An Overview of Tractor/Trailer Simulation at the NADS

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Abstract

The NADS models and cab for a class 8 tractor/trailer have recently been reviewed, enhanced, and implemented for a NHTSA study. A panel from the Federal Motor Carrier Safety Administration (FMCSA) reviewed the status of the NADS simulation capabilities and made several recommendations for improving its fidelity and realism. This paper is devoted to describing recent enhancements made to the models, visuals, and cab to address the recommendations from the FMCSA review, with a general introduction to the tractor/trailer model. In addition, some capabilities were added to support a NHTSA study on braking that was completed in early 2007. One of the noted problems was a lack of synchronicity between the transmission and engine model running locally on the cab computer (CFS), and the transmission and engine model running under vehicle dynamics (VDS). This was addressed by porting the CFS model into VDS, to obtain completely synchronous simulations. Another noted problem was the lack of accurate trailer visualization, which was addressed up to the current capabilities of the NADS visual system. Other enhancements include new brake model data, validation of the steering system and brake pedal feel, and a new vibration model providing motion feel through the hexapod and dome vibration actuators. In conclusion, the work to provide a realistic tractor/trailer simulation experience is ongoing; with the current state-of-the-art being appropriate and sufficient for certain types of heavy truck studies.

Introduction

The National Advanced Driving Simulator (NADS) at the University of Iowa is a very high fidelity simulator that provides a realistic driving experience using a wide range of cabs and scenarios. The capabilities of the simulator include a motion base with 13 degrees of freedom, eight projectors that provide a 360 degree horizontal field-of-view (FOV), surround sound audio cues that are correlated with road and dynamics inputs, fully instrumented OEM vehicle cabs, and high fidelity multibody dynamics models. The intention is to provide an environment that requires very little training or adaptation for a non-expert driver participant with no simulator experience.

Studies using passenger cars and SUVs have been ongoing since 2001; however, studies using heavy (class 8) trucks have begun more recently. The first such study examined the braking effectiveness of different types of brakes and completed data collection in February, 2007. All work described here, other than future work, was completed prior to the braking study.

FMCSA Review Summary

Prior to the brake study, the truck simulation environment was evaluated by a panel of experts from the Federal Motor Carrier Safety Administration (FMCSA). That review took place in 2005 and a report was published that detailed their findings [1]. While several positive elements were noted, a list of criticisms negatively impacted their conclusions on the suitability of using the NADS for truck studies. The summary of these criticisms is included here:

1. The current truck configuration does not permit the proper use of the truck cab mirrors. The visual scene presented in the rear view mirrors is not accurate.
2. The truck cab operates two simulations simultaneously; one for vehicle dynamics and one for the transmission. However, the system was not synchronized at the time of the evaluation. Thus, it was possible for the “truck” to be travelling at simulated highway speeds, have the engine stall due to improper shifting, and still continue to proceed down the road at an unabated speed.
3. The dynamics of the truck while performing simple maneuvers, such as a turn at an intersection with a trailer, were not well replicated. The motion was restricted, as though the vehicle was performing a series of smaller, straight line maneuvers.
4. Steering feedback during maneuvers was not adequate. There was excessive play in the wheel during most maneuvers. In addition, there was excessive feedback through the steering wheel during turns. Yet, there was minimal feedback when the simulated vehicle exited or entered the roadway. The feedback from steering and road feel, such as vibration or shaking was minimal and not realistic.
5. The replication of pedestrians was poor. Pedestrians were represented as non-articulated, two-dimensional figures.
6. The vehicle brakes were not well replicated in the single trailer configuration. The braking felt as if the vehicle were much heavier than indicated.

7. The replication of vehicle movement while performing turns at intersections was not adequate. The simulated vehicle did not properly replication the movement of the trailer around the turn or the steering feedback in the tractor.
8. Vehicle acceleration was not properly replicated. The simulated vehicle acceleration too quickly for the engine, trailer, and load configuration being driven.

A major purpose of this paper is to address these criticisms and show how they have been, or will be corrected. In the sequel, when a specific item from the list is affected by an enhancement, the item number in the list above will be referenced.

Truck Overview

A brief overview of the truck simulation is given, beginning with the multibody dynamics model. Then the NADS truck cab is discussed, as well as the software environment that links the cab to the dynamics.

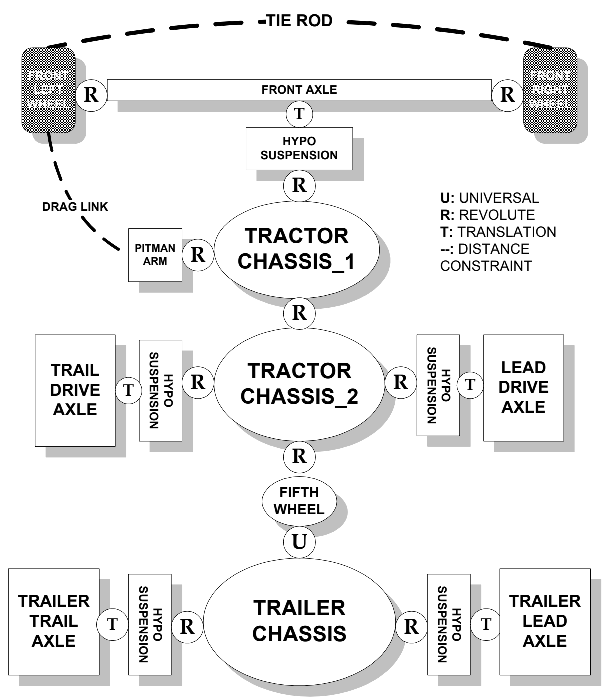


Figure 1 Truck Multibody Topology Diagram

Vehicle Dynamics Model

The tractor-trailer modelled is a 1992-GMC truck manufactured by Volvo GM Heavy Truck, model WIA64T and a 1992 Fruehauf trailer model FB-19.5NF2-53. Geometric and inertial parameters were measured for the chassis, steering, and suspension components. The performance properties of the three suspensions and torsional stiffness of the vehicle frames and fifth wheel coupling were also measured. Figure 1 contains a schematic of the rigid body model. Universal, revolute, and translational joint types are used, as are distance constraints for the tie rod and drag link. More details on the truck model, including the modelling of the dual tires, roll axis, leaf springs, compliances, and steering kinematics are given in [2].

Truck Cab

A fully instrumented Freightliner truck cab was one of the four original cabs provided to the NADS by Dynamic Research, Inc. of Torrance, CA. The cab is equipped with an 18 speed transmission shifting trainer (TST) supplied by ISIM (now MPRI Ship Analytics). The TST includes a gear shift mechanism with split and range switches, and is actuated by a motor at its base to provide active force feedback. Software is also included to model the engine and transmission, as well as operation of the gear shifter. The TST is able to simulate realistic shifting, including gear grinding, through tactile and audio cues.

Realistic brake feel is achieved through a pneumatic system installed in the cab to give the pedal the correct force-displacement properties. Also connected to the pneumatic system are the parking brake, brake release, and trolley valve. The audible 'whoosh' that accompanies the cycling of the trolley valve is thus present and accounted for.

Software Environment

The NADS software simulation environment is based on distributed subsystems that run on various PCs, and that are connected via Ethernet and a high speed reflective memory network (SCRAMNet). Some of the currently used subsystems are listed in Table 1. Depending on a subsystem's fidelity and complexity, it may require a dedicated PC, or it may share a PC with other subsystems.

Table 1. NADS Subsystems

Dynamics (VDS)	Motion Control and Washout (MTS)
Control Feel (CFS)	Visual Information (VIF)
Cab Information (CIS)	Audio Information (AIF)
Motion Information (MIF)	Data Acquisition (DAQ)

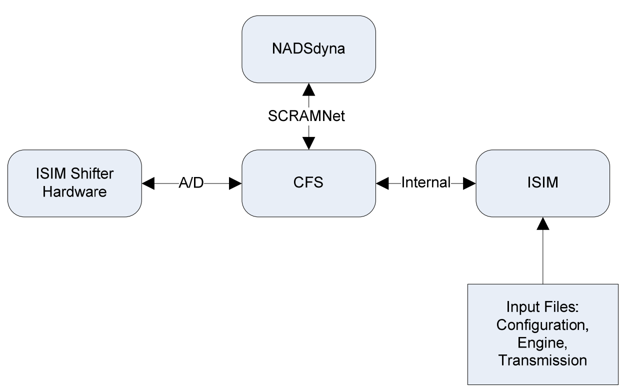


Figure 2 Integration of TST with other NADS systems

The models responsible for simulating the truck are distributed between the VDS and CFS subsystems. The TST models have been integrated into the larger CFS software, while the major share of the truck models run on the VDS, using the NADS in-house dynamics application, NADSDyna. This distribution of computational responsibility is illustrated in Figure 2.

Powertrain Models

One serious deficiency of the truck model, as noted by the FMCSA, was the use of different transmission and engine models that did not operate synchronously, or even produce the same behaviour. This happened because the CFS subsystem ran the ISIM TST model, while the VDS ran the NADSDyna models. This deficiency was corrected by porting the ISIM software over to NADSDyna, so that both the CFS and VDS subsystems run the same models. The TST model on the CFS was not eliminated completely so that some transmission signals could be used locally by the CFS and CIS software; however the CFS and VDS models are identical and receive the same inputs.

This solution directly addresses item two on the FMCSA list of criticisms. It also indirectly addresses item eight, since the ISIM TST model is more appropriate for the truck simulation than the standard NADSDyna models.

Validation

The truck dynamics were validated by VRTC using experiments performed on the test track, and using procedures developed for other NADS vehicle model validation efforts [3, 4]. The maneuvers selected for comparison were lane change, slowly increasing steer, pulse steer, step steer, and straight-line braking. A complete report of the validation tests is given in [5].

More recently, the major elements of the truck cab were also validated. The cab elements that have a 'feel' are the steering wheel, brake pedal, accelerator pedal, and gear shifter. The TST used as the gear shifter is a stand-alone product and was assumed to have been validated for the truck simulators it was designed for. The FMCSA review indicated flaws with the perceived steering and braking of the truck, so these two elements were targeted for work.

Brake Pedal Force

It was noted earlier that the brake pedal is connected to a pneumatic system in the cab, and this system gives the brake pedal force-displacement curve its shape. A scaling factor is present in the software and can be modified to change the magnitude of the force-displacement curve that gets reported to VDS; however, the actual feel of the pedal cannot be changed without modifying the design of the pneumatics.

A force sensor was fastened to the brake pedal so that the measured force could be compared to the reported force. A set of discrete brake pedal positions were measured with a ruler to estimate the force-displacement curve. This curve matched up well with pedal force measured from a Volvo truck. It was found however, that the reported pedal force was smaller than the measured force by a factor of three. The scaling factor in the software was changed to correct the discrepancy, and resulting perception of braking to a stop became much more realistic. Item six in the FMCSA list makes sense in light of these findings, since dynamics had received a braking force three times too small, greatly increasing the stopping distance.

Steering Wheel Torque

A set of discrete steering wheel torque and angle measurements were taken using a force meter applied at a given lever arm, and a steering angle chart overlaid on the wheel. These direct measurements could be compared against torque readings reported on the SCRAMNet network. This comparison showed close agreement between the measured and reported steering torque, giving a degree of confidence to the sensed torque signal. Then, continuous measurements were taken by applying a ramp steer input and recording the reported torque with the NADS data acquisition (DAQ) subsystem.

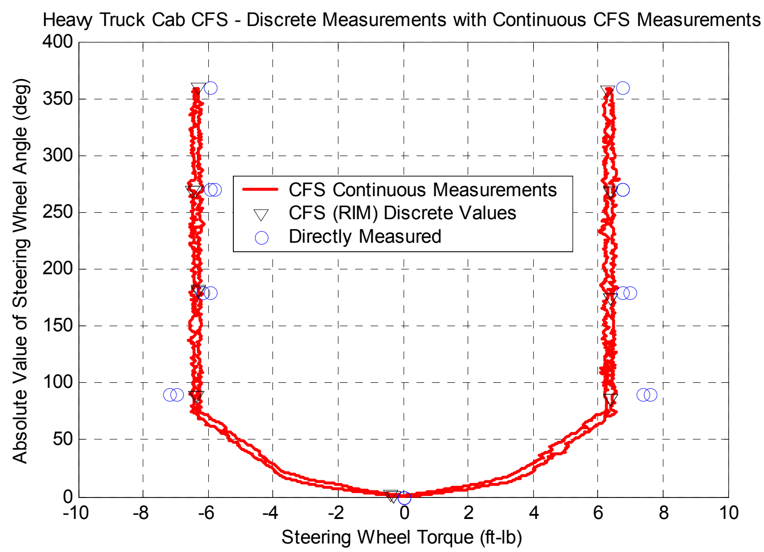


Figure 3: Continuous CFS Steering Data with Discrete Measurements

Several modifications to the CFS steering system model parameters had to be made to obtain the desired steering torque characteristic. Moreover, it was found that a steering deadband of plus or minus five degrees was being used, when the measured deadband was only plus or minus two degrees.

The discrete and continuous measurements, after correcting the parameters, are shown in Figure 3. This correction addresses items four and seven on the FMCSA list of criticisms. An additional reason for the description of the trailer navigating the turn in item seven, was that the articulation of the fifth wheel was not properly represented at the time of the review. In fact, the trailer visuals resembled the behaviour of a straight body truck more than anything else. Once this was corrected, the trailer visualization was greatly improved.

Enhancements

Two enhancements to the truck model were made for the braking study. The first was to create brake data files for three specific brake types and validate their performance. The second was to add a validated vibration model. These are described in this section.

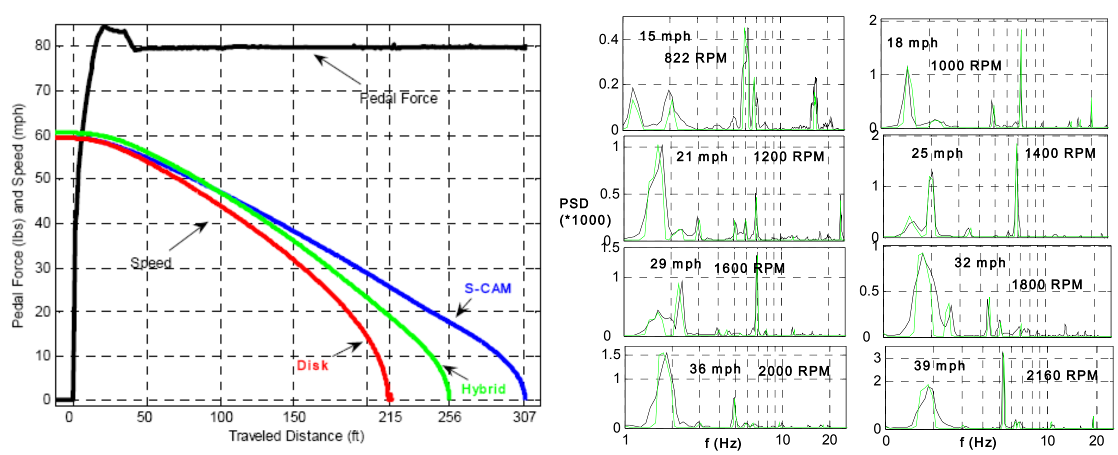
Brake Model Data

NADSDyna supports several types of brake systems, including hydraulic manual, hydraulic with vacuum assist, and pneumatic. The brakes described in this section were all modeled using the pneumatic formulation [6, chapter 2.4]. This model type assumes that air is used as the energy transmission medium. It uses first order differential equations to represent each caliper pressure change due to compressibility of the air volume in each brake line. The time needed to reach 90% of maximum pressure at the caliper is used to determine the coefficient of the corresponding differential equation. Each caliper can have a proportioning valve. These valves have a cut-in pressure, where the output pressure is reduced as a percentage of the input pressure. Data for these valves are specified as a pressure and a slope. Setting the slope to zero after the knee point implies that a limiting valve is used instead of a proportioning valve. This modeling approach allows the brake subsystem to represent several classes of vehicles.

Three new sets of brake data were developed and validated against measured stopping distances of a tractor with a fully loaded trailer [7]. The three brake types modeled were:

- S-cam brakes are used on all wheels
- Enhanced version of an S-cam brake on the steer axle, regular S-cams elsewhere
- All wheels of the tractor equipped with air disc brakes.

The brake parameters were set such that severe braking from 60 mph provides a stopping distance of 307 feet for standard brake, 256 feet for enhanced brakes, and 215 feet for disc brake. The stopping distance in the simulator was compared to these measurements to validate the performance of the new brake data (see Figure 4a).



(a) (b)

Figure 4: (a) Brake performance on the NADS (b) Power spectrum of measured and modeled vibrations

Vibration Model

One cue that was lacking from the truck simulation was the vibration from the engine. A sum-of-sines model was developed to generate a rumble with a quasi-random feel to it. The vibrations were modelled with harmonic functions to emulate the measured power spectrum. Series of harmonic functions were developed to represent different RPM levels. The harmonic functions are formulated as follows,

$$F = mass\sum_{i=1}^{n} A_i \sin\left(2\pi f_i * time\right)$$

If the vibration actuators accept acceleration as input, as they do in the NADS, then *mass* = 1. This parameter can be adjusted to scale the vibration magnitude.

The range of the spectrum is limited to about 25 Hz, and the formulated harmonics have most important fundamental frequencies around 2 Hz, 5~7 Hz, and other secondary higher frequencies. The 2Hz frequency is due to mass/spring effect and the 5~7 Hz is due to power train vibrations including engine mounts. This latter is important because it is close to frequencies that 'disturbs' or affect human vibration feel. The modelled and measured vibrations at different speeds are shown in Figure 4b above. The vibration model addresses the comment about road feel in item four of the FMCSA list.

Current and Future Work

Work continues on the truck simulation experience to improve its realism and broaden the scope of studies that it can be used in. The next enhancement to take place is an expansion of the Field-of-View (FOV) by replacing the passenger side mirrors with LCD displays. The view in the passenger planar and convex mirrors is currently not useful, as the eyepoint cannot be set properly in the image channels within that view. Moreover, the convex mirror brings the dome floor into view. The view in the driver's side planar mirror is currently set to have the correct eyepoint. The driver's convex mirror has the same limitation as the passenger's; and may eventually also be replaced by an LCD display. This work will directly address item one in the FMCSA list.

Conclusions

The simulation environment for heavy trucks in the NADS has been reviewed by the FMCSA; and several suggestions have been made to improve the realism and make the capability more useful. After a review of the truck dynamics and software environment, the solution to the parallel transmission simulations is described. Validation work was done on the truck cab, specifically on the steering wheel and brake pedal feel. Good agreement between measurements and simulations was achieved after some modifications. New brake data for three specific brake types were added and validated. Additionally, a vibration model was created from measured vibration data, and integrated into the dynamics. Finally, work is ongoing to improve the FOV from the truck cab by modifying the passenger-side mirrors. Item five on the FMCSA list, regarding the replication of pedestrians, was not addressed in this work; but improvements to pedestrian simulation are in the planning stage.

The current truck simulation capability in the NADS is appropriate for a broad range of studies. The current limitations have to do with the FOV, and would preclude studies that involve heavy use of the mirrors, such as would be required by backing up or frequently changing lanes in traffic.

References

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