Race Car Manufacturer Uses Finite Element Analysis to Simulate Chassis Performance

Building a Formula 1 race car requires accurate analysis of structural features and constraints.

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The monocoque chassis of a Formula 1 race car is a sandwich structure, made of high-performance carbon-epoxy composite face sheets and an aluminum or aramidic honeycomb core. High-modulus and high-strength composites, with aerospace-class toughened epoxy resins, are used in order to obtain the maximum safety performance/weight ratio.

All attachment points for the engine, suspensions, rollhoop, etc., are made through inserts embedded in the lamination stack during the production phase. In order to minimize weight and thermal expansion differential, and maximize the adhesion, the inserts are made as thick (about 18-mm) laminated composite plates to be machined to the required dimensions and thickness.

At the first stage of the design, where the global shape of the chassis has to be defined, the main things to take into account are:

- desired wheelbase
- engine interface (width, height, fittings)
- desired fuel capacity (the fuel is between the pilot back and the engine interface wall)
- aerodynamics design, especially for the front nose position
- suspension system layout
- driver measurements

Under all of the above constraints, the general criterion used for determining the shape of the chassis is that it should have the smoothest and flattest shape possible. This has advantages, considering the peculiarities of the prepreg composites technology. The fiber orientation actually obtained in the hand layup process can be very similar to what has been

Figure 1. **Chassis Flexural Stiffness** test set-up.

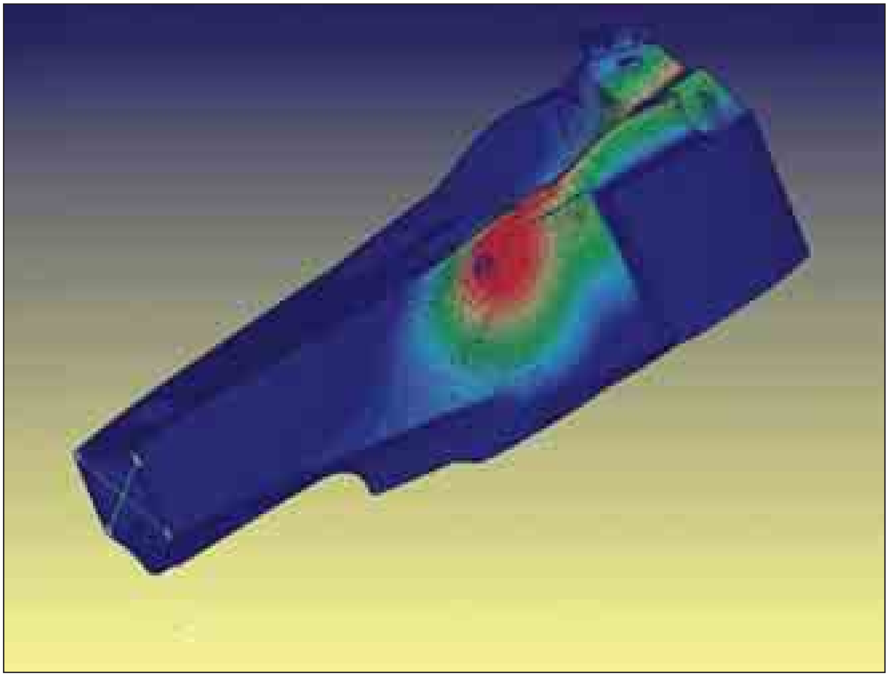

Figure 2. This **FE Model** of the chassis shows the displacement field calculated for a local crush simulation.

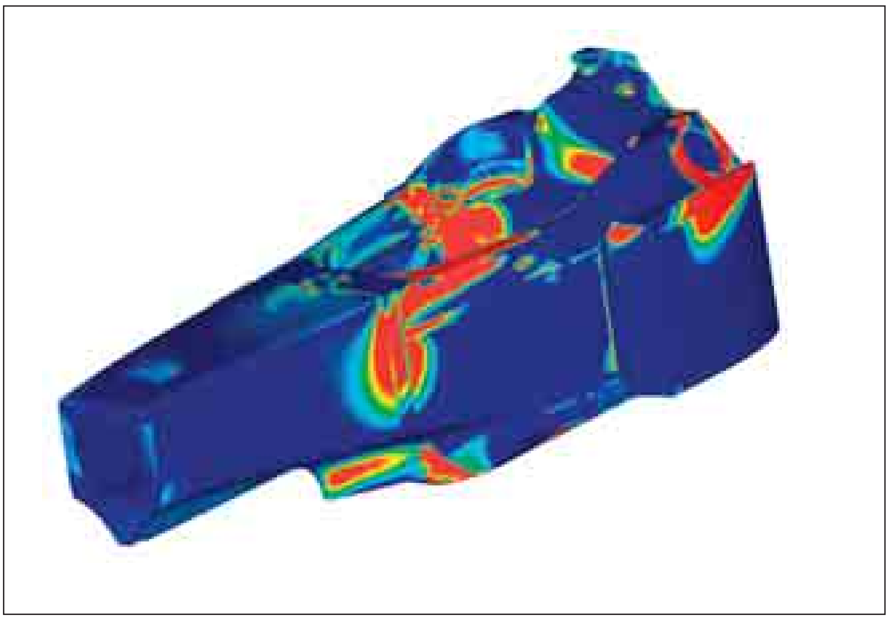

Figure 3. An FE model of the **Fiber Stress** in a ply of the lamination stack under a side crash case.

designed, if the mold surface is regular. In addition, the ply overlapping and cuts that have to be made in the production phase are at a minimum, and the fibers must work in tension/compression conditions and are not bent.

The safety regulation requirements are the main driver of the chassis design, both from the global layup and from the local reinforcement standpoints. There are a number of impact tests to pass. The main tests are:

- Side crash. This is the most restrictive. A 780-kg trolley impacts the side of the chassis at a speed of 10 m/s. The impact is first taken by lateral crash appendices (crash cones). Requirements are maximum deceleration of less than 20 g, maximum force on a cone of less than 80 kN, each cone must take from 15% to 35% of the total energy, and no damage can be found on the chassis.
- Crash cone push-off. These are flexural tests on the cones to verify the robustness of their attachments to the chassis.
- Front crash. This test mainly determines the nose design. The chassis is not highly stressed.
- Penetration test. A square, flat plate with the same layup of the chassis in the side area is quasi-statically (2 mm/s) penetrated with an aluminum conical impactor until a penetration of 150 mm is measured. Requirements are absorbed energy greater than 6000 J and reaction load greater than 250 kN.
- Main roll-bar crush. The roll-bar is statically pushed with a force of about 120 kN via an inclined plate, impacting the main roll-bar top. Requirements are deformation of less than 50 mm, and the damaged area must be within 100 mm from the load application plate.
- Front roll-bar crush. The front roll-bar is a reinforcing structure located just

behind the steering wheel. A similar test as above is made, with a 75 kN vertical force.

- Lateral local crushes. Several specific locations of the chassis side have to be loaded with forces varying from 12.5 kN to 30 kN. Maximum displacement and no damage requirements are prescribed.

Other experimental measurements made on the chassis related to the handling behavior of the car include torsional stiffness, which can range from 15,000 to 40,000 N m/°; flexural stiffness; and engine fitting local stiffness. This test is made to check if the rear wall of the chassis is stiff enough to avoid a "hinge effect" at the interface with the engine, where there is a very high stiffness change. Once the safety targets are met, the global stiffness requirements typically are satisfied.

Basically, all of the tests listed above are simulated in a finite element analysis (FEA) environment. Some of them can be replicated closely, while others cannot (e.g. the penetration test). Where a realistic simulation of the test cannot be done, a simplified correlated calculation has been set up and validated with many years of experimental data fitting.

The CAE group at Minardi consists of seven people who cover FEA, CFD (computational fluid dynamics), multibody, and hydraulics design and analysis. It takes approximately two months for two CAE operators to come to the first definition of the chassis structure. Then, including optimization, refining, and other changes, 25% of the CAE potential is dedicated to the chassis during a racing season. The workflow of the monocoque chassis structural design, from the conceptual phase issues to the regulation checks and the optimization process, requires accurate and easy-to-use analysis.

Currently, NEiNastran is used as general-purpose FEA software for static analysis (stress, stiffness), buckling (linear-nonlinear, especially on crash cones), and surface contact (roll-bar crush). All of the calculations are correlated with experimental measurements, thus enabling a continuous refinement of methodologies and material data.

In order to reach the targets defined above, several optimization runs are made by modifying material choice, layup sequences, local reinforcements, foams, bulkheads, and inserts. In this phase, it is important that the FEA package be productive in managing and editing the existing FE model, solving the problem, and giving accurate and detailed postprocessing information, so effective modifications can be decided by the engineers.

During the six-month evaluation of NEiNastran, one of the main benefits found was reduced modeling time. Using FEMAP and Smart|Browser/Smart|Laminate features, the creation of the FE model of the chassis was done in about half the time required by the previous FE package. Another benefit was training and technical support. With very focused custom training, Minardi was productive on the new FE platform in a few weeks.

A surface contact feature enabled a more general and accurate approach to some of the regulation test simulations that were solved through a more approximated scheme in the past. During the transition phase, where NEiNastran and the previous Nastran package co-existed, the input and output data generated could be shared without incompatibility issues.

This work was performed by Paolo Marabini, Analysis and Calculation Chief Engineer at **Minardi F1***, Faenza, Italy, using NEiNastran analysis software from* **Noran Engineering***, Westminster, CA. For more information on NEiNastran, contact Noran Engineering at 714-899-1220, ext. 207; email: info@noraneng.com; or visit www.NENastran.com.*