POLITECNICO DI TORINO

Master's Degree
In Automotive Engineering

Master's Degree Thesis

Slipstream test of a rolling car during heavy rain condition
Improvement of experimental simulation inside the wind tunnel

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Un grandissimo ringraziamento a mia moglie Alice, ai miei colleghi di FCA e ai professori del Politecnico di Torino che mi hanno permesso di raggiungere questo risultato.

SUMMARY

1. INTRODUCTION

The purpose of this research is improving the slipstream test of a rolling car during heavy rain condition, simulated in the climatic wind tunnel. This is part of the LP.7T003 FCA standard, which validates the air intake system for what concern water ingestion. In particular, this standard includes slipstream test and water fording test.

This research was born from a request of the climatic wind tunnel manager: to understand if it is necessary to upgrade the rain simulation plant.

The student, with the help of the FCA Aerothermal team, managed all the phases of the research:

- Understand the real requirement: is the rain simulation consistent with reality?
- Look for the best method to analyze the problem;
- Setup of the research car;
- Perform the tests;
- Evaluate the results;
- Draw conclusions and propose possible improvements.

All the results, testing instrumentations and facilities belong to FCA Italy SpA.

2. THE AIR INTAKE SYSTEM

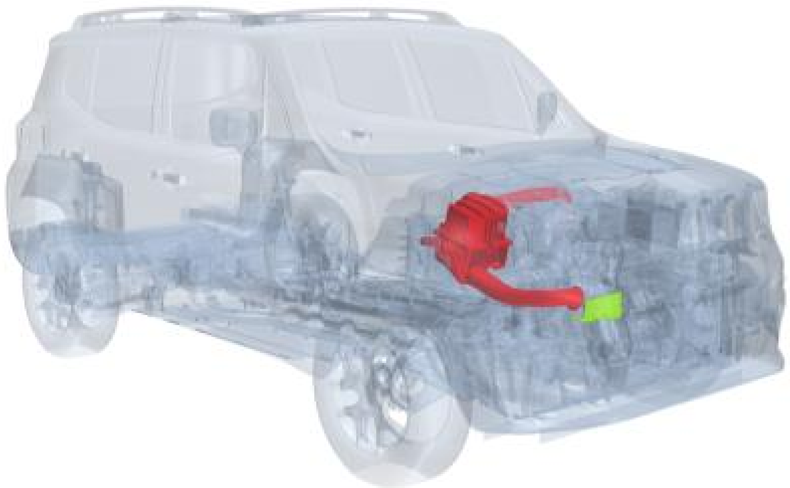


Figure 1: the intake system of a Jeep Renegade 2.0 Diesel; air ducts and filter box are highlighted in red

In a vehicle, the air intake system is the assembly that allows the air to enter inside the engine. It is designed to maximize the airflow and at the same time to avoid that objects or liquids could enter inside the combustion chambers.

Starting from the front bumper of the car it is usually composed of:

- Front end: this is the portion of the front bumper where the air is sucked by the air ducts. It can be reasonably considered part of the intake system since the shape of the bumper influences aerodynamics and so the flow of the air.
- Dirty air duct, called in this way since the filter still has not cleaned the air. Its main purposes are:
  - Directing the fresh air from the front end into the filter box;
  - Being the first drain for liquids by designing small holes in key points that don’t interfere with the air flow or designing the pipes with a siphon shape;
  - Avoiding air backflows that, for an NVH or Quality analysis, are not acceptable.
- Filter box, which contains the air filter. In the part of the box before the air filter, there can be other small holes for water draining.

  In the clean air side of the filter box there can be a couple of holes, about 3 cm diameter, closed by a one-way membrane, that let a small amount of air to flow when the filter is obstructed, for example by snow. Since these passages works without filtering any air, they must guarantee the engine working only in recovery mode (very low speed).

- The air filter, which is the main barrier for every type of unwanted object or liquid. Its purpose must be balanced by the necessity of letting the air pass through without too much pressure drop so its design is fundamental for a correct engine calibration.
- Clean air duct, which is sealed from the outside and brings the previously cleaned air towards the engine; it can have very different length depending of the engine type.

  The throttle valve is placed in a segment of this duct, generally before the manifold. Other recirculation pipes can be connected to the clean air duct, for example, the ones of the EGR system, of the blow-by system or of the tank purge system. The gases that come from those pipes change the composition of the air so, before the intake manifold, lambda sensors control the amount of oxygen present in the air and calibrate the right amount of fuel to inject for the combustion. In supercharged engines, the clean air duct is even longer because it is even composed of the supercharger and the intercooler, water or air-cooled.
- Intake manifold, where the air splits in different flows depending on the number of the cylinders; except for direct fuel injection engines, here the fuel is premixed with the air and then the mix enters the combustion chamber to start the combustion cycle. The most advanced supercharged gasoline engines have the intake manifold built inside the cylinders head, with the throttle and the water intercooler close coupled to it, in order to achieve a better thermal efficiency (smart cooling systems).

3. INTAKE SYSTEM WATER INGESTION: WATER FORD AND SLIPSTREAM TESTS

In order to validate the sealing from water of the intake system there are two mandatory tests, the water ford test and the slipstream test simulation in the climatic wind tunnel.

3.1 Water ford test

This is the most severe test but the less likely to happen; it simulates the real condition of driving during a flood or actually passing through a water ford. It is performed by driving the testing vehicle through a 30 m length ford of several water heights with no engine breakdown. The number of crossings, the heights of the ford and how many times the air filter needs to be replaced, depend on the vehicle segment: except for specialty cars, every FCA car must pass the 40 cm ford test but only specific off road vehicles need to pass the 76 cm – 30 inches – ford.

Figure 2: Balocco Proving Ground, water ford testing facility

The vehicle is equipped with cameras placed firmly in different key points of the car that usually are on the bumper, inside the hood and facing the dirty air duct entry. There's an endoscope placed and sealed inside the clean air duct that is facing the air filter box; all these cameras are synchronized to record the ford crossing.

While the pilot is focused on driving, the passenger technician can live view what is happening during the ford crossing and, if he detects water in the clean air duct, can promptly press the emergency engine shutdown button to prevent engine failure due to water block. Water in the clean air duct means that the air filter has been saturated and cannot keep any more fluid; in this condition, the test is negative.

Figure 3: inspection of a filter box, clean air side, after a water ford test. The test is negative because the water passes through the filter. Note the two yellow membranes that closes the back-up holes

For supercharged vehicles, if a small flow of water is detected through the air filter, the test will be repeated without pressing the engine shutdown button; in this case, the negative test condition becomes engine breakdown. That's an acceptable condition due to the fact that the longer duct and the intercooler can help vaporizing the drops of water; the air will be more humid and as a consequence the lambda sensor will recalibrate the combustion but it won't cause damages.

If the car is stopped in the middle of the test, by will of because of an engine failure, a third technician not in the car, or the staff of the facility alerted by radio, will open the valves, emptying the ford and towing the car out.

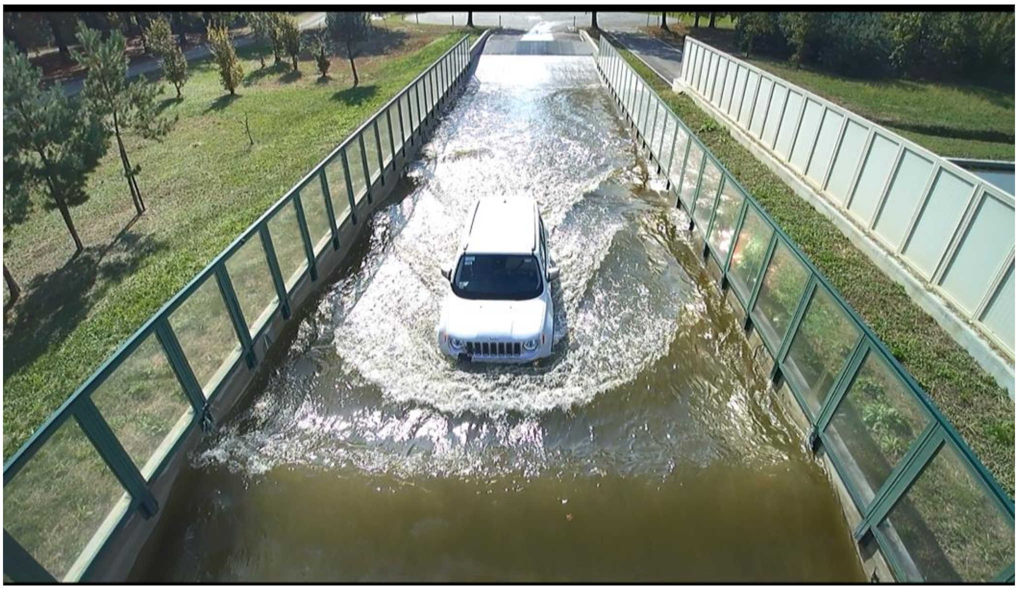


Figure 4: Balocco Proving Ground, the Jeep Renegade crossing 40 cm water ford, aerial view

For the early stages of a new intake system design, where water ingestion is more likely, there are tools that prevents water from entering inside the engine even in the worst cases. Installing these systems means to modify parts of the car body like the hood, which usually is not so important for a mule vehicle. What is important is that these modifications do not change significantly the design of the front area of the vehicle, which is very relevant for this test.

The main tools used are the cyclone and the bonus ball.

3.1.1 Cyclone

The cyclone is a way to extend the dirty air duct measuring at the same time how much water goes inside. It is a barrel-like container, with staggered input and output that separates and collects the water, letting the air keep going on its path. It is usually linked between the end of the dirty air duct and the filter box and it is used mainly to check the dirty air duct or the front-end design.

Figure 5: the cyclone

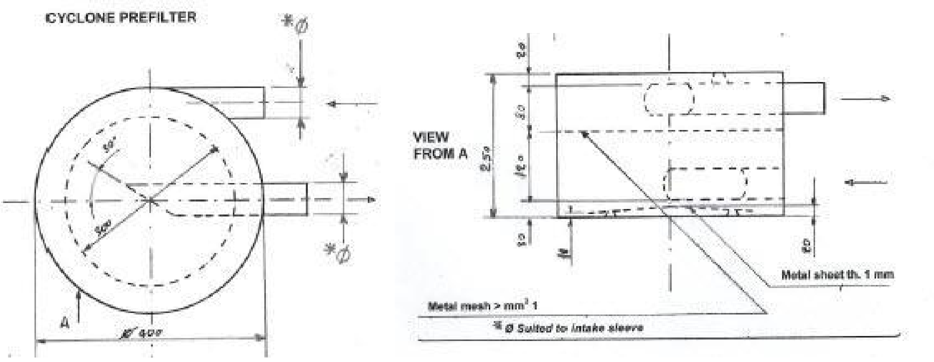


Figure 6: cyclone design

3.1.2 Bonus ball

The bonus ball circuit extends the clean air duct vertically, adding an upside down siphon pipe in the circuit; there is a floating plastic sphere in the first vertical segment, where the air flows from below to the top. If water enters the circuit, the ball will start floating inside the pipe, reducing the flow rate of the air. The driver will notice a power loss due to this airflow reduction. At the limit, the ball will reach the top of the pipe, which is shrunk, closing it completely and the engine will stop due to the lack of air, preventing failure.

Figure 7: a bonus ball system mounted on a prototype

3.2 Slipstream test

This test is performed to check if in extreme situations, like drafting cars or trucks during heavy rain weather, the intake system is working properly without drawing too much water. Due to the high risk and the low repeatability in real life conditions, it is simulated in the climatic wind tunnel.

The test can be performed with cameras like the water ford test – usually the car used is the same for both – or without additional equipment. According to the two setups the acceptability criteria change: in the first scenario the acceptability criteria is no water drops after the air filter detected with the endoscope; in the latter is the weight of the filter, which is evaluated before and after the test. The delta weight cannot exceed tabulated value. If a power loss occurs, the test is immediately stopped and the filter weighted.

The test is carried out in the climatic wind tunnel, placing a row of four nozzles in front of the vehicle, directed so that the flow strikes the front end of the vehicle, under the following conditions:

- Ambient temperature 15°C/59°F
- Test duration = 125 min (5 minutes dry + 120 minutes under water flow)
- 4^{th} gear
- Roller speed = 100 km/h (62 mph)
- Wind speed 80 km/h (50 mph)
- Wide open throttle
- Water Flow Rate = 2.6 l/min total (4 nozzles)
- Air pressure of the water spraying system: 3 bar

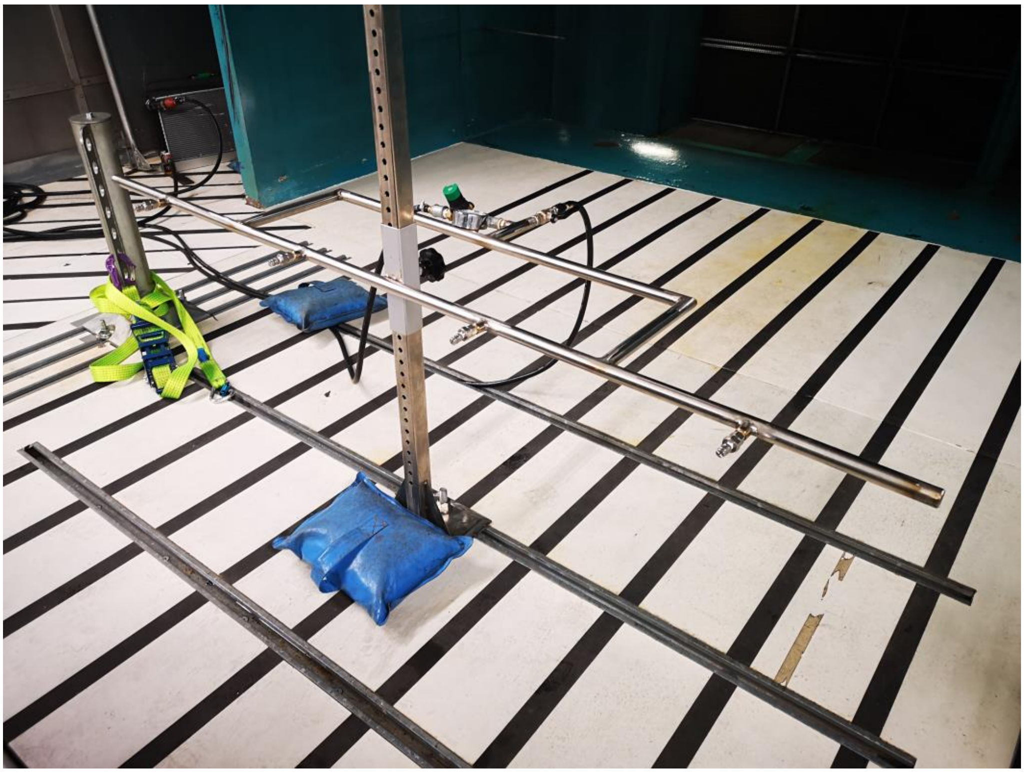


Figure 8: the hydraulic system of Aerothermal climatic wind tunnel with the four nozzles

The aim of the first 5 minutes in dry condition is to acquire the traction load of the reference vehicle. If during the following 120 minutes any power loss or malfunctioning light is detected the test is negative. Before starting the fuel tank is filled completely; if the fuel range doesn’t allow to complete the 120 minutes rolling in WOT, the test will end when the remaining fuel percentage will decrease under 5%, before any power loss due to lack of fuel.

Figure 9: the Jeep Renegade before the start of the test

Figure 10: the Jeep Renegade during the methodology tests

4. SLIPSTREAM TEST ANALYSIS

4.1 The current slipstream test origin and methodology

The slipstream test was developed in mid ‘90ies, using experimental data.

The methodology tests were carried out during heavy rain on high speed track, driving at 100 km/h speed for two hours in the wake of the car ahead, then the air filter of the car was immediately weighted using a portable scale.

Therefore, the correlation in the climatic wind tunnel was obtained finding the correspondence of the filter weight in different wind speed / water flow rate configurations; the optimal test configuration obtained was the one mentioned in paragraph 3.2.

The slipstream test, as it currently is, has proven to be quite effective over the years; however, the methodology testing mentioned above is showing some limitations, mainly related to advancing automotive technologies:

- The use of max engine load in 4^{th} gear derives from original track tests which are about 25 years old and doesn’t represent anymore a real driving condition on cars with 5+ gears and very different engines. Moreover, cars with engine displacement over 2 liters in W.O.T condition hardly end the test because they ran out of fuel prior to the end.
- The rain during two hours of test could not be constant along the whole track.
- Basing the test procedure on the weight of the filter only, shifts the significance of the test on the dirty air duct position and shape – *how the engine intake sucks the rain* – leaving a marginal contribution to the aerodynamics of the front end – *how the rain hits the car*.

Due to these aspects, it is necessary to understand if this test is still suitable to validate the impermeability of the intake system and eventually what improvements to make.

4.2 Arranging a new methodology test

In order to understand how to improve the slipstream test, new methodology tests have been carried out using current technology, such recording vehicle CAN line data and rain sensors.

To better design a methodologic research, the following questions have been taken into account:

- What is the purpose of the methodology research?
- Which tests must be performed to achieve the purpose?
- Which instrumentation is necessary to perform the tests?

4.3 The purpose

The purpose is to evaluate how the rain hits the front bumper of a vehicle while taking the wake of a car or a truck during heavy rain weather in real roads and then simulate it in the wind tunnel. This does not necessary mean to find the worst case in which the air filter draws more water.

Moreover, methodology measurements cannot last 120 minutes because, even on a circular track, finding always the same weather condition and the same wet asphalt would be very unlikely. These measurements must be quick, just some minutes, repeatable and comparable.

After completing the road tests, it's necessary to analyze the data and match the real life behavior with the tunnel simulation, acting on the direction of the spray nozzles, adding another row of nozzles or modifying the water flow rate and air pressure.

4.4 The tests

Take the wake of cars or trucks on public roads, with dry asphalt, is a very dangerous way of driving and it's even forbidden by the most traffic laws in the world. Doing it with bad weather and wet asphalt condition is even more dangerous: braking distances lengthen, rear tires of the preceding car raise a lot of water, driver's mind is focused on more aspects like controlling wipers, defogging windscreen and so on. However, there can be situations, for example medium traffic on a highway road, where the speed is quite high, around 80 – 90 km/h and the distance between cars is lower than the safety one.

It's important to remember that, according to the European Directive 91/226/CE, transposed by Italian traffic law art.72 comma 2-ter, revised with the Ministerial Ordinance D.M. 07/08/2006, twin wheels trucks and trailers that transit in Italy, and consequently in the European Union, must mount mud-guards and splash-guards, in order to minimize the water risen behind them.

Figure 11: the splash-guard of a trailer

Therefore, it's important to identify the test conditions that are close to reality and then pushing a little beyond the limit to consider even extraordinary situations. It's even important to be careful about not to exceed, in order to avoid overdesign which translates in extra costs for the manufacturer.

To achieve a better design of experiment, reducing the test to only the most significant ones, some considerations are made:

- Perform a test in free road, no slipstreaming, in order to evaluate the effect of the wake. Then repeat the tests taking the wake of the front vehicle at different distances.

- The vehicle to take the wake from, need to have twin wheels in the rear axle in order to raise more water behind it; a good choice is a medium-duty or heavy-duty truck.
- The speed considered is the highest allowed for the vehicle ahead, shifting only the distance between the two vehicles.
- Using a low gear with high engine load and then shift to the higher gear to evaluate the differences.

Taken into account the considerations above, the road tests have been arranged in this way:

- Test vehicle: FCA model 520 – Jeep Renegade MY2018
- Drafted-by vehicle: Iveco Strails truck with trailer
- Anello Iveco truck in Balocco Proving Ground
- All the tests performed with vehicles speed of 90 km/h
- 4th gear, four minutes each test, distances:
    - free road;
    - slipstreaming @ 30 m;
    - slipstreaming @ 10 m.
- 5th gear, four minutes each test, distances:
    - free road;
    - slipstreaming @ 30 m;
    - slipstreaming @ 10 m.

4.5 The instrumentation

4.5.1 Rain sensors

The main instruments for this research are rain sensors. The most important technical aspect for this experimentation is that they must be able to work even in dynamic conditions with a high frequency.

The two main technologies for these sensors in the industrial market are conductive and optical technologies.

The conductive sensors are small, cheap and reliable in steady state or slow speed, but tend to lose accuracy at higher speeds and with big water drops. They are widely used on weather stations and automatic garden irrigation.

Figure 12: a conductive sensor

Optical sensors are more expensive and much bigger than a conductive sensor but don’t have issues with high speed or the size of drops.

The sensor chosen for the research is an optical one, model RG-11 from Hydreon Company. It has a semi spherical shape with four infrared beams inside, therefore it detects drops from all directions. It is rugged and can be simply connected to a frequency counter data logger.

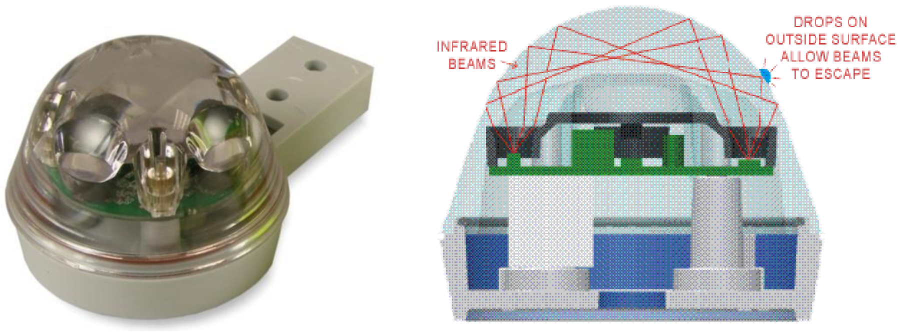


Figure 13: optical Hydreon RG-11 rain sensor

The sensor can be set in multiple ways, giving for example inputs to other devices like make automatic irrigator start or stop or, as in this case, working as a drop detector.

It is used at its maximum sampling rate, 50 Hz. The acquisition of the sensor is made with a formula that count the number of drops detected for four minutes.

Therefore the maximum data acquirable for each sensor, for each test is:

$$Max\ sensor\ data = sampling\ rate \times test\ duration = 12000\ input$$

The drop detection has been set to *medium* in order to remain distant from the maximum sensor data and avoid to lose accuracy due to sensor saturation.

4.5.2 CAN line data logger

With data loggers especially made for automotive application it's possible to acquire signals from the internal sensors of the car using the CAN line data protocol, plus external sensors for experimentation purposes like sensors of temperature, voltage and frequency.

The data logger was configured to use the C-CAN line data input and five frequency inputs of the rain sensors.

The main signals taken from the CAN line of the vehicle are:

- Front Vehicle Distance [m]:
  The radar placed on the front bumper, used for many recent ADAS systems, is used for measuring the distance of the following car. It is designed to work even in bad weather conditions, so it is suitable to measure the distances between the two vehicles without using expensive systems like the IMUs, inertial measurement units.

- Vehicle Speed [km/h];
- Engine speed [rpm];
- External temperature [C];

4.6 Vehicle setup

For the research, five rain sensors were used. They were placed on the car in order to control the main surfaces of the front area, especially the zone of the front end.

The CFD analysis made by Aerothermal virtual simulation team, gave a first glimpse of the possible distribution of the water respect to the front end, taking into account even the position of the dirty air duct.

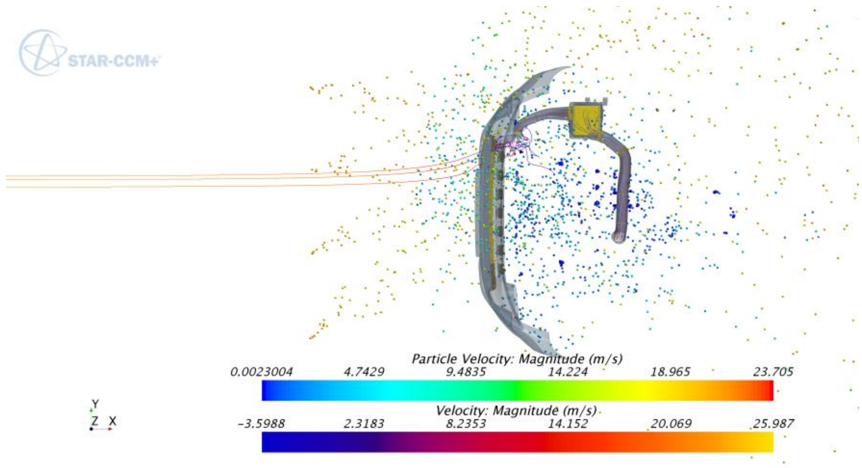


Figure 14: CFD analysis, vehicle top view, water particles velocity and impact

In order to cover as much area as possible of the bumper, the sensors were placed asymmetrical respect to the mid longitudinal plane.

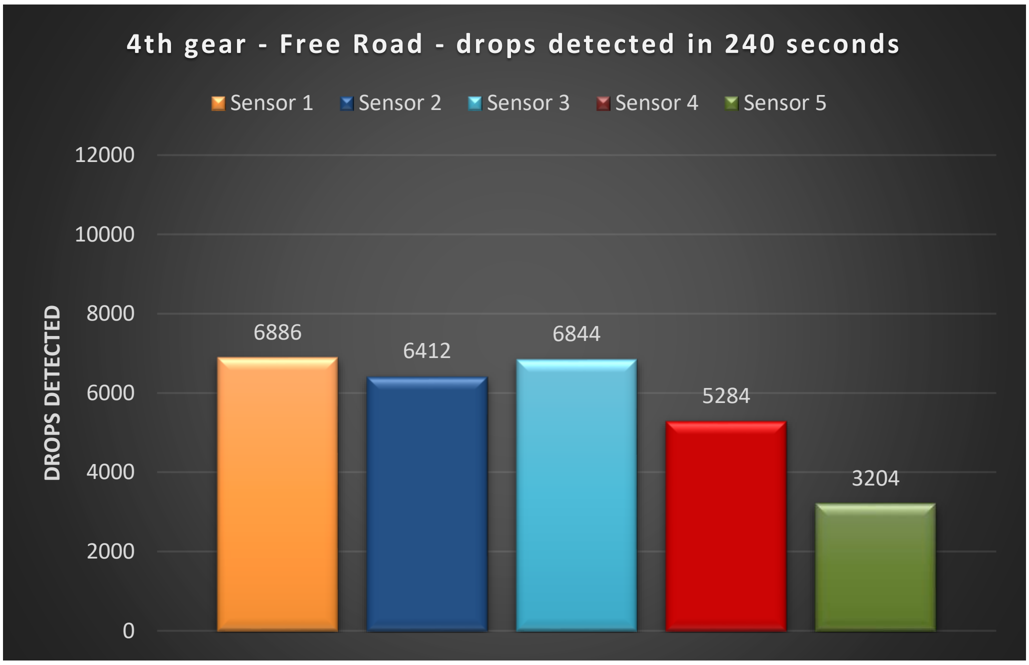
Figure 15: the layout of the sensors on the front bumper.

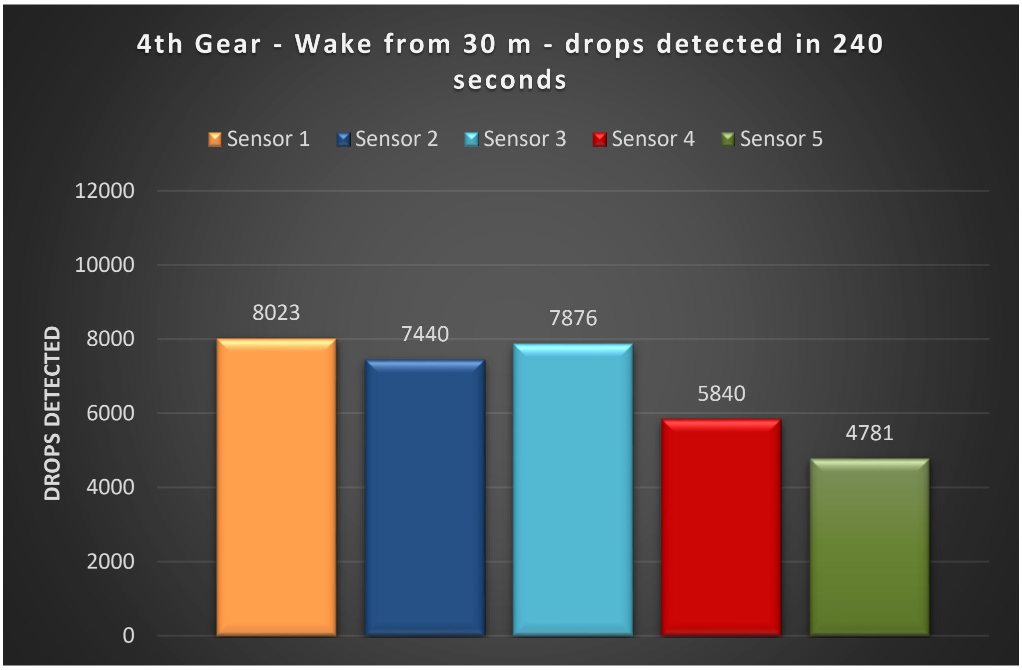
- Sensor 1: it's the one closer to the front end and the dirty air duct, the most likely to collect the rain drops.
- Sensor 2: placed in front of the crosspiece, on the opposite side of the front end.
- Sensor 3: placed on the front grille exactly in the middle, it's still in an area that communicate with the dirty air duct.
- Sensor 4: placed on the upper side of the front grille, which is only aesthetical.
- Sensor 5: placed on the hood in order to better collect the vertical rain that comes from the sky.

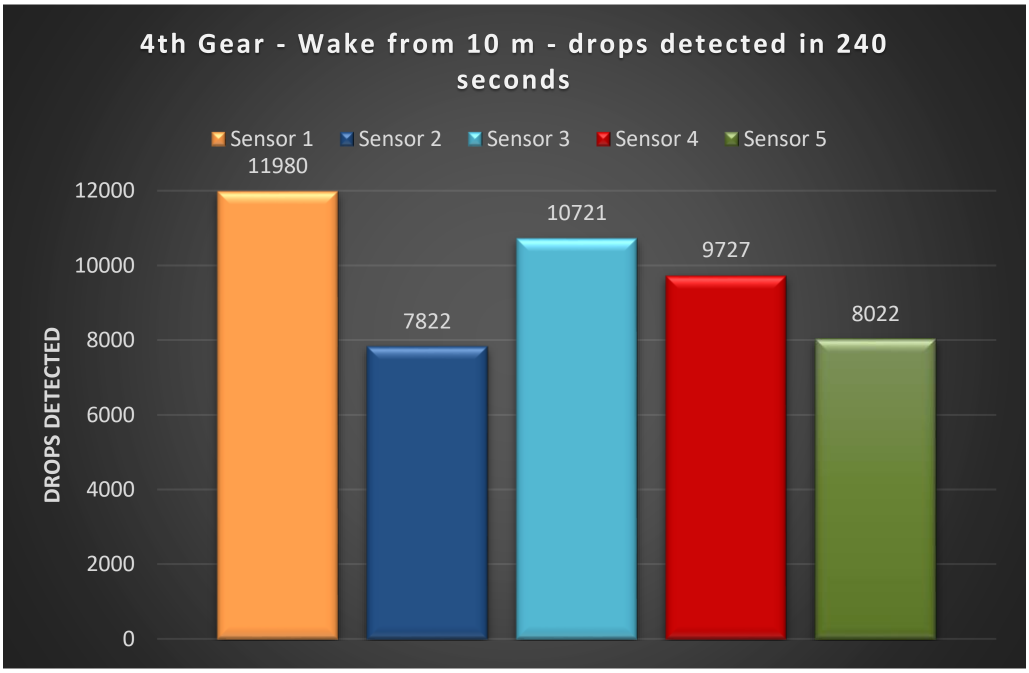
5. ROAD TESTS

Road tests were performed in Balocco Proving Ground (VC), the testing facilities of FCA group. The reference track was the Anello Iveco, a medium speed ring – maximum speed allowed 130 km/h – especially made for truck tests. They took place on November 8th 2018, one of the most rainy day of Fall 2018. The amount of rain fallen [mm/m²] was not available.

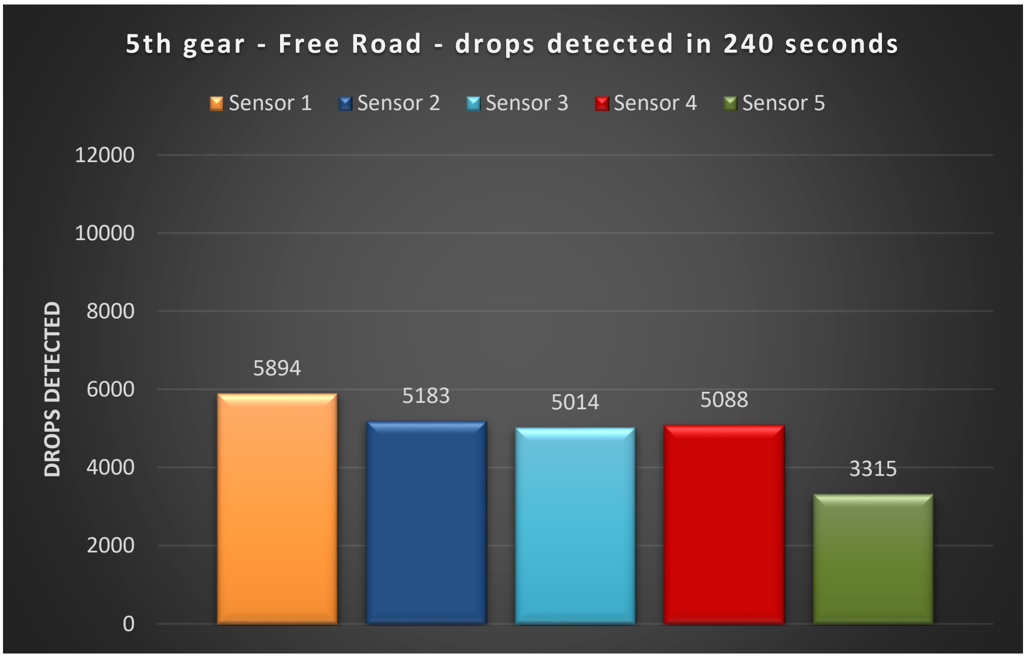
5.1 Configuration 4th gear, 90 km/h speed

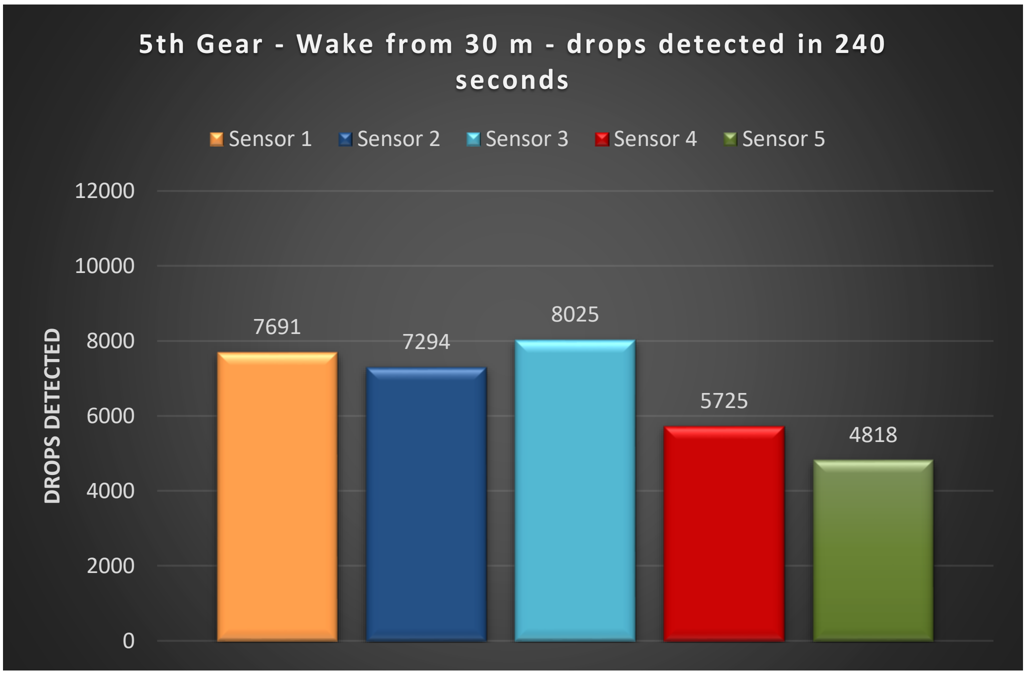


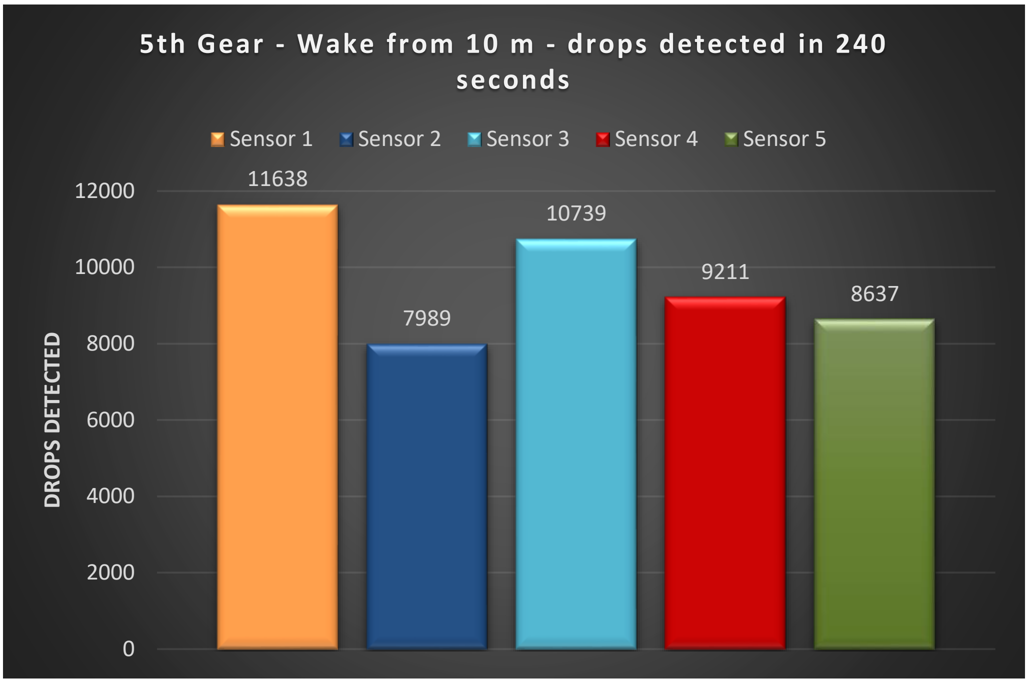

4th Gear - Wake from 30 m - drops detected in 240 seconds
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
DROPS DETECTED
12000
10000
8000
6000
4000
2000
0
8023
7440
7876
5840
4781


4th Gear - Wake from 10 m - drops detected in 240 seconds
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
DROPS DETECTED
12000
10000
8000
6000
4000
2000
0
11980
7822
10721
9727
8022

5.2 Configuration 5th gear, 90 km/h speed



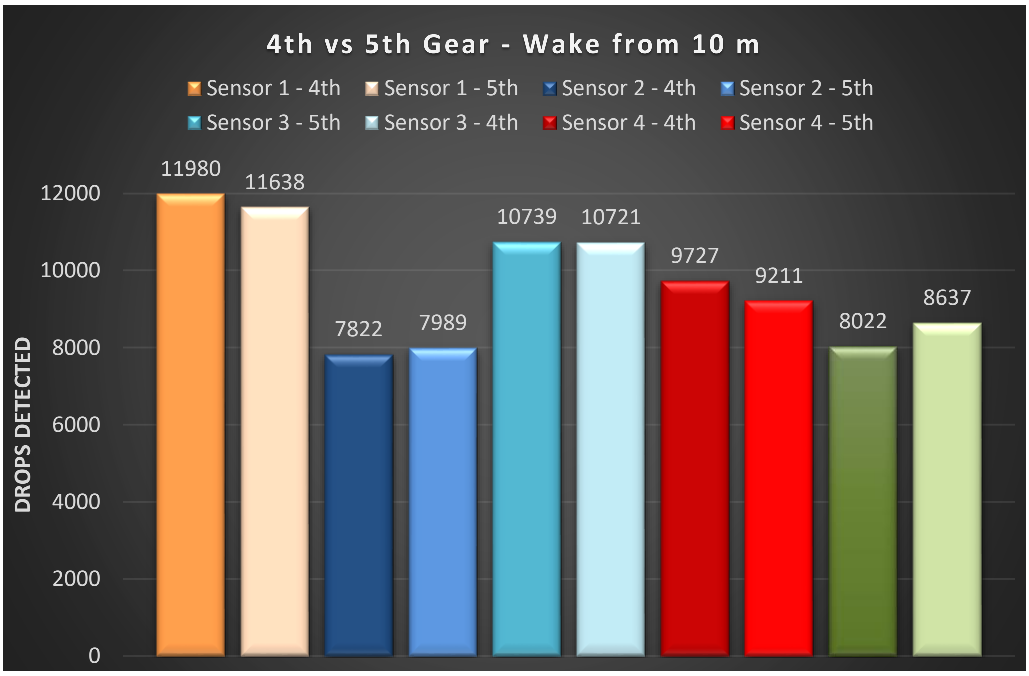



5th Gear - Wake from 10 m - drops detected in 240 seconds
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
DROPS DETECTED
0
2000
4000
6000
8000
10000
12000
11638
7989
10739
9211
8637

5.3 Results analysis

Analyzing the data collected, it was possible to formulate the following considerations:

- The worst condition, where the rain sensors and especially the ones near the front end gather more water, was the test at 10 meters of distance.
- At very close distance, the lower part of the bumper took always less water than the medium and high areas.
- Different gears brought very slight differences; for high engine revs condition, the opening of the throttle wasn't the main factor impacting on the results. Taking into account the tests done at 10 meters, the results in 4th and 5th gear were very similar:



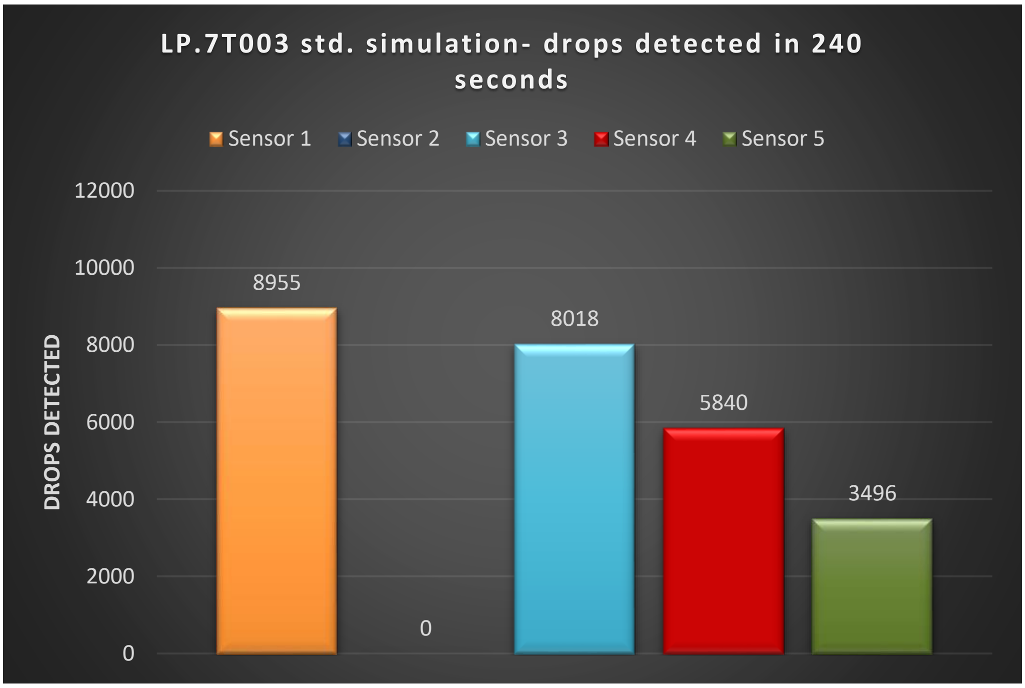
The results confirmed what was visible during the road test: at longer distances the splashguards and the anti-intrusion bar of the truck prevent most of the water to be raised from the asphalt; instead at closer distances like 10 meters, the splashguards fail to mitigate the effect.

6. FROM THE ROAD TO WIND TUNNEL

6.1 LP.7T003 Standard wind tunnel test

The vehicle with the same set up of the road test has been put in the wind tunnel in order to improve the old standard simulation.

The first simulation has been performed for 240 seconds with the standard method in order to understand the differences with the road test:



The results exposed two main issues:

- **The sensor 2 did not detect a single drop**. Considered immediately an electrical failure, the area of the bumper around that sensor has been checked after the test and, actually, it was completely dry, the sensor was working correctly. The not correct alignment of the nozzles has likely created an “air bubble” in front of that part of the bumper that kept the area completely dry. This type of mistakes are very critical because, if the “air bubble” is forming in front of the dirty air duct area, can create false positive during the validation tests.
- **The low height of the nozzles**, which made the water on the hood not compliant; the deviation of the results could be more significant for larger and higher vehicles.

Considering the speed of the car and of the wind to be invariant, the possible corrective actions, in order to obtain the desired results, were applied on:

- Traction load of the car;
- Water flow rate and number of the nozzles;
- Nozzles realignment in position and height;
- Air pressure of the nozzles.

6.2 Traction load

Differences in the traction load of the car, if already high, showed little contribution in affecting the results of road tests. Therefore, the new traction load for the climatic wind tunnel tests was chosen to be high but as plausible as possible:

- Flat road simulation;
- 90 km/h of roller speed and 80 km/h of wind speed;
- Second-last gear, which in these tests was the 5^{th} gear;
- GCVW, gross combined vehicle weight that is laden vehicle with its admissible laden trailer.

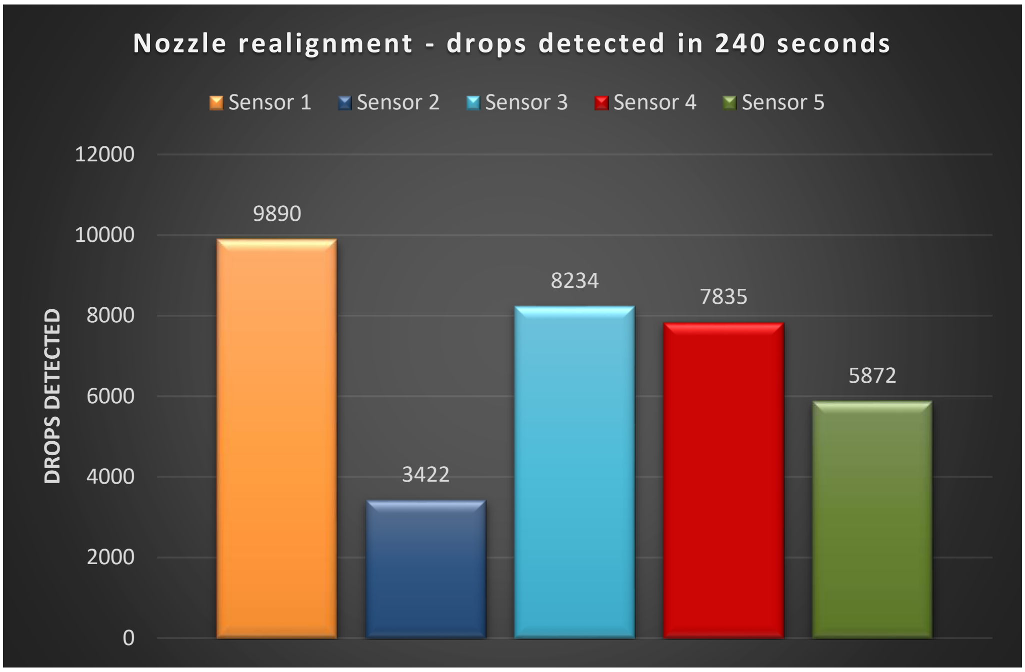
6.3 Water flow rate and number of nozzles

Acting on the water flow rate and the number of nozzles wasn't an immediate option; the actual flow rate is the maximum allowed by the hydraulic system, and new nozzles would require maintenance work, so this option has not been investigated.

6.4 Nozzles realignment

The easiest corrective actions were to adjust the nozzles directions and rise the nozzle height. In this way, it was possible to align the water distribution of the wind tunnel with the ones measured on the road test.

The best combination of nozzle realignment and height modification gave the following results:



It was very difficult with only one row of nozzles to obtain the same result of the road data; moreover, the detection rate still was inferior.

6.5 Air pressure decrease

In the different configurations checked to find a good correlation, the decrease of the air pressure of the nozzles has been quite effective for get closer to the target.

The effect obtained by changing the air pressure of the system could be explained by the fact that the spray, with 3 bar of air pressure, is more similar to mist instead of rain. The droplets are so small that become more difficult to be detected by the sensors with a level of detection set to medium. It wasn't possible to set the sensors to a more sensitive level because, as noticeable in the 10 m distance road tests, they were already close to the maximum data acquirable.

Figure 16: the spray at 3 bar of air pressure, similar to mist

With the air pressure set at 2 bar instead, the drops are clearly visible even with the naked eye and easier to be detected by the sensors.

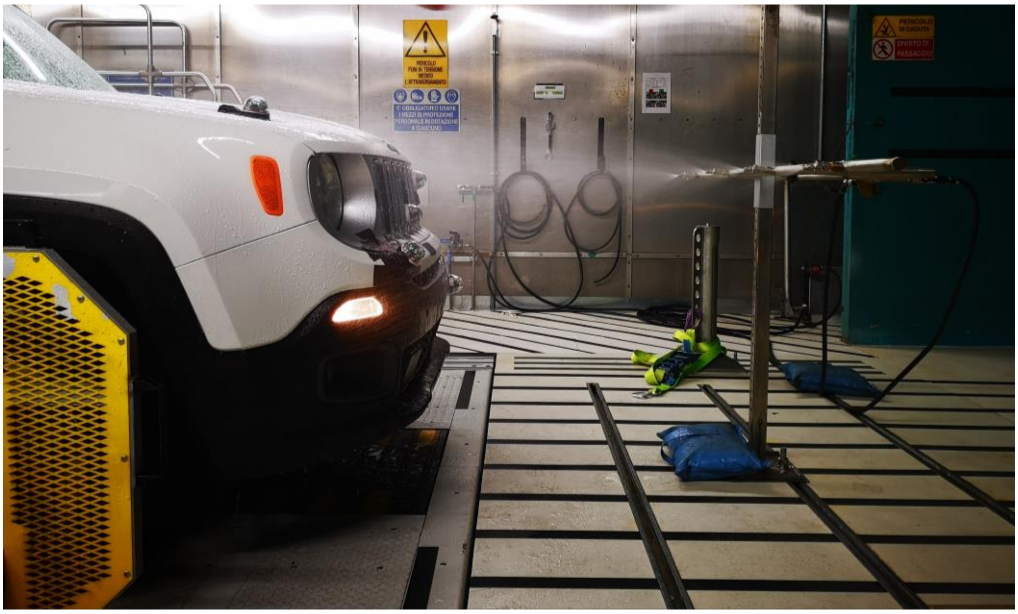
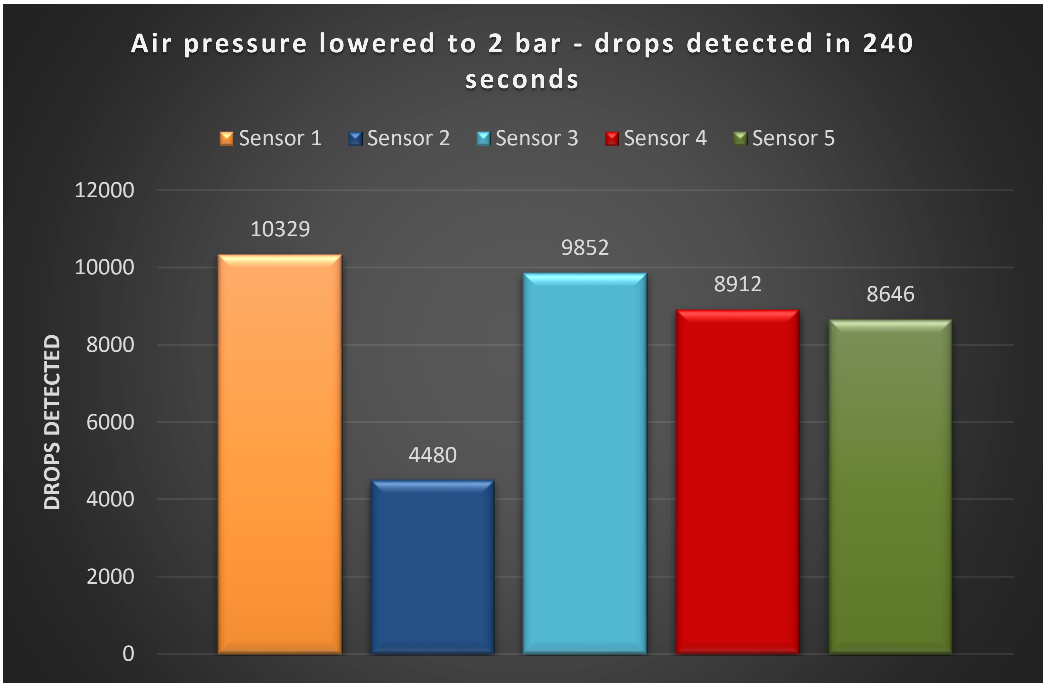


Figure 17: the spray at 2 bar of air pressure, drops are clearly visible

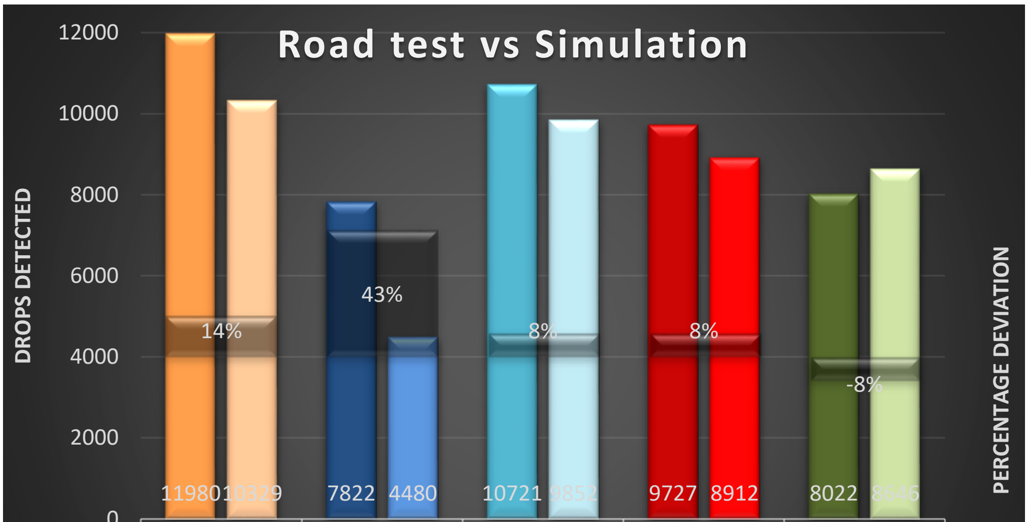
Figures 18 and 19: the windscreen a couple of seconds after turning on the wipers; on the left picture the air pressure system is 3 bar, on the right picture the air pressure system is 2 bar

Therefore in the following test the air pressure was decreased from 3 bar to 2 bar, obtaining a significant improvement:



7. CONCLUSIONS DRAWN AND FUTURE ACTIONS

The last test performed in the climatic wind tunnel showed that the new setup of the simulation plant has greatly improved the results. The road test, 10m wake – 4th gear, still showed a higher detection of about 14% for sensor 1, 8% for sensor 3 and 4, -8% for sensor 5. The sensor 2, in the lower part of the bumper, showed a large difference of about 43%.



	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5
Road	11980	7822	10721	9727	8022
CWT	10329	4480	9852	8912	8646
Deviation	14%	43%	8%	8%	-8%

Even if modifying the layout of the nozzles and decreasing the air pressure have brought a good improvement, reaching the uniformity of the values found during the road tests on all the sensors was not possible. As the chart shows, the main difficulty is to direct the flow of the nozzles to cover the surface, both below and above, as the road test pointed out.

Moreover, considering that the Jeep Renegade used for this research is a small SUV, find the right nozzles layout that ensure the uniformity of the spray even on larger vehicles implies the necessity of realign the nozzles every time, which couldn't be accurate unless using on each simulation the rain sensors.

7.1 Number of nozzles and water flow rate

The best way to achieve water distribution on the bumper, as found in the road tests, is having more water outlets, so that the re-alignment of the nozzles is no longer necessary and each one can direct the flow to a specific area.

The proposal is building a new row of four nozzles above or below the existing one, increasing even the water flow rate, giving to the second row a separate hydraulic circuit so they can be controlled separately.

The proposal has been approved by the management and will be implemented within the current year. Adding a second row of nozzles with its water line involves carrying out maintenance work on the hydraulic system of the wind tunnel, which needs time to be completed.

As proposed, the hydraulic maintenance plan involves creating a second row of spray nozzles and the new water circuit, actually doubling the flow rate. Two separates valves will control the flow on each row.

With the new system put into operation, the tests in the climatic wind tunnel will be repeated, in order to find the best layout of the nozzles and the flow rate of the water in the two different circuits.

7.2 Validate the test and update LP.7T003 standard

The last step of this research is to perform the wind tunnel simulation on the car for 120 minutes twice, the first as written in the old standard and the latter it with the new parameters and then compare the results, weighting the filters.

Another couple of test will be performed with a car of another market segment, without the rain sensors, and the weight of the filters compared again.

In this way, if no anomalies occur, the test can be considered validated and proposed for the update of the standard.

If the author of the standard is going to accept the results obtained, all the new inputs will be added to the LP.7T003 standard, which then will be officially updated by the standardization body.

8. CONSIDERATIONS ABOUT THIS EXPERIENCE

The opportunity to arrange this research represented an extremely useful way to **think outside the box**, which should be the foundation of every methodological experimentation. Every phase, starting from the original question *"is the rain simulation plant still suitable to perform slipstream tests?",* passing through the search for the sensors suitable for testing, up to the road and wind tunnel tests and their results, had to be thought from scratch.

The continued **cooperation** with Aerothermal colleagues led to an evolution of the research; the original question turned into the real problem: *"how much rain hits the front of the car?"*, problems and opportunities analyzed, proposals for improvements shared and approved by the management.

Nowadays methodological experimentation assisted by **technology** more and more advanced, new generation instrumentation flanked by virtual analysis, allows us to examine physical phenomena that up until a few decades ago could only be managed by human experience.

These three inputs: thinking different, cooperation and technology, are the keys to achieve excellent results, especially in the automotive field of tomorrow.