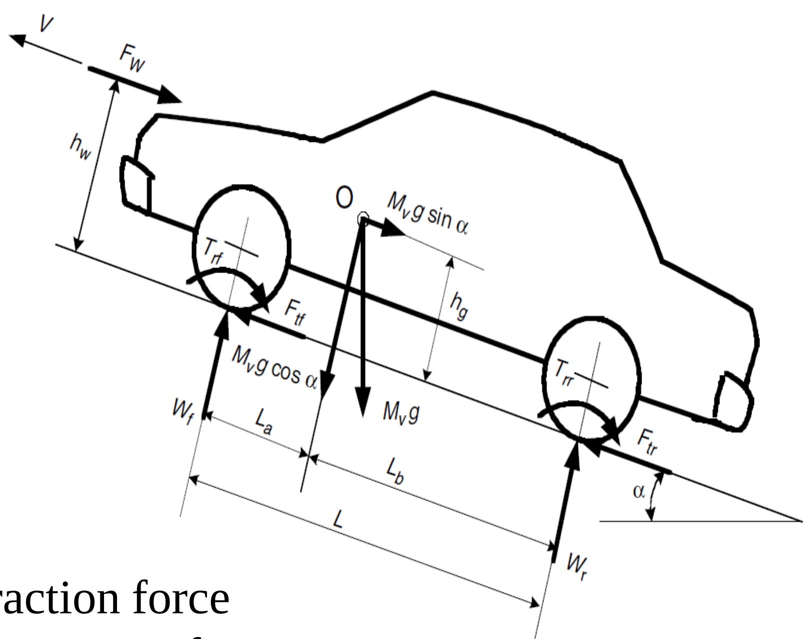
Vehicle Fundamentals

Forces acting on a vehicle

Newton's second law for vehicle traction

$$\frac{dV}{dt}=\frac{\Sigma F_t - \Sigma F_{tr}}{\delta M_v}$$



F_t: traction force

F_{tr}: resistance force

M_v: total mass

δ: mass factor

V: vehicle speed

Basic definitions.

- Ground vehicles consist of:
  - a frame: either one rigid part or some articulated components
  - ground support: wheels, tracks, or pods, and suspension
  - steering mechanism (sometimes coupled to suspension)
  - power plant (engine)
  - drive train (transmission, gear box, differential, brakes)

Ground vehicle dynamics addresses all these issues by providing models for each of the components.

From now on, "ground vehicle" = "car".

WHAT YOU MUST KNOW

Driving conditions

- Race Track perfectly at road, absolutely no obstacle
- Well Maintained Street , at surface, hills, no obstacles
- Bumpy Road mostly at surface, some holes and bumps, hills, small obstacles
- Rough Road not very at, many holes, small and big obstacles
- Off Road arbitrary terrain conditions, arbitrary obstacles

These are increasingly difficult when it comes to finding the contact points on the wheels or track, and computing the forces between the ground and the ground support. Off road will require full rigid body model as well as detailed geometric interference computation (collision detection).

Race track driving requires very little geometric information.

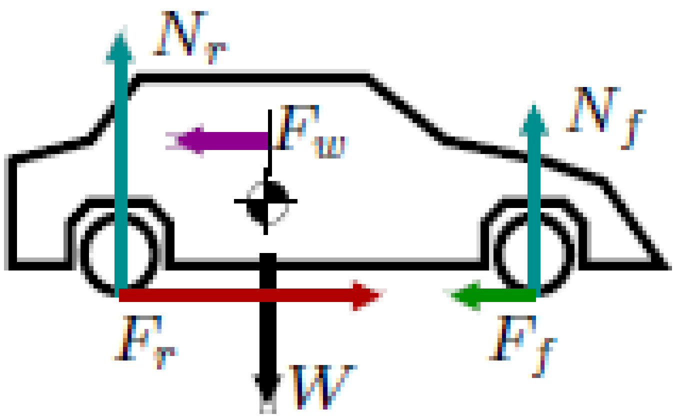
We will concentrate race track conditions but build a model that is suitable for bumpy road conditions.

Some basic numbers

- Car driving at 100 Km per hour is : 28 metres per second
- Typical wheel: 35cm radius =12 revolutions per second
- At 60 frames per second, that's 1/5 revolution per frame or 1.2 rad per frame.
- Small angle formula i.e., sin() works only for ≈ 0:2. We're way off.
- Racing car: 200km per second, 25 revolutions per second, 2.5 rads per frame!
- Using real wheels to simulate race cars is difficult!
- This is why we concentrate on a point approximation for the wheels i.e., the car is now a frame and at most one contact point per wheel.

Basic physics of a simple car

- The forces acting on a car.

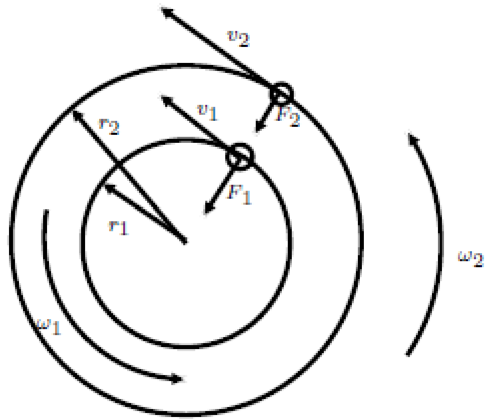


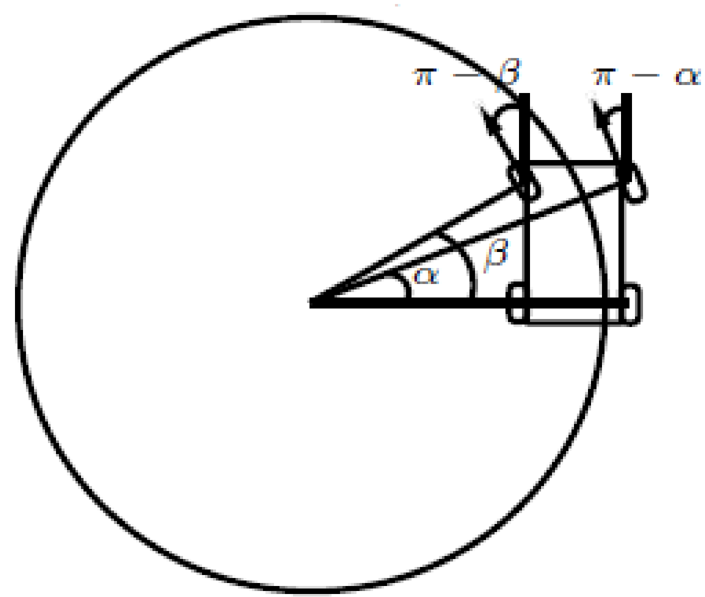
N_r Normal force on the rear wheel
N_f Normal force on the front wheel
F_r Traction (friction) force on the rear wheel
F_f Traction (friction) force on the front wheel
W Gravitational force on Center of Mass (CM)
F_w Drag resistance on CM
The diagram is that of a rear traction car which is accelerating.

- Note carefully: gravity acts on the CM but normal, traction, and braking forces act at the contact area of the wheels.
- Traction, braking and normal forces apply torques on the CM.

Because of this, we need a rigid body model for the frame, at least. Wind drag also applies torques but that will be neglected.

What does that mean for cars



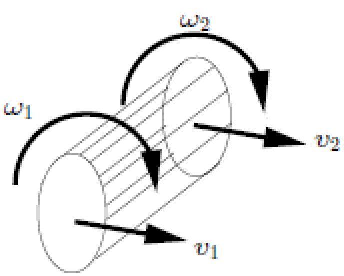


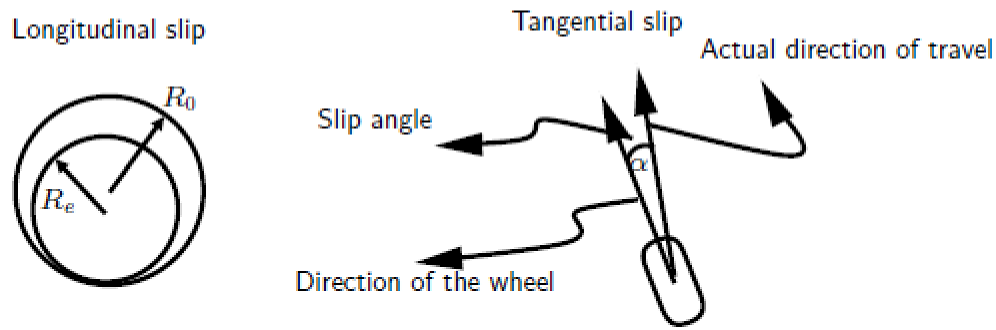
Inside and outside wheels are on different radii during cornering.
To turn without skidding, need different linear velocities for inside or outside.
Wheels are subject to tangential force of mv_2 / r which can be high.

Essential relationships:
Linear velocity $v = \omega / r$
Centripetal force $F = mv^2 r$, without this force, you don't turn!
Velocity ratios for common angular velocity:
$v_2 = v_1 r_2 / r_1$

Basic Wheel Physics

- A perfectly cylindrical wheel cannot turn without slipping!
- Details of wheel-ground contact

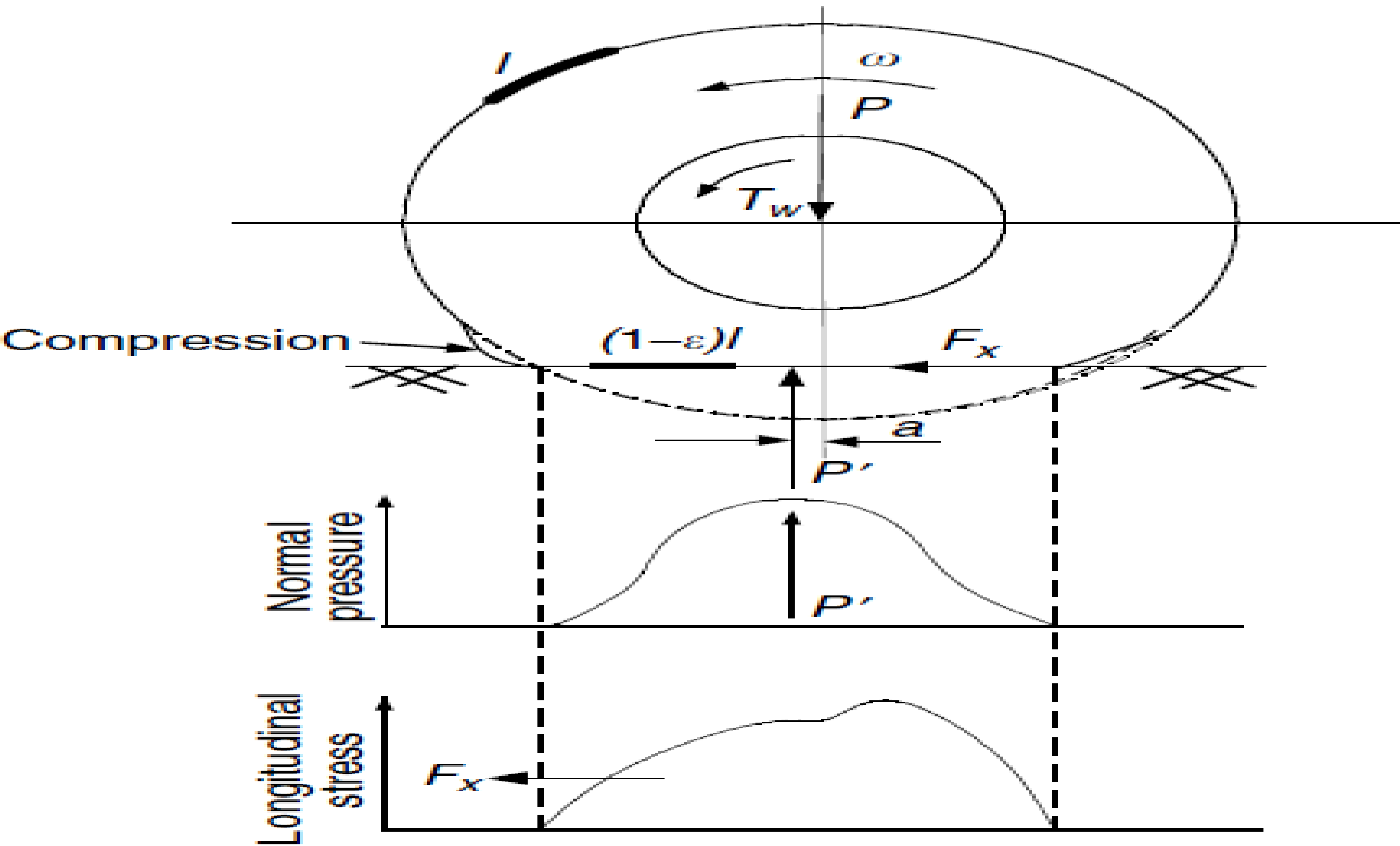




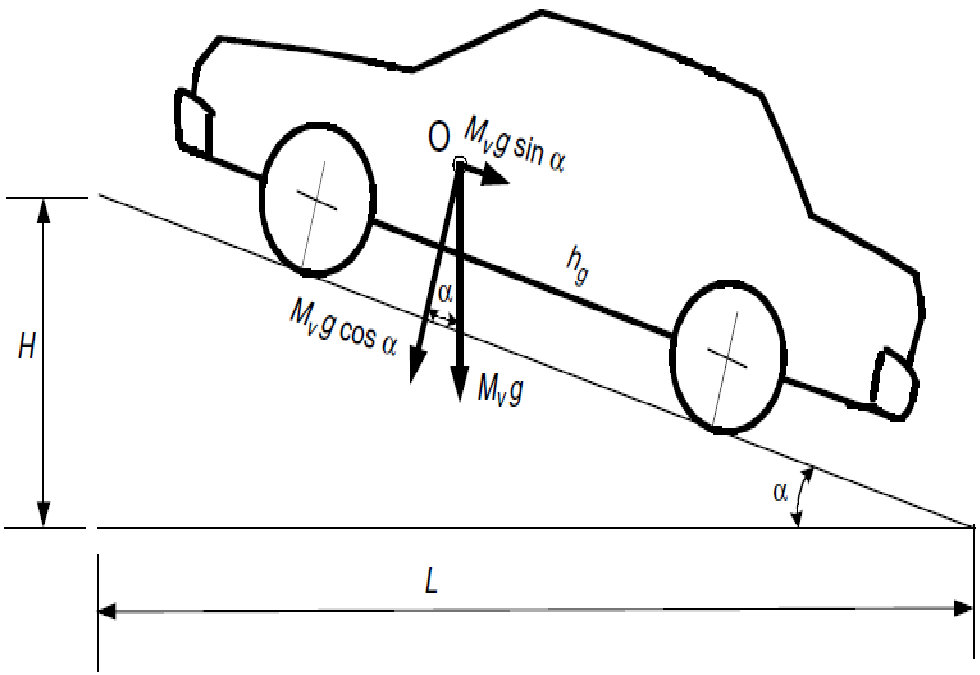
I.e., $\omega_1 = \omega_2$ and $v_1 = v_2$ so we can only have straight line motion. This is why we use tires which are deformable. A tire under stress will deform and slip i.e., direction of travel will differ from that of a perfectly rigid cylinder.
Despite the abundand folklore, tire slip has nothting to do with the contact patch slipping on the ground. Tire slip is the net kinematic result of bulk tire deformations.

When the tire is under a load, it compresses and the effective radius is $R_e < R_0$; i.e., the velocity of the center of the wheel is not $v = R_o\,\omega$ but instead, $v = R_e\,\omega$. This generates a friction force because work is done to compress the tire, not because the contact patch slips on the ground!!!! When there is a tangential force on a tire, it compresses tangentially and doesn't go along a line of travel that is in the vertical plane.

Behaviour of a tire under the action of driving torque



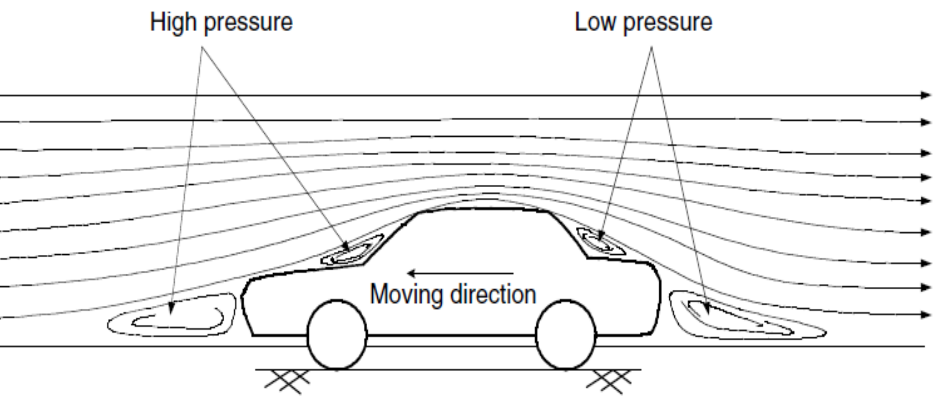
Grading Resistance



$$F_g = M_v g \sin\alpha$$

- When a vehicle goes up or down a slope, its weight produces a component, which is always directed to the down ward direction, as shown in figure. In vehicle performance analysis, only uphill operation is considered. This grading force is usually called grading resistance. The grading resistance, from above Figure , can be expressed as

Aerodynamic Drag



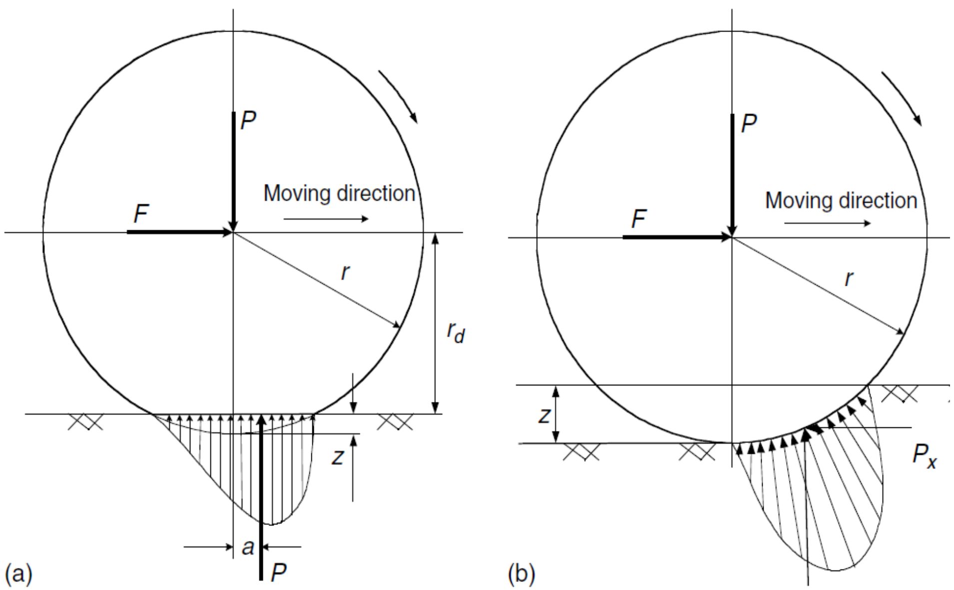
Skinfriction: Air close to the skin of the vehicle moves almost at the speed of the vehicle while air far from the vehicle remains still. In between, air molecules move at a wide range of speeds. The difference in speed between two air molecules produces a friction that results in the second component of aerodynamic drag. Aerodynamic drag is a function of vehicle speed *V*, vehicle frontal area A_f, shape of the vehicle, and air density ρ. Aerodynamic drag is expressed as

$$F_w = \frac{1}{2}\rho A_f C_D (V + V_w)^2$$

- A vehicle traveling at a particular speed in air encounters a force resisting its motion. This force is referred to as aerodynamic drag. It mainly results from two components: shape drag and skin friction.
- *Shape drag:* The forward motion of the vehicle pushes the air in front of it.
- Where C_D is the aerodynamic drag coefficient that characterizes the shape of the vehicle and V_ω is the component of wind speed on the vehicle's moving direction, which has a positive sign when this component is opposite to the vehicle speed and a negative sign when it is in the same direction as vehicle speed.

Vehicle Resistance

- Rolling Resistance



Tire deflection and rolling resistance on a (a) hard and (b) soft road surface

- Vehicle resistance opposing its movement includes rolling resistance of the tires rolling resistance
- torque T_{rf} and T_{rr}, aerodynamic drag F_w, and grading resistance ($M_v g \sin\alpha$)

- The rolling resistant moment; $T_r = Pa$
- To keep the wheel rolling, a force, *F*, acting on the center of the wheels, is required to balance this rolling resistant moment. This force is expressed as

$$F = \frac{T_r}{r_d} = \frac{Pa}{r_d} = Pf_r$$

- where *rd* is the effective radius of the tire and $f_r = a/r_d$ is called the rolling resistance coefficient.

$$F_r = Pf_r$$

- The equivalent force is called rolling resistance with a magnitude of

$$F_r = Pf_r \cos\alpha$$

- Where *P* is the normal load, acting on the center of the rolling wheel When a vehicle is operated on a slope road, the normal load,*P*, should be replaced by the component, which is perpendicular to the road surface. That is,

$$F_r = Pf_r \cos\alpha$$

- where α is the road angle

Rolling Resistance Coefficients

Conditions	Rolling resistance coefficient
Car tires on concrete or asphalt	0.013
Car tires on rolled gravel	0.02
Tar macadam	0.025
Unpaved road	0.05
Field	0.1–0.35
Truck tires on concrete or asphalt	0.006–0.01
Wheels on rail	0.001–0.002

The values given in above Table do not take into account their variations with speed. Based on experimental results, many empirical formulae have been proposed for calculating the rolling resistance on a hard surface.