

# Case Study



## TREK BICYCLES TAKES SIMULATION TO THE EXTREME

With the power duo of SIMULIA Abaqus and True-Load, Trek models the toughest riding scenarios to push performance to the next level

Whether you're an avid mountain biker or a road-riding enthusiast, the challenge is to go farther, climb higher, land that perfect jump, and pedal faster—all in the spirit of nailing that next level of performance.

The engineering team at Trek Bicycles embraces the same mantra, not just on the bike trail, but in research and development with simulation. What started out as a casual jaunt into simulation territory to analyze the occasional composite structure evolved into a rigorous exercise across all their bike programs—once Trek engineers got a taste for how the methodology raises the bar on design optimization.

For a culture steeped in hard-driving performance, it wasn't much of a stretch for Trek's design engineers to extend their passion for biking to the immersive 3D experience of simulation.

"Lighter, stiffer, faster, and better ride quality are common goals," says Jay Maas, analysis engineer, who joined Trek in 2010 as a dedicated specialist to help expand the simulation efforts and who cycles nearly every day. "We couldn't have stayed ahead of the competition without pushing our analyses to the next level."

### PUTTING SIMULATION TO THE TEST

With its 1,600 worldwide employees, 1.6 million bikes sold each year, and claim as North America's largest manufacturer of carbon bikes, it's fair to say Trek is making good strides in lapping the competition.

The bike manufacturer took its first spin with simulation in 2009, complementing its use of the Dassault Systèmes CATIA 3D design and engineering applications with the Abaqus finite element analysis (FEA) application from SIMULIA. Trek's initial use of the tools was primarily limited to simulating laboratory testing to help predict bicycle stiffness performance characteristics such as sprinting, climbing, and cornering.

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—Jay Maas, Analysis Engineer, Trek

By predicting stiffness values in the virtual world, they could better balance the need to put physical bike gear through its paces in order to meet performance targets.

"We'd previously been doing more design iterations and expending significant resources to get the bike weight and stiffness to a target we were happy with," Maas recalls. "Using simulation to predict that weight and stiffness ahead of time reduced the number of make-and-break cycles necessary to get where we needed to be."

Fresh off those early successes, and with Maas and another specialist onboard to champion simulation, Trek engineers across various bike programs were ready to branch out to other types of analyses. Maas was a perfect candidate to grow the simulation campaign, having done similar work in the aerospace industry for 12 years.

Even better, Maas' simulation knowledge dovetailed with his passion for all things bike-related. "It was a perfect fit doing everything I love about engineering and using Abaqus to design a product that I love, which is bikes," he says.



This Abaqus model of a Trek full-suspension mountain bike depicts solid and shell elements linked with constraints and connectors, a welded butted aluminum frame, and a magnesium rocker link.

The accessible user interface of Abaqus combined with its integration of implicit and explicit capabilities in a single tool-set made it easy for Maas to encourage the extended engineering team to apply FEA to other initiatives, from cross-country to downhill bicycles. Trek maintains many different mountain bike platforms and each platform has multiple frame sizes, adding up to a host of configurations. "We have many dozens of bikes with many load cases each running through the analysis group in a given year," Maas says. "It is a really large quantity of work."

Once the team began embracing FEA, the engineers became interested in applying the tools to address other questions beyond the standard test cases in the lab. One item of interest was understanding more about what happens to bikes when they are being ridden in the field, especially by Trek's professional racers, who specialize in gravity-defying stunts like front flips across a 72-foot canyon or barreling down the side of a mountain at 60+ miles per hour. During these extreme events, the professional racers' bikes can experience some extreme loading conditions.

"These athletes push the bikes well past the average consumer and are hyper-sensitive to variations in stiffness and where that stiffness is within the bike," Maas explains. "They also push for faster, lighter, and better ride quality so they can excel and win races which, in turn, pushes us to design faster and lighter bikes without compromising strength, durability, and ride quality."

## TAKING IT TO THE EXTREME

It was about this time that the Trek team crossed paths with Wolf Star Technologies, a SIMULIA partner that offers True-Load, a complementary solution that could leverage Trek's existing FEA models to identify the optimum locations on which to place strain gauges on the physical bikes—and then back-calculate loading. Wolf Star president Tim Hunter developed and refined the technology over his decades of work at a major motorcycle company. Once strains are collected, the data is read into True-Load to calculate load-time histories that are guaranteed to match the measured strain to within 2% at every point in time. This enables the Trek team to accurately quantify the loads created in the field and then compare that load to current laboratory tests.

"Jay realized the need to capture true loading of his bike frames in order to drive realistic simulation that matched the real world," says Hunter. "True-Load was a tool that could provide a clean, complete solution to meet those needs."

The Trek team is blessed with a private trail system—236 acres of pristine single track that serves as an outdoor laboratory—perfect for testing extreme riding conditions. The team picked two of the most extreme trails within their system to test drive its Abaqus/True-Load simulation combination for the bike's load cases: The first was Deer Hunter (see Figure 1), a large drop capable of fully compressing the rear suspension and the second was Mojo, a jump also capable of fully compressing the rear suspension, but which allowed the rider to rotate the bike.

The team employed a miniature on-board data acquisition system (DAS), which was small enough so it didn't hinder the rider, and outfitted a Session 29er bike with 12 strain gauges, three tri-axial accelerometers, one linear potentiometer, one Hall Effect sensor, a custom-designed wire harness and carriage system, and an on-board battery (see Figure 2). They also used high-speed cameras and Go Pro video to capture the event.

Using True-Load and Abaqus, the team set up a linear static model in which the boundary conditions and unit load cases mirrored the field-collected data from the bicycle frame (see Figure 3). The material model and mesh also reflected exact strain-gauge placement and orientation—all critical fine-tuning that wouldn't have been possible without Abaqus and True-Load, Maas says.

Strain data is extracted from the event file for when the bicycle is in a quasi-steady state and when the suspension is fully compressed. This also corresponds to the peak loading during the event. This strain data is used within True-Load/Post-Test

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Figure 1. (Left) The Abaqus/True Load simulation used two extreme events to test drive the bike's load cases: Deer Hunter (shown above: a bike and rider poised to drop from a raised platform down to the ground) capable of fully compressing the rear suspension, and Mojo, a jump that did the same but also allowed the rider to rotate the bike. Figure 2. (Right) Strain gauges attached onto a bike frame.

where unit loads are scaled throughout time to minimize errors between the FEA strains and the measured strains. The resulting loads created a near perfect match between simulated strain and measured strain.

As part of the True-Load/Post Test process, an HTML report is output to showcase error reporting, load amplification curves, and strain history plots. Wolf Star's True-Load QSE tool came into play to perform additional post processing to obtain external (reaction forces) and internal loads (loads from free body diagram cuts).



Figure 3. Abaqus/True Load model.

The analysis work confirmed that loads produced by the professional riders can exceed those generated in normal use. Trek engineers also learned that the load share in the rear end of the bike is different for each bike model.

The exercise now gives them a process to determine real-world loads for other bikes going forward. By understanding the load distribution in the rear end of the bike and how professional riders can cause different types of stresses, the engineering team can make specific design changes that better address those performance needs for all types of riders.

Trek's professional riders won't be the sole beneficiaries of the company's expanded simulation capabilities. Maas says this initial True-Load project has once again sparked interest across Trek's engineers, many of whom are now ready to race ahead with their own simulations on different bike platforms.

Says Maas, "We race to make bikes better. It's what drives our development and we will continue to keep the engineering groups informed about all these capabilities so we can cross-pollinate our tools and methods and let everyone take advantage of them. We believe this will make bikes better for all riders."

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