

Dynamic Aerodynamic Forces Generated by Vehicle Motion and Their Effects on Vehicle Motion

- Full-Scale Vehicle Excitation Tests in a Wind Tunnel -

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The effects of aerodynamic devices that enhance vehicle dynamic performance cannot be sufficiently explained solely by steady aerodynamic forces—such as lift and yawing moment—measured in conventional wind tunnel tests. It is therefore considered necessary to focus on the dynamic aerodynamic forces generated by the motion of the vehicle. In this study, an excitation system was installed in a full-scale vehicle wind tunnel to excite the vehicle, and the occurrence of dynamic aerodynamic forces on an actual vehicle was confirmed. Based on these results, the necessity of considering dynamic aerodynamic forces in the evaluation of vehicle dynamic performance was clarified.

To induce motion in the vehicle within the full-scale wind tunnel, an excitation system was installed (Fig. 1). At the contact patches of the four tires, vertical, lateral, and longitudinal excitation can be applied, and by synchronizing the four wheels, combined six-degree-of-freedom excitation is also possible. Wire ropes are looped around the circumference of each tire to fix them in place, so that the tires do not rotate during the tests. The floor is equipped with a boundary-layer suction system to ensure reproducibility of the flow field in the vicinity of the road surface.

To obtain the aerodynamic derivatives—namely the aero-added mass (m_{af} , m_{ar}), aero-damping (c_{af} , c_{ar}), and aero-stiffness (k_{af} , k_{ar})—a frequency-sweep excitation test was conducted (Fig. 2). A compact passenger car was used as the test vehicle, and tests were performed at wind speeds of 0 and 80 km/h. Excitation was applied in the pitch direction (target acceleration: 0.1G), using sinusoidal input at frequencies of 0.4, 0.8, 1.2, 1.6, 2.0, and 3.0 Hz. As test cases, the baseline vehicle condition was examined with and without wind for comparison.

Figure 3 (front axle only) shows the excitation force (F_{rdf}) and vertical motion (G_{bf}) response organized as functions of pitch displacement (θ_{rd}). Results for wind speeds of 0 and 80 km/h, as well as their difference, are presented, revealing a difference in excitation force. In the case of pitch motion at 0.8, 1.6 Hz with a front-rear displacement difference of 20 mm, a vertical aerodynamic force of 33, 85 N acts on the front axle. This indicates that the wind suppresses the motion of the front end.

From these measurement results, the frequency response of the excitation force with respect to the vehicle pitch angle θ_b and the relative pitch angle θ_x between the vehicle and the ground was calculated. Under the 0 km/h condition, the vehicle mass, damping coefficient, and spring coefficient were identified, and by subtracting these values from those obtained under the 80 km/h condition, the inertance (inertial equivalent quantity), damping coefficient, and spring coefficient corresponding to the aerodynamic forces were determined.

As a result, the following values were obtained:

$$m_{af} = 101[Ns^2/m](13\% \text{ relative to the } 0 \text{ km/h value}),$$

$$m_{ar} = 8[Ns^2/m](2\%),$$

$$c_{af} = 138[Ns/m](2\%), c_{ar} = -172[Ns/m](-3\%),$$

$$k_{af} = 14700[N/m](14\%), k_{ar} = 3320[N/m](5\%)$$

These results indicate that the aerodynamic forces have a non-negligible influence on the vehicle parameters, particularly as inertance on the front side and as spring components at the front and rear. Furthermore, it was quantitatively demonstrated that the aerodynamic forces act as a restraining force on the pitch motion of the vehicle.

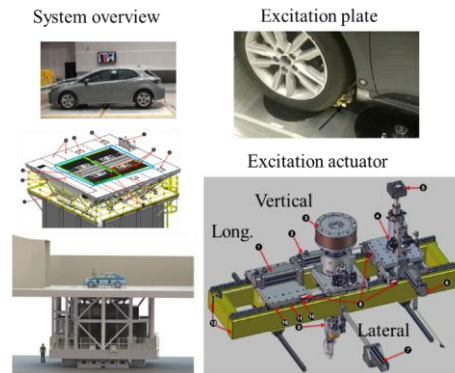


Fig.1 Schematic overview of the excitation system installed inside the wind tunnel.

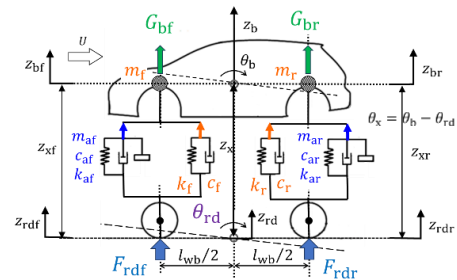


Fig.2 Definitions and symbols: vehicle motion, vehicle parameters, dynamic aerodynamic force and excitation parameters.

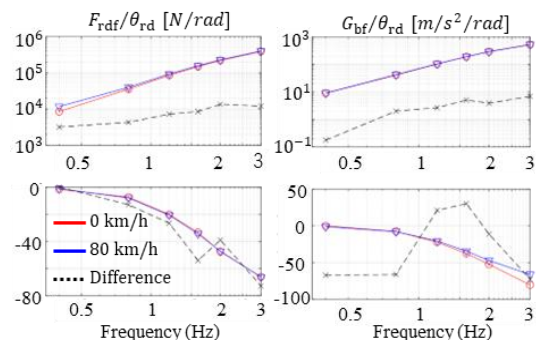


Fig.3 Pitch excitation response at the front axle: excitation force and vertical acceleration at 0 km/h and 80 km/h.