Efficient Hybrid Approach for Vehicle Soiling Simulations

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Abstract:

Vehicle soiling refers to the accumulation of water, snow, or other contaminants on the surface of a vehicle. Vehicle soiling does not only impact appearance – in fact it can considerably impede safety, for example when the visibility of the exterior rearview mirror is obstructed. Soiling can also have a huge negative impact on the function of sensors resulting in severe impairments or even complete failure of Advanced Driver Assistance Systems (ADAS). Up till now, simulations for soiling were too time-consuming, expensive or inaccurate to be applied to a vehicle project. Soiling tests in the wind tunnel can be performed only at a very late stage of development after initial prototypes of the complete vehicle are available. In an aerodynamic development process that was developed over many years, Magna has integrated new approaches that combine simulations and tests to tackle challenges of the vehicle's passenger safety and system safety successfully. A hybrid simulation approach was deployed to optimize costs and development time while concurrently facilitating a stable basis for vehicle and system functions in complete vehicle development.

1 Simulation of complete vehicle soiling

In complete vehicle development, a differentiation is made when it comes to cause between foreign soiling and soiling caused by the vehicle itself (self-soiling) as is shown in Figure 1. Dirt whirled up by vehicles driving in front as well as snow and rain come under the category of foreign soiling. Self-soiling refers to dirt or precipitation whirled up by the vehicle itself. This differentiation is taken into consideration in the newly developed simulation process and modeled as realistically as possible.

Contribution: 2025 FKFS Conference on Vehicle Aerodynamics and Thermal Management
15 – 16 October 2025 | Leinfelden-Echterdingen

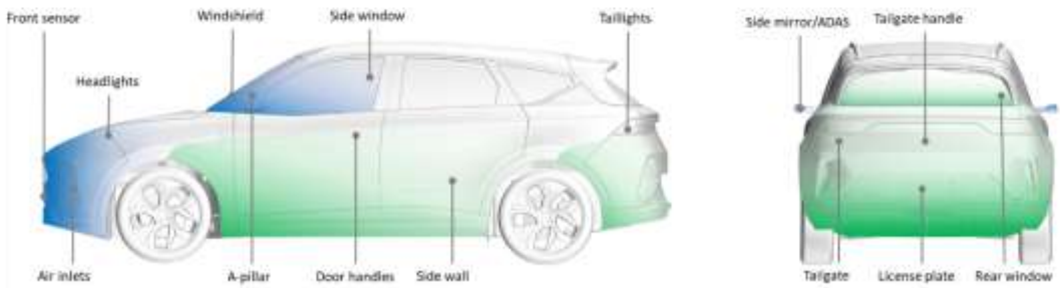

Figure 1: Vehicle areas affected by self-soiling (green) and foreign soiling (blue)

Water is used as a medium for soiling in these investigations. Just like in a wind tunnel test, a matrix of injectors in front of the vehicle is modeled in the simulation of foreign soiling to bring a defined quantity of water into the flow field and distribute it evenly. Modeling the wheel as the source for self-soiling is far more complex. Magna has developed a model for this based on the geometric data of the tire and data from measurements [1, 2] and calculates the mass ratios of different injection areas, injection speed, injection direction and distribution of the diameters of drops at each injection position. To model the trajectories of airborne water drops, this data is used for the injection of Lagrangian particles in the Simcenter Star-CCM+ simulation software. It models the drops as point masses, which are computationally efficient and robust. To validate the model, measurements done by Spruß [3] were used. Figure 2 shows a good match between the model and soiling tests in a wind tunnel.

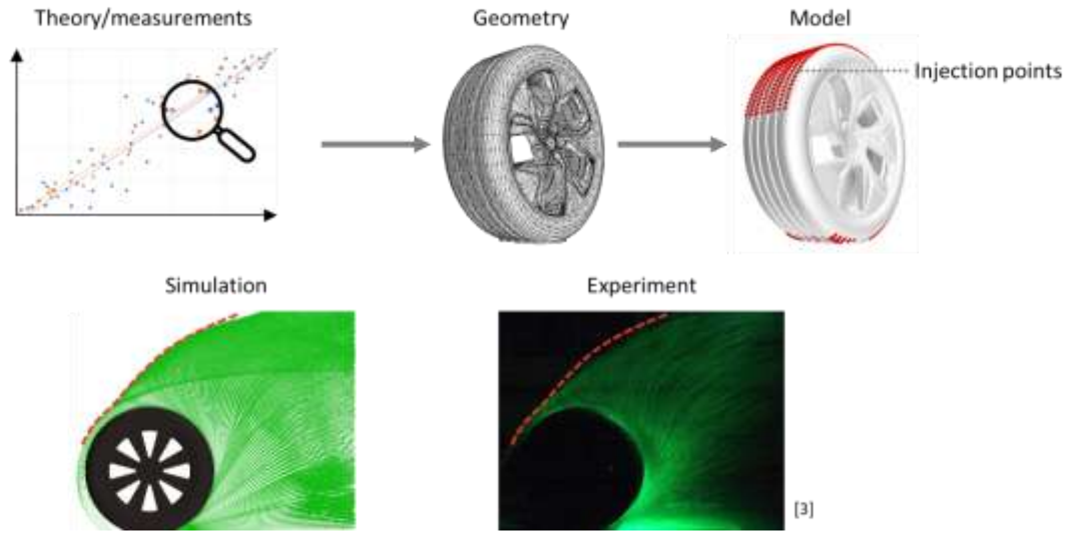

Figure 2: Modelling of the simulation (top) and comparison between simulation and experiment (bottom)

The modeled injectors are integrated in the vehicle aerodynamics simulation. This detailed simulation contains around 200 million cells in which the flow in the boundary layer is tracked accurately using the low Y+ approach and a Detached Eddy Simulation (DES) turbulence model. For the simulation of the soiling, it is essential that the areas close to the wall are tracked as exactly as possible. The injected Lagrangian phase is connected with the Euler phase by a one-way coupling, i.e. the air is not influenced by particles. According to Sommerfeld et al. [4], this simplification is acceptable up to a volume fraction of 1*10-6. In tandem with the aerodynamic forces and momentums, the soiling of the complete vehicle can also be calculated. This increases the simulation time by only 25 %. During the simulation, it is recorded where and how many particles hit the area on average; this in turn allows for calculating the average incident mass flux field across the complete vehicle, Figure 1Figure 3.

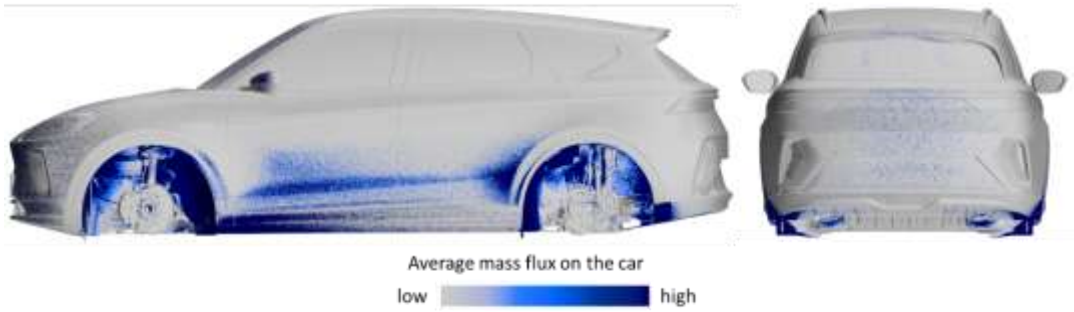

Figure 3: Average mass flux distribution on the body due to self-soiling and foreign soiling.

The slight additional effort makes it possible to compare different variants quickly and easily. Based on these simulation results, the positioning of sensors and cameras can be decided in early project phases, the soiling rate of the rear window and rear lights can be optimized and the side wall and door handle soiling assessed. A huge advantage of the simulation compared to real measurements is the opportunity to do a detailed soiling analysis. By tracking the trajectories of Lagrangian particles the source of the soiling can be determined. This creates a clear trajectory along which measures to improve the resulting pollution can be derived. Moreover, the simulation provides a basis for deciding on what areas a detailed study of the vehicle soiling should be done.

2 Detailed study in the submodel

To analyze the soiling of specific areas in greater detail, submodels are used which use the information gained from the soiling simulation of the complete vehicle and are roughly ten times samller. To illustrate this, the soiling of the side mirror and how it affects the resultant soiling of the side window are considered as an example. The degree of modeling must be significantly increased for these detailed examinations. In addition to the Lagrangian particles/phase and the air as Euler phase from the simulation of the complete vehicle, two more Euler phases are added in the submodel, depicting the water based on different approaches. The first is the fluid film model, a 2-D approximation of wall-bound water [5]. This model is useful in places where the water drops or water films on the surface are small compared to the geometric form of the body. Studies performed at Magna showed that this model provides good results for slightly curved surfaces and, if additional models are used to describe the detachment, also for sharp convex edges. For strong curves, for example the rear edge of a side mirror, the approximations of the fluid film model are no longer valid [6]. The second model is used in these areas: The so-called Volume of Fluid model depicts the flow characteristics of the water far more accurately than the fluid film model, thus providing better results. However, this advantage means heightened requirements for the mesh, smaller time steps and thus a greater calculation effort [7]. A typical side mirror soiling simulation needs around 130000 CPUh to simulate 3s of physical time. The four phases presented together constitute a hybrid simulation approach for solving the complex problem of vehicle soiling as efficiently as possible. This is necessary especially because the iteration cycles are short in the early phases of vehicle development. In addition to the phases, the contact angle of the surface must be taken into consideration. It determines how a surface is wetted by the water and depends a greatly on the material. Especially in concept development, this parameter is still unknown. During this phase, Magna relies on its experience to choose the right values. The trajectory of a water drop on a side mirror is simulated in the hybrid approach as follows: Initially the drop is injected in the submodel as a Lagrangian particle. When the drop hits the surface of the side mirror, several scenarios may occur. The drop can adhere completely to the surface; it may splashes on the surface, partially adhere to the surface and bounce off as smaller droplets; or it bounces off completely. Drops that bounce off can then hit the side window or fly out of the submodel’s domain. Drops that adhere to the surface are transformed into a fluid film. On slightly curved surfaces, the drop then flows along the side mirror until it hits a zone where it must be transformed in the Volume of Fluid model. This usually takes place on the rear end of the side mirror. If the drop does not flow back in a fluid film zone and is transformed back, it often accumulates with several drops at the back edge, until the water detaches from the side mirror. After drops have completely detached from the mirror, they are transformed into Lagrangian particles again. From there, the drops then follow the air flow again until they either hit a surface again or fly out of the calculation domain. Figure 4 shows what the phases look like in the simulation.

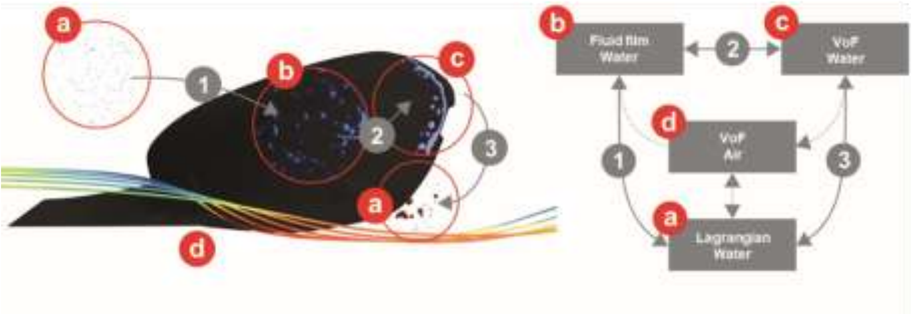

Figure 4:The simulated path of the water on the side mirror is shown on the left. The pattern of couplings and combinations in the hybrid simulation approach is depicted on the right.

With this simulation, local water accumulations and their detachment can be predicted accurately, different geometrical variants can be compared with each other, and risks detected. This provides a good basis for the optimization of soiling behavior. The differences between the variants, for example in the side mirror housing geometry, can be analyzed based on objective factors and thus be analyzed qualitatively. The focus here is on the analysis of the mirror glass and the core areas of the side window. Figure 5 shows the good match of the simulation results with real tests in the soiling wind tunnel. As in the real test, the water accumulates at the rear area of the side mirror and behind the parking assistant camera at the bottom (marked with green circle), flows to the bottom and detaches at the bottom edge of the mirror housing (marked with red ellipse). The soiling of the side window by the splash and spry from the side mirror also matches the real test.

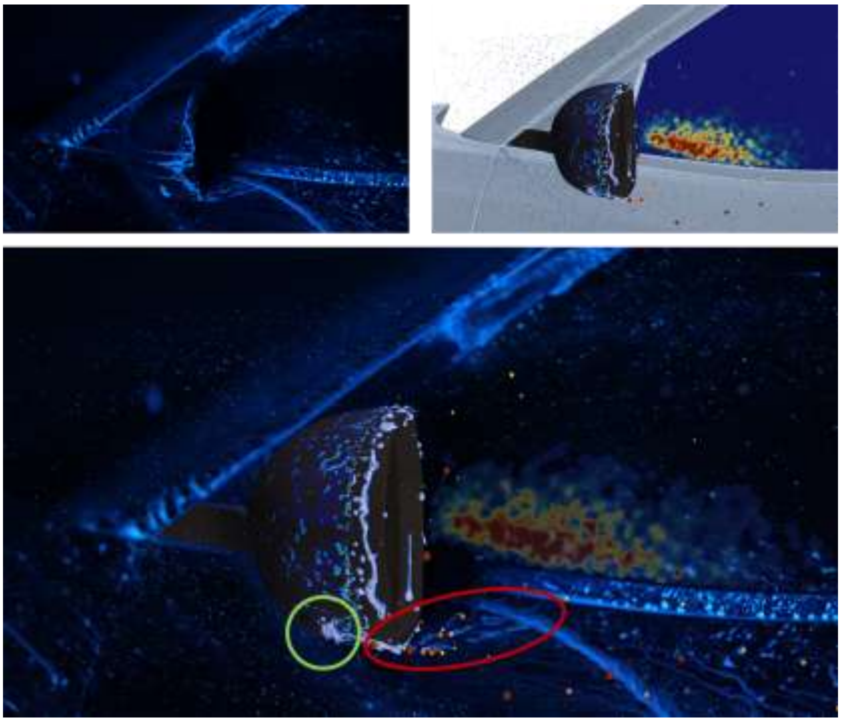

Figure 5: Top: Simulation and test results of side mirror and side window soiling. Bottom: Simulation and test superimposed.

3 Summery and outlook

The complete vehicle simulation presented here offers a good overview of the critical areas of soiling entailing little additional effort in the standard aerodynamics simulation. The multistage simulation process that was developed uses detailed submodels where detailed examination is necessary and simple modeling methods are no longer accurate enough. With this hybrid simulation, Magna has developed an approach that meets the requirements for state-of-the-art vehicle development with respect to quality, time and costs. The virtual development via simulation is supported by wind tunnel tests over various hardware generations. Thus, Magna can develop not only the traditional areas for keeping visibility clear – such as for the side window, side mirror and rear window – but also for side walls, doors, handles, rear lights, ADAS sensors, for example, on the complete vehicle. Thus, development risks continue to be minimized and key functions such as aerodynamics, aeroacoustics and soiling are optimally balanced. The hybrid simulation approach presented here has become possible in recent years because computing power has vastly increased, and new modeling methods have been developed. Yet not all soiling topics can be simulated at present. The simulation of the overflow of the A-pillar as a major cause of side window soiling cannot be done in a reasonable time frame with the method described here. Just how complex such simulations are was shown by Demel [8]. The transition from the traditional, mesh based computational fluid dynamics simulation to the smoothed particle hydrodynamics method might be a possible alternative here.

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