Study of Vehicle Aerodynamics with the ICFD Solver and its Application to the Quarkus P3 Pikes Peak Version

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1 Introduction

The study of external aerodynamics is now an integral part of the development of new vehicles. Indeed, in the current context of reducing energy consumption, it is essential for a vehicle to minimize losses wherever possible. Optimizing external aerodynamics limits the aerodynamic drag generated by the vehicle and therefore optimizes its energy efficiency. Moreover, in a car race context, it is also important to improve downforce to keep the vehicle on track in corners.

For a long time, manufacturers have used simplified models to carry out these studies. However, given the growth in computing capacity and the need to obtain results faithful to experiments, the models have become more complex.

This paper helps to highlight the capabilities of the LS-DYNA software and its incompressible fluid mechanics (ICFD) solver with respect to the transient resolution of external aerodynamic problems for models with complex geometry and with calculation times similar to steady state solutions. It provides a methodology adapted to the ICFD solver in order to solve external aerodynamic problems with reliability by intervening on different parameters linked to the surface mesh, the volume mesh, the boundary layer or even the turbulence model.

This paper presents the results of this methodology implemented to verify and improve the aerodynamic design of the Quarkus P3 which participated in the Pikes Peak race in June 2024.

2 Quarkus P3 Pikes Peak Version

Quarkus is the name of a French Supercar developed and produced by the young start-up of the same name, founded by Damien Alfano.

Why give it the name Quarkus? Quark is the smallest elementary particle which makes up, among others, protons and neutrons. This word symbolizes Quarkus' ambition, to return to basics. Because times are changing and today, the automobile no longer necessarily smells of sanctity. It is accused of all evils: pollution, danger, toxicity, destruction of the planet. This awareness leads to the search for solutions to reduce negative impacts.

And the solution is obvious: we must reduce the mass! This therefore gives a very light car entirely made of composites, thermal engine, low displacement, compatible with synthetic fuels and slightly hybridized, sequential gearbox and 300 horsepower at 12,500 rpm for less than 600 kilos.

The Quarkus is above all intended for the gentleman driver, passionate about motorsport and who exercises his driving skills on the circuit. The tubular composite chassis was developed for racing, as were the running gear, ground clearance, etc. This is a real racing car. The little extra is that it is also designed for the road. A technical miracle, a simple button allows you to switch the car from a circuit configuration to the approved one for the road.

Dynas+ group is Quarkus partner for all digital simulation activities in the current development phases of the Quarkus 2 and 3 prototypes with LS-DYNA. For the Quarkus P3, a specific version has been developed to participate to the Pikes Peak International Hill Climb, which is a world-famous hill climb race held on the mountain of Pikes Peak in Colorado in the United States. The route is 19.93 km long and has 156 turns. The start takes place at an altitude of 2,865 meters and ends around 1,440 meters higher, hence its nickname: “The race to the clouds”. Arriving near the summit, the ravine reaches 600 meters at its highest and there are few protective barriers. The danger is real: the race (training phases included) experienced its fifth and sixth fatal accidents for two motorcycle drivers in 2014 and 2015.

Fig.1: View of the Quarkus P3 Pikes Peak Version

3 First ICFD calculations on P3 Version

In order to better understand the aerodynamic characteristics of the Quarkus P3 (flows, turbulences, pressures, drag, balance and downforce), wind tunnel simulations are performed using the ICFD solver of LS-DYNA.

As always with this solver in aerodynamic calculations, only the tunnel surfaces and external car surfaces need to be meshed using triangles, and the volume mesh is performed automatically. Dimensions used for the tunnel are about ten times the car dimensions in each direction to avoid any effect of the boundary conditions.

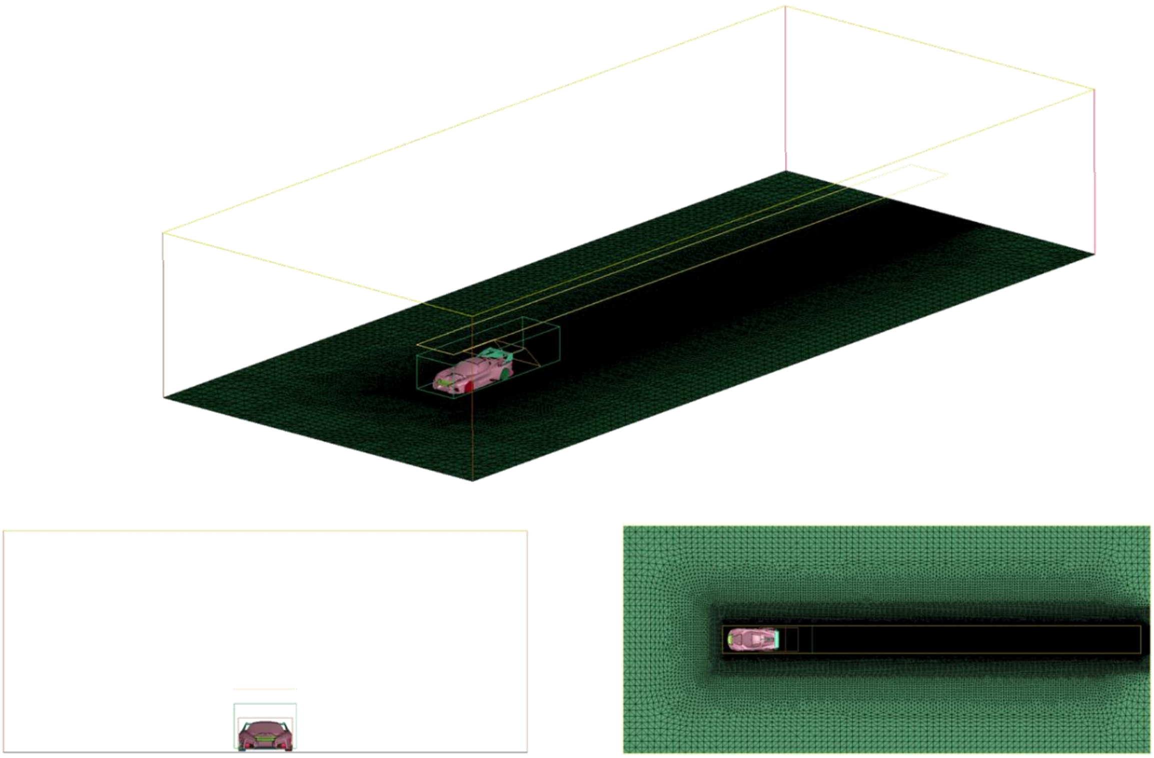

Fig.2: Views of the wind tunnel model

For the Quarkus P3 itself, DEP MeshWorks meshing tools are used to create a fine draping mesh with maximum details, leading to a mesh size between 5 and 20 mm. In this first version, some internal flow details are simplified compared to real ones. However, this model is quite complicated because it integers the openings at the front, near the wheels, next to the side windows and near the rear wing attachment in order to obtain an internal air circulation up to the engine under the rear hood of the car.

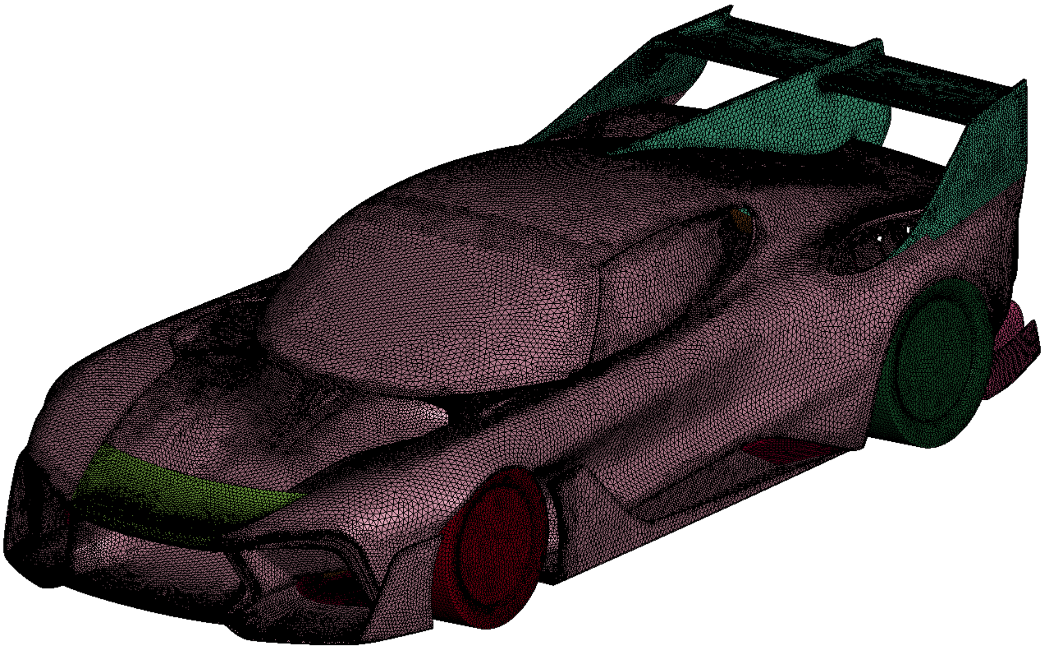

Fig.3: View of the Quarkus P3 first draping mesh

After a sensitivity study on several numerical parameters (mesh size and dimensions of the refinement box around the car, turbulence models, time steps, remeshing, number of elements in the boundary layers), a configuration is chosen in order to have sufficient accuracy with quite fast calculations. The principal options used for the final calculations are the default turbulence model of ICFD solver, two elements in the boundary layer and a close gap between wheels and ground.

First calculations have been realized for an air speed of 50 km/h in order to observe the aerodynamic behavior of the car at low speed. The following figure shows an example of stream lines observed.

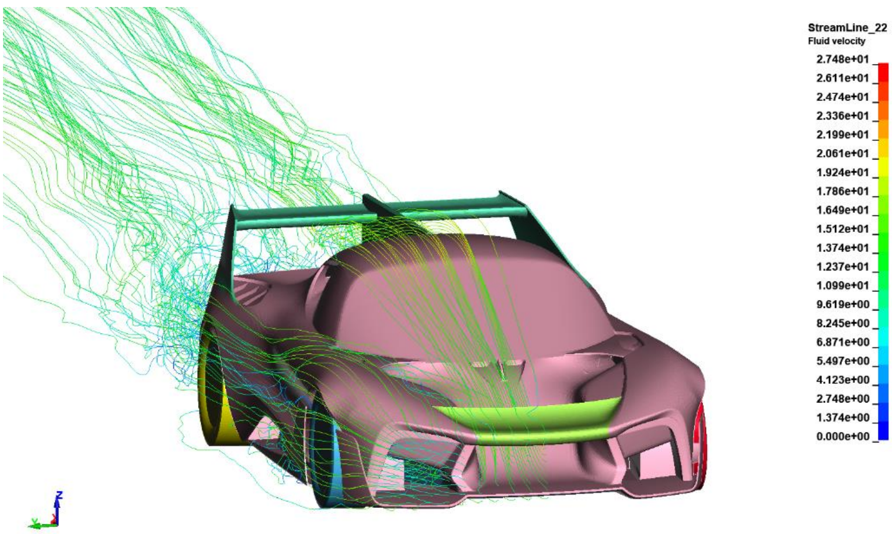

Fig.4: Stream lines of Quarkus P3 at low speed (50 km/h)

The Pikes Peak race taking place at high altitude, a calculation test was made with the atmospheric conditions (air density and viscosity) at an altitude of 2500 meters. At this low speed, the results in terms of Drag and Lift (see next picture) show that the altitude could cause a reduction of around 15-20% in drag and downforce. The Drag/Lift ratio seems to be a little bit better than at sea level but the decrease of downforce could be a problem to well hold the road in the sharp turns of Pikes Peak Mountain.

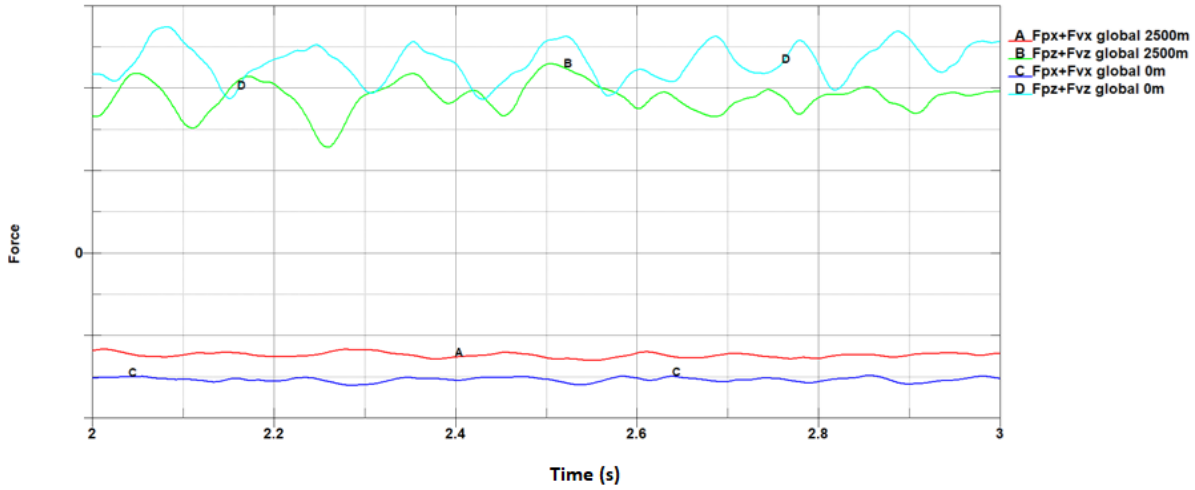

Fig.5: Drag and lift of Quarkus P3 at low speed (50 km/h)

Other calculations at different speeds (70, 150 and 200 km/h) and different altitudes (2500, 3300 and 4500 m) have been performed in order to give to Quarkus an overview of what kind of challenges they are facing in terms of aerodynamics.

4 ICFD calculations on P3 Pikes Peak Version

In addition to the results provided by Dynas+ on the aerodynamic performance of the P3 on a race like Pikes Peak, Quarkus has identified additional needs for engine performance at high altitude. Therefore, in order to increase downforce and to bring more fresh air to the engine, Quarkus modified the aerodynamic kit.

To evaluate the impact of the aerodynamic kit evolution, Dynas+ modified the numerical model to make new simulations with several objectives:

- Observe air flow at different altitudes at the level of the engine air inlet scoops,
- See the evolution of aero support at different levels,
- Evaluate drag and lift depending on the spoiler angle,
- See the effect of addition/removal of internal flows in the bodywork.

For this purpose, modifications of the draping mesh have been performed using DEP MeshWorks software morphing and meshing capabilities to quickly include the following design evolutions and tests:

- Increase of the rear spoiler size,
- Addition of a front funnel in the hears,
- Addition of a funnel at the rear brake,
- Addition of splitters,
- Modification of the front shape,
- Modification of lateral air inlets,
- Modelling of the exact shape for internal flows in the bodywork,
- Modification of the rear spoiler angle.

A view of the modified surface mesh of Quarkus P3 Pikes Peak Version is shown on next picture.

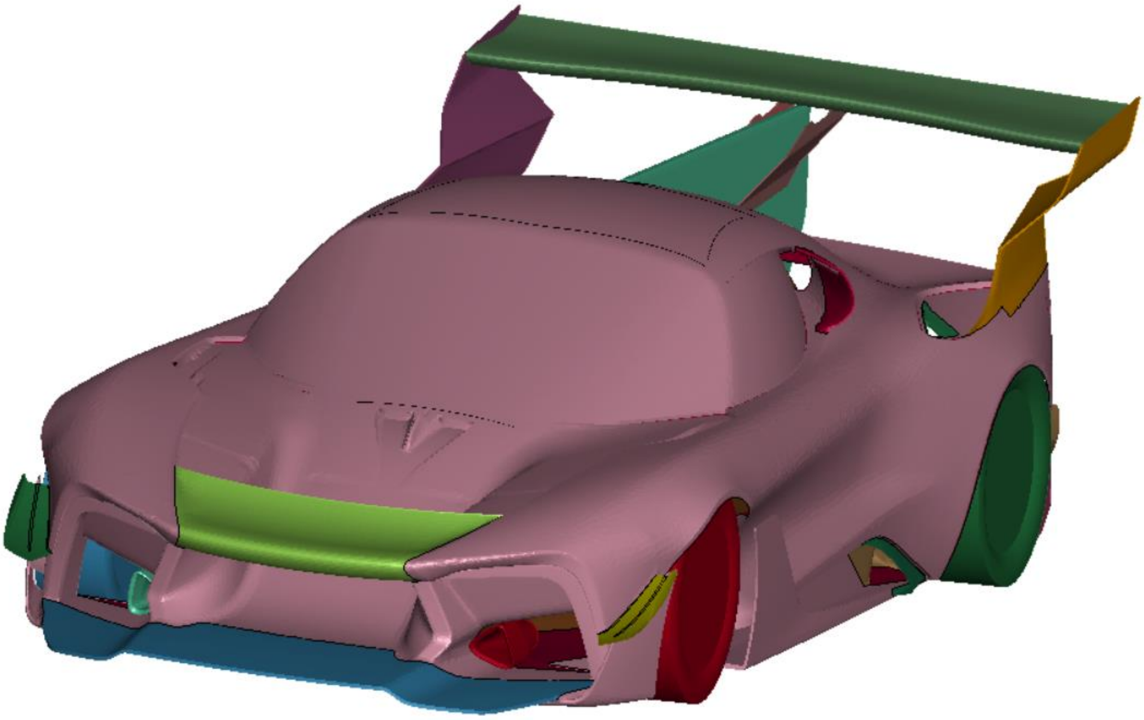

Fig.6: View of the modified Quarkus P3 Pikes Peak Version model

The influence of these modifications has been intensively tested with dozens of simulations at several altitudes and speeds, in order to provide Quarkus inputs to validate the final design of the Pikes Peak Version.

As a first example, a study on the effect of the new design at 200 km/h and 3300 m altitude showed that global drag of the car in this case is increased by 19% but global downforce is increased by 134%, reassuring Quarkus in its choices.

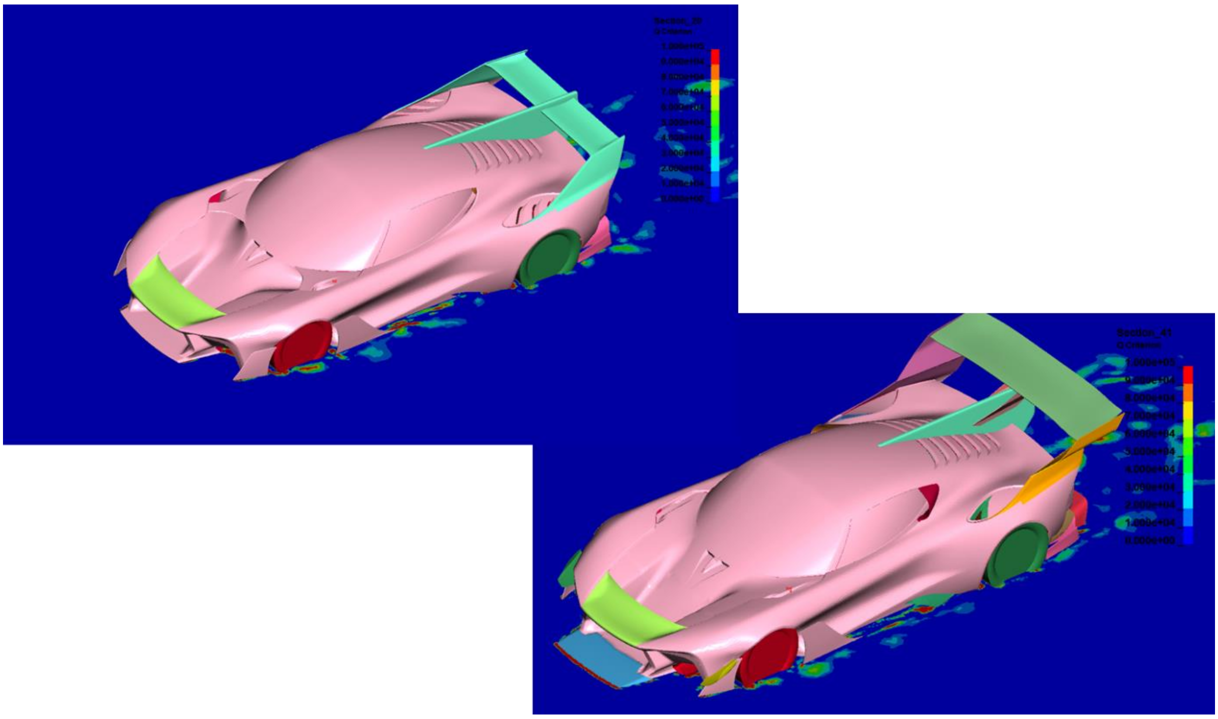

Fig.7: Example of comparison between P3 and P3 Pikes Peak versions (200 km/h, alt. 3300 m) – Q criterion around the vehicle

As a second example, a study on engine air intake scoops with a comparison between P3 and P3 Pikes Peak Version showed that, playing on the openings, it is possible to increase by 10% the air flow reaching the engine while increasing the overall drag by only 0.2%.

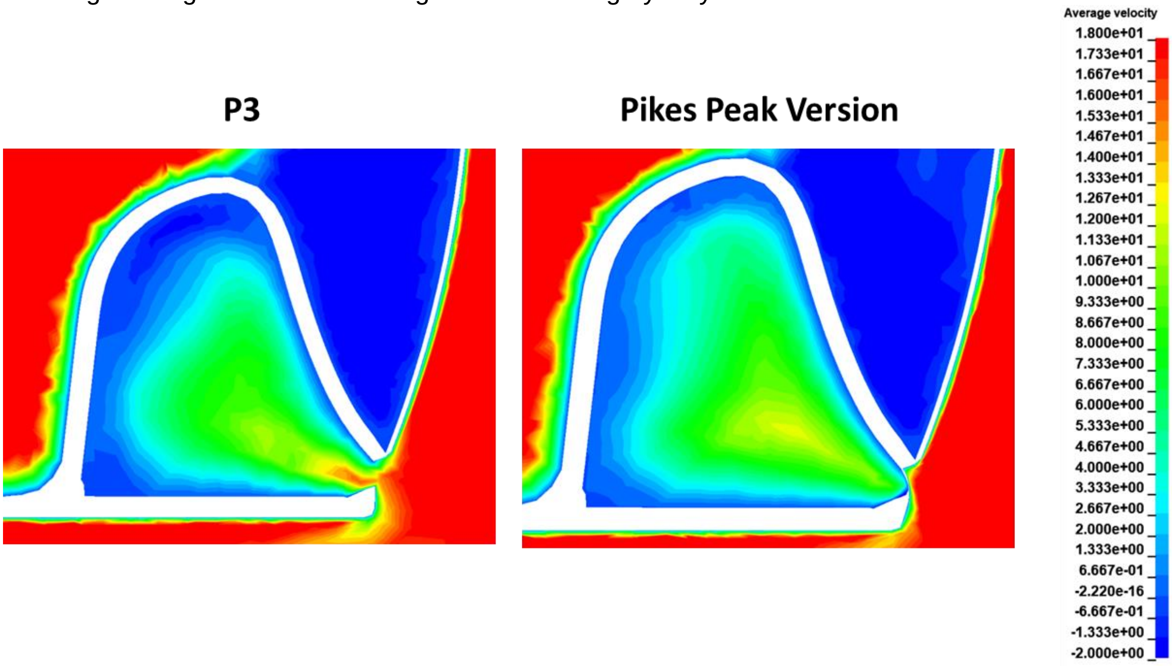

Fig.8: Example of comparison between P3 and P3 Pikes Peak versions (150 km/h, alt. 3300 m) – Average velocity in the hears

As a last example of the contribution of CFD simulations to the project, a sensitive study has been performed on the front splitter length using morphing capabilities of DEP MeshWorks. Values tested started from 0 to 200 mm, in order to observe a potential increase of front downforce. This study highlighted an improvement of this downforce up to 4%.

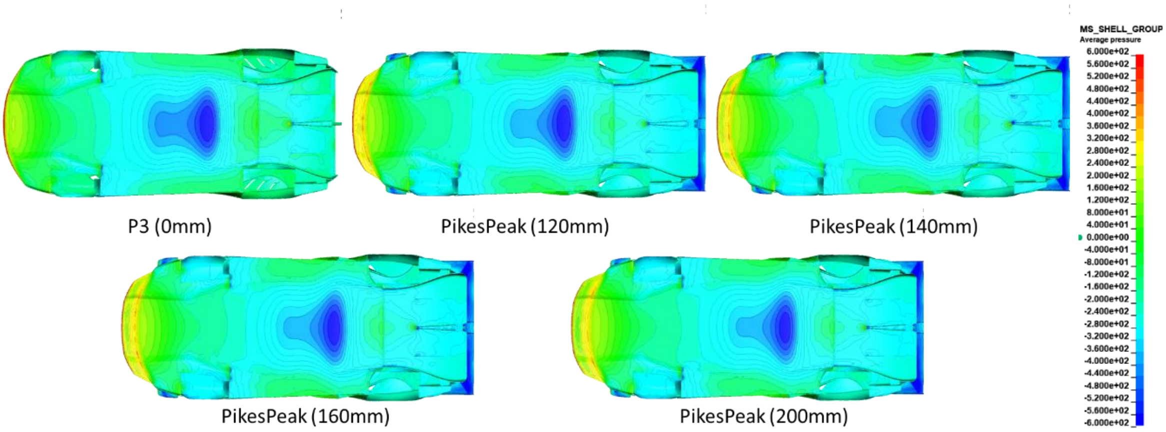

Fig.9: Example of parametric study on the front splitter length – Average pressure under the vehicle

5 Conclusion

This paper presented an overview of the work realized by Dynas+ on the aerodynamic part of the Quarkus P3 Pikes Peak Version project. The objective was to help Quarkus to validate major changes in aerodynamic kit, made necessary by the extreme profile of the race.

Simulations performed with ICFD solver of LS-DYNA have allowed to verify that modifications made by Quarkus on its Pikes Peak Version are efficient to bring a good airflow in order to supply the engine with oxygen and to ensure aerodynamic support in order to maintain good trajectories in each sector of the race.

In the future, Dynas+ and Quarkus will extend their productive collaboration using Ansys LS-DYNA solvers and methods to address the following innovation pathways:

- Bonding strategy: resistance to static, dynamic & crash stresses,
- Optimum solutions for the knots of the tubular frame,
- Chassis/powertrain and chassis/body connection solutions,
- Energy absorption strategy integrated into the body/chassis,
- Aerodynamic optimization taking into account aeroelastic coupling,
- Take full advantage of coupled fluid/structure capabilities for active control.

6 Literature

[1] ICFD Theory Manual, Incompressible fluid solver in LS-DYNA – I. CALDICHOURY, R. PAZ, F. DEL PIN, LSTC, Wednesday 8th October, 2014.

[3] LS-DYNA® KEYWORD USER'S MANUAL VOLUME III Multiphysics Solvers – Ansys LST, 16th February, 2024.