

Transient Behaviour

Steady State Behaviour

When the car is cornering at constant speed it is in a steady state

Yaw velocity is constant

Yaw Acceleration = 0

All elements could be described as being in equilibrium

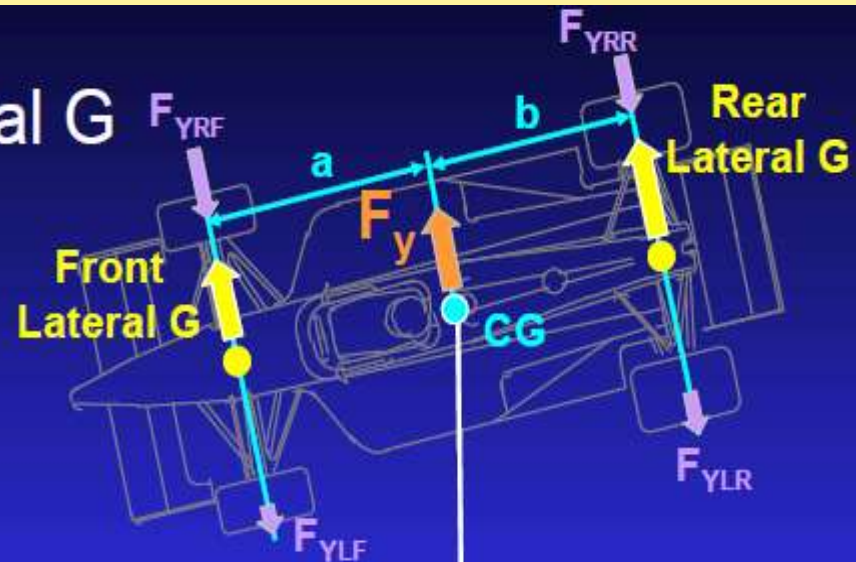
Transition

The transition from steady state straight running to cornering then requires other aspects of the vehicle to be taken into account and can lead to a further range of descriptions of oversteer and understeer.

Balance Between Front and Rear Yaw Moments

$$F_Y = \text{Mass} \times \text{Lateral G}$$

$$= m \times \frac{V^2}{R}$$



$$M_{Y_{aw}} = (F_{YLF} + F_{YRF})a - (F_{YLR} + F_{YRR})b$$

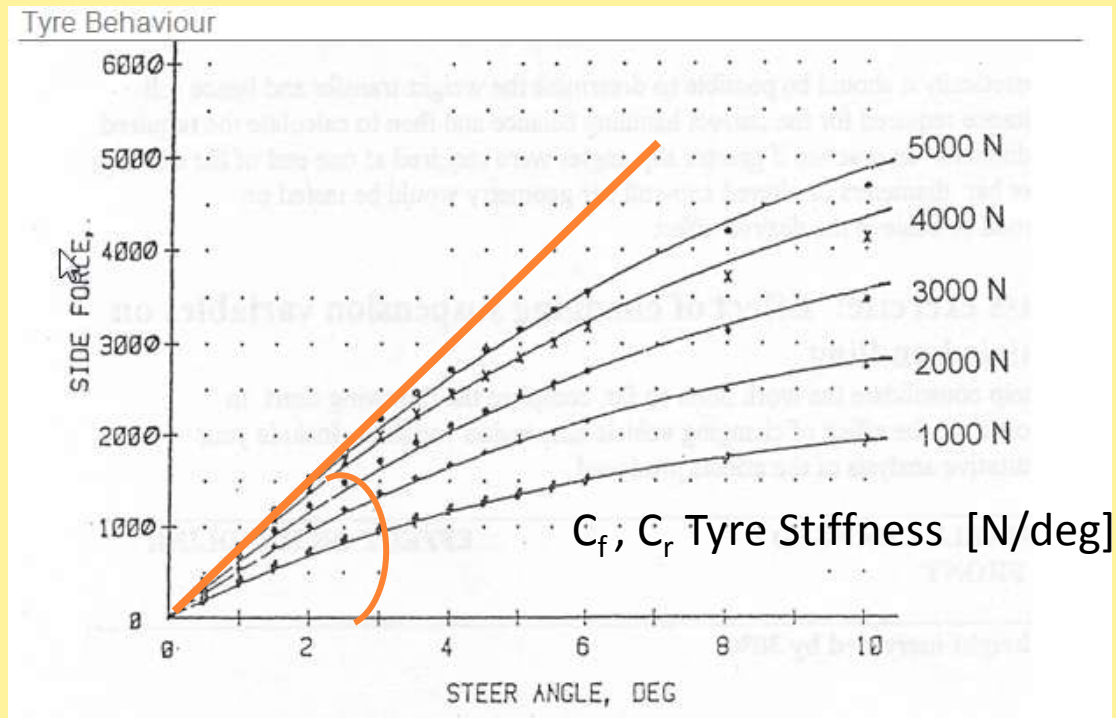
Combining Above Equations Gives

$$M_{Y_{aw}} = (m_F \times \text{Lat } G_F)a - (m_R \times \text{Lat } G_R)b$$

Claude Rouelle

Balancing Yaw Moments

Sharp (2002) consider the balance in terms of front and rear tyre stiffnesses and the resulting yaw moments produced.



Balancing Yaw Moments

$(C_f \times \text{Slip Angle})$ is a force that is acting about the CG which creates a Yaw moment.

If front and rear moments are not equal a yaw acceleration is produced dependent on magnitude of the difference in front and rear yaw moments and the rotational inertia of the car.

Transient Oversteer and Understeer

Neutral steer = $C_f \times a = C_r \times b$

Oversteer = $C_f \times a > C_r \times b$

Understeer = $C_f \times a < C_r \times b$

Transient Oversteer and Understeer

If the Yaw Moment, $M_{\text{yaw}} \neq 0$ the car will experience a yaw acceleration.

The magnitude of this yaw acceleration will depend on the rotational inertia of the car in the rotational equivalent of the linear form $F=ma$.

Yaw Acceleration

Calculating Yaw Acceleration & Moment

$$\ddot{\Theta} = \frac{d\dot{\Theta}}{dt} = \frac{d \frac{\text{Lateral G}}{V_x}}{dt}$$

Measured With
Inertia Rig

Calculated or
Measured with Gyro

$$\text{Yaw Moment} = \text{Inertia}_{\text{Yaw}} \times \ddot{\Theta}$$

Yaw Acceleration + Yaw Inertia

gives Yaw Moment

Increasing Yaw Acceleration Capability of a Vehicle

$$M_{Y_{aw}} = I_{Y_{aw}} \times \ddot{\Theta}$$

Yaw Moment = Inertia_{Y_{aw}} x Yaw Acceleration

To Increase Yaw Acceleration

1. Increase Yaw Moment
2. Decrease Yaw Inertia
3. Increase Yaw Moment & Decrease Yaw Inertia

Increasing Yaw Acceleration

1. Increase Yaw moment –achieved by optimisation of suspension and steering geometry, wheel loading and tyre design.
2. Decrease Yaw inertia –achieved by moving masses towards centre of car and reducing mass especially at the periphery of the car such as wheels and brakes etc. As an example, the inertia for a Ford Focus is 2170 kgm^2 and a Chrysler Voyager 4635 kg m^2

Car Responsiveness

The faster a car can accelerate in rotation the more responsive it will be but this is limited by the **maximum achievable response time of the driver.**

The way a car's responsiveness can be characterised will be discussed in later classes

Measuring Yaw Acceleration

A yaw acceleration is required to make the transition from straight running to cornering.

If data from a yaw velocity sensor is differentiated then this will give Yaw Acceleration.

Limitations

The problem with this approach is that the noise generated in the differentiation process is likely to make the analysis of such a signal difficult to interpret. Nonetheless it is an interesting approach to defining the behaviour of a car

Characterising oversteer and understeer by yaw acceleration

When changing direction there will be a yaw acceleration.

The transient behaviour could be characterised by determining the yaw acceleration required to change from one heading to another in the time period of the manoeuvre.

Understeer and Oversteer by Yaw Acceleration

If the Yaw acceleration measured is greater than that required for the transition then Oversteer is indicated

If the Yaw acceleration measured is less than that required for the transition then Understeer is indicated

Summary Definition of Oversteer and Understeer by Yaw Acceleration

Claude Rouelle, 2008 suggests that:

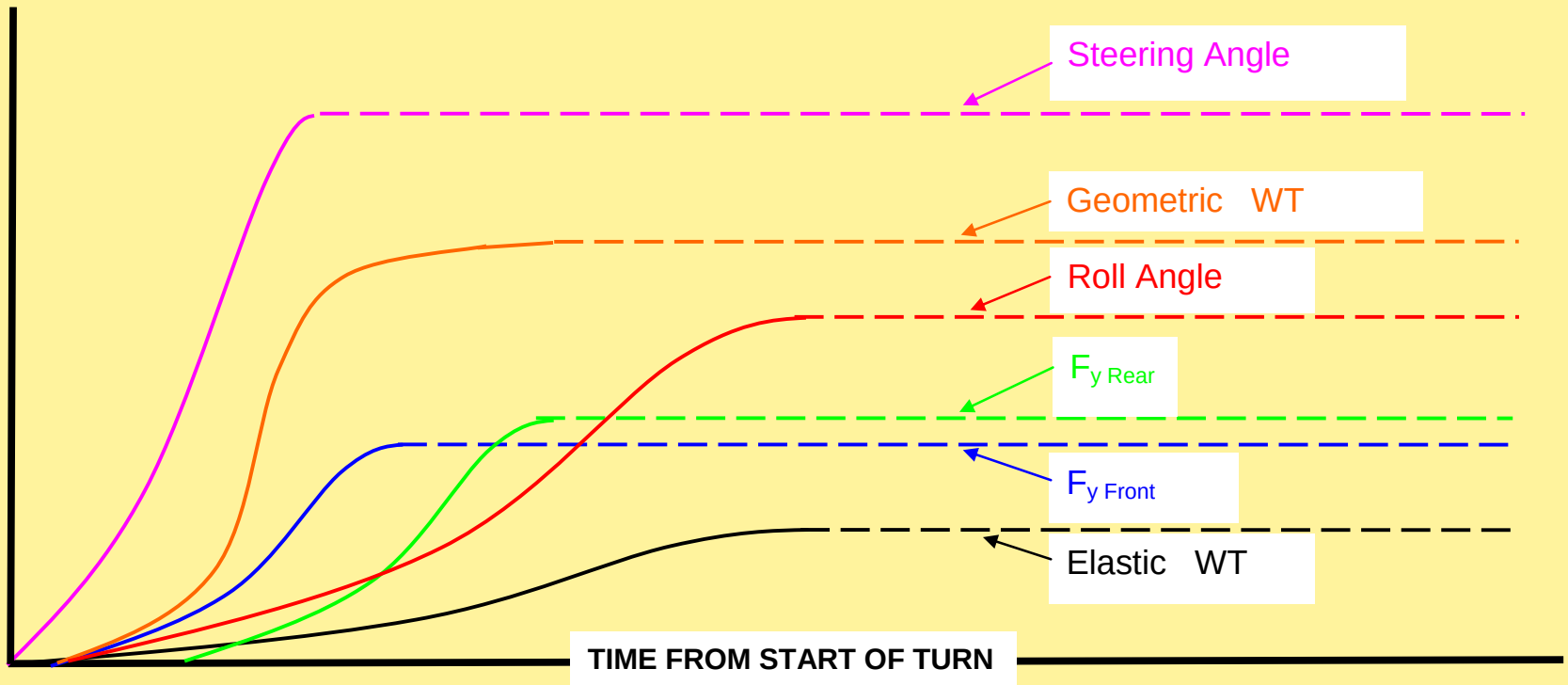
‘There is no such thing as understeer or oversteer, there is only under and over yaw acceleration’

Summary definition of oversteer and understeer by yaw acceleration

Understeer occurs (which means under yaw acceleration) because:

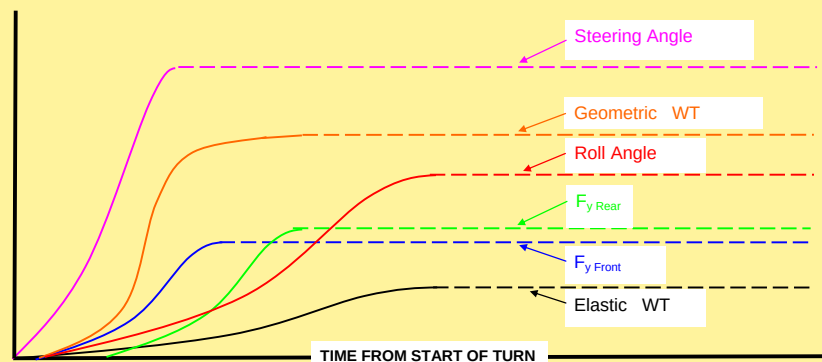
- *There is not have enough front tire grip*
- *There is too much rear tire grip*
- *There is not the ideal weight (and aero) distribution (distance a and b)*
- *There is too much yaw inertia*

Cornering Process



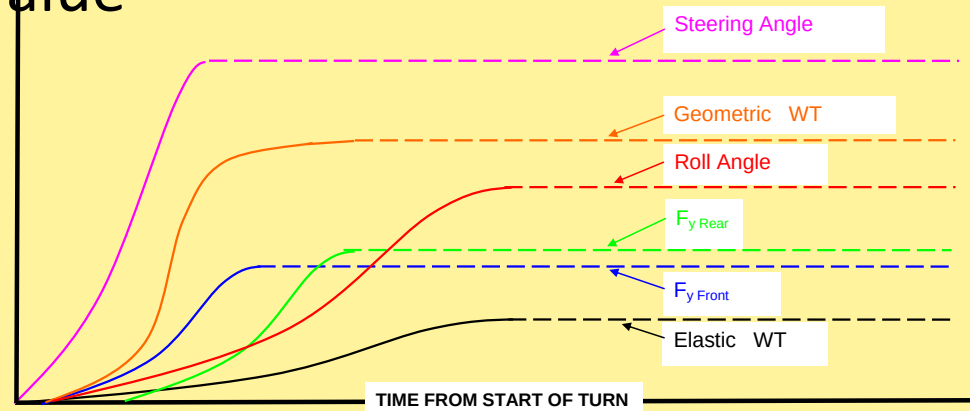
Cornering Sequence by weight transfer

1. Steering turned to initiate cornering creating a slip angle in front tyre
2. Front tyre builds up lateral force (F_y Front) after initial $\frac{1}{4}$ rotation delay to distort tyre structure
3. Geometric weight transfer developed proportional to front lateral force
4. Vehicle starts to roll in response to lateral acceleration produced by front lateral force
5. Elastic weight transfer builds up in response to roll angle

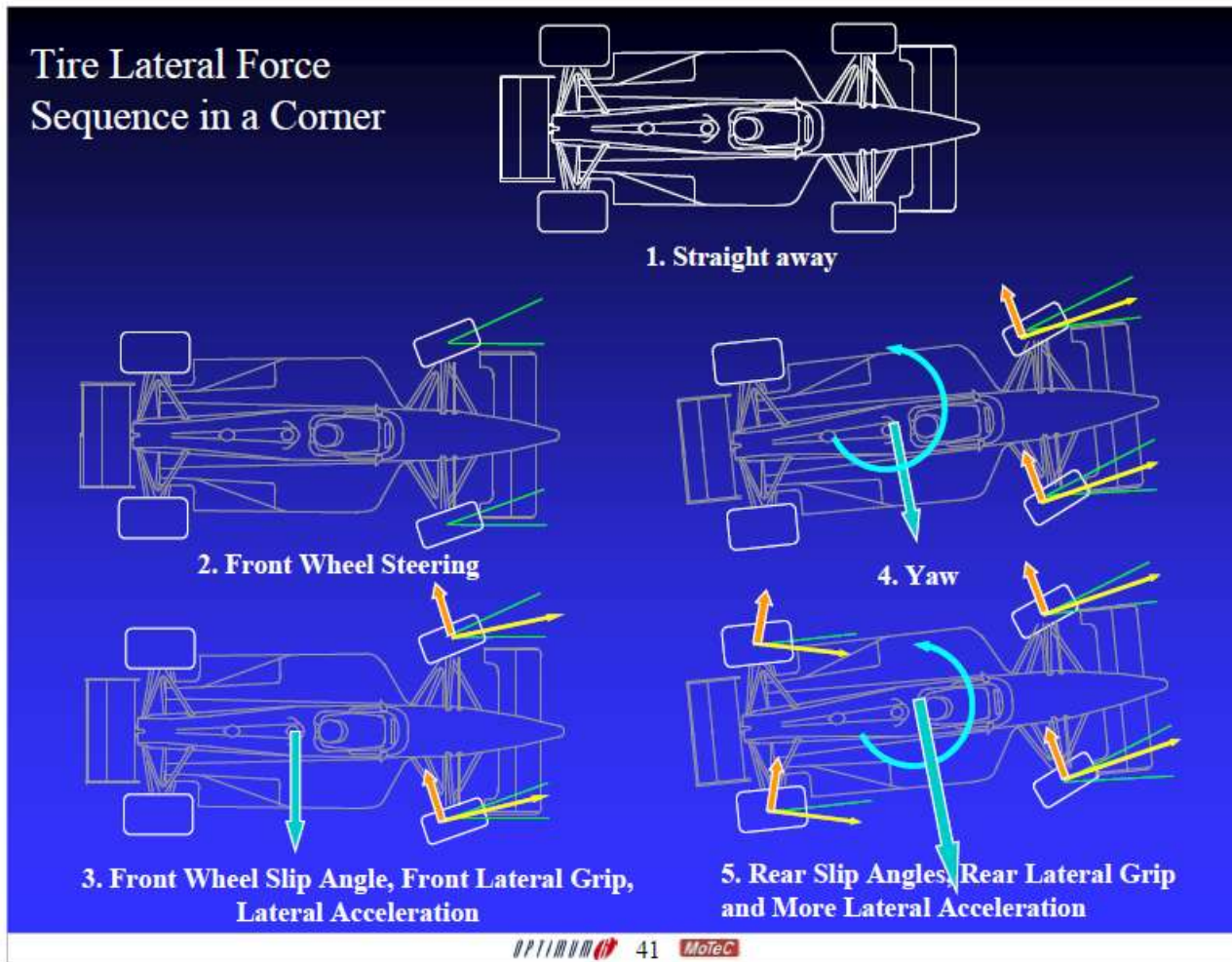


Cornering Sequence by weight transfer

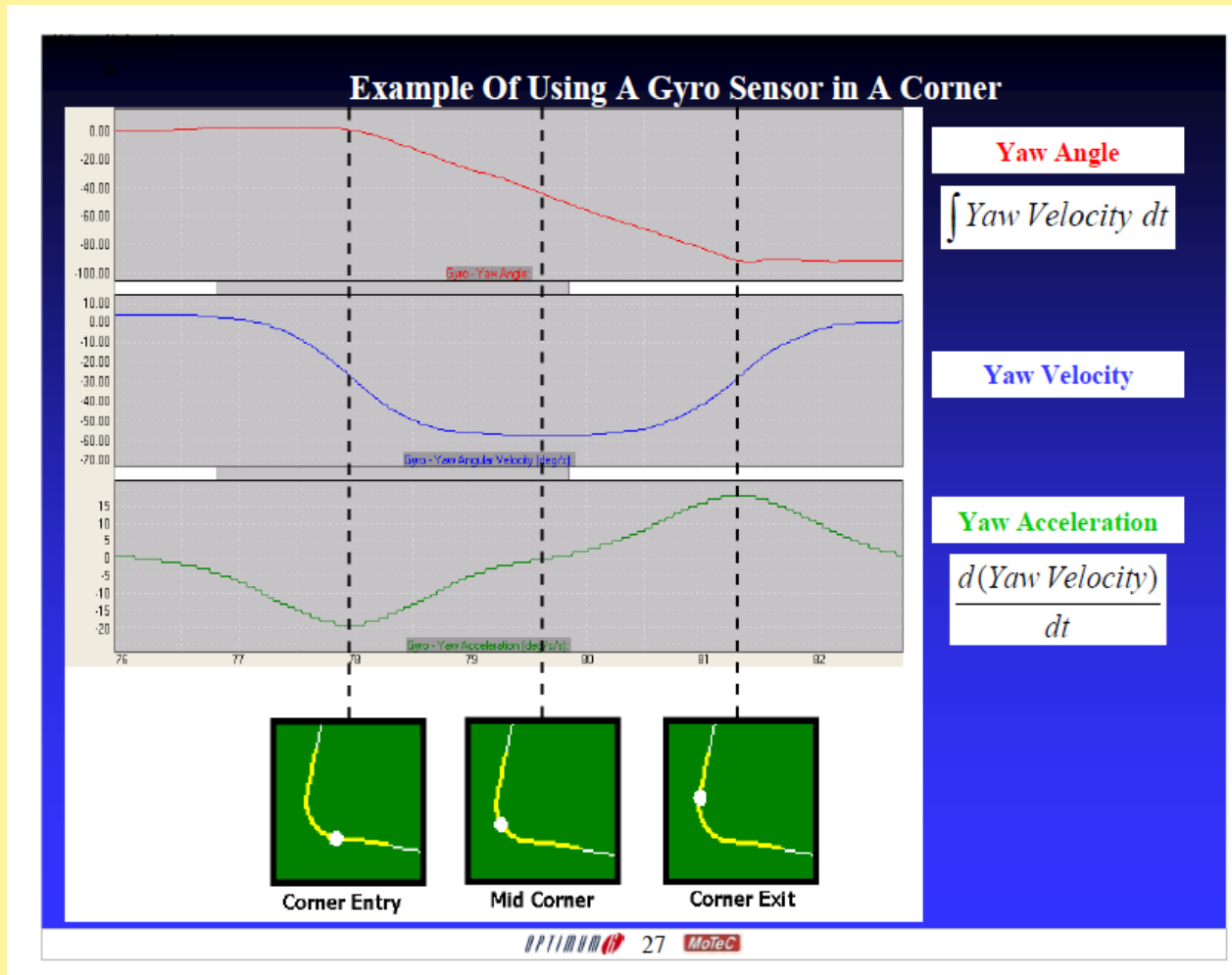
5. Rear tyre lateral force (F_y Rear) builds up in the same way as the front increasing level of geometric weight transfer
6. Increased rate of vehicle roll and elastic weight transfer in response to rear lateral force build up
7. Steady state roll angle achieved.
8. Dotted lines represent conditions at steady state which are likely to oscillate in practice until damped to constant value



Cornering Sequence by Tyre Lateral Force



Yaw, Yaw Velocity and Yaw Acceleration Through a Corner



Vehicle Handling - Summary

Comments from Claude Rouelle

Race car performance is not only about maximum lateral acceleration it is also about longitudinal acceleration.

Lateral and longitudinal accelerations are functions of the tyre's lateral and longitudinal properties and the ability of the driver to exploit them. It is also about yaw acceleration.

Yaw acceleration is a function of the car's yaw inertia and the car's yaw moment

Yaw inertia needs to be measured on a inertia test rig or determined by calculation

Vehicle handling - Summary

Comments

Yaw moment is a function of the tyre's longitudinal and lateral forces, the wheelbase the front and rear tracks.

The ideal yaw acceleration on a steering pad (steady state) is 0

The ideal yaw acceleration required in transient manoeuvres depends on the speed, and the radius of the corner being negotiated