Vehicle Ride Analysis of a Tractor-Trailer

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1. Abstract

The purpose of this analysis was to study the ride quality of the International tractor, and to analyze and directionally predict the effects of configuration changes on that ride quality. The long-term goal of the effort is to support the determination of components and sub-system level specifications. The main objective of the project was to establish a set of best practices to use to study the ride quality of the vehicle.

Working with International, MDI developed the following process for evaluating the ride quality of the tractor-trailer:

- Create a simple model of the tractor.
- Create models of the subsystems and validate those based on test data provided by International.
- Import the subsystem models, one by one, into tractor model. Simulating after each addition to verify the model.
- Incorporate a flexible cab and frame into the tractor model.
- Validate the tractor using physical test data obtained from the tractor.
- Create a model of the trailer.
- Merge the trailer model with the tractor model.
- Validate the tractor-trailer model using physical test data.
- Make small configuration changes to the physical truck and measure the ride quality. Make the same configuration changes to the model and measure the ride quality to test if the model can directionally predict the ride quality.

2. Introduction

Companies that manufacture everything from automobiles to cellular phones are striving to reduce the cost and design cycle time required to bring a new product to market. At the same time, their customers are demanding higher quality and better reliability, demands which tend to increase costs and design cycle times. Traditional design processes that rely heavily on physical prototyping fall short of meeting customer requirements or company goals.

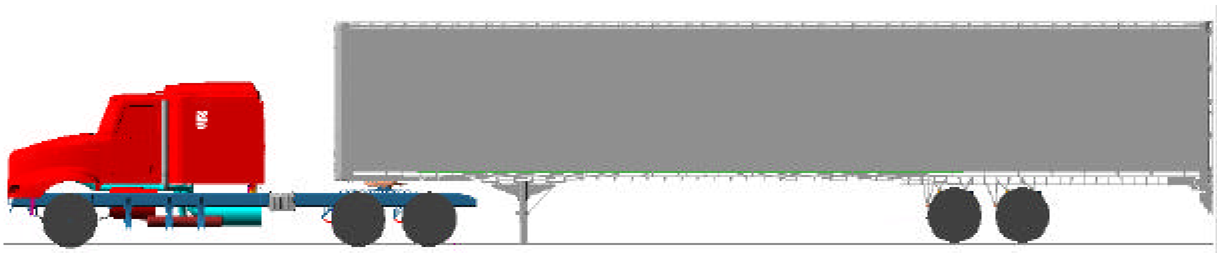

Figure 1: International Truck model

International is experiencing the same challenges as other companies. In recognizing the need to better develop concepts early in the design process, International decided to use ADAMS to simulate their heavy trucks. By using ADAMS, they hope to be able to develop concepts early in the design process which will help to reduce costs and design cycle times. At the same time, they hope to improve driver safety and comfort.

One way in which International is using ADAMS is to perform a ride analysis on the International 9400i Class 8 heavy duty truck. Mechanical Dynamics, Inc. worked with International to build the ADAMS model of the full vehicle, including a trailer. The long term goal of the project was to produce a model that could be used to determine the component and system level specifications. In studying the ride analysis, it was hoped that the model could be used to analyze and directionally predict the effects of configuration changes on the ride quality. As the project progressed, best practices for modeling a tractor-trailer to analyze ride quality were developed.

The business goal was to implement the modeling process in the Systems Engineering approach, where the sub-system design targets are cascaded to the design group or to suppliers. The next step is to validate that the full system targets were met. See Figure 2.

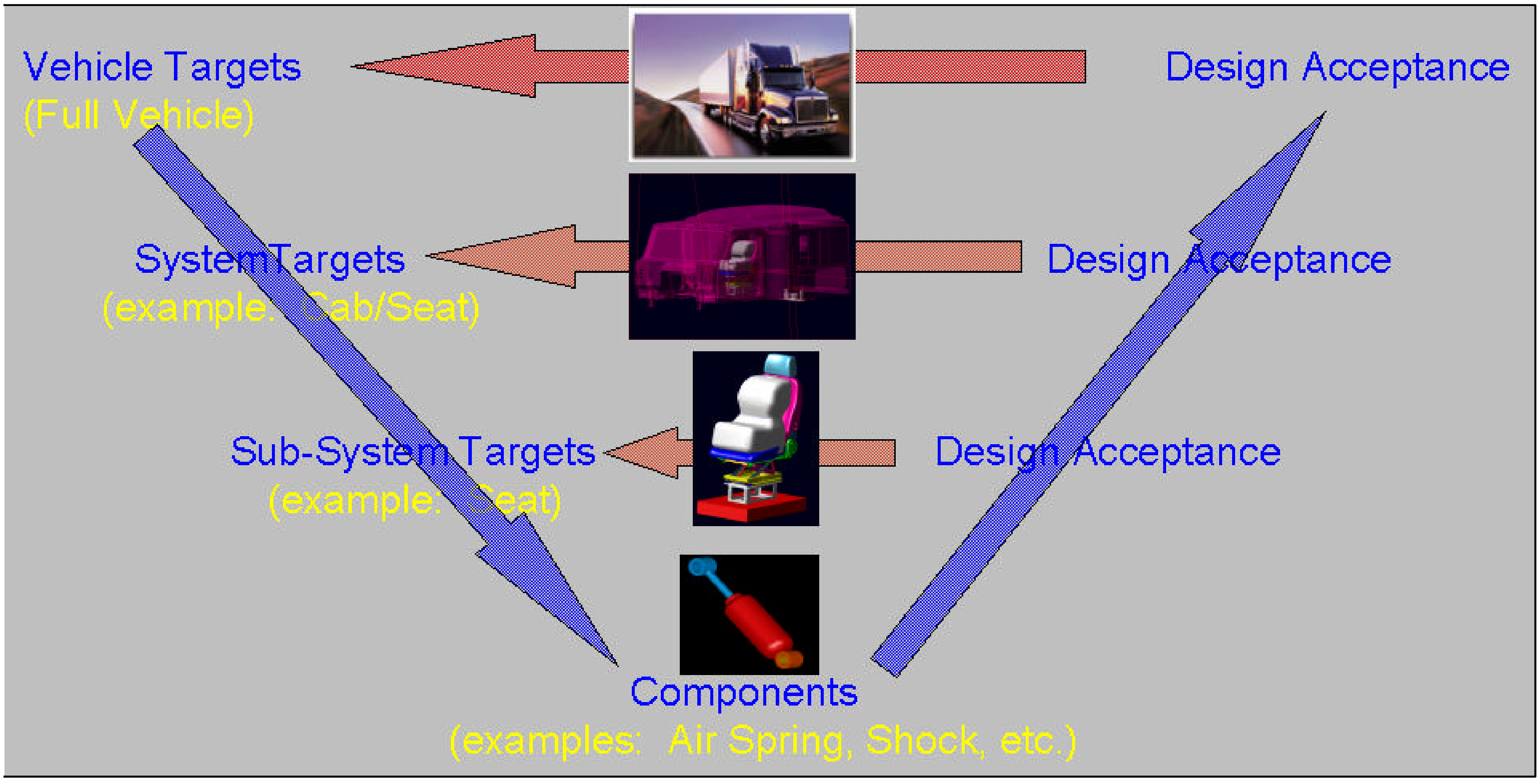

Figure 2: System engineering approach

3. Building a Virtual Prototype

The first step in building the virtual prototype of a tractor-trailer in ADAMS was to start with a simple model of the tractor. The sub-systems were built and correlated individually. They were then added to the tractor model, one at a time. The model was compared to test data before the next sub-system was added. This section discusses the model-building process.

3.1 Building and Correlating Sub-Systems

The truck was broken down into sub-systems for front suspension, rear suspension, cab suspension, engine and transmission, flexible frame, and flexible cab. The physical sub-systems were tested separately, and the data was used to validate the ADAMS models. In some cases, components in the sub-systems were modeled and validated separately prior to being added to the sub-system models.

3.1.1 Front Suspension

The front suspension consists of the front axle, steering linkage, shocks, and leaf springs.

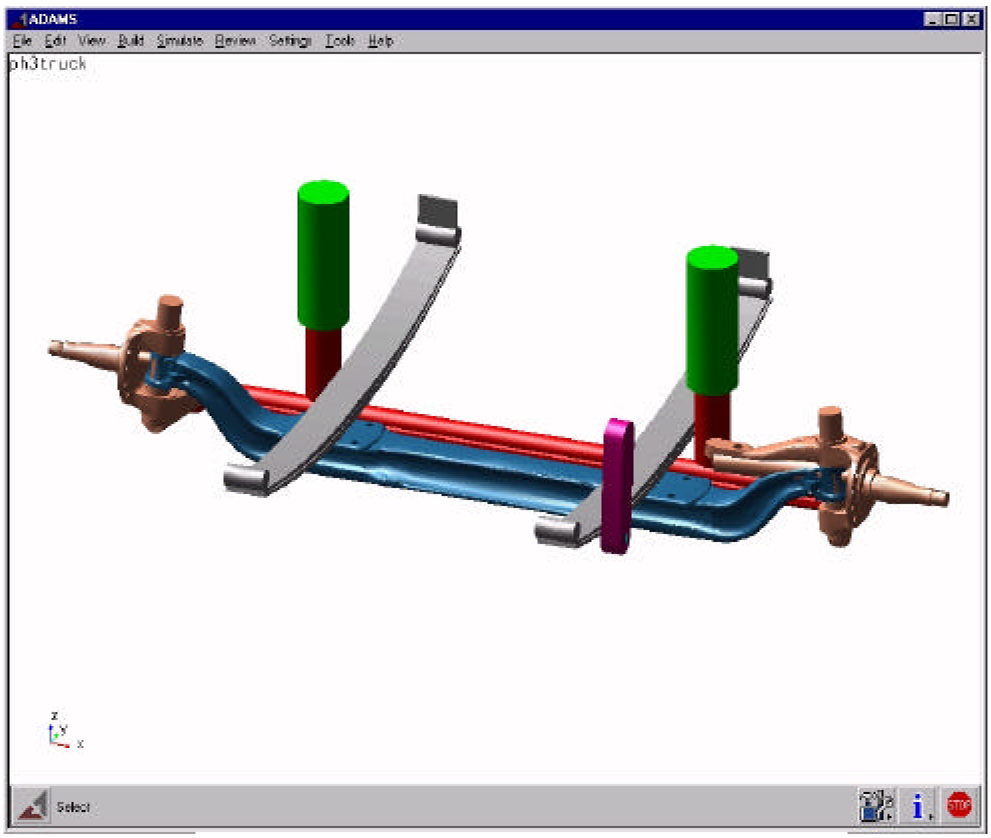

Figure 3: International Front Suspension

The leaf springs for the front suspension were built using a module of ADAMS specifically for building leaf springs. Each leaf is a series of parts connected with beams. The leaves are connected with bushings at the leaf seat. Vector forces define the contact forces between the leaves with impact statements. The same vector forces also define the friction between the leaves. A STEP function based on the relative velocity of the leaves at the point of contact is used to define the direction of the friction force. The leaf springs were validated separately before being added to the front suspension model.

International tested the shocks. The resulting force-velocity data was fit to a curve and used to define an ADAMS spline. The shocks were validated prior to being added to the front suspension model.

3.1.2 Engine and Transmission

The engine and transmission were modeled as a sub-system. The engine and transmission are modeled as two rigid bodies, attached with a fixed joint. The engine is attached to the frame with four vector forces that emulate the engine mounts.

3.1.3 Cab Suspension

The cab suspension is an air suspension that supports the rear of the cab.

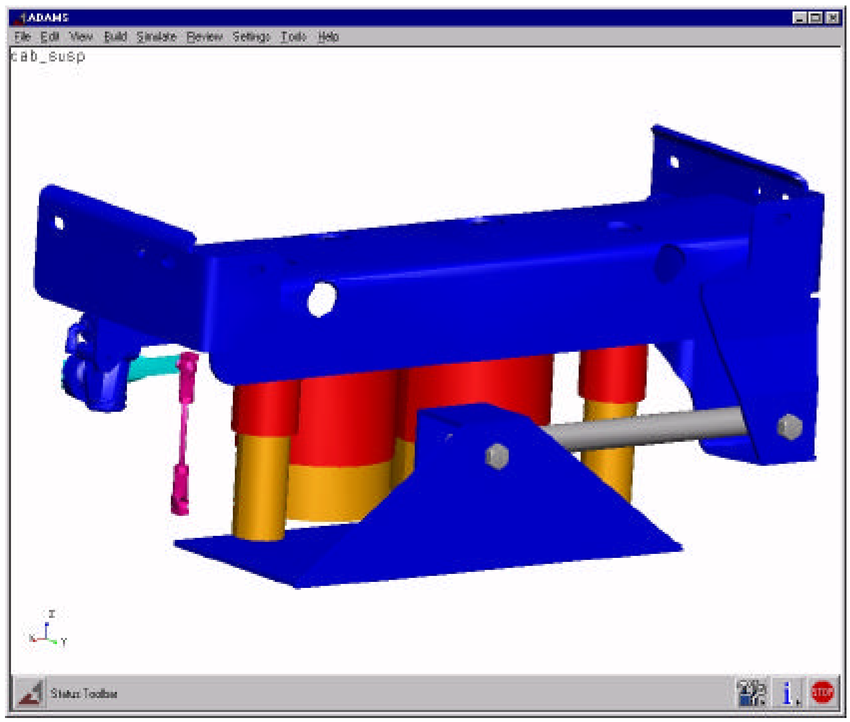

Figure 4: International Cab Suspension

The air bags are modeled as preloaded linear springs. The force-velocity data for the shocks was curve-fit and used to define a spline.

The cab suspension was validated and the results were compared to data that was measured by the cab suspension supplier.

3.1.4 Rear Suspension

The rear suspension is a tandem axle air suspension. The axles are attached to the frame via flexible main support members. The main support members were modeled in NASTRAN and imported into ADAMS. They are attached to the frame with bushings. The axles are each modeled as two rigid parts that are connected with a spherical joint and a bushing in order to account for axle flexibility. As with the other shocks on the truck, the rear suspension shocks were modeled with an ADAMS spline that was generated from test data. The air bags were also modeled with an ADAMS spline that was generated from test data.

3.1.5 Flexible Frame

A flexible frame is necessary to accurately capture the behavior of the vehicle for ride analysis. The frame was modeled in NASTRAN, and the modal content was extracted from the finite element model. The flexible frame was validated by comparing the results of an ADAMS/Linear analysis and the NASTRAN analysis.

The flexible frame had more than 200 modes that had corresponding frequencies over 10,000 Hz. Enabling all of the modes for the flexible frame was not an option because of the simulation time required. Also, the accuracy of the modes at the higher frequencies was not known. Therefore, the strain energy technique was used to determine which modes should be enabled.

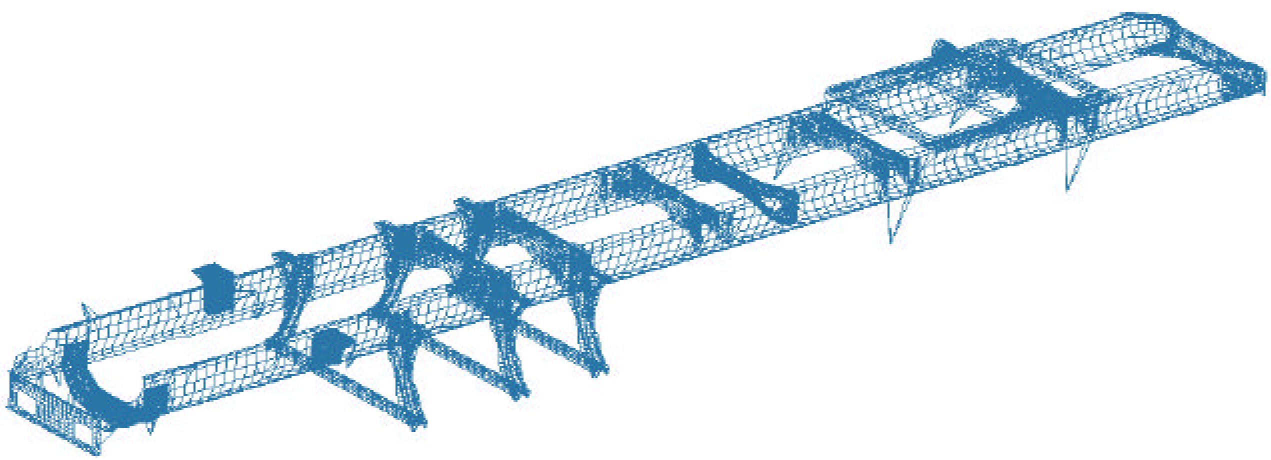

Figure 5: Flexible Frame

3.1.6 Flexible Cab

A flexible cab is also necessary in order to simulate the ride quality of the vehicle. The flexing of the cab floor can significantly affect driver comfort. The same process that was used to create the flexible frame was used to create the flexible cab. The mass properties of the cab were critical to the model results. The mass properties were initially approximated, but the simulation results were not correlating well to test data. International added more detail to the cab in order to improve the precision of the mass properties, and the simulation results improved.

The strain energy technique was used to determine which modes should be enabled on the cab.

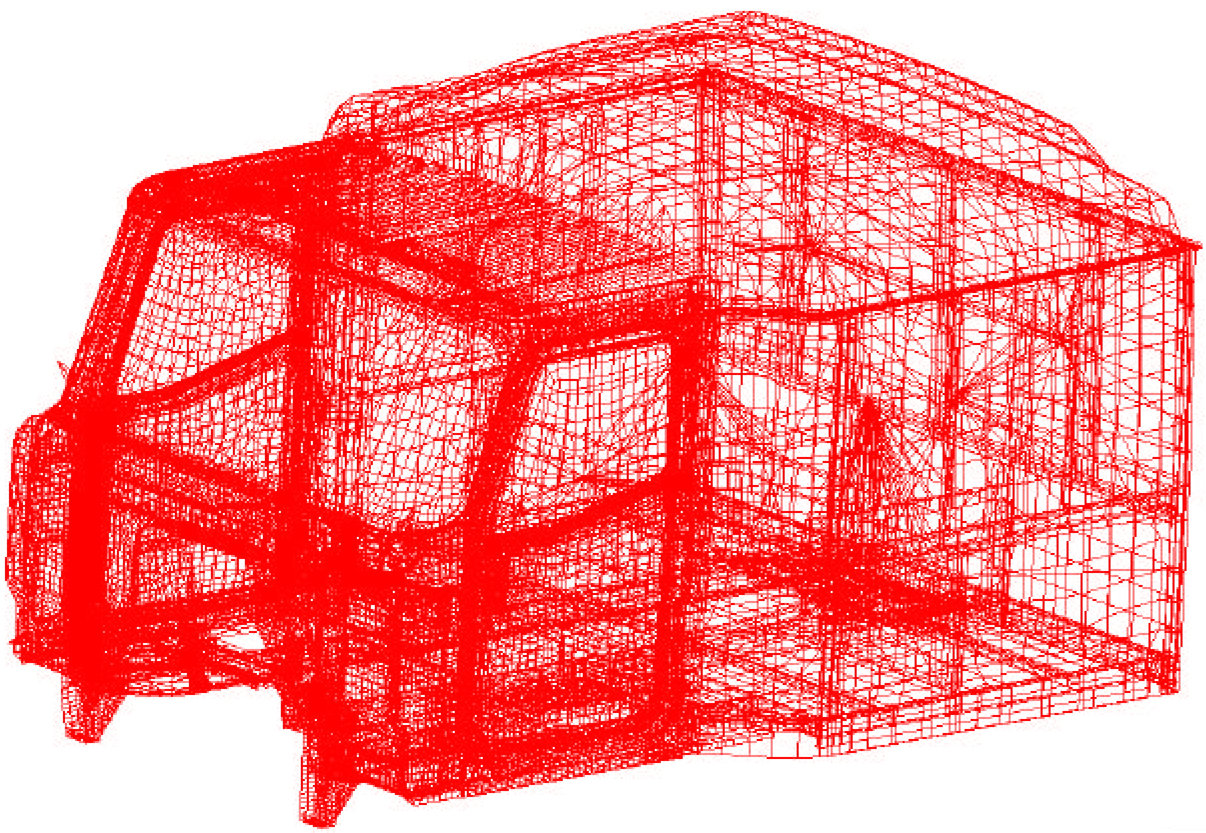

Figure 6: Flexible Cab

3.2 Building the Full Vehicle Model

Two full vehicle models were created. The first was the "bobtail" model. A bobtail is a tractor with an attached load frame rather than a trailer.

The bobtail model was composed by merging the initial simple tractor model with the subsystem models. After each subsystem addition, the model was simulated to ensure that the model results were as expected.

As the bobtail model was being completed, a separate trailer model was built. The trailer was initially built as a rigid part. The rigid trailer was eventually replaced with a flexible part.

When the bobtail model results were satisfactory, the load frame was removed and the trailer model was merged in to complete the tractor-trailer model.

4.0 Validating

The model validation took place throughout the building process. The sub system models were correlated to test data before they were added to the full vehicle model. The full vehicle model was correlated as the sub systems were added. Final model tuning took place after the subsystem and components were in place.

4.1 Validating the Subsystems

The subsystem models were correlated according to how the physical subsystem was tested. The models were set up to emulate the physical test. International and International's suppliers provided the data for the subsystems.

The front, rear, and cab suspension models were validated based on vertical force-deflection data. The rear suspension was also validated based on roll stiffness and roll-steer data.

The engine and transmission subsystem was correlated to accelerations that were measured on the physical truck during road tests.

The flexible cab and frame were correlated to the NASTRAN models.

4.2 Validating the Full Vehicle Model

In order to validate the model, extensive data was needed to understand the truck's behavior. The truck was instrumented with 70 accelerometers. It was then driven on three different roads and on the test track at various speeds. Of the 70 channels of data, some were inputs for the model and some were outputs depending on the configuration of the truck. Rather than adding tires to the model, the model was driven at the axles with data measured at the same locations on the truck axles, as if the truck were on a test rig. For the bobtail model, 21 channels were measured on the axles to provide inputs to the model. In the model, requests were created at the other 49 accelerometer locations. The model results were compared directly to the test data.

For the tractor-trailer model, 24 channels were measured on the truck and trailer axles to provide inputs to the model. As in the bobtail model, requests were created at the remaining 46 accelerometer locations. An example of the results from the tractor-trailer model is shown in Figure 7. It shows the vertical acceleration of the left front cab mount on the cab side. The red curve is the test data, and the blue curve is the simulation data.

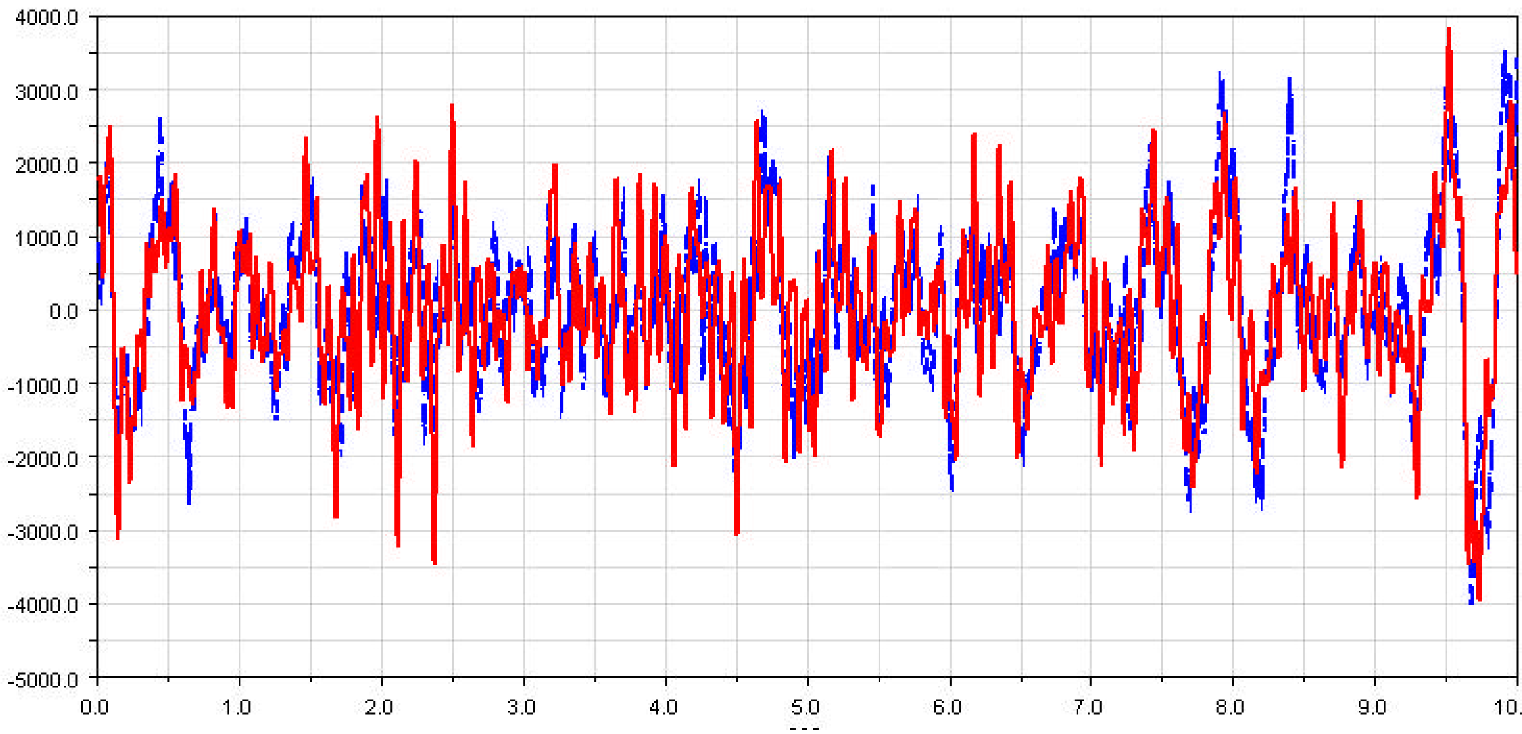

Figure 7: Channel 1 - Acceleration at Left Front cab mount

Blue - simulation data, Red - test data

The ride quality for each test was also measured. International uses an algorithm which measures the accelerations felt by the driver and assigns a number that quantifies the ride quality. The ride quality was assessed for the simulations in the same manner. The ride quality numbers for the tests and simulations were compared to evaluate the model.

In the final step of evaluating the full vehicle model, tires were added and the axle inputs were removed. The 5.2.1 Durability tire was used. PSDs showed that the tires were not accurately capturing the frequency content of the road. Driving the model with axle inputs provided better results.

4.3 Robustness Tests

As a final check of the tractor-trailer model, robustness tests were performed to verify that the model would directionally predict how the ride quality would change as a result of changes to the truck configuration. Four changes were made to the truck configuration: cab mounts were replaced with softer cab mounts, the frame structure was modified, the cab structure was modified, and the payload was removed from the trailer. The truck was tested after each change, and the ride quality was measured. The same changes were made to the model. The model was simulated after each change, and the ride quality was evaluated. All of the robustness tests except the empty trailer configuration were driven with axle inputs. The empty trailer configuration was simulated with tires and compared to the baseline model with tires.

The results for the rough road robustness tests are shown in the table below. The overall ride quality number generated from simulation data for the baseline model was 7.4% lower than the test data, for the rough road test. The table below shows how the ride quality number varied for each robustness test compared to the baseline test, for test data and simulation results.

Table 1: Directional Ride Number Results

Model	**% Difference to Baseline Test Data**	**% Difference to Baseline Simulation Data**
Cab mount change	+ 6.9%	+ 2.9%
Frame structure change	- 2.4%	- 1.6 %
Cab structure change	- 6.6%	- 2.5%
Remove payload from trailer	- 0.7%	- 0.8%

5.0 Conclusions

Building a full vehicle model of a tractor-trailer for ride analysis provided many challenges. The level of detail required in the model for ride analysis, the model and vehicle size, and the tractor-to-trailer interaction are some of the challenges.

In the process of building this model, some best practices were learned. The most significant is regarding how to handle flexible parts. Determining which modes should be enabled in the flexible parts is a difficult task. In the end, the strain energy technique was used to determine the enabled modes. The mass properties of major flexible parts, such as the cab, can impact the model results. Inaccurate mass and inertias lead to poor results for the full vehicle model.

In hindsight, it probably would have been wise to test the truck on a test rig prior to testing on the road and test track. It might have been easier to validate the truck model with the more simple data from the simulator. The rear suspension was validated with static data only. Dynamically testing the rear suspension might have led to a better validated model.

5.1 Usefulness of the Model

The model has proven to be useful in directionally predicting changes in the ride quality. It can be used to quickly evaluate changes to the truck configuration.

The vertical channels correlated well to test data, but the model's lateral and longitudinal response can be improved. International is continuing to refine the model.

5.2 Future Use of the Model

The model is being used to build a fully parameterized truck model. The parameterized truck model will be used to quickly build and evaluate other truck configurations. The plan is to use these models for ride analysis and durability.

Future work will include adding a ride analysis tire to the model. A ride tire is expected to produce better results than the current method of applying accelerations from test data at the spindles.