish the cgh of your car

Rear Suspension Side View

- Anti-lift (braking):
  - Instant center above ground and forward of tire/ground or below ground and aft of tire/ground.
  - Brake hop if distance from wheel center to instant center is too short.

Rear Suspension Side View

- Anti-squat (rear wheel vehicle acceleration)
- “Cars are like primates. They need to squat to go.”—Carroll Smith
  - independent
    - wheel center must move aft in jounce
    - instant center above and forward of wheel center or below and aft of wheel center
    - increases effective spring rate when accelerating.
  - beam
    - instant center above ground and forward of tire/ground or below ground and aft of tire/ground.

Rear Suspension

- Scrub radius:
  - small negative insures toe-in on braking
- Spindle length:
  - small values help maintain small acceleration steer values

Rear Suspension

- Camber change:
  - at least the same as the front is desired
  - tire wear is a concern with high values
  - leveling allows higher values

Rear Suspension

- Roll Center Height:
  - independent
    - avoid rear heights that are much higher than the front, slight roll axis inclination forward is preferred
  - beam axle
    - heights are higher than on independent suspensions no jacking from roll center height with symmetric lateral restraint

Rear Suspension

- Roll center movement:
  - independent:
    - do not make the rear 1 to 1 if the front is not
  - beam
    - no lateral movement
    - vertical movement most likely not 1 to 1

Rear Suspension

- Ride steer / roll steer:
  - independent
    - small toe in in jounce preferred
    - consider toe in in both jounce and rebound
      - gives toe in with roll and with load
      - toe in on braking when the rear rises
  - beam
    - increasing roll understeer with load desired
    - 10 percent roll understeer loaded is enough
    - roll oversteer at light load hurts directional stability

Rear Suspension

- Anti-lift:
  - independent
    - instant center to wheel center at least 1.5 times track (short lengths compromise other geometry) to avoid brake hop

Dampers- A Really Quick Look

- Purpose of Dampers
- Damper Types and Valving
- Performance Testing
- Development of Dampers

Introduction

Primary function: dampen the sprung and unsprung motions of the vehicle, through the dissipation of energy.

Can also function as a relative displacement limiter between the body and the wheel, in either compression or extension. Or as a structural member, strut.

Simple model: force proportional to velocity.

$$\text{Force} = kx + c\dot{x}$$

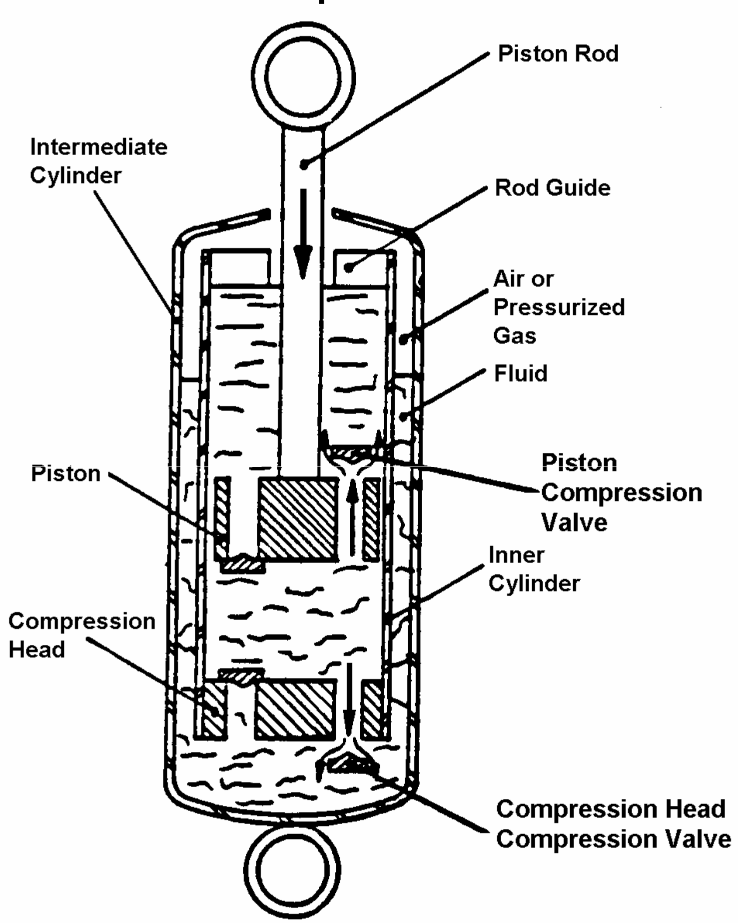
Real World:

- The multi-speed valving characteristics of the damper (low, mid and high relative piston velocity) permit flexibility in tuning the damper.
- Different valving circuits in compression (jounce) and extension (rebound) of the damper permits further flexibility.
- Also generates forces that are a function of position, acceleration and temperature.

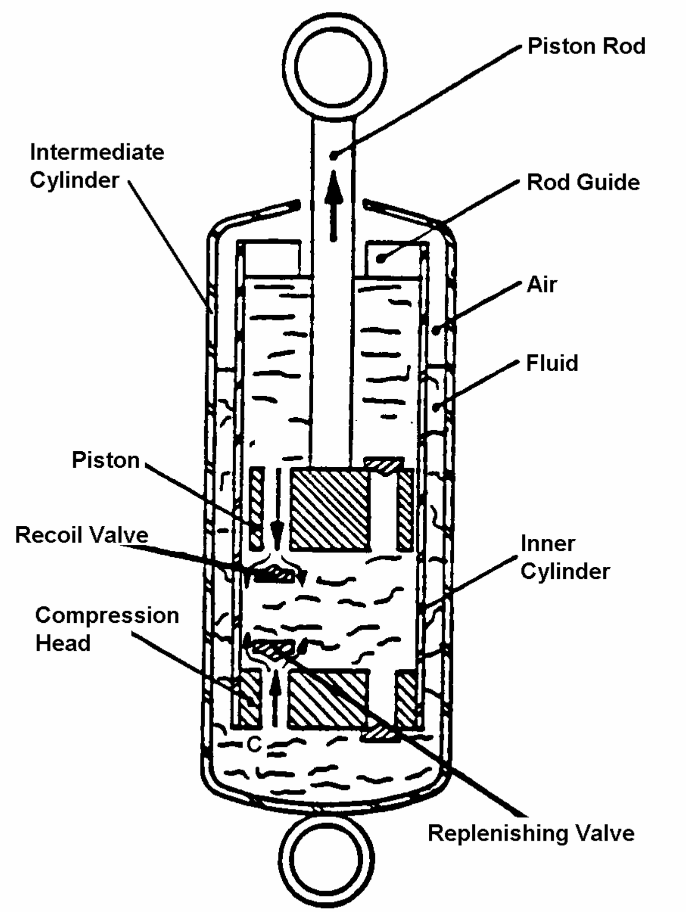
$$\text{Force} = kx + c_1 x + c_2 \dot{x} + c_3 \ddot{x} + c_4 T$$

Twin Tube Damper

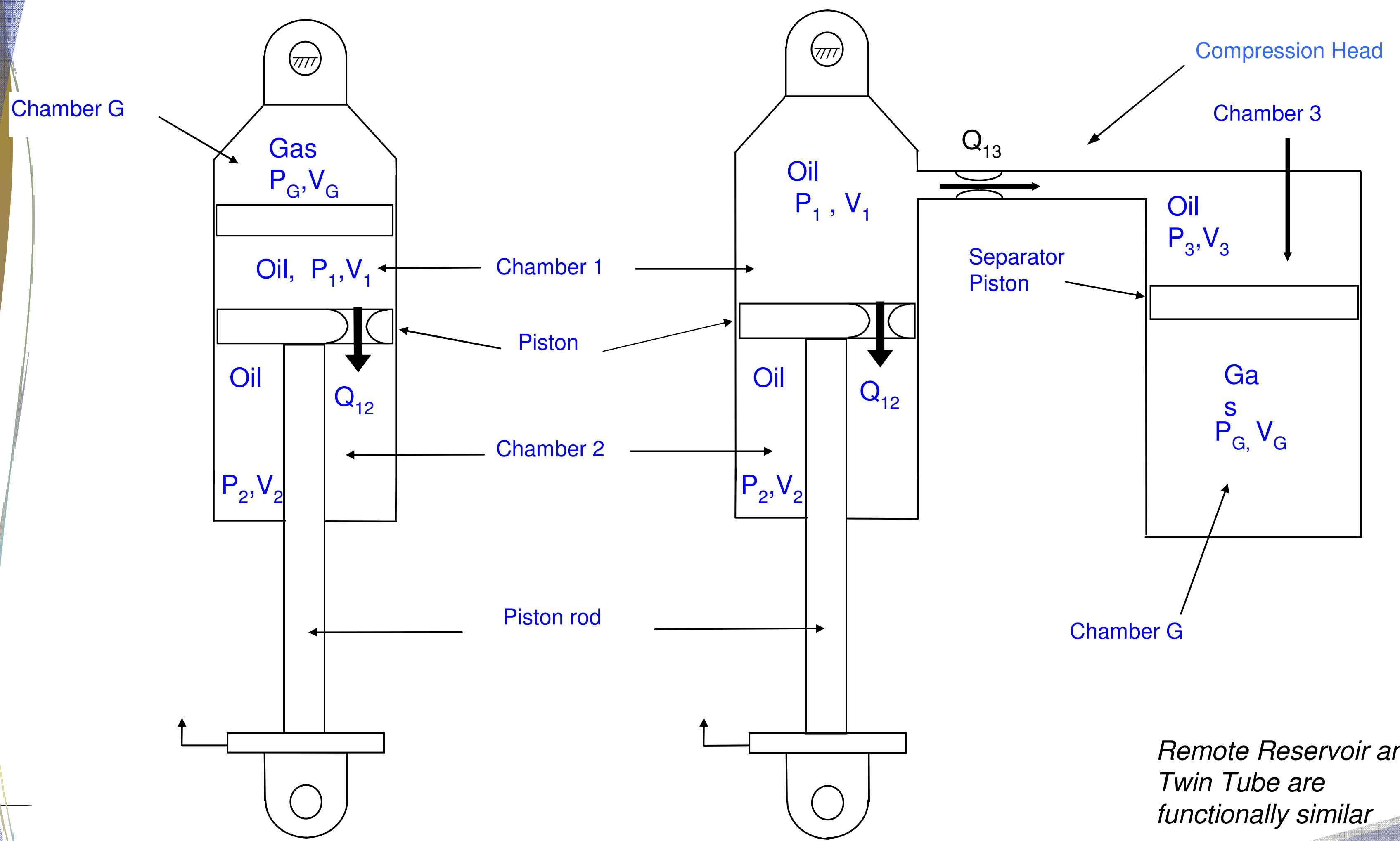
Compression



Rebound



Monotube Damper Schematics

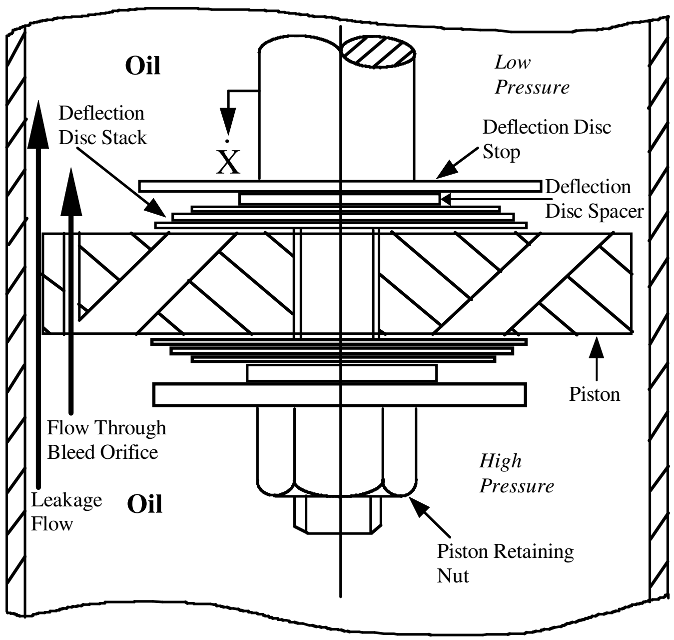


a) Monotube (b) Remote Reservoir

Schematics of monotube and remote reservoir dampers.

Remote Reservoir and Twin Tube are functionally similar

Monotube Low Speed Damping Force



Schematic of low speed compression valve flow.

At low speeds, total DAMPER force might be influenced more by friction and gas spring, then damping.

Low speed flow is normally controlled by an orifice.

Types of orifices:

- **Hole in piston (with or without one way valve)**
- **Notch in disc**
- **Coin land**

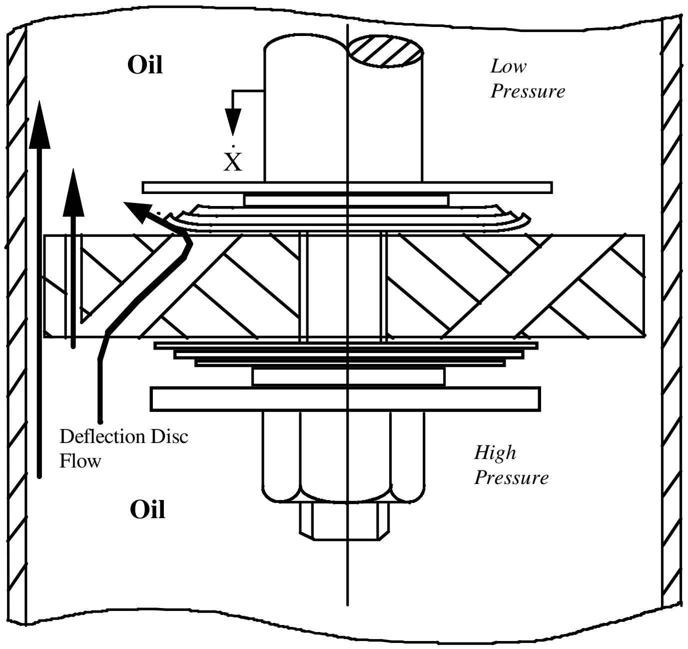
For turbulent flow:

$$\Delta P = \left(\frac{Q}{C_d \cdot A_{eff}} \right)^2 \cdot \frac{\rho}{2}$$

As flow rate Q is equal to relative velocity of the piston times the area of the piston in compression (piston area – rod area in rebound):

Orifice damping force is proportional to the square of the piston speed.

Monotube Mid Speed Damping Force



Schematic of mid speed compression valve flow.

Mid speed flow is normally controlled by an flow compensating device.

Types of flow compensating devices:

•Deflection Discs (typically stacked)

•Blow off valve (helical spring)

Preloaded on the valve determines the cracking pressure, and hence the force at which they come into play. Define the knee in FV curve.

Preload:

•Disc, shape of piston, often expressed in degree.

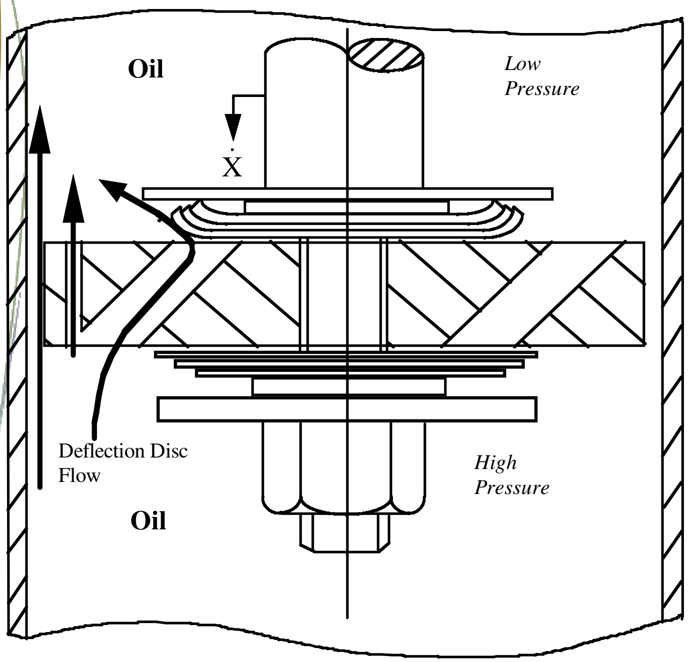
•Disc, spring to preload (sometimes found in adjustable race dampers)

•Spring, amount of initial deflection.

•Torque variation on jam nut can often vary preload. Undesired for production damper,

With flow compensation pressure drop and force are proportional to velocity.

Monotube High Speed Damping Force



Schematic of high speed compression valve flow.

High speed flow is controlled by restrictions in effective flow area. i.e. effectively orifice flow.

Flow restrictions, typically which ever has smaller effective area:

•Limit of disc or blow off valve travel.

•Orifice size through piston.

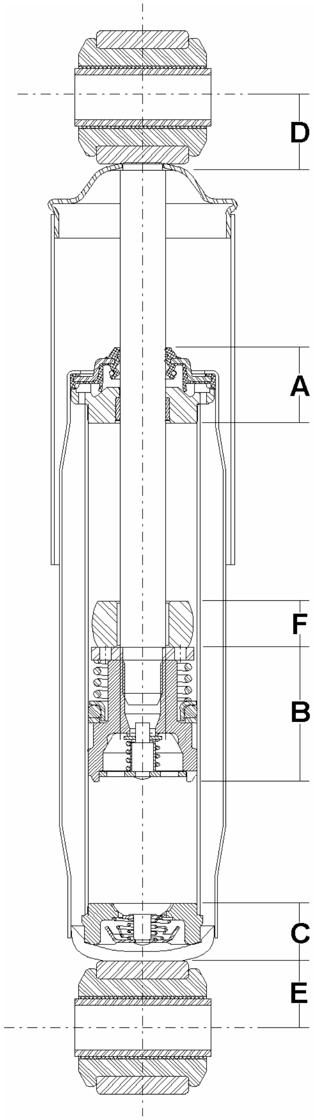
As per low speed damping, pressure drop and force are proportional to velocity squared.

Rebound damping and pressure drops across compression heads (foot valves) are similar to those discussed here.

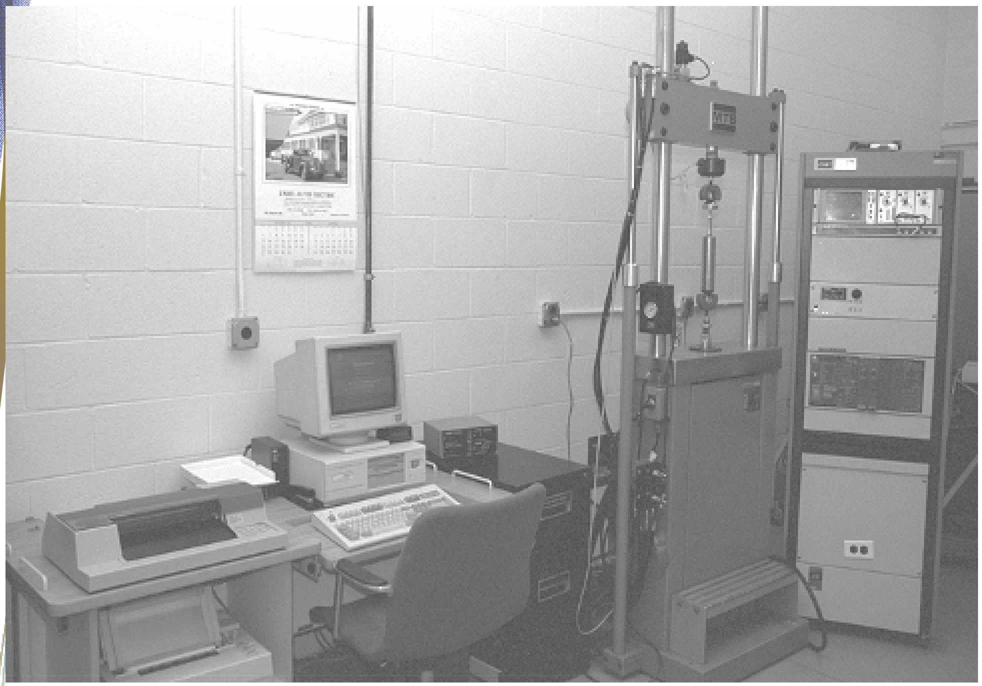
Dead Length

Dead Length = A + B + C + D + E + F

Max Travel = (Extended Length – Dead Length) /2



Performance Measurement



Computer Controlled Servo Hydraulic Shock Dyno

Various wave forms can be used to test, sinusoidal, step, triangular, track measurements, etc.

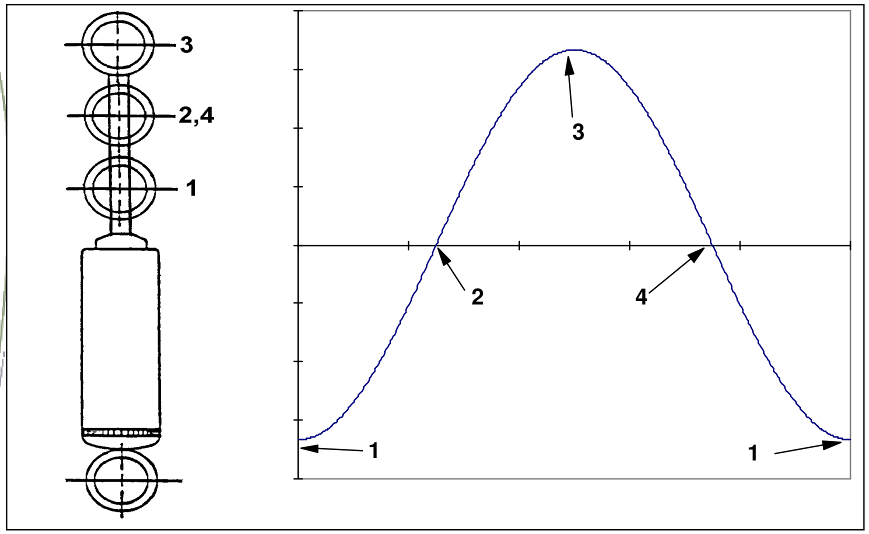
Data captured for further manipulation.

Easy to vary input freq. and amplitude.

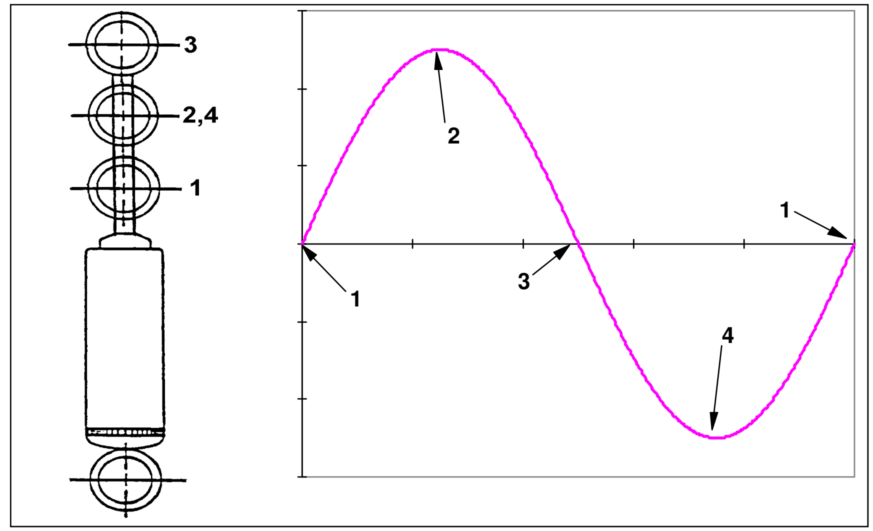
Offers potential to perform low speed friction and gas spring check, which are removed from the damper forces, to produce damping charts.

Need to know which algorithms are used.

Sinusoidal Input



Sine Wave Displacement Input



Corresponding Velocity Input

Sinusoid, most Common Input form for Shock Testing

Displacement = X sin (ωt)

Velocity = V = X ω cos (ω t)

Where w = 2 * π * Freq.

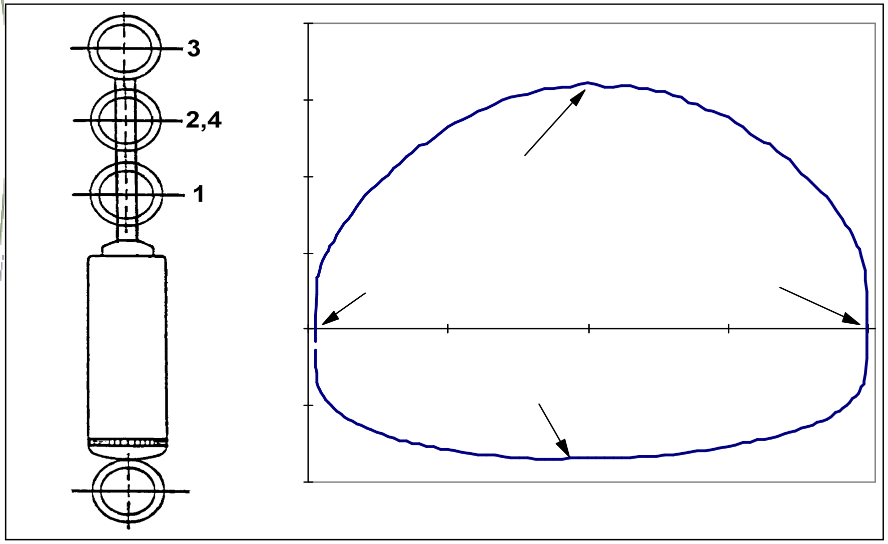
Peak Velocity = X * ω

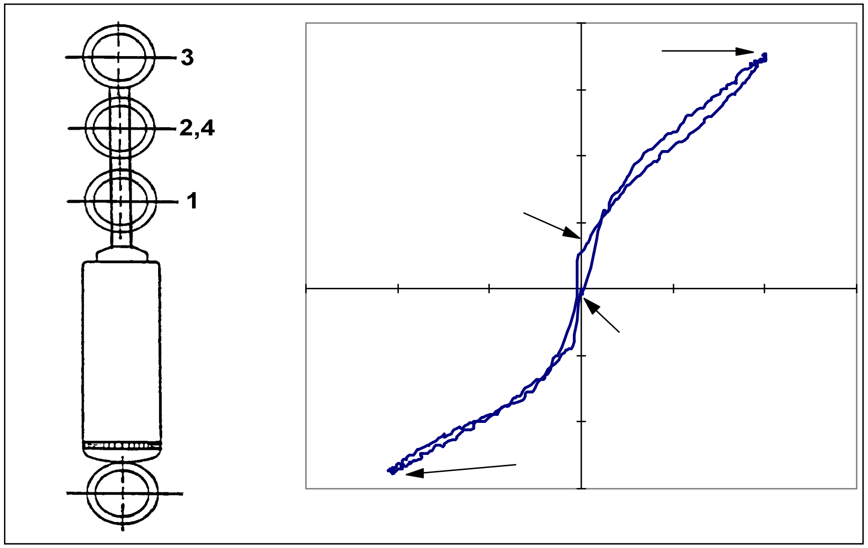
Typically test at a given stroke and vary frequency.

Suspension normally respondes at forcing freq. and natural frequencies.

So should we test at bounce and wheel hop freq.?

Test Outputs

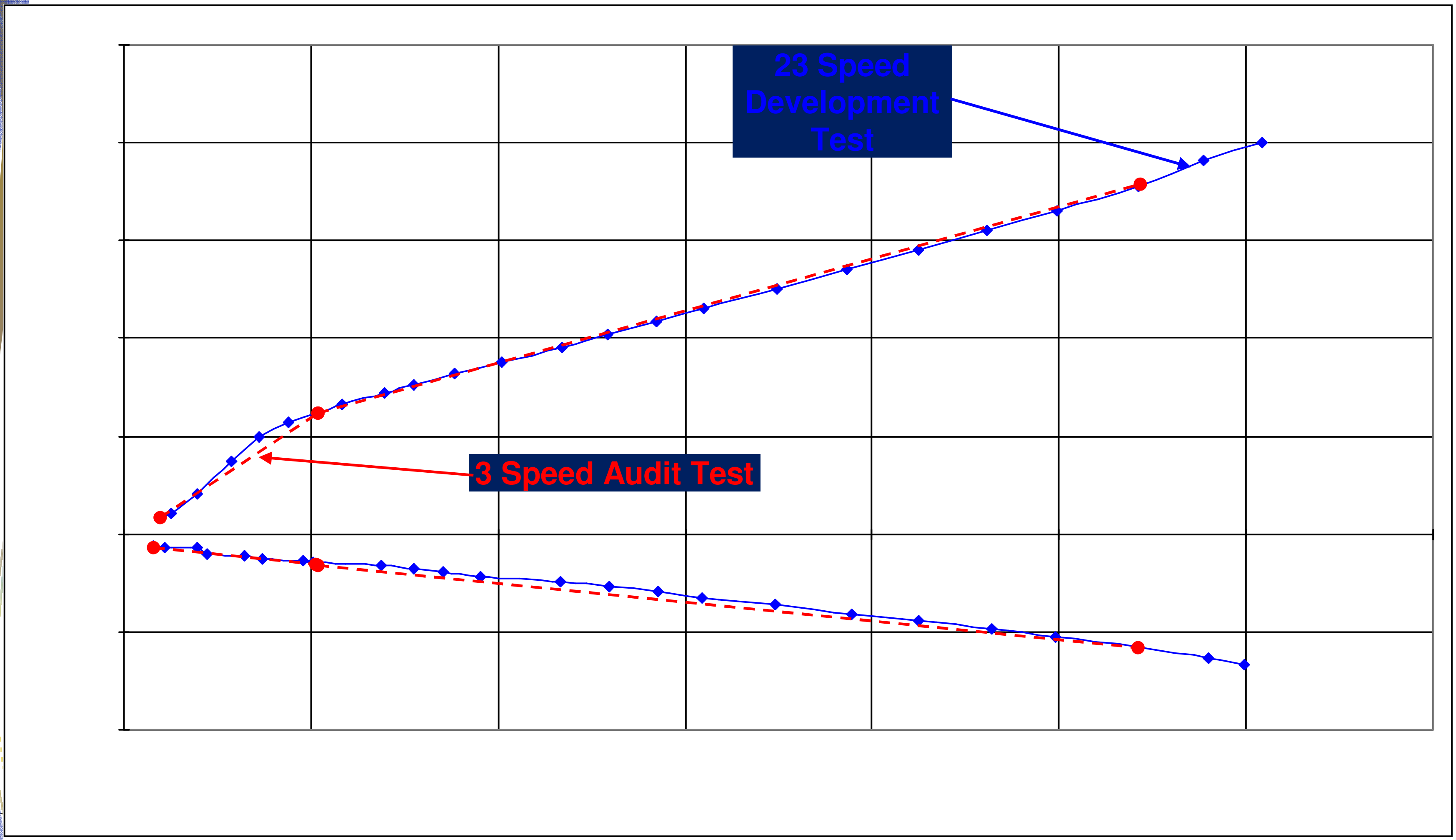




Force-Displacement Plot

Force-Velocity Plot

Peak Force - Peak Velocity Plot



Typical Peak Force - Peak Velocity Plot

Monotube vs. Twin Tube

Advantages / Disadvantages of Twin Tube and Monotube Shock Absorbers

	Twin Tube	Monotube
Cost	Less	More
Weight	More	Less
Packaging	Less dead length. Minor external damage OK. Must be mounted upright.	Longer dead length. Minor external damage can cause failure. Can be mounted in any position
Rod Reaction Force	Low	High
Sealing Requirements	Moderate	High
Fade Performance	Moderate	Better

Twin tube has greater sensitivity to compressibility and hence acceleration.

Suspension Loads

- Avoid taking primary loads (control arm, anti-roll bar, spring/damper) in the middle of a frame tube
- Primary loads should be taken in double shear
- No rod ends in bending, please!
- Recommend obtaining data for engine block stiffness and bosses if engine used as load bearing member

Suspension Loads

- Instantaneous overload
  - Number of event reps= <10 (curb impacts, pot holes, sustained high g cornering, drag starts, panic braking)
  - Load amplitude= $>10^4$ N
- Fatigue
  - Number of event reps $\geq 10^2$ (gator teeth, rumble strips)
- Acceptance criteria depends on your strength:weight and power:weight goals

Load cases

- Vertical symmetrical (bending about the Y-Y axis)
- Vertical asymmetrical (torsion about the X-X axis, bending about the Y-Y axis)
- Fore/aft (decel, accel, obstacles, towline)
- Crashes (not covered in this discussion)

Load factors

- 3g bump, 1.5g lat and long
- SF depends on your design goal and common sense
- In the 90's, I saw a roll hoop yield on an FSAE car being gently towed back to the paddock
- Think about how your car will be used

Good luck on your design work. Now, the door prize question?

The car pictured in the terminology section of this presentation was in an understeer, neutral steer, or oversteer condition??

The first slip drawn from the hat with the correct answer and your name and your school name wins a Bell Sport SA 2010 racing helmet for your team. The drawing will be held before the Q&A session.