Development & Validation of a Finite Element Model for the 2001 Ford Taurus Passenger Sedan

Background
A finite element (FE) model of a 2001 Ford Taurus passenger sedan was developed through the process of reverse engineering at the National Crash Analysis Center (NCAC) of The George Washington University (GWU) under an FHWA contract. This model was validated to the National Highway Traffic Safety Administration (NHTSA) frontal New Car Assessment Program (NCAP) test for the corresponding vehicle. This model was developed to support NHTSA occupant risk and vehicle compatibility studies and FHWA crash research and barrier development efforts. This technical summary provides details on the important features of this FE model and its validation.

Modeling
A production 2001 Ford Taurus passenger sedan was purchased as the basis for the model. The reverse engineering process systematically disassembled the vehicle part by part. Each part was cataloged, scanned to define its geometry, measured for thicknesses, classified by material type, and meshed to define elements. All the data were entered into a computer file to create a computer representation (i.e., finite element model) that reflected all of the structural and mechanical features of the vehicle in digital form.

The resulting FE vehicle model has 855,379 elements and does not include the interior components or restraint system. 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.

The properties of materials used in the vehicle parts were established or confirmed by testing specimens taken from the vehicle in the reverse engineering process. Material characterization followed accepted procedures using multiple samples. From the material testing, appropriate stress vs. strain curves were determined and assigned to each part to allow the accurate crush behavior in the simulations.

![Figure 1 – FE Model of the 2001 Ford Taurus passenger sedan](image)

This set of parts 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. The result of these efforts was an FE model with the following characteristics:

- Number of Parts: 778
- Number of Nodes: 882,225
- Number of Shells: 784,259
- Number of Beams: 4
- Number of Solids: 66,523
- Number of Elements: 855,379

The modeling effort detailed all components of the vehicle. Figure 2 shows the details of the model for the unibody frame for this vehicle. The engine, not shown in the figure, was modeled with a coarse mesh, as simulation experience has found that it reacts as a large rigid mass in crashes. Interior components of this vehicle were not included in this version of the model.
FIGURE 2 – Details of the modeled unibody frame for the vehicle

Model Validation
After general verification of the model using LS-DYNA, efforts were initiated to simulate the crash of the Taurus FE model as in the NHTSA full-frontal impact test, as shown in Figure 3. The objective of the NHTSA’s full-frontal impact into a stationary barrier at 35 mph is to provide consumers a crashworthiness assessment of the vehicle structure and performance of the restraint system. Data from NCAP Test 3248 was used for comparison [1].

The FE vehicle model was run using LS-DYNA Code Version 971 on an Itanium 2 platform. Total duration of the simulation was 150 milliseconds to capture the initial impact until the rebounding of the vehicle from the wall. The approximate computation time using 8 processors on a single precision SGI workstation was 31 hours.

For this simulation, accelerometers were positioned in the same locations as the NHTSA NCAP test (Figure 4). The most commonly benchmarked accelerometers for NCAP performance are the left rear seat, right rear seat, engine top, and engine bottom. 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.

The NCAP simulation was performed using the LS-DYNA non-linear, explicit finite element code [2].

Table 1 provides specific data for key parameters of the FE model and the vehicle used in the NCAP test. It is easily noted that all were very similar. More information on the NHTSA’s NCAP test vehicle information like weight distribution, test vehicle attitude, center of gravity (CG) location, and fuel tank capacity are published in the NHTSA’s report for Test Number 3248.

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

<table>
<thead>
<tr>
<th>Location</th>
<th>Node ID</th>
<th>Location</th>
<th>Node ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left seat</td>
<td>3740178</td>
<td>Right seat</td>
<td>3740186</td>
</tr>
<tr>
<td>Engine Top</td>
<td>2912569</td>
<td>Engine Bottom</td>
<td>2912577</td>
</tr>
</tbody>
</table>

FIGURE 3 – NHTSA frontal NCAP test set-up

FIGURE 4 – Accelerometer locations in the FE model

The overall global deformation pattern of the FE model was very similar in the side view to that of NCAP Test 3248 (Figure 5). Additionally, Figure 6 shows the bottom view of the vehicle from the
simulation and the test after impact. The areas with the circles in the figure show the similarity of the floor deformation observed in the test and the simulation.

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

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 seat cross member acceleration plot shown in Figure 7 indicates that the FE model tracks the test response in vehicle deceleration up to 60 ms into the crash event. Following 60 ms, the FE model shows greater acceleration than the physical test. This is also reflected in the average velocity comparison shown in Figure 8. The FE model very closely tracks the test response up to 60 ms, after which the FE model slows down faster than the test vehicle. This indicates that FE model may be stiffer in some parts of the crush zone. Possible reasons include a coarser mesh or absence of failure criteria in the rail components.
The global response of the engine top and engine bottom accelerometers also tracks the response from test vehicle as shown in Figures 9 and 10. The figures show reasonable comparisons between the test and simulation. The engine bottom peak acceleration from the simulation is lower than in the test which could be attributed to softness in the engine cradle.

Figure 11 shows the comparison of the total force exerted by the vehicle on the load cell wall between the simulation and test. These plots show good correlation between the test and simulation.

Figure 12 shows the total vehicle displacement, which tracks closely between the test and simulation over time. The total vehicle displacement from the FE simulation is greater than the test by 50 mm.

FIGURE 8 – Comparison of velocity for rear seat cross member

FIGURE 9 – Comparison of test and simulation data for engine top accelerometer

FIGURE 10 – Comparison of test and simulation data for engine bottom accelerometer

FIGURE 11 – Comparison of test and simulation data for total force

FIGURE 12 – Comparison of test and simulation data for total displacement
Figure 13 shows the comparison of the force-displacement curves. The cross plot of force and displacement shows similar behavior of the vehicle in the test and simulation.

Last, the global energies plot (Figure 14) shows the energy balance throughout the simulation. The total energy for the crash simulation is nearly constant. During the initial stages of simulation, the kinetic energy of the system is at a maximum and internal energy of the 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 were not significant relative to the total energy, they are not shown in the plot.

Summary and Conclusions
A finite element model of the 2001 Ford Taurus passenger sedan was created by a reverse engineering process. This vehicle was modeled to support a wide range of NHTSA and FHWA research efforts. The modeling effort led to a detailed model that consisted of 726,756 elements.

The model was validated by comparison to images and data derived from the NHTSA NCAP Test 3248 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 rear 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 flat rigid wall simulations. The model was also run at 25, 30, 35, and 40 mph to ensure stability.

References

For More Information
See the NCAC website (www.ncac.gwu.edu) for more information, or contact:
- FHWA Office of Safety R&D
  Dr. Kenneth Opiela, PE
  202-493-3371
  kenneth.opiela@dot.gov
- NCAC Staff
  Dr. Steve Kan (Director, NCAC)
This Technical Summary was produced under FHWA Cooperative Agreement DTFH61-02-X-00076 “Operation & Maintenance of the FHWA/NHTSA National Crash Analysis Center” with The George Washington University.