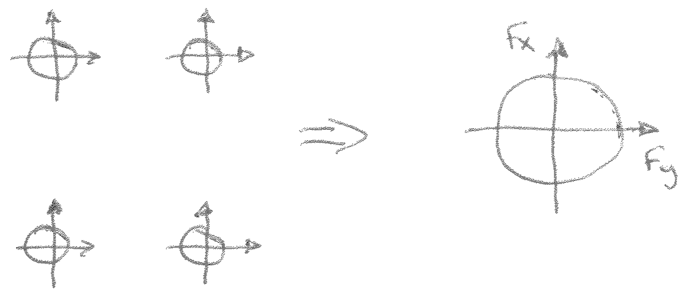
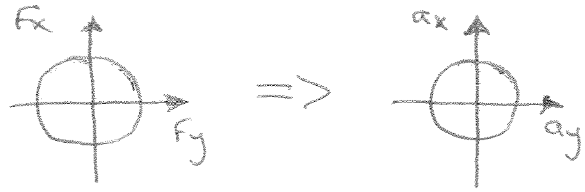
The Friction Circle and Racing

If each of the four tires has a "friction circle" that describes the limit on the magnitude of the combined lateral and longitudinal force, we can think of a similar picture for the whole car:



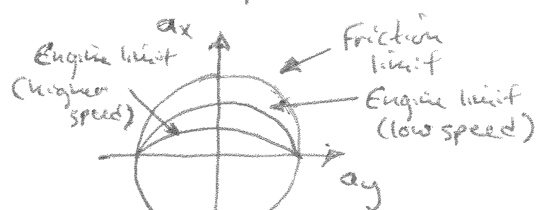
In reality, this is more complicated as a result of load transfer, but a good starting point.

Invoking Newton's second law, we can think of translating that force to acceleration:

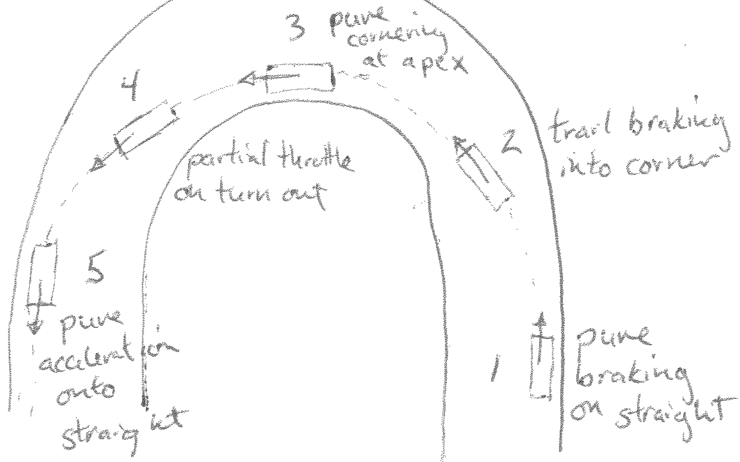


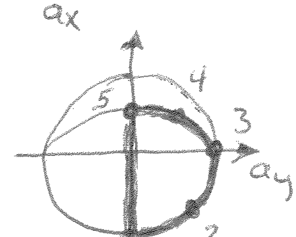
To go fast, we want to always be accelerating as much as possible.

Engine power generally limits the possible acceleration (as a function of speed) but the brakes are usually able to get to the maximum possible deceleration. So we have capabilities something like this:



To get around the track as fast as possible, we want to always be on the edge of our acceleration limits. This means the following approach to a corner:

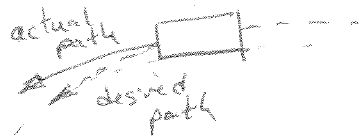




Easy, right?

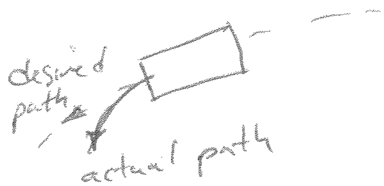
The challenge here is that the front tire and the rear tire almost never have the same friction capability (or coefficient μ). This means one axle will run out of force capability before the other.

If the front axle runs out of friction, the car will not turn anymore. This is known as limit understeer (the car is understeering the driver command) or in racing terms as "push" or "plow".



This is a big problem if the limit understeer causes you to leave the track.

If the rear axle runs out of friction, the car will begin to spin. This is known as limit oversteer or a "loose" condition. It is generally more critical than limit understeer since it requires driver correction immediately.



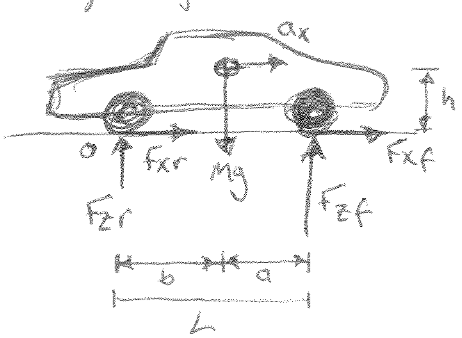
The car in this case is no longer stable and the driver must countersteer.

It would be ideal in most cases to set the car up to be just slightly understeering. But the fact that the car needs to accelerate and decelerate makes that a big challenge for two reasons:

(1) Brake or drive forces change the peak lateral force available at each axle and the tire curves themselves.

(2) Braking or accelerating change the normal forces at each tire.

The normal forces have to change since the vehicle's center of gravity is above the ground



$$\sum F = ma \Rightarrow F_{xf} + F_{xr} = ma_x$$

$$\sum M_o = ma_x h$$

$$\Rightarrow mgb - F_{zf} L = ma_x h$$

$$F_{zf} = \underbrace{\frac{b}{L} mg}_{\text{static load}} - \underbrace{\frac{h}{L} ma_x}_{\text{weight transfer}}$$

$$F_{zr} = \frac{a}{L} mg + \frac{h}{L} ma_x$$

When the car accelerates, the rear wheels gain normal force and thus can support a greater force magnitude. The front wheels, however, lose normal force.

In braking, the opposite happens: the front wheels gain normal force and the rear wheels lose force.

In determining whether the vehicle will experience limit understeer or limit oversteer, it is important to know where the longitudinal forces are applied. In a front wheel drive car, acceleration will clearly give more tendency to limit understeer - the loss of normal force reduces peak force capability and the drive force uses some of that force. For a rear wheel drive car, these effects compete - acceleration produces more normal force at the rear but uses some of that force for longitudinal (drive) forces. The normal force increase can be significant, hence the advice to not lift off of the throttle when cornering in a highly powered rear wheel drive car.

In braking, it is important that the brake force be proportioned in some way so that more brake force is applied to the front wheels at higher levels of deceleration. This proportioning of brake force has a huge impact on handling and race cars often have the ability to adjust this on the fly so the driver can avoid excessive understeer or oversteer on braking.

Go karts generally drive and brake the rear wheel only (though some karts have four wheel brakes).