AN INTRODUCTION TO MOTORCYCLE DYNAMICS

IN 10 SLIDES

E. Cabrol

April 2020

If you're looking for books or publications, you won't avoid the following authors (*) :

- Robin Sharp (First publication in 1971 : « *The stability and control of motorcycles* »)
- Tony Foale (motochassis.com), author of the book « *Motorcycle Handling and Chassis Design* »
- Vittore Cossalter (Univ. Padova), author of the book « *Motorcycle dynamics* »
- Roberto Lot (multibody.net)
- Simos Evangelou (Imperial college, London)

One of them is an engineer (having more patents than publications in his career), the others have academic profiles. I let you guess who is who ☺

Some academic teams :

- Bicycle and Motorcycle Engineering Research Laboratory (Univ. Wisconsin)
- Motorcycle Control (Univ. Oxford)

(*) in « order of appearance » in the last 50 years

Discussions about motorcycle dynamics always begin by arguments about countersteering and gyroscopic effects.

this 3' video by the Cambridge Science Centre is a crystal clear explanation of the first point : The Physics of Countersteering

Gyroscopic effect is not the only reason for straight line stability (nor is trail), and this has been shown (at least for bicycles) by the work done by Arend Schwab, Andy Ruina and Jim Papadopoulos, summarized on this webpage : http://bicycle.tudelft.nl/schwab/Bicycle/index.htm

In particular, have a Look at :

- The paper "*A bicycle can be self-stable without gyroscopic or caster effects*" they published in Science in 2011
- this video : TMS Bicycle, stable without gyros or trail

While emphasis for vehicle (car) dynamics has been put (at least at the beginning) on steady-state and low-frequency behavior (< 5Hz), most of the academic work regarding motorcycles focused very early on stability and safety issues (*), looking at higher frequency (5-20Hz) phenomena.

- Some vibration modes can be unstable, mostly wobble and weave
- Weave is at a lower frequency (<5 Hz) than wobble (5-10 Hz)
- Weave mode involves the whole body
- Wobble involves only the front of the motorcycle
- A well-known illustration of wobble can be seen on this video

(*) for rather obvious reasons I would say

Also of importance is chatter, especially for racing drivers because it is usually happening when riding close to the limits. This is a high frequency phenomenon (15-20 Hz), explained by Steve Parrish in this video

… and also illustrated on this 2012 footage of Ben Spies (at t=0'24''), in this case on the rear suspension but most of the time it's a major concern for the front.

Some publications by the usual suspects :

- *The chatter of racing motorcycles* (V. Cossalter, 2008)
- *Chatter vibrations of high-performance motorcycles* (R. Sharp, 2013)

About Tires

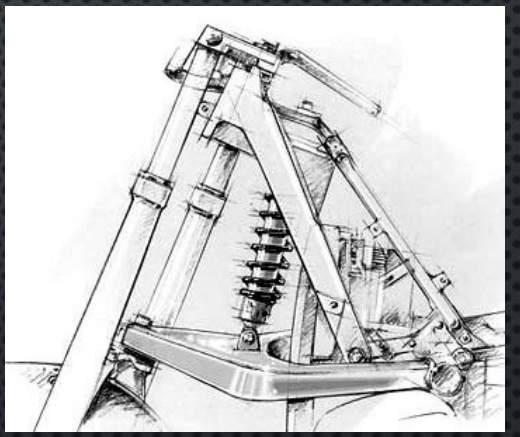
- Camber thrust is important (more than for automotive application)
- Pacejka Magic Formula still works
- The MF-Swift model of TNO/TASS has been extended in version 6.2 for motorcycle tires, as shown in this excerpt of the documentation :

- **MF-Swift for motorcycle tyres**
  It is now possible to apply the MF-Swift functionality for motorcycle tyres. More specifically the rigid ring modelling has been validated for motorcycle tyres and the Contact Method for 2D and 3D roads has been extended. This functionality is activated if the motorcycle contour parameters (MC_CONTOUR_A and MC_CONTOUR_B) are defined and nonzero in a MF-Swift 6.2tyre property file (FITTYP = 62). In these cases first the enveloping model is used to determine the effective road plane. Next the motorcycle contact is applied on this effective road plane.
  Additionally, when using the 'smooth road contact, circular cross section (motorcycle tyres)' Contact Method, now also (smooth) uneven road surfaces are supported when using the motorcycle contour parameters (MC_CONTOUR_A and MC_CONTOUR_B).

- CDTire can also be adapted for motorcycle tires in its 3D version
- Hard to pick only one academic paper, may be this one from Roberto Lot (2004) :

A Motorcycle Tire Model for Dynamic Simulations: Theoretical and Experimental Aspects

Motorcycle suspension is a widely discussed topic. A lot of designs have been studied as alternatives to the imperfect but still ruling telescopic fork : leading link, trailing link, telelever, duolever, hub-center steering, double wishbone …



Some names : Earles, Hossack, Fior, Foale, Di Fazio

A great history of the front ends, in five parts, begins here :

https://www.bikeme.tv/index.php/history-of-the-front-end-part-i/

You can also have a look at : Steer for the Future (2002, Tony Foale)

By the same author, illustrations of the diversity in its Front End Gallery

A stiff (as stiff as possible) frame/chassis sounds like a reasonable assumption when dealing with motorcycle or car dynamics, so that the chassis flexibility does not interfere with the suspension setup.

However, there has been a trend in MotoGP in recent years towards softer chassis.

Two newspapers articles on the subject by well documented journalists :

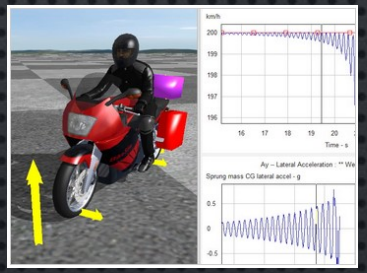
- Why MotoGP has gone soft (2019) by Mat Oxley
- MotoGP Chassis Wars (2015) by Kevin Cameron

I'm still not completely convinced by Oxley's assertion that "If the tyres are softer, the chassis must be made softer to match", but facts seem to prove me wrong.

See also this video presented by former F1 driver David Coulthard

Photo credit

- Softwares for motorcycle dynamics simulation
  - The most famous is probably BikeSim . The vendor (Mechanical Simulation Corp.) is also the editor of CarSim, well known in the automotive industry.
    A nice bibliography can be found in the « Publications » section of their website : https://www.carsim.com/publications/technical/motorcycle.php ...
    With a lot of contributions from the trio R. Sharp, D. Limebeer, S. Evangelou
  - Vi-Grade provides the Vi-Motorcycle solution, based on MSC Adams solver.
  - FastBike is a software developed by V. Cossalter & Al.
    The website Dynamotion will remind memories to those who knew the famous dinamoto.it (here on the wayback machine for example)



- A lot of simpler softwares for geometry and suspension design exist, such as ZeroOne, MotoSpec or Motorcycle setup software by … Tony Foale.

Other valuable resources

- Mike on Bikes youtube channel :
  - Motorcycle geometry explained (2019)
  - Motorcycle Suspension | How does it work? (2020)
  - Wider tires require MORE Lean angle (2020)
  - Hanging off: The science behind it (2020)

More advanced

- Development and validation of an advanced motorcycle riding simulator (2011), by V. Cossalter
- Modeling of a Motorcycle in Dymola/Modelica (2009), MSc thesis by T. Schmitt