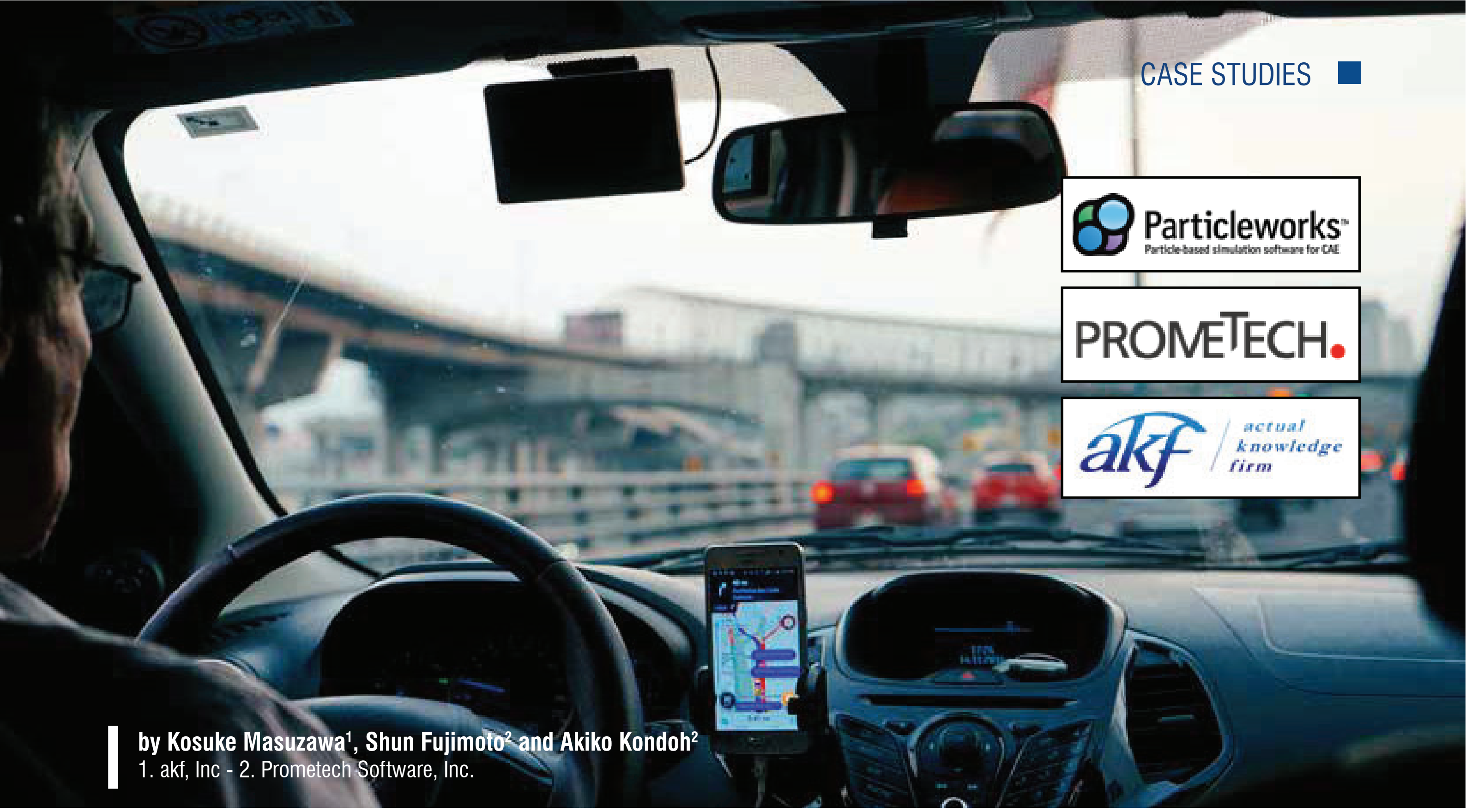

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# Application of Particleworks to the design and performance evaluation of waterproofing for automotive air conditioning systems

When it comes to cars, people tend to focus on driving performance and safety. However, one should not forget about the air conditioning system, which plays a crucial role in enabling a comfortable ride over long periods, even in extremely hot or cold weather conditions or in heavy rain. There was a time when air conditioning in cars, which we now take for granted, was a luxury only found in expensive cars. After years of development and innovation, all vehicles today are equipped with air conditioning systems. However, the design of such systems is not simple since they operate at full capacity in all weather conditions. As with the vehicle body and various other automotive parts, it is necessary to evaluate the system's performance through experiments that assume driving under real weather conditions and through simulations using CAE. This article introduces a case study on the waterproofing of an automotive air conditioning system for rainy conditions using Particleworks, a particle method CFD software.

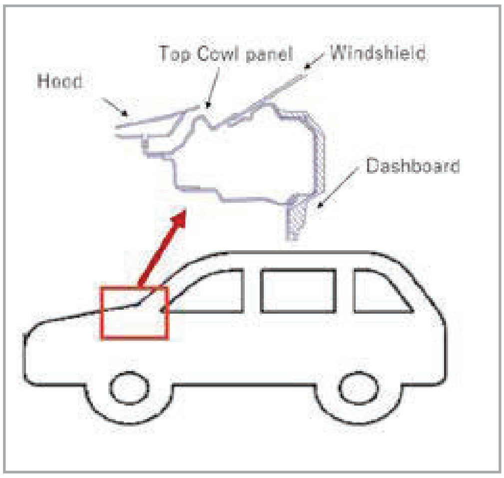


*Fig. 1 - Cross-section of top cowl panel*

Air conditioning in cars inevitably requires ventilation inlets to introduce external air. A waterproof design is necessary since rainwater is likely to enter with the exterior air. To evaluate the impermeability of an air conditioning system, a simulation tool that considers water droplets and free surfaces is required. Using these tools usually requires a high degree of skill. However, Particleworks, which uses the particle method, is a simple tool that non-professionals can use to study waterproofing.

In many modern cars, the air conditioning system, commonly referred to as an HVAC, provides integrated air conditioning control with heaters (heating), ventilation, and air conditioning (air conditioning and cooling).

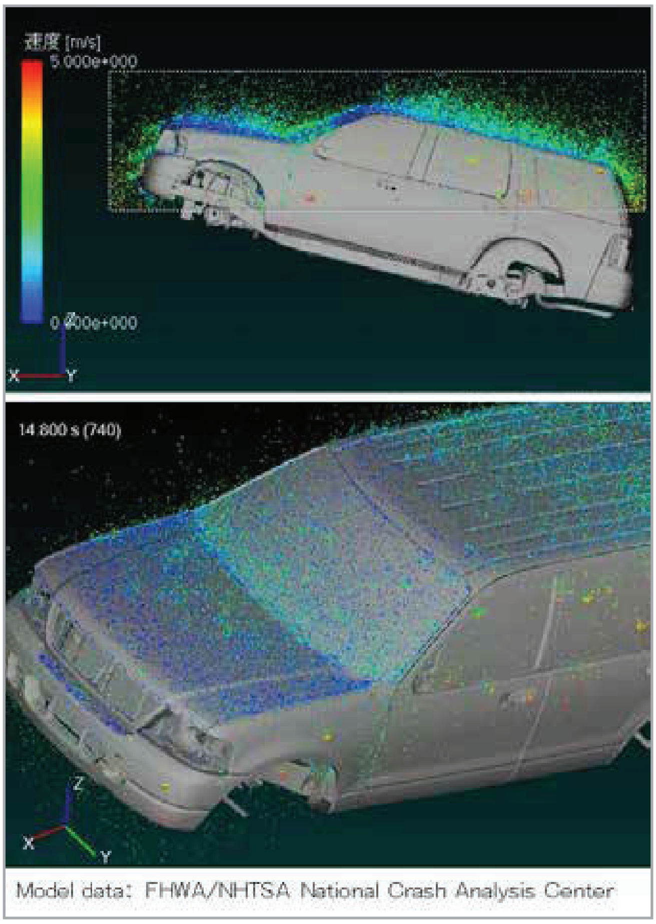


*Fig.2 - Rainfall simulation of the whole vehicle body inclined uphill at a 15-degree angle*

The heater heats the interior air of the vehicle with a radiator using hot coolant from the engine, while the ventilation function controls between recirculating internal air and introducing external air. In addition, air conditioning sends cool air into the car through a refrigeration cycle that uses a compressor and a condenser. This simulation using Particleworks, focused on the ventilation portion of the system.

Internal air recirculation, which is one of the ventilation functions, only enables the recirculation of air inside the car without any incoming air from outside. It is used to improve the cooling capacity in scorching weather. It operates when the user deliberately blocks polluted external air from entering, such as when driving behind a large vehicle. However, there are some disadvantages, including the tendency for windows to fog up due to increased humidity in the cabin. There is also the possibility that the driver's concentration may fall due to the lack of oxygen because of decreased air freshness.

On the other hand, external air induction is a function that delivers fresh air from outside the car into the cabin. By drawing external air from the front of the vehicle and expelling it from vents in the rear of the vehicle, the air inside the car cabin is refreshed. Most modern cars are equipped with automatic air conditioners. In setting up their control, it is common to essentially set the air conditioner to introduce external air, except in scorching weather.

So, what do we need to pay attention to when introducing external air? Since the HVAC system is located in the front of the vehicle, external air is introduced from the front of the vehicle. However, the front of the vehicle is also home to the engine compartment that generates heat due to the combustion from the engine itself, and is also the site of the heat dissipation from heat exchangers such as the air conditioning condenser and radiator. This means that it is essential to introduce fresh air that avoids these high temperatures. Therefore, as shown in Fig. 1, it is common to introduce external air from the upper cowl vents between the windshield and the hood. However, the problem arises that water enters through these vents during rain. It is therefore necessary to design a waterproofing system that separates the air from the liquid, allowing only the air to enter the HVAC system and preventing water from entering the passenger compartment.

In the Particleworks simulation, we first analyzed the rain patterns for the full vehicle when parked to reproduce the overall rain situation. Here, assuming that the car was parked on a flat surface, we were able to confirm that the rainwater falling on the vehicle body flowed to the top of the cowl across the windshield. Next, to evaluate the results in more severe conditions, a rainfall analysis was performed with the vehicle body inclined uphill at a 15-degree angle. This confirmed that a large amount of rainwater flowed back to the car cabin from the hood area, and mainly from the windshield when stopping the car (Fig. 2). In other words, it was apparent that it was necessary to design the top section of the cowl to allow fresh air to flow in and to enable waterproofing of the cabin.

To evaluate the water flow into the top of the cowl in greater detail, a simplified model as shown in Fig. 3 was used. The area enclosed by the black dotted frame and surrounded by the windshield, hood, and fenders, and including the exterior air inlet, is the subject of this analysis. This model is well separated from the engine compartment when viewed from the side and has holes on both ends for drainage. The red frame seen on the inside of the model is the air intake for the HVAC unit and we will study its design to prevent rainwater from entering here.

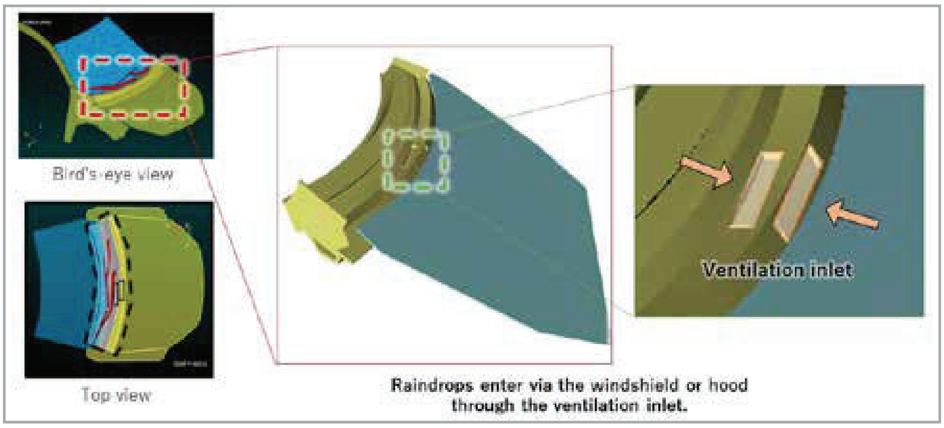


*Fig. 3 - Simplified simulation model*

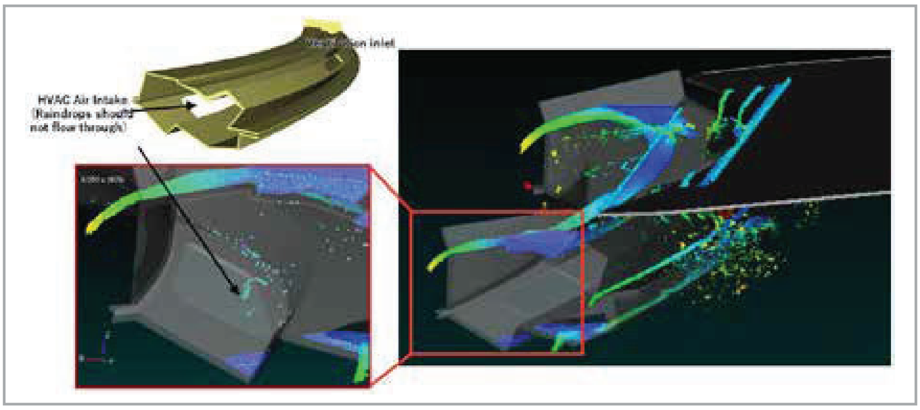


*Fig. 4 - Water flow simulation of top section of cowl at a 15- degree uphill incline*

Fig. 4 shows the results of the water flow analysis at the top of the cowl top with a 15-degree inclination. In this case, based on the results of the whole car rain analysis, the mass flow rate conditions were set to reproduce the flow from the windshield and hood areas, and the other conditions were analyzed using the Particleworks default settings. We were checking to see if water was entering the exterior air inlet. At this 15-degree inclination, it was confirmed that the water flow from the hood was the inflow path to the top of the cowl. We also found that the water that had accumulated due to the slope was overflowing into the vicinity of the external air inlet.

Having confirmed the above, it was found that there are two possible routes for water to enter the external air inlet: one being the path where raindrops that have entered and dripped down enter as droplets, the other being the water that has accumulated near the opening overflows and enters when the car inclines. Various countermeasures can be considered here, and the design plan will be discussed while factoring in the cost.

In this study, we considered two countermeasures for the original cowl top and conducted simulations. Countermeasure 1 adds a simple wall to the bottom edge. Although it is basically necessary to prevent all splashes, and a simple wall would not be sufficient, we decided to only add a wall in countermeasure 1 to see what improvement could be achieved at the lowest cost. In countermeasure 2, we examined the shape of a cover to simultaneously prevent splashing and water overflow. We modeled a part that inverted a typical range hood or duct cover (see Fig. 5).

Fig. 6 shows a comparison of the initial shapes, countermeasure 1 and 2 and the simulation results, and Fig. 7 shows a graphical comparison of the number of particles (the amount of water) entering into the air inlet with the initial shape, with countermeasure 1, and with countermeasure 2. We found that countermeasure 1 prevented the water from overflowing, but was not sufficient to prevent droplets. In contrast, countermeasure 2, a design proposal that adds a duct cover, reduced water infiltration by about 90% compared to the initial shape.

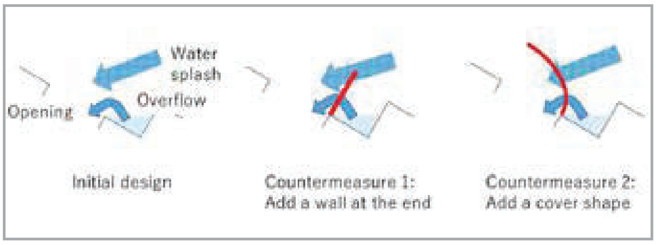


*Fig.5 - Considerations of countermeasure design ideas*

Using Particleworks to study the waterproofing design of the external air intake of a car air conditioning system, it is possible to visualize the event itself by simulation, to clarify the problems and causes generated by the initial shape, and study the countermeasures and their effectiveness. As you can see from the simulation results, we were successfully able to use Particleworks to improve the waterproofing performance by preventing drops from entering the cabin.

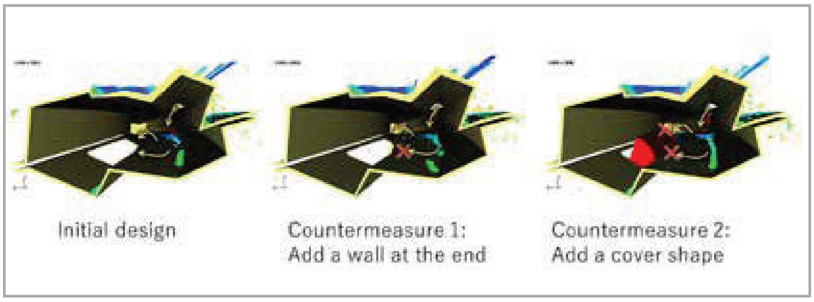


*Fig.6 - Comparison of simulation results for each countermeasure design proposal*

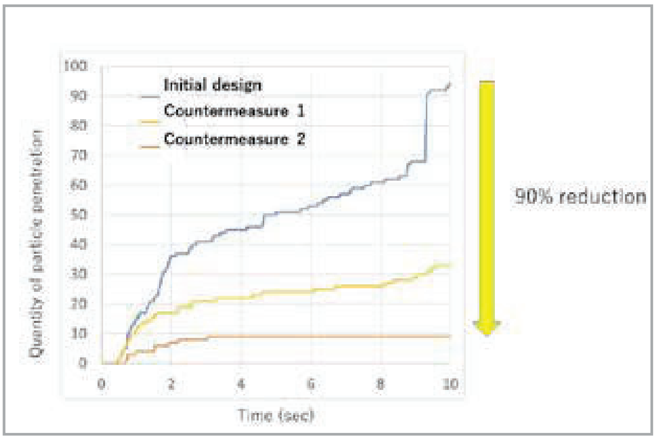


*Fig.7 - Comparison of water inflow for each countermeasure design idea*

The advantage of using Particleworks in this project was that it was easy to model and simulate without any meshes. In particular, we were able to quickly compare multiple design proposals, reflecting simple countermeasure shapes.

Particleworks is expected to be used more widely in the future as a tool that can quickly and stably simulate such various fluid behaviors.

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