Influence of aerodynamic lift and centre of pressure position in motorcycle stability

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Abstract:

Motorcycles are systems with complex dynamic behaviour that can become unstable under certain driving conditions. The basic study of motorcycle stability considers four degrees of freedom (DoF) (Sharp, 1971), and demonstrates the three well-known modes of vibration of a motorcycle: weave, wobble and capsize (Lot, 2021). Capsize is a non-oscillatory roll motion of the chassis, similar to an inverted pendulum, which is typically stable within a certain range of longitudinal speed. Contrarily, wobble and weave are oscillatory modes, with motions mainly of the front and rear chassis respectively, that can become unstable above or below certain speeds, making them particularly dangerous. Additionally, the existence of instabilities makes the motorcycle difficult to handle since the behaviour is less predictable and the rider needs to introduce corrective measures to attenuate them. Avoiding such instabilities from the design stage is not trivial since they depend on various interrelated parameters, such as geometry, mass distribution, rider interaction, suspension system, and aerodynamics, among others.

Aerodynamic forces in a vehicle can be essentially described by its longitudinal and vertical components together with its point of application on the vehicle. The former are known as drag and lift forces respectively, while the latter as the centre of pressure (CoP). Several studies had shown that aerodynamic forces have an influence on stability. For example, (Cooper, 1983), indicates that introducing a fairing or windshield can significantly stabilise wobble from cross-winds. While, (Bridges et al., 1987), showed that the addition of a topbox can excite the wobble mode. More extensively, (Meijaard et al., 2006) studied aerodynamic drag and suspension effects on the stability of a motorcycle in a straight line and steady cornering. They explain that drag influences stability through four mechanisms: dampening lateral motion, and changing weight distribution, tire cornering stiffness, and rake geometry. They found that these mechanisms combined result in a tendency to stabilise wobble and destabilise weave. In general, aerodynamic forces can improve or worsen stability, therefore the introduction of aerodynamic devices needs to be judicious.

It is well known that in motorsport performance needs to be enhanced continuously and aerodynamics can be used to this end. During the last years, MotoGP motorcycles had been equipped with diverse aerodynamics devices such as front and rear winglets, and are in strong development. Aerodynamic specialists are taking advantage of the variable aerodynamics of two-wheeled vehicles due to leaning angle and changing rider position to introduce devices that are useful only in certain situations. These changes in motorcycle aerodynamics can be summarised as a moving CoP with variable force magnitude. Changing the CoP position and the addition of lift force certainly affect the four mechanisms described by (Meijaard et al., 2006), but their effect on stability had not been described in the literature. Therefore the aim of this research is to extend on (Meijaard et al., 2006) research, by analysing the influence of CoP position and aerodynamic lift in motorcycle stability in straight line and steady cornering.

To this end, we perform a stability analysis on a motorcycle with variable CoP and lift. Particularly, we use the 11 DoF motorcycle model described by (Meijaard et al., 2006), add various lift forces magnitudes, and consider the CoP, in various positions. In straight
line, we consider it ahead, aligned, and behind the motorcycle centre of mass, and in cornering we consider it on both sides of the symmetry plane of the motorcycle to account for rider lateral displacement. For these situations, we perform the bifurcation analysis to identify the influence on stability. The result contributes to the understanding of motorcycle aerodynamics providing new insights into how to use aerodynamics to enhance stability. The results apply directly to racing motorcycles, but can also be extended to road motorcycles to enhance safety. As in (Meijard et al., 2006), the effect of the rider as a controller was neglected, and needs further study.

Important note: This research is in progress at the date of this submission, we will update a final version in June.

References


