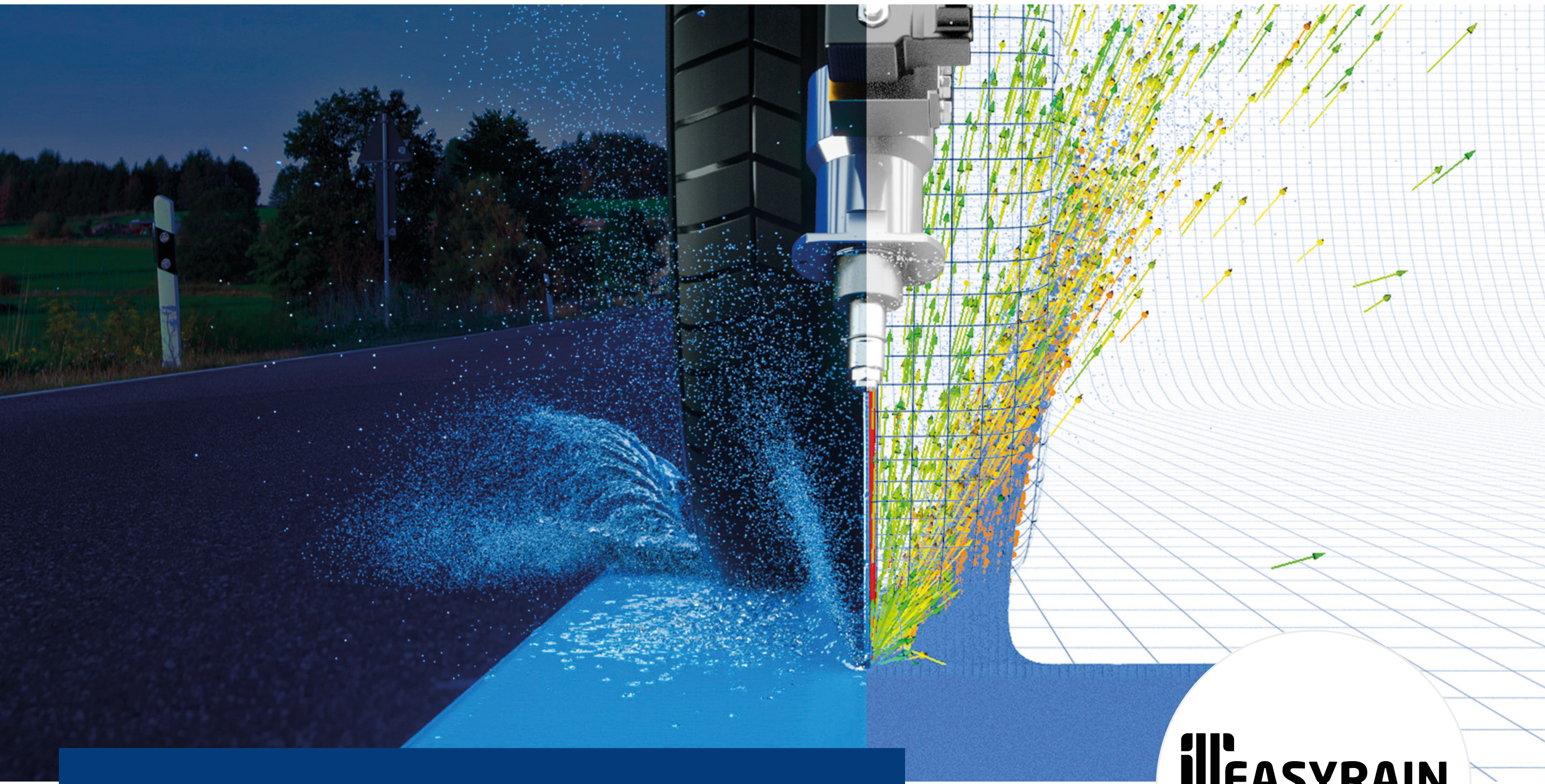

Optimization of water spray parameters by 3D CFD particle simulation for an automotive anti-aquaplaning system

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One in four accidents in the United States (according to the National Highway Traffic Safety Administration) is due to adverse weather conditions.

The same study reports that wet roads are more dangerous than icy and snowy roads (46% of accidents versus 30%). Aquaplaning and hydroplaning occur when water, accumulated on the road surface or splashed by vehicles ahead, forms a thin layer between the asphalt and the car tyre.

This layer prevents the tyre from properly adhering and gripping, making the vehicle uncontrollable and often causing accidents. In this paper, we discuss the digital modelling and simulation of the EASYRAIN Aquaplaning Intelligent Solution (AIS) using mesh-free moving particle simulation (MPS). We used MPS to study the impact of the pressurized water jet of the AIS system. First, we verified the jet forces predicted by the CFD methodology with experimental configurations and compared the MPS results with the results of track tests. Furthermore, we analysed the influence of different working parameters

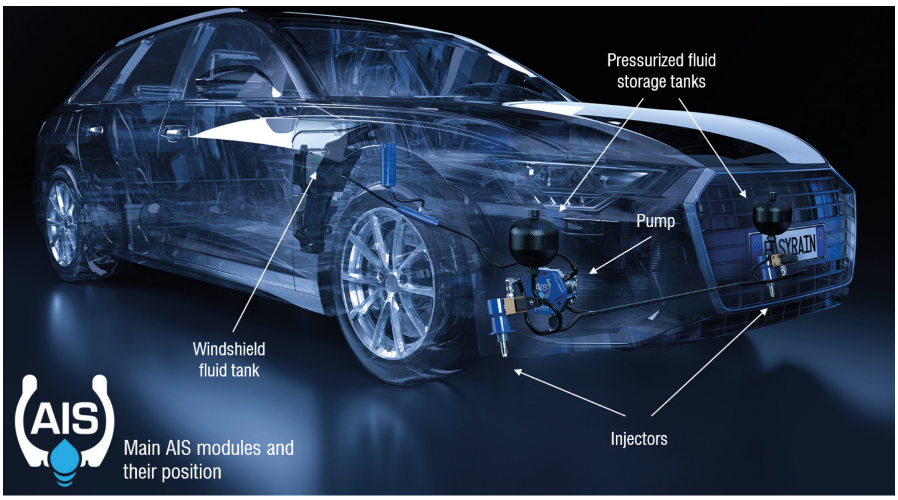

Fig. 1. Overview of the AIS solution and its hydraulic system.

(such as water jet pressure, spray angle and injector position) on the efficiency of aquaplaning prevention. Considering the speed of a car, it is important to take into account aerodynamic effects and their influence on the jet. For this reason, we used a finite volume solver embedded in the CFD software itself and fully coupled with the liquid phase MPS. Thanks to the reported validations and experimental correlations, EASYRAIN can thus design and improve the AIS system without the need for time-consuming physical prototypes and expensive track tests, resulting in the best solution for a wide range of car bodies and hydraulic systems.

EASYRAIN mission and vision: saving lives by reducing aquaplaning

Aquaplaning occurs when a thin layer of water accumulates between the car tyre and the road surface. This causes a loss of grip that results in an unresponsive vehicle. Founded in Italy in 2013, EASYRAIN's main mission is to save lives by developing advanced safety solutions to prevent aquaplaning. EASYRAIN's flagship product is the Aquaplaning Intelligent Solution (AIS), a safety device that can be fitted to a wide range of vehicles (including autonomous and electric vehicles).

The AIS directs a controlled jet of water in front of the front tyres to break up the water layer, effectively counteracting aquaplaning and restoring tyre grip and vehicle control. The Aquaplaning Intelligent Solution (AIS) is shown in Fig. 1. It consists of two injectors, pressurized fluid tanks, and a pump. The system is connected to the windshield fluid tank, which holds most of the water.

EASYRAIN is also developing EASYRAIN Digital Platform (EDP) and EASYRAIN Cloud (ERC). EDP is a platform that hosts virtual sensors that recognize dangerous road conditions, based on vehicle network data combined with EASYRAIN's patented algorithm. The Digital Aquaplaning Information (DAI), the first virtual sensor to be developed within the platform, recognizes dangerous wet road conditions and provides three levels of warning to the vehicle. ERC is a cloud service to expand and enhance the performance of AIS and EDP.

Moving particle CFD and simulation overview

We present a simulation to analyse the water sprayed by the AIS nozzles. The digital prototype of the injector is created using a mesh-free MPS (moving particle simulation) CFD approach. MPS is an innovative CFD (computational fluid dynamics) method for simulating free surface flows and liquid jets [1]. As this method does not require a computational grid, it streamlines and accelerates the simulation of complex geometries and moving parts. As far as vehicle simulation is concerned MPS is widely used to analyze the soiling of windows and other critical regions [2], or to optimize tyres to reduce splashes towards the car body [3].

As schematized in Fig. 2. the simulation focuses on the area close to the front tyre. An inflow is placed at the injector and water is initialized on the road surface, representing the water layer that

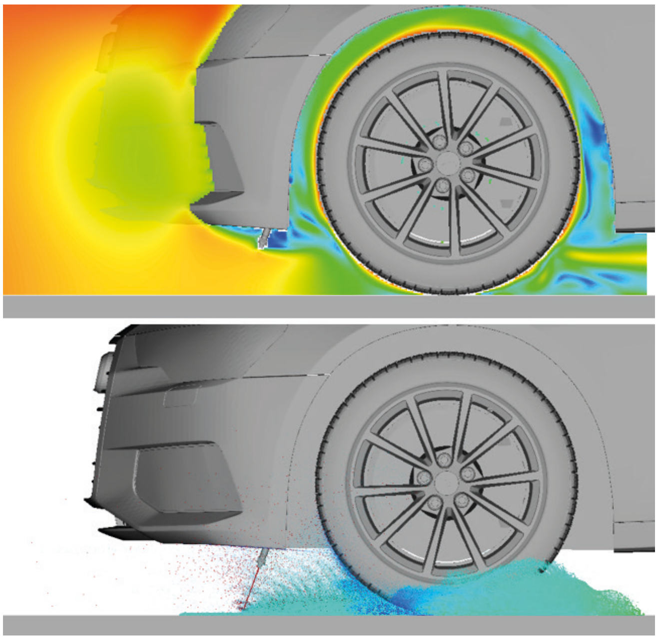

Fig. 2. The images show the simulated region and the car component considered. On the left is the velocity profile of the finite volume method calculated in the software, on the right an example of the moving particle simulation showing the jet (in red) and the tyre interacting with the puddle.

induces aquaplaning. The car then moves towards the puddle; the tyre rotation is also modelled. Prior to the MPS simulation, by taking advantage of a finite volume solver incorporated in the Particleworks MPS software, we modelled the aerodynamics of the system using the same simulation configuration without either meshing or preparing any geometry (the software calculates an automatic Cartesian grid). Although the built-in FVM (finite volume method) allows for a coupled MPS-FVM simulation, we decided that the one-way coupling approach might be more suitable to reduce simulation time. After stabilization of the FVM simulation, the airfield was transferred to the MPS simulation.

With regard to the numerical settings of the simulation, an appropriate particle size of 0.6mm was selected: small enough to capture the jet profile while still allowing reasonable simulation times. At its peak, the simulation took into account 10M particles (particles were removed from the domain when they splashed out of the area of interest). The transient simulation analysed 2-3s; the corresponding hardware time was approximately 3-4 days (on 1xGPU, NVIDIA RTX3090).

Validation of simulation results: force prediction on flat plate and aquaplaning

Before using the CFD methodology for R&D considerations and improvements to the AIS system, the model was validated by EASYRAIN with experimental observations.

First a flat-plate pressure gauge was modelled in Particleworks. The forces on the flat plate were compared with the experimental values. The simulation setup is briefly shown. The inflow is positioned in the injection area and the pressure profile is written in the software to match the pump characteristics and working conditions.

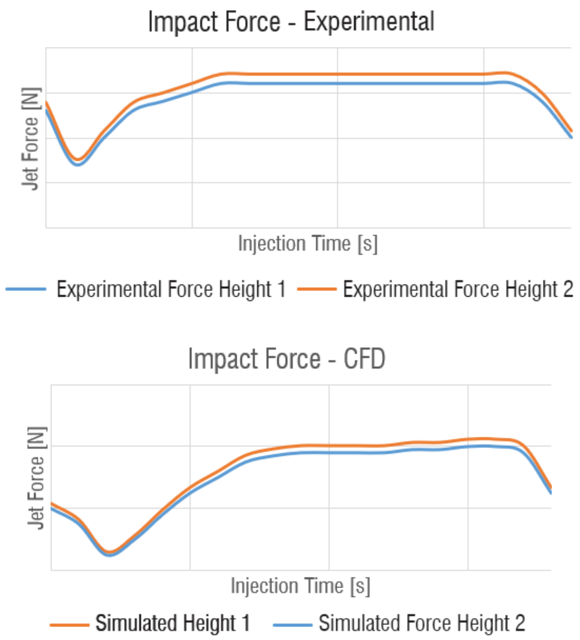

Fig. 3. Top: Experimental forces measured on a flat plate while varying the height of the AIS nozzle, Bottom: MPS predictions for corresponding jet heights.

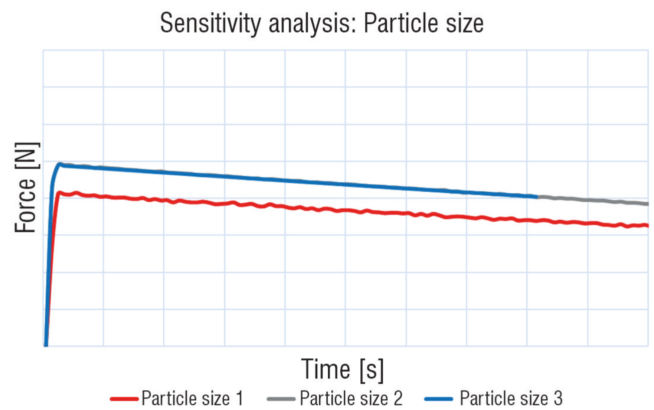

Fig. 4. MPS prediction of flat-plate force during AIS activation. A clear convergence with decreasing particle size is observed.

The main objectives of this simulation were to verify:

- The influence of particle size on force predictions
- The correspondence between the pressure profile and predicted force on the plate
- The influence of the casting height (relative to the plate) on the measured forces

In Fig. 3 we show the comparison between the flat-plate experimental data and MPS force predictions during AIS jet activation. The simulated trend closely resembles the experimental signal. Moreover, the influence of the water height on the jet forces is quantitatively significant: the relative difference between the two heights falls within an error range of 3%, compared to the experimental values.

To further corroborate the MPS results, we performed a sensitivity analysis on them by varying the particle sizes (Fig. 4). This process is commonly found in CFD analysis to verify the mesh independence of computational predictions. As can be seen, by decreasing the particle size and improving the resolution of the MPS simulation, we achieved convergence on the predicted forces.

After the flat-plate correlation, EASYRAIN compared the video footage on the track with the flow prediction simulated by the software. By simulating conditions (speed, puddle depth) known to be critical for aquaplaning, EASYRAIN was able to verify whether the same critical conditions were observed in the digital model. As can be seen, the opening capabilities of the jet stream are captured closely by the software. In addition, the simulation also predicts other phenomena that directly affect the performance of the jet; this information remains confidential.

Digital comparison between prototypes (AIS Proto-1 vs AIS Proto-2)

For development reasons, the AIS underwent several technical modifications prior to the CFD simulations. Specifically, the pumping system was updated, resulting in a significantly different pressure curve during AIS activation (Fig. 5).

Since track data was only available for AIS Proto-1, Particleworks enabled an initial evaluation of the influence of the modifications on the performance of AIS Proto-2.

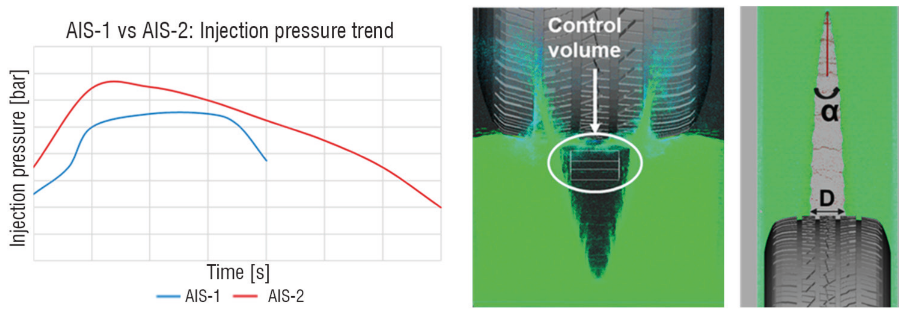

Fig. 5. Left: comparison of the pressure profile between AIS Proto-1 and Proto-2, right: close-up of the control volume that monitors water accumulation in front of the tyre. A display of the partial distance (D) is also shown.

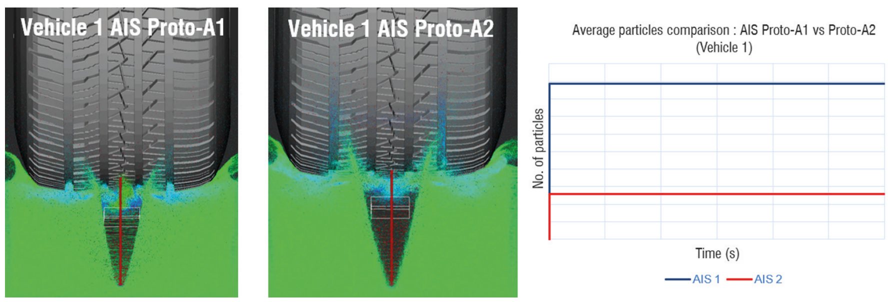

Fig. 6. Left: side-by-side comparison of jet opening capacity for two AIS prototypes, Right: number of particles (related to water volume) in the front of the tyre, with a 25% improvement in water removal.

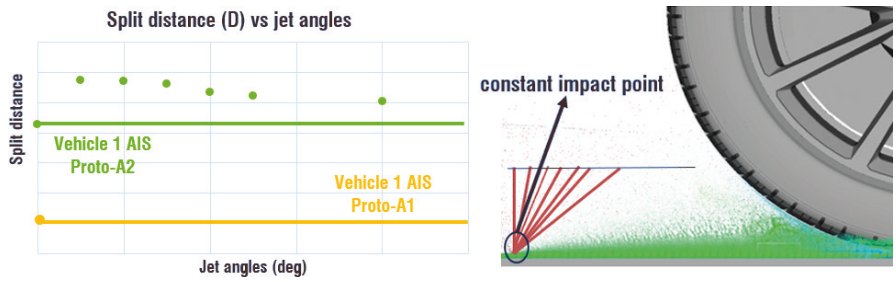

Fig. 7. Split distance at different jet angles (constant jet impact point).

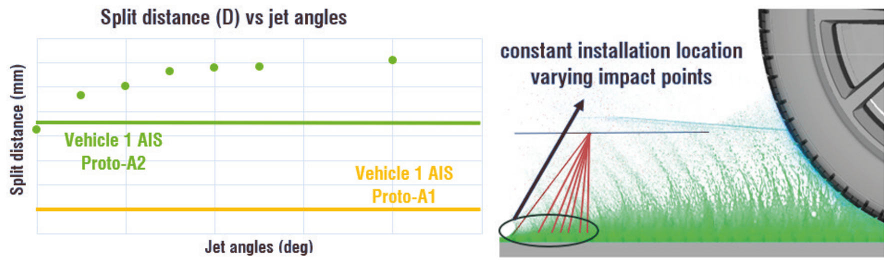

Fig. 8. Split distance at different jet angles (constant installation position for the injector).

As can be seen, compared to AIS Proto-1, the MPS simulation suggests that the second prototype results in a 25% improvement in clearing capabilities. These results have increased EASYRAIN's confidence in the improved efficiency of the system. EASYRAIN intends to use future tests to seek further confirmation of the simulation results with track tests.

Parametric improvement of the AIS Proto-2 system

After validating the methodology with experimental data and evaluating the ability of the post-processing results to discriminate between and compare the performance of AIS based on working conditions (pressure profile), we examined the influence of other parameters such as jet position and inclination. This analysis is crucial not only to gather further insights into the system, but also because some car bodies limit the installation angles or positions of the AIS system. Therefore, in order to adapt the AIS Proto-2 system to vehicles that differ from the initial EASYRAIN reference (vehicle 1), a sensitivity analysis was performed on the position of the AIS nozzle.

One piece of information that could be of interest is the clearing ability while maintaining the same point of impact. As can be seen (Fig. 7) changing the jet angle while maintaining the clearing region at a fixed distance from the tyre can result in better partial clearance, reduced aquaplaning, and improved safety. The trend is non-linear, with a clear optimum jet angle, after which the efficiency decreases.

In other AIS applications, the mounting position of the nozzle may be limited by the car body design. For these cases, changing the impact angles will result in different distances between the clearing region and the tyre. The influence of the jet impact angle for a fixed installation position is shown in Fig. 8. In this case, increasing the jet angle will result in improvements in the clearing capabilities. The methodology is thus promising for the identification of the best combination of mounting positions and jet angles, depending on the car body constraints and other technical requirements.

Conclusions and future work

In this paper we described the analysis of and improvements to the EASYRAIN Aquaplaning Intelligent Solution (AIS) using moving particle simulation (MPS), a mesh-free CFD strategy. We reported the validation of the simulation results by comparing the flat plate force predictions at different injection pressures.

Real-life footage of track tests was also used as confirmation of the MPS results. In addition, we digitally compared two prototypes, allowing an initial estimation of the anti-aquaplaning efficiency of the new prototype for which no track data is currently available. The method also provided information on mounting angle and position, allowing guided design when considering other car bodies with different and unique geometric/hydraulic constraints. Once AIS Proto-A2 track tests further validate the methodology, EASYRAIN will continue to use MPS to further fine-tune the injection parameters.

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About EASYRAIN

EASYRAIN is an auto-tech company focusing on road safety for human-driven and autonomous vehicles. We have extensive experience in wet road, dangerous wet road, aquaplaning conditions and other grip-related issues. We have built the most complete ecosystem of safety solutions, including AIS (anti-aquaplaning system), the first on-board actuator to counter aquaplaning; EDP (EASYRAIN Digital Platform) on-board virtual sensors for vehicle dynamics; and ERC – EASYRAIN Cloud Platform for off-board analysis of road safety.

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