GETTING A GRIP ON TIRE ENGINEERING WITH SIMULATION

The number of miles the global vehicle fleet travels increases every year, and by 2030 industry analysts expect the world population to drive 20 trillion miles per year—cumulatively, nearly the distance to the nearest star. In addition, electric cars are gaining mainstream acceptance and autonomous vehicles are reaching advanced stages of testing. Together, increased mileage and the rapid diversification of the vehicle fleet means the demand for tires is likely to increase greatly.

To compete in this market, tires need to be competitive on safety, price, lifespan, fuel efficiency and ride comfort, and innovations in these offer considerable advantages to the manufacturers. Tire manufacturers focus on optimizing the "magic triangle" of design requirements: wet grip, wear resistance and rolling resistance, which are generally in competition with each other. In addition, supply chain optimization, material management and production costs all play a major role in setting the price of a tire.

This whitepaper will show the integrated tire design and engineering solution from Dassault Systèmes. This lets manufacturers push the magic triangle beyond current boundaries with advanced physics simulation, offers integration between design and simulation, and goes beyond traditional design platforms by bringing all the project data and requirements together into a single place.

CHALLENGES IN TIRE DESIGN

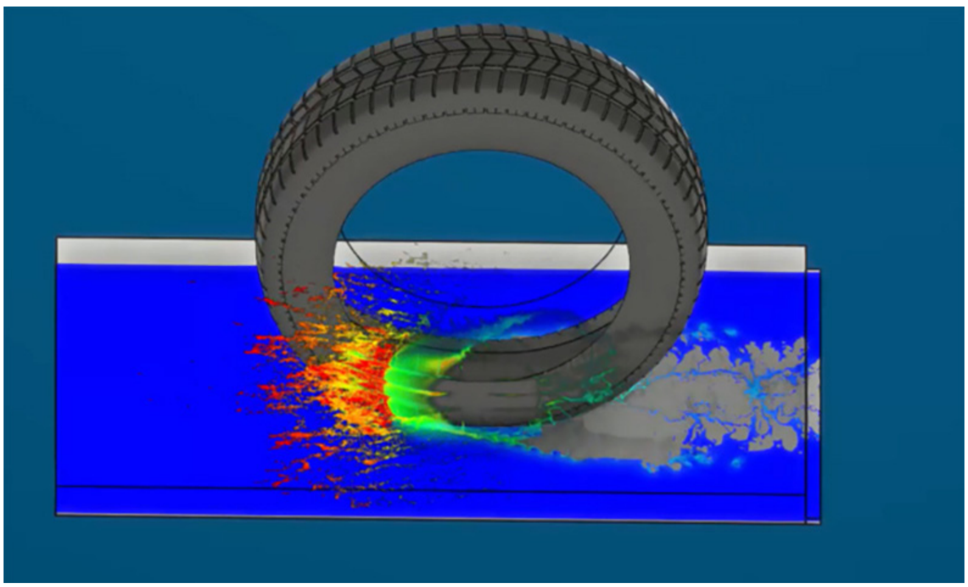


Figure 1: A tire passing through water. Hydroplaning is a complex fluid-structure interaction that can be hard to predict and expensive to test.

Tire design still involves many manual processes and a lot of disconnected tools. These push costs and time-to-market up, and make it difficult to fully explore the design space. There is often a lack of collaboration between different departments, and poor traceability of data can add delays to the design flow.

Testing tire designs is another challenge. Manufacturing prototypes and evaluating key tire performances indicators such as traction, drive-by-noise, wear, soiling, aerodynamic drag, wet grip, ride comfort is expensive, and can often only take place relatively late in design. Tires need to perform in challenging environments, including water, snow, ice, mud and dirt, and in extreme heat and cold, and replicating these in test conditions is difficult.

Changing vehicle technology is also disrupting the traditional tire design process. OEMs increasingly demand entire corner modules, consisting of the tire, wheel, brakes, rotor, hub, bearing and spindle (and sometimes even suspension and motors) integrated into a unit. Embedded technology allows smart tires, with built in sensors that can monitor variables such as pressure and road condition, which are important for autonomous driving systems, while many companies are exploring disruptive airless tires.

What all these challenges have in common is that their solution requires collaboration between many different tools and processes—sharing data between teams in an accessible, traceable way; simulating structure, friction, aerodynamics and thermal performance together; or designing all the components of a corner module to work together as a system. Design and simulation on the **3D**EXPERIENCE® platform offers exactly these kinds of solutions.

BENEFITS OF THE INTEGRATED TIRE ENGINEERING SOLUTION

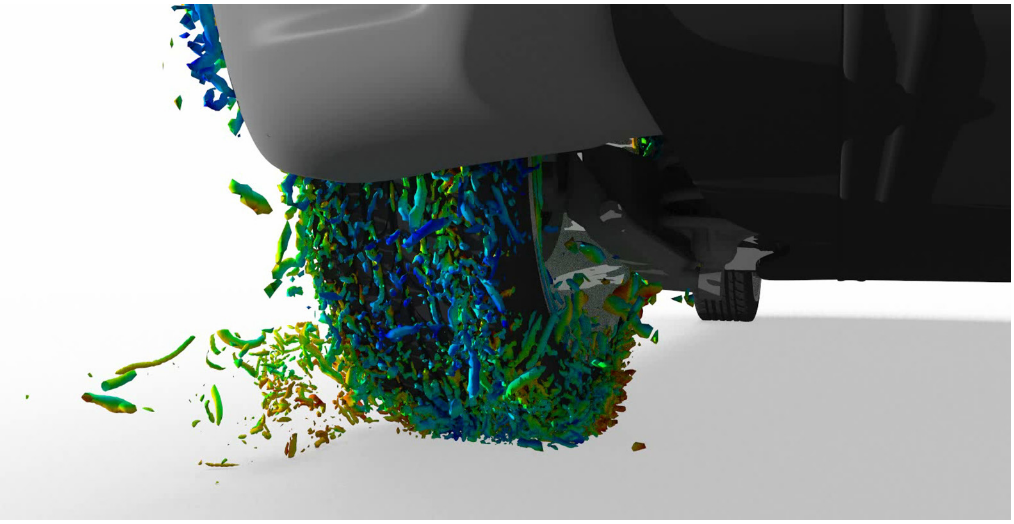


Figure 2: Aerodynamic drag from a tire. SIMULIA solutions bring together many different simulation technologies to allow

The behavior of the tire is determined by all aspects of the design, all domains of physics, and all stages of manufacturing, and how all these factors interact. The array of tools on the **3D**EXPERIENCE platform for computer aided design (CAD), product lifecycle management (PLM), simulation and system integration enable multi-attribute optimization and decision making, allowing all the many competing design requirements to be balanced.

The Dassault Systèmes SIMULIA portfolio of simulation tools covers a wide range of domains of physics, including structures (for forces and resistance), fluid-structure interaction (for evaluating tire performance in hydroplaning), aerodynamics (for calculating aerodynamic drag), electromagnetics (for sensors) and vehicles systems dynamics (for modeling full-system behavior and the interaction between components. High fidelity simulations offer significant cost savings with virtual validation, and reduce the changes required during testing by 20-60%.

The fully automated process for easy design space exploration with design of experiments (DOE), and the link to other tools such as CATIA on the **3D**EXPERIENCE platform results in an integrated design and simulation process in a single environment. With the integrated solution, the key tire performance evaluation time is reduced to hours instead of days and weeks, while automated processes for creating designs from templates speed the design process by 15-30%.

Bringing all the project data onto one platform provides full digital continuity and traceability across disciplines, including requirements, design, simulation, and project planning. The single platform cuts the time taken for peers to check design and reduces the risk of error, increasing productivity by 20-40% while reducing retrieval time by 40-60%.

DESIGN WORKFLOW

The process is straightforward: by using market requirements and past testing history, engineers can virtually create their tire cross-section, and design their desired tread patterns. From there, multiple advanced simulations can be run to analyze results and meet performance targets.

Within research & development (R&D), the tire engineering process comprises 2 main subprocesses: green tire engineering and cured tired engineering.

A green tire is the tire before curing, meaning that it has no tread patterns. It comprises the tire envelope with all the constructions and over 20 sub-assemblies. The green tire has many layers, made from as many as 200 different raw materials, including metals (belts and wires), elastomers, other chemicals and textiles. Here, the main design needs are cross-section and layout development, and simulating indoor and outdoor testing.

The cured tire meanwhile is the tire after vulcanization. Applying heat and pressure to the tire gives it its final shape and applying heat energy stimulates the chemical reaction between the rubber and other materials. Concerns here include the thread geometry and styling, international standards and marketing requirements.

However, the green tire and cured tire engineering processes are closely tied, with requirements of the finished product affecting the layout of the green tire, and the design of the green tire forming the starting point of the curing process. The tire engineering process requirements many iterations and optimization between the two in a cycle.

Both design processes start with customer or market requirements or benchmarking analyses. From these inputs, and all the testing and simulation history, tire engineers need to predict the tire performance with the best historical information available. Using the Performance Study app on the **3D**EXPERIENCE platform provides them with baselines for them to create the appropriate tire cross section and layout. At the same time, based on tread styling and performance prediction, the tire engineer designs the appropriate tread pattern to be used for the cured tire.

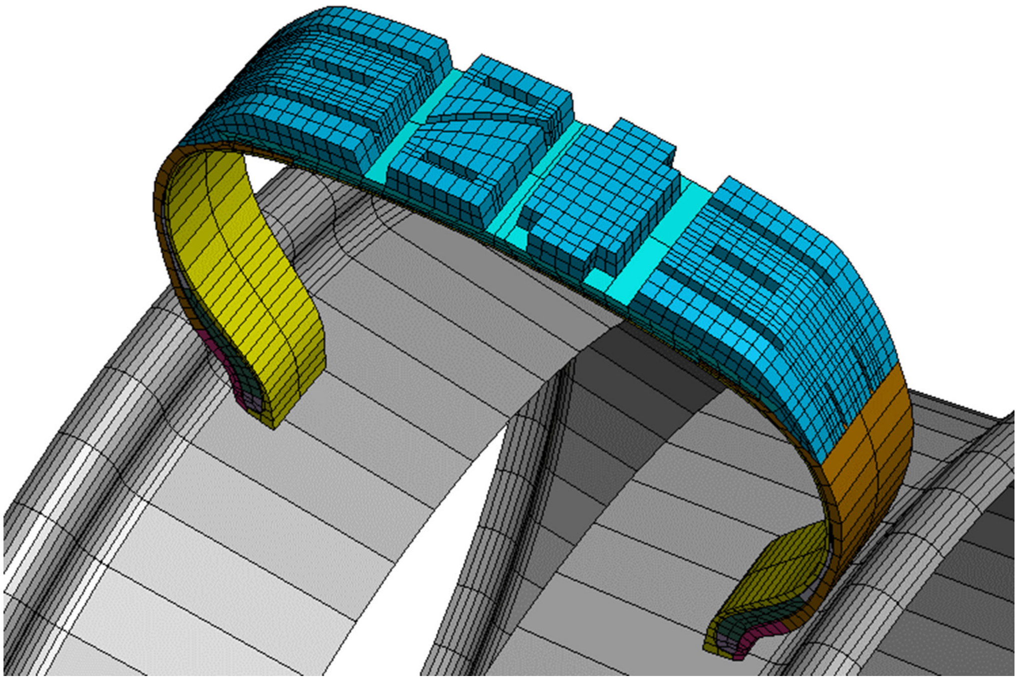


Figure 3: 3D section of geometry.

The parametric cross section of a tire is generated with Generative Shape Design application and then mesh is generated and a sequence of simulations are carried out with the help of Process Composer application to evaluate the key performance of the tire for an array of different parametric designs. Multiple types of advanced simulations are then carried out to meet the expected performance targets:

- **Footprint, Steady State Rolling, Braking and Cornering**: In almost all cases, the first step is to work on a detailed, 2D axisymmetric model to perform rim mounting and inflation (since both these operations are "axisymmetric" in nature). Create a 3D model from the axisymmetric model (step 1) using "symmetric model generation" (SMG) in Abaqus. Similarly, "symmetric results transfer" (SRT) will also transfer the results of the axisymmetric model onto the 3D model – the 3D tire model at the end of this step would, therefore, represented an inflated tire to determine the "footprint" solution – basically, determine the contact patch/pressure due to the weight of the vehicle. The Steady State Transport analysis capability in Abaqus is used to achieve the "steady state rolling" condition based on the radius of the inflated tire and the linear velocity of the vehicle. Usually, this can be extended to other scenarios such as braking, acceleration, transient rolling, and so on.The objective is to meet standards such as SAEJ 2704 for force, deflection and contact patch, and SAE J1269_200609 for rolling resistance, and to ensure grip in conditions such as braking, cornering and camber.

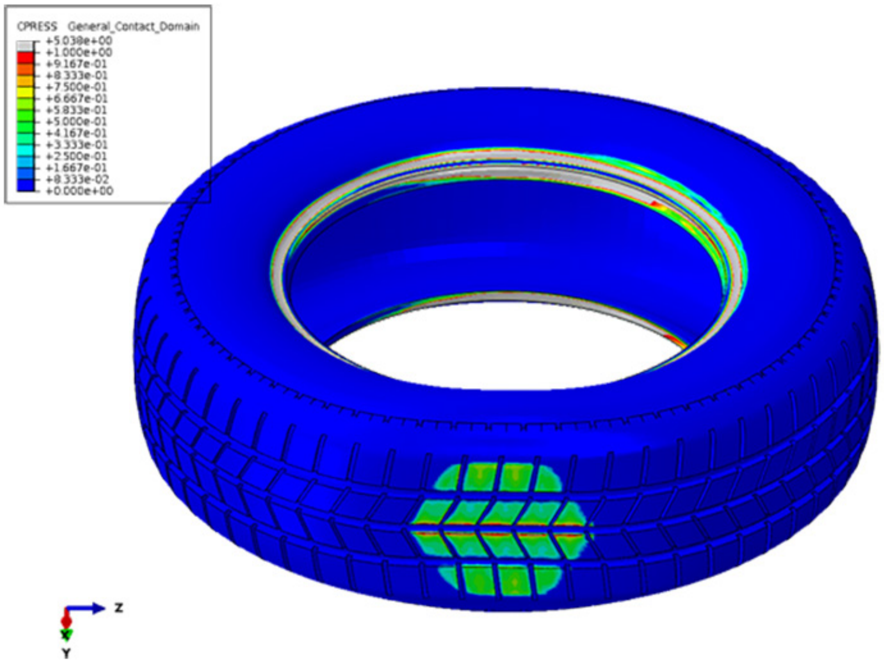


Figure 4: Contact Pressure plot from a steady state rolling simulation

- **Impact and burst**: When a tire strikes a bump, the impact can jolt the vehicle or even burst the tire. This requires transient analysis, and this can also be performed with SIMULIA Abaqus technology.
- **Wet grip (hydroplaning)**: Wet road conditions significantly affect the performance of tires, with hydroplaning posing a major risk of skidding. Testing wet grip with a physical prototype is expensive, and the complex fluid-structure integration (FSI) problem mean it's essentially to accurately model the behavior of the water. Co-simulation between Abaqus and XFlow SIMULIA technologies provides a very high fidelity solution to this challenging FSI problem.
- **Wet grip (tire-snow interaction)**: Coupled Eulerian-Lagrangian (CEL) technique is used to model the interaction between the tire and the snow with the Abaqus technology. The Abaqus model can also include the brake and anti-lock braking system (ABS), and co-simulation with the DYMOLA model can implement the ABS logic in the simulation.
- **Wear**: Tire wear is obviously an important aspect of tire safety as it can have catastrophic consequences. In Abaqus, tire wear is modeled using a general user subroutine called UMESHMOTION. This does not remove elements to simulate wear – instead, it "moves" nodes on the surface based on the wear law that is being used. The "wear law" defines the rate of material removal (wear, erosion) as a function of one or more dependent variables (such as pressure, frictional slip, viscosity, temperature and so on). Although wear laws are available in the literature, they need to be calibrated based on test data. Another option would be to come up with "empirical" wear laws based on the available test data
- **Noise, vibration and hardness (NVH)**: The main causes of tire noise are due to structural excitations at the tire-road contact patch and air pumping through the tread groves. SIMULIA Abaqus and Wave 6 technologies can help predict tire noise efficiently. Structural excitations at the contact patch are computed with Lagrangian rolling in Abaqus/Explicit. The deformed tire and the results of this analysis are the input for a subsequent acoustic analysis in Wave6. Wave6 calculates the surface source strength and radiated sound. Because tires affect the noise and ride comfort of the whole vehicle, OEMs increasingly demand accurate full-system NVH predictions. A mixed Eulerian-Lagrangian scheme is used to compute the steady state rolling configuration of tires, with dynamic substructures to account for preloading and gyroscopic effects of a rolling tire. The flexible tire model increases the fidelity of the full vehicle NVH simulations.

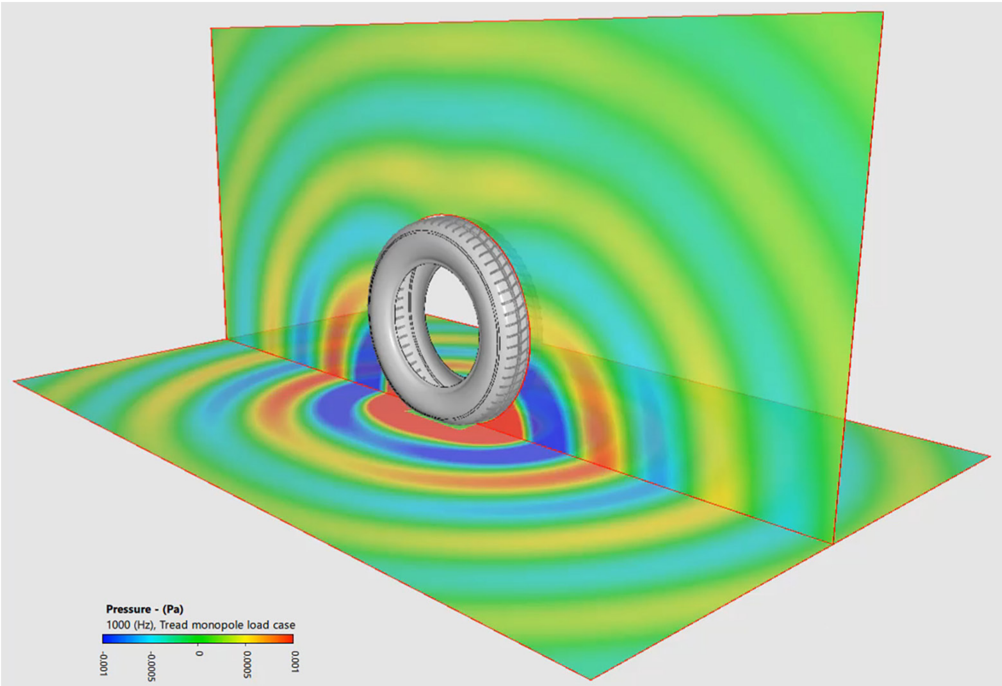


Figure 5: Acoustic radiation: SPL plot

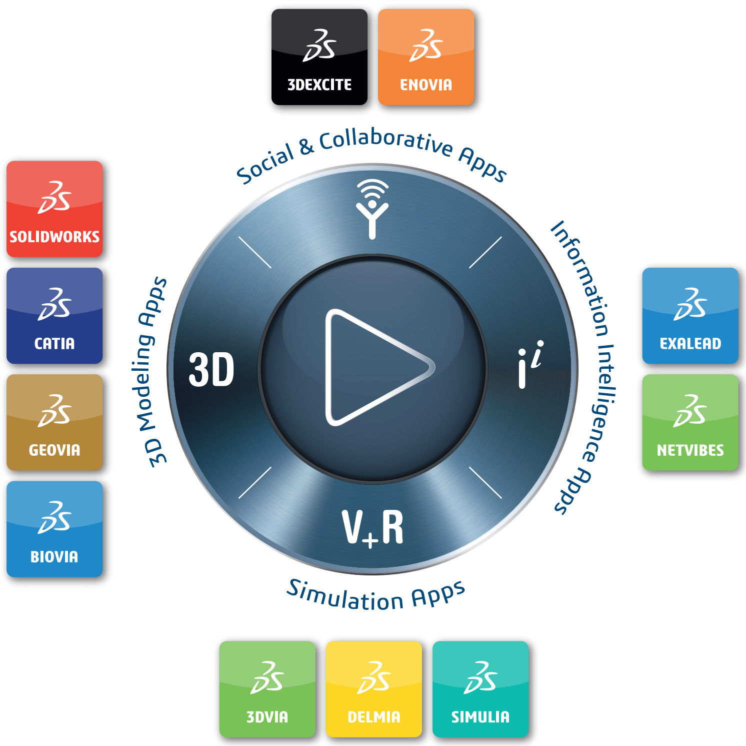
- **Aerodynamic drag**: As much as 20% of drag on a vehicle is associated with the tires, and the worldwide harmonized light vehicles test procedure (WLTP) standards require tire drag be taken into account. SIMULIA PowerFLOW can simulate rotating tires including tread details and accurately predict drag generated from tires, including underbody, engine compartment. This enables rim & tire aerodynamics to be optimized in a realistic environment with a moving ground, instead of a wind tunnel. Every tire and wheel configuration can be digitally tested to ensure WLTP requirements are satisfied.
- **Vehicle dynamics**: Ride comfort is determined by how the entire vehicle system transfers forces from the tires on the road to the passenger in the seat. Analyzing ride comfort therefore means modeling the whole corner module or even the whole vehicle system. Simpack-Abaqus co-simulation can evaluate subsystems or the complete vehicle, using the simulation results from Abaqus to generate tire models for Simpack.
- **Tire sensor design**: Sensors are increasingly important for diagnostics, cruise control and autonomous driving, informing the car computer of the type of tire, its position, pressure, vehicle weight, and road conditions. The SIMULIA electromagnetics tool CST STUDIO SUITE can calculate electric and magnetic fields around the sensors, and can not only simulate the sensor response itself but also optimize the transmission and reception of signals from the sensor to the vehicle computer.

With the simulation results gathered, Process Composer can be used to carry out a design of experiments (DOE) to explore the design space allowing the Tire Engineers to select the best possible design using Results Analytics application.

SUMMARY

Dassault Systèmes CATIA and SIMULIA solutions are widely used in the tire industry to optimize tire performance, reduce costs and develop innovative products. The combination of design, PLM and simulation tools on the **3D**EXPERIENCE platform means these solutions are even more powerful in combination, allowing advanced design and simulation workflows integrated over the entire tire design cycle.

This improves communication between design teams, making project data and specifications easily available to all, and allows multi-attribution optimization and decision making in order to achieve the best trade-off between the magic triangle and other variables. Cumulatively, this allows more verification cycles in same amount of time with higher confidence and increases the chances of passing SAE standards without test failures, cutting both cost and time-to-market.



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