Current Status of EFD/CFD Techniques for Road Vehicle Aerodynamics and Development of the Unsteady Aerodynamic Simulator

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Second Workshop on Integration of EFD and CFD

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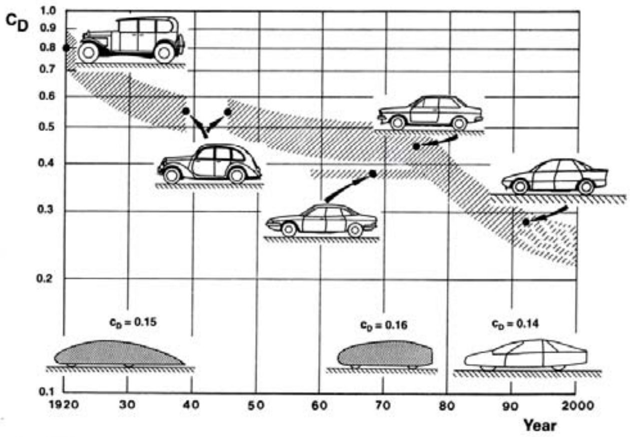
Automotive Development

- Competitive
  - *More than 10 companies in Japan!, around 20 worldwide major.*
- Fast
  - *4 years from the kick-off to the market (About a year shorter than typical Europe or US company).*
- Parallel
  - *20 to 30 new models per year in Japan.*
  - *Every company develops several models in parallel.*
- Toward Green Mobility
  - *Major source of CO2 emission (around 20% by vehicle driving in Japan).*
  - *Around 50% less for the next 10 years!*

Time history of Cd

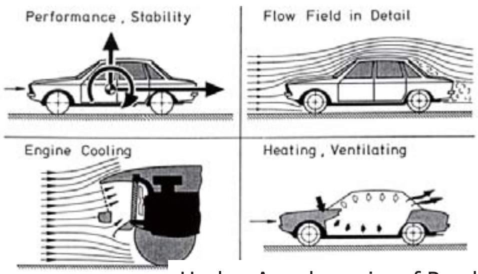


- Still smaller Cd is required.
  - Cd=0.26 to 0.20 can reduce F.C. to 10% less at 100km/h drive.
  - Cd~0.15 in 2030 by an active control or an innovative aerodynamic devices.

Breakthrough is indispensable!

Severe Aerodynamic Development for Road Vehicle

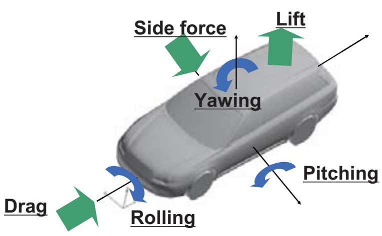
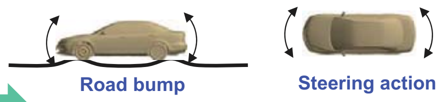
- Complexity
  - *Bluff-body flow..................complicated turbulence.*
  - *Interactions among flow, heat and mass, vehicle body...*
    ......complicated physics.
  - *Wide variety of types.........complicated geometry.*
- Wide range of problems
  - *Aerodynamic performance, engine cooling, ventilation, aerodynamic noise, soiling*



Hucho, Aerodynamics of Road Vehicle

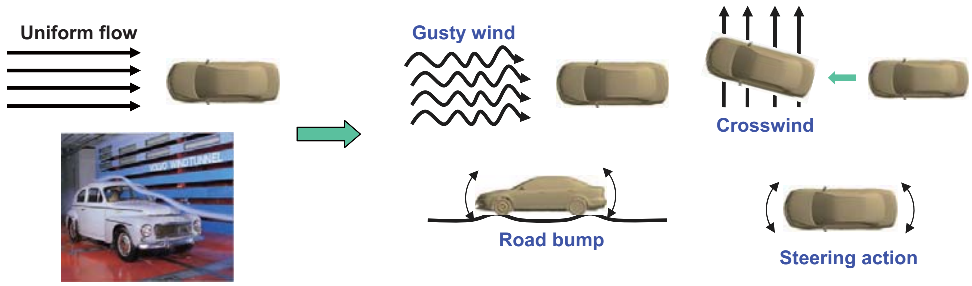
Requirement of Coupled Aerodynamics

- Coupled effects to be considered from the initial stage.

Monotonic analysis	Coupled analysis
 *Integral forces and moments*	 *Vehicle body in motion* *Thermal management* *Aero-acoustic noise*

Unsteady Aerodynamic Simulator

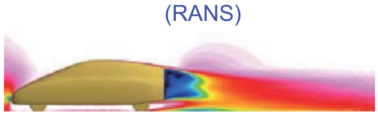
- Unsteady aerodynamics for innovative aerodynamic Design.



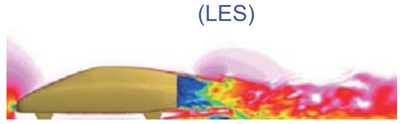
- To provide additional data which wind-tunnel is difficult to measure.
- To eliminate the gap between wind-tunnel and on-road measurements!

- Large Eddy Simulation (LES)

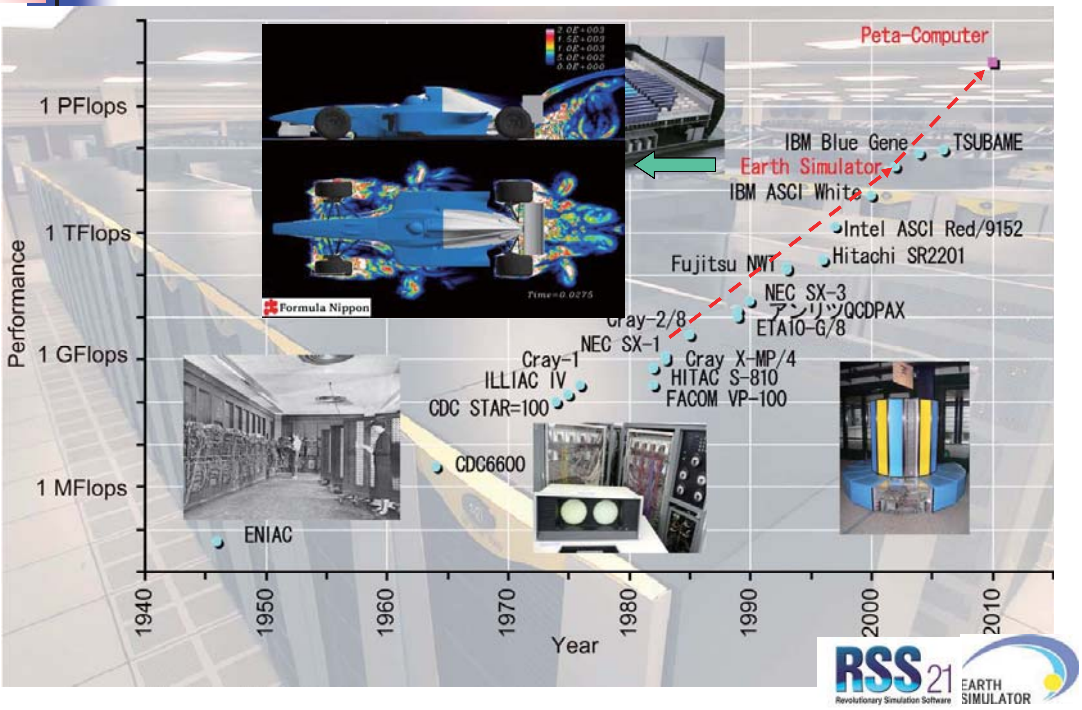
Reynolds Averaged Navier-Stokes (RANS)



Large Eddy Simulation (LES)



High-Performance Computing for Vehicle Aerodynamics



Numerical Methods
Governing Equations and Physical Models

- Spatially Filtered Navier-Stokes Equation

$$\frac{\partial \overline{u}_i}{\partial x_i} = 0$$

$$\frac{\partial \overline{u}_i}{\partial t} + \frac{\partial}{\partial x_j}(\overline{u}_i \overline{u}_i) = -\frac{\partial \overline{P}}{\partial x_i} + 2\frac{\partial}{\partial x_j}(\nu + \nu_{SGS})\overline{S}_{ij}$$

- Standard Smagorinsky's model

$$\nu_{SGS} = (C_s f_s \Delta)^2 \sqrt{2\overline{S}_{ij}\overline{S}_{ij}} \qquad C_s=0.15$$

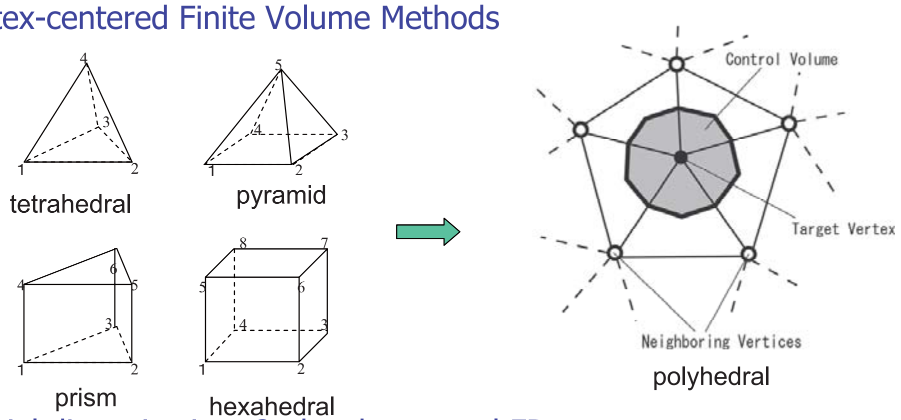
$$f_s = 1 - \exp\frac{-y^+}{25}$$:Wall damping function (Van-driest)

$$\Delta = (\Delta x_1 \Delta x_2 \Delta x_3)^{1/3}$$:Grid width

- Wall-layer models on the solid surface (Log-law)
  - First grid point with a log-layer (y+~100)

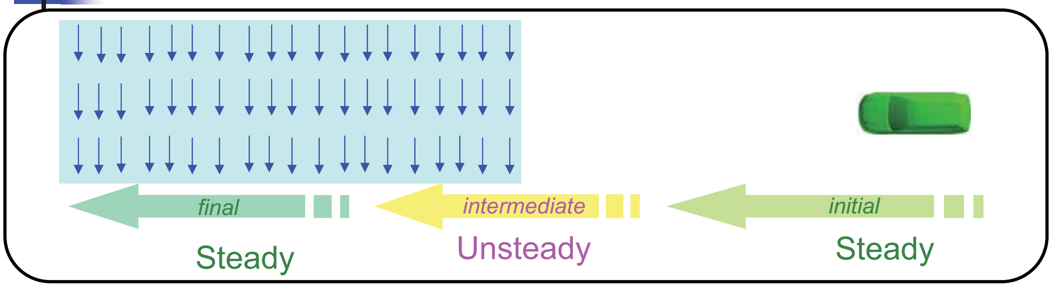
Numerical Methods
Unstructured Finite Volume Methods

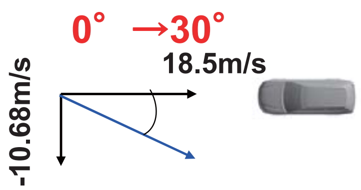
- Vertex-centered Finite Volume Methods

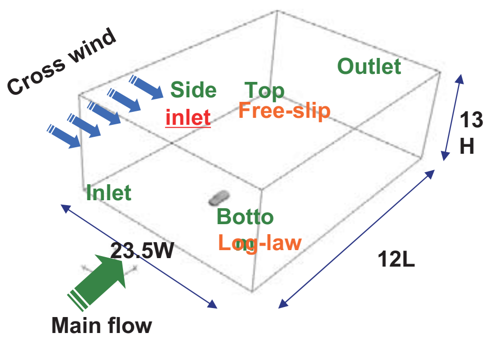


- Spatial discretization: 2nd-order central FD
- Convective Term: Blend of upwind scheme (several %)
- Time Marching Method: 2nd-order Adams-Bashforth
- Pressure-Velocity coupling: SMAC method
- Pressure-Poisson: ICCG
- Front Flow/red

Sudden Crosswind
Problem and Method

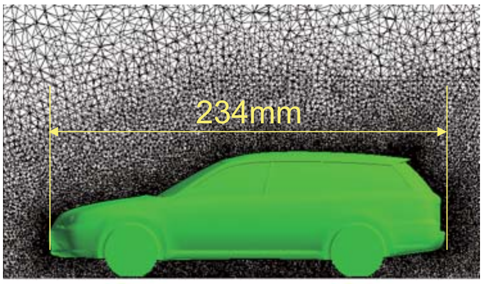


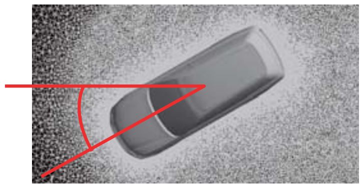




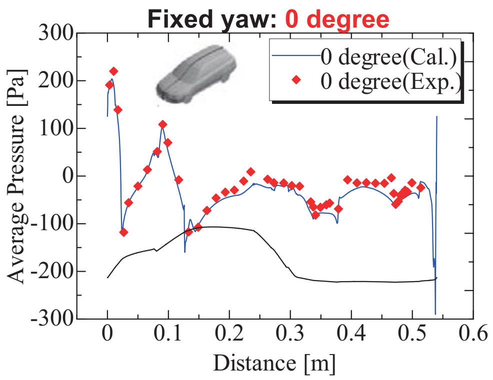
Sudden Crosswind
Target and Validation (Fixed-yaw cases)

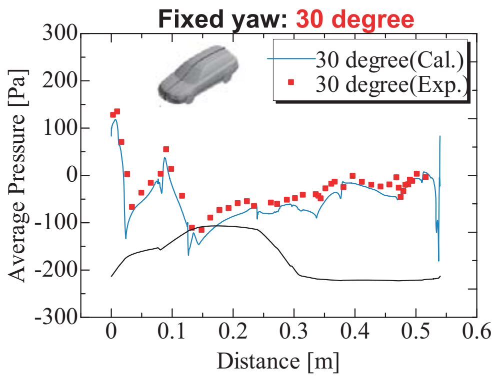
1/20 scale model



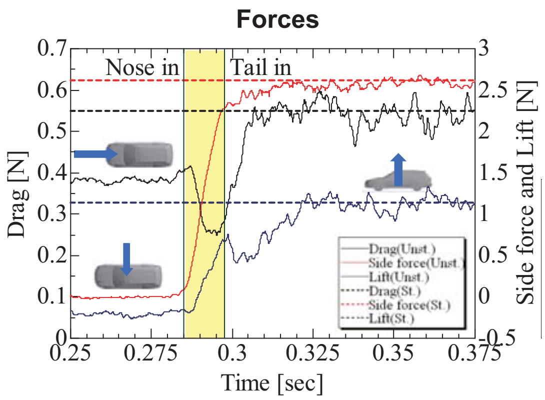


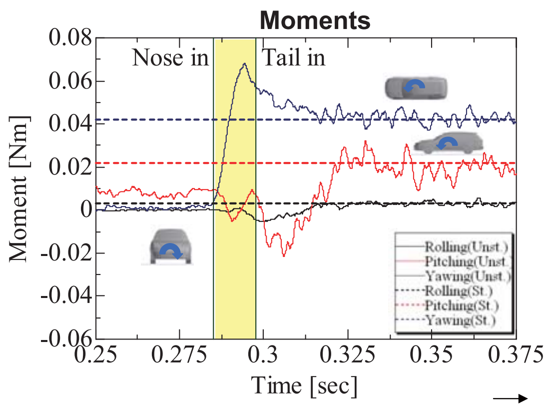
Wind tunnel measurements at Toyama Univ.
Tanaka et al., #20 CFD Symp. A6-2 in Japanese (2005)





Sudden Crosswind
Transient forces and moments





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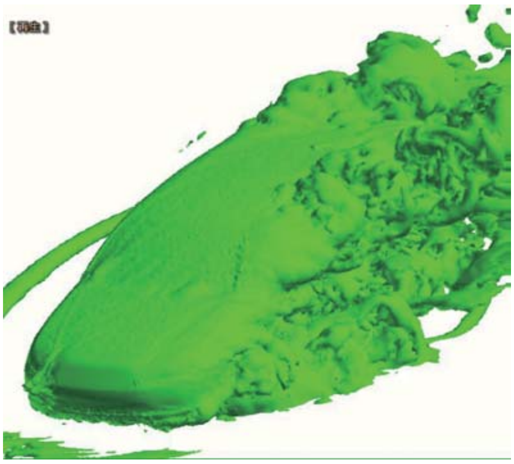
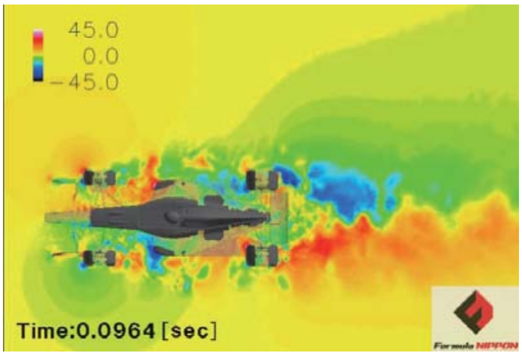
Sudden Crosswind
Eddy Structures around the Vehicle

Before subjected to a crosswind

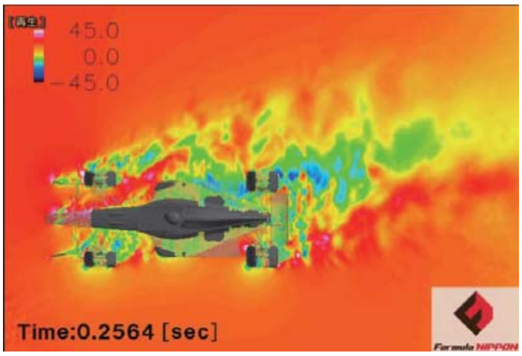


After subjected to a crosswind

Sudden Crosswind
Formula-car case (1)



Before subjected to a crosswind

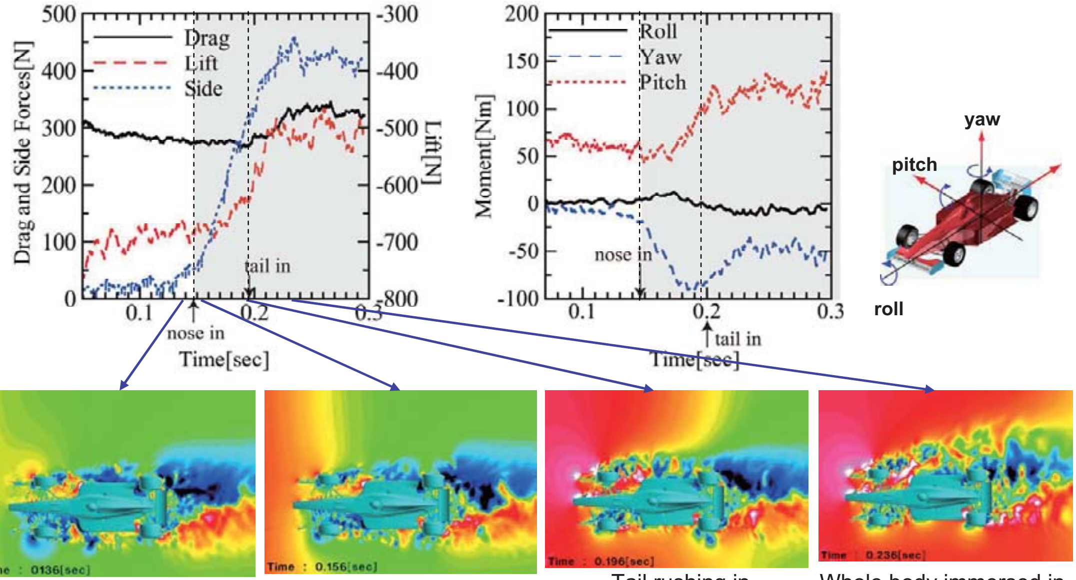


After subjected to a crosswind

Sudden Crosswind
Formula-car case (2)

Tsubokura et al., SAE Tech. paper No. 2009-01-0007(2009)

- *Overshoot and Undershoot during rushing into crosswind*

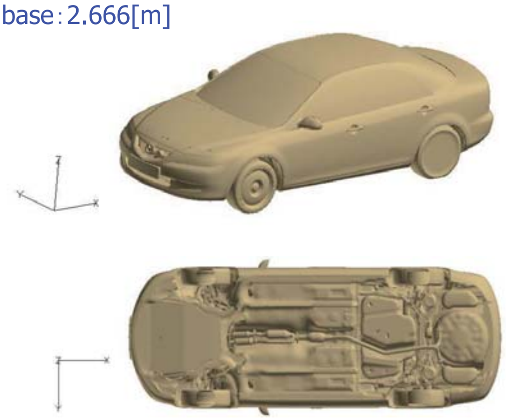


Just before　　Nose rushing in　　Tail rushing in　　Whole body immersed in

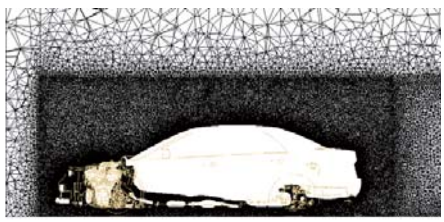
Eddy Structures
Target and Experimental Setup

Full-scale model with detailed geometry

length(L) : 4.670[m]
width(W) : 1.954[m]
hight(H) : 1.594[m]
wheel base : 2.666[m]

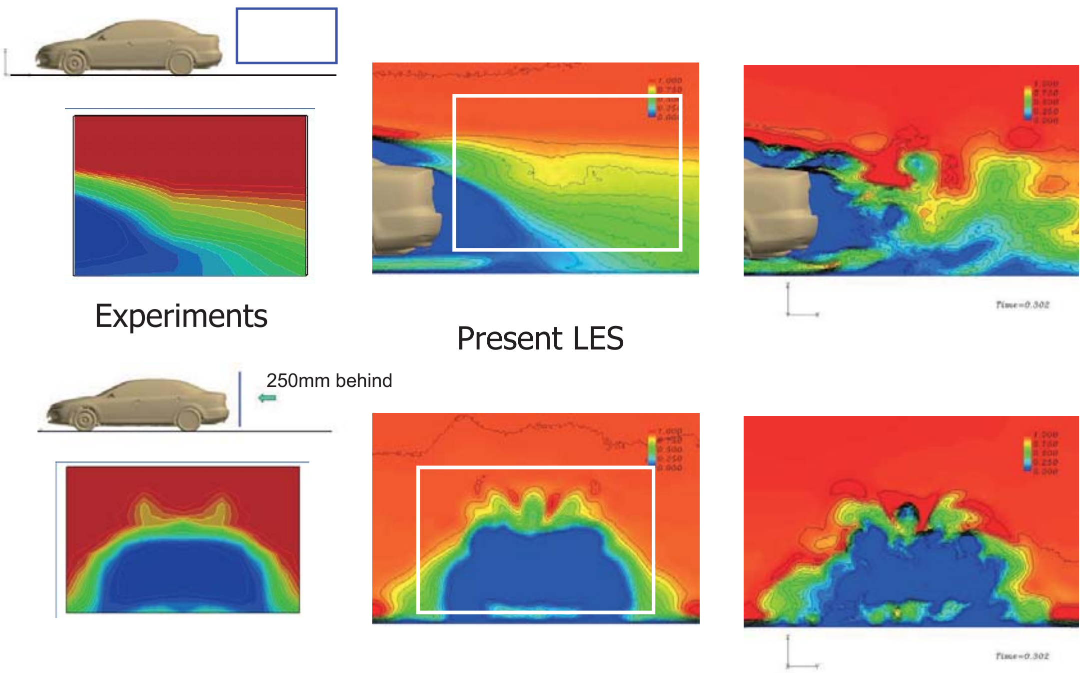


- Grids
  - type : tetrahedron
  - nodes : 6,579,897
  - elements : 37,870,527

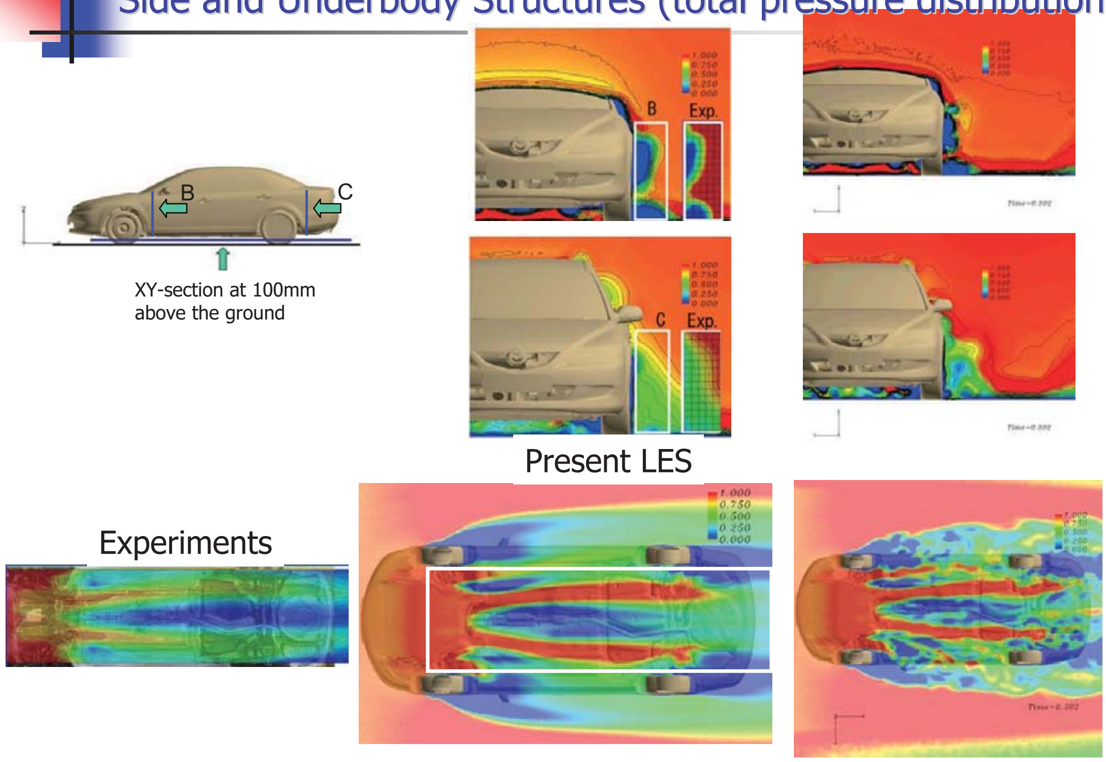


Tsubokura et al., Computers & Fluids, vol.38, 981-990(2009)

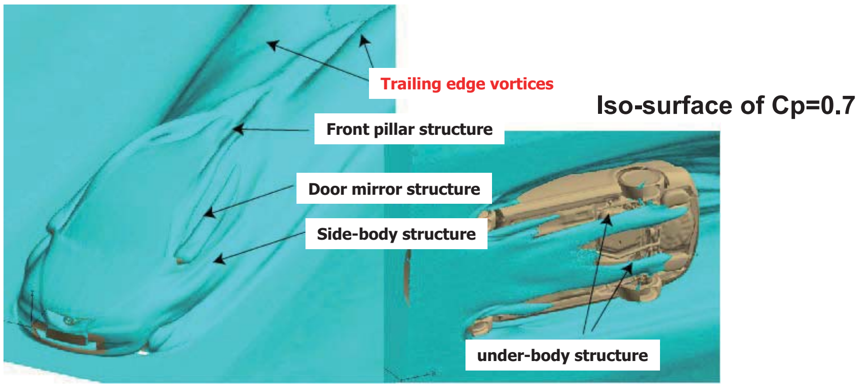
Eddy Structures
Wake Structures (total pressure distribution)

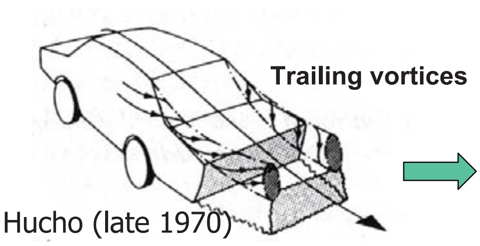


Eddy Structures
Side and Underbody Structures (total pressure distribution)



Eddy Structures
Schematics of Overall Structures around the Vehicle



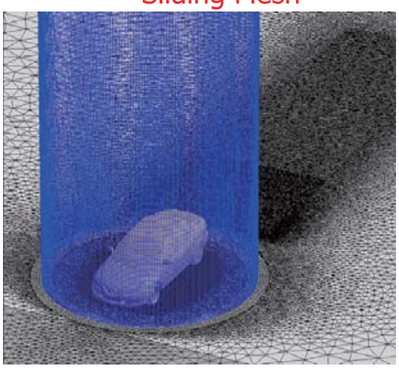


Several vortices appear, which rotate like gearwheels engaging each other!

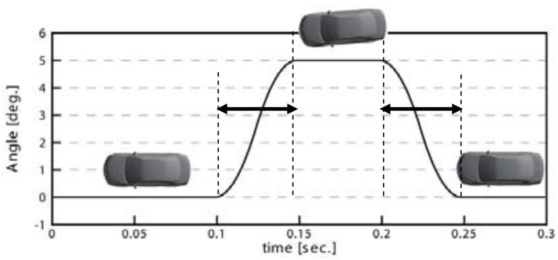
Dynamic Yaw-angle Motion
Target

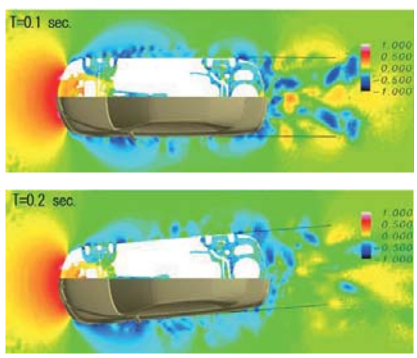
- Vehicle in yaw motion

Sliding Mesh



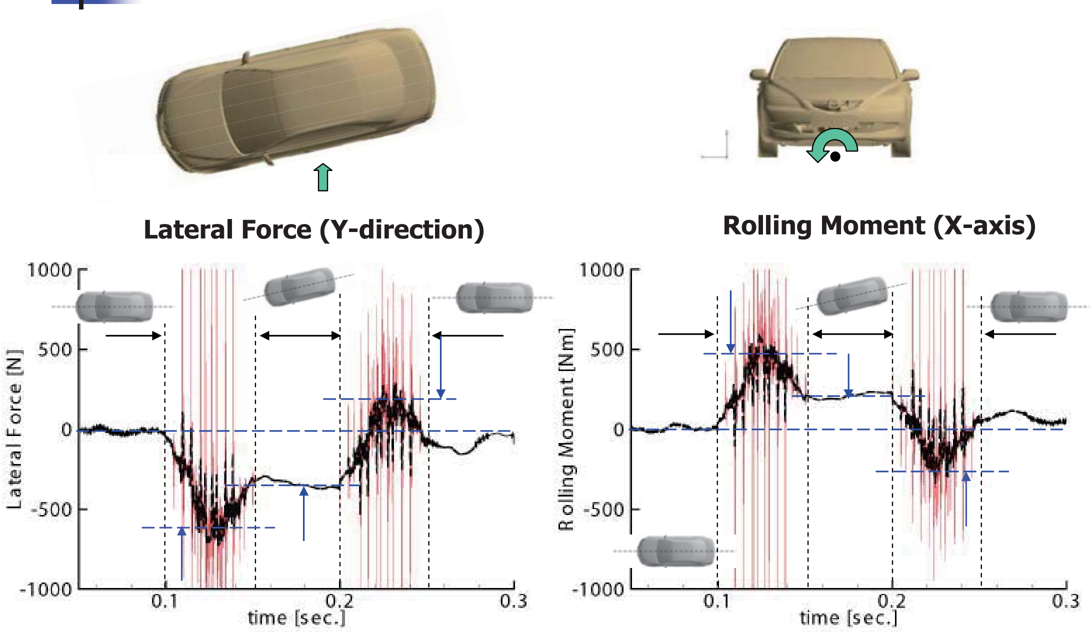
•Grids
type　　:tetra+hexa hybrid
nodes　:　7,229,633
elements: 39,285,753



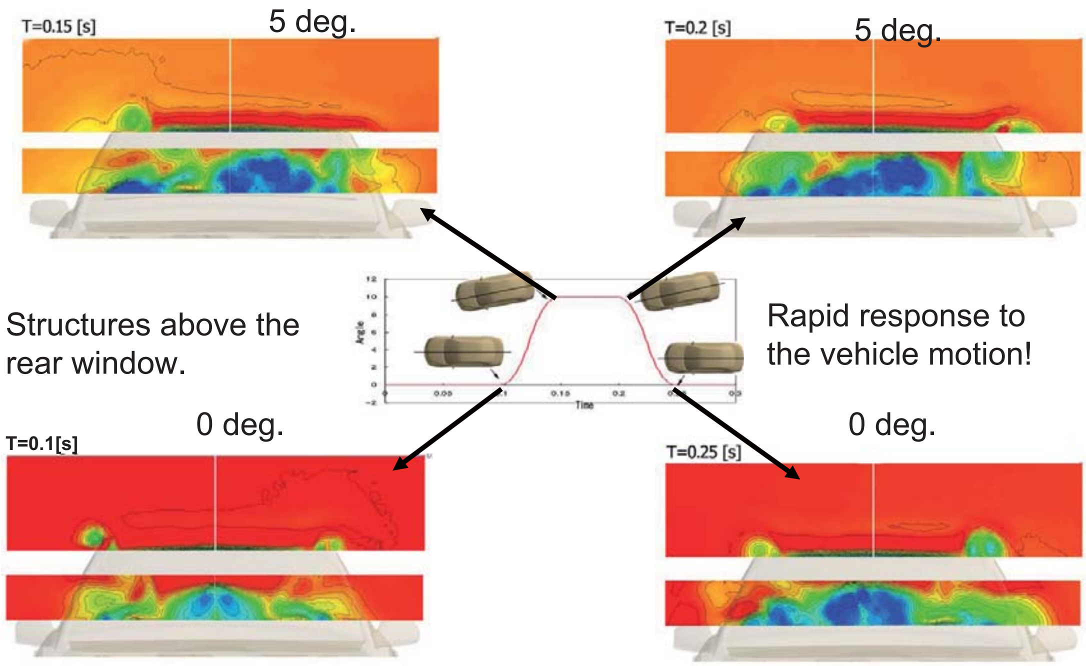


Snapshots of pressure distribution

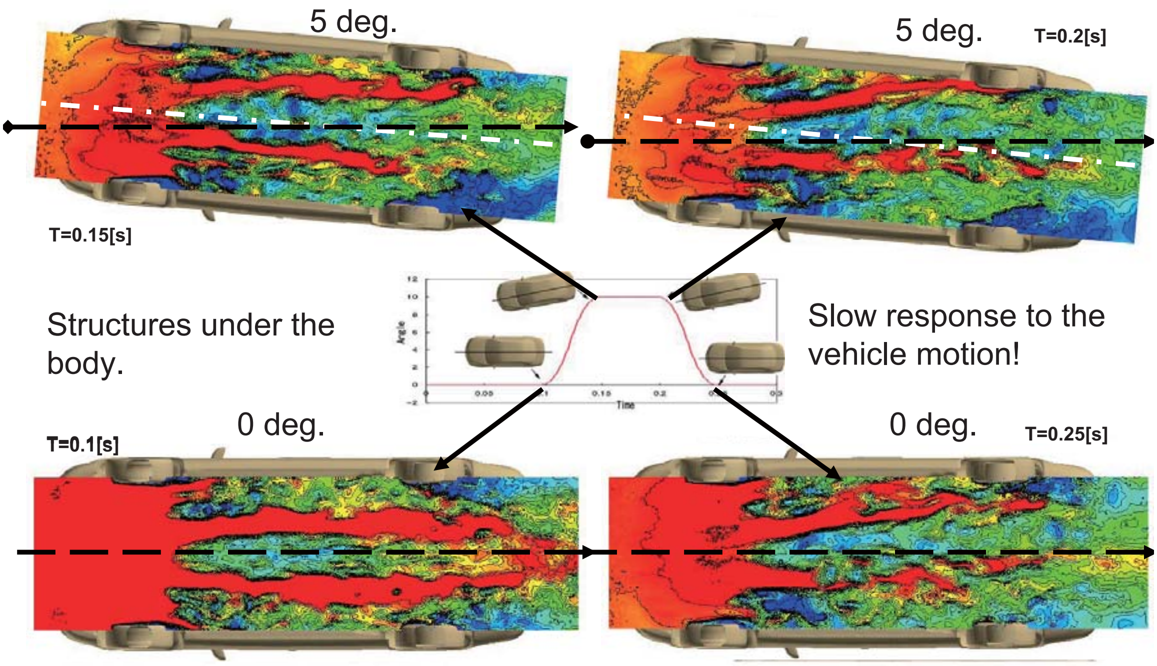
Dynamic Yaw-angle Motion
Transient Force and Moment



Dynamic Yaw-angle Motion
Time Response of Flow Structures



Dynamic Yaw-angle Motion
Time Response of Flow Structures

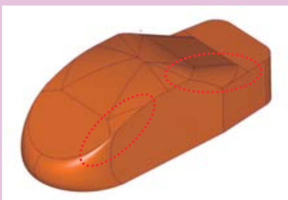


Dynamic Pitch-angle Motion
High-Speed Stability

Nakashima et al., SAE Tech. paper No. 2009-01-0006(2009)

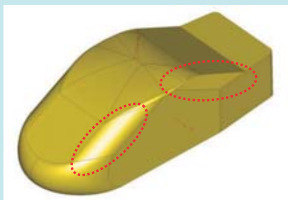
- Two simplified models with different pillar shape.
  - Type A: Unstable
  - Type B: Stable
  - L:210mm x W:80mm x H:65mm

Type A



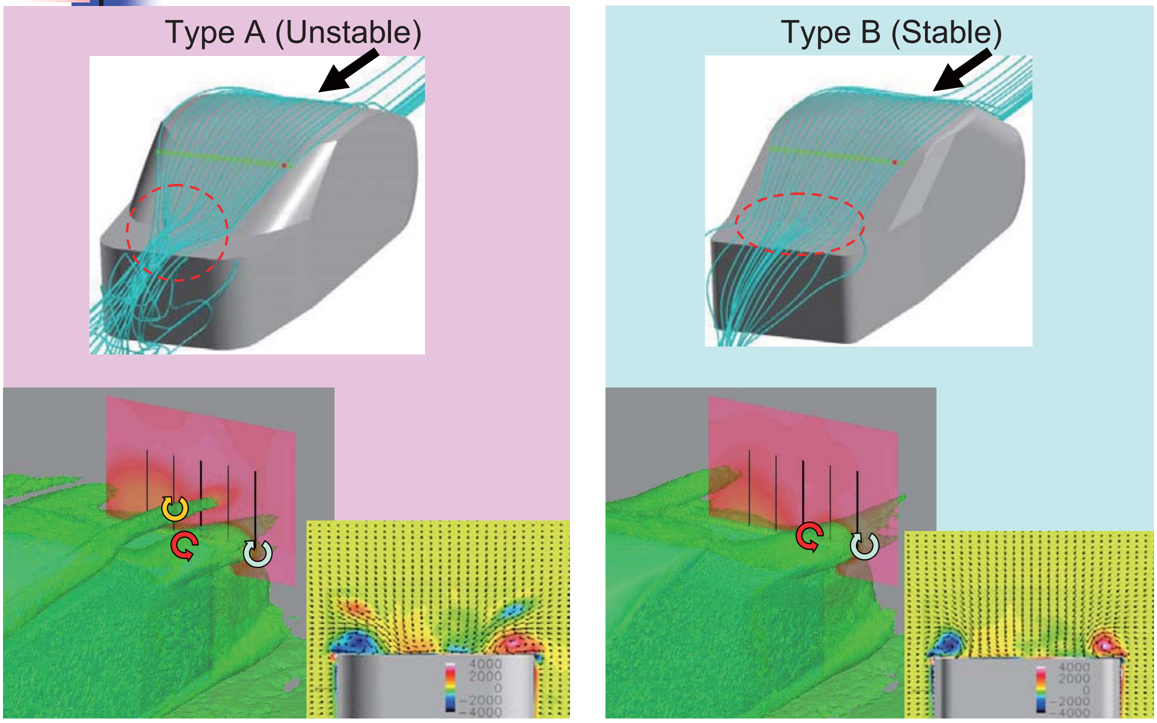
Edged front-pillar
Rounded rear-pillar

Type B



Rounded front-pillar
Edged rear-pillar

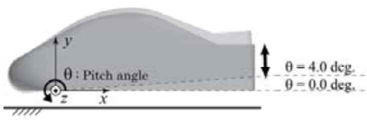
Dynamic Pitch-angle Motion
Flow Structures above the Trunk Deck

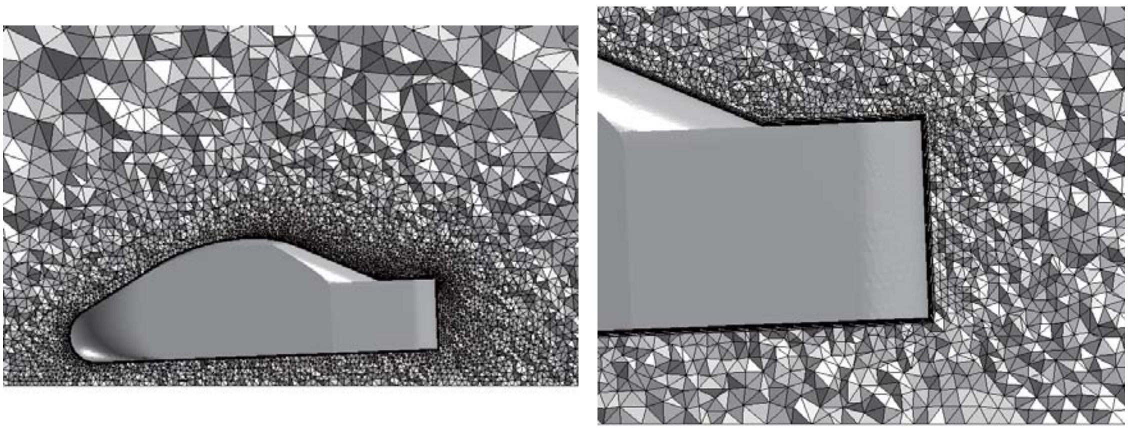


Dynamic Pitch-angle Motion
Forced Oscillation

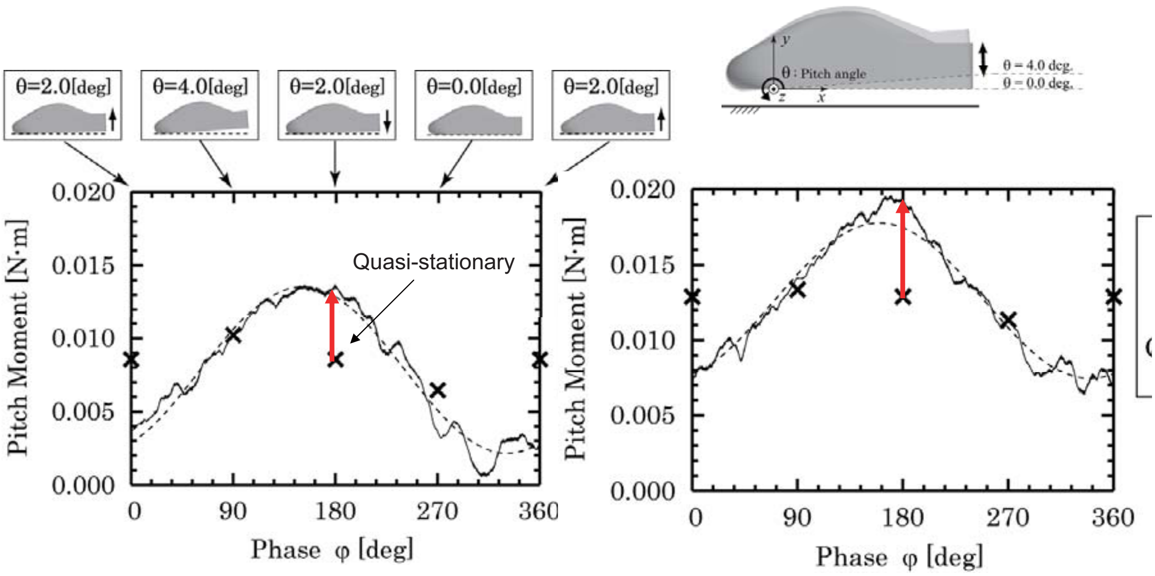
- ALE Method
- Forced Sinusoidal oscillation: $\theta = \theta_0 + \theta_1 + \sin 2\pi f t$

$$\theta_0 = \theta_1 = 2.0[\text{deg.}], f = 10[\text{Hz}]$$





Dynamic Pitch-angle Motion
Transient Pitch Moment



Type A (Unstable)

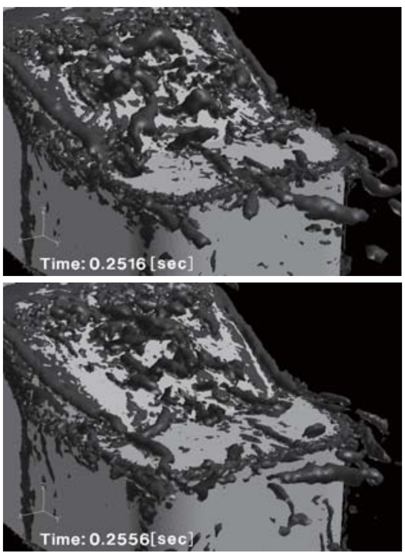
Type B (Stable)

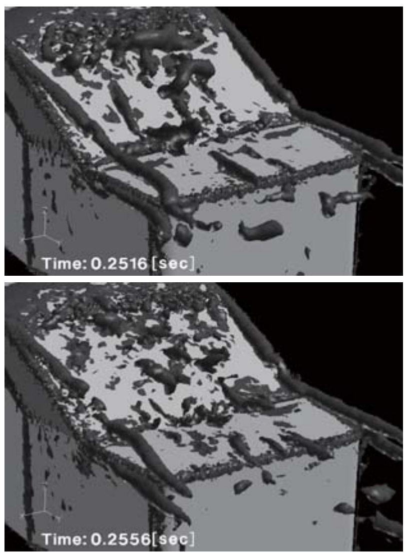
Dynamic Pitch-angle Motion
Vortex Structures above the Trunk Deck

- Type A is more continuous, Type B is more intermittent?

Type A (Unstable)

Type B (Stable)





Summary and Acknowledgements

- Severe process of road-vehicle development requires an innovative aerodynamic technique.
  - Reduction of drag, establishment of driveability and comfort.
  - Optimization to new power train (fuel cell…).
  - Weight saving enhances the importance of vehicle aerodynamics.
- Establishment of the coupled analysis between aerodynamics and heat/mass, acoustics, vehicle motion is a current issue.
- Unsteady aerodynamics will be a key for the innovation.