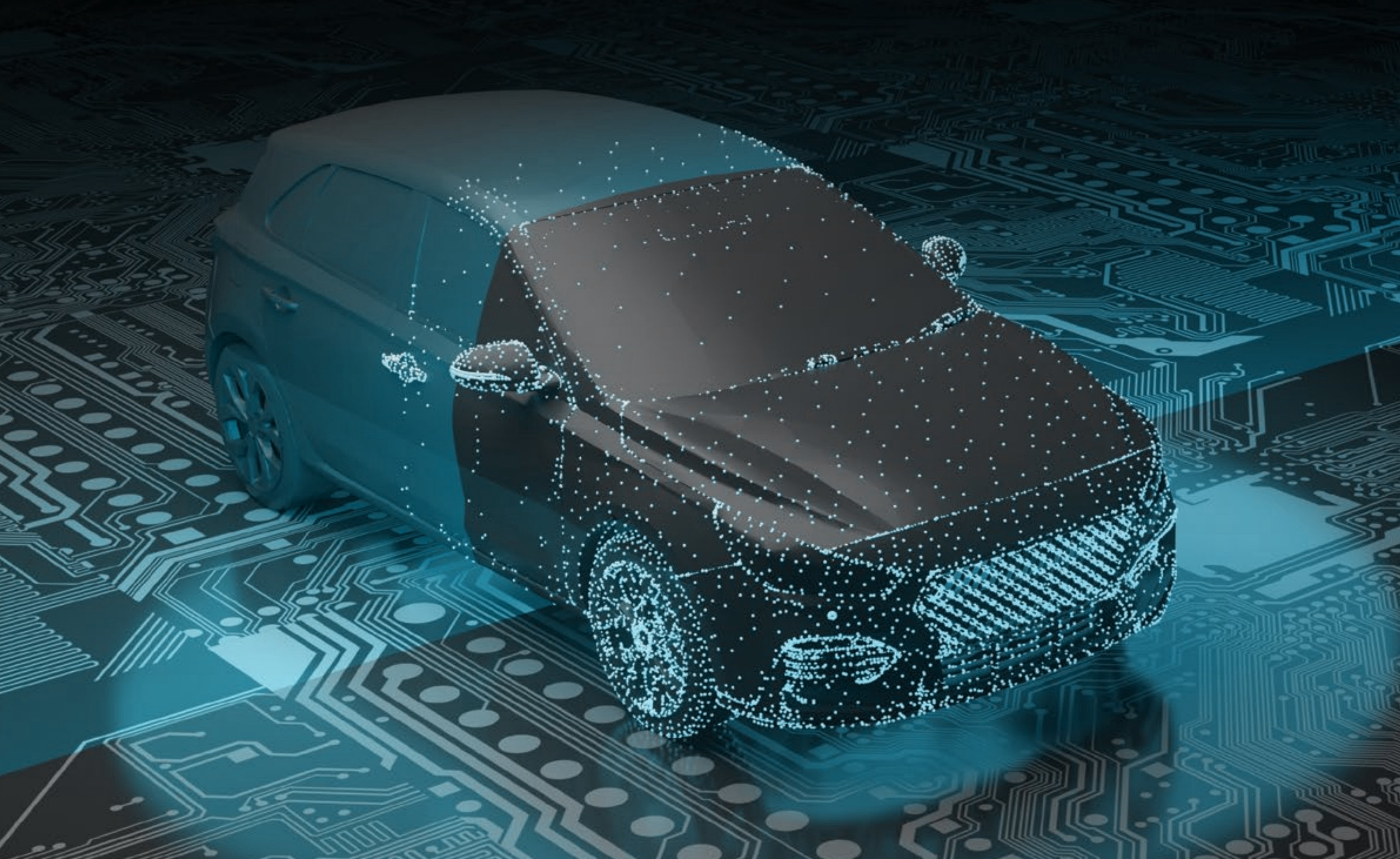
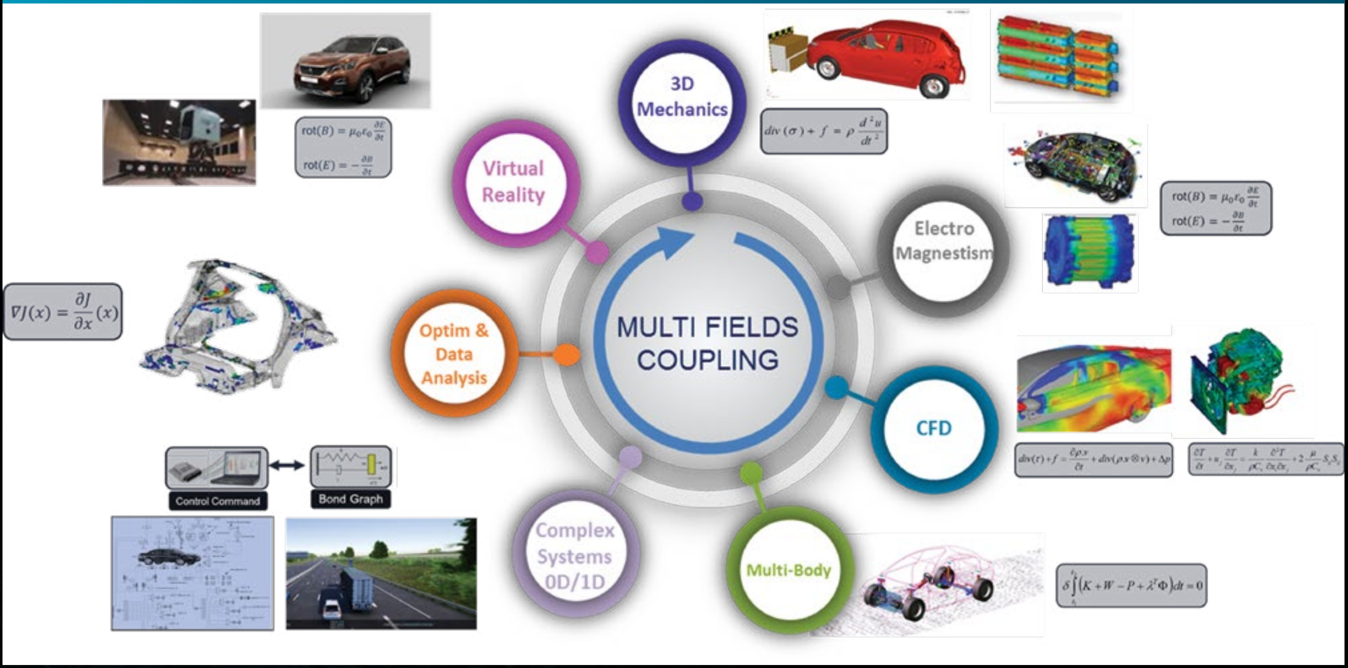
Laurent di Valentin, Stellantis - PSA, France

The complementarity of Machine Learning with CAE for vehicle development



Laurent di Valentin from Stellantis (the former PSA, Peugeot Citröen in France) was recently interviewed by *Engineering Reality Magazine* on his thoughts regarding the adoption of Machine Learning (ML) and AI (Artificial Intelligence) as applied to automotive CAE design processes. His own engineering background includes twelve years as a technical expert in simulating structural NVH, durability and crash plus managing CFD and 0D/1D systems modelling together with CAE methods and processes. An early advocate of ML and AI inside automotive design & engineering departments, he has been instrumental in pushing beyond tried-and-trusted CAE design space exploration and design of experiment (DoE) approaches towards machine learning and beyond to improve productivities of CAE engineers in automotive design while not compromising on simulation accuracy.

Main CAE fields



Q. Explain the CAE processes you have been involved with at Stellantis/PSA?

A. In my view computer-aided engineering should cover the full life of a vehicle project. CAE is well established now in all automotive workflows and has resulted in a drastic reduction in the number of physical tests involved compared to say 10 or 20 years ago. This is due to the possibility of us covering modelling of all the major fields in CAE physics: mechanics (vibration, crash, structural fatigue), thermal and fluid (aerodynamics, combustion), electrical (motors, ECUs) and chemical (batteries). It is therefore natural that through the understanding of these physical phenomena and the constant development of CAE behavioural models that digital simulation has increasingly imposed itself upon project decision-making processes. Numerical CAE models, although delivering detailed and very rich information, remain an approximation of reality however, and are always limited by the computing power available on site. But the need for more and more CAE calculations never stops growing as we seek to optimise a car's design in a faster manner yet maintaining simulation robustness.

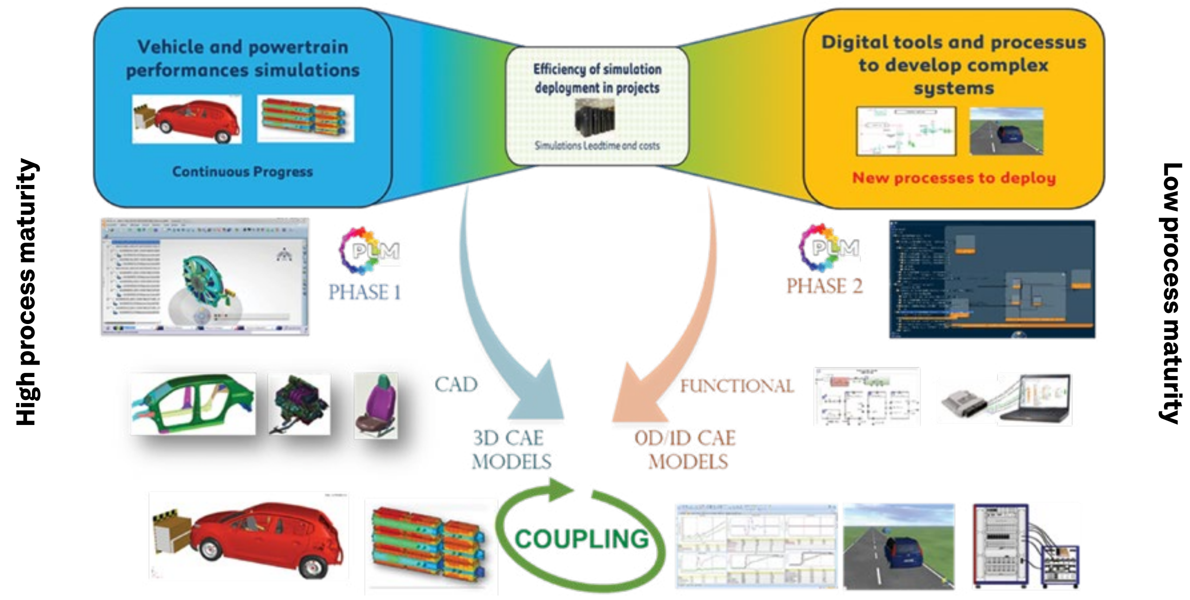
Q. What are the big trends you see impacting the automotive industry?

A. The automotive industry is impacted by the big megatrends in the world today in terms of a growing global population (predicted to be 8.5 billion by 2030 and 10 billion in 2050) wanting more mobility than ever before; 3 billion more mobile people than today. However, environmental and sustainability challenges are accelerating the need for eMobility with 35% of all car sales in 2030 projected to be electric vehicles. Connected cars are also coming with 5G enabled cars reaching 16 million in the US, China and the EU today. Autonomous vehicles have not quite been delivered but they are coming for sure, and of course automotive manufacturing operations need to digitally transform today and that will require ever more engineering simulations in future.

Q. Tell us about your philosophy of CAE coupled with ML/AI?

A. In order to build more efficient CAE processes and to cut the Gordian Knot of productivity limitations, behavioural models based on artificial intelligence can provide very interesting answers I feel. We are endeavouring to show how these different models - of knowledge and behaviour - can be articulated in order to bring greater efficiency to the project design and our CAE validation processes. In Stellantis/PSA, we are not interested in simple understanding or CAE modelling physics, but in creating mathematical models linking outputs with input parameters. Each approach delivers very different knowledge and behavioural models can be mixed in order to increase efficiency in a project from design to validation. I see these as the two main CAE processes shown on the next page. The classical approach is at a high maturity stage but the new ML/AI approach is in its early stages and is a new kind of revolution coming into automotive CAE simulation processes - AI and ML. DoE has been around for 15 to 20 years and is common in our industry. It's how we've been deploying CAE for a long time, and it produces reliable simulation. We standardised our design processes around a decade ago. For DoE, we need design parameters and the more the better to make it work; typically 10 to 15. We usually set up our models to do a large amount of CAE calculations on a Friday over a weekend to get results on our HPC computer arrays for Monday morning. Our outputs were usually scalar outputs, eg stresses, pressures. We optimised those scalars for frequency and we aim to maximise the performance of our designs. We have worked out tools and methods to optimise these CAE workflows.

Two main CAE processes



Q. So how do you distinguish between AI and ML?

A. Machine Learning is not an extrapolation of what we have done already with CAE simulations; rather, it's an interpolation. It allows us to enlarge our search area at minimal extra computational expense. It basically allows us to accelerate the building of our DoEs. ML makes DoE building more efficient, and it allows us to find the optimal design point so we can build a better 3D CAE model based on these new parameters. I would argue that ML is not new in mathematics; indeed, it is quite an old approach. HPC applied to CAE simulations over the last 10 years was a lever for growing CAE usage but ML with ROMs on laptops when trained by our full 3D CAE simulations will allow our engineers to do design space simulations more quickly. The advent of more HPC, cloud and GPUs are enabling ML coupled with CAE to be applied to more complex models than ever before and will allow us to size the problem faster. ROMs that we use will have to take into account high levels of model complexity. Indeed, if we build ROMs for a Friday and run them over a weekend, they can be configured to optimise designs almost on a live basis to change parameters to get an optimal design by Monday morning. Artificial Intelligence methods by comparison, will use not just simulation scalars but curves of simulation data based on for example scalars varying over time. We can therefore use Reduced Order Models (ROMs) to get answers and parameters for more complex 3D CAE outputs. Outputs could be a full definition of a car for instance undergoing 3D deformation in a crash. We start to enter into the 2D and 3D world with this approach rather than the 0D we were in in the past (see diagram on the next page).

Q. What do you see as the advantages of ML and ROMs in CAE simulations?

A. ML and ROMs are game changers because they will allow CAE engineers to spend their time thinking about parameters to vary rather than wait 6-8 hours for one result to come in which is what has tended to happen in the past. Now engineers can get almost instantaneous results. Basically, once trained to a 3D CAE problem, ML and ROMs will allow engineers to get near real-time results so they can spend their time making engineering decisions rather than in simulation set up and waiting for results. ML is in my experience a tool to accelerate engineering decision making but the engineer should always remain in the centre of our processes. I view ML and AI as being in the same areas of mathematics as 'Digital Twins'. They allow us to mix CAE simulation results with results from experimental test. Indeed, I foresee less and less physical tests and more and more simulation tests as these integrate together. Data from physical tests are still very important but they will be used more and more to improve the reliability of the simulation tests into what I call a "Hybrid Twin", a hybrid between physical test results and a numerical model. We invariably do this anyway as at the start of all new car projects we start from real and prediction data from a previous similar car's design that has all of our hard-earned experience and know-how baked in.

Q. What do you see as the advantages of ODYSSEE ML/AI from Hexagon in CAE simulations?

A. We first started engaging with CADLM and their ODYSSEE suite of software several years ago for its ROM capabilities as an enabler to accelerating our CAE processes. We applied it to crash modelling first because crash simulation is difficult to do since it involves non-linearity and deformation. We started with side crash events and found it good to apply ROMs as they generated design curves versus time and not just

Advantages / drawbacks of knowledge models

3D:

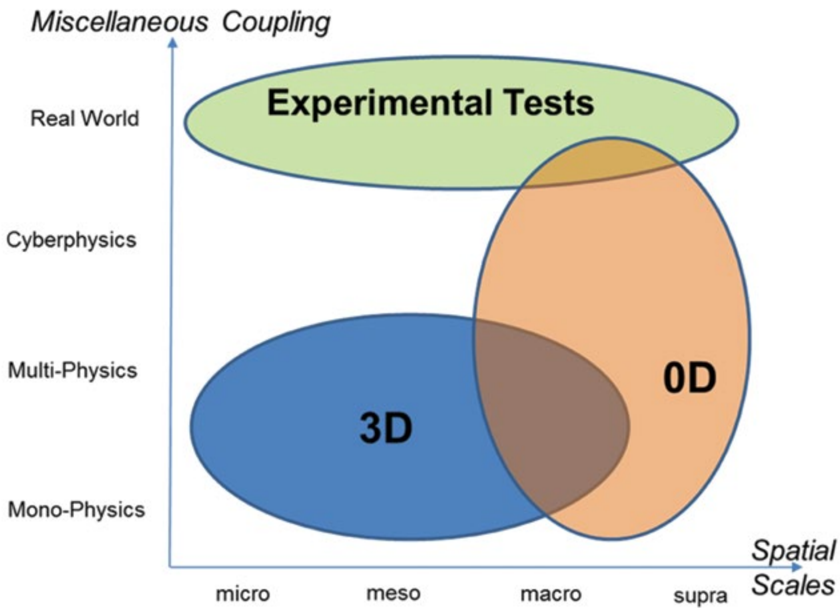
Efficient to predict local physical phenomenon (X, Y, Z) at different scales ...

But: interdomain coupling quite difficult to implement

0D:

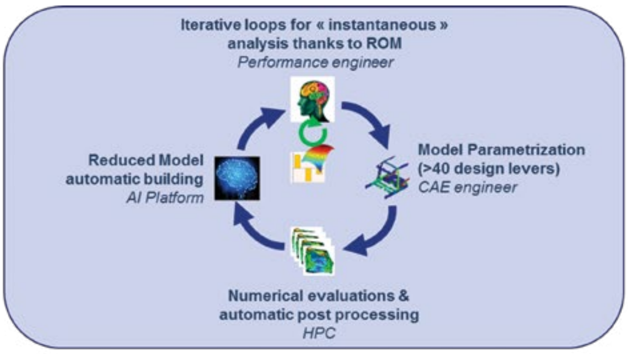
Efficient to optimise the behaviour of a set of systems of very different natures (physics, software, experimental) ...

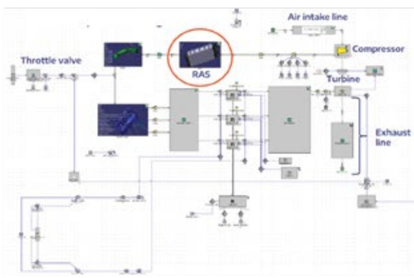
But: doesn't allow to analyse local phenomenon



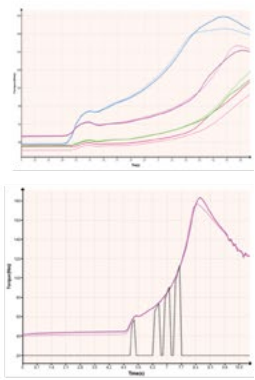
maximal deformations. We were also able to get great animations of the crash event from this approach. Our second application of ODYSSEE was in 0D-1D modelling of thermal calculation curves. We were then able to use this approach to build a DoE for the best combination of contact. We basically calculated a curve to get a scalar which was one of the benefits of the CADLM approach. We are now at the second stage of applying this ML approach to particular CAE users. We are seeing CAE engineer lead times decreasing in all projects. Between 2016 and 2020 we saw a two-fold increase in engineer efficiency and productivity because of process automation and standardisation. These types of ML deployments lead to improvements in building the CAE models (the 'CAD to Model') and in reducing the number of iterations to get to a meaningful result. It is important to say that we are not aiming to remove the specialist CAE skillset; we see ML as a way of making them more efficient and to use their specialist knowledge better during the work week. CAE engineers are trained to solve engineering problems using physics-based techniques and solving equations. It is important for them to learn and to improve their productivity, not to be replaced but to make their life more interesting and to be more efficient with their time. The human engineer should always be in the centre pushing the buttons to get results and interpreting the results.

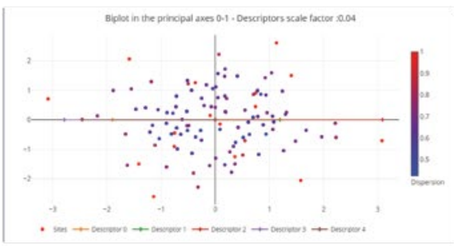
Model reduction: real time usage

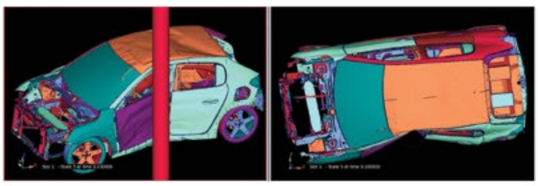




Thermal 1D Application







Crash 3D Application

Q. How do you see the impact of Cloud Computing on ML/AI in CAE simulations?

With regard to Cloud Computing and the application of AI/ML to CAE simulation, we need to explore further. These types of cloud-ready models involving HPC and GPUs might require training, eg two hundred 3D CFD models need to be simulated on the Cloud to build a reduced order model easily. The ROM could be launched during peak usage of hardware overnight and the results reviewed and analysed during the day to come up with a very different CAE simulation model than the previous day. We just haven't had access to such compute capacity in the past. It will be a major shift in thinking and workflow processes.

Q. How do you see ML and AI in CAE simulations in 5 to 10 years' time?

Today, ML is limited to ROM in the context of CAE simulation with parameters as inputs and results as outputs. We have geometry as an input and scalars as inputs too. ML has algorithms that bridge between inputs and outputs. ROMs can act as neural networks that bridge between inputs and outputs. AI, by contrast, uses algorithms that do a task where a machine learns from doing it. If I use the analogy of autonomous driving levels. Today, most auto makers offer some sort of level 3 or 4 autonomy in terms of ADAS. They are basically preprogrammed to react in a similar way to a human in a controlled way. Full Level 5 autonomy for machines would be extreme AI with "no feeling" involved. That is, a machine would produce Level 5 mechanically via technical algorithms, without any human moral or feeling involved, for example in the classic crash situation where the car is about to hit school children or elderly on a pedestrian crossing – which ones to crash into? Perhaps in 5 to 10 years some sort of AI will be built into autonomous cars that involves feelings. AI/ML will also just augment engineers' decision-making abilities. I see applications for AI and ML across all physics disciplines such as Crash, CFD, NVH etc. It will produce more reliable CAE where we can't do enough simulations today. It will lead to a better balance between physical tests and virtual simulations. AI and ML will be a bridge between 0D, 1D and 3D simulation techniques to help get the inherent advantages of each without compromising on accuracy and the creation of hybrid Meta Models. I see ML and ROMs permitting more 'vertical apps' for specific CAE application areas. So, for instance a 3D model can be reduced to a component effect inside a more complex 0D/1D model for assessing multiphysics couplings. A good example might be an unsteady 3D subsystem model appearing as a ROM in a bigger steady state 0D/1D systems model.

CAE & machine learning complementary