Curved Barrier Impact of a NASCAR Series Stock Car

Eric A. Nelson and Li Hong
Altair Engineering
ean@altair.com
lmh5@altair.com

Abstract

A detailed finite element model of a NASCAR Series stock car has been developed by Altair Engineering and used to study a curved barrier impact. This paper will review some of NASCAR's capabilities in the area of motor sports safety research and provide an overview of a study that has been performed by Altair Engineering. Specifically, the author will compare and contrast results from a curved barrier impact in 3 different scenarios:

- *Controlled full vehicle crash test*
- *On-track incident with very similar impact conditions*
- *Detailed finite element analysis using LS-DYNA*

Background

Altair Engineering is currently partnered with NASCAR in a variety of projects to enhance motor sports safety. Specifically, Altair has assisted NASCAR by developing detailed finite element models of a NASCAR vehicle and performing extensive crash simulation using LS-DYNA.

There are 3 specific areas of NASCAR's research and development program that have combined to increase the understanding of stock cars and their crashworthiness:

- Crash simulation using detailed finite element models
- On-track data acquisition through the use of "black box" technology
- Large and small scale crash testing

The synergies that exist between each of these areas have allowed NASCAR and their partners to gain a deeper insight into on-track incidents that do occur and to study possible improvements through changes to vehicle structure, barrier systems, and restraint systems. A brief explanation of NASCAR's current capabilities in each of these areas is provided below.

Crash Simulation

Through their involvement with Altair Engineering, NASCAR has funded the development of detailed finite element models of a NASCAR vehicle for crash simulation. These models can be used to simulate any impact condition, predict the vehicle forces, and visualize the deformations of the structure as it undergoes an impact. To date, these models have been used to study a variety of structural modifications to the vehicles, to compare a series of unique impact conditions, and to evaluate different barrier systems. In the case of NASCAR, where each vehicle is unique, the use of simulation technology is particularly advantageous because the uncertainty that arises due to vehicle to vehicle variation can be eliminated from the study.

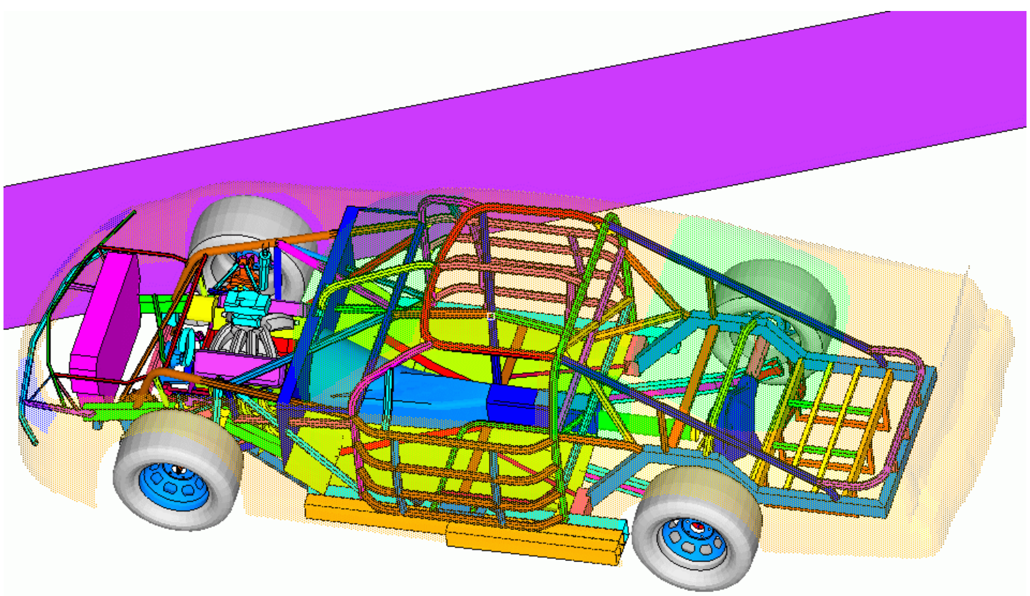

Figure 1. Crash Simulation

"Black Box" Technology

Since the 2002 season, NASCAR has required the use of the Independent Witness Inc. (IWI) data recorder called "The Witness" for all race series. This wireless unit is installed on the vehicle side rail adjacent to the driver's seat and records vehicle crash information such as G-loads and Delta-V. The data from all on-track incidents are extracted following each event and retained in a NASCAR database for future evaluation and comparison. The retention of such data allows for a better understanding of the vehicle forces from all kinds of impacts and over time will lead to safer racing as countermeasures can be considered for the most serious impact conditions.

Figure 2. "The Witness"

Crash Testing

Through their involvement with the Midwest Roadside Safety Facility (MwRSF) at the University of Nebraska, NASCAR has been able to perform both full scale and reduced scale crash tests to study vehicle and barrier design. Crash tests aid the development of vehicle and barrier systems by validating performance and confirming that the assumptions made during the engineering process were valid. In addition, the ability to use additional data acquisition tools and numerous video angles during these tests makes them valuable for gaining an even deeper understanding of the impacts observed in NASCAR racing.

Figure 3. Barrier Test

Introduction

Following a serious on-track incident that occurred early in 2001, Altair developed the initial NASCAR vehicle model and correlated this model to a high-angle barrier impact similar to the accident condition (54 degree non-tracking impact).

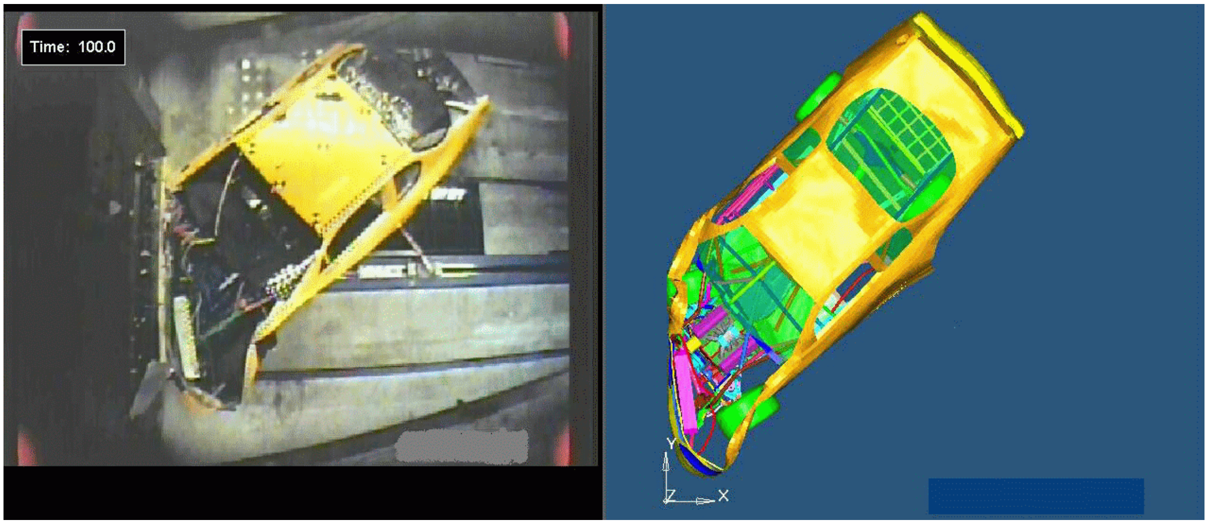

Figure 4. Model Correlation Effort

No data had previously been available to investigate the model correlation at other impact conditions. However, in November 2002, a full scale curved barrier impact test of a NASCAR vehicle was performed at the MwRSF. The impact condition for this test was a 24.7 degree, 135.6 mph tracking impact.

In addition a nearly identical curved barrier impact occurred in a NASCAR event during the 2002 season. The data from this accident was captured using the IWI data recorder installed on the vehicle and was retained in the NASCAR database.

Since there was a significant amount of data for very similar impact conditions in both the curved barrier test and the on-track incident, Altair proposed a project to:

- Evaluate the performance of the model in a low angle impact
- Compare and contrast the vehicle response in test, race, and simulation
- Identify areas for further study

Model Setup

A 25 degree, 140 mph impact baseline model from an earlier project was selected as the start point of the study. A number of minor modifications were made to the vehicle structure in this model to match the vehicle content of the curved barrier impact test vehicle, and the curved barrier of the appropriate radius was added to the model.

The impact condition of the curved barrier impact test and the simulation performed for this project is shown below.

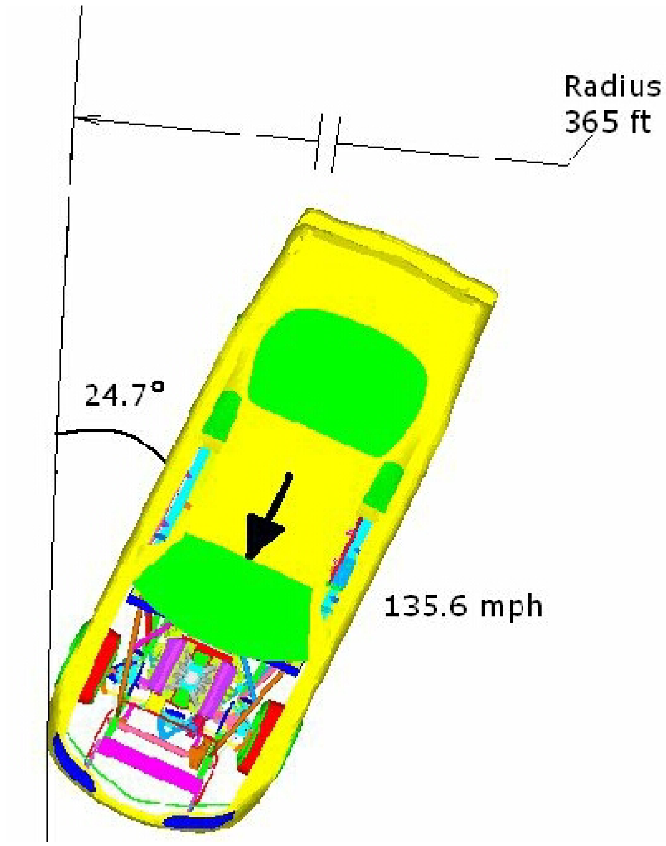

Figure 5. Curved Barrier Impact Condition

Flat Barrier Results

Although it was slightly outside of the initial scope of the project, Altair decided it was important to begin the comparison of test and analysis results with a flat barrier impact. Fortunately, data was available for a flat barrier impact test that was conducted at MwRSF using similar impact conditions (approximately 25 degrees, 140 mph). This impact condition had been simulated during an earlier project using the same baseline model.

The plots below show the lateral and longitudinal pulse curves for the flat barrier impact test overlaid with the simulation results. Although it is believed that there were some minor differences in the vehicle content for the flat barrier impact test, good agreement is observed between the test results and the simulation results.

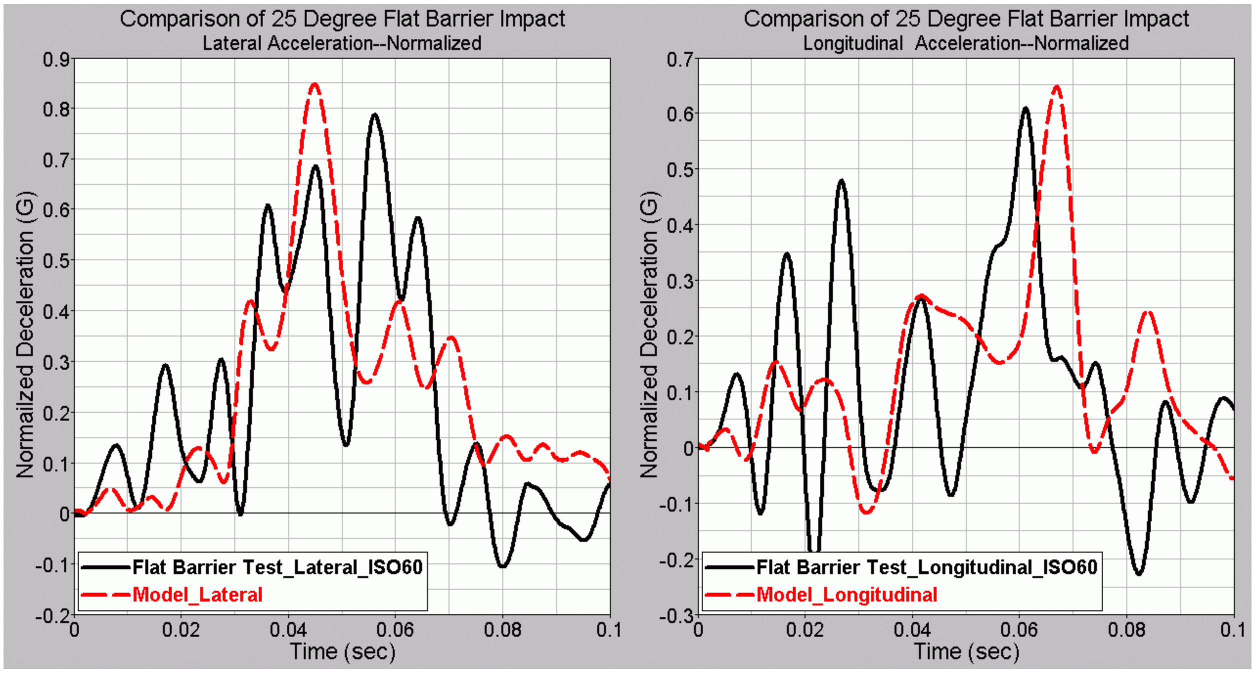

Figure 6. Comparison of Flat Barrier Vehicle Response

The MwRSF staff, NASCAR, and Altair collected an extensive collection of pre- and post-test photos. The images below provide a sample of the post-test photos with comparable post-analysis images from the flat barrier simulation.

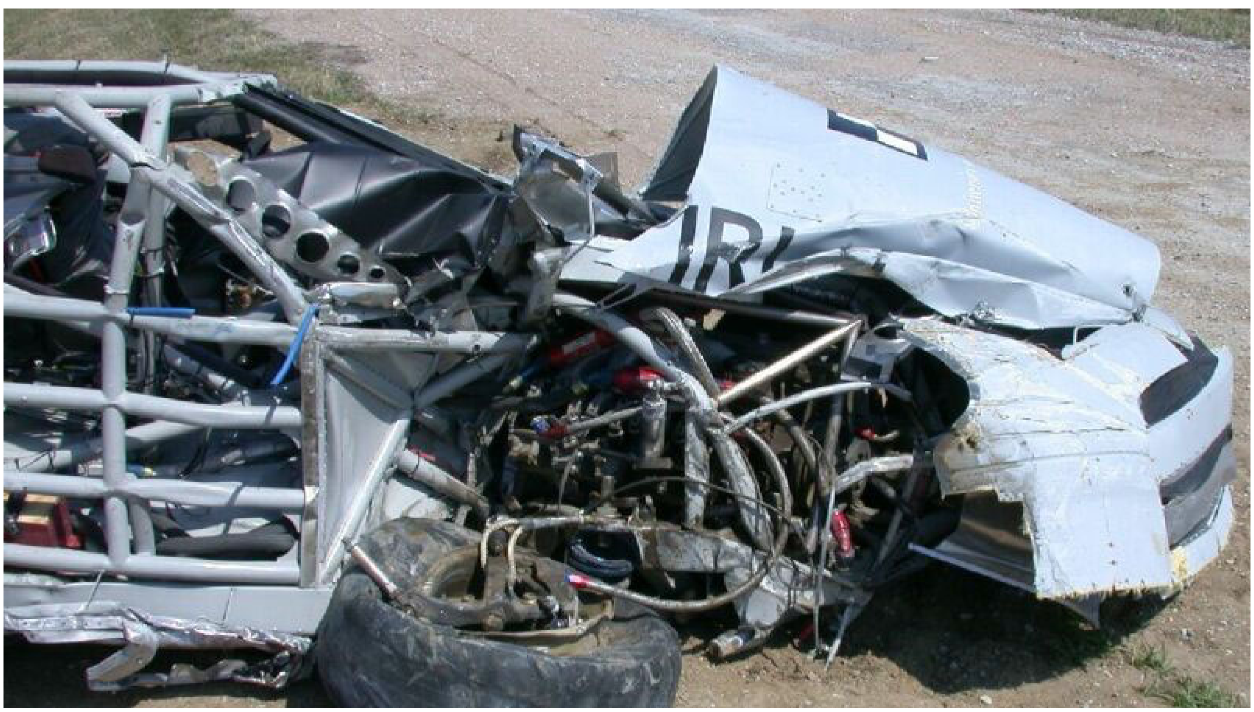

Figure 7. Flat Barrier Test Photo

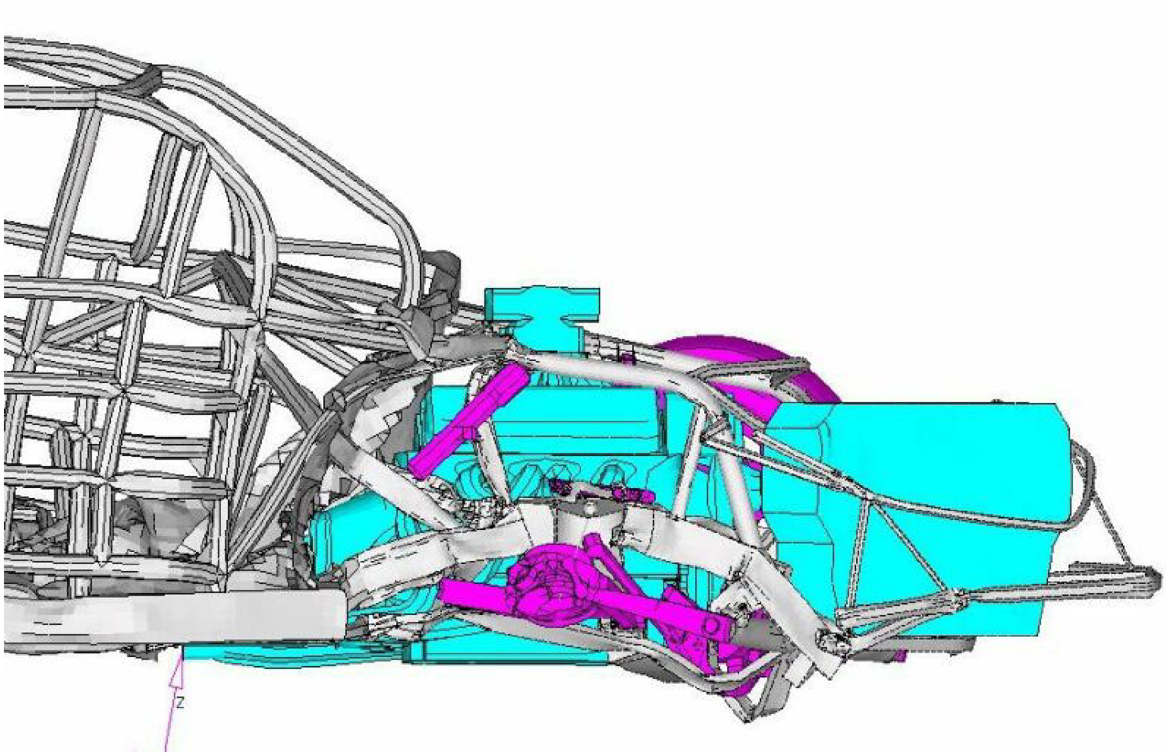

Figure 8. Flat Barrier Simulation Image

Curved Barrier Results

The initial simulation of the curved barrier impact test did not show the level of correlation observed in the flat barrier simulation. As intended, several iterations of the curved barrier impact condition were performed to improve the level of correlation obtained. These iterations mainly involved minor modifications to the RF lower control arm since the vehicle used in the curved barrier impact test used a different control arm design that appeared to be considerably stiffer.

The plots below show the lateral and longitudinal pulse curves for the curved barrier impact test, the simulation model, and the on-track incident.

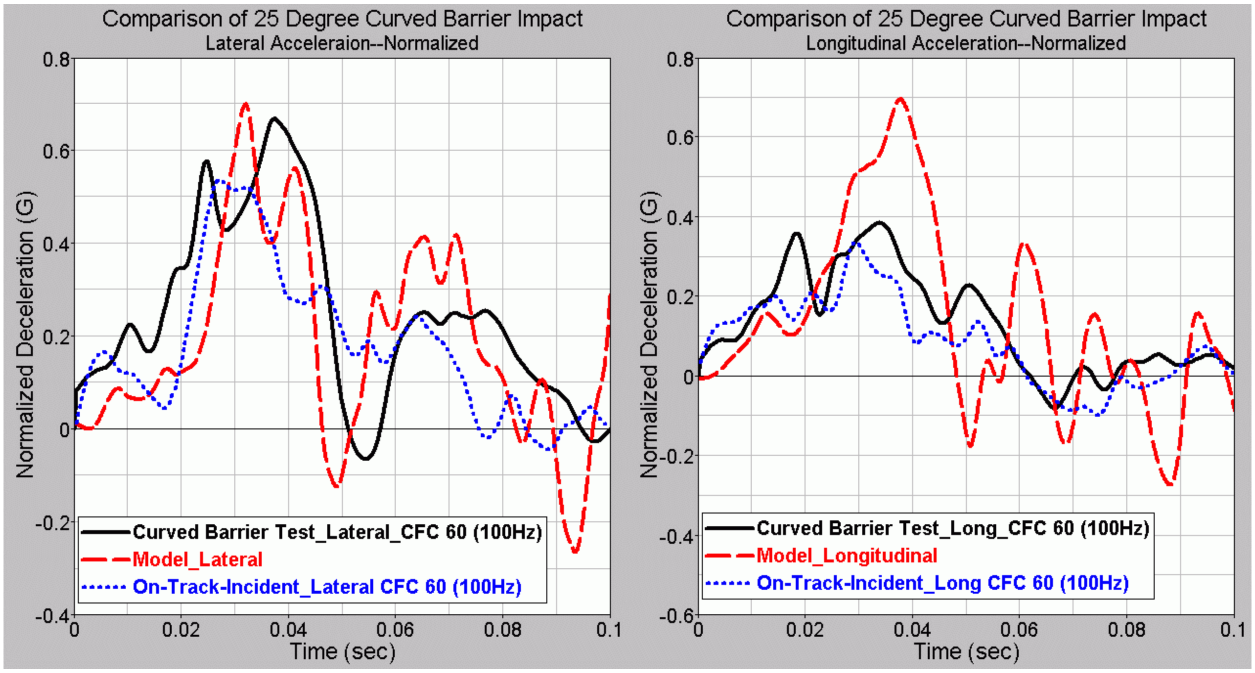

Figure 9. Comparison of Curved Barrier Vehicle Response

Several observations can be made from the overlaid curves shown above:

- Although it is likely that there are some differences in the vehicle content for the 2 scenarios, the vehicle response for the curved barrier impact test and the on-track incident show good agreement (solid vs. small dashes). This indicates that the barrier tests performed at the MwRSF are representative of on-track incidents for similar impact conditions.
- The lateral deceleration for the simulation shows good agreement to the curved barrier impact test (large dashes vs. solid).
- The simulation over-predicts the longitudinal deceleration by approximately a factor of 2 (large dashes vs. solid).

As with the flat barrier impact test, an extensive collection of pre- and post-test photos was collected. The images below provide a sample of the post-test photos with comparable post-analysis images from the curved barrier simulation.

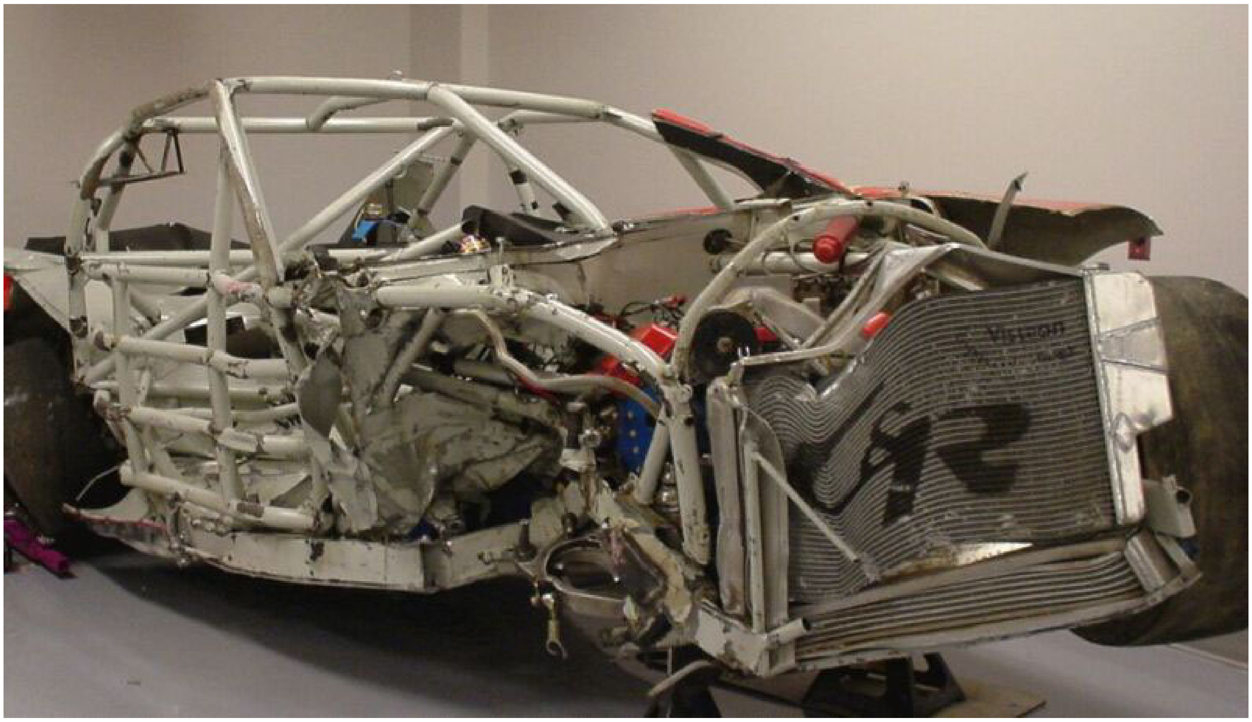

Figure 10. Curved Barrier Test Photo

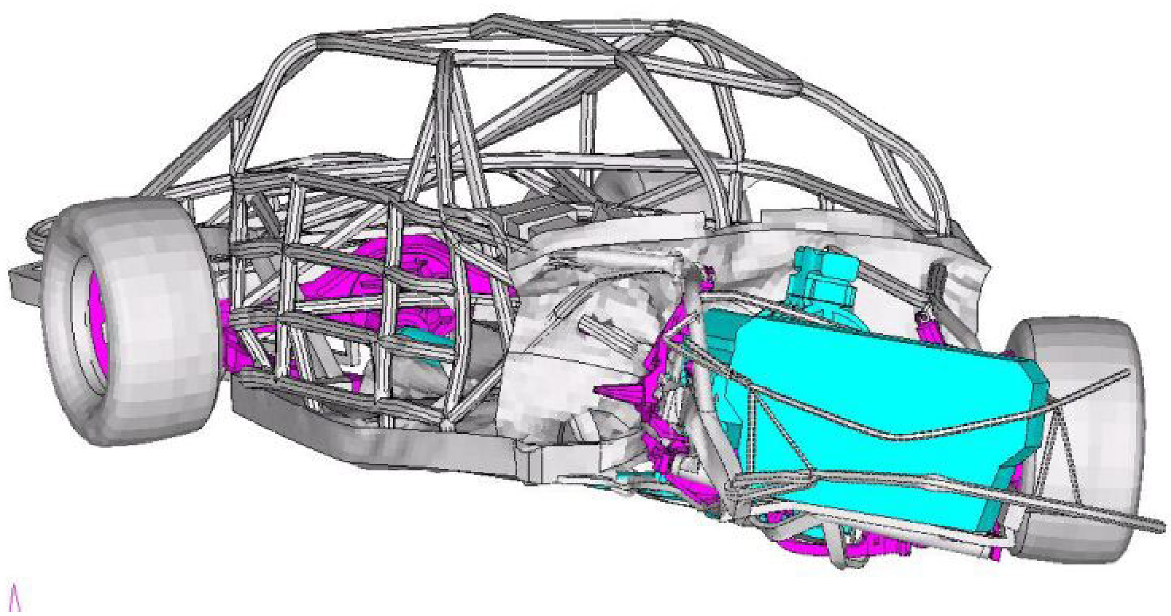

Figure 11. Curved Barrier Simulation Image

Figure 12. Curved Barrier Test Photo

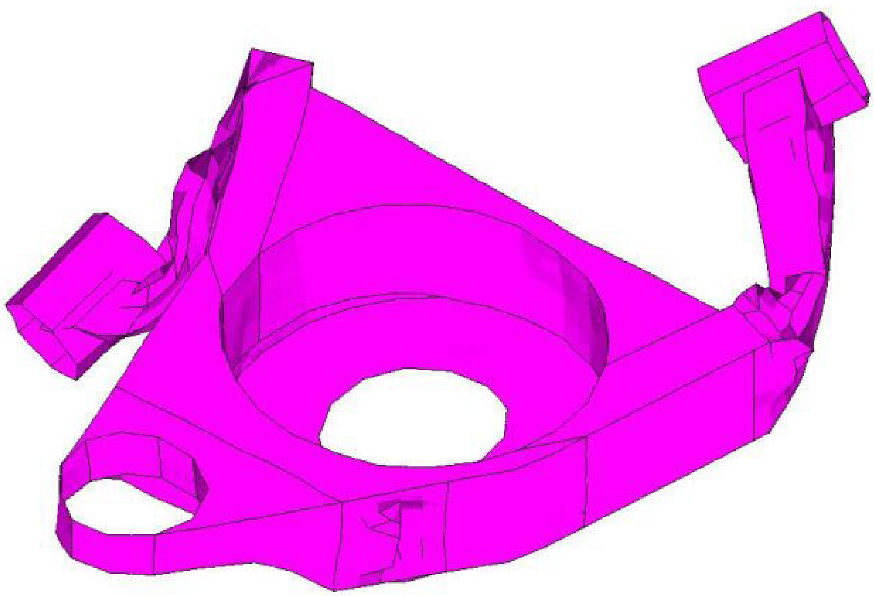

Figure 13. Curved Barrier Simulation Image

One significant difference that was noted between the flat and curved barrier impact test vehicles was that many joints failed in the curved barrier test vehicle. These joint failures may explain the fact that the peak-G values for the curved barrier impact test were considerably lower than the peak-G values for the flat barrier impact test. The images below provides a sample of the post-test photos from the curved barrier impact test showing the joint failures which were prevalent in that vehicle.

Figure 14. Curved Barrier Test Photo

Figure 15. Curved Barrier Test Photo

Comments on Model Correlation

Based on viewing the animations and test video for the curved barrier impacts, Altair felt that the longitudinal deceleration may be closely tied to the rotation of the vehicle in the impact. NASCAR has also indicated that experience with the IWI data recorders tends to support this theory.

With that in mind, there are 3 areas of the analysis that Altair has considered for the difference in the longitudinal deceleration values for the test and the simulation. A brief explanation of each of these areas and the rationale for the potential differences in the results is provided below.

Barrier Coefficient of Friction

2 additional iterations of the curved barrier impact simulation have been performed with reduced values for the barrier coefficient of friction. Up to this point, the value of 0.2 has been used for the barrier coefficient of friction for all simulations. The 2 additional iterations used values of 0.1

and 0.02 instead for comparison.

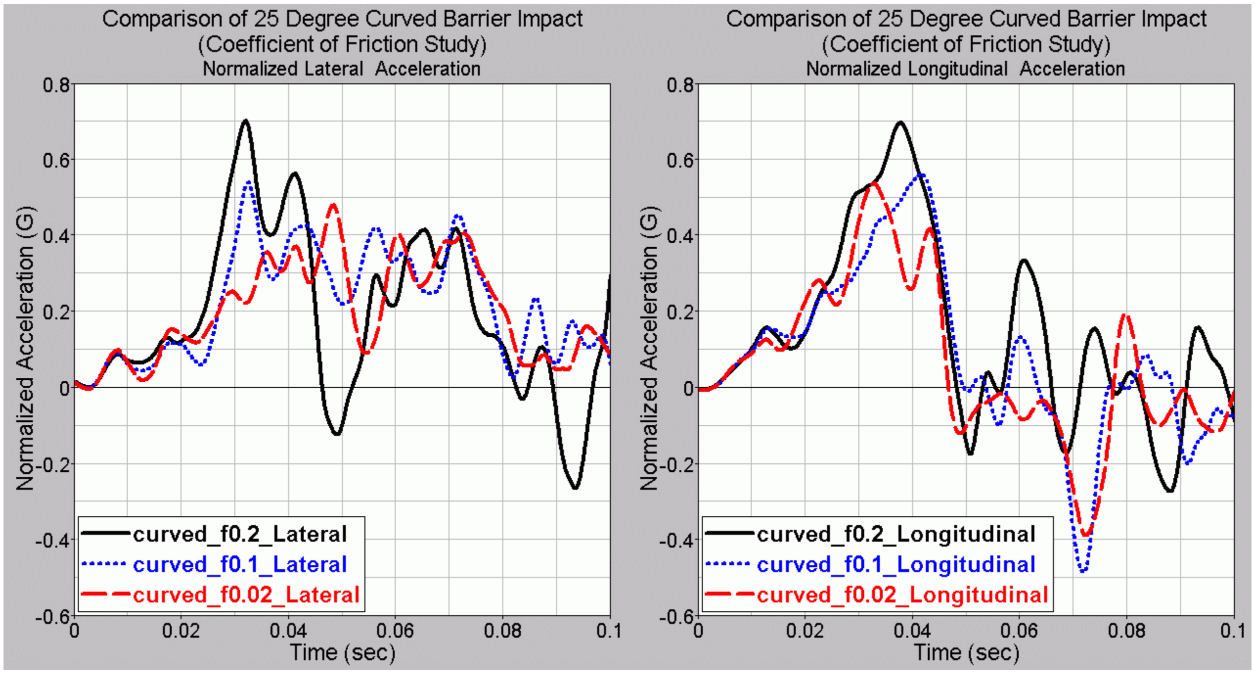

Figure 16. Comparison of Vehicle Response with Different Friction Coefficients

While the plots clearly indicate that a "slippery" barrier surface tends to result in lower peak values for the longitudinal peak-G values, the deformations observed in these additional analyses appeared to be much less realistic than the original simulation results. In addition, further research indicated that the coefficient of friction between steel/concrete and rubber/concrete is at least 0.2.

Vehicle Inertia Properties

The weight of the NASCAR vehicle used in the analysis performed at Altair has been specified at 3600 lbs. for the duration of these projects. This value represents the 3400 lb. minimum vehicle weight as specified in the NASCAR rulebook [1] and a 200 lb. addition for driver weight. Since many of the vehicle components that do not affect crashworthiness are excluded from the finite element model, the vehicle weight is "scaled" up to the 3600 lb. value by placing additional weight near the vehicle CG. If indeed the rate of vehicle rotation affects the longitudinal deceleration values then it may be that the vehicle's rotational inertia properties need to be "tuned" to be more realistic.

MwRSF staff have indicated that they have estimated the rotational inertia of the NASCAR vehicle (about the vertical axis) to be approximately 3100 $kg*m^2$. The simulation output for one of the analysis models show that the rotational inertia of the model is approximately 2200 $kg*m^2$.

Although the difference in the inertia properties of the vehicle appears to be significant, it may not be the primary reason for the differences in the longitudinal pulse curves for the curved barrier impact simulation. If it were, one would expect to find a similar discrepancy in the flat barrier impact simulation as well.

Joint/Weld Failure

Although it is possible to simulate material failure in the welded joints analytically, this has not been attempted in the NASCAR vehicle model up to this point because:

- A thorough understanding of the heat affected zone and the local material properties would be required.
- There is known to be considerable variation in the fabrication process for the different chassis manufacturers and teams.

The flat barrier test (with minimal weld failure) shows good agreement with the simulation results for both the lateral and longitudinal vehicle pulse. Since the model does not predict joint failure, this indicates that one possible explanation for the discrepancy in the longitudinal values for the curved barrier impact is the extensive joint failure that occurred in the curved barrier impact test. At the time of this project, it was considerably out of the scope of this project to attempt to simulate such joint failure in the simulations.

Conclusions and Suggestions for Future Studies

Having studied the flat and curved barrier impact tests, the on-track incident, and the various simulation models extensively Altair has drawn the following conclusions:

- Very good agreement is observed between analysis and test for the flat barrier impact.
- The rotational inertia of the vehicle model may not accurately represent that of an actual NASCAR vehicle and this may contribute to the discrepancies in the longitudinal vehicle pulse for the curved barrier impact.
- The extensive weld failure in the curved barrier impact test may be the primary reason for the discrepancies observed in the longitudinal vehicle pulse curves for the curved barrier impact.

The amount of variation in the weld integrity between the 2 vehicles and 2 tests (and the apparent effect on the model correlation) was an important take-away from this study. This variation makes it difficult to expect consistent responses from similar impacts and results in uncertainty when trying to study the effects of vehicle structure or barrier system changes. As such, NASCAR has engaged industry experts to inform and educate race teams about the performance and integrity of welded joints and to demonstrate how to best create those joints.

References

1. "NASCAR Winston Cup Series, 2001 Rule Book," National Association for Stock Car Auto Racing, Inc., Daytona Beach, FL, 2001.