Sun and Simulation Power-up Solar-Car Performance

University of Toronto Blue Sky team uses Abaqus FEA to ensure robust design for their *World Solar Challenge* race vehicle

One week across the Australian Outback in a sleek but cramped vehicle powered only by the Sun: Would you be up to it?

The Blue Sky team from the University of Toronto was: they finished 8th in the *Bridgestone World Solar Challenge (WSC)*, a unique race founded in 1987 that now takes place every other year. This year's event, held October 6-13, included 40 teams from 22 countries. As usual, the competition started in Darwin on Australia's north coast and ended 3,021 kilometers (1,877 miles) later in the southern coastal city of Adelaide, splitting the island continent approximately in half.

The student-built, solar-powered vehicles entered in the contest were strangely-shaped, sleekly aerodynamic, and cutting-edge: "arguably the most efficient electric vehicles" on the planet, according to the race website. Averaging speeds of between 60-90 kilometers-per-hour (37-56 mph), cars completed the course in 33-48 hours, with driving limited to daytime (from 8 a.m. to 5 p.m.).

Success in this noteworthy event depended on the relationship of power to drag. In pursuit of the optimal ratio, teams worked to find a winning combination of aerodynamic profile, lightweight composites, photovoltaic advances, vehicle dynamics, and more.

The team and the car

In the summer of 2011, the 50 students of the Blue Sky team began design on the school's seventh-generation solar car ("B-7") and their entry in the 2013 WSC. They had a wide range of backgrounds and abilities: from first-year through graduate level and from virtually every engineering discipline.

"We don't discriminate among those who come knocking at our door," says Ahthavan Sureshkumar, chief engineer for the team. "We're looking for people who are willing to commit their time to get the job done."

According to Paul Park, the team's managing director, "Everyone is somewhat clueless when they join. But they all come out at the end with really strong technical knowledge."

Specifications for this year's most popular *Challenger* class were many: for the first time, four wheels were mandatory; there were also stringent stipulations about driver vision combined with upright seating.

"These new regulations posed a very difficult design challenge for us, mainly in the area of aerodynamics and driver packaging," says Blue Sky chief advancement officer Tiffany Hu. "In recent years the *World Solar Challenge* has been shifting towards more practical designs, which is very exciting."

Abaqus opens virtual window into performance

Aventec, Canada's leading provider of Dassault Systèmes (DS) **3D**EXPERIENCE technology portfolio in nearby Markham, Ontario, recommended that Blue Sky use DS SIMULIA's Abaqus finite element analysis (FEA) for realistic simulation and CATIA for CAD-based virtual product design and collaboration.

"This was the first generation car on which we used the Dassault Systèmes' platform. Not only did it help us collaborate better and improve work flow tremendously, it was critical to us being able to design and deliver the vehicle so quickly," says Sureshkumar.

According to Park, "CATIA allowed us to fully integrate the systems in the vehicle and gave us the flexibility to design a world-class aerobody, while SIMULIA's Abaqus highlighted potential problems early in the design process and helped us avoid over-design."

Abaqus FEA was employed to predict how evolving design iterations for specific components and systems would behave under real-world conditions. The team, which had never used realistic simulation, focused their analyses on optimizing the composite aerobody and chassis structures for weight and strength.

In the previous car, student engineers had relied solely on simple beam calculations (torsional and bending stiffness) to determine how their composite monocoque chassis design would perform. From there they approximated both the number of composite layers and whether the structure could withstand specific loading.

This imprecise method ignored certain factors, though, such as stiffness contributed by the roll cage and the aerobody itself. The result was an overdesigned and heavier vehicle: every layer of carbon fiber contributed an extra 10 kg, a significant increase when target weight was approximately 200 kg (approximately 440 lbs). "Without FEA, we had difficulty identifying how the chassis would actually behave. So we played it safe," says Park.

To start the analysis, CATIA models were imported into Abaqus. There were surface models for both the lower aerobody, containing the chassis, and the upper aerobody, which encompassed its own substructure. Aerobody components are often analyzed individually in automotive applications because they are designed to separate during a collision. There were also solid models for both the roll cage (including front and rear roll bars) and the

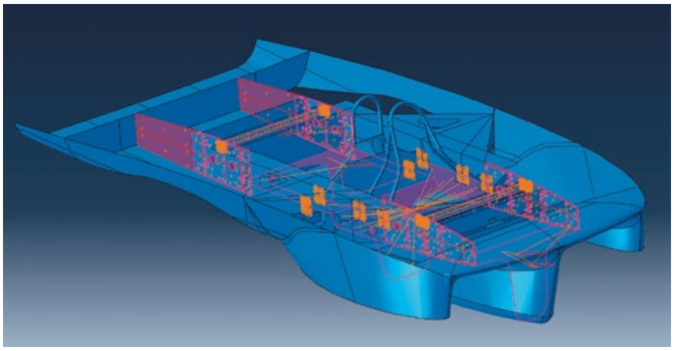

Figure 1. This screen shot from Abaqus of the lower aerobody model (including the chassis) identifies where structural components are constrained to the chassis surfaces (orange and pink). Point masses are also constrained to the chassis (purple lines).

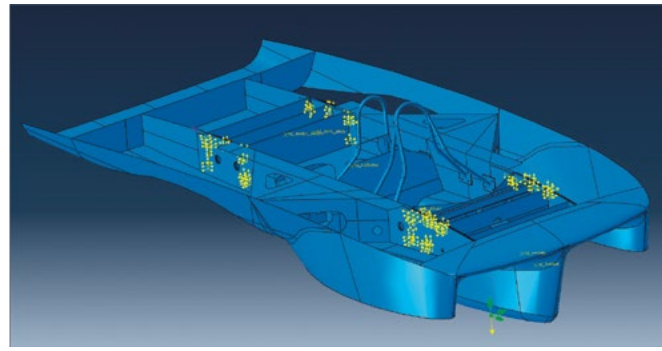

Figure 2. Loads were applied to the suspension hard points in the lower aerobody model (yellow dots) as indicated in this screen shot from Abaqus.

suspension reinforcement bars (connecting both left and right suspensions).

All models were meshed in Abaqus. For the aerobodies, Abaqus automated this process around the complex curves and holes that are an integral part of their surfaces. For the solid models, a Python script in the software was used to define mesh elements and make updating easier as the design evolved. Tie constraints were next defined in the lower aerobody model between the mesh and surfaces of the chassis sandwich panels, which were part of the model (see Figure 1).

Python scripting capabilities in Abaqus also helped automate the previously repetitive and time-consuming task of manually applying loads to the models. Each load case involved calculating, further defining, and then reapplying reaction forces at five suspension clevises (connection points). Now parameters could be changed, node sets redefined, and loads reapplied in a matter of seconds. This method made the determination of contact regions much more accurate than was previously possible (see Figure 2).

Other features in Abaqus further enhanced accuracy and efficiency. Established layup definitions in the software provided a convenient way to try out varying ply schedules for the chassis and to fine-tune stiffness and strength for the upper and lower aerobody's surface layups and sandwich-board construction. With the aid of FEA, the team was able to minimize B-7's weight, using only half as much carbon fiber as in the previous car. "Abaqus helped us determine how much stress our lighter design could take," says Park. "It highlighted potential problems early in the design process."

While simulation of varying ply schedules helped with weight-minimization, Abaqus also provided valuable mass estimates that the team used in controlling the vehicle's center of gravity. The team further determined through theory, testing, and calculations that weight, aerobody shape, tires, and wheel bearings were the most critical factors when looking to reduce drag and enhance vehicle speed.

FEA also provided design insights that would have been missed in prior years. Looking at loading, for example, the student engineers learned that a .75G braking scenario placed as much stress on the car as a 6G bump (see Figure 3). Equally surprising to the team was the fact that the front and rear roll bars contributed little to the chassis' torsional rigidity, while the inherent stiffness of the aerobody (especially the driver fairing) played a major role.

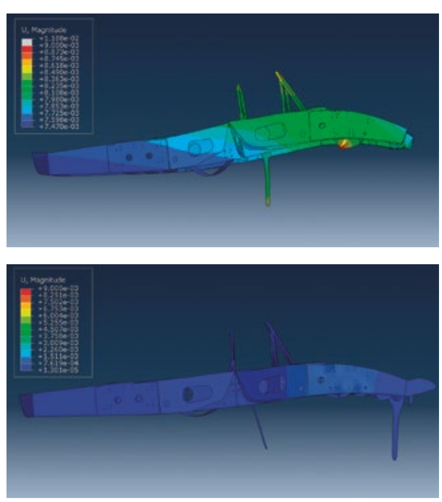

Figure 3. These screen shots (side view of the lower aerobody chassis) show the resulting deformation from a 6G front bump of the sandwich panel chassis without the aerobody skin (top) and with it (bottom), using the same deformation upper bound. This illustrates how the rigidity of the aerobody coupled with the sandwich panel results in an order of magnitude decrease in deformation.

"It was far beyond our capabilities to consider all of these various structures together without Abaqus," says Sureshkumar. "The software allowed a much more integrated analysis and modeled external loads extremely accurately. Abaqus gave us confidence in the complex design decisions and tradeoffs we made."

The sun and simulation: a winning combination

As race day dawned in Darwin, design decisions had all been made, composite layups completed, decals applied, test drives logged. After countless all-nighters, the gleaming B-7 stood poised, reflecting the spring sun, ready for the starting gun. It was a remarkable achievement for a volunteer group of students, 19 of whom had been chosen to travel to Australia to support the car.

How the race was run depended on more than just sunny skies. "There's a remarkable amount of strategy," says Park. "Tactics depend not only on the weather, but on road conditions, other teams that impede your speed and, yes, even the occasional kangaroo crossing your path. We go as fast as possible but take every precaution to make sure that two years' work doesn't break down in the middle of the Outback."

While more than half of the entries in the competitive *Challenger* class did break down during the race, B-7 didn't, placing second among North American entries and achieving the Blue Sky team's goal of a spot in the Top 10. The B-7 completed the 3,021 km/ course in 45 hours, 38 minutes with an average speed of 65.7 km/hr.

"The race was the climax of an incredible two-year engineering journey," notes Sureshkumar.

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