Ground Vehicle Simulation of Military Vehicles Using High Performance Computing

by
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Abstract

In support of Department of Defense-mandated acquisition reform initiatives, the Tank Automotive Command, Research, Development and Engineering Center's National Automotive Center (TARDEC-NAC) is using simulation-based strategies to investigate the dynamic performance of ground vehicles throughout the vehicle development, testing, and fielding life cycle process. State-of-the-art high-performance computing (HPC) facilities are allowing the integration of virtual prototyping and dynamic modeling expertise into a complete wheeled- and tracked-vehicle system simulation capability and are routinely called upon to provide modeling and simulation (M&S) support to the US Army, industry, and academia. TARDEC-NAC is effectively using M&S to evaluate new designs prior to selection and testing, support operational and developmental testing, evaluate field mishaps and/or accident situations, investigate configuration management changes, product improvement programs, and alternative payloads on virtually all types of wheeled and tracked vehicle systems. Recent major upgrades in TARDEC-NAC's HPC facilities now allow the highly detailed, computationally-intensive models to be run in a fraction of the time, and, more importantly, many more 'what if' studies can now be performed that were not possible with previous generation computing resources. Hundreds of simulations can now be set-up and run on a daily basis to investigate every aspect of vehicle design that might impact overall vehicle performance. The major driving force behind high-resolution, computational dynamics is its cost-effectiveness. Low cost, high performance computers and powerful software are making real time, high-resolution vehicle system simulations a reality. Representative model predictions can augment and/or replace costly or dangerous field and laboratory tests. More stringent performance specifications are also being placed on vehicles to meet changing battlefield requirements and varying mission scenarios. The objective of this paper will be to describe model verification in the virtual prototyping process and discuss how M&S and HPC technologies are being applied to specific case study examples throughout the vehicle development life cycle. This paper will describe a simulation-based engineering project as well as some case studies utilizing HPC that build on the Army's simulation investments as a tool to investigate and answer real-world vehicle design, acquisition, and engineering support questions.

Introduction

This report describes an effort by TARDEC-NAC to verify a dynamic model of a 5-ton tractor towing an M900 series, 5000 gallon, fuel-dispensing, tank-semitrailer. TARDEC-NAC's Analytical Simulation Team was tasked by the Project Manager – Force Projection to develop a high-resolution computer-based model of a 5-ton tractor towing an M900 series tank-semitrailer for the purpose of investigating

the dynamic stability while negotiating various on-road maneuvers over a range of vehicle speeds and to verify the model. Once verified, the model will be used during upcoming source selection evaluation activities (SSEB) to select a contractor to build the new M900 series tank-semitrailer. The analytical models will be employed to assist TARDEC-NAC in assessing the feasibility of towing contractor-concepted tank-semitrailer(s) with the tractor and to determine the safe operating envelope of the combination with respect to movement and operations during normal and abnormal operations. Limited verification was performed by comparing model predictions with data generated during actual field tests. The model was considered accurate enough to predict various aspects of ride quality and stability performance, critical to mission needs. Performance evaluations were made by analyzing state variable time histories during one-to-one comparisons of the test vehicle and the model operating in various terrain and obstacle negotiation conditions. This combination is routinely operated across secondary and unimproved roads, and on paved roads at normal highway speeds in varying environmental conditions. The Army has the requirement to acquire and maintain an over-the-road tank-semitrailer system capability, capable of transporting liquids into rearward re-supply areas as well as being able to maintain convoy speeds during tactical and combat operations in varying climates and environments, thus, it becomes necessary to quantify the combination's dynamic performance. This work was initiated because the Army is applying computer-based models to quantify the operation and dynamic performance of its fleet of combat and tactical equipment. Prior to the simulation analysis, a set of carefully controlled and instrumented field tests were conducted to understand inherent stability problems, determine performance limits, and to collect instrumented data to verify the high resolution, spatial, computer-based dynamic models. Figure 1 shows the field test vehicles and the model graphics.

Figure 1. Field and Virtual Tractor/Tank-semitrailer Combinations.

This report primarily documents the effort to verify the model by direct comparison of TARDEC-NAC model simulation results to actual hardware field-test results.

Objectives

The objective of this report is to compare data from a set of instrumented field tests to a series of analytical simulation results to determine how well the data sets correlate. Tests[1] were conducted on the combination in two configurations: empty, and with a 3000 gallon payload. Due to the difficulty in

modeling the tanker's liquid sloshing dynamics that adversely affects the stability and handling of the combination during normal operations, the tests were also conducted with 3000 gallons of liquid so that field data could be compared with the simulation data. A crude liquid-sloshing-dynamics-model was constructed, and subsequently, model simulation results were compared to field-test results to evaluate model accuracy.

Discussion

Many studies have been conducted on the analysis of dynamic performance of the Army's fleet of combat and tactical equipment using linearized models, but these models generally fall short in determining the upper bounds of safe and acceptable usage. This is primarily because large subsystem displacements often involve many nonlinearities which, if incorrectly modeled, could lead to erroneous predictions and conclusions. Thus it is vital to accurately characterize and model critical components and to verify predictions against controlled and instrumented field and laboratory tests. Subsystem characterization and model verification through carefully controlled and instrumented laboratory and field tests are the most valuable tools available.

The Dynamic Analysis and Design Systems[2] (DADS) methodology was used to assemble analytical models of the 5-ton tractor and the M900 series tank-semitrailer (figure 2), run the simulations, and analyze and display the simulation results.

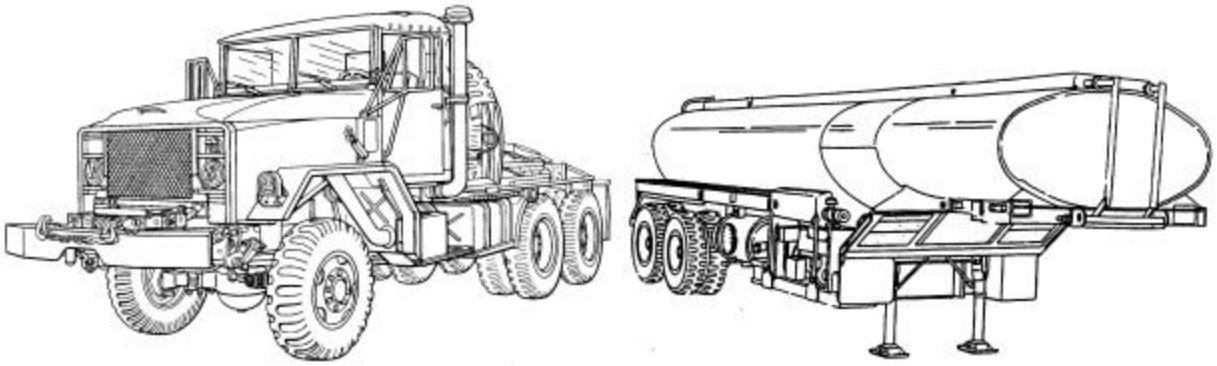

Figure 2. 5-Ton Tractor and M900 Series, 5000 Gallon, Tank-semitrailer, Test Vehicles.

The DADS methodology is a highly detailed general purpose modeling and simulation method for determining the spatial, transient-dynamic response of controlled, articulated multibody mechanical systems to excitation by irregular external and internal effects. The methodology consists of a library of subroutines defining primitive rigid body, kinematic joint, control element, and force building blocks which can be combined in numerous ways to assemble complex system models to the level of detail and accuracy deemed necessary for a given problem. The DADS program consists of three main parts, a preprocessor, main processor and post processor. The preprocessor allows much of a system's parametric and topological properties to be defined in an interactive environment without having to be concerned with the supporting equations. The preprocessor then sends this information to the main processor which uses it to assemble the equations of kinematics and dynamics. The main processor also has a number of user interface subroutines which allow more detail to be added to the model then possible with the primitive building blocks. This feature makes the representation of highly nonlinear vehicle system properties possible and yields much more representative models. The main processor also automatically integrates the resulting equations of motion for a specified period of time and outputs

the states at regular time intervals. The post processor allows these states to be plotted and, when supplied with geometrical outline descriptions of the bodies comprising the system, can generate animations of the results. DADS has been under development for many years and is well documented and reliable.

Tractor / Tank-semitrailer Combination Model Development

Both parametric and topographical data was compiled on the tractor and tank-semitrailer by collecting a variety of data from different sources. For this particular analysis it was assumed that deformable rubber bushings and flexible vehicle frames would not play a major role. Therefore, all of the bodies used in the model were rigid in nature. Making this assumption reduced the complexity of the model. Suspension components were modeled using equivalent kinematic linkages and force elements. Forces in both the shocks and the leaf springs were represented using translational spring-damper-actuator (TSDA) elements. Using the parametric engineering data supplied on the various suspension components, attachment points and force curves were incorporated in the TSDAs to closely represent the kinetic nature of the suspension system. Representative force versus deflection and force versus velocity curves for their respective TSDAs were used. A total of four TSDAs were used per wheel on each axle. One TSDA represented the jounce stops, another the shock, and the remaining two were used to represent the leaf and rubber springs. Each bogie leaf spring was modeled using two TSDAs, one per axle, and a revolute joint element to model the trunnion. Damping was added to the leaf spring TSDAs to accurately represent the coulomb friction resulting from relative motion between the individual leaves in the spring system.

Revolute joint elements and distance constraint elements were used to represent attachment points of the axles and also restrict their motion. Revolute joints representing the attachment of the wheels to the axles allowed free rotation of the tractor and tank-semitrailer wheels about their respective axes. The distance constraints were used to accurately model the attachment of the axles to the chassis while also restricting the motion of the axles. Distance constraint was added to model the leaf spring attachment points, thus restricting fore-aft movement and rotation about a vertical axis. Two other constraints were added, one to prevent lateral movement and the other to restrict rotation about the axle's longitudinal axis.

The steering methodology that was used for this model was somewhat simple in nature considering that the steering of the vehicle was not a major factor in the simulation runs. Spindles on the wheels of the tractor steering axle were modeled as separate bodies with revolute joints attaching them in an orientation similar to that of the kingpins. A distance constraint was added to the model to represent the center link which attaches the right and left spindles. Rotational Spring-Damper-Actuator (RSDA) elements were used to model the force exerted by the steering bump stops if and when excessive turning was experienced. Steering of the tractor was handled by applying a constant torque to the spindles of the front axle wheels.

The drive train methodology for this tractor/tank-semitrailer system was a control algorithm which was written and included with pre-existing DADS modules. This code was compiled and linked with the rest of the source code to generate the analysis engine. This control structure consisted of an input of current vehicle velocity and an output of a torque to be applied to each of the six wheels of the tractor

to maintain the desired speed. This simplified driving routine did not take into consideration any of the contributions of the individual drivetrain components.

Field Tests

Comparisons with the simulations were made on 27 field tests as outlined in Table 1. No test data were eliminated because of questionable results or instrument failures. All field tests were performed by trained test personnel and were considered to be correct if inconsistencies were found when compared to simulation results. During data collection, all data channels were checked after each individual test and if there was excessive noise, signal drop outs, instrument failure, or any other discrepancy in the data, the test was re-run until acceptable data was collected.

Table 1. Field/Simulation Tests w/ Empty Tank-semitrailer.

	SPEED (Miles per Hour)											
	2.5	**5**	**7.5**	**10**	**12.5**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
COURSE												
Slalom 11' x 270'				**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**
6" Bump		**X**		**X**		**X**	**X**	**X**				
12" Bump		**X**		**X**		**X**						
18" Bump		**X**	**X**									
6" Pothole		**X**		**X**		**X**	**X**	**X**				
9" Pothole		**X**		**X**		**X**						
12" Pothole	**X**											
1.34" RMS		**X**	**X**	**X**		**X**						
1.79" RMS	**X**	**X**	**X**	**X**								
3.42" RMS	**X**	**X**	**X**									

In order to obtain carefully controlled and representative off-road transient response data for model validation, a number of instrumented tests were performed. The most effective and least expensive field test procedures for system characterization and model verification involve the incorporation of short duration, transient inputs into the system with carefully controlled initial conditions, and direct comparison of the dynamic response characteristics with identical simulations. In the field, the tractor speed and pitman arm steering angles were recorded. The trajectory of the tanker was recorded by using a pressurized water/paint bottle methodology that laid down a trace on a carefully constructed grid from which longitudinal and lateral position points could be measured. This methodology worked well at slow speeds and calm wind conditions but tended to degrade quickly as speeds increased above 25 miles per hour (MPH). Relative chassis/suspension and axle displacements were measured using string potentiometers and displacement transducers. Triaxial rate gyros were used to measure roll, pitch and yaw rates. Accelerometers were placed on the axles to determine precisely when critical events such as bottoming out, wheel lift-off and contact with ground or obstacles occurred. The field tests were recorded on video for subsequent observation and comparison with computer-generated animations of the same tests for model validation purposes. The field tests were intended primarily to study the combination's dynamic responses, and consequently, to verify the model. Therefore, the field

measurements can be roughly classified as those signals required as driving inputs to the tractor model, synchronizing signals and tank-semitrailer comparison data. Measured tractor speed and pitman arm angle were used as second-order control signals to the tractor model. Model verification thus consisted primarily of insuring that input and output transient response signals correlated and that extreme displacements were similar. The analytical models were simulated through the exact same tests and conditions as the field test vehicles.

Analytical and Field Test Data Comparisons

The first set of simulations consisted of driving the left side of the tractor/ tank-semitrailer combination over a number of specially designed positive and negative ramps to study dynamic roll stability. The vehicle speed, ramp slopes and heights/depths were varied to emulate the field tests exactly. The systems were also simulated at various speeds through a lane change slalom course. Lastly, three sinusoidal RMS courses were used for this model validation test sequence to further extend and enhance the process. The RMS courses selected were measured and digitized which allows engineers to simulate the models across them and re-create the same effects as encountered during field tests. Worst-case positive bumps and negative pothole speeds and ramp heights/depths were taken at 7.5 and 2.5 MPH and 18 and 12 inches, respectively. The vehicle combination was tested on the obstacle avoidance maneuver at speeds up to 45 mph when vehicle instabilities became readily apparent, and the 1.34, 1.79, and 3.42 inch RMS courses were up to maximum speeds of 15, 10, and 7.5 mph before the tests were stopped. The models were carefully instrumented to replicate the physical instruments used at the test site and the instruments were placed at the same locations as recorded by test personnel. When comparing transient response data for model verification, it is important to record initial conditions on field tests and to insure that corresponding initial conditions on computer-based simulations are the same. The easiest method is to have the vehicle moving on a smooth, level surface at steady-state speed, and have it encounter a discrete maneuver or obstacle.

The discrete event tests such as those described above drive the subsystems into highly nonlinear regions of operation. Short duration, discrete event tests allow the initial conditions to be carefully controlled. They avoid excessive phase and amplitude differences between measured and simulated results which could completely mask correlation studies in highly nonlinear systems. Currently, direct visual comparisons are made between superimposed plots of measured and simulated states. Model validation and refinement is a critical part of system simulation. By simulating actual field tests, it is possible to determine with a fair amount of confidence which parameters should be adjusted and where the model needs to be improved or even where it can be further simplified.

The transient-response TARDEC-NAC models can output time histories of virtually any desired system state. It is important to select those states which give the maximum amount of information for correlating the computer-based model predictions with field tests. It is also important to select those states which are economically feasible to instrument and record. In addition, the monitored states should provide the maximum amount of feedback for changing the model topology and parameters for better representation of the system.

Positive Bump Course Comparisons and Correlation

Comparisons were made between the DADS simulation data and the field test data for vehicle speeds varying from 2.5 (idle) to 25 MPH and bump heights of 6, 12 and 18 inches. Figure 3 shows examples of the tank-semitrailer traversing a bump during the field tests and the simulation analysis.

Figure 3. Tractor / Tank-semitrailer Combination Traversing a Bump.

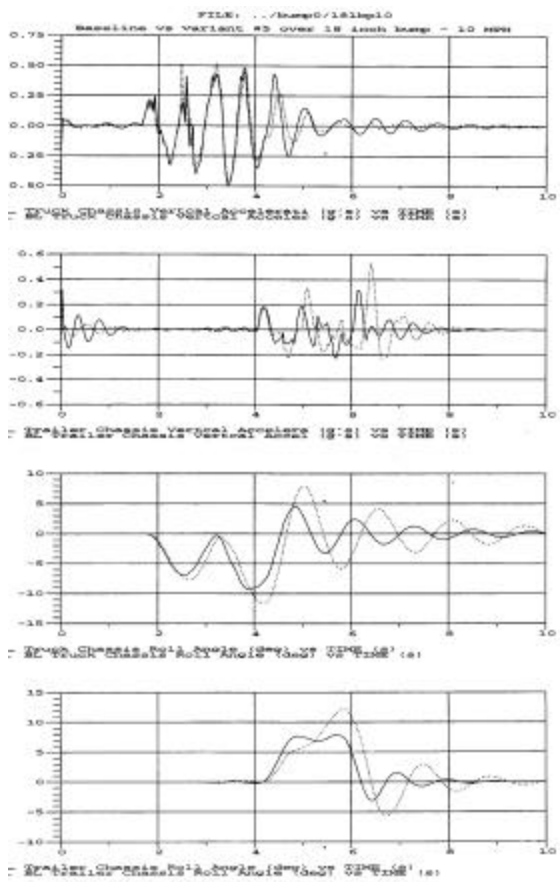

Figure 4. Overlay Plots of Field Test Vs Simulation Data Traversing a Bump.

The combination traversed the 6 inch ramps up to 25 MPH at which time the tests were stopped. The tank-semitrailer experienced roll instabilities and de-stabilized considerably as the speeds approached 30 MPH. The system traversed the 12 and 18 inch ramps at speeds up to 15 and 7.5 MPH, respectively. Higher speeds were not attempted during tests due to interference problems between the tank-semitrailer and the obstacles. No noticeable tractor instabilities were observed due to the relatively slow speeds. The intent of these tests was not to determine the rollover thresholds of the system, but to provide adequate inputs in the system for model validation efforts. Sample overlay plots of the tractor and tanker chassis vertical accelerations and roll angles are shown in Figure 4. The results of the correlation studies show that the average standard deviation of percent error (%Esd) per channel is about 9 percent on all channel comparisons across all bumps. The maximum absolute value percent error (|%E|) for each channel ranges from 8 to 16 percent. Examination of the overlay plots shows that

in most cases the response curves were replicated in a consistent manner with the field test measurements.

Pothole Course Comparisons and Correlation

Comparisons were made between the DADS simulation data and the field test data for vehicle speeds varying from 2.5 (IDLE) to 25 MPH and pothole depths of 6, 9 and 12 inches. Figure 5 shows examples of the tank-semitrailer traversing a pothole during the simulation analysis.

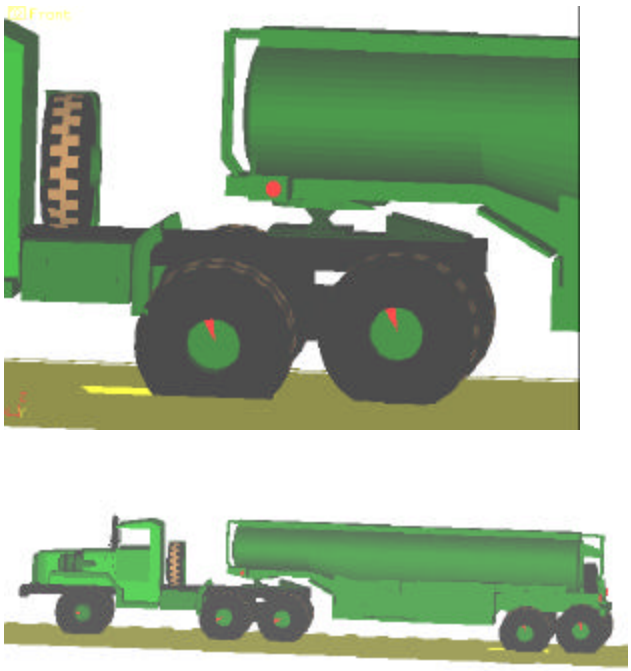

Figure 5. Tractor / Tank-semitrailer Combination Traversing a Virtual Pothole.

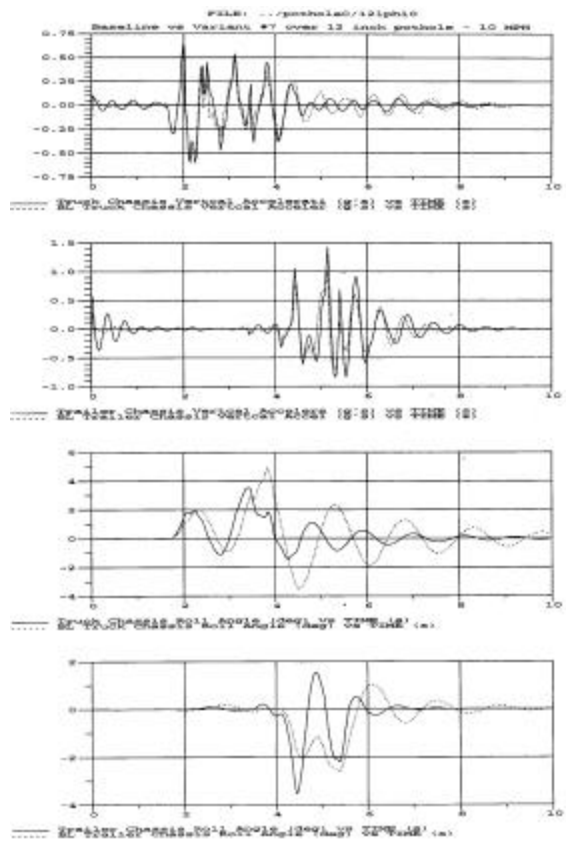

Figure 6. Overlay Plots of Field Test Vs Simulation Data Traversing a Pothole.

The tractor/tank-semitrailer combination traversed the 6, 9, and 12 inch holes at speeds up to 25, 15, and 2.5 MPH, respectively, at which time the tests were stopped due to vehicle interference or perceived instabilities. The tank-semitrailer experienced some roll instabilities at the slower speeds and stabilized considerably as speeds increased. As the speeds increased, the left tires were increasingly unable to drop to the bottom of the hole, and consequently, hit the opposite side of the hole very hard. This could result in vehicle damage. Higher speeds were not attempted due to interference problems between the tank-semitrailer and the hole or because some stability and handling instabilities occurred. Sample overlay plots of the tractor and tanker vertical accelerations and roll angles are shown in figure 6. The results of the correlation studies show that the average standard deviation of percent error (%Esd) per channel is about 3 percent on all channel comparisons across all potholes. The maximum absolute value percent error (|%E|) for each channel ranges from 2 to 17 percent. Examination of the overlay plots

shows that in most cases the response curves were replicated in a consistent manner with the field test measurements.

Slalom Course Comparisons and Correlation

Comparisons were made between the DADS simulation results and the field test data for vehicle speeds varying from 10 to 45 MPH. Figure 7 shows examples of the tractor/tank-semitrailer combination traversing a slalom course at 20 MPH, during the field-validation tests and the simulation analysis.

Figure 7. Tractor / Tank-semitrailer Combination Traversing a Field Slalom.

The tank-semitrailer had little difficulty traversing the course up to 35 MPH. From 40 MPH and higher, there was some excessive sliding as the combination maneuvered from one lane to another. Sample overlay plots of the tractor and tanker vertical accelerations and roll angles are shown in figure 8. The results of the correlation studies show that the average standard deviation of percent error (%Esd) per channel is about 12 percent on all channel comparisons across all slalom maneuvers. The maximum absolute value percent error (|%E|) for each channel ranges from 2 to 17 percent. The errors on these comparisons tend to run somewhat higher than the bumps and pothole correlations. This is attributable to the errors introduced into the simulations by the simplified steering and tire models which come into play in much greater way in the slalom courses. Examination of the overlay plots shows that in most cases the response curves were replicated in a consistent manner with the field test measurements. The magnitudes and signal shapes were reproduced

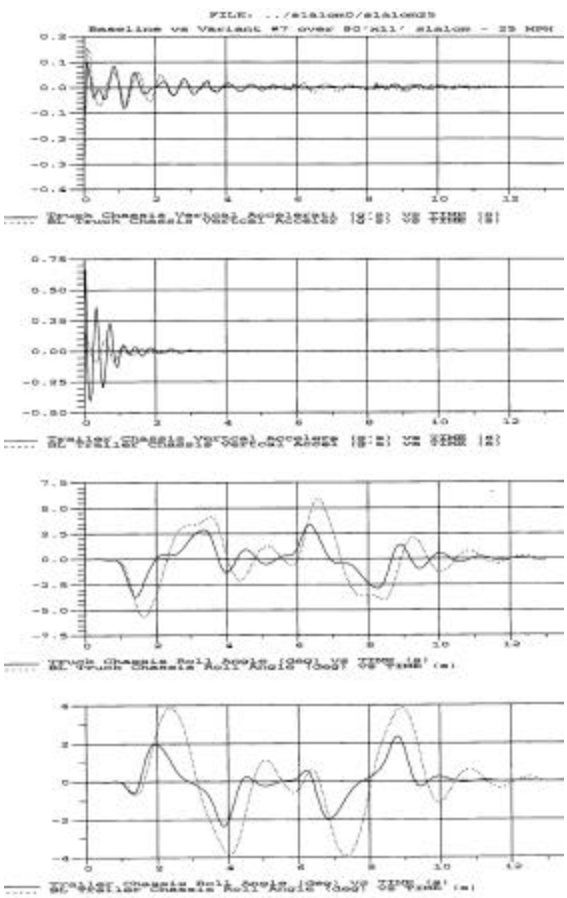

Figure 8. Overlay Plots of Field Test Vs Simulation Data Traversing a Slalom

well throughout the slalom course runs at all speeds.

1.34”, 1.79”, and 3.42” RMS Course Comparisons and Correlation

Comparisons were made between the DADS simulation data and the field test data for vehicle speeds varying from 5 to 15 MPH, 2.5 to 10 MPH, and 2.5 to 7.5 MPH on the 1.34”, 1.79”, and the 3.42” RMS courses, respectively. Figure 9 show examples of the tractor traversing the 3.42 inch RMS course at 10 MPH.

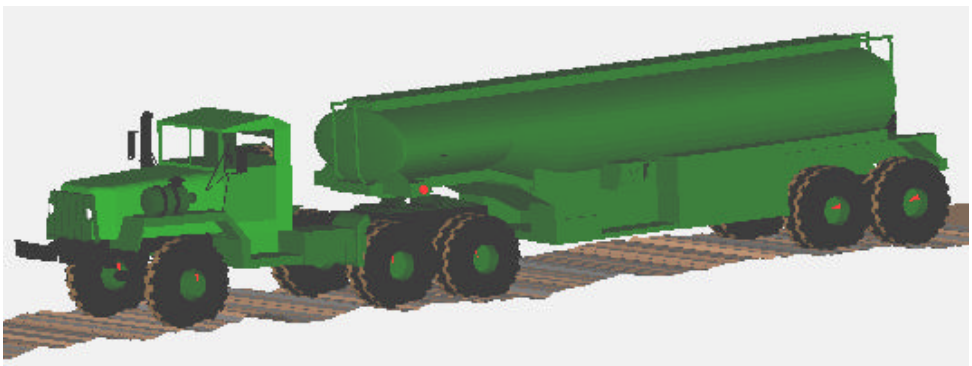

Figure 9. Tractor/Tank-semitrailer Combination Traversing a 3.42” RMS DADS Course.

The system had much difficulty traversing this course at speeds above 5 MPH due to some excessive bouncing and sliding. Sample overlay plots of the tractor and tanker vertical accelerations and roll angles are shown in figure 10. Although good correlation between the RMS course simulations and field tests were observed, they were not used in the error calculations due to the difficulties in synchronizing the trajectories and speed transients. The results of the comparison studies show very good correlation between the field-test and simulation signals, matching the amplitude and width of the pulses extremely well on all channels across all maneuvers.

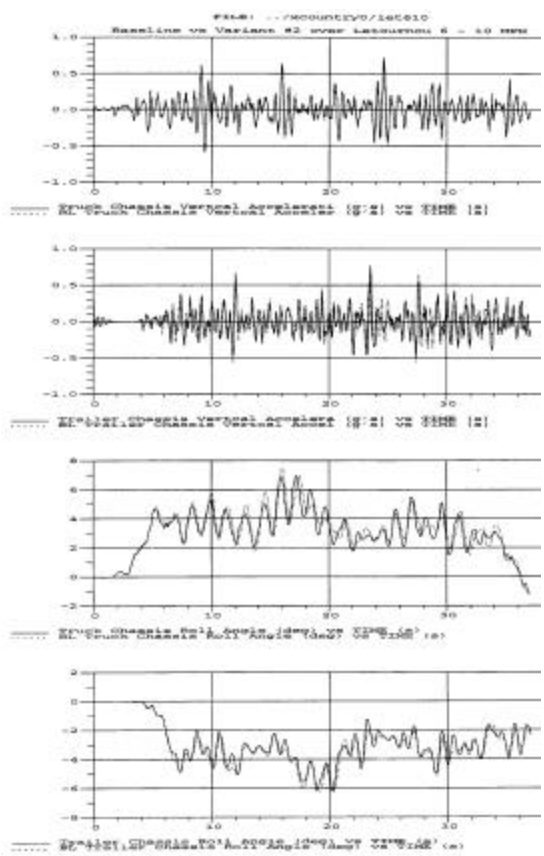

Figure 10. Overlay Plots of Field Test

Results

The average results for all the simulations and field test comparisons are tabulated and

summarized in Table 2 for the bumps, potholes, and slalom maneuvers. RMS course simulations and field tests correlations were not used in the error calculations due to the difficulties in synchronizing the course profiles, initial conditions, speed transients, brake torque application times, vehicle slew rates, and road surface coefficients throughout the constantly changing RMS maneuvers. A legend is provided below the Averages chart that briefly describes how the average percent error (%Eavg), average absolute value of percent error (|%E|avg) and standard deviation of percent error (%Esd) were calculated. The %E values in the table were calculated for all 27 runs for each channel of data.

Table 2. Average Values For All Bump, Pothole, and Slalom Simulations.

CH#	CHANNEL NAME	%Eavg	|%E|avg	%Esd
1	Truck Axle 1 left vert. displacement	-0.1	4.8	7.7
2	Truck Axle 1 left vert. acceleration	0.0	3.1	6.8
3	Truck Axle 2 left vert. displacement	0.1	5.2	8.8
4	Truck Axle 2 left vert. acceleration	0.0	3.3	7.2
5	Truck Axle 3 left vert. displacement	0.0	4.7	9.3
6	Truck Axle 3 left vert. acceleration	0.0	3.6	7.1
7	Tanker Axle 1 left vert. displacement	-0.3	6.9	13.0
8	Tanker Axle 1 left vert. acceleration	0.0	1.7	4.6
9	Tanker Axle 2 left vert. displacement	0.0	5.9	12.4
10	Tanker Axle 2 left vert. acceleration	0.0	5.4	9.1
11	Truck Chassis Pitch Rate	0.1	9.0	13.7
12	Truck Chassis Roll Rate	-0.1	8.7	13.5
13	Truck Chassis Yaw Rate	0.2	10.9	15.8
14	Tanker Chassis Pitch Rate	-0.1	7.8	14.2
15	Tanker Chassis Roll Rate	0.1	7.1	12.9
16	Tanker Chassis Yaw Rate	0.2	10.0	15.5
17	Truck Chassis X acceleration	0.0	10.4	15.8
18	Truck Chassis Y acceleration	-0.1	5.0	8.8
19	Truck Chassis Z acceleration	0.1	6.8	10.8
20	Tanker Chassis pitch rate	-0.1	7.5	13.6
21	Tanker Chassis roll rate	0.0	9.8	14.7
22	Tanker Chassis yaw rate	-0.2	8.7	14.3

%Eavg = average percent error, |%E|avg = average absolute value of percent error, %Esdv = standard deviation of percent error, %E=100*(field data-simulation data)/(field data maximum-field data minimum)

The final complete averages indicate that the model results produce an average of about 8% error per channel of data with an average standard deviation of approximately 13% per channel. Some of the channels correlate extremely well over the wide range of tests conducted and other channels do not. There are many ways to interpret these numbers and it is very undesirable to put a single number on such a large array of comparisons between simulations and tests, especially when there is so much room for potential errors. Better correlations could have been achieved if only the displacements had been compared, instead of lumping comparisons between all of the signals together. The largest errors were present in much of the acceleration and rate gyro field data due to road noise and structural ringing. In addition, it is assumed that all field test data collected were correct and were used as a baseline for comparison with the simulation data. Examination of the field test data clearly shows that there are errors in some of the field measurements. For instance signal drifts, noise and signal losses, and malfunctioning instruments may have significantly affected the results shown in the table. In addition,

instruments may have been installed incorrectly during the field tests and could have given erroneous results. Lastly, recording of the exact locations of the instruments (in 3 dimensions) may have been in error. Exact dimensions are crucial in the simulations. The analytical representation of instruments must be in the exact locations as the field instruments so their output quantities can be compared on a one-to-one basis.

A secondary objective was to more closely approximate the field test results by performing a number of parameter and design sensitivity studies using parameter estimation techniques. After an extensive set of parameter and design studies, better correlations between the simulation results and the field tests results were achieved due to errors in modeling some of the payload placements and suspension components. Numerous iterations were conducted until the simulation results were within acceptable ranges when compared to the field test results. Exact correlation, or close to it, was unachievable due partly to errors introduced into the model results by the use of simplified tire, powertrain, and steering models. These oversimplified models could have led to 20 percent or more error in response to predictions for various critical on and off-road assessments such as mobility, roll and steering stability, and obstacle negotiation. Therefore, it was concluded that further attempts to improve correlation between the data sets by refining the models parameters would be futile until better subsystem models are developed.

Conclusions/Recommendations

The results of the correlation analysis show that the analytical simulation tractor/ tank-semitrailer (empty) model is **adequate** for predicting proper system response and stability under normal operating conditions which do not demand highly accurate steering and powertrain inputs. Tankers have relatively high center's of gravity (cg) which can shift considerably due to the liquid sloshing actions. This combination of elevated cg and transient inertial force loads due to the shifting load can induce rollovers at much lower speeds than normal. It must be emphasized that the results of these simulations do not include any of the combined heavy tactical vehicle/liquid sloshing dynamics, but assume that all containers are completely empty, and the resulting mass and inertias of those empty containers were utilized for this analysis. Assuming that the empty and fully loaded tankers are probably best-case scenarios, the situation could only deteriorate and worsen as liquids are added/removed, and any remaining liquids are allowed to slosh around unimpeded in the tank. As road dynamics are introduced in the system, the sloshing liquids and subsequent shifting cgs will most likely act to destabilize this combination, especially during lateral maneuvers, braking, large obstacles, and obstacle avoidance situations. During off-road maneuvers the degradation in stability is less pronounced, most likely due to the reduced speeds. The small jounce clearance on the front axle of the tank-semitrailer and the limited wheel travel induces excessive pitch and roll motion on obstacles and cross country terrains at speeds above 40 MPH. Improvements in these areas could improve obstacle and cross-country negotiation of the tank-semitrailer significantly. With a 5,000 gallon payload, the structural integrity of many of the subsystem components clearly need to be investigated as dynamic loads are introduced into the system. Component failures induced by excessive use could result in premature system failures. Hence, it is recommended that the speeds of the be restricted to 40 MPH on-road and 10-15 MPH off-road, and even less for more severe mission profiles and extremely rough terrains. Logic would suggest that worst-case configurations will be present when tanker volumes are at 1/2 to 2/3 of the tanker's capacity. Consequently, shifting cg loads will produce progressively worse performance depending on

mission specific external forces acting on the system and resultant internal forces that control system stability, handling, and performance.

Other Case Studies

Recently, during source selection activities on the Army and Marine Corps Medium Tactical Truck Remanufacture (MTTR) program, TARDEC-NAC used high-resolution, computer-based models to assist in assessing and evaluating the performance of new vehicle designs submitted in response to a formal solicitation. Prior to the source selection process, engineers used M&S to establish and define desired performance and handling characteristics. Representative models of each bidders' concepts were developed based on contractor supplied data, and then used to evaluate the performance of the newly designed systems to insure compliance with RFP mandated performance requirements (Figure 11).

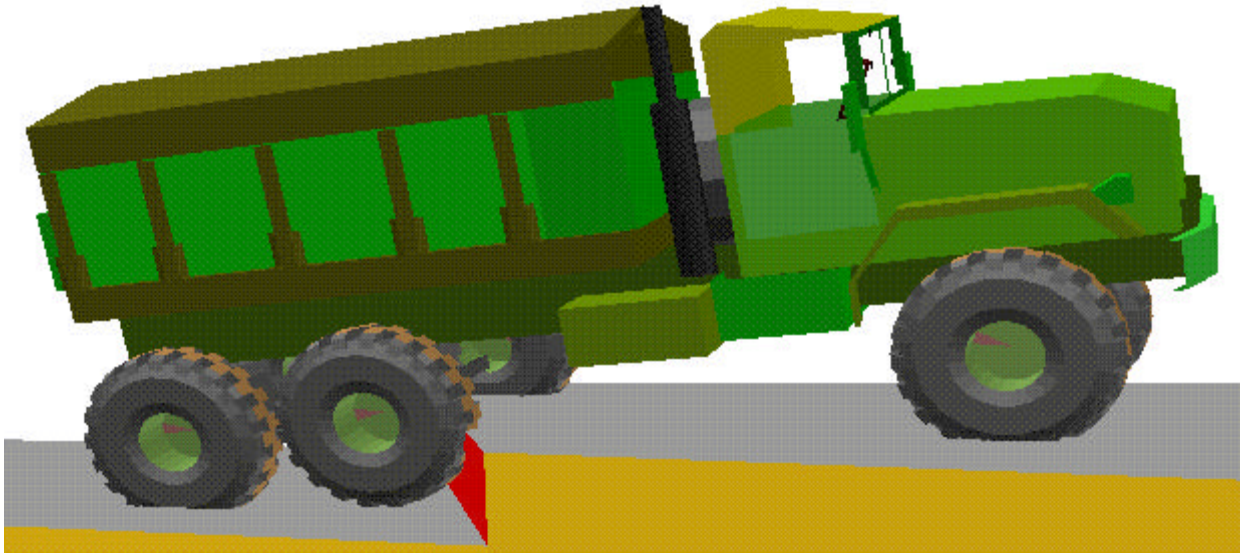

Figure 11. MTTR Vehicle Designs Being Evaluated On The Virtual Proving Ground.

In support of the Program Executive Officer-Armored Systems Modernization (PEO-ASM), TARDEC-NAC developed models of an Improved Recovery Vehicle towing an M1 Tank (Figure 12), intended primarily to evaluate various towbar designs and external braking mechanisms. Engineers applied models to assess traction devices designed to enhance pulling and braking capability, augment field tests, and facilitate vehicle modifications.

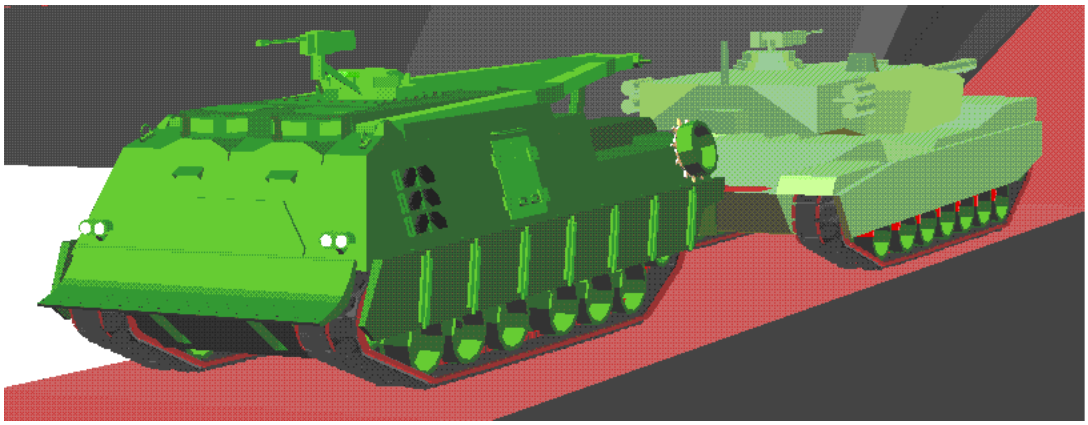

Figure 12. Field systems being evaluated on the virtual proving ground.

An effort was initiated to develop and evaluate concepts to explore alternative uses for the Palletized Load System (PLS). Designers were tasked to determine and develop viable alternatives to be used with the PLS to include volume water and fuel transportation as well as specialized combat engineer missions. TARDEC-NAC used M&S to evaluate the stability and handling characteristics of the PLS Truck / Trailer combination (Figure 13) while transporting newly designed PLS variant payloads.

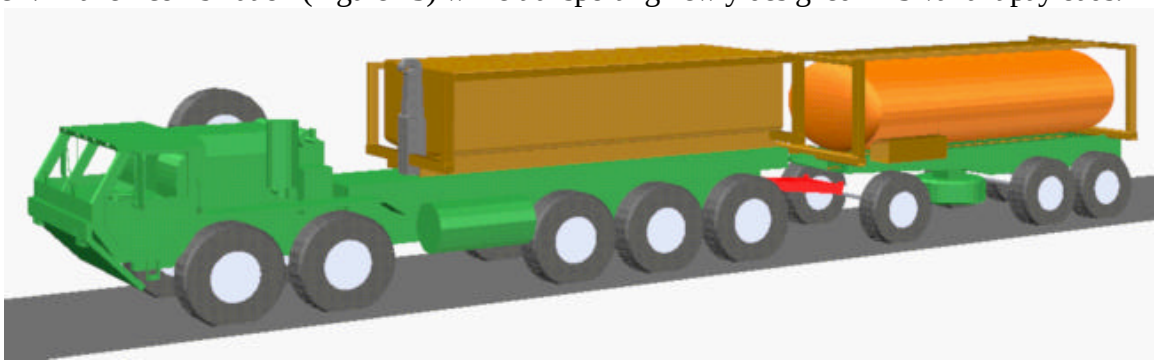

Figure 13. Evaluating PLS/PLST Performance With Alternative Loads.

Analytical models can be further employed to assist TACOM-TARDEC engineers in assessing the feasibility of towing trailing-units behind various prime movers. Virtual assessments of a prime mover/trailing units' stability and handling characteristics and overall system performance can be investigated prior to field-testing and implementation. Vehicle models can be upgraded as dictated by product improvements, configuration management changes, and varying payload configurations to assess the performance of the systems throughout their useful life, and, subsequently, are utilized by TARDEC-NAC to help in the selection of performance requirements for replacement vehicles. Engineers were asked to develop and verify models of a 5-Ton Truck towing a 155 mm howitzer (Figure 14) for the purpose of investigating truck/howitzer dynamic stability while negotiating specially designed on-road braking maneuvers over a range of vehicle speeds. The follow-on analysis was also intended to determine what influences the 8-ton+ howitzer has on the stability of the truck during braking maneuvers when the truck is operating in an unloaded condition.

Figure 14. Evaluating Towed-load Effects on Prime Movers.

Acquisition reform encourages vehicle developers to utilize MS wherever possible on new vehicle system programs to save time and costs when feasible. Wheeled and tracked vehicle systems must be capable of operating on the virtual proving ground and in synthetic environments for testing, training, design and trouble shooting evaluations. Computer generated forces (CGF) are becoming increasingly important in distributed battlefield simulation, and the task of representing their behavior has gained commensurate interest as a research topic. Drawing on simulation, limited field testing and vehicle characterization, TACOM-TARDEC engineers are attempting to reproduce ground vehicle behavior that is both autonomous and more realistic. Figure 15 shows a fully three-dimensional M2A3 Bradley Model that was created using an in-house-developed equation generation methodology. The model was developed to provide dynamic feedback to driver and crew during soldier-in-the-loop physical simulation.

Figure 15. Virtual Prototyping of the Bradley Vehicle.

References

1.) "Computer-based Model Verification of 5-ton Truck/Tank-semitrailer Combination", Dominic Salafia, Yuma Proving Grounds, Test Record # RS-EL-A-3-96, November 1999.

2.) Dynamic Analysis and Design Systems, Computer Aided Design Software, Inc., PO Box 203, Qakdale, Iowa 52319.