Cosimulation of an Automotive Control System using ADAMS and Xmath

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Abstract

Increasing use of automotive control systems which affect vehicle dynamic behavior has prompted the need for a more effective method of analyzing control systems coupled to detailed ADAMS vehicle models. Typically, vehicle models are simplified in the controls arena and control systems are simplified in the vehicle dynamics arena. Cosimulation provides a more complete representation of control system and vehicle by selectively using the strengths of each application. Rapid iteration of the control system and insight into its effects on vehicle dynamics are achieved by a wider user base.

This paper describes how ADAMS/Controls and Xmath are used to simulate a Vehicle Attitude Control (VAC) system requiring 300 states to represent the vehicle model in ADAMS and 30 states to represent the control system in Xmath. Xmath users make changes to the control system and initiate simulations from the familiar Systembuild environment. Accurate modeling of a fixed frame controller in the discrete time domain is made possible in this cosimulation environment. Interface bandwidth issues between ADAMS and Xmath applications are explored.

Cosimulation results are compared to modeling the entire system in ADAMS using the ADAMS Data Set. Line over line correlation between the two methods is achieved when differences in controller evaluation are taken into account. Simulation times of both methods are discussed.

Finally, predicted results using cosimulation are compared with actual vehicle data.

Introduction

ALTERNATIVES TO COSIMULATION

Generally, two approaches have been used to simulate complex control systems and vehicle models within the ADAMS environment. The first approach is to write the control system algorithm and plant in the ADAMS data set, simulating it along with the vehicle model in ADAMS. This method is tedious, prone to error, and prevents accurate modeling of a discrete control system. The second approach is to write or autocode the control system and plant in C language linking this code to ADAMS for execution by the ADAMS solver. While this method is more automated, simulation run times can become excessively long for stiff systems since the integration step size for the entire model must be set to accommodate the fastest dynamics in the system. This approach also prevents modeling the controller at a fixed loop time. The increase in automotive control systems which affect vehicle dynamic behavior such as Antilock Brake Systems (ABS), Interactive Vehicle Dynamics (IVD), and Vehicle Attitude Control (VAC) has prompted the need for a more effective method of analyzing control systems coupled to detailed ADAMS vehicle models. Cosimulation addresses this need.

GOALS OF COSIMULATION

The cosimulation tool seeks to preserve the user interface already established for the individual ADAMS and Xmath applications. This makes ADAMS vehicle models and Xmath control system models available to a larger user base. Vehicle models approximated in Xmath can now be replaced by more accurate ADAMS models which undergo years of development and validation. The advantages of using ADAMS models are available to Xmath users through the Xmath interface. Fixed frame control loops are generally not available in an ADAMS model. However, with the control system modeled in Xmath, a true discrete control algorithm and control system can be modeled.

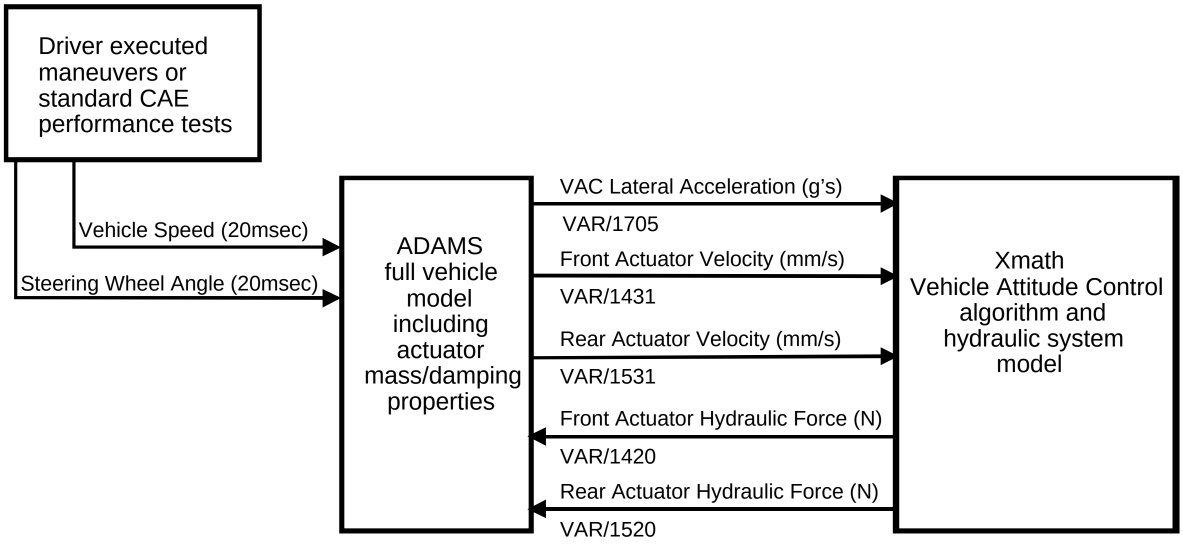
Cosimulation of a Complex ADAMS/Xmath Model

DESCRIPTION OF COSIMULATION

Cosimulation uses ADAMS and Xmath creating an interface for variables to be passed across control system and vehicle boundaries. As shown in figure 1, Xmath initiates the session by commanding the ADAMS model to statically simulate (achieve static equilibrium) and execute the first integration time step. During this time, variables passed to the ADAMS model are set to initial condition values. Once ADAMS has completed the first integration time step, Xmath uses the outputs passed from ADAMS to calculate solutions at its first time step. Once Xmath completes its first time step, it commands ADAMS to integrate to the next time step. The process repeats itself in a serial fashion until the simulation is completed.

Vehicle Attitude Control

Cosimulation Environment



Step 1: Xmath initalizes the VAC model and initiates the simulation session.
Step 2: Xmath calls on ADAMS to perform a static simulation and then simulate to the first time step using initial condition values in lieu of interface input variables from Xmath.
Step 3: Xmath simulates to the first time step using the output generated by the ADAMS model and then passes its output results to ADAMS for use during integration to the next time step.
Step 4: Xmath calls on ADAMS to simulate to next time step until the simulation is complete.

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Xmath hosts the simulation session and proceeds at a fixed integration step. However, based on parameter behavior in both ADAMS and Xmath models, evaluation of the

ADAMS model may not occur at each time step. This strategy yields a reduction in simulation time when applied to the VAC simulation problem.

Vehicle simulation of the VAC system is driven by steering wheel and vehicle speed data taken from maneuvers conducted by a professional driver. The ADAMS vehicle model responds to these inputs and generates a vehicle lateral acceleration which is passed over to Xmath as an input to the control system. Based on lateral acceleration, the controller commands hydraulic pressure and the control system plant generates actuator forces. These actuator forces are passed back to the ADAMS model and applied to the vehicle to control vehicle attitude.

GETTING STARTED

It is helpful to model in Xmath the entire cosimulation environment (including control system, simplified vehicle model, and interface) prior to running cosimulation with ADAMS. Delays in the interface between vehicle and control system can be created to help understand key dynamics in vehicle, control system, and interface. This approach provides the opportunity to determine the minimum number of signals and the lowest possible bandwidth which will support the dynamics in the vehicle and control system models. The bandwidth and number of signals sent across the interface should be minimized since these properties significantly affect simulation time.

COSIMULATION BANDWIDTHS

Three dynamics of particular importance to cosimulation are:

- the fastest dynamics in Xmath
- the fastest dynamics in ADAMS
- the fastest dynamics of the loop being closed across interface.

These dynamics define how the integrators in each application respond as well as how tightly coupled the Xmath and ADAMS models will be. For a fixed step interface, the interface step size is chosen to support both the fastest dynamics in ADAMS and the fastest dynamics of any loops being closed across the interface. Even though these dynamics may only occasionally be active, this small step size will be used over the entire simulation. If a variable step integrator is chosen, the Xmath model will be evaluated at the interface step size or smaller as Xmath model dynamics dictate.

For the VAC system, three dynamics of importance are:

- the compressibility of hydraulic fluid in Xmath (24Khz bandwidth)
- the actuator mass/spring/damper system in ADAMS (680 Hz bandwidth)
- the actuator velocity used in flow equations across the interface (680 Hz bandwidth)

The variable step integrator used in Xmath will determine the appropriate step size for dynamics associated with the compressibility of hydraulic fluid. The fastest dynamics in

ADAMS and the fastest dynamics across the interface are both related to the hydraulic actuator for the VAC system. To provide sampling of 10 times these dynamics, an interface step size of 1.25e-4 seconds was chosen. This small step size makes simulations of eight second maneuvers take 3.5 hours to run. An improvement beyond the fixed step interface between ADAMS and Xmath was pursued.

VARIABLE STEP INTERFACE

The variable step interface was developed to improve simulation times in cases where combining the control system with the vehicle creates a stiff system. This interface is especially beneficial when the vehicle model in ADAMS is larger and possesses slower dynamics than the control system model which is principally modeled in Xmath. This is the case for the VAC system, where the vehicle model alone contains 300 states and will integrate at an output step size of 1.0e-2 seconds. While the control system model contains 30 states and integrates at an output step size of 1.25e-4 seconds. The strategy applied to the variable step interface is to evaluate the slower and larger ADAMS model as infrequently as possible while allowing the smaller Xmath model to be evaluated more frequently to track faster dynamics.

COMPARISON OF SIMULATION RUN TIMES

To compare performance of a VAC model entirely in ADAMS and cosimulation, a standard simulation was conducted on an SGI Octane with 64 bit operating system. A comparison of simulation run times is shown in table 1 below.

Run	Method	Output Time Step	Run Time
1	ADAMS Only	0.001 seconds	435 seconds
2	ADAMS Only	1.25e-4 seconds	2245 seconds
3	Cosimulation - Fixed Step	1.25e-4 seconds	2335 seconds
4	Cosimulation - Variable Step	1.25e-4 to 1.0e-3 seconds	1945 seconds

Table 1

Run 1 models the VAC system in ADAMS (includes all control system dynamics) with an output time step chosen to provide sufficient resolution for data analysis. This is the most computationally efficient run since the integrator steps down to smaller step sizes only as model dynamics require.

Run 2 is shown for comparison to cosimulation which requires an interface time step of 1.25e-4 seconds. Since the time step is forced to be small over the entire run, regardless of model dynamics, simulation times are significantly longer.

Run 3 uses cosimulation with a fixed step interface set to 1.25e-4 seconds. Passing variables across the interface and separately evaluating models in Xmath and ADAMS increases simulation run time by only 4% when compared to run 2. However, simulation run time is over 5 times greater than run 1. Again, since the time step is forced to be small over the entire run, regardless of model dynamics, simulation times are significantly longer.

Run 4 uses cosimulation with a variable step interface. Interface step size is allowed to vary between 1.25e-4 seconds and 1.0e-3 seconds based on parameter behavior in both ADAMS and Xmath models. A 17% reduction in simulation run time is achieved compared to run 3.

Comparison of Cosimulation to “ADAMS Only” Method

Fortunately an “ADAMS Only” model containing the vehicle, control system plant, and control algorithm was available for use in validating the cosimulation tool. Insistence on line over line correlation of outputs improved both the cosimulation tool and model fidelity. For the “ADAMS Only” method, the ADAMS integrator evaluates the controller and entire model as necessary to support a continuous time simulation. This prevents modeling the controller as a fixed frame discrete time system. As a result, time delays associated with a fixed frame controller are not represented and the controller is evaluated at an inconsistent time step. So that cosimulation results could be compared directly to the “ADAMS Only” method, the controller in cosimulation was set to a loop time small enough to simulate the continuous controller running under the “ADAMS Only” method.

CORRELATION OF METHODS

Figure 2 shows that identical steering wheel angle inputs were used to drive both cosimulation and “ADAMS Only” methods.

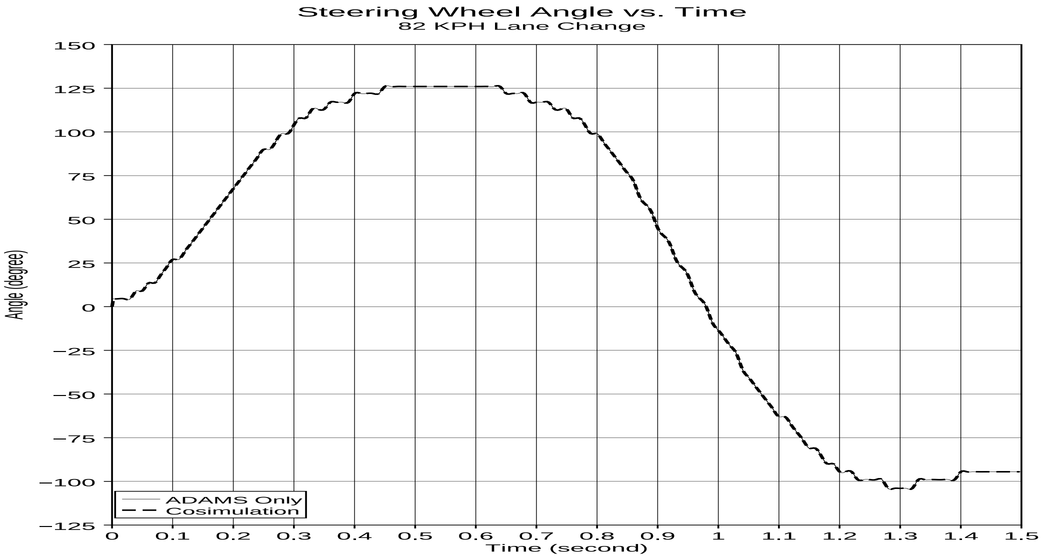

Figure 2

Precise tracking of vehicle lateral displacement confirms equivalent execution of the steering system, tires, and suspension system in the vehicle model. Not shown in figure 3, but indicated by like vehicle lateral displacements, is the correlation of vehicle lateral acceleration which is used as an input to the VAC controller.

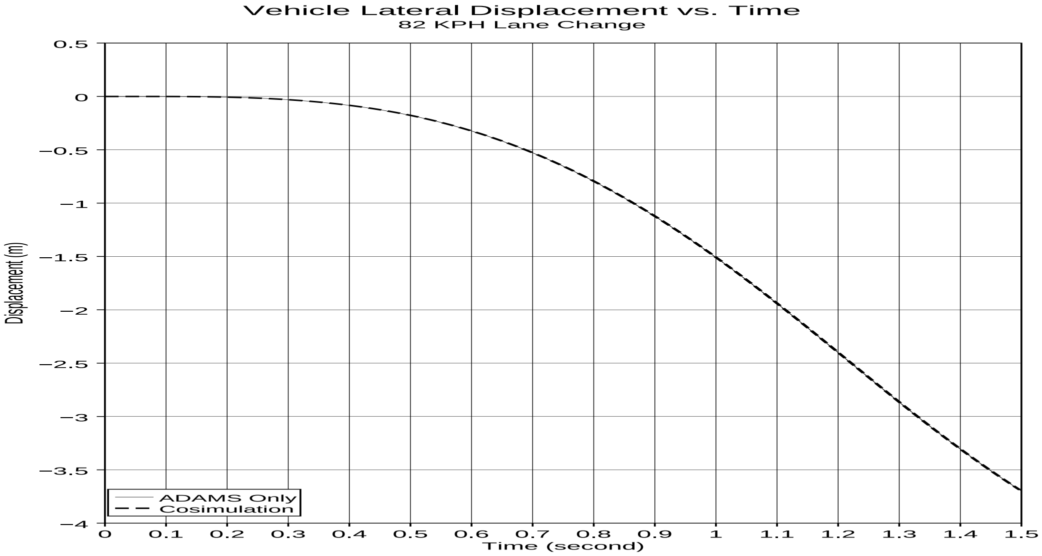

Figure 3

Figure 4 shows correlation of commanded system hydraulic pressure validating like execution of controller logic by both methods.

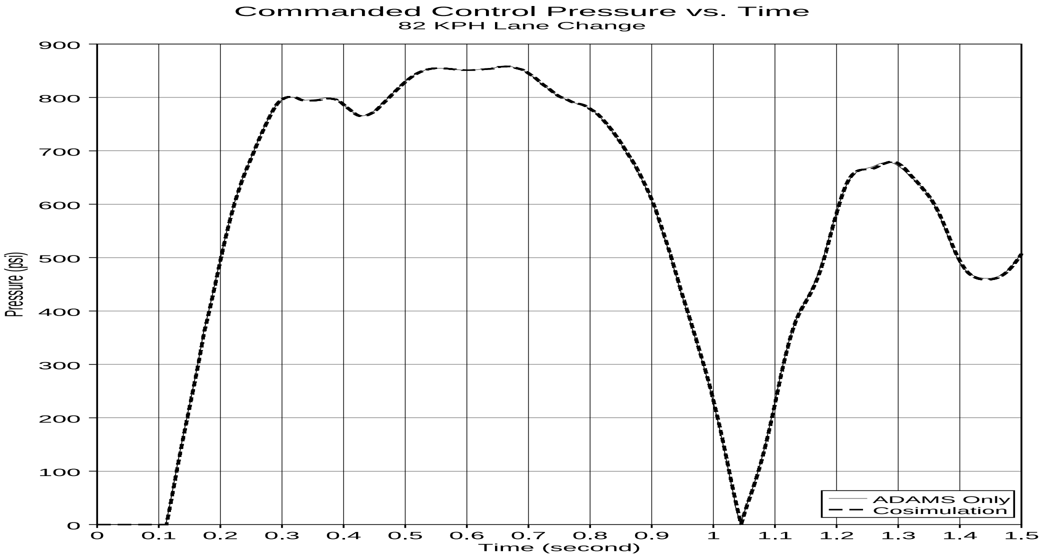

Figure 4

Figure 5 illustrates equivalent evaluation of the control system hydraulic plant by both cosimulation and "ADAMS Only" methods.

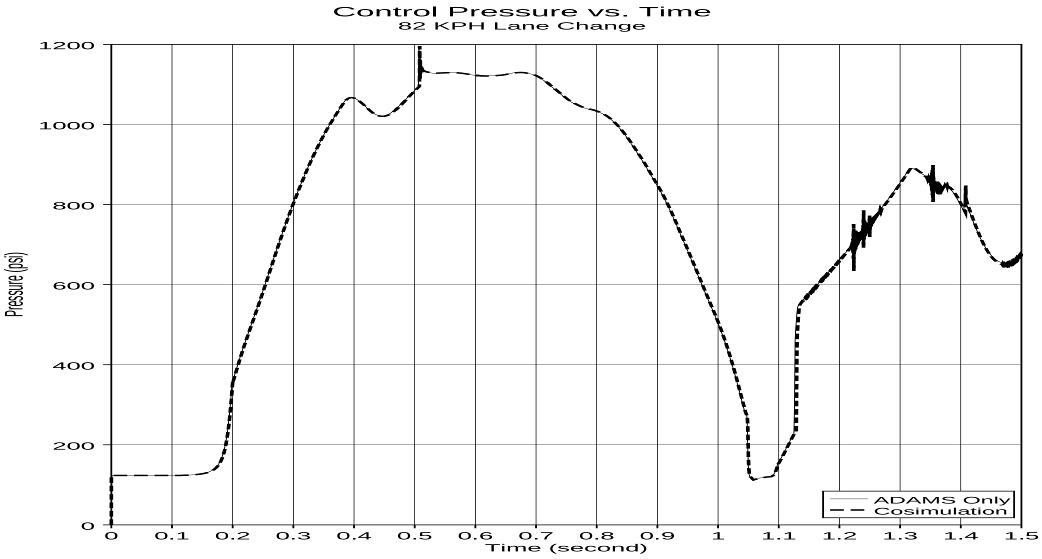

Figure 5

The comparison of vehicle attitude angle shown in figure 6 is the "acid test" in correlating cosimulation to the "ADAMS only" method. Cumulative errors in evaluating vehicle and control system transfer functions would prevent a consistent prediction of vehicle attitude by both methods.

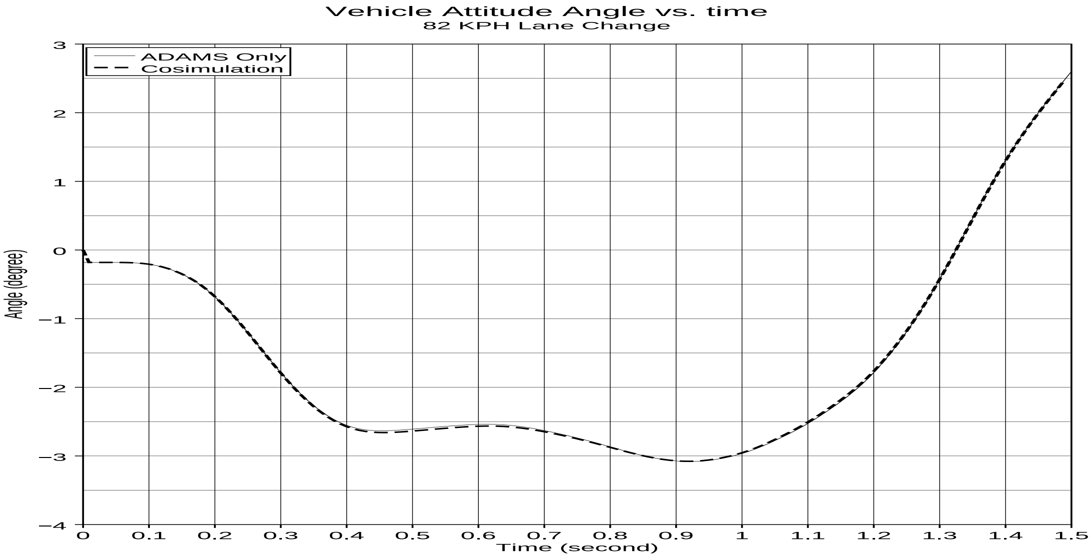

Figure 6

Comparison of Predicted Results to Actual Vehicle Data

Vehicle and control system data were collected from an aggressive lane change maneuver performed by a professional driver. Simulation of the VAC system uses some of these data (steering wheel and vehicle speed) to drive the ADAMS vehicle model. The remaining data are used to compare actual vehicle performance to predicted values generated by cosimulation. The level of correlation shown in the traces below has been useful in supporting directional decisions during the design phase of the VAC system.

Steering wheel angle is used to drive the ADAMS model through a double lane change maneuver as shown in figure 7 below.

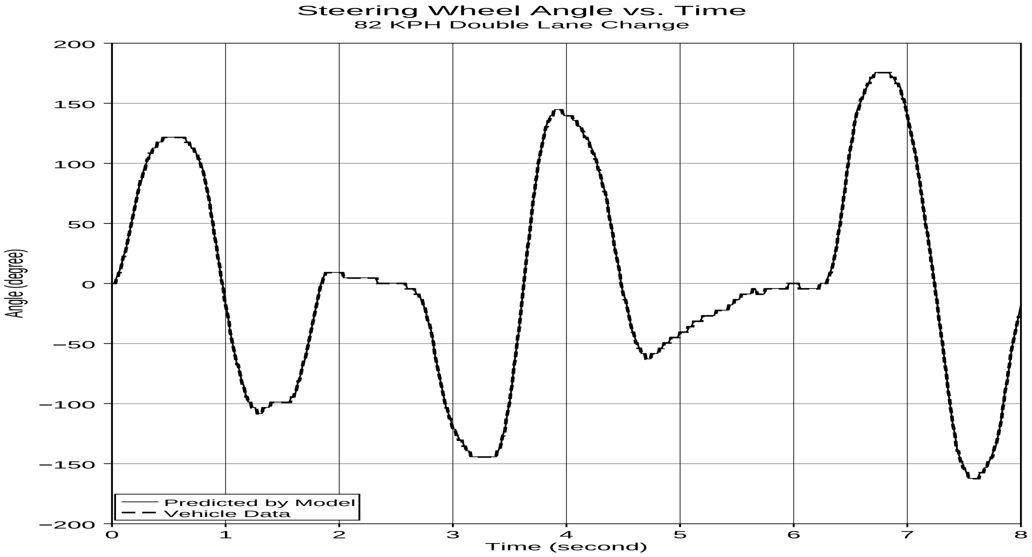

Figure 7

The comparison of vehicle lateral acceleration in figure 8 shows that predicted lateral acceleration falls short in amplitude when compared to measured data. The accelerations achieved in this maneuver are well beyond the linear range of tires and suspension causing predictive capability to erode as the handling limit is approached.

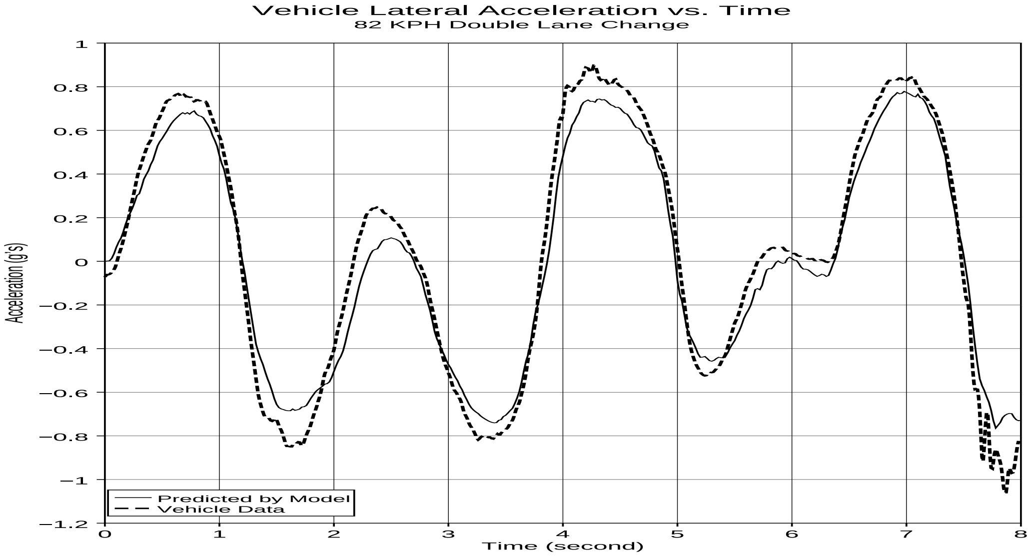

Figure 8

The model predicts a more responsive hydraulic plant than is actually measured. Prediction of pressure when dwelling in the lower pressure regime is consistently high.

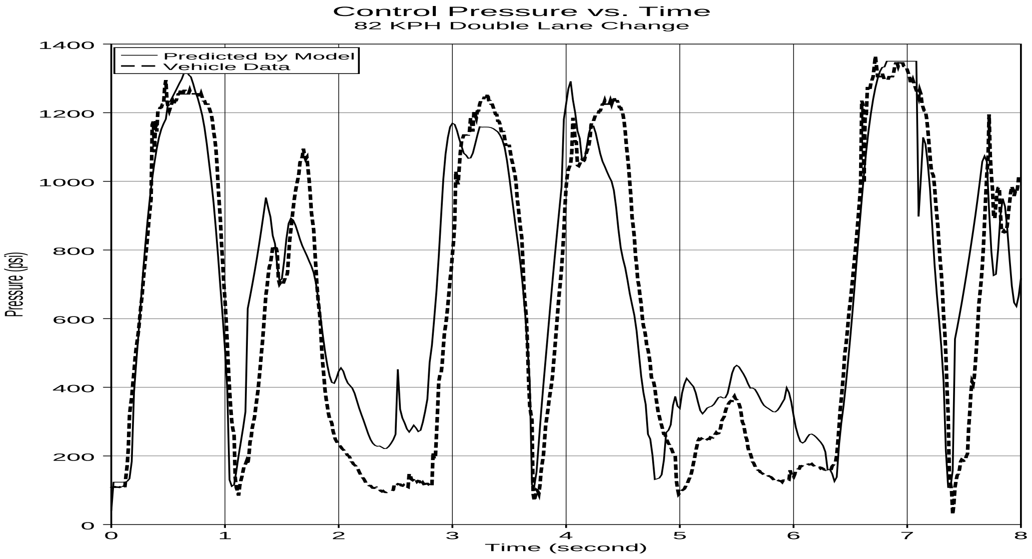

Figure 9

Prediction of vehicle attitude angle deviates from the measured attitude angle most when lateral acceleration exceeds 0.6 g. Examples of this can be found at 1.0 and 4.0 seconds. As lateral accelerations associated with the handling limit are approached, the predictive capability of the model begins to erode.

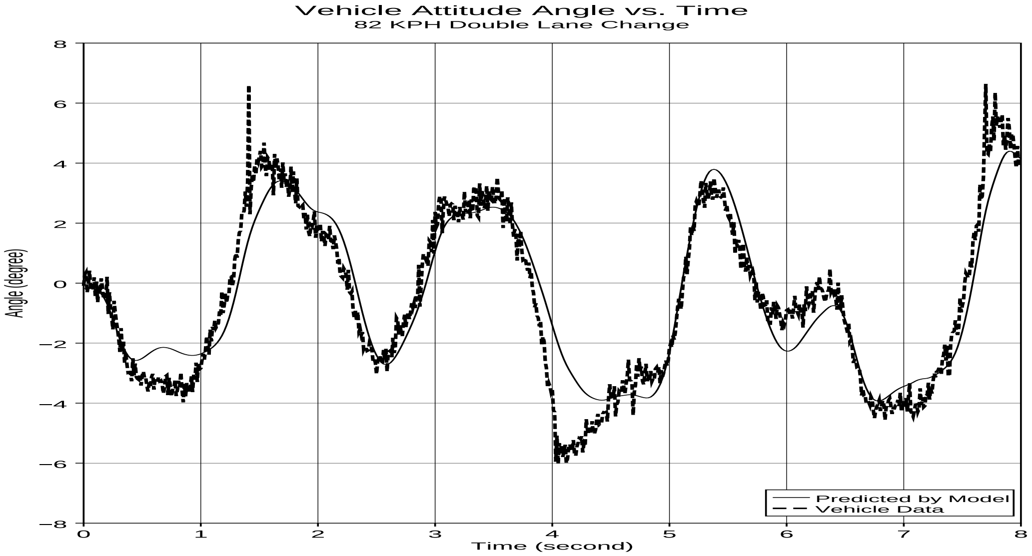

Figure 10

Conclusion

Cosimulation provides an effective method of analyzing control systems coupled to detailed ADAMS vehicle models. Cosimulation provides a more complete representation of control system and vehicle by selectively using the strengths of each application. An accurate model of a discrete control algorithm and control system is made possible through Xmath. Line over line correlation between cosimulation and the “ADAMS Only” method is achieved when differences in controller evaluation are taken into account. Cosimulation applies to complex models such as the VAC system with 300 vehicle states and 30 control system states. Longer cosimulation run times can be reduced by variable step interface techniques.

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