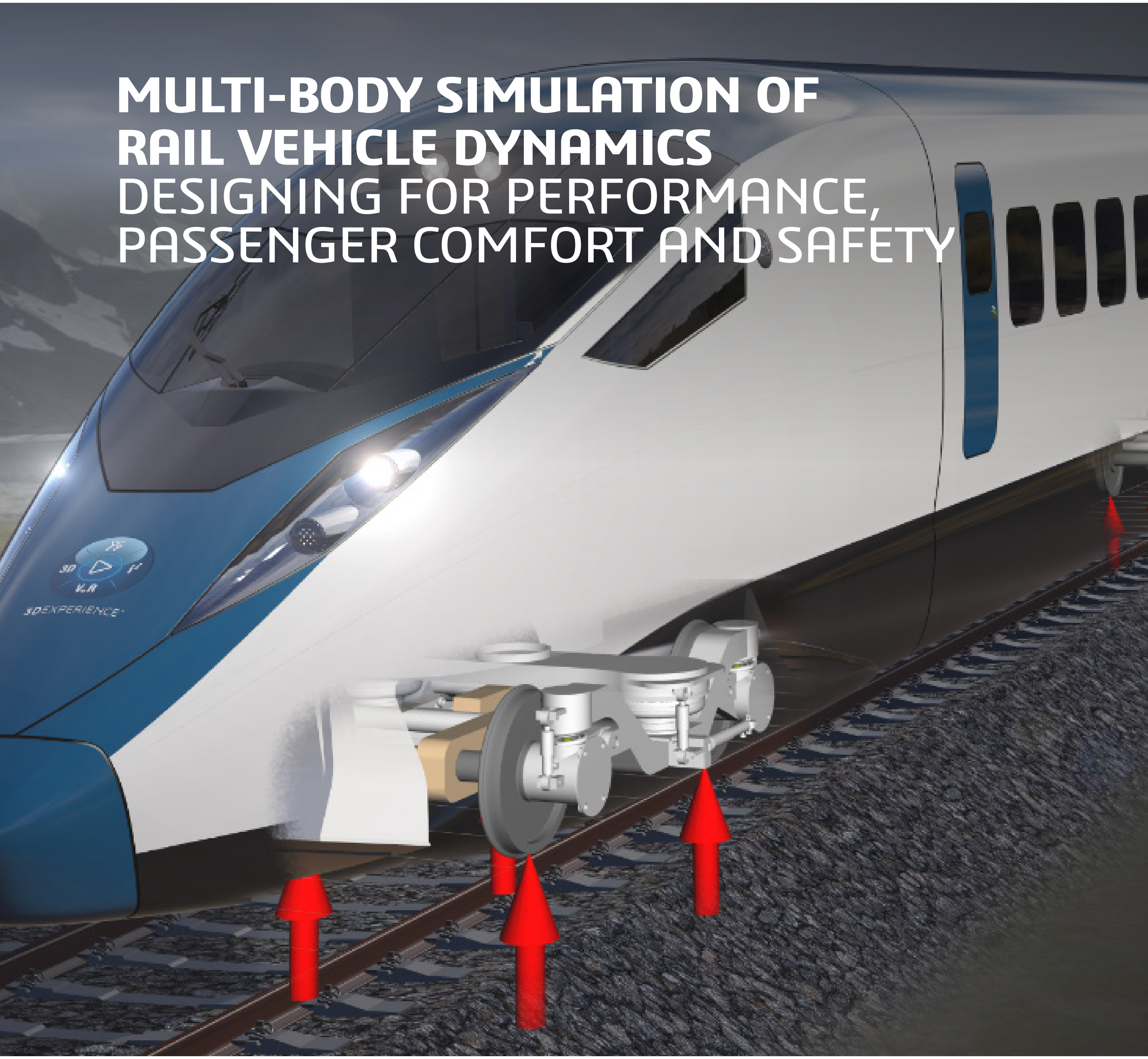
SIMULIA

3DEXPERIENCE®

MULTI-BODY SIMULATION OF RAIL VEHICLE DYNAMICS
DESIGNING FOR PERFORMANCE, PASSENGER COMFORT AND SAFETY



DASSAULT SYSTEMES

INTRODUCTION

Technological breakthroughs and increasing environmental awareness mean that rail industry has seen renewed investment and is innovating on many frontiers. Line speeds are steadily increasing, while new infrastructure projects are increasing capacity and bringing train services into previously unserved areas. Both the tracks and the rolling stock that run on them need to be designed to an exceptionally high level of performance and safety.

Rail vehicles are physically complex systems, and their performance is determined by the interaction of numerous different components. The rail-wheel interface, suspension, bogies, couplings and other moving parts all affect how the train moves along the tracks. Mastering these forces is essential to ensure safety, speed, reliability and comfort.

This whitepaper will show how multibody simulation is useful in understanding and improving the dynamics of rail vehicles including locomotives, multiple units, passenger and freight trains, trams and metros, and even unconventional vehicles including monorails, suspended trains and rollercoasters. Using Simpack Rail, simulation engineers can analyze critical speed of the vehicle for safe operation, passenger comfort, safety against derailment, gauging, wear and fatigue, overhead line/pantograph interaction and vehicle homologation scenarios.

CHALLENGES

The complexity and sheer length of the trains makes simulating their running dynamics a demanding task. Each individual vehicle will have multiple wheelsets, most likely mounted on bogies with various types of suspension components. A typical train will then consist of multiple such vehicle units—whether these are locomotives and unpowered carriages, or the cars of a multiple unit—coupled together and possibly sharing components of the bogies. Altogether, a multibody system model of a full train will have to account for all possible relative motions between the individual components thereby making it a challenging engineering problem to solve.

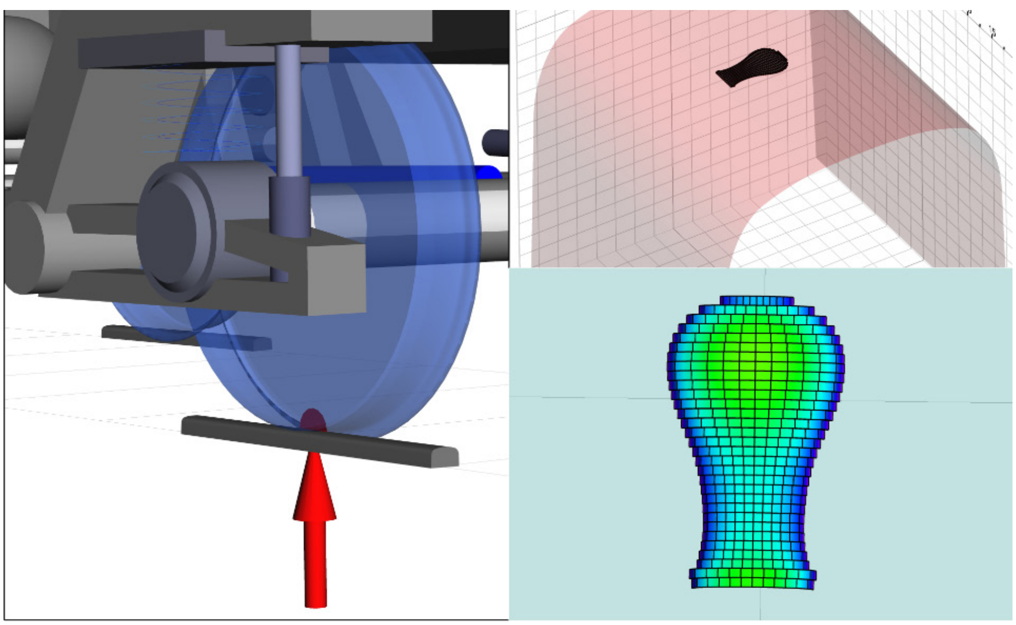


Figure 1: Contact patch calculation. The heavy load on a very small area leads to a complex non-linear interaction.

The track too can be complex to model. The rails will flex under load and so does the sleepers and ballast structures below it. Moreover, rails also wear off over time which changes their profile shape. Such effects can influence the vehicle running characteristics significantly. In addition, there are also special considerations for structures such as railway bridges, points aka switches and crossings which play an important role in ensuring safety and reliability of railway operations.

On top of this, the interaction between the wheels and rails is very challenging to model precisely. Very heavy loads are concentrated in an extremely small contact area, the shape and size of which depends on the precise relative position of the wheel on the rail—adding to it, the wheel-rail contact interaction is also non-linear in nature (Figure 1). Understanding the nuances of the contact, is essential to predict phenomenon such as rolling contact fatigue (RCF) and wear.

Finally, real world operating conditions can be very different to the scenarios that can be tested in a laboratory environment. Speed, loading, and weather conditions could affect the dynamics of a rail vehicle significantly. Adequate clearance from infrastructure like overhead wires and tunnels needs to be maintained at all times, no matter how the train is moving. Safety regulations in the rail sector are very strict, and manufacturers need to demonstrate compliance with all legal requirements—often multiple different standards across countries.

BENEFITS OF SIMULATION

Simulation doesn't require physical prototypes. This makes it cheaper and faster than physical testing, and means it can be carried out much earlier in the development. Rather than waiting for a prototype to be manufactured and transported to the test site, engineers can immediately use the digital computer aided design/simulation (CAD/CAE) model to build a virtual prototype for analysis. The viability of a design can be tested in hours or days instead of in months or years.

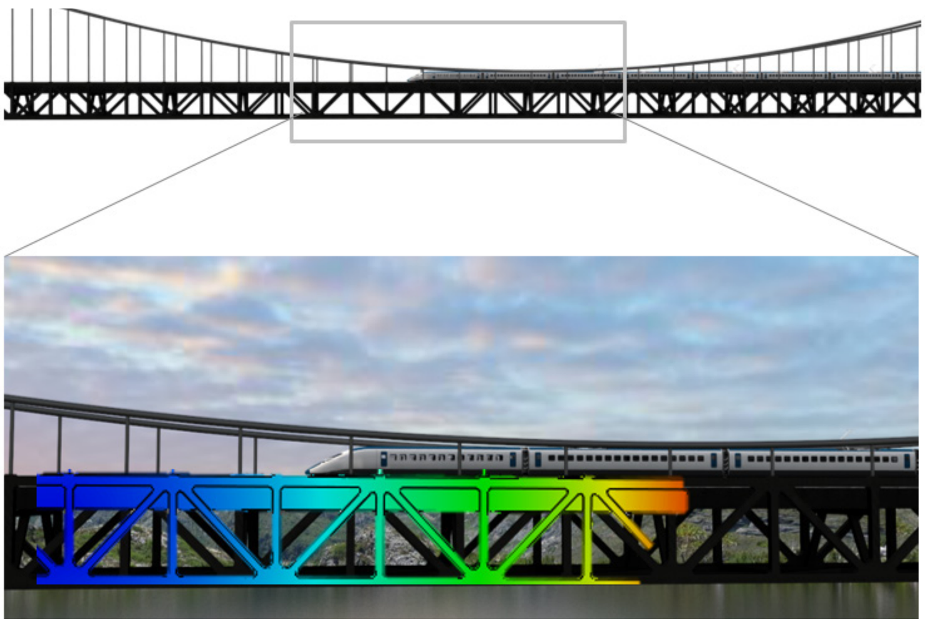


Figure 2: Deformation of a bridge under a dynamic loads from a moving train.

Numerous different test cases can be replicated in the simulation (see box). In effect, the software becomes a virtual lab, where a design can be assessed before committing to the cost of manufacturing. Should a design fail to pass, the cost of rectifying problems is much lower if caught early and no re-building is needed. Simulation can significantly lower risk and increase confidence that a rail vehicle will meet all regulatory standards.

By allowing testing very early in the development cycle, simulation also makes it much easier to explore different designs. Multiple key performance indicators (KPIs) can be compared, in order to find the design that offers the best trade-off between competing design alternatives.

Physics can be visualized—users can see exactly what the contact patch between the rail and wheel looks like or even see the deformation that occurs in a bridge as a train passes over it (Figure 2). This helps to understand exactly how the train behaves and inspires innovation and new solutions to problems.

Rail infrastructure can be virtually constructed in the software even before the first prototypes have been transported to site. Clearance from tunnel walls and contact between the pantograph and overhead wires can be checked, taking into account the actual movements of the vehicle such as lean around corners.

Analyzing derailment risk helps keep trains safe and reduces the risk of problems being discovered later and trains needing to be withdrawn from service for an overhaul. Simulation can also be used after incidents in order to help understand the dynamics that led up to the event retrospectively.

APPLICATIONS OF MULTIBODY SYSTEM SIMULATION IN THE RAIL INDUSTRY

Safety

- Track/curving analysis
- Critical speed
- Derailment
- Gauging
- Switches and crossings
- Flexible track and bridges

Comfort

- Ride comfort
- Acoustics

Quality, lifetime, cost

- Overhead line equipment and pantograph
- Rail-wheel wear prediction
- Fatigue

Special use cases

- Software in the loop (SIL), human in the loop
- Real-time simulation
- Maglev
- People movers
- Monorails
- Rollercoasters

Test lab measurements can be replicated in the simulation software. For example, the roller rigs used to test wheels can be set up virtually. This offers a bridge between the real and virtual worlds—the simulation model can be validated by measurement and then used as a "virtual twin". Regulatory test scenarios such as derailment testing (EN14363) or ride comfort (EN12299) can be modeled in order to see whether the prototype is likely to pass before starting physical testing.

SPECIAL SIMPACK RAIL FEATURES

Simpack is a general purpose multibody systems simulation solution used in the railway industry worldwide to design and analyze systems at every level: components, vehicles, trains and infrastructure. The specialized Simpack Rail module includes numerous features for setting up railway scenarios and quickly extracting the data of interest.

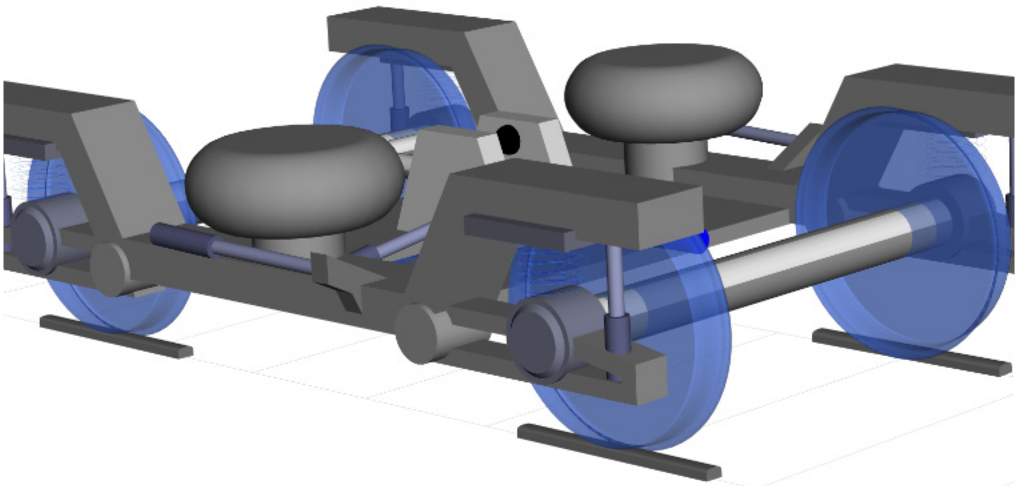


Figure 3: Model of a bogie with various components, including pneumatic, hydraulic and coil suspension elements.

Simpack Rail contains modelling elements suitable for the different components of rail vehicles. Accurate models of suspension components of various kinds—including rubber, metal springs and pneumatic suspension—can be selected from a library of elements and inserted into the design (Figure 3). For a more realistic representation of vehicle structures such as carbody shell and bogie frames, bodies can be modelled as flexible bodies, adding the necessary compliance to the system.

For standard railway applications, various wheel and track models can be quickly set up. With a variety of wheelset types and bogie arrangements, most common rail vehicle types can be created quickly. For more specialized applications, such as monorails, industrial rail systems and rollercoasters, Simpack also supports arbitrary wheel and track arrangements (Figure 4). Measured track coordinates can even be imported into Simpack in order to analyze rail vehicle dynamics in real, surveyed conditions.

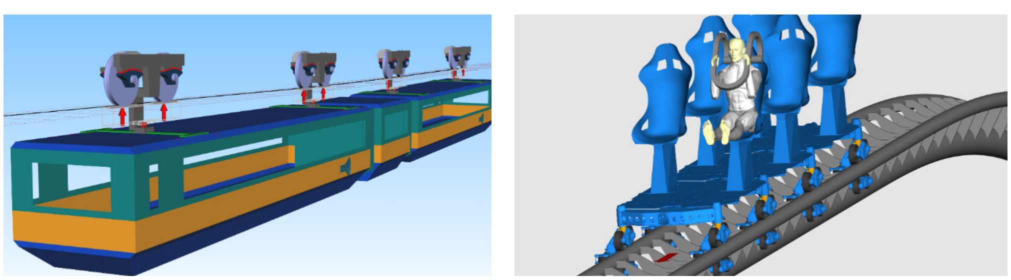


Figure 4: A suspended monorail (left) and rollercoaster (right), examples of rail vehicles with complex non-standard wheels and track.

Trains are built up of multiple vehicles coupled together, which are themselves made up of individual components such as wheelsets and bogies. This means that there is a clear hierarchical structure to a train, and considerable effort and computation can be saved by building the model in a modular way. Simpack's substructuring methodology offers a convenient workflow for building and configuring full vehicle models, thereby offering a very efficient way to set-up and manage complex models.

Simpack supports both time and frequency domain analysis cases. The linear system analysis is a frequency domain solution that offers a fast simulation of vehicle dynamics about an equilibrium state. Non-linear dynamic analysis, on the other hand, can model acceleration and deceleration, and changes in the track such as curves and switches along with their impact of the vehicle motion characteristics.

As well as Simpack, SIMULIA offers a portfolio of other simulation tools. Of particular interest to the rail industry are applications such as aerodynamics, aeroacoustics and cabin comfort simulation, using fluid simulation; strength, durability and fatigue analysis using structural simulation; and analysis of high voltage systems and electronics using electromagnetic simulation.

The **3D**EXPERIENCE platform offers links to other simulation tools from SIMULIA that can cover these applications, allowing different groups working on these topics to collaborate, share expertise and find trade-offs between competing design requirements. The **3D**EXPERIENCE platform also connects other brands of Dassault Systèmes, such as the 3D design solutions from CATIA and SOLIDWORKS and the operations planning solutions from DELMIA.

SUMMARY

The rail industry has very high standards for safety, reliability and performance. In order to meet and exceed these standards, engineers need a deep understanding of the dynamics of rail vehicle dynamics. This is complex behavior arising from the interaction between the wheels, rails, components such as suspension and bogies, and the other coupled cars of the train.

Multi-body simulation with Simpack offers designers and engineers the tools they need to meet these challenges. Safety, comfort, performance and quality can be optimized, and phenomena such as the rail-wheel interaction, wear and vehicle dynamic behavior can be understood even before the first physical prototype is manufactured.

Analyzing rail vehicle dynamics early in the development process reduces the risk of issues being discovered later during physical testing or even in service, significantly reducing the risk of expensive redesigns and overhauls. Real world scenarios that are difficult to test can be modeled in software to ensure performance in all conditions. Simulation also accelerates the design process and reduces the amount of physical testing needed, cutting development costs.

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