

BUILDING THE MODEL AND ENVIRONMENT FOR VALIDATION OF A CLASS-8 TRUCK

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ABSTRACT

Many studies have been conducted by analyzing crash data that included road profile, site conditions, vehicle configurations and weights, driver behavior, etc. However, limited studies have been conducted evaluating the impact of these factors on crashes and/or rollover through simulations. This is mainly due to lack of availability of verified full vehicle flexible-body models. The verification process is costly as it requires instrumentation of a heavy vehicle, scanning of road surfaces, and collection of data by running the vehicle over different road conditions, performing various maneuvering, etc. This paper presents the reverse engineering process of a class-8 truck and validation of a full flexible-body simulation model of a Wabash 53-foot trailer against the strain data recoded from proving ground testing of an instrumented truck. Simulation results show that, with the exception of the noise from the strain gage data from instrumented test run at 30 mph, there is a good agreement in periodicity and relative amplitude with the ADAMS model. A comparison of strain data from the flex-body model and the instrumented truck shows that the modeling and verification approach presented in this paper can be confidently used to validate the full flexible-body models developed for specific analyses.

Keywords: ADAMS simulation, Class-8 truck, Flexible-body, Instrumentation, Road profile

INTRODUCTION

According to the 2008 data published by the National Highway Traffic Safety Administration, in the U.S. alone, 380,000 large trucks that weigh more than 10,000 pounds were involved in crashes. Out of the 380,000 crashes, 4,066 were fatal crashes while 66,000 were injury crashes. As a result of these crashes, 4,229 were killed and 90,000 were injured (NHTSA 2008). It has been noted that the fatality rate for occupants of large trucks in single-vehicle crashes with a rollover is over 64 percent (NHTSA 2003). Vehicle rollover causes immense safety, economic, and environmental problems (McKnight and Bahouth, 2008). The majority of the studies have been conducted by analyzing crash data that included road profile, site conditions, vehicle configurations and weights, driver behavior, etc (McKnight and Bahouth, 2008; Braver et al. 1997; Gothie', 2006; Pont 2006). However, limited studies have been conducted evaluating the impact of these factors on crashes and/or rollover through simulations (Douglas et al. 2009). Full flexible body simulation is vital to understand the significance of these factors on heavy vehicle crashes and/or rollover and to develop accident prevention techniques. Though the current technology is adequately developed to perform the full flexible body simulations, the progress is limited due to lack of verified models. The verification process is costly as it requires instrumentation of a heavy vehicle, scanning of road surfaces, and collecting data by running the vehicle over different road conditions, performing various maneuvering, etc.

The main objective of this paper is to discuss instrumentation, road surface scanning, the reverse engineering process of a class-8 truck, and validation of the full flexible-body model of a Wabash 53-foot trailer against the strain data recoded from proving ground testing in ADAMS environment simulating one out of six testing scenarios. Scope of the paper is limited to instrumentation, road surface scanning, reverse engineering, challenges or technology limitations, and verification of a flexible-body model using limited test data. The paper does not necessarily address a model development process for any specific analysis such as crashworthiness.

INSTRUMENTATION AND DATA ANALYSIS

Instrumentation

A Peterbilt 379 truck and a Wabash 53-foot trailer were instrumented. One Oxford RT2500, inertial measurement system, was secured to the floor in the cab on the right hand side of the driver's seat. An Oxford RT3100, inertial measurement system, was mounted to a stand and secured to the floor of the trailer. Both inertial systems were used to collect vehicle dynamics data from each independent body for yaw, pitch and roll angles, rates and acceleration as well as GPS location. The SOMAT eDAQ placed in the cab is connected to all sensors. The information offers overall performance to confirm and guide the development of the multi body flex models of the truck and trailer in a computer environment, MSC.ADAMS. It is important to document the behavior of vehicle components at the same time to understand the interaction of each component and the behavior of the entire vehicle in order to validate the flex-body model developed in a computer environment for further analysis. Data from air bag pressure sensors, in both the rear truck suspension and the trailer suspension, were recorded. Linear displacement sensors were placed in parallel positions of the front and rear truck shocks as well as the trailer

shocks. A combination of rosettes was placed on the sidewall of the truck frame and in the same axis with single strain gages on the top and bottom flanges. The rosettes were used for capturing strain from torsion while the single gages on the flanges capture strain from vertical bending. Two sets of this combination were used on the left and right front section of the frame as well as two more sets at the left and right mid-point of the rails, just behind the cab. Figure 1 depicts the locations of the sensors installed on the truck and trailer. A list of sensors used in this project is listed below.

- 28 single strain gages
- 5 rosette strain gages
- 4 air pressure transducers
- 6 linear displacement sensors
- 3 accelerometers
- 1 rotory potentiometer
- 1 wireless driveline torque sensor
- 2 Oxford inertial measurement systems
- 4 micro camera system
- Tractor can bus data

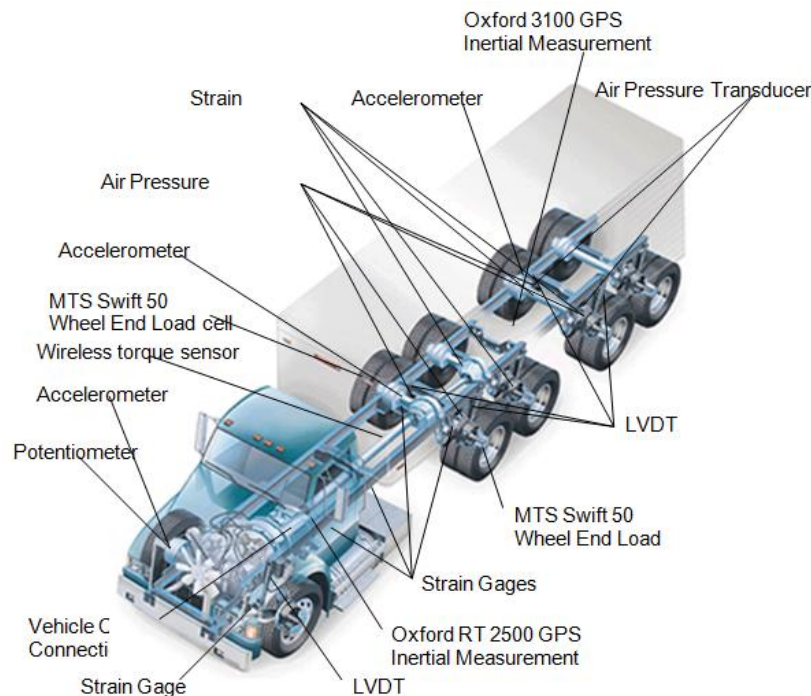


Figure 1 Instrumentation layout

Data collection over several special events at the Bosch Proving Ground was performed, in addition to simpler events like straight line braking (confirm weight transfer of the models), high speed oval lane change (transient lateral load transfer of the models), constant radius (steady state lateral loading of the model), and the chuck hole (single event impact load transfer). The listing of test scenarios is provided below.

- 30mph double lane change
- 33mph braking
- 65mph braking
- 65mph double lane change

- Big oval at 32 mph
- Big oval at 62 mph

Data Analysis and Challenges

The Bosch Proving Ground test data were analyzed primarily by using the Glyphworks software. The software was used to read and analyze the data recorded by the eDAQ unit. The software was used to translate files into *.asc format which does have some benefits for analysis by more statistically oriented software than Glyphworks. However, the files were too large to be used in statistical packages such as MINITAB. MINITAB was capable of reading the files of about 10M lines, but took over 40 minutes to calculate a simple average. In order to overcome this challenge sampling of approximately 10% of the data was performed. This data reduction was very useful for reducing the analysis time to a reasonable level. A simple histogram of driveshaft RPM is shown below (Figure 2). Though data analysis time was drastically reduced with this data reduction approach, further studies are needed for evaluating the impact of data reduction on analysis results if all the data were to use. Detailed discussion on instrumentation and data analysis is given in Liou et al. (2008).

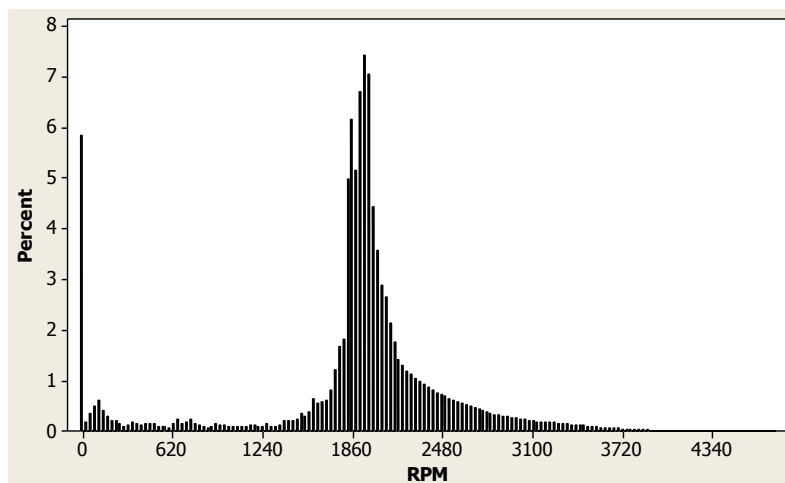


Figure 2. Histogram of driveshaft RPM

ROAD EVENTS SCANNING

The proving ground testing track has events varying from 10.5 feet wide to 17.5 feet wide with a very uneven surface made for testing trucks and cars. An event is the section of the track that is built for some specific purpose. For example frame twist bump is an event which is used to test the vehicle for frame deformations under torsion. Figure 3 shows a couple of events of a testing track. The section of the track in Figure 3(a) is called the staggered bumps and the one in Figure 3(b) is called the cobble stones. These two are just a few of many events of the track. Each event of the track has varied height, depth, and width.



(a) Staggered Bumps



(b) Cobble Stones

Figure 3 Example events of the testing track

The testing track is not all flat surfaces that can be measured easily with conventional tools. For this reason, a special scanning trailer was designed to allow movement of the scanners smoothly over the testing track and record accurate and precise data while scanning. The trailer built was light, yet rigid, easy to assemble and disassemble for transportation. Wheel spacing of the trailer was made adjustable from 10.5 feet to 17.5 feet in the interval of 6 inches to facilitate scanning of various events of the testing track.

Two scanners were fixed rigidly on the trailer. The first scanner was elevated several feet above the ground and placed on a platform supported by a triangular mounted structure on the trailer, so that even a 100 degree scan can cover the entire width of the event. The height of the scanner from the ground was also made adjustable. The second scanner was fixed rigidly to the frame of the trailer.

The trailer wheel movement was controlled using self-guiding rail guides. The rail guides were placed on the flat surface on both sides of the road profile which allowed steady motion of the trailer over the reference plane defined by the rail guide system. The guide rails were very light and could be carried and adjusted by a single person, the length varied from 20 to 60 feet and could be easily extended for longer events.

The trailer has a special box to accommodate and carry a car battery, a power inverter, two laptops and few tools for assembling/disassembling and those needed during the measuring process. Figure 4 shows the trailer with the scanners and the profiles of the scan lines. Figure 5 shows the picture of the trailer with scanners and imaginary scan lines.

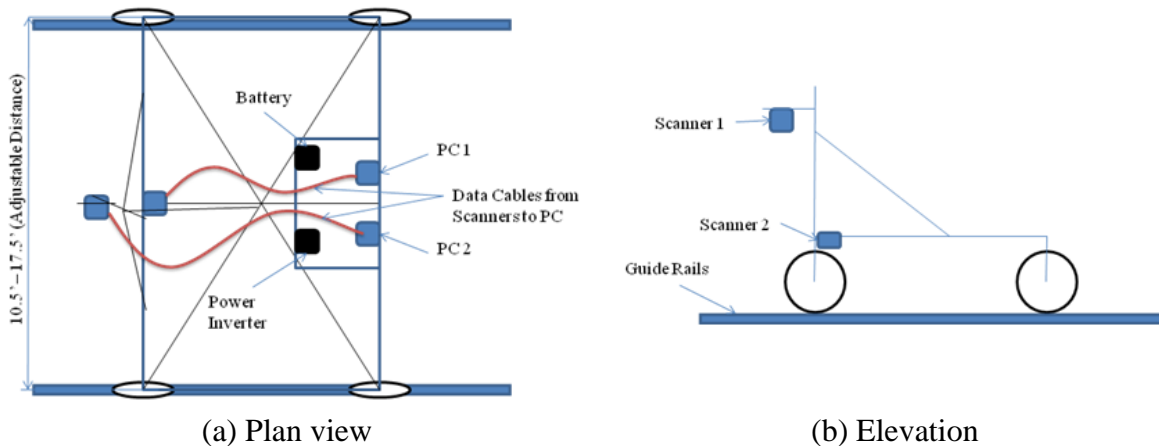


Figure 4 Plan and elevation views of the trailer with scanners and other accessories

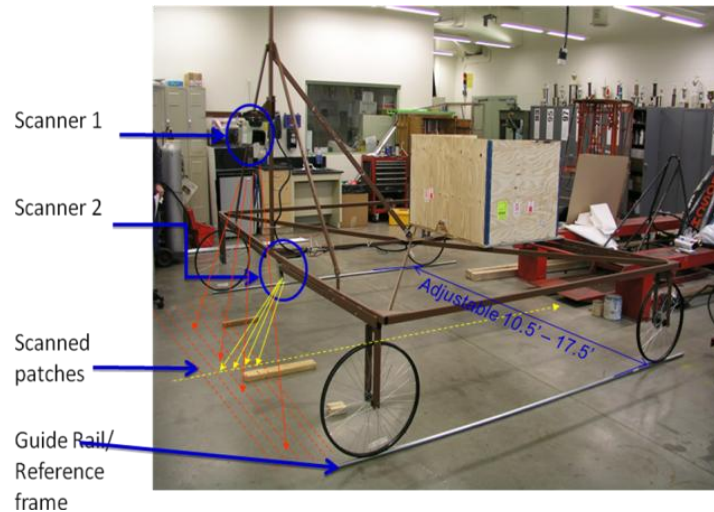


Figure 5 Picture of the trailer and imaginary lines of scanned path

Scanning Process and Surface Construction

Both scans were started simultaneously. The scanning frequency was 1 Hz. The speed of the trailer is kept constant. The pitch of successive scans depends on the trailer speed. One scanner scanned and recorded the data in the XZ plane along the width of the trailer while the other scanner scanned and recorded the data in the YZ plane.

Each of the scanners on the trailer gives the 2D information about the road profile, which when combined together using the scan matching algorithms gives the 3D data. This 3D data or the point cloud data set was filtered to remove the outliers. Later the data was processed to reduce the noise. Refined point cloud data was then used to create the mesh surface. Feature extraction gave a high quality representation of the road profile. A schematic flowchart shows how the laser scanner measuring system operates (Figure 6). The surface model is then exported/saved as

stereo-lithography (.stl) 3D data format to use in MSC.ADAMS simulation software. Detailed discussion on road profile scanning and surface generation is given in Liou et al. (2008).

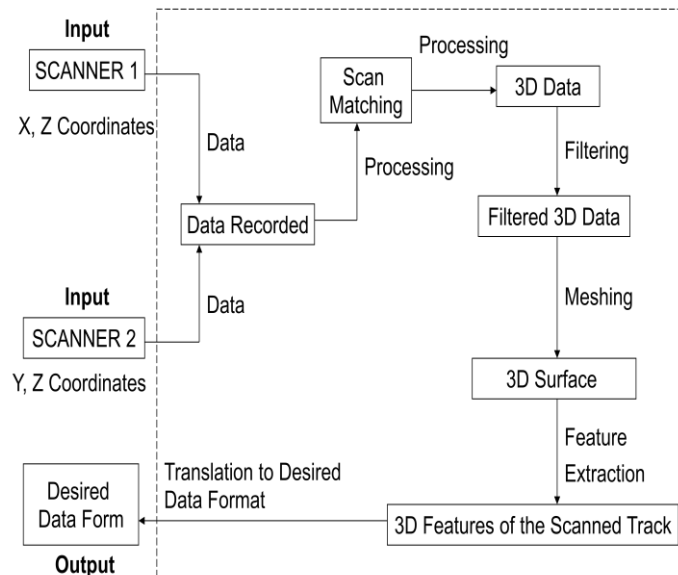


Figure 6 Schematic diagram of the road scanning system

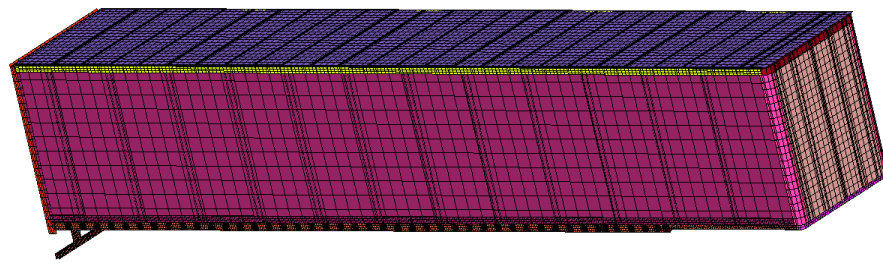
FLEX-BODY MODELING AND SIMULATION

Finite Element Modeling and Modal Neutral Files

The process of developing a flexible body model of the class 8 truck involved several steps. It began with reverse engineering the tractor and trailer into solid model components. Reverse engineering of the trailer was accomplished through measurements and photographs being transferred to solid model geometry. This was augmented with some sparse digital scan data.

Once the geometry was complete, it was further processed in HyperMesh (Altair 2010) and ABAQUS (2010) by generating finite element meshes that were converted into modal neutral files. The components that comprise the main structural system mass and stiffness of class-8 truck are: trailer box, frame, slider, and axle; tractor frame, fifth wheel, and axles. The complete trailer box and frame model consist of 89,540 nodes and 85,237 shell elements (S4 and S3) (Figure 7). Natural frequency analysis, which provides mode shapes coupled to each mode of free vibration, was performed and the mode shapes were utilized to verify the connections between individual components.

FE models of slider box, axel arms, and axles consist of shell elements (S3 and S4) as well as solid brick elements (C3D8). Once the connections were verified between components, master nodes were assigned to the required positions referring digital images and the original CAD files. Rigid beam elements in ABAQUS were used to develop the master nodes (Figure 8, Figure 9, and Figure 10). Similar procedure was followed for generating FE models of tractor frame, fifth-wheel, and the axles.



(a)



(b)

Figure 7 Complete trailer box and frame FE model

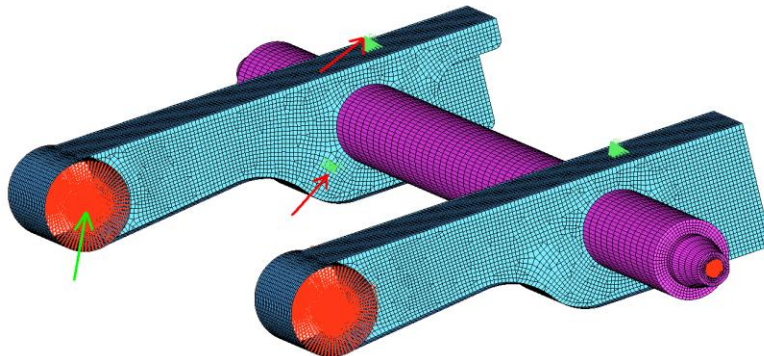
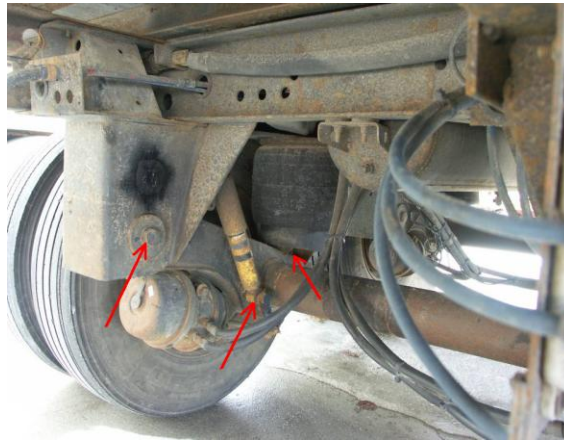


Figure 8 Connecting points between axle-bushing plate, axle-damper, and axle air suspension

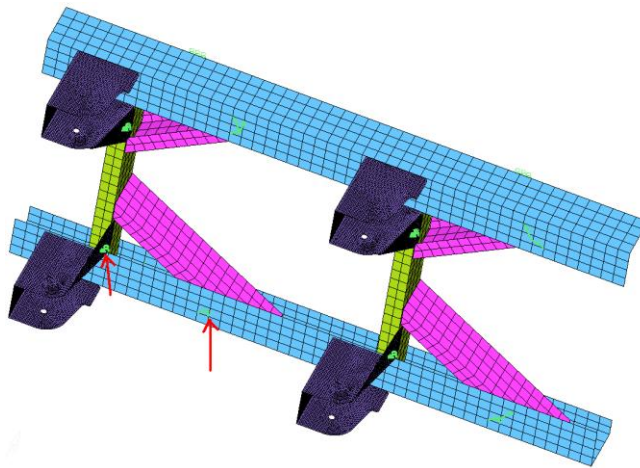


Figure 9 Connecting points on slider frame

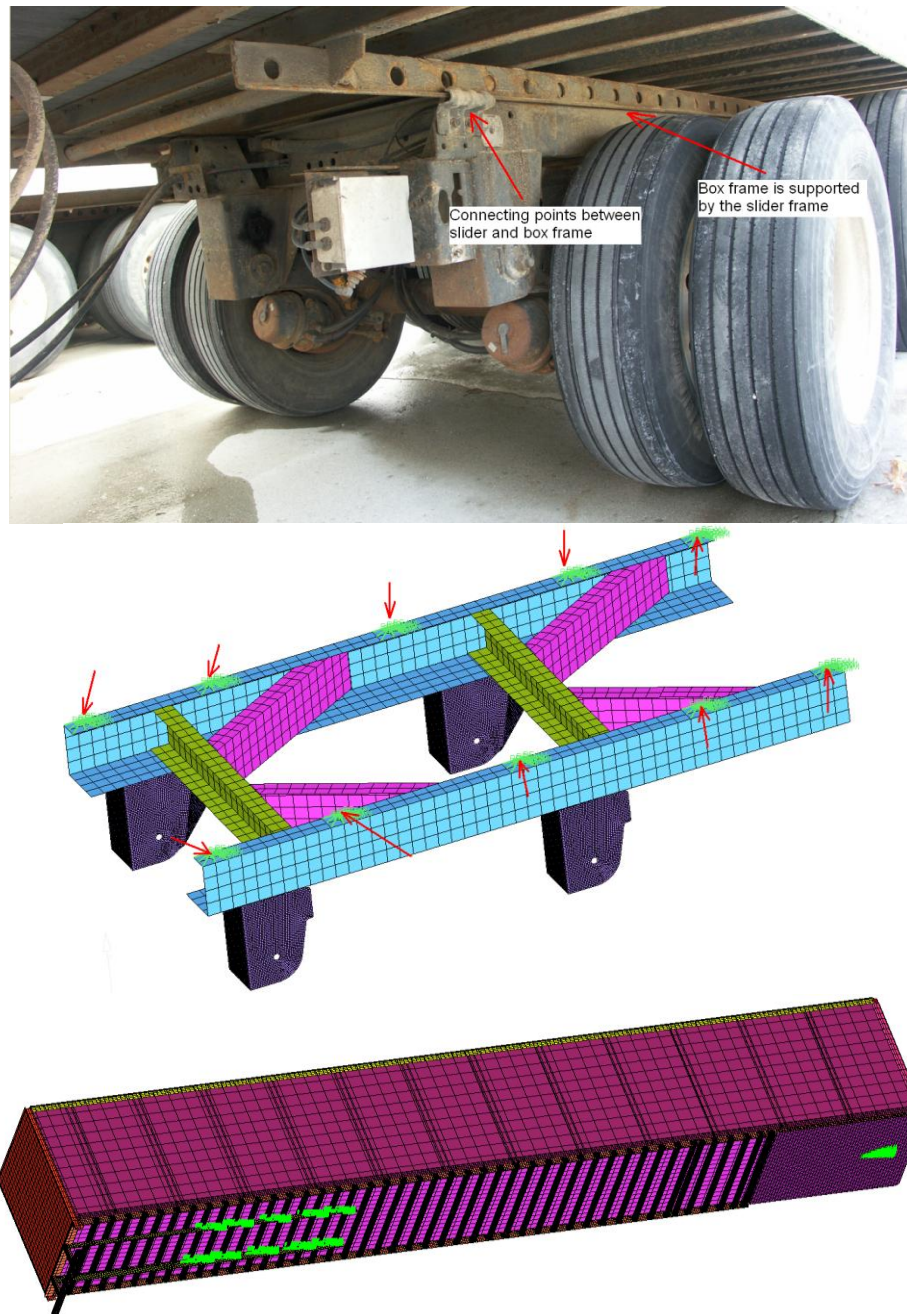


Figure 10 Master nodes on the slider, the trailer frame, and at the king-pin

Flexible body dynamic simulation using MSC.ADAMS require modal neutral files of these structural components or their assemblies. The level of accuracy depends on the finite element model refinements and the level of actual geometric data in the model. Hence, refined finite element models were developed closely representing the actual geometry but within the limits of computer hardware capacity to analyze such detailed models. Substructures were developed by assembling components and assigning master nodes. ABAQUS generates a list of fixed-interface vibration modes. The ABAQUS interface for MSC.ADAMS combines these fixed-interface

modes with the static constraint modes to compute an equivalent modal basis to be used by ADAMS/Flex. These frequencies are written to the screen when executing the ABAQUS interface for MSC.ADAMS. Once the modal neutral files were imported to ADAMS/Flex, a list of frequencies were obtained and compared with the frequencies displayed on the screen during modal neutral file conversion using ABAQUS interface for MSC.ADAMS. The frequency matching verifies an accurate transfer of models between ABAQUS and MSC.ADAMS. Following this procedure, modal neutral files of the assemblies were developed, imported to MSC.ADAMS, and verified to be accurate in the transfer of models between ABAQUS and MSC.ADAMS. After the files were imported and assembled in ADAMS to generate flexible bodies, the analysis was performed by incorporating various tire models (e.g., FTire, Fiala, and Pacejka) and road profiles.

Flex-Body (ADAMS) Simulation, Challenges, and Model Verification

Models of the class 8 truck were developed in ADAMS using flexible elements. This approach was followed because of discussions with analysts from DANA Corporation where it was found that rigid structures often gave erroneous results. However, modeling the truck in ADAMS Car proved to be problematic. The initial problem was that the software required several patches in order to run 18 wheeled vehicles. Once the patches were successfully installed, work on the truck model began by using templates for flexible and rigid tractors and trailers.

Even with the patches it took several weeks to get the template to work since they are incomplete. A rigid tractor-trailer assembly was finally made functional from one template. This was followed by a flexible tractor. The flexible trailer template was never made functional.

The solid modeling efforts on the trailer assembly far outpaced the tractor. Thus, the model of the flexible trailer was developed first. The original plan was to incorporate components into the flexible trailer template, but as noted, the flexible trailer template was never made functional. The rigid trailer template was therefore used to develop the flexible model of the trailer.

Several software tools were used on the project, but ADAMS played a significant role as the project moved forward. For example, Figure 11 shows a full flexible-body model of a trailer with a rigid tractor that was developed using modal neutral files generated from ABAQUS.

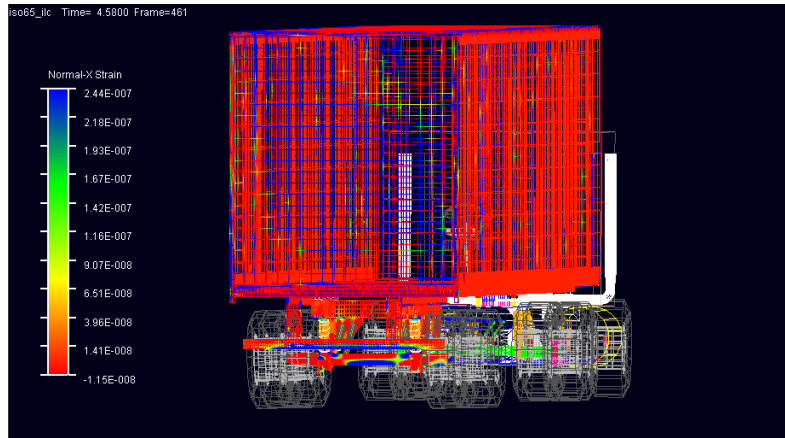


Figure 11 Full flexible-body model of a trailer with a rigid tractor

The power of ADAMS modeling can be seen in Figure 12 where one node on the model has been selected to study the strain history during a lane change maneuver.

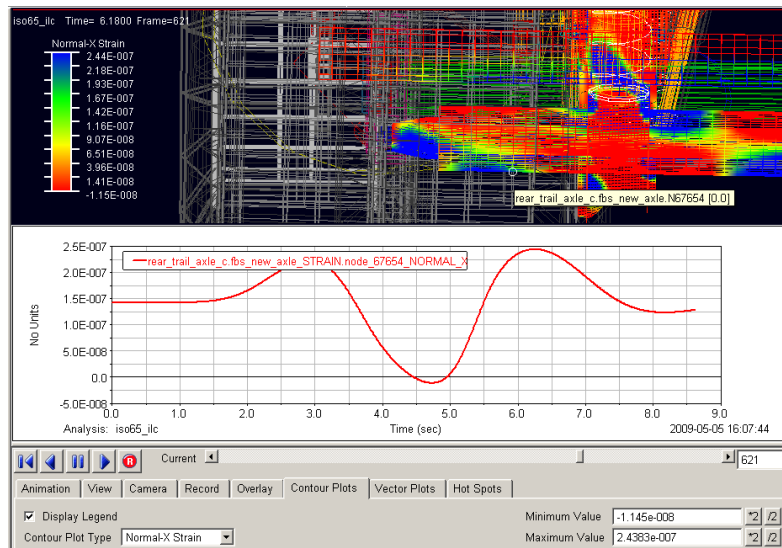
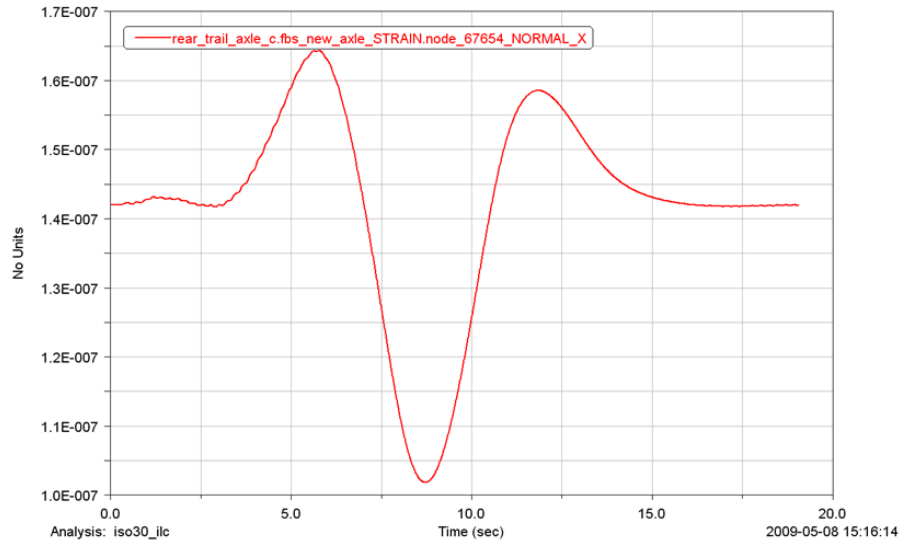
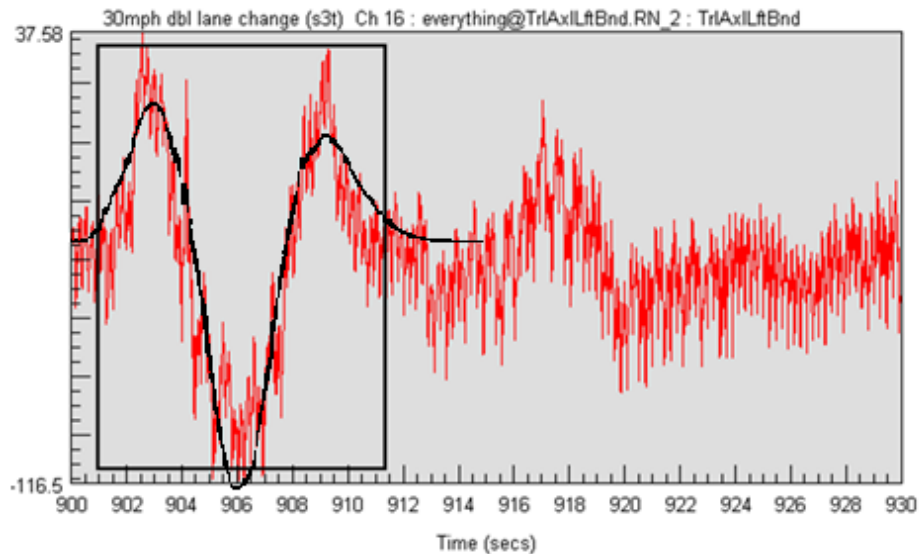


Figure 12 A time history of strain on a node in the model

The strain history of this node was then compared to data taken from a strain gage mounted on the trailer axle at a similar location (Figure 13). The strain gage data in Figure 13 has been highlighted in a bounding box to correspond to the ADAMS output. With the exception of the noise from the strain gage, one can see there is good agreement in relative amplitude and periodicity with the ADAMS model. Comparison of strain data from flex-body model and instrumented truck shows that the flexible body model is adequately refined for further analysis.



(a) Strain data from ADAMS run at 30 mph



(b) Strain data from instrumented test run at 30 mph with ADAMS run overlay
Figure 13 ADAMS output compared to strain gage data

SUMMARY & CONCLUSIONS

The study presented here included the reverse engineering process of a class-8 truck and validation of the flexible-body simulation model of Wabash 53-foot trailer against the strain data recoded from proving ground tests. Simulation results show that, with the exception of the noise from the strain gage data from instrumented test run at 30 mph, there is a good agreement in periodicity and relative amplitude with the ADAMS model. Agreement with periodicity represents accurate distribution of mass and stiffness in the model. It is unrealistic to match the actual amplitude unless the model is tweaked through a parametric study that requires significant amount of time and effort due to complexity of the model. An additional objective of this article is to disseminate the information on availability of complete CAD model of the truck, instrumented truck test data for six different maneuvers, and road surface scan data. In future,

full flexible-body models of semi-trailer can be developed targeting specific analyses and be verified using available test data to conduct rollover or crashworthiness to understand impact of various parameters for developing safe trucks.

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