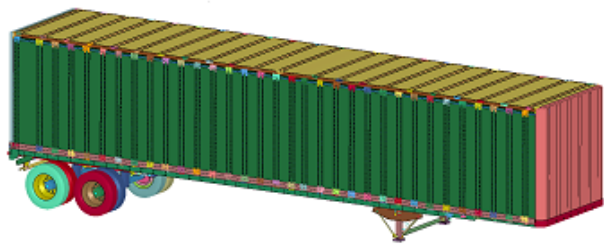
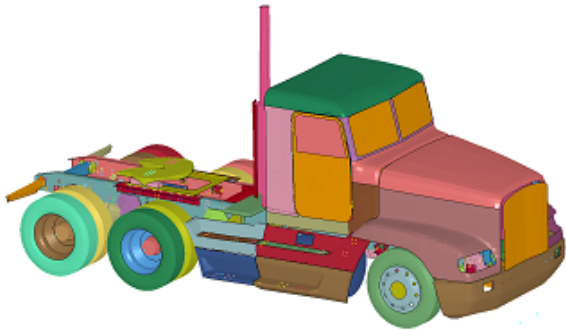


# Tractor-Semitrailer FE Model



## User's Manual / Release Notes

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Memorial  
Institute

# Table of Contents

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List of Figures .....	3
Introduction .....	4
User Notes.....	6
Contact Us.....	7
Basic FE Model Statistics .....	7
Actual FE model Vehicle Masses and C.G. Locations .....	12
FE Model File Organization .....	13
Quick-Start Overview of FE Models on SharePoint Site.....	13
List of Files on the Share Site: .....	13
Phase A Final Report and Simulation Videos .....	13
Phase B Final Report and Simulation Videos .....	13
Phase C Final Report and Simulation Videos .....	13
Tractor-Trailer Models .....	13
TTUserManual.....	13
General Description of Input Files for the Day Cab Tractor + 45-foot Trailer Model.....	15
General Description of Input Files for the Day Cab Tractor + 48-foot Trailer Model.....	16
General Description of Sleeper Cab Tractor + 48-Foot Trailer Model and Miscellaneous Input Files ...	18
More Detailed Description of File Organization and Content .....	20
Tractor to Trailer Connection .....	28
Accelerometer Locations .....	32
Element Types Used.....	35
Connection Schemes Used.....	36
Moveable Wheelset (Bogie).....	37
Passive Steering Compliance .....	39
Front Suspension U-Bolt Connections, Contacts and Failure .....	40
Use of ADAP Scripts .....	42

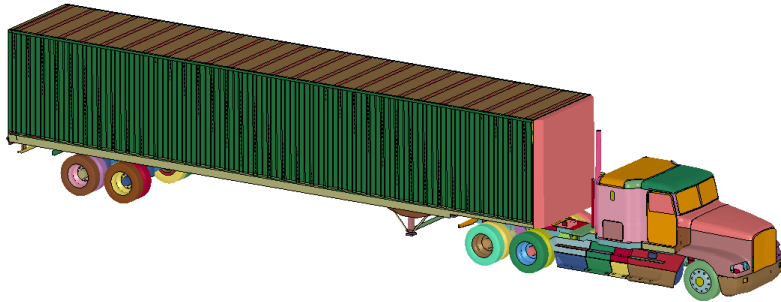
Example of Tractor Model Modification Steps .....	43
Tires and Tire Pressures .....	43
Time Step .....	44
Computer CPU, Run Time, and Storage.....	44

## List of Figures

Figure 1. Illustration. Sleeper cab tractor model information window from LS-PrePost.....	8
Figure 2. Illustration. 48-foot semitrailer model information window from LS-PrePost .....	9
Figure 3. Illustration. FE model CG locations and origin .....	10
Figure 4. Illustration. Finding CG information in LS-PrePost.....	12
Figure 5. Illustration. Main keyword input file - 00Main.k .....	22
Figure 6. Illustration. Main keyword input file - 00Main.k .....	23
Figure 7. Illustration. Example input file listing.....	24
Figure 8. Illustration. Equilibrium position of the tractor model with pre-stressed leaf-spring model.....	25
Figure 9. Photograph / Illustration. Tractor Airide™ rear suspension .....	26
Figure 10. Chart. Load-deflection data for Airide component at 20 and 60 psig pressure.....	27
Figure 11. Illustration. Spherical joints for tractor to semi-trailer connection .....	30
Figure 12. Illustration. Parts in contact for tractor to semi-trailer connection.....	31
Figure 13. Illustration. Accelerometer locations in long wheelbase tractor .....	33
Figure 14. Illustration. Accelerometer location in 48-foot semi-trailer .....	34
Figure 15. Illustration. LS-Dyna input for initial velocity.....	35
Figure 16. Photograph. Front view of trailer vehicle frame and bogie .....	38
Figure 17. Illustration. Front view of trailer FE model frame and bogie .....	39
Figure 18. Illustration. Input for bolt-tightening in LS-Dyna .....	41
Figure 19. Illustration. Effect of initial penetrations correction on beam-to-shell-edge contact shown with element dimension display turned on .....	42
Figure 20. Illustration. Run-time data for 3-second tractor-semitrailer simulation .....	45

# Tractor-Semitrailer FE Model User's Manual and Release Notes

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## Introduction

This Tractor-Semitrailer vehicle FE model is the product of three year's work. Many hours of research were spent to determine the best and most accurate material property definitions, critical components were characterized and validated by experimental testing and countless simulations were run and rerun to test, validate and debug this vehicle model. The main focus of this work was to validate the FE model for redirective type impact scenarios which are the most prevalent use of vehicle FE simulation. Markedly different impact scenarios such as head-on, rollover, or rear impact would need similar specific validation work.

There were several versions of the tractor and the trailer FE models developed throughout the course of this work. The level of development of each of the FE models is tied directly to availability of full scale crash test data. A long wheelbase sleeper cab tractor was developed from NCAC's original tractor-only FE model. This tractor model was modified to reflect NCAC's full scale tractor-only crash test

(No.03008) and validated against that test. To date the accuracy of the combined tractor-semitrailer model has been assessed by comparing analysis results against two full scale crash tests: MwRSF Test TL5CMB2 and TTI Test 7069-13. In each case, the baseline models of the tractor and semitrailer were modified to be similar to the test vehicles' length dimensions and mass properties.

Test TL5CMB-2 involved a 79,705-lb (36,153-kg) tractor-semitrailer vehicle impacting a concrete median barrier at 52.7 mph (84.9 km/hr) and impact angle of 15.4 degrees. The test vehicle was a 1991 White GMC tractor with a 1988 Pines 48-ft (14.6-m) semitrailer. The test article was a 42 inch (1.067 m) tall concrete median barrier with an installation length of 200 ft (60.9 m).

Test 7069-13 involved a 1979 International TranStar 4200 tractor with a 1977 Pullman van-trailer ballasted to 50,050 lb (22723 kg) impacting the barrier at 51.4 miles per hour (82.7 km/hr) and 16.2 degrees. The installation length of the barrier was 100 ft (30 m), and the impact point was 24 ft (7.3 m) from the upstream end.

All assessments of the models' results have so far been done by comparison to redirective type impacts with longitudinal rigid barriers (e.g., impact speed and angle of 80 km/hr and 15 degrees, respectively). The simulation results have indicated that this tractor-semitrailer FE model is *reasonably* valid for this type of crash simulation and that it will provide useful results in general barrier design evaluation work, regarding impact loads and general vehicle-barrier interaction. The model has not, however, been assessed for use in other applications, such as high-energy impacts (e.g., full frontal impact with bridge pier), general vehicle dynamics (e.g., vehicle response due to steer maneuvers) or vehicle-to-vehicle impacts, to name a few.

The information in this manual is generally applicable to all the tractor and trailer FE Models. Specific details are best found in the LS-Dyna keyword input files or through the online user's guide. The link to the SharePoint site where the FE models reside is: <http://websps1.battelle.org/heavyfem/home/Models/Shared%20Documents/Forms/AllItems.aspx>

The link to the Tractor-Trailer web site and On Line User's Guide at ORNL is:

<http://thyme.ornl.gov/FHWA/Tractor/index.cgi?VAR1=0>

## User Notes

From the experienced-user's perspective, there are some basic model-usage issues, and model-specific practical considerations that users of this FE model should be aware of:

The tractor-semitrailer FE model used for simulating the MwRSF test TL5CMB-2 needs about 300 milliseconds (0.300 seconds) pre-impact time to stabilize and settle under gravity. The front suspension's oscillations damp out almost immediately. The rear suspension seems to take longer for the oscillations to damp out. Another approach taken by the research team was to "time" the rear suspension's oscillations such that the rear tires were most firmly pressed against the ground at the time of rear wheelset impact with the barrier, similar to the rear wheelset action in the video of the actual crash test. This resulted in a starting position of the tractor-semitrailer at 4.7 meters from the impact point of the barrier. This strategy also resulted in a good correlation of the simulation results with the crash test data. This initial offset distance takes less computation time than the 300 millisecond pre-impact time stabilization approach.

The tractor-semitrailer FE model used for simulating the TTI test 7069-13 includes additional input files (i.e., nodesin.k and dynain.k) that contain necessary node and element information for "full" gravity initialization of the model prior to start of the analysis. One important note about the "nodesin.k" file is that this file **replaces all node definitions in all the input \*.k files** when the gravity initialization approach is used. The original node definitions are still in the input files; they are defined at the end of the files, and are "commented out" by the insertion of a \*END right before the node definitions. This provides the user an easy way to reinstate the original node definitions in any input file by removing the \*END line before the node definitions if the user desires to run a simulation using this model without gravity initialization.

Orienting vehicle and barrier models for a particular simulation **should not be done "manually"** by moving nodes/elements in a pre-processor. Use the \*DEFINE\_TRANSFORMATION and the \*INCLUDE\_TRANSFORM options in LS-Dyna (in the 00Main.k file) **only** for any re-orientation of the vehicle or the barrier. The reasons for this are: 1) There are several inertias defined that are not exactly orthogonal to the global coordinate system, but they are defined in the global coordinate system. 2) The shell element stress tensors defined for the front suspension preload are defined relative to each element's local coordinate system.

Changing the orientation of the tractor or the trailer with a pre-processor may not properly account for the correct orientation of specified inertias and initial stress information. Transformations and orientations that are done "within" LS-Dyna using \*DEFINE\_TRANSFORMATION and \*INCLUDE\_TRANSFORM will guarantee that stresses and inertias are accounted for properly.

The tractor and trailer models are oriented orthogonal to the global coordinate system such that X is forward, Y is to the left, and Z is up. Barriers or other targets can then be oriented relative to the vehicle (global) coordinate system.

All the various tractor and trailer FE models, the Airide™ suspension models, and to some extent the ballast FE models are designed to be modular and can be interchanged relatively easily to facilitate other combinations of tractors and trailers. This is most easily done using the \*INCLUDE and \*TRANSFORM options via a "00Main.k" file.

A minor bug in LS-PrePost when writing an FE model that has the \*MAT\_SIMPLIFIED\_RUBBER\_WITH\_DAMAGE option is that the unloading load curve number is written in scientific notation to 4 significant digits rather than as an integer. This creates an error condition when LS-Dyna tries to read the keyword file because LS-Dyna is expecting an integer.

### Contact Us

Please submit questions and comments on the model to Chuck Miele at Battelle by telephone at (614) 424-4023 or by e-mail at [miele@battelle.org](mailto:miele@battelle.org). The Program Team will respond as quickly as possible to resolve issues identified.

## Basic FE Model Statistics

An example of the FE model information summary that is generated directly by LS-PrePost is shown in figures 1 and 2. These model statistics are for reference only, and are approximate. They are based on the original long-wheelbase tractor model and the 48-foot semitrailer model. The actual count of parts, mass, CG locations, etc. are best found by generating them from the most current FE model via the online user's guide.

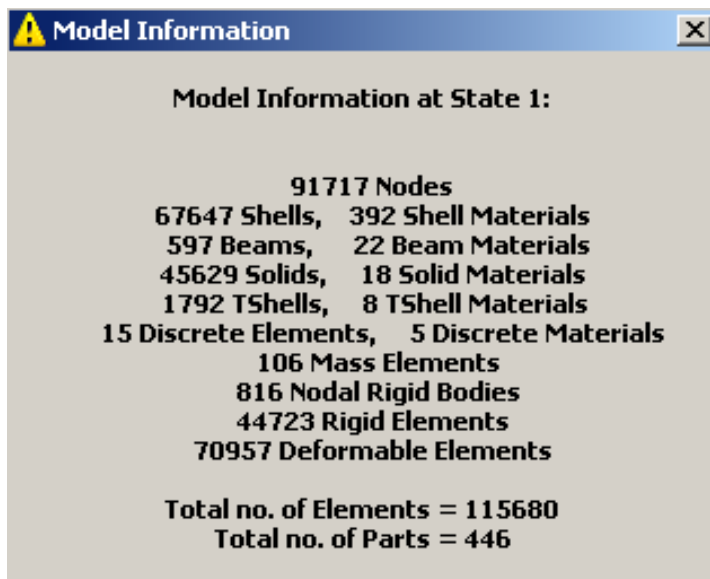


Figure 1. Illustration. Sleeper cab tractor model information window from LS-PrePost



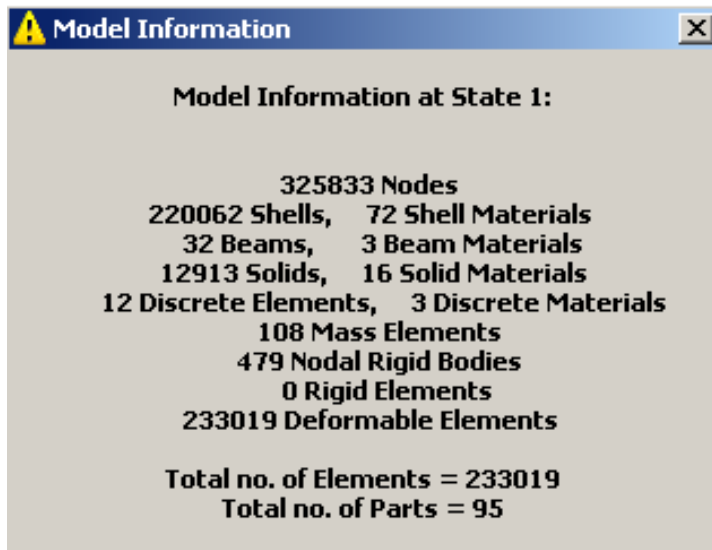


Figure 2. Illustration. 48-foot semitrailer model information window from LS-PrePost

Table 1. FE Model Masses:

<b>Long Wheelbase Tractor</b>	<b>17,110 Lbs (7,762 Kg)</b>
<b>Short Wheelbase Daycab Tractor</b>	<b>15,506 Lbs (7,703 Kg)</b>
<b>48-foot Semitrailer</b>	<b>13,626 Lbs (6,181 Kg)</b>
<b>45-foot Semitrailer</b>	<b>13,125 Lbs (5,954 Kg)</b>
<b>Ballast for MwRSF Test</b>	<b>50,920 Lbs (23,098 Kg)</b>
<b>Ballast for TTI Test 7069-13</b>	<b>22,360 Lbs (10,134 Kg)</b>

The mass values shown in table 1 and the CG locations shown in figure 3 are for scale and perspective only.

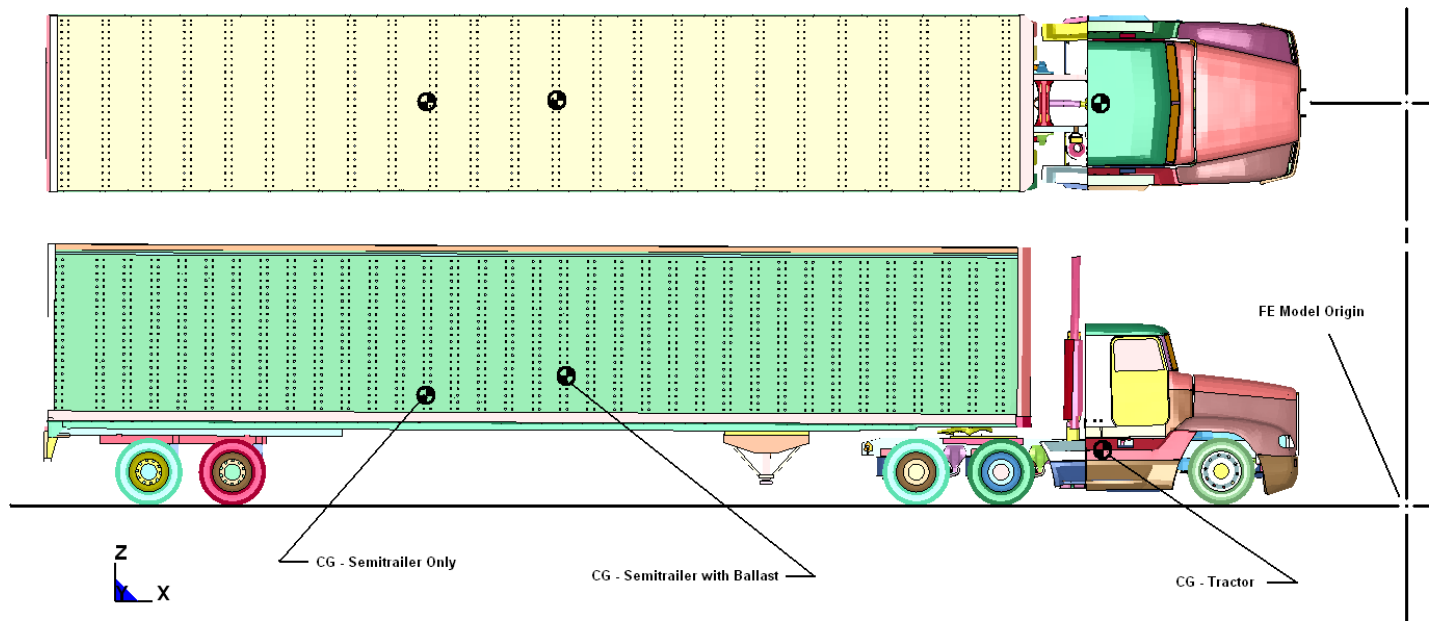


Figure 3. Illustration. FE model CG locations and origin

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## Actual FE model Vehicle Masses and C.G. Locations

Figure 3 is a schematic showing the approximate locations of a tractor's and a semitrailer's CGs. Use LS-PrePost to obtain the values and locations for a specific FE model. Go to the "Measure" command in Panel 1, Item: Inertia. Select and display the desired part or parts, check "Active Elements Only", and "All", highlight "X-cg", then click on "Apply". Figure 4 shows a screen snapshot of this operation for a tractor FE model.

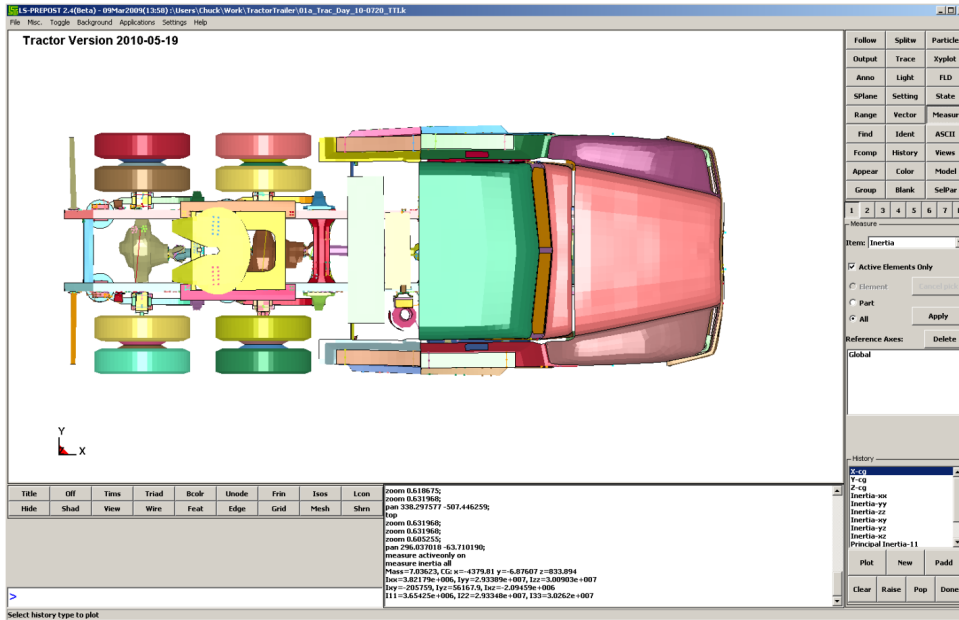







Figure 4. Illustration. Finding CG information in LS-PrePost

# FE Model File Organization

## Quick-Start Overview of FE Models on SharePoint Site

### List of Files on the Share Site:

-  **Phase A Final Report and Simulation Videos**
-  **Phase B Final Report and Simulation Videos**
-  **Phase C Final Report and Simulation Videos**
-  **Tractor-Trailer Models**
-  **TTUserManual**

Chuck Plaxico 8/4/10 12:22 PM

**Comment:** Once the project is complete, I expect that access to the model will be through the website only. We will need to reflect this in the User Manual.

The four directories' names are self-explanatory. The Tractor-Trailer Models directory contains three subdirectories where the LS-Dyna keyword input files reside for the two simulations used to compare to crash tests TL5CMB2 and 7069-13, and a directory containing the original sleeper cab tractor FE model. The FE models of the TL5CMB2 and 7069-13 test simulations are the most recent and more debugged than the FE models in the original sleeper cab directory. The larger keyword input files are also provided as zipped files for a more convenient download size.

The LS-Dyna d3plot and binout results files are available for download for the two crash test simulations in subdirectories called “d3plots-binouts” directly under the keyword file directories.

The Word document “TTUserManual2010” is the printable written-document User’s Manual for the Tractor-Semitrailer FE Vehicle models.

The following lists the names and a brief description of the input files that are available on the SharePoint Site as of this writing. A more detailed description of each file follows in the next section.



## General Description of Input Files for the Day Cab Tractor + 45-foot Trailer Model

1. **00MainGravInit.k:** This is the input file that is submitted to LS-Dyna for analysis. It uses the \*INCLUDE command to combine all the input files for the model.
2. **01a\_Trac\_Day\_10-0621\_TTI.k:** The finite element model of a Freightliner FLD120 tractor geometrically modified to be the Day Cab tractor from the TTI test 7069-13. All nodes, elements, materials, connections, etc. for the tractor are included in this file.
3. **01b\_Initial-stress\_Tractor.k:** File containing initial stress state for the front leaf springs of the tractor to account for equilibrium load on the leaf spring components under gravity loading. Without this file, the tractor would displace significantly under gravity load, altering the center of gravity and bumper height.
4. **01c\_AirRide20psi.k:** Part, Section and Material definition for the discrete element model of the Airide suspension with properties corresponding to 20 psi internal pressure for a tractor-only simulation.
5. **01c\_AirRideTractor45psi.k:** Part, Section and Material definition for the discrete element model of the Airide suspension with properties corresponding to 45 psi internal pressure. Used in tractor-semitrailer model for trailer ballasted to 50,000 lbs (22,700 kg).
6. **02a\_SemiTrailer45\_10-0621\_TTI7069-13.k:** The finite element model of 45-ft Stoughton semitrailer. All nodes, elements, connections, etc. for the trailer are included in this file.
7. **02c\_AirRideTrailer20psi.k:** Part, Section and Material definition for the discrete element model of the Airide suspension with properties corresponding to 20 psi internal pressure for an empty trailer.
8. **02c\_AirRideTrailer45psi.k:** Part, Section and Material definition for the discrete element model of the Airide suspension with properties corresponding to 45 psi internal pressure.
9. **02b\_TrailerMaterials\_2010-0217.k:** Material database for the semitrailer

10. **03Tractor2Trailer\_connection.k**: Creates a spherical joint connection between the trailer kingpin and the tractor fifth-wheel. Also, defines contact between the kingpin box and fifth-wheel.
  11. **05NJB-Ballast2-foam11b.k**: Ballast for the trailer model with mass of 10,134 kg
  12. **05Contact11.k**: Tie contact between ballast bolts and trailer floor, the ballast parts with the trailer and ballast self-contact.
  13. **15TL-3\_7069-13\_Bridge\_Parapet\_Elastic2.k**: Impacted bridge parapet barrier
  14. **15contact-tractor2010-0323.k**: Contact between tractor and median barrier
  15. **15contact-trailer2.k**: Contact between trailer and median barrier
  16. **20control1.k**: Defines \*CONTROL, \*DATABASE, \*CONTACT\_INTERIOR for the entire model. This file is always read in last and overrides any previous definitions of these parameters from the earlier input files.
  17. **dynain.k**: Gravity-initialized stresses for the entire FE model
  18. **nodesin.k**: Gravity-initialized nodal locations for the entire FE model
- 

### General Description of Input Files for the Day Cab Tractor + 48-foot Trailer Model

19. **00Main2.k**: This is the input file that is submitted to LS-Dyna for analysis. It uses the \*INCLUDE command to combine all the input files for the model.
20. **00MainBackedUp.k**: This is the input file that is submitted to LS-Dyna for analysis with the tractor-semitrailer backed up 4.7 meters from the barrier. It uses the \*INCLUDE command to combine all the input files for the model.
21. **01a\_Trac\_Day\_2010-0520.k**: The finite element model of a Freightliner FLD120 tractor geometrically modified to be a Day Cab tractor. All nodes, elements, materials, connections, etc. for the tractor are included in this file.



22. **01b\_Initial-stress.k**: File containing initial stress state for the front leaf springs of the tractor to account for equilibrium load on the leaf spring components under gravity loading. Without this file, the tractor would displace significantly under gravity load, altering the center of gravity and bumper height.
  23. **01c\_Airide\_60psi.k**: Part, Section and Material definition for the discrete element model of the tractor Airide suspension with properties corresponding to 60 psi internal pressure. Used in tractor-semitrailer model for trailer ballasted to 80,000 lbs (36,000 kg).
  24. **02a\_semitrailer48\_10-0521.k**: The finite element model of 45-ft Stoughton semitrailer. All nodes, elements, connections, etc. for the trailer are included in this file.
  25. **02b\_AirRideTrailer72p5psi.k**: Part, Section and Material definition for the discrete element model of the Airide suspension with properties corresponding to 72.5 psi internal pressure. Used in tractor-semitrailer model for trailer ballasted to 80,000 lbs (36,000 kg).
  26. **02b\_TrailerMaterials\_2010-0217.k**: Material database for the semitrailer.
  27. **03Tractor2Trailer\_09-0206.k**: Creates a spherical joint connection between the trailer kingpin and the tractor fifth-wheel. Also, defines contact between the kingpin box and fifth-wheel.
  28. **05NJB-Ballast-foam11b.k**: Ballast for the trailer model
  29. **05contact11.k**: Defines contact between the ballast parts and the trailer.
  30. **15TL-5\_Median\_Barrier\_Elastic.k**: Impacted bridge parapet barrier
  31. **15contact-tractor2010-0323.k**: Contact between tractor and median barrier
  32. **15contact-trailer2.k**: Contact between trailer and median barrier
  33. **20control1.k**: Defines \*CONTROL, \*DATABASE, \*CONTACT\_INTERIOR for the entire model. This file is always read in last and overrides any previous definitions of these parameters from the earlier input files.
-

## General Description of Sleeper Cab Tractor + 48-Foot Trailer Model and Miscellaneous Input Files

34. **00Main500x.k**: This is the input file that is submitted to LS-Dyna for analysis. It uses the \*INCLUDE command to combine all the input files for the model for analysis with the tractor-semitrailer 0.50 meters from the barrier.
35. **00MainAtBarrier.k**: This is the input file that is submitted to LS-Dyna for analysis with the tractor-semitrailer at the barrier. It uses the \*INCLUDE command to combine all the input files for the model.
36. **01a\_Trac\_Sleepr\_10-0308.k**: The finite element model of a Freightliner FLD120 Sleeper Cab tractor. All nodes, elements, materials, connections, etc. for the tractor are included in this file.
37. **01b\_Intial-stress.k**: File containing initial stress state for the front leaf springs of the tractor to account for equilibrium load on the leaf spring components under gravity loading. Without this file, the tractor would displace significantly under gravity load, altering the center of gravity and bumper height.
38. **01c\_Airide\_60psi.k**: Part, Section and Material definition for the discrete element model of the tractor Airide suspension with properties corresponding to 60 psi internal pressure. Used in tractor-semitrailer model for trailer ballasted to 80,000 lbs (36,000 kg).
39. **02a\_semitrailer48\_10-0521.k**: The finite element model of 45-ft Stoughton semitrailer. All nodes, elements, connections, etc. for the trailer are included in this file.
40. **02b\_AirRideTrailer72p5psi.k**: Part, Section and Material definition for the discrete element model of the Airide suspension with properties corresponding to 72.5 psi internal pressure. Used in tractor-semitrailer model for trailer ballasted to 80,000 lbs (36,000 kg).
41. **02b\_TrailerMaterials\_2010-0217.k**: Material database for the semitrailer.
42. **03Tractor2Trailer\_09-0206.k**: Creates a spherical joint connection between the trailer kingpin and the tractor fifth-wheel. Also, defines contact between the kingpin box and fifth-wheel.
43. **05NJB-Ballast-foam11b.k**: Ballast for the trailer model

- 44. **05contact11.k**: Defines contact between the ballast parts and the trailer.
  - 45. **15TL-5\_Median\_Barrier\_Elastic.k**: Impacted bridge parapet barrier
  - 46. **15contact-tractor2010-0323.k**: Contact between tractor and median barrier
  - 47. **15contact-trailer2.k**: Contact between trailer and median barrier
  - 48. **20control1.k**: Defines \*CONTROL, \*DATABASE, \*CONTACT\_INTERIOR for the entire model. This file is always read in last and overrides any previous definitions of these parameters from the earlier input files.
-

## More Detailed Description of File Organization and Content

The LS-Dyna FE model of the tractor-semitrailer vehicle is organized using the \*INCLUDE options in LS-Dyna. This organizational strategy allows users to easily reconfigure the simulated crash vehicle and the simulated crash-test device. All of the model input files required for a particular simulation are brought together in a “main” file. This main file is typically named 00Main.k. The intent of the leading zeros are to place the main file at the top of the file list in the directory. One advantage of using the LS-Dyna \*INCLUDE file option is that entire (keyword file) models can be positioned via the \*TRANSFORM option and can also be conveniently renumbered into ranges that are meaningful and useful to the analyst. Figures 5 and 6 show an example of a “00Main.k” file annotated with explanations of the \*INCLUDE command inputs. This assumes the standard analysis-file organization “convention” for LS-Dyna/Linux environments of creating a separate directory for each simulation.

The baseline tractor vehicle FE Model is based on the original NCAC-developed FE model of a sleeper-cab style tractor with a 242-inch wheelbase. Variations on this baseline FE model are accomplished using the ADAP scripts developed by ORNL. Variations include a day-cab style model and various (shorter) wheelbases. Completed variations are available for the day cab tractors used in MwRSF and TTI crash tests TL5CMB2 and 7069-13.

Note that the position of the semitrailer rear wheelset assembly (bogey) is adjustable (fore-aft) by the user for any cargo box length and bogey position. Some care must be taken when doing this. In the FE model, the part of the bogey frame that adjusts its relative position on the trailer longitudinal rails is connected using \*MAT\_SPOTWELD (solid) elements. These elements are a type of tied contact, so they do not have to be “manually” disconnected and reconnected when the bogey position is adjusted. The bogey and these \*MAT\_SPOTWELD elements are selected and then translated using LS-PrePost. The direction of this fore-aft motion is not \*exactly\* along the global X direction because the trailer is angled 2° downward from the rear wheels to the kingpin. Given this, the actual translation should be done by choosing the appropriate “N1-to-N2” reference nodes in the translation utility in LS-

PrePost. Also, when the wheels are moved, the locations of the wheel rotation \*JOINTs and the rotation centers for the \*INITIAL\_VELOCITY option must be updated by the user. If the user needs to make this adjustment for several different cases, separating the bogey assembly into its own keyword file with specific joint and initial velocity definitions may be preferable. The user can call this separate bogey k file into the 00Main file using the \*INCLUDE\_TRANSFORM option.

Many of the keyword files themselves contain comment lines with information about the content of the particular file as well as comments about revisions and modifications to the content.

```

*KEYWORD
$
$ ----- Tractor -----
$
*DEFINE_TRANSFORMATION
101 _____ ID to associate origin, translation, rotation, etc.
TRANSL, 0, 0, 0 _____ Type and actual magnitude
$
*INCLUDE_TRANSFORM _____ Include the file with a transformation
Trac_Day_Cut_v6.k _____ File to operate on
0, 0, 0, 0, 0, 0, 0 _____
0, _____
0, 0,0, 0, 0 _____ Numbering offsets for nodes, elements, parts,
                                materials, properties, etc.
101 _____ Transformation ID
*INCLUDE _____ Include the file without a transformation
01b_Initial-stress.k
*INCLUDE
01c_Airride_60psi.k
$
$ ----- Semi-Trailer -----
$
*INCLUDE_TRANSFORM
02a_SemiTrailer48_09-0725.k
0, 0, 0, 0, 0, 0, 0
0,
0, 0,0, 0, 0
101
*INCLUDE
02b_AirRideTrailer60psi.k
*INCLUDE
02c_TrailerMaterials_09-0413.k
*INCLUDE_TRANSFORM
03Tractor2Trailer_09-0206.k
0, 0, 0, 0, 0, 0, 0
0,
0, 0,0, 0, 0
101
$

```

Figure 5. Illustration. Main keyword input file - 00Main.k

```

$ ----- Ballast -----
$
*DEFINE_TRANSFORMATION
1
TRANSL, 1600.0, 0, -6
*INCLUDE_TRANSFORM
05NJB-Ballast-foam11.k
1000000, 1000000, 1000000, 1000000, 1000000, 1000000, 1000000
1000000,
0, 0,0, 0, 0
1
*INCLUDE
05contact11.k
$
$ ----- Barrier -----
$
*DEFINE_TRANSFORMATION
15
ROTATE 0, 0, 1, -152.435, -1120.61, 806.027, 0.5000
TRANSL, 4716.6, 410, 0
$ velocity = 23583.000 mm/s
*INCLUDE_TRANSFORM
15TL-5 Median_Barrier_R10.k
0,0,0,0,0,0,0
0,
0, 0,0, 0, 0
15
*INCLUDE
15contact-tractor.k
*INCLUDE
15contact-trailer.k
$
$ ----- Control Cards -----
$
*INCLUDE
20control.k
*END

```

Figure 6. Illustration. Main keyword input file - 00Main.k

Figure 7 shows a typical listing of LS-Dyna input files and a brief description of each file's purpose. The file names are generally meant to be self-explanatory of their contents. More detailed descriptions of some of these files are provided below where their content/purpose is not obvious from their names or description in the figure.

00Main.k	_____	<b>Main file for creating a simulation</b>
01a_Trac_Day_v1a_090506.k	_____	<b>Tractor FE Model</b>
01b_Initial-stress.k	_____	<b>Tractor front leaf spring initial load stresses</b>
01c_Airride_20psi.k	)_____	<b>Tractor rear suspension for loaded and unloaded cases</b>
01c_Airride_60psi.k		
02a_SemiTrailer48_09-0725.k	_____	<b>Semitrailer FE Model</b>
02b_AirRideTrailer20psi.k	)_____	<b>Semitrailer rear suspension for loaded and unloaded cases</b>
02b_AirRideTrailer60psi.k		
02c_TrailerMaterials_09-0413.k	_____	<b>Semitrailer materials input</b>
03Tractor2Trailer_09-0206.k	_____	<b>Tractor-to-semitrailer interface - contacts, joints, etc.</b>
05contact11.k	_____	<b>Ballast to semitrailer contact definitions</b>
05NJB-Ballast-foam11.k	_____	<b>Semitrailer ballast</b>
15contact-tractor.k	_____	<b>Tractor to barrier contact definition</b>
15contact-trailer.k	_____	<b>Semitrailer to barrier contact definition</b>
15TL-5_Median_Barrier_R10.k	_____	<b>Barrier FE Model</b>
20control.k	_____	<b>LS-Dyna *CONTROL options</b>
Trac_Day_Cut_v6.k	_____	<b>Tractor FE Model</b>

**Figure 7. Illustration. Example input file listing**

### **00MainGravInit.k**

This "00Main" file contains all the \*INCLUDE file specifications for every FE model component for the simulations of the TTI test 7069-13. It also includes the special gravity initialization - initial stress and initial node location - dynain.k and nodesin.k files for the entire tractor-semitrailer FE model.

### **00MainBackedUp.k**

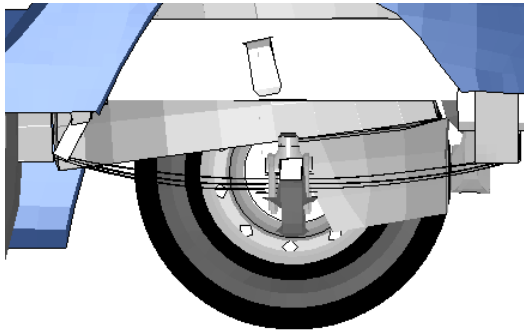
This "00Main" file contains all the \*INCLUDE file specifications for every FE model component for the simulations of the MwRSF test TL5CMB2. It is configured such that the tractor-semitrailer starts the simulation initially positioned 4.7 meters from the barrier impact point. This was done to allow (simulation) time for gravity initialization of the FE model.



### **01b\_Initial-stress\_Tractor.k**

This file contains a set of stresses that provide the preloaded, prestressed state of the front leaf springs, at the geometric shape representing their equilibrium position (shown in Figure 8) under gravity loading. The front leaf spring suspension is supporting approximately 4,845 lb (21,550 N) under gravity load.

To obtain this set of initial stress, an analysis was conducted to compress the leaf-spring model into its proper equilibrium position. The nodal coordinates of the suspension in this deformed state were extracted and put back into the leaf-spring suspension model. The element stresses at this position were also obtained from the analysis (via \*INTERFACE\_SPRINGBACK option in LS-Dyna) and were used to apply pre-stress to the leaf-spring elements (via the \*INITIAL\_STRESS\_SHELL card in LS-Dyna). Figure 10 shows the equilibrium position of the tractor model under gravity load with the pre-stressed leaf-spring model.



**Figure 8. Illustration. Equilibrium position of the tractor model with pre-stressed leaf-spring model**

### **01c\_Airide\_20psi.k , 01c\_Airide\_45psi.k and 01c\_Airide\_60psi.k**

These files are the three currently available options for the tractor's rear suspension stiffness. The 20 psi option is to be used to simulate the rear suspension (Airide™) stiffness associated with a simulation that has either no semitrailer, or an unloaded

semitrailer. The 45 psi and 60 psi options are used to simulate the rear suspension (Airide™) stiffness associated with a simulation has a partially or fully loaded semitrailer. Figure 9 shows a view of the actual tractor Airide™ rear suspension system and a view of this rear suspension as modeled.

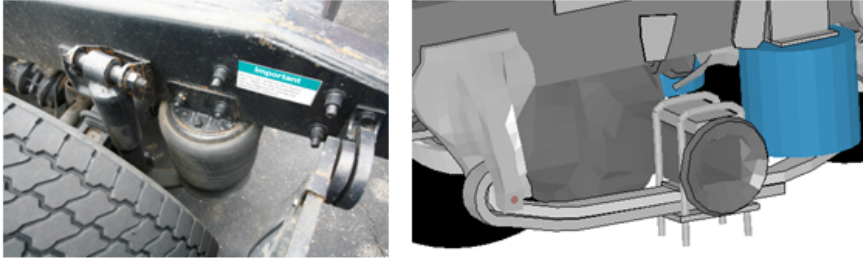
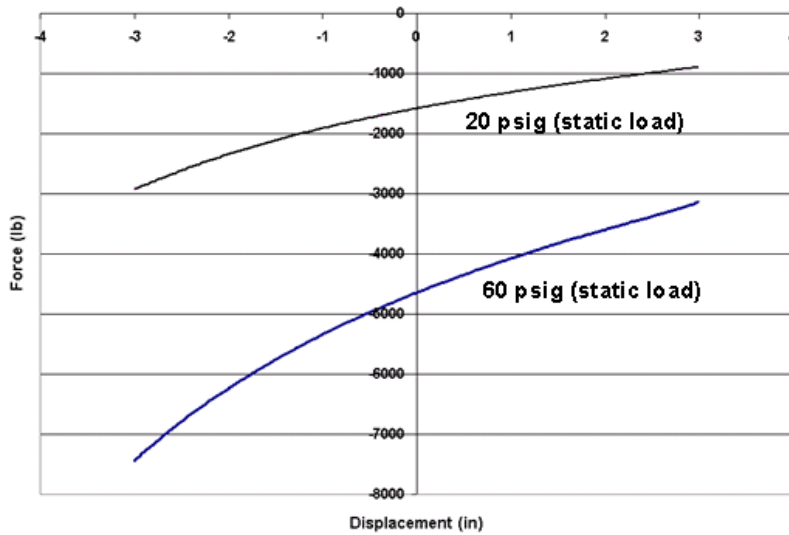


Figure 9. Photograph / Illustration. Tractor Airide™ rear suspension

Static load-deflection data from laboratory tests conducted at 20 psig and 60 psig bag pressures are shown in Figure 10.



**Figure 10. Chart. Load-deflection data for Airide component at 20 and 60 psig pressure**

**02b\_AirRideTrailer20psi.k, 02b\_AirRideTrailer60psi.k and  
02b\_AirRideTrailer72p5psi.k**

These files are the currently available options for the semitrailer's rear suspension stiffness. The 20 psi option is to be used to simulate the rear suspension (Airide™) stiffness associated with a simulation that has an unloaded semitrailer. The 60 and 72.5 psi options are used to simulate the rear suspension (Airide™) stiffness associated with a simulation has a partially or fully loaded semitrailer. The suspension stiffness properties included in the 60 psi files are the original data from the trailer airide suspension tests the suspension stiffness properties included in the 72.5 psi files were created by extrapolation for the fully loaded 48-foot semitrailer.

**02\_TrailerMaterials\_2010-0217.k**

This file contains all the material data for the LS-Dyna material models used in both the 45 and 48-foot trailers. Various material models are used, including elastic, elastic-plastic, Johnson-Cook, and wood. The majority of the metallic materials are specified as piecewise-linear plasticity with an initial elastic modulus.

**03Tractor2Trailer\_connection.k**

This file contains the \*JOINT and \*CONTACT definitions for the tractor fifth-wheel interface with the trailer kingpin area. This connection is explained further in the next section.

**05NJB-Ballast-foam11.k**

This file contains the specific semitrailer ballast used in the MwRSF crash test TL5CMB-2. This same ballast model with modified mass is used in the TTI crash test 7069-13.

**05contact11.k**

This file contains the contact definitions for ballast self contact and ballast to trailer.

## **15contact-trailer2.k and 15contact-tractor2010\_0304.k**

These files contain the tractor-to-barrier contacts and the trailer-to-barrier contacts. Contact (and friction) can be specifically defined for the tires and wheels to the barrier and for the tractor or trailer body to barrier.

## **Tractor to Trailer Connection**

The tractor is connected kinematically to the semitrailer via three spherical joints and contact between the Fifth Wheel and the King Pin Box. Figure 11 shows the locations of the spherical joints, and Figure 12 indicates the two parts that are in contact. This is the simplest mechanical connection that provides the correct functionality. This connection typically does not fail in redirective-type crash tests, so no failure mechanism has been specified for this connection.



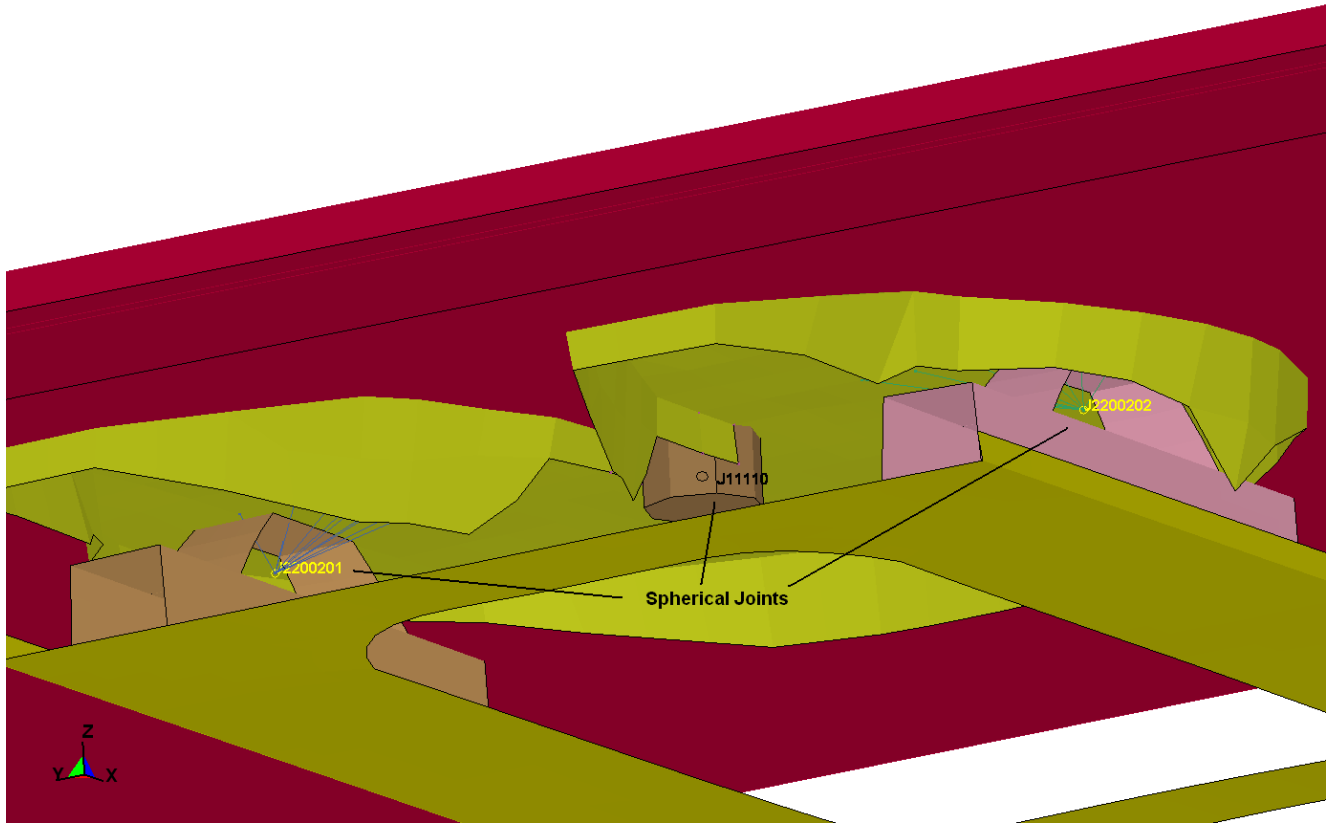


Figure 11. Illustration. Spherical joints for tractor to semi-trailer connection

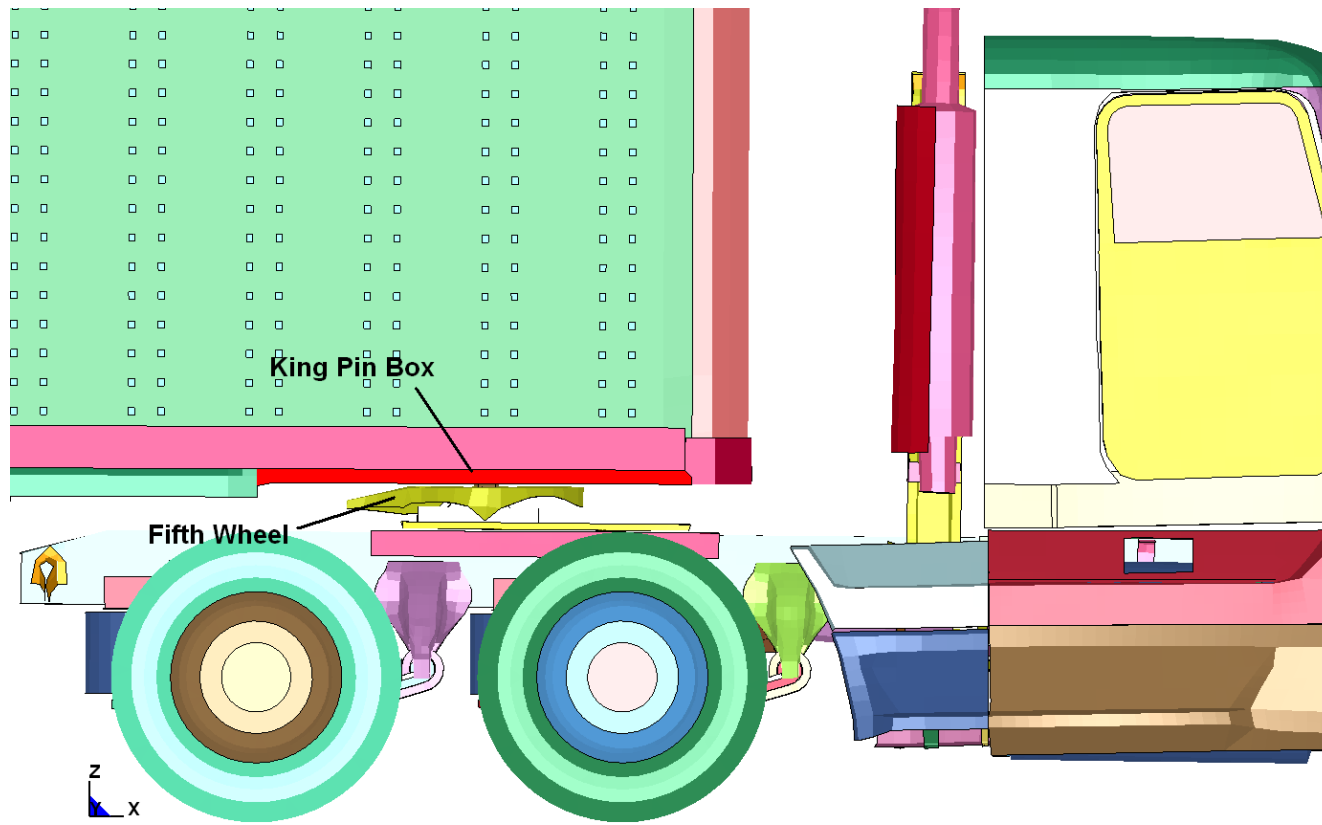


Figure 12. Illustration. Parts in contact for tractor to semi-trailer connection

## Accelerometer Locations

This FE model uses the LS-Dyna option:

\*ELEMENT\_SEATBELT\_ACCELEROMETER to define accelerometer locations and orientations. The baseline tractor vehicle FE model has 15 of these accelerometers defined. The baseline semitrailer vehicle FE model has one accelerometer defined. Figures 13 and 14 show the locations of the origin-node of these accelerometers. All these accelerometers are oriented with their local X-directions (initially) in the global X direction.



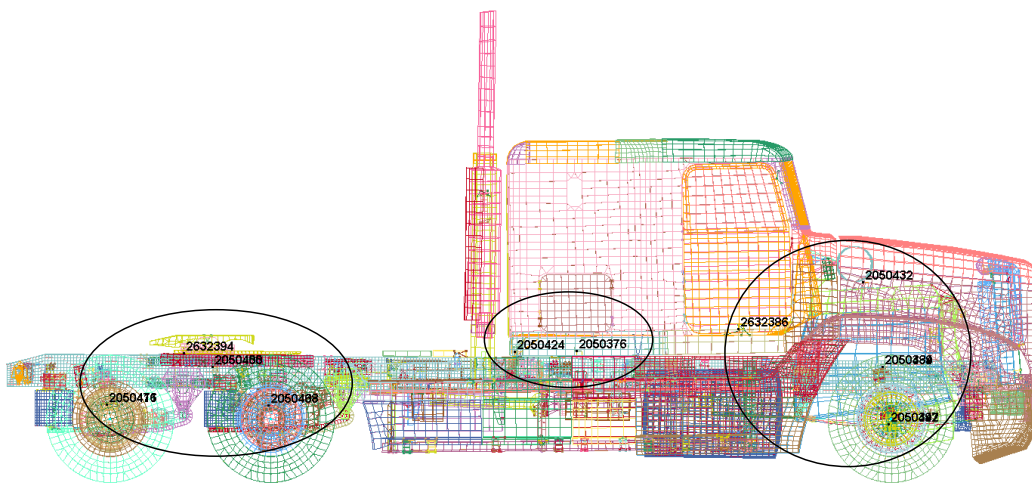
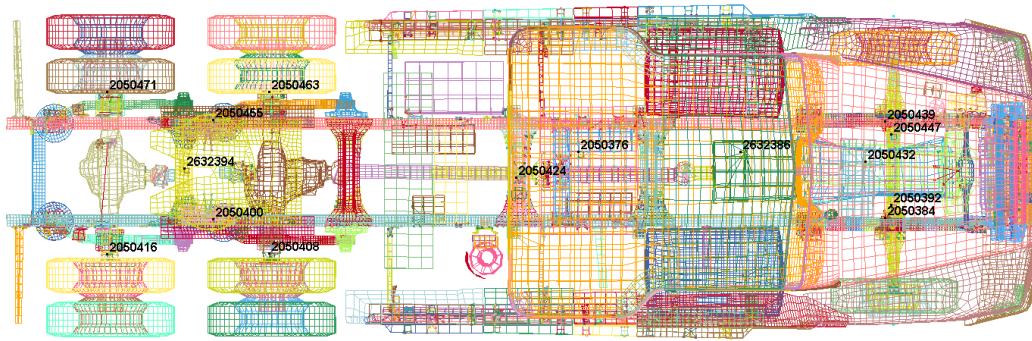


Figure 13. Illustration. Accelerometer locations in long wheelbase tractor

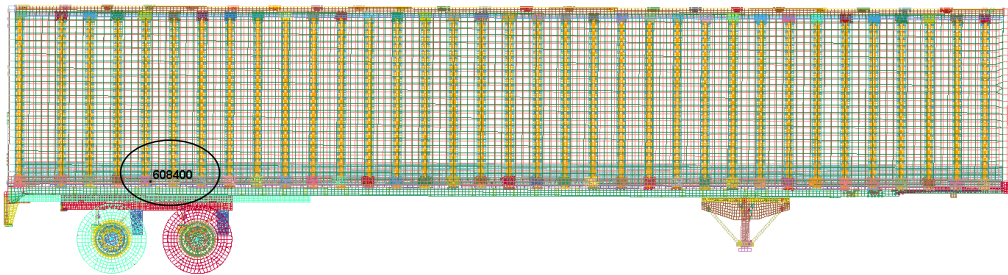
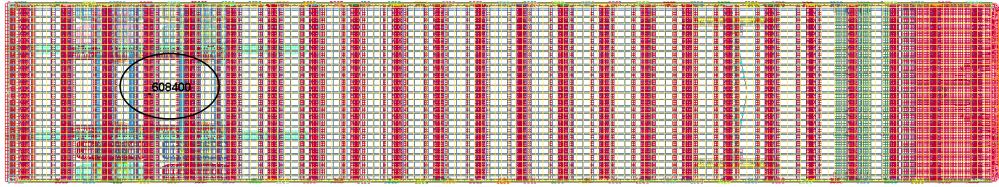


Figure 14. Illustration. Accelerometer location in 48-foot semi-trailer

## Initial Velocity Control

The vehicle model is given an initial translational velocity at every node along its longitudinal (X) axis using the \*INITIAL\_VELOCITY\_GENERATION option in LS-Dyna. Figure 15 shows a typical example of this from an LS-Dyna input file. In addition to this initial translational velocity, each node on every tire, wheel, and associated rotating component is given an initial rotation about its rotational axis. The user should ensure that these rotations are positioned exactly collinear with the center of the wheel-set and are proportional to, and consistent with the O.D. of the tire.

```
*INITIAL_VELOCITY_GENERATION
$#nsid/pid      styp      omega      vx          vy          vz
  2000001        1 46.866699 23583.000
$#      xc      yc      zc      nx      ny      nz      phase
-1162.5800     0.000 501.82800    0.000  1.000000
  2000002        1 46.866699 23583.000
-6043.5801     0.000 501.82800    0.000  1.000000
  2000003        1 46.866699 23583.000
-7308.0801     0.000 501.82800    0.000  1.000000
  2000004        1      0.000 23583.000
  0.000      0.000      0.000      0.000  1.000000
```

Figure 15. Illustration. LS-Dyna input for initial velocity

There is a specific initial velocity specification for each keyword-file defined model that has motion associated with it, rather than one overall initial velocity specification for everything in one file. There is also a specific initial velocity specification used for the TTI test 7069-13 simulation with gravity initialization that reflects the gravity-deflected nodal positions in that model.

## Element Types Used

Throughout the tractor and semitrailer FE models, shell elements are specified and type 2 and 16. These are fairly efficient, robust fully integrated shell-formulations. Type 16 elements will also accommodate some warping. Shell elements in areas that were expected to see significant bending were assigned 5 integration points through the thickness. Shell

elements in other areas were assigned the default 3 integration points through the thickness.

Solid element type 2, fully integrated/selectively-reduced integration elements, was used to model deformable or geometrically complex solid parts. Solid element type 1, single-integration-point elements, was used for less structurally detailed parts such as spotwelds, and accelerometer elements, or rigid elements.

## Connection Schemes Used

In the many areas of the FE model where parts needed to be connected, various methods were used to implement the connections:

*Common-Node:* Wherever possible, intersecting and adjoining plates were modeled with simple common-node connections that required no further complication.

*Constrained Nodal Rigid Bodies (CNRB):* CNRB's were used to connect parts that were more-or-less permanently connected and were not likely to be modified by the user.

CNRBs were used to connect adjoining parts that had mesh-dissimilarities such as different mesh size or element type (shell-to-solid, shell-to-beam, etc.).

*Tied Contact:* In many areas of the model, parts are connected using the \*CONTACT\_TIED option in LS-Dyna. Care must be taken when using this option to avoid possible conflicts with other constraints, such as CNRBs. The advantage of using this constraint method is that the associated parts can be remeshed without having to redefine the constraints.

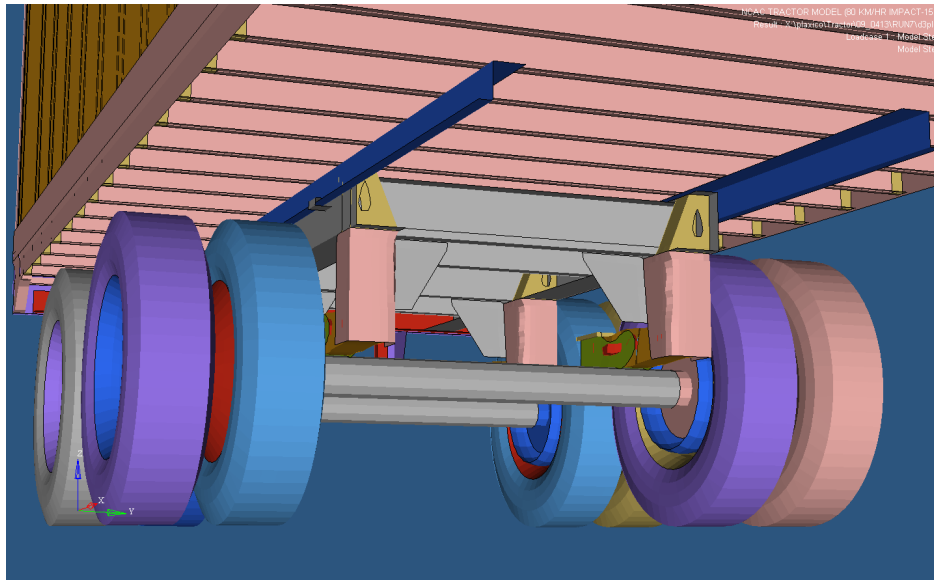
## Moveable Wheelset (Bogie)

The semitrailer FE model has a moveable wheelset (bogie) with fore-aft position adjustment just like actual semitrailers. The wheelset is attached to the cargo box via a sliding connection to allow for positioning of the trailer's wheels fore-aft for various loading conditions. This sliding connection is the (nested) interface of the wheelset's subframe (Z-channel) members with the cargo box main longitudinal frame (Z-channel) members. Figures 16 and 17 show the actual semitrailer and the FE model wheelset respectively.

LS-Dyna \*MAT\_SPOTWELD elements were used to model the connection components of the wheelset subframe to main longitudinal cargo box frame. The \*CONTACT\_TIED option in LS-Dyna was used to constrain the \*MAT\_SPOTWELD elements to both the subframe and main cargo box frame. This connection method allows the user to reposition the moveable assembly of the wheelset to any fore-aft position without the need for remeshing, reconnection or redefinition of connection elements. To adjust the bogey position \*MAT\_SPOTWELD elements are selected and then translated using LS-PrePost. The direction of this fore-aft motion is not \*exactly\* along the global X direction because the trailer is angled 2° downward from the rear wheels to the kingpin. Given this, the actual translation should be done by choosing the appropriate "N1-to-N2" reference nodes in the translation utility in LS-PrePost. Also, when the wheels are moved, the locations of the wheel rotation \*JOINTs and the rotation centers for the \*INITIAL\_VELOCITY option must be updated by the user. If the user needs to make this adjustment for several different cases, separating the bogey assembly into its own keyword file with specific joint and initial velocity definitions may be preferable. The user can call this separate bogey k file into the 00Main file using the \*INCLUDE\_TRANSFORM option.



Figure 16. Photograph. Front view of trailer vehicle frame and bogie



**Figure 17. Illustration. Front view of trailer FE model frame and bogie**

## Passive Steering Compliance

The response of the tractor during a redirective impact is dependent to a great extent upon the response of all the various components and kinematics of the front suspension system. One of the critical elements in this system is the compliance or stiffness with which the front wheels tend to resist an externally-forced steer. This compliance is dependent upon the overall kinematics and stiffness of the steering linkage mechanism. This compliance must be measured experimentally and input as a discrete spring/damper in the FE model. This measurement has not been done for the current version of the tractor FE model. There is a discrete spring/damper in place for this, but the values of stiffness and damping are "placeholders".

## Front Suspension U-Bolt Connections, Contacts and Failure

The main connection that holds the leaf springs together and the leaf spring assembly to the main frame rail is two large “U-Bolts” on the left and on the right front suspensions. These U-Bolts are tightened down during the first 0.001 second of the simulation by thermal contraction. This is accomplished using the \*LOAD\_THERMAL\_VARIABLE and \*MAT\_ELASTIC\_PLASTIC\_THERMAL options in LS-Dyna. As shown in Figure 18 the thermal expansion coefficient for the bolt is set to 1.0, the delta-temperature is set to 1.0, and that delta-T is scaled by the load curve to increase from 0.0 to -0.4 over 0.001 seconds and hold steady for the entire simulation. This effectively induces a (tensile) strain of 40% in one element in each of the U-Bolts – shortening the bolt and tightening the connection. This particular value of -0.4 will generate an initial tensile force in each bolt, but the actual magnitude of the tensile force is highly dependent upon the initial geometry and orientations of the connected parts.

Some more detailed explanation of the contact between the U-Bolts and the surrounding structure needs to be made. The U-Bolts are represented with beam elements, so the \*CONTACT\_GENERAL contact option is used. That contact option works well when beam elements need to be in contact with other parts.

The U-Bolt beam elements also have to have geometrically accurate “shell edge” contact with the sides of the leaf springs. LS-Dyna by default adds “thickness” to the edge of shell elements that are involved in contact to eliminate gapping and consequent node-snagging of internal element edges when there is significant bending in a shell structure. To accurately model the geometry of a shell structure, this added thickness at the edge of an element needs to be "turned off" at the free edge of a shell. The LS-Dyna User's Manual states that this added thickness can be turned off at shell free edges by flagging the SHLEDG variable on the \*CONTROL\_CONTACT card. It turns out that this flag does not work in the recent versions of LS-Dyna 971. Figure 19 shows the effect that this has on beam/shell edge contact interfaces when initial penetrations are corrected at the start of a simulation. The workaround that is currently used to avoid this in the tractor FE model is to add a set of small-diameter coincident beam elements to the U-Bolt beam elements and make these small-



diameter coincident elements be the elements in contact with the leaf spring shell elements rather than the true-diameter beam elements representing the U-bolts.

```

*DEFINE_CURVE
##      lcid      sidr      sfa      sfo      offa      offo      dattyp
      2200007      0      1.000000      1.000000
##              a1              o1
              0.000              0.000
              0.0010000      -0.4000000
              5.0000000      -0.4000000

*MAT_ELASTIC_PLASTIC_THERMAL
##      mid      ro
      2200037      7.8900E-9
##      t1      t2      t3      t4      t5      t6      t7      t8
      0.000      2000.0000
##      e1      e2      e3      e4      e5      e6      e7      e8
      2.0000E+5      2.0000E+5
##      pr1      pr2      pr3      pr4      pr5      pr6      pr7      pr8
      0.3000000      0.3000000
##      alpha1      alpha2      alpha3      alpha4      alpha5      alpha6      alpha7      alpha8
      1.0000000      1.0000000
##      sigy1      sigy2      sigy3      sigy4      sigy5      sigy6      sigy7      sigy8
      896.00000      896.00000
##      etan1      etan2      etan3      etan4      etan5      etan6      etan7      etan8
      1380.0000      1380.0000

```

Figure 18. Illustration. Input for bolt-tightening in LS-Dyna

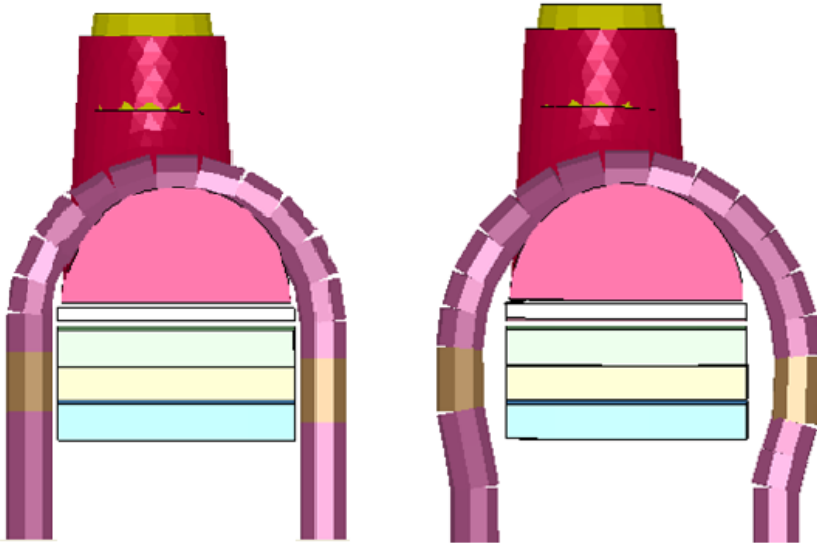


Figure 19. Illustration. Effect of initial penetrations correction on beam-to-shell-edge contact shown with element dimension display turned on

## Use of ADAP Scripts

A set of model modification scripts; Automated Dimensional Adjustment Program (ADAP) was developed that can be used to modify the tractor FE model wheelbase and cab style and the length of the semitrailer FE model to represent more closely the actual tractor-semitrailer models used in crash tests.

The operations executed using these scripts perform a sequence of basic model modifications through stand-alone programs. Each modification step results in a syntactically valid LS-DYNA input file, which allows for easier procedure development and debugging.

Charles R Miele 9/17/09 1:09 PM

Comment: Srdjan to write this part

## Example of Tractor Model Modification Steps

Several basic operations were developed for LS-DYNA model modifications:

1. Elimination of connections of a (list of) part(s) with other parts in the structure
2. Removal of a (list of) part(s)
3. Cutting of a segment from a (list of) part(s)
4. Scaling of the geometry of a (list of) part(s)
5. Rotation of the geometry a (list of) part(s)
6. Translation of a (list of) part(s)
7. Merging of a (list of) part(s)
8. Joining of parts.

All of the above operations can be applied to the specified part region only. These basic operations are combined to yield the desired geometry through a sequence of steps. The programs are reasonably general and can be used for other FEM model modifications. The emphasis of the project was not on computational efficiency of the modification process, but on accuracy and flexibility. In any case, the modification is executed in several minutes, which is negligible compared to a new model development. For the availability and instructions please contact the authors of this report.

## Tires and Tire Pressures

The tires of the tractor and the semitrailer are very simplified compared to real tires. The tires are modeled as a homogeneous isotropic elastic material with no beads, plies, cord or belt with a constant thickness of 10 mm. There is no provision for tire failure, de-beading or blowout – that is commonly observed in actual truck crashes.

The air pressure in the tires in the tractor and the semitrailer is simulated using the \*AIRBAG\_SIMPLE\_PRESSURE\_VOLUME option. This

option allows simple, direct input for pressure inside a volume. The tire pressure set for all tires is 0.69 MPa (100 psi).

### Time Step

The target minimum time-step specified on the \*CONTROL\_TIMESTEP card was set to -1.400 microseconds. This minimum time step was specified with the contingency that mass scaling would be used to maintain it. During a recent simulation, there were only about 40 elements that required a smaller time step. Of these 40 elements, the smallest required time step that LS-Dyna calculated was about 1.19 microseconds. With the mass scaling option invoked, the total mass added to the entire model in this simulation was 8.2 kilograms. The element length that corresponds to the specified 1.4 microsecond time step for steel and aluminum is about 7 to 10 mm. The target element size for structural elements is 25 to 100 mm (1.0 to 4.0 inches). To model the geometry everywhere with reasonable accuracy, the actual element sizes in the model ranged from about 8 mm to about 120 mm.

### Computer CPU, Run Time, and Storage

The full tractor-semitrailer FE model with a typical barrier takes roughly 1 day per 1.0 second of simulation time using 8-cpu's in a Linux cluster. A 1.5 second simulation uses 10 – 12 GB disk storage with typical output requests.

The details of the (Linux-based) computer system used are:

- 10-Node Dual-Core (20 cpu) Beowulf Cluster
- Red Hat Enterprise Linux 4 OS
- 64-bit Dual-Core Intel Xeon

- 3.0Ghz Processor
- 4Gb of memory
- Infiniband 4X DDR Network (20Gb)

Figure 20 shows a printout of a 3-second simulation that was run on 12-cpu's.

```

Problem time      = 3.0000E+00
Problem cycle    = 2083334
Total CPU time   = 141991 seconds ( 39 hours 26 minutes 31 seconds)
CPU time per zone cycle = 296 nanoseconds
Clock time per zone cycle= 294 nanoseconds

Parallel execution with 12 threads
NLQ used/max      96/ 96

C P U   T i m i n g   i n f o r m a t i o n

-----
Processor  Hostname                      CPU(seconds)
-----
# 0      m4.EDMS-MEGALODON.battelle.org 1.4199E+05
# 1      m4.EDMS-MEGALODON.battelle.org 1.4208E+05
# 2      m2.EDMS-MEGALODON.battelle.org 1.4205E+05
# 3      m2.EDMS-MEGALODON.battelle.org 1.4203E+05
# 4      m5.EDMS-MEGALODON.battelle.org 1.4202E+05
# 5      m5.EDMS-MEGALODON.battelle.org 1.4201E+05
# 6      m3.EDMS-MEGALODON.battelle.org 1.4215E+05
# 7      m3.EDMS-MEGALODON.battelle.org 1.4207E+05
# 8      m8.EDMS-MEGALODON.battelle.org 1.4219E+05
# 9      m8.EDMS-MEGALODON.battelle.org 1.4225E+05
# 10     m10.EDMS-MEGALODON.battelle.or 1.4190E+05
# 11     m10.EDMS-MEGALODON.battelle.or 1.4210E+05
-----
T o t a l s                               1.7048E+06

Start time 01/09/2008 11:38:34
End time   01/11/2008 03:26:10
Elapsed time 143256 seconds( 39 hours 47 min. 36 sec.) for 2083334 cycles

N o r m a l   t e r m i n a t i o n

```

Figure 20. Illustration. Run-time data for 3-second tractor-semitrailer simulation