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Analysis of Eigenmode Responses in Motorcycle Cornering Dynamics

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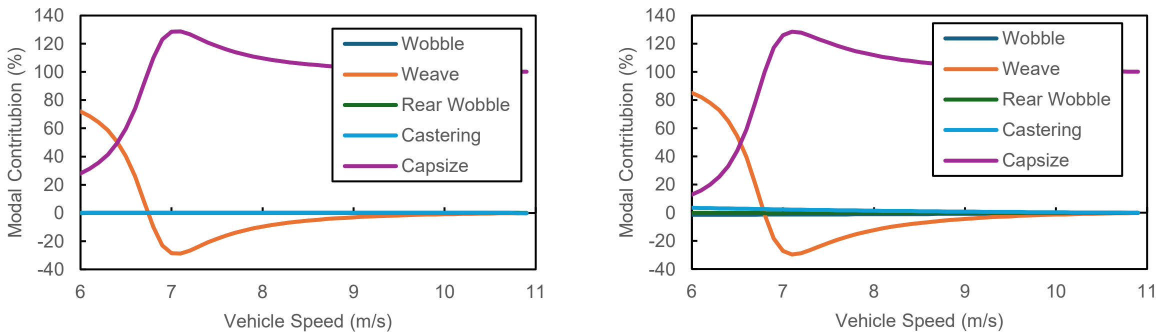
Motorcycle cornering involves complex maneuvers, most notably counter-steering, where riders maintain balance by interacting with the vehicle's inherent self-stability. This study investigates the underlying mechanisms by decomposing the response to a step steering torque input into its constituent eigenmodes using a linear 4-degree-of-freedom model. The modal decomposition is performed based on the step response function

$$\boldsymbol{x}(t) = \boldsymbol{V}\mathrm{diag}\left(\frac{e^{\lambda_1 t}-1}{\lambda_1}, \frac{e^{\lambda_2 t}-1}{\lambda_2}, \dots, \frac{e^{\lambda_n t}-1}{\lambda_n}\right)\boldsymbol{V}^{-1}\boldsymbol{B}u_c$$

derived from the general solution of the state-space equation, allowing for a quantitative evaluation of both steady-state and transient contributions of each mode.

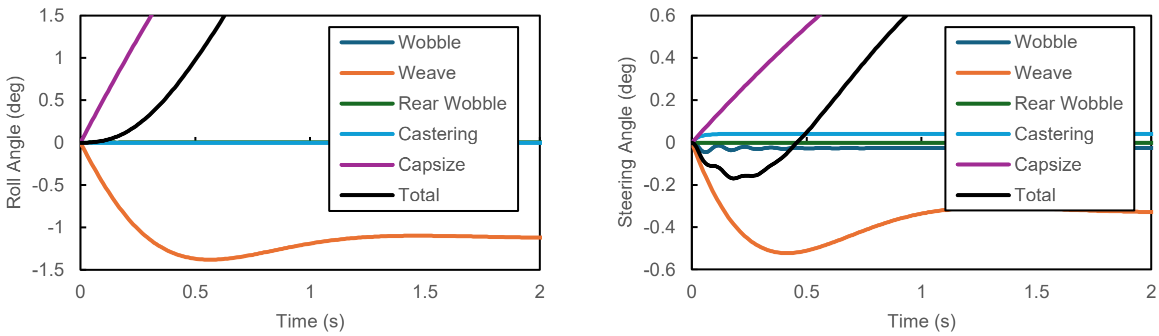
The steady-state contribution of each mode is proportional to the reciprocal of its eigenvalue and varies significantly with vehicle speed. As shown in Fig. 1, the dominant contribution to the steady-state roll and steering angles shifts from the weave mode to the capsize mode as speed increases within the stable range ($6 \le v \le 11\ m/s$). This transition indicates that in the typical speed range, the backbone of the roll dynamics is fundamentally shaped by the first-order lag characteristics of the capsize mode.



(a) Roll Angle Response (b) Steering Angle Response

Fig.1 Modal Contributions vs. Vehicle Speed

Regarding the transient phase immediately after the input (Fig. 2), the roll angle exhibits an exponential growth characteristic of divergent systems, resulting from a balanced cancellation between the weave and capsize modes. In contrast, the steering angle response is dominated by the initial slope of the weave mode, which is the primary driver of the characteristic counter-steering behavior. Furthermore, it was confirmed that the high-frequency wobble mode has a negligible impact on both steady-state and global transient turning dynamics due to its spectral separation, remaining non-dominant even when steering damping is removed.



(a) Roll Angle Response (b) Steering Angle Response

Fig.2 Modal Decomposition of Transient Responses ($v = 8m/s$)

In conclusion, motorcycle cornering dynamics can be systematically understood through a modal structure where the capsize mode dictates the primary first-order lag dynamics of roll and self-steering, while the weave mode governs transient delays and counter-steering behaviors.