

Prediction Method for Water Intrusion into the Engine Air Intake Duct while Running on Flooded Road at the Early Stage of Vehicle Development

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ABSTRACT

Vehicles are required durability in various environments all over the world. Especially water resistance on flooded roads is one of the important issues. To solve this kind of problem, a CFD technology was established in order to predict the water resistance performance of the vehicle at the early development stage. By comparison with vehicle tests on flooded roads, it is clarified the following key factors are required for accurate prediction; the vehicle velocity change, the vehicle height change and the air intake flow rate. Moreover, these three key factors should be appropriately determined from vehicle and engine specification to predict water intrusion for flooded roads at the early stage of development. In this paper, a methodology which determines appropriate analysis conditions mentioned above for flooding simulation from vehicle and engine specification is described. The methodology enables us to determine whether the vehicle provides sufficient waterproofness. Further, it is confirmed that the CFD with the methodology can successfully reproduce critical phenomena for water intrusion into the air intake duct.

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INTRODUCTION

Because of recent global warming, vehicles are required even better fuel economy. Aerodynamic performance which has a strong effect on fuel economy has to be balanced with exterior design and packaging. And also vehicle sales are expanding to all over the world, so it is important to secure durability at various environments. In the frigid zones, an air intake duct is required not to intake too much ice and snow which is raised by leading vehicle. And in the torrid zones, larger front grille openings are preferable to cool the engine. Furthermore, since these days the regions where the flooding occur increase due to unusual weather, vehicles are required to run through flooded roads at some certain condition. The front grille opening has trade-off relationship among such aerodynamics performance, heat resistance and water resistance. Hence, it is required to predict the front grille design effect on these performances at the early development stage.

Honda has developed simulation technology for predicting aerodynamic performance(1)(2), which is related to fuel economy performance, and for predicting snow-resistance(3) and heat-resistance(4), and has applied this technology to vehicle development. On the other hand, water-resistance performance while running on flooded roads has mainly been evaluated by actual running tests. This kind of development often leads to extra time to make countermeasure at the later development stage. An attempt was therefore made to develop technology that uses simulations to predict flooded road running performance.

The VOF (Volume of Fluid) method is one for analyzing two phase flow of gases and liquids, and there are many applications to free surface phenomena. Khanape et al.(5) made a method to predict pressure at under floor components during a full vehicle running through a pool with employing VOF method for free surface and overset mesh method for moving vehicle. Still, they did not mention waterproofness of engine system. Iizuka et al.(6) and Mohan Makana et al.(7) and Shayan(8) developed the technology that uses this VOF method to predict running performance on flooded roads, with water moving toward the vehicle instead of vehicle moving. Iizuka showed that their predicting method could reproduce water level by using experiment vehicle velocity history. And Mohan showed that they could use their techniques to determine whether water resistance was enough or not with employing constant vehicle velocity. These two papers apply different velocity conditions. And Shayan indicated that a vehicle was lifted up while running on flooded road due to buoyancy and a dynamic effect of water. This vehicle height change should be considered as analysis condition in order to predict accurate water level to an air intake duct. Shayan also developed simple method to predict height rise of vehicle due to hydrostatic pressure. However they concluded that the dynamic effect of water due to vehicle moving should be also considered in order to predict vehicle height change more accurately.

This study measured and analyzed the phenomena occurring in tests and verified the validity of the analysis conditions to be applied for CFD. In addition, it was ascertained that the analysis conditions could be used to predict the water intrusion amount into air intake

duct and the water level around the air intake duct, which are needed to accurately determine water resistance. And also in order to apply this technique at the early vehicle development stage where the prototype test is not conducted, we devised a method for determining the appropriate analysis conditions such as vehicle height or air intake amount from the vehicle shape and engine performance. It was shown that this method made it possible to judge whether the water resistance was sufficient prior to prototype through simulations using the determined analysis conditions.

OBSERVATION OF VEHICLE RUNNING ON FLOODED ROAD

In this section, actual flooded road tests to be reproduced in CFD are described. By analyzing the observation results of the tests, the key phenomena to predict water intrusion amount into an air intake duct and water level around the air intake duct were obtained.

Overview of the Tests

Physical quantities were actually measured to define the conditions that should be taken into account in the simulation. Fig. 1 shows the measured subjects, which are the compact car and the SUV. The tests were conducted at the course which consists of inlet, outlet slope and pool located at the Honda proving ground. The test driver was required to maintain a constant velocity while driving through the pool. The required constant velocity and pool depth are specified by Honda's requirements. The items shown in Table 1 were measured at that time. The tests were conducted for two configurations. One is the mass-production shape which has sufficient waterproofness (Case A). The other is a shape which has insufficient waterproofness, and consequently, takes in water from the duct (Case B). Fig. 2 shows these different shapes.



Figure 1. Test vehicles.

Table 1. Measurement and observation objects and sensors used in test.

Measurement and observation object	Measurement sensor
Vehicle velocity	GPS velocity sensor
Vehicle height	Suspension stroke sensor
Water level under hood	Water level sensor
Water behavior	CCD camera
Air intake flow rate	ECU monitor
Pressure loss at air intake duct	Air pressure sensor at air intake duct
Judgment of vehicle splashdown	Water pressure sensor at lower grille

	Sufficient waterproofness (Case A)	Insufficient waterproofness (Case B)
Compact Car		
Specification	Mass production	No hood seal nor splashguard Intake duct cut
SUV		
Specification	Mass production	Intake duct cut

Figure 2. Shape difference around air intake duct.

Analysis of Test Results

Water Level and Water Behavior Around Air Intake Duct

First, the water intrusion phenomena are described for the shape with insufficient water resistance (Case B). Fig. 3 shows the water behavior and water level around the air intake duct for the compact car of Case B. Water intruded from the gap where the hood seal should be as soon as the compact car splashed down(1). After the splashdown, the water level just in front of the air intake duct became lower than the air intake duct. Consequently, water intrusion did not occur(2,3). This shows that for the compact car, water intrusion occurred immediately after splashdown, and that water intruded into the air intake duct due to the water momentum.

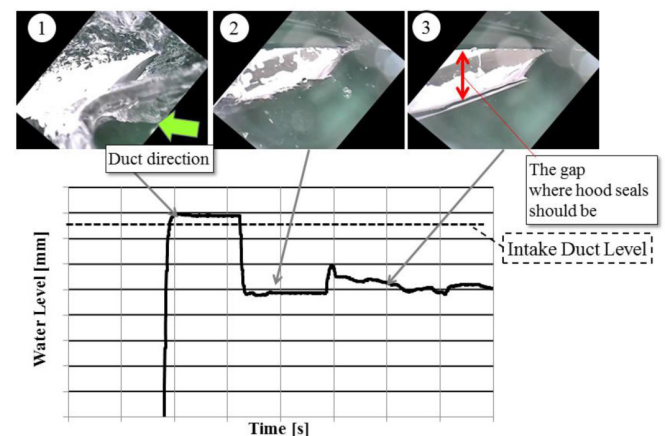
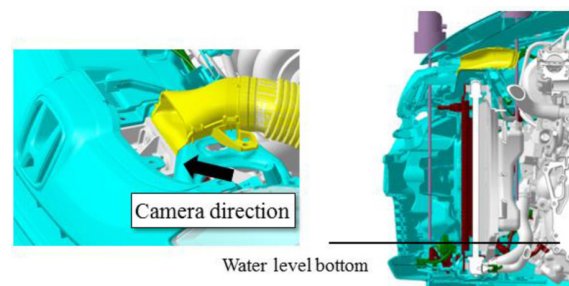


Figure 3. Water level and water behavior around intake duct of the compact car of Case B (insufficient waterproofness case).

Next, the SUV is discussed. As shown in Fig. 4 the air intake duct was located behind the head light, but water did not reach the duct immediately after splashdown. Instead, the water level at the air intake duct rose gradually as the vehicle proceeding through the flooded road, and reached the cut air intake duct. As a result, water intruded into the air intake duct just before vehicle exited the flooded road. These results show that the water intrusion timing and pattern depend on the relationship between the vehicle shape and the air intake duct position.

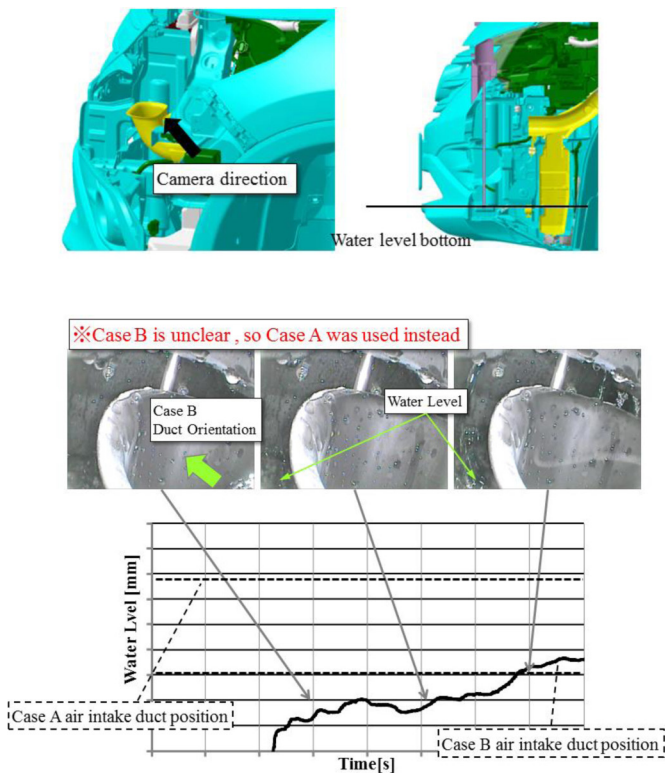


Figure 4. Water level and water behavior around air intake duct of the SUV.

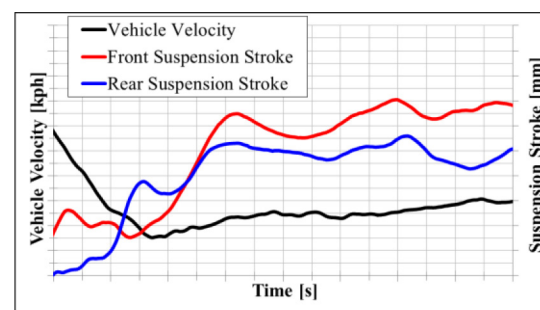
Vehicle Velocity History and Vehicle Height History

Fig. 5 shows the vehicle velocity and vehicle height time history for each vehicle. Both the compact car and the SUV decelerated significantly at splashdown because of the resistance of the water, and then accelerated slightly thereafter. The drivers tried to keep the velocity as constant as possible, but this change in velocity seems to be unavoidable due to the resistance of the water. In addition, examination of the vehicle height shows that the height of both vehicles increased from immediately after splashdown due to the resistance and buoyancy of the water. After that, vehicle height became stable while the vehicle velocity change was little. It was, however, found that the change in vehicle height was of a degree that cannot be ignored when predicting the water level precisely.

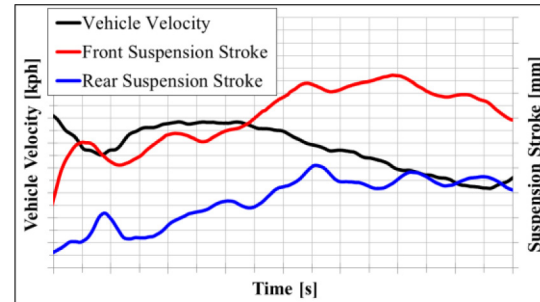
Air Intake Flow Effect to Water Intrusion

Additionally, the air pressure at the intake duct was monitored at the position shown in Fig. 6. The pressure history for the compact car (Fig. 7) shows that the intake duct air static pressure for the case with water intrusion greatly dropped during the water intrusion. The reason for this is that the air intake duct was blocked by water during the water intrusion, increasing the air total pressure loss. This indicates that when water reaches the air intake duct, the influence of the air intake increases the water intrusion. For this reason, it was found that the air intake effect should not be ignored for water intrusion amount prediction with accuracy.

It was, consequently, decided to apply the changes in vehicle velocity and vehicle height and the air intake amount at the air intake duct as the analysis conditions.



(a). Compact car



(b). SUV

Figure 5. Vehicle velocity and suspension strokes.

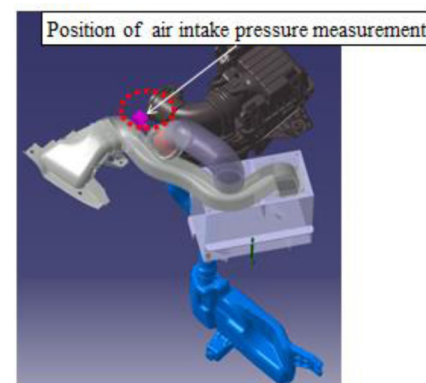


Figure 6. Air intake pressure measurement position of the compact car.