Development & Validation of a Finite Element Model for the 2002 Ford Explorer

Background
A finite element (FE) model based on a 2002 Ford Explorer was developed through the process of reverse engineering at the National Crash Analysis Center (NCAC) of The George Washington University (GWU). This model was validated to the National Highway Traffic Safety Administration (NHTSA) frontal New Car Assessment Program (NCAP) test for the corresponding vehicle. This vehicle was selected to represent the Sport Utility Vehicle (SUV) class of the fleet in vehicle and highway safety studies.

Modeling
A production version of the 2002 Ford Explorer SUV was purchased as the basis for the model (VIN 1FMDU72KX3UA60597). The reverse engineering process systematically disassembled the vehicle part by part following established procedures [1,2,3]. Each part was cataloged, scanned to define its geometry, measured for thicknesses, and classified by material type. All data was entered into a computer file, and then meshed to create a computer representation for finite element modeling that reflected all of the structural and mechanical features in digital form.

The resulting FE vehicle model has 619,161 elements and does not include the interior components or restraint system. This detailed FE model was constructed to include full functional capabilities of the suspension and steering subsystems. A representation of this model is shown in Figure 1.

Parts were broken down into elements such that critical features were represented consistent with the implications of element size on simulation processing times.

Material data for the major structural components was obtained through coupon testing from samples taken from vehicle parts. From the material testing, appropriate strain rate values were determined to include in the model for the analysis of stress and strain behavior in crash simulation.

![FIGURE 1 – FE model of the 2002 Ford Explorer](image_url)

The properties of the various materials identified were determined by testing of specimens taken from the parts. The test data and/or standard material types were assigned to each element.

This set of elements was translated into an FE model by defining each as a shell, beam, or solid element in accordance with the requirements for using LS-DYNA software [4]. The result of these efforts was a finite element model with the following characteristics:

- Number of Parts: 791
- Number of Nodes: 632,166
- Number of Shells: 585,418
- Number of Beams: 48
- Number of Solids: 33,695
- Number of Elements: 619,161

The modeling effort detailed all components of the vehicle. Figure 2 shows the details of the model for the frame and power train for this vehicle. The
engine was not modeled in detail as simulation experience has found that it reacts as a large rigid mass in crashes. Figure 3 is a close-up of the front steering and suspension system. These moving parts were detailed to provide the capability to simulate suspension and steering response in the simulation analyses. Interior elements of this vehicle were not initially modeled.

![FIGURE 2 – Details of the modeled vehicle frame and drive train](image)

![FIGURE 3 – Details of the modeled steering and suspension subsystems](image)

This model was validated by comparing the simulation of the NCAP frontal wall test with the actual data from NCAP Test 3730 for a comparable vehicle [5].

Table 1 compares key parameters of the FE model and the vehicle used in the NCAP test. It can be noted that all were very similar. More information on the NCAP test vehicle information like test vehicle weight distribution, test vehicle attitude, center of gravity location, and fuel tank capacity are published in the NHTSA’s report for Test 3730.

### TABLE 1 – Comparison of parameters for FE model and vehicle used in the NCAP test

<table>
<thead>
<tr>
<th></th>
<th>FE Model</th>
<th>Test 3730</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (Kgs)</td>
<td>2240</td>
<td>2323</td>
</tr>
<tr>
<td>Engine Type</td>
<td>4.0L V6</td>
<td>4.0L V6</td>
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<tr>
<td>Tire size</td>
<td>P235/70R16SL</td>
<td>P235/70R16SL</td>
</tr>
<tr>
<td>Attitude (mm)</td>
<td>As delivered</td>
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</tr>
<tr>
<td></td>
<td>F – 840</td>
<td>F – 835</td>
</tr>
<tr>
<td></td>
<td>R – 870</td>
<td>R – 866</td>
</tr>
<tr>
<td>Wheelbase (mm)</td>
<td>2885</td>
<td>2885</td>
</tr>
<tr>
<td>CG (mm) rear of front wheel C/L</td>
<td>1392</td>
<td>1468</td>
</tr>
<tr>
<td>Body Style</td>
<td>5 Passenger</td>
<td>7 Passenger</td>
</tr>
</tbody>
</table>

**Validation Results**

After verification of the model, efforts were initiated to simulate a crash of this vehicle into a wall at 35 mph as required under the NHTSA NCAP testing (Figure 4). For this simulation, accelerometers were placed at the same locations as in the test (Figure 5).

The most commonly benchmarked accelerometers for NCAP performance are the left rear seat, right rear seat, engine top, engine bottom, and instrument panel top. The left rear seat and right rear seat accelerometers are used to measure the deceleration response and velocity of the vehicle after impacting the rigid wall.

![FIGURE 4 – NCAP full frontal wall test set-up](image)
The FE model NCAP simulation was performed using the LS-DYNA non-linear explicit finite element code. The FE vehicle model was run using LS-DYNA Code Version 970 on a single precision Itanium 2 platform. The FE model response would be expected to vary for other facilities depending on hardware, LS-DYNA version, and precision used. Total duration of the simulation was 150 milliseconds to capture the initial impact until the rebounding of the vehicle from the NCAP load cell wall. Approximate computation time to run 150 milliseconds using 4 processors on a single precision SGI workstation was 85 hours.

The overall global deformation pattern of the FE model was very similar to that of NCAP Test 3730 (Figure 6). It was noted in the initial side view comparison that there was excessive bending of the frame rails in the model. Further investigation of the model and the actual vehicle indicated that the initial version of the model did not reflect the true characteristics of the frame rails. After adjusting the material characterizations and geometry, the simulation was rerun and, as can be noted in Figure 7, there was less deformation of the frame rails.

The global response of the vehicle was further benchmarked against the NCAP test data by comparing the average acceleration responses from the rear seat cross member accelerometer, average velocity of the vehicle, and engine top and bottom acceleration.

The data from the accelerometers mounted on the left rear seat and right rear seat were averaged and compared to the accelerometer response from the test. The timing and shape of the peak acceleration in the test was matched in the FE simulation (Figure 8). The average velocity in the simulation closely tracked the average velocity noted in the test (Figure 9).

The global response of engine top and engine bottom accelerometers also compares well to the response from test vehicle as shown in Figures 10 and 11.
Figure 12 shows the comparison of the total force exerted by the vehicle on the load cell wall between the simulation and test. The plots are similar up to 50 milliseconds, after which the wall force from the simulation tends to drop off faster than that of the test, indicating that the FE model is rebounding earlier than in the test.

Figure 13 shows the total vehicle displacement, which tracks closely in both the test and simulation over time. The rebound effect is noted here as well.
Figure 14 shows the comparison of the force-displacement curves. The cross plot of force and displacement shows similar behavior of the vehicle in both the test and simulation.

Last, in Figure 15, the total energy plot shows the energy balance throughout the simulation. The total energy for the crash simulation is nearly constant. During the initial stages of the simulation, the kinetic energy of the system is at a maximum and internal energy of system is at a minimum. As the simulation progresses, the kinetic energy decreases and internal energy increases, as would be expected. However, the total energy is balanced and remains constant. Since the sliding energy and system damping energy are not significant relative to total energy, they are not shown on the plot.

Summary & Conclusions
A finite element model of the 2002 Ford Explorer SUV was created by reverse engineering. This vehicle was selected to represent the SUV class of vehicles on U.S. highways. The modeling effort led to a detailed model that consisted of 619,161 elements with representation of the steering and suspension subsystem functions.

The model was validated by comparison to images and data derived from the NHTSA NCAP Test 3730, which involved frontal impact into a rigid wall at 35 mph. Comparisons of data from the test and the model included:
- View of side and underside deformations,
- Acceleration and velocity changes for the seat cross member,
- Movement of the accelerometers on the top and bottom of the engine,
- Total forces over time,
- Displacement over time,
- Force displacement plots, and
- Total crash energy and energy balance.

Both the vehicle kinematics and the accelerometer output data were compared and the simulation results showed good correlation with the physical test results.

The FE model was found to be stable in full frontal rigid wall simulations. The model was also successfully run at 25, 30, 35, and 40 mph to ensure stability.
The first version of the model was posted on June 1, 2007. A subsequent release of the model included the interior components to allow its use for occupant risk analysis.

References

For More Information
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