Formula 1 Race Car Design Takes Finite Element Analysis
To the Next Level

By Dennis Sieminski, P.E.

Formula 1 or Grand Prix racing is known for its extensive use of advanced technology, huge monetary investment, and the attention-grabbing looks of its highly aerodynamic, open-wheeled race cars. According to F1 rules, each team must design and build its own car. This typically requires an investment upwards of $1 million for each car and an annual race team budget that can run in the $100s of millions. The races are very technologically demanding because of the high speeds (cars are capable of +200mph lap speeds), multi-turn paved courses, and the fact that races are run under all weather conditions in a variety of venues around the globe. Plus the schedule is intense, with the F1 program typically involving 17 races a year.

Technology and Talent Provide the Edge

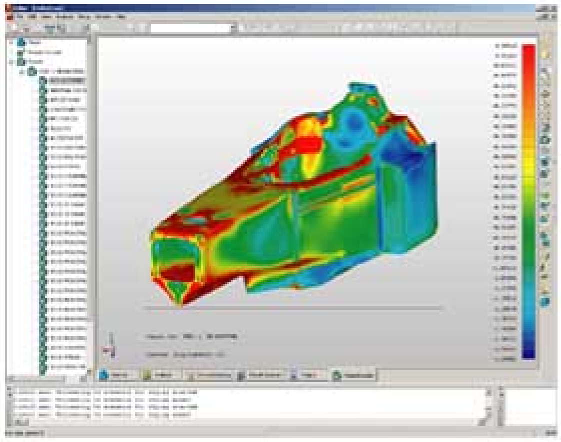
The Minardi Formula 1 Race Team is not the biggest of the Formula 1 racing teams, but that is exactly what provides the motivation for them to find and exploit technologies that can neutralize this disadvantage. Since its founding by Gian Carlo Minardi in 1979, the Minardi Team, based in Faenza, Italy, has imprinted its unique spirit-in-the-face-of-adversity character on this extremely challenging sport, bringing an instinct for innovation and eye for talent. One example of Minardi innovation is the introduction of the titanium gearbox in 2000. In the talent department, Minardi lays claim to grooming a number of well known drivers, such as Fernando Alonso, who started with them in 2001.

A Search for FEA Simulation Capable of Replacing Prototyping and Testing

In 2004, Minardi began to study how it could improve the structural design of its Formula 1 race cars. An important aspect of this program was determining how they could enhance the chassis for safety and performance without incurring the massive costs that prototyping and physical testing in their design process imposed. While Minardi had been using Finite Element Analysis (FEA) software for many years, the team members felt they were not getting the full potential from the technology. The team began a six month test with Noran Engineering's CAD-independent NEiNastran with the objective of improving the analysis and simulation results in a way that would significantly reduce the huge investments they were making in physical prototypes.

The chassis design is quite unique. Paolo Mirabini, Manager of Minardi's CAE Group, offers an excellent summary of the multi faceted demands on this component: “The chassis has to end up with the smoothest and flattest shape possible within the many engineering constraints which exist. These constraints include desired wheelbase, engine interface, desired fuel capacity, aerodynamic requirements, and even the driver dimensions!

To complicate matters, the construction details used in assembling the chassis also affect its design." That is because the chassis is a monocoque structure made of high performance carbon-epoxy composites with either an aluminum or aramidic honeycomb core. The fibers within the materials have to be oriented according to the design, and not bend, while the ply overlapping and necessary cuts are minimized. Getting any of these aspects wrong can affect the performance of the chassis.



NEiNastran Modeler screenshot showing displacement field from an analysis of the Minardi chassis.

Once a design concept is in place, modifications and further evolution continuously interplay with the very stringent safety requirements for the chassis with the safety regulations becoming the overriding driving force in the design process.

Physical Testing Validates the Simulations with NEiNastran

There are 15 Impact tests the F1 chassis must survive. Being able to simulate them correctly in a finite element analysis environment has the potential to save an enormous amount of time, money, and resources in prototyping and testing. In addition, such a process allows Minardi engineers to optimize the design and gain an edge on the race course. Again the words of Paolo Mirabini offer the best testament to the demands on the software simulation: “We tested the 3D model in NEiNastran with more than 15 impact tests, including side crash, crash cone push-off tests and more. The software surpassed our expectations – and those expectations are very high.”

Chassis test rig at the Minardi Lab in Faenza, Italy.

Following is a brief description of several of the Impact and Performance Tests to which Mirabini is referring. These provide a sense of the power, precision, and accuracy that is required in the engineering analysis software to produce a useful simulation.

Side Crash - This is the most demanding test. A 780Kg cart impacts the side of the chassis at 10 m/s, and lateral crash appendices (called Crash Cones) are measured, which include maximum deceleration and maximum force on a cone. Each cone has to take from 15-35% of the total energy, and no damage can be found on the chassis.

Penetration Test - A square flat plate with the same layout of the chassis in the side area is quasi-statically penetrated with an aluminum conical impactor until a penetration of 1500 mm is measured. The model must respond to absorbed energy >6000 J, and reaction load >250kN.

Main Roll Bar Crush - The roll bar is statically pushed with a force of about 120kN via an inclined plate, impacting the main roll-bar top. Requirements are that deformation is less than 50mm, and the damaged area must be within 100mm from the load application plate.

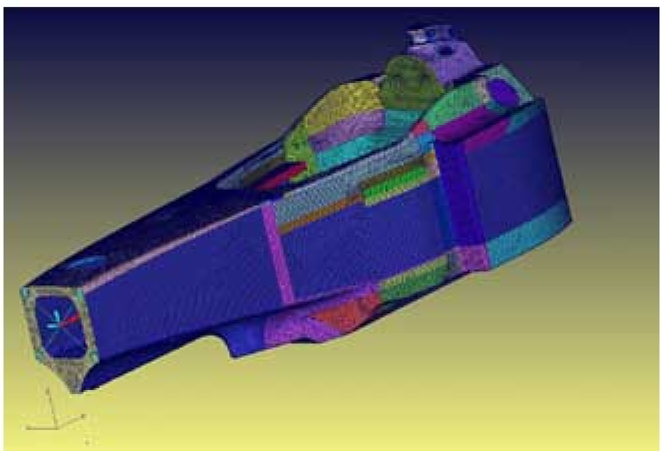
Front Roll Bar Crush - The front roll bar is a reinforcing structure located just behind the steering wheel. A similar test as in the Main Roll Bar Test is made with a 75kN vertical force.

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

Torsional Stiffness - Each team has developed its own tradition for desired torsional stiffness ranging from 15,000 – 40,000 N M/o

Flexural Stiffness - This test is made to check that 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.

All of the tests above were simulated in the NEiNastran analysis environment and most were able to be replicated very closely. However, there are a few exceptions that require different handling. For example, the Penetration Test uses a simplified correlated calculation validated by years of experimental data that was developed within Minardi.



The NEiNastran model used laminated shell elements and solid elements for foam-filled areas.

The team used NEiNastran to simulate these tests, checking static analysis, buckling and surface contact. All calculations were correlated with experimental measurements. This enabled a continuous refinement of methodologies and material data. During the testing, several optimization routines were executed involving modifications on material choice, layup sequences, local reinforcements, foams, bulkheads, and inserts. In these optimization exercises, NEiNastran proved flexible enough to manage the existing model while solving various alternates thrown at it providing highly detailed and accurate post-processing information. In this way, the effects of the modifications were able to be well understood by the engineers.

Software Features and Strong Tech Support Make a New Design Process Possible

Minardi worked with Noran Engineering's Master European Distributor SmartCAE in the evaluation and implementation of NEiNastran. After the six-month evaluation, the Minardi team was satisfied that a number of key benefits would be achieved with a software change. In late 2004, the Minardi Team made the change official and switched to NEiNastran. Following are several factors the Minardi F1 Team said were instrumental in their decision to change:

• Faster and better designs. The amount of prototype testing could be reduced significantly because the accuracy of results using NEiNastran's Surface Contact feature was an improvement over the previous method. Similarly, the nonlinear analysis setup and solution finding also proved far more robust than their former software.

• Fast implementation. An excellent training program combined with timely support from Noran Engineering allowed the new software system, NEiNastran, NEiAdvanced Composites and Smart/Browser to be implemented and used by the Minardi team within a matter of weeks.

• Access and use of legacy data. The system was designed to enable bi-directional access to legacy and new data without any compatibility issues.

• Reduced 3D modeling time. The creation of the FE model of the chassis was achieved in about half the time compared to previous software because of the power inherent in the NEiModeler (FEMAP) Pre and Post Processor which includes the modules NEiAdvanced Composites and Smart/Browser.

Conclusion

The performance of Minardi's new cars in the upcoming Formula 1 season will of course have the attention of its race fans. But other Formula 1 Race Teams will also be looking with a critical eye. They will want to know whether Minardi's knack for finding a new technical edge might be at work again, and if this means they may need to tune up their FEA software.

Visit the Noran Engineering website to check out other case studies from innovative companies and learn more about NEiNastran. Information on the Minardi Formula Race Team can be found at the Minardi FI Team website. See SmartCAE website for additional information on that product.

Dennis Sieminski is responsible for directing the marketing programs at Noran Engineering and works with a network of international dealers on customer support and the development of new applications and business. Mr. Sieminski's academic credentials include engineering and business degrees, as well as a *professional engineer's license. His previous work experience and background in product development in a range of industries provides him with a hands-on appreciation for the role and benefits of design, analysis, and simulation software.*