Flat Ride

PAPER # 2012-01-0445

Motivations (Flat Ride)

- Aero Effects on Flat Ride of Vehicle
  - Questions:
    - How much does ride height affect **steady lift** and flat ride?
    - How does **unsteady lift** occur?

Conclusions (Flat Ride)

- How much does ride height affect steady lift and flat ride motion?
  - Aero effects on flat ride is equivalent to up to 7% of damping force of vehicles .
- How does unsteady lift occur?
  - Due to pitching motion, the floor of the vehicle looks curved to the fluid passing between ground and floor .

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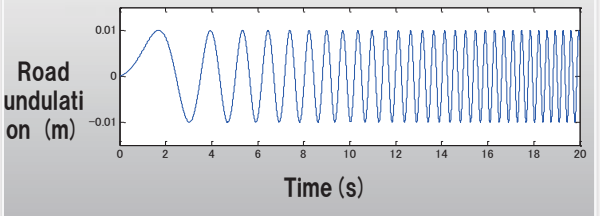
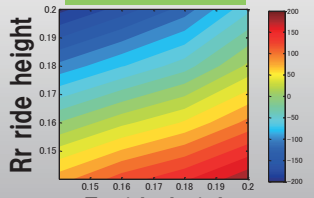
Methodology (Steady Aero)

Input from Road

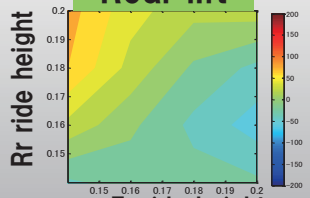


Wind tunnel data

Front lift

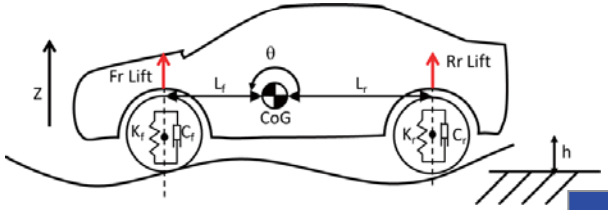


Rear lift



35% detailed model

Two-degrees-of-freedom spring mass model



$$m_b \ddot{z} = F_{sus\_fr} + F_{sus\_rr} + F_{aero\_fr} + F_{aero\_rr}$$

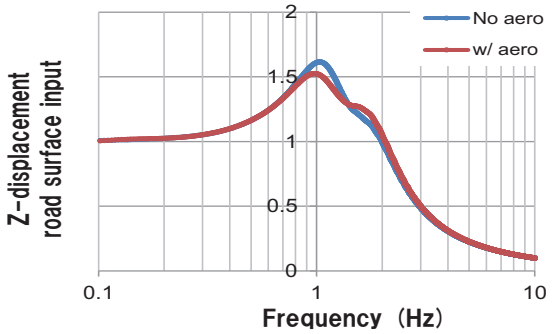
$$I_{yy} \ddot{\theta} = -L_f F_{sus\_fr} + L_r F_{sus\_rr} - L_f F_{aero\_fr} + L_r F_{aero\_rr}$$

$$F_{sus\_fr} = 2K_f \left(L_f \theta - z\right) + 2C_f \left(L_f \dot{\theta} - \dot{z}\right)$$

$$F_{sus\_rr} = -2K_r \left(L_r \theta + z\right) - 2C_r \left(L_r \dot{\theta} + \dot{z}\right)$$

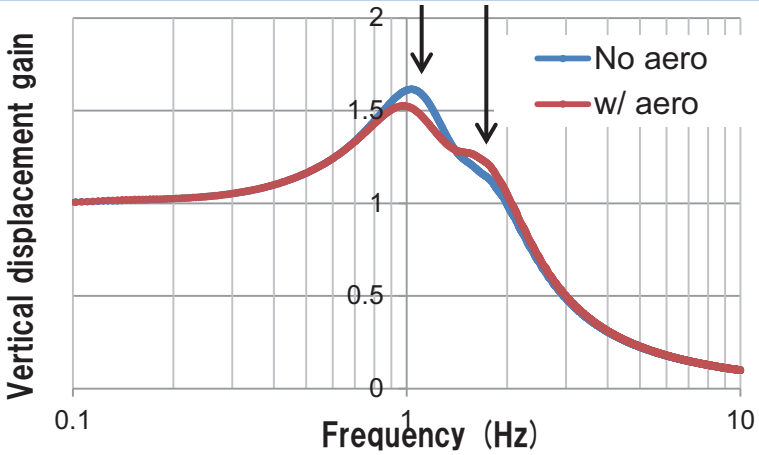
Frequency response analysis

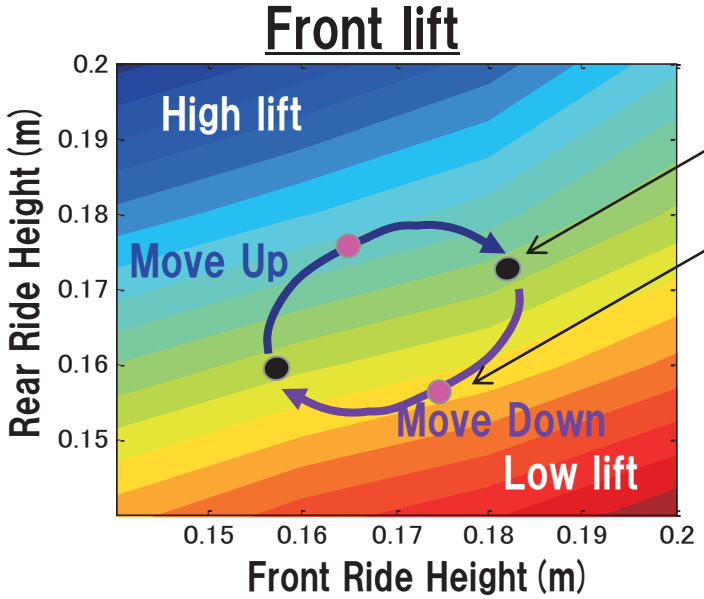
Vertical displacement gain



Results (Steady Aero)

The gain changes by aero, the resonance frequency remains the same





Lifts at the top/bottom are the same

Lift changes are greater at high z-speed

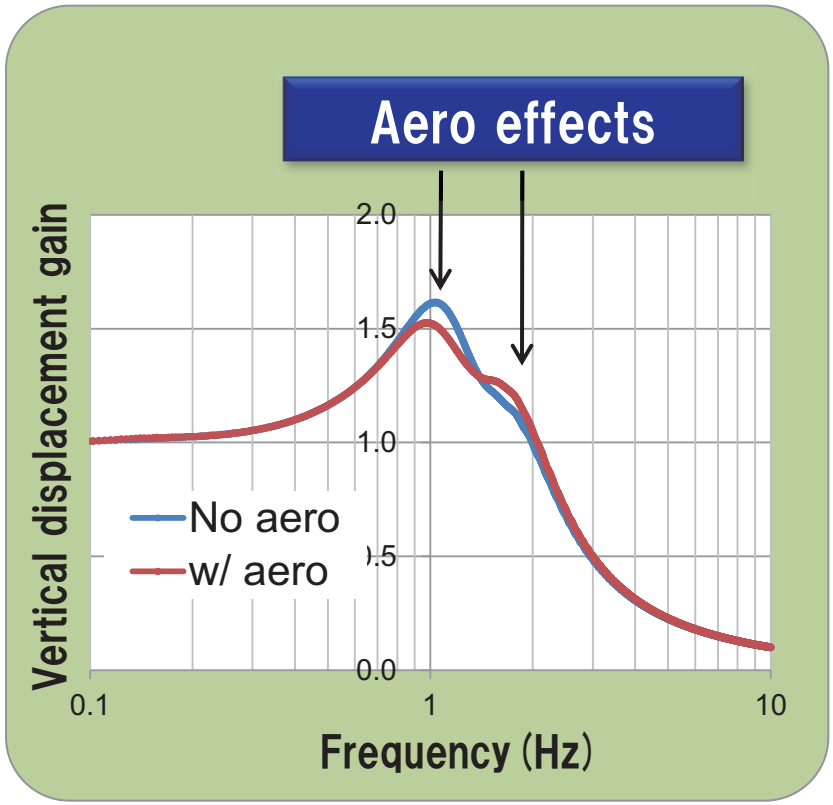
Similar phase to that of “damper”, not that of “spring”

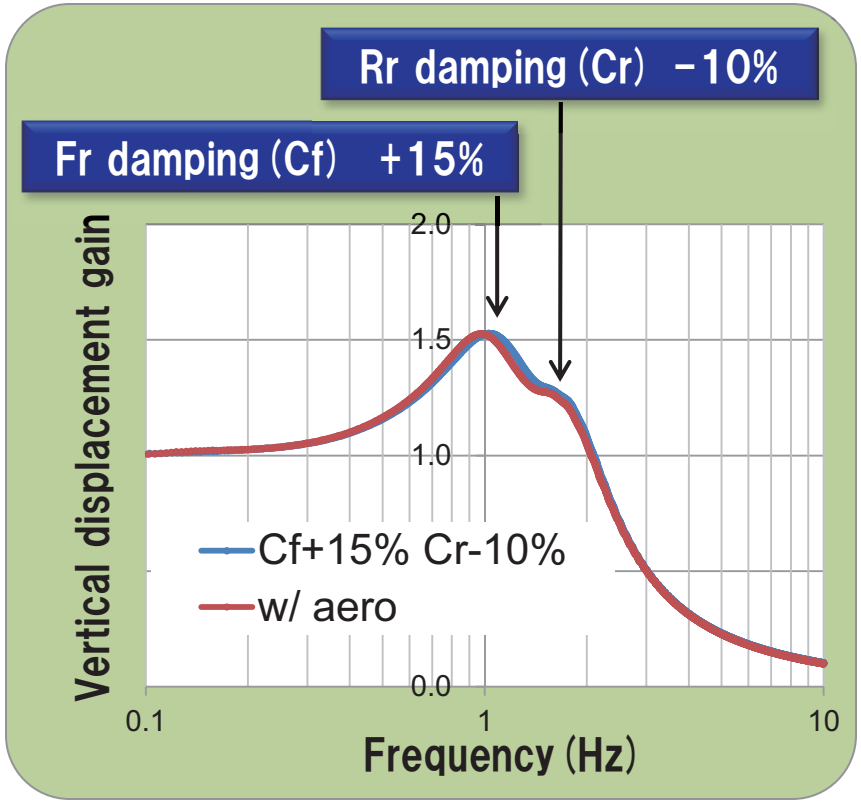
Therefore, the resonance frequency remains unchanged

It is possible to convert aerodynamic force into damping force

Discussions (Steady Aero)

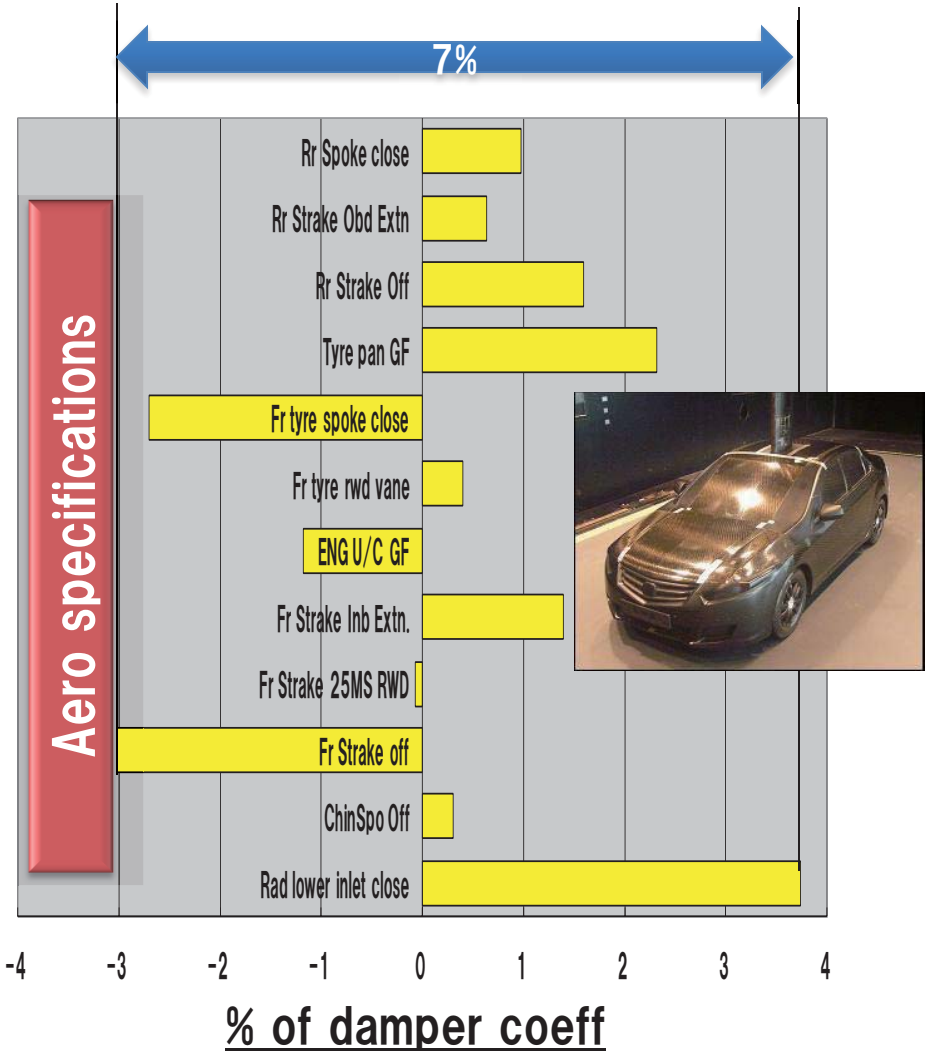
Conversion of fr&rr lift into a damper coefficient of vehicles

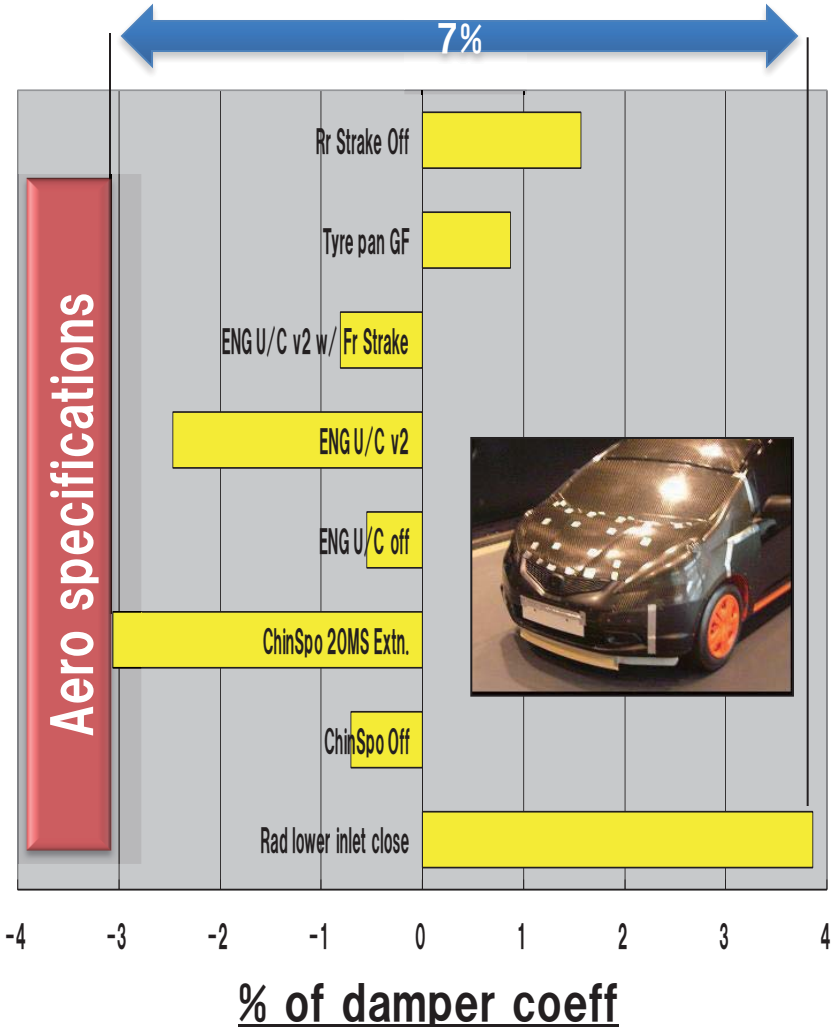




Discussions (Steady Aero)

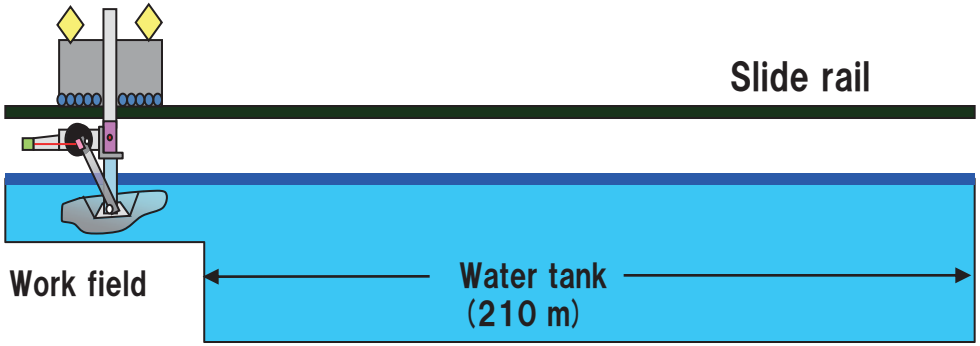
Aero effect equivalent to % of damper coefficient of vehicles

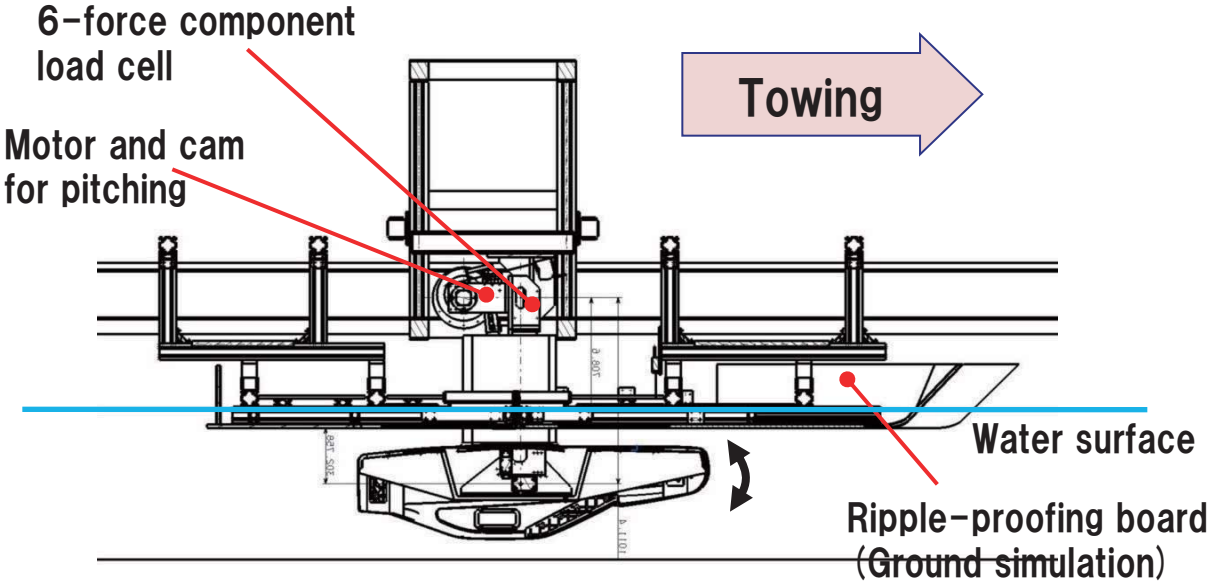




the converted damping forces vary up to 7% depending on models and aero devices

Methodology (Unsteady Aero)





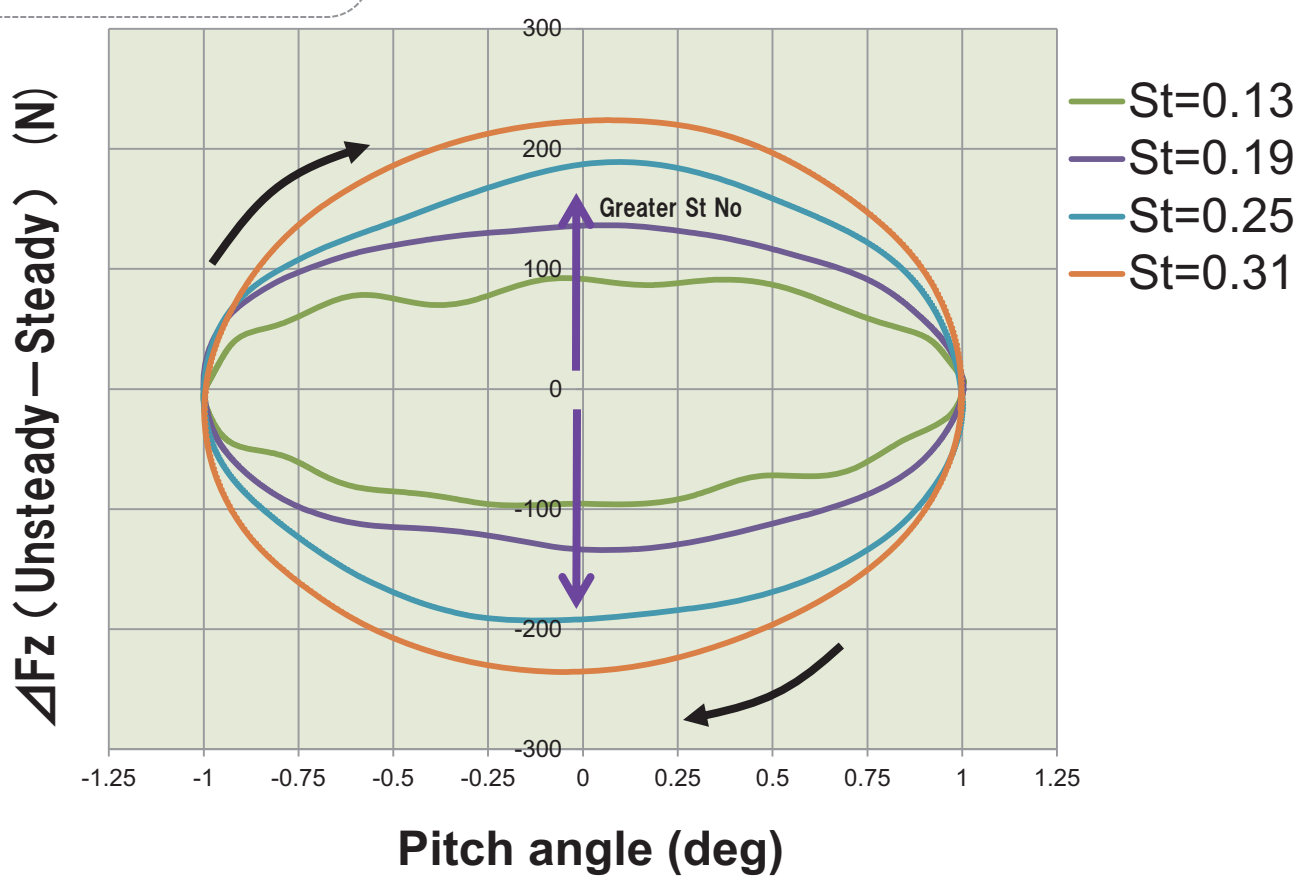
Results (Unsteady Aero)

Strouhal number

$$St = \frac{f \cdot L}{U}$$

f : Frequency
U : Car speed
L : Wheel base

Stouhal # of 0.1 corresponds to an oscillation of 1 Hz of a vehicle running at 160 kph.

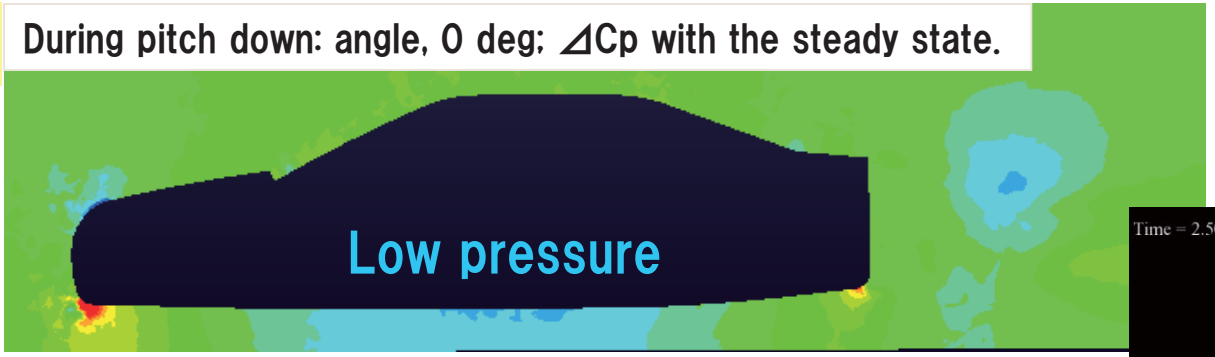


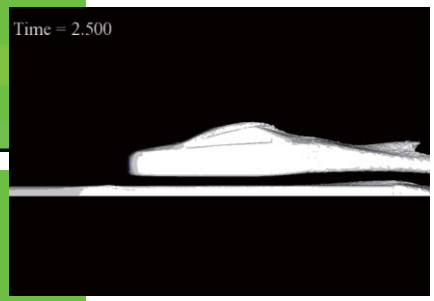
the higher frequency, the larger unsteady aero force

Discussions (Unsteady Aero)

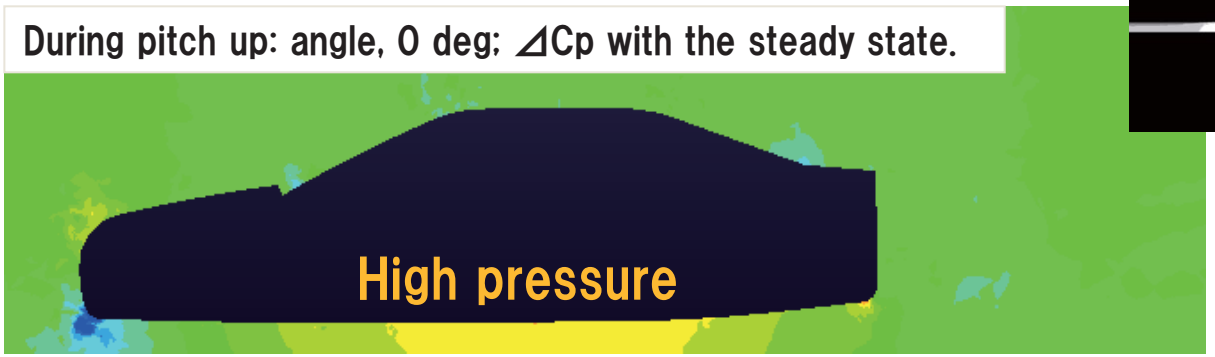
CFD results

During pitch down: angle, 0 deg; ⊿Cp with the steady state.

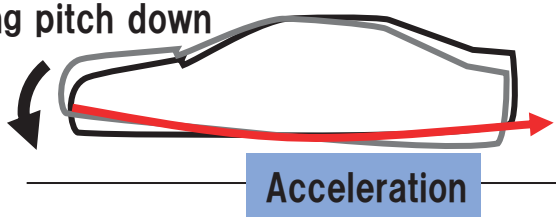




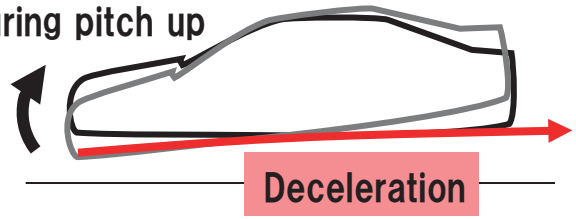
During pitch up: angle, 0 deg; ⊿Cp with the steady state.



During pitch down



During pitch up

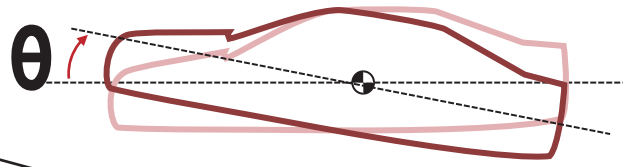


When viewed from the fluid passing under the floor, the floor looks curved due to vehicle motion.

Discussions (Unsteady Aero)

A linear expression for unsteady lift to be analyzed in the spring mass model.

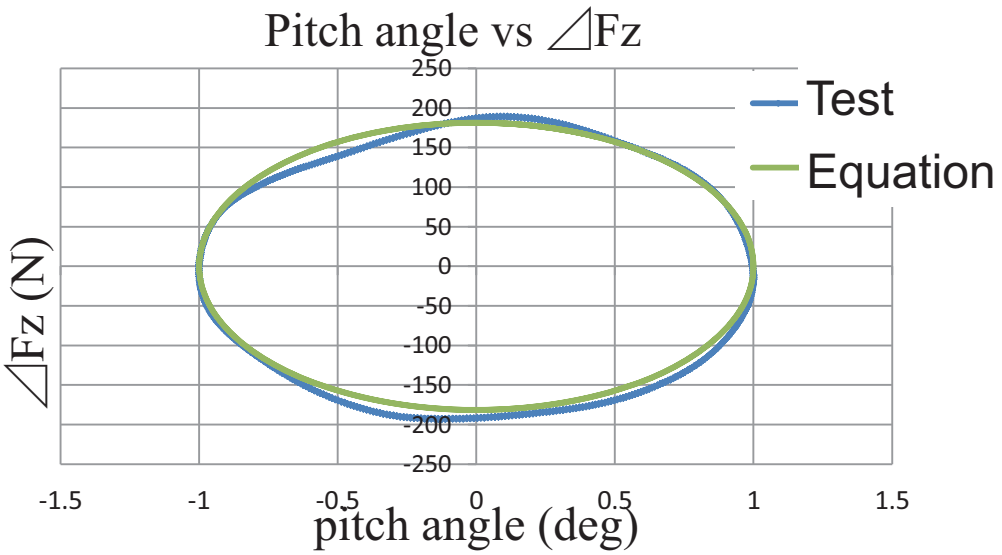
$$\Delta Fz = \alpha \cdot vol \cdot \rho u \dot{\theta}$$



Vehicle volume

Coefficient determined by vehicle shape

Pitching angular velocity



Unsteady lift is linearized as a function of angular velocity using geometry coefficients.

Summary (Handling Response)

- A new index "Equivalent Lift Map" was proposed to combine lifts, aero side force and yaw moment to outline aero target in early stage of vehicle developments.

Summary (Flat Ride)

- Steady lift forces affect on flat ride equivalent to 7% of damping force of vehicles .
- Due to pitching motion, the floor of the vehicle looks curved to the fluid passing between ground and floor which generates unsteady lift forces.

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Thank you for your attention!

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