

# Aerodynamic effects by cooling flows within engine room of a car model

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**Abstract.** The purpose of this research is to clarify the change of characteristics of aerodynamic drag and lift of a car by the engine loading system (engine arrangement) and the air inlet system (opening area and position) with and without a radiator in wind-tunnel experiments. A simplified car model with 1/5 scale is generated with reproduction of the engine room covered with the transparent acryl externals for visualization. In the wind-tunnel experiments, the moving-belt ground board is adopted to include ground effects with force measurements by use of load cells. The flows are visualized by the smoke method. As results, with enlargement of the opening area, the drag increased overall although depending largely on the engine loading system and the inlet opening position, the front lift increased and the rear left decreased; the effect of the radiator was to relieve the change of the drag and lift.

## 1. Introduction

Recently improvements of car fuel efficiency becomes an important topic due to aggravation of the global warming and the energy problem, and therefore reduction of the aerodynamic drag that greatly influences fuel efficiency is proceeded[1,2]. Basic classification of the aerodynamic drag is pressure and friction drags, and as for cars, more concrete classification is made as a shape drag (mainly pressure drag), an inner-flow drag, an induced drag, an interferential drag and a friction drag. Since the shape drag occupies 75% of aerodynamic drag of whole car, it is the optimization for car configuration that has been regarded as most important in aerodynamic developments of cars[2,3,4]. History of improvements of the car shape dates back to the 1920s'. The then average for coefficient of drag ( $C_D$ ) is about 0.8 but nowadays passenger cars with  $C_D$  less than 0.3 are produced, which shows the evolution of car shapes during about 100 years. To realize further reduction of aerodynamic drag, not only the shape drag but also the inner-flow drag should be considered. The inner-flow drag is the drag that is generated by taking the traveling wind from the front inlet into the engine room for cooling of a radiator and an condenser for air conditioning. As another one, there is a drag due to traveling wind passing through the cabin for using air conditioning facilities, with very small drag values. Therefore, as countermeasures for the inner-flow drag, those in the engine room region are mainly conducted. The inner-flow drag within an engine room occupies about 10% of the whole aerodynamic drag of car[2], which is not small as for today circumstances of car aerodynamics, and the reduction of the inner-flow drag in the engine room becomes important[2,5,6,7]. Furthermore, with regard to the engine-room aerodynamics, there exist some reports about the drag and the cooling efficiency, but there are very few documentations about the stability performance of cars such as reduction of lift and side-wind stability, and therefore further research is considered to be necessary.



The final goal of this research is to reduce of undesirable influences in aerodynamics due to airflows within the engine room. A simplified car model with 1/5 scale was generated with reproduction of the engine room. By this car model it is possible to change the placement of the engine loading system and the opening area and position of the air inlet system and to attach and remove a radiator. In the wind tunnel with a moving-belt ground board, the drag and lift forces are measured with flow visualization, and aerodynamic effects by the engine loading system and the air inlet system with and without a radiator are investigated.

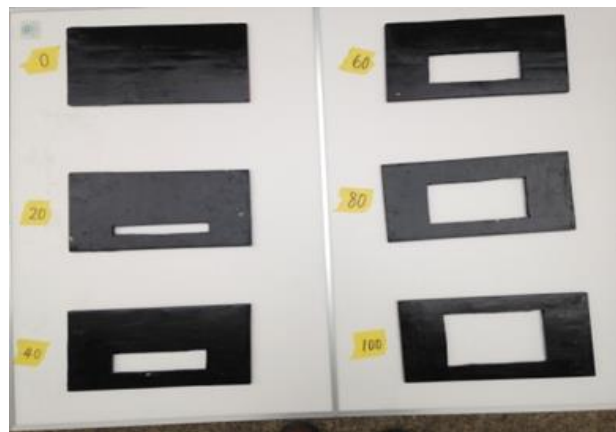
## 2. Experiments

### 2.1. Test model

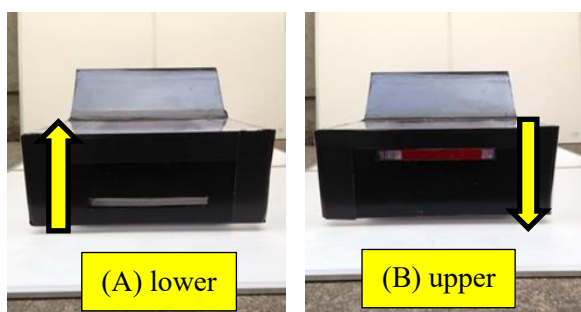
The 1/5 scale car model (Fig.1, Table.1) was generated by main frames with surface treatment, pasted exteriors with surface treatment except for front parts, and acrylic plates as a bonnet and a fender for visualization. The air inlet can be chosen from 6 types of opening area including “without opening” (Fig.2) and each dimension of the opening is described in Table 2. As the air inlet system, totally 12 patterns were reproduced with being larger from the lower (Fig.2) and from the upper by reversing these air inlets (Fig.3). As the engine loading system, 2 types of arrangements (Fig.4), length placement and width placement, were reproduced. Further, a radiator model (Fig.5) was generated, so that the loss of pressure coefficient ( $C_p$ ) be equivalent to that of an actual car radiator. By combination of the air inlet system, the engine loading system, and existence/nonexistence of a radiator, totally 48 patterns were experimentally investigated.



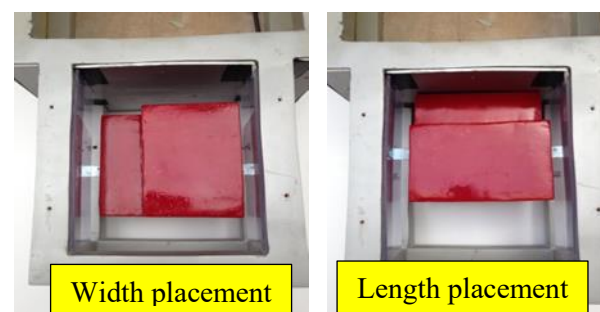
**Figure 1.** 1/5 scale car model.



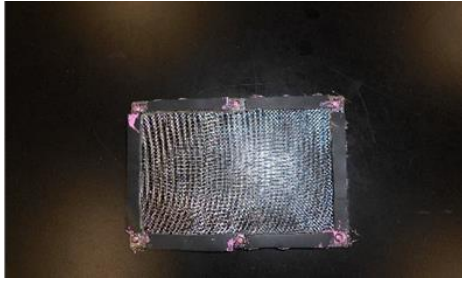
**Figure 2.** Six types for opening area of air inlet.



**Figure 3.** System of air inlet enlargement.



**Figure 4.** Engine loading system.



**Figure 5.** Radiator for test model.

**Table 1.** Dimensions of test model.

reduced scale	1/5
full length	980 mm
full width	340 mm
full height	315 mm
wheel base	670 mm

**Table 2.** Dimension of air inlet

width of air inlet	height of air inlet
180mm	0mm
180mm	20mm
180mm	40mm
180mm	60mm
180mm	80mm
180mm	100mm

## 2.2. Experimental setup

The drag and lift forces were measured by using the large-scale low-speed wind tunnel of Tokai University (nozzle exit: 1.0m [height]  $\times$  1.5m [width])[8] and the moving belt ground board, where the test model was supported by rods and wires connected to load cells. From the load cells the electric signals were sent through the strain amplifier and A/D converter to a computer, with sampling period of 10ms and sampling number 1024. Experiments have been carried out with speed of 20 m/s for both the wind and the moving-belt, and road clearance of 30 mm.

## 3. Results and discussion

Transforming the voltage values obtained in experiments to the coefficients of drag and lift,  $C_D$  and  $C_L$ , how  $C_D$  and  $C_L$  are changed for each experimental pattern is evaluated. Figures 6, 7 and 8 show changes of  $C_D$ , front  $C_L$  and rear  $C_L$  in a vertical axis, respectively, for opening heights of the air inlet in a transverse axis, where (A) and (B) indicate the cases without radiator and with radiator, respectively. In the graph legends, “width placement” and “length placement” indicate the engine arrangement shown in Fig. 4, and “lower” and “upper” in ( ) indicate the lower and upper opening position shown in Fig. 3. In Fig. 6, with enlargement of the opening height, the drag increases overall, regardless of existence of a radiator, and even for same height of the air inlet, difference is brought to the drag by differences of opening position and engine loading system. For example, at 20 mm height, the case with the width placement engine and the upper opening position records the lowest drag and the case with the length placement engine and the lower opening position does the highest drag. Figure 9 shows smoke visualization for the former case, where the smoke smoothly flows above the transmission device, while figure 10 shows the latter case at the same opening height but opposite position, where the smoke impinges against the engine and forms eddies in the engine room. From these it is considered that the drag becomes lower as the inner flow within the engine room moves more smoothly without impingement. And Figure 6 also indicates that with the radiator equipped, increase of the drag for enlargement of the opening height and also for each legend pattern is made small. In Fig. 7 (A) the front lift increases with enlargement of opening height. The reason is considered that increase of the inflow volume rate through the opening area by running wind would cause increase of downward momentum of air exhausted from the engine room to the outside. Further from Fig. 7 (B) with the radiator, compared with cases without the radiator, the lift increases for the

smaller opening height, the range of the lift for each legend pattern becomes narrow, and the lift decreases at 80mm and 100mm of the opening height in the length placement. The reason for the lift increase in the cases with the smaller opening area is considered that the airflow moving from the upstream side of the radiator to the underbody would increase since the radiator interferes with the flow going straight. And the reason for the lift decrease at 80mm and 100mm height in the length placement is considered that the momentum of airflow moving from the downstream side of the radiator to the underbody would decrease by equipping the radiator. In Fig. 8 (A) the rear lift decreases with enlargement of the opening height, which is considered that due to enlargement of the opening height, the flow rate and velocity of the underbody would increase. Further from Fig. 8 (B) with the radiator, the tendency is same as in (A) but the lift value becomes minute, which is considered that due to the equipment of the radiator, the flow rate and velocity of the underbody would decrease, and therefore the effects to the rear lift is limited.

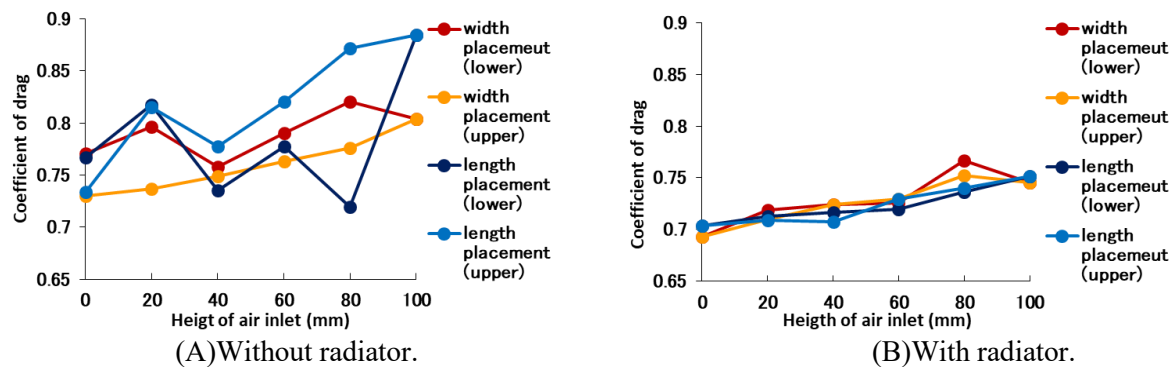


Figure 6. Relation of Drag and height of air inlet.

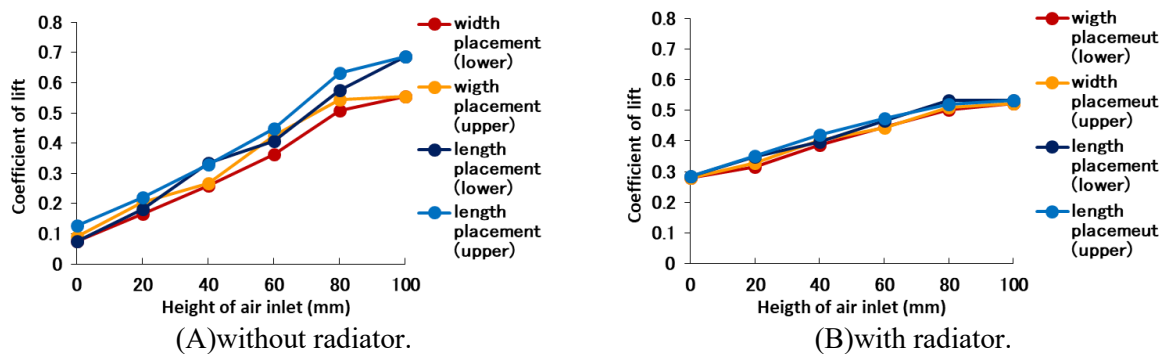


Figure 7. Relation of front Lift and height of air inlet.

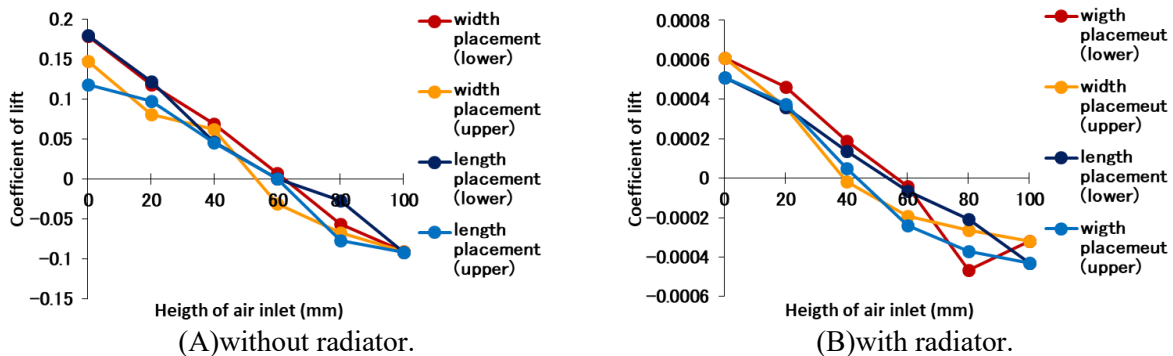
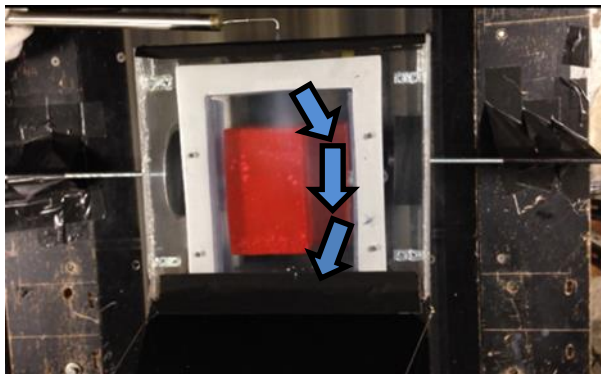
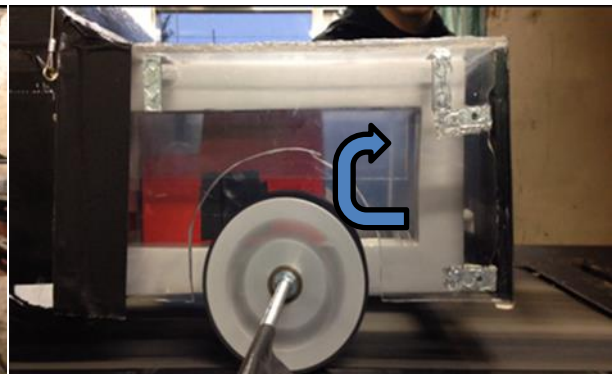


Figure 8. Relation of rear Lift and height of air inlet.



**Figure 9.** Smoke visualization in engine room with width placement and upper position of air-inlet height 20mm.



**Figure 10.** Smoke visualization in engine room with length placement and lower position of air-inlet height 20mm.

The above findings can be summarized as follows:

- 1) With enlargement of the air-inlet height, the drag increases overall and slightly.
- 2) Even for same height of the air inlet, difference is brought to the drag by differences of opening position and engine loading system, since the drag is influenced by states of engine-room inner flows based on the air inlet system and the engine loading system.
- 3) The front lift increases with enlargement of the air inlet height.
- 4) The rear lift decreases with enlargement of the air inlet height and enters into a downforce region with border height of 40~60mm.
- 5) Equipment of a radiator relieves the change of drag and lift:
  1. the increase of drag due to enlargement of the air-inlet height is relieved, and difference of drags due to position of the air inlet and the engine arrangement is made small.
  2. the front lift increases for the smaller air-inlet height, and decreases at 80mm and 100mm height in the length placement.
  3. the rear lift value becomes minute.

#### 4. Conclusion

With enlargement of the air-inlet height, the drag tends to increase slightly but depends remarkably on the engine arrangement and the air-inlet position, since the drag is affected by the inner flows within the engine room. On the other hand, the lift depends on the height of the air inlet. These changes of drag and lift are relieved by equipment of a radiator.

As future study, verification by suitable visualizations is necessary for inner flows within the engine room and outflows to the underbody. On the basis of these results, methods to reduce undesirable aerodynamic influences will be made clear.

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