



Vehicle Dynamics

James Hatherill

Andrew Harrison

Wales Institute for Science & Art

BEng Automotive Engineering

Introduction

Vehicle dynamics have influenced the development and design of vehicles over the last century. Using a vehicle's movement relative to the driver's inputs. Key considerations an engineer must account for when designing new vehicles are listed below. The vast majority of these factors have an impact on the handling of the vehicle.

In addition to ensuring the vehicle can handle the harsh road conditions and forces during cornering, engineers must consider the comfort of the passengers and internal space. These key requirements have led to many variations in vehicle design. Over the past century, cars and other vehicles have evolved from runabout, phaeton, and sedan's to modern styles like hatchbacks, SUVs and crossovers.

Key considerations

- Forces acting on a vehicle – Includes the longitudinal forces from acceleration and braking, as well as vertical forces acting on the body of the vehicle.
- Vehicle centre of gravity – Has a significant impact on overall handling and stability.
- Tyres – Factors such as the coefficient of friction, tyre load, slip angle, and lateral forces are important in tyre performance.
- Drivetrain configuration – is the location of the engine within the vehicle, and which axle or axles are being driven.
- Suspension systems – Required to support the vehicle's weight while maintaining a constant tyre to road connection. Also, to decrease the overall body roll.

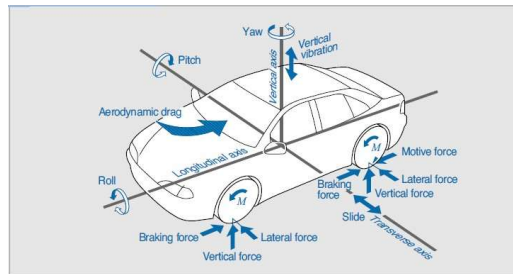
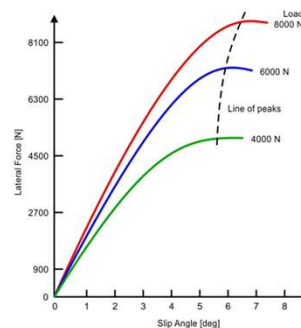


Figure 2 shows how forces are exerted on the tyres while cornering and the centrifugal forces exerted on the centre of mass.



Graph 1 shows the relationship between slip angle and lateral force of different vertical loads under a tyre. As the slip angle increases, the lateral force rises to a peak, then declines, indicating a loss of grip. Higher vertical load increases the maximum lateral force the tyre can generate.

$$F_{\text{centripetal}} = m \frac{v^2}{r}$$

$\frac{v^2}{r}$ is the centripetal acceleration



Figure 3 shows how the centripetal force acts on the vehicle and affects the acceleration. Centripetal force is how the vehicle follows the radius of the corner.

Figure 4 shows how centrifugal force is used to pull the vehicle away from the centre of the turn.

Centrifugal Force

$$F = m \times \frac{v^2}{r}$$

$$F = m \times \frac{(\omega r)^2}{r} \text{ or } F = m \times \omega^2 r$$

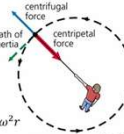


Figure 1 shows an understanding of forces from everyday use in normal conditions. The main constraint that changes is when the vehicle is driven under different conditions, for example, on track days, where high forces are generated through the tyres and axes during high-speed straights and cornering.

Calculations

Centrifugal Force – where F is the centrifugal force (N), m is vehicle mass (kg), v is vehicle velocity (m/s), and r is turning radius (m).

$$F = m \frac{v^2}{r}$$

Centripetal Force – where v^2/r is the centripetal acceleration.

Tyre Grip & Weight Shifts.

The overall balance between the tyre friction and the applied forces decided whether the vehicle maintains traction or slides out. This is particularly noticeable in high load conditions such as cornering. Weight transfer also plays a key role, as shown when the load shifts between the axles when the vehicle is braking and accelerating. This alternates the tyre contact points as grip levels alternate.

Acknowledgements

Thank you to Andrew Noble for the constructive assistance with this poster, providing a deep insight into this subject

References

- Gill, B., Sehdev, M. & Singh, H., 2018. Four-wheel drive system: Architecture, basic vehicle dynamics and traction. *International Journal of Current Engineering and Technology*, 8. Available at: <https://doi.org/10.14741/ijcetv.8.2.28Doe>.
- Hu, Z., Liu, Y. & Wen, Y., 2022. Improvement for the dynamics of Formula One car based on an analysis of center of mass. *Highlights in Science, Engineering and Technology: MAME* 2022, 13, p.59.
- Rehman, Muhammad. (2023). Race Car Vehicle Dynamics. ResearchGate
- Milliken, W. F. & Milliken, D. L. (1995) *Race car vehicle dynamics*. Warrendale, Pa: Society of Automotive Engineers.