Flexible Vehicle Simulation
or
Modeling Vehicle Suspension Compliance at Ford Motor Co. Using a Coupling of ADAMS™ and MSC/NASTRAN™

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ABSTRACT

The Core Development Technology group at the Ford Motor Company is actively involved in correlating analytical (ADAMS) vehicle models with objective (telemetric) data from instrumented vehicles. In the past, vehicle compliances were introduced into the ADAMS model by using the ADAMS elements; TIREs, nonlinear BUSHINGs and BEAMs. With the advent of ADAMS/FEA™, a data translator which provides a two-way interface between ADAMS and MSC/NASTRAN, vehicle models may now include the effects of geometrically complex component stiffness and total body compliance in the ADAMS full vehicle simulation. This paper examines the effects of these added compliances on an ADAMS vehicle model by comparing the dynamic toe and camber angles of a vehicle with rigid upper and lower control arms to a vehicle with flexible upper and lower control arms built from MSC/NASTRAN data. The results demonstrate that complex problems can be very efficiently modeled and simulated by combining finite element analysis (MSC/NASTRAN) and mechanical system simulation (ADAMS) technologies.

I Introduction

At the Ford Motor Company, ADAMS is used to model vehicle components and system for a variety of purposes. Full vehicle models are used to study vehicle dynamics and chassis design effects on vehicle handling. In the Core Development Technology group at Ford, the Vehicle Dynamics New Methods C.A.E. section is analyzing vehicle dynamics, using an advanced data acquisition system and ADAMS vehicle models to correlate objective vehicle data with analytical model results. Part of the analytical model involves consideration of the vehicle body and suspension component compliances in addition to the tires and nonlinear bushings to determine their effect on vehicle handling. As an initial step, the rear suspension upper and lower control arms of a prototype vehicle design were modeled as compliant parts using MSC/NASTRAN and the ADAMS/FEA interface. The simulation maneuver consisted of a 60 mph double lane change maneuver to examine the component compliance effects of suspension geometry.

II Objective Data

Figure 1 displays the correlation system between the analytical (ADAMS) vehicle model and the objective (telemetry) data. Vehicle handling parameters are collected from an instrumented vehicle using the Precision Location data acquisition system (PLx). This system transmits all vehicle instrumentation data to a fixed base station and also tracks the position of the vehicle. The system's software provides a plot of vehicle path that is synchronized with the instrumentation data. This provides a method of verifying the driven vehicle path with the modeled vehicle path and allows detailed analysis of any portion of the maneuver. Additionally, the ADAMS vehicle models are capable of being "driven" using Plx vehicle data as input. Driver input data, such as steering wheel position and road wheel torque, from the actual vehicle test can be used as input to drive the ADAMS model through the maneuver. The model output is then compared against the desired output from the objective vehicle test.

NMCAE - VEHICLE DYNAMICS
OBJECTIVE / ANALYTICAL FLOW

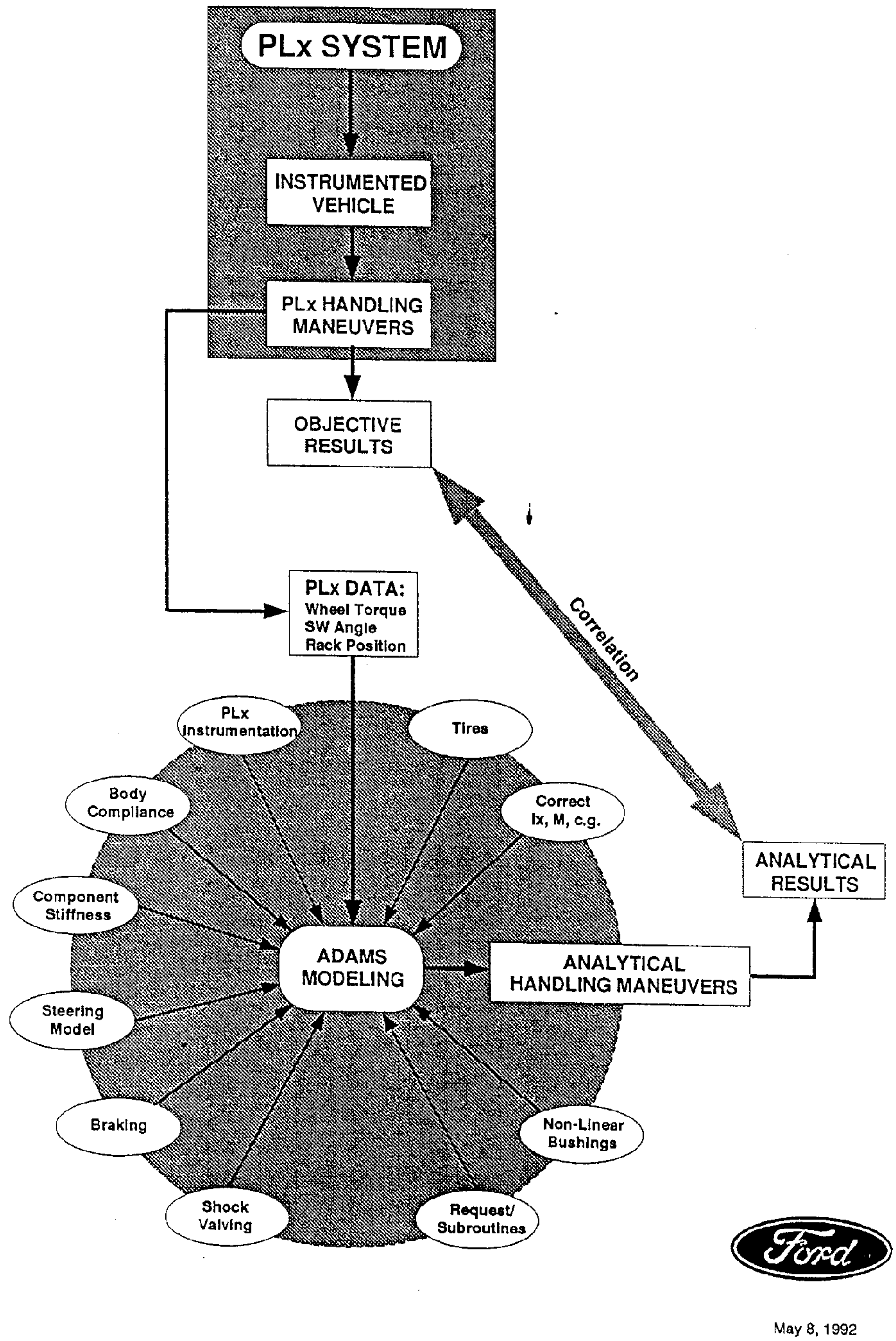

Figure 1 Ford Motor Company Vehicle Measuring and Correlation System.

III Vehicle Model and Analytical Data

An existing full vehicle ADAMS model is under continuous development to incorporate the latest component modeling techniques from throughout Ford Motor, including the Advanced Vehicle and Light Truck activities. Additionally, the model is "instrumented" through appropriate REQUEST routines to duplicate the real vehicle instrumentation.

Traditionally, all structural components (body, subframes, suspension) are modeled as rigid parts. To increase model accuracy, compliance elements such as ADAMS BUSHINGs, and BEAMs are added into the ADAMS simulations to account for bushing deflections and tie rod stiffness. Using the ADAMS/FEA interface, geometrically complex components can now be introduced into the model as compliant parts. Modeling complex component deflection, the ADAMS analysis is predicted to increase the accuracy of the model. Up until this point, it has not been known as to what extent these added compliances would have on the model and subsequently; vehicle dynamics. Since suspension components are typically an order of magnitude stiffer than bushings, the added component compliances were assumed to be negligible. The body and subframe stiffnesses were also not included but can have an effect on vehicle handling; consider the many body structure modifications required in convertible automobiles. These modifications are added to return the vehicle's handling and ride quality to an acceptable level through increased body rigidity. The subject of this paper is an inquiry into the effects of including these compliances in the model.

Both dynamic and static analyses are used to correlate the objective data with the analytical model. A static method is used to measure wheel toe and camber on the vehicle as the suspension is moved through its full range of motion from jounce to rebound (static suspension geometry). Currently, the analytical model provides good correlation to vehicle static geometry data. For a maneuver, vehicle dynamics parameters (body roll, tire slip, lateral acceleration, etc.) can be measured and used for correlation of the model. Dynamic wheel toe and camber during a maneuver can also be measured for a vehicle. The resulting data is the sum of the static geometry based on suspension height during the maneuver plus the system compliance effect on toe and camber. Previously, the ADAMS model used only the bushing rates to account for the suspension system compliance. The model developed for this study, incorporates suspension component flexibility to further define the vehicle system compliance.

IV Model Development

To determine the effects of the additional compliances on the analytical model, an inquiry plan was developed. The plan, as displayed in Figure 2, is a staged investigation consisting of running simulations of increasing complexity. An existing ADAMS vehicle was selected to be outfitted with the flexible upper and lower control arms. ADAMS/FEA was used to transfer the mass and stiffness characteristics of both control arms to ADAMS. The MSC/NASTRAN data representing the flexible control arms was generated by running MSC/NASTRAN with special DMAP inclusions required to produce the geometry topology data, mass and stiffness matrices for ADAMS/FEA. ADAMS/FEA was then used to automatically convert the data into an ADAMS Data Language (ADL) file. This file contains all the ADAMS PARTs, MARKERs, GRAPHICs, NFORCEs and MATRIX data necessary to represent the flexible member in ADAMS. Figure 3 displays the graphical model of the upper control arm created by ADAMS/FEA as displayed in ADAMS.

Compliance Effects Inquiry Plan

Covered in this Paper:

1. Examine the dynamic deflections of one flexible control arm in the full ADAMS model during a 60 MPH lane change maneuver.
2. Examine the dynamic camber and toe of a wheel flexible upper and lower control arms.

Future Work:

3. Develop an ADAMS model complete with all suspension components as flexible including a flexible sub-frame and body.
4. Evaluate the correlation improvements of the complete flexible model.

Figure 2 Phased Inquiry Plan

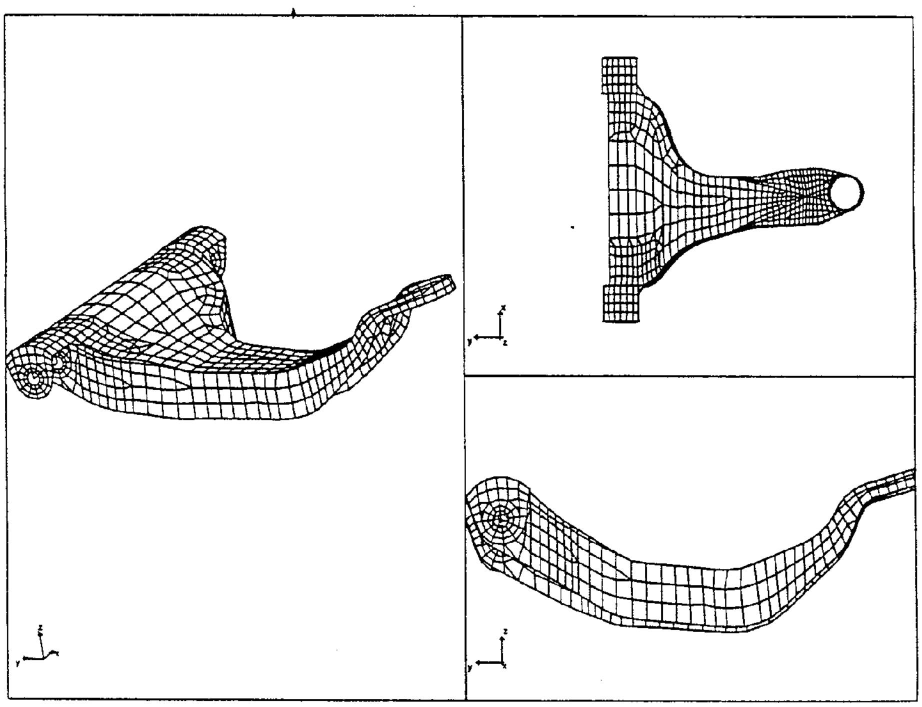

Figure 3 Flexible ADAMS Model of the Upper Control Arm.

V Initial Validation

To validate the fidelity of the stiffness representation in ADAMS, a series of static tests were run on the control arm which was isolated from the rest of the vehicle to compare the deflection of the model in MSC/NASTRAN and the model in ADAMS. The arm was anchored at the sub-frame junction by constraining the attach points to ground in ADAMS, and by using SPCs in MSC/NASTRAN. A 5000 Newton load was applied at the ball joint which connects the arm to the knuckle. The table below displays the results of the static validation tests for both the upper and lower control arms.

Static Validation Test Data

Ball Joint Deflections for a 5000 Newton Load (Millimeters)

UPPER ARM		ADAMS	MSC/NASTRAN
X Force	X=	6.640622	6.632388
	Y=	1.31122757	1.261131
	Z=	.83694	.6199036
Y Force	X=	1.300136	1.261131
	Y=	2.18758	2.075939
	Z=	6.19958	5.877226
Z Force	X=	.679890	.6199036
	Y=	6.369907	5.877226
	Z=	27.384069	27.588091

LOWER ARM		ADAMS	MSC/NASTRAN
X Force	X=	.73	.6596
	Y=	.169	.1676
	Z=	1.22	1.233
Y Force	X=	.1666	.1676
	Y=	.3838	.3867
	Z=	2.088	2.0189
Z Force	X=	1.223	1.233
	Y=	2.0189	2.0199
	Z=	17.16	17.2599

The good comparison between displacements proved that the stiffness representation in ADAMS was as accurate as the stiffness representation in MSC/NASTRAN. To verify the accuracy of the mass distribution, modal analyses were performed in both MSC/NASTRAN and ADAMS/LINEAR™. Again, correlation was good, as the results of both analyses compared to within 10% for the first ten frequencies for both control arms.

VI Full Vehicle Simulation

With the verification steps completed and the flexible representations validated, the upper and lower control arms were then introduced into the vehicle. (See figure 4).

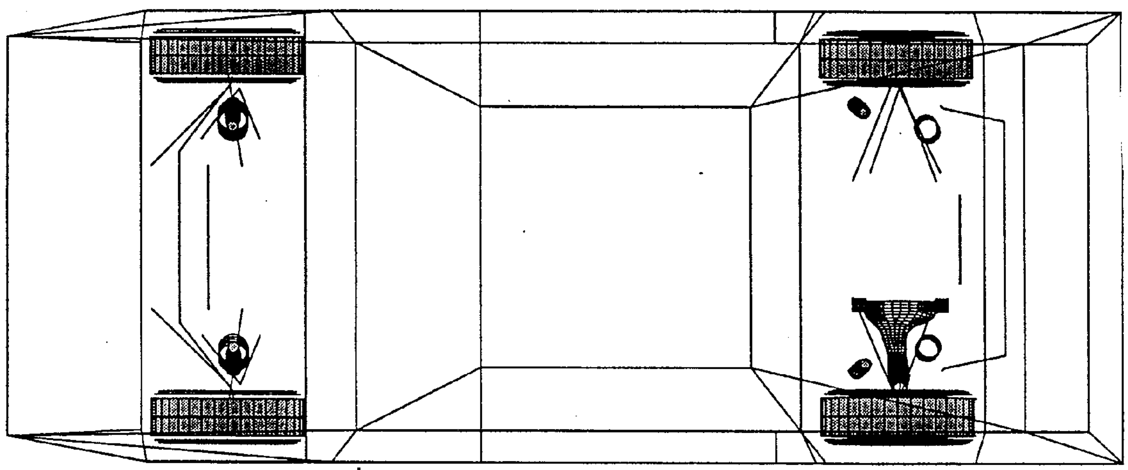

Figure 4 Upper Control Arm Merged into the ADAMS Model.

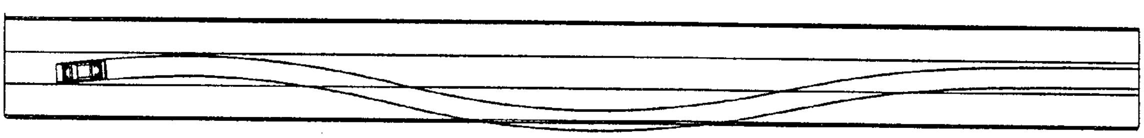

Figure 5 Lane Change Maneuver.

The maneuver being simulated in this analysis is a lane change at 60 mph. (See Figure 5). A special REQSUB routine was included to calculate the instantaneous camber and toe angles of the wheels. The vehicle analysis was then performed in ADAMS for .01 second increments for 4 seconds, or 500 total output steps for both a model with rigid control arms and a model with the flexible control arms.

VII Simulation Results

The initial simulation for step one in the inquiry plan involved a model with the left rear upper control arm modeled as flexible. The deflection of the control arm was tracked by monitoring the magnitude of the displacement between two most distant points on the arm. (see figure 6) Even though the deflection is thought to be exaggerated by modeling only one flexible component, a deflection of ~17 millimeters warranted further investigation and reason to proceed to step 2 in the inquire plan.

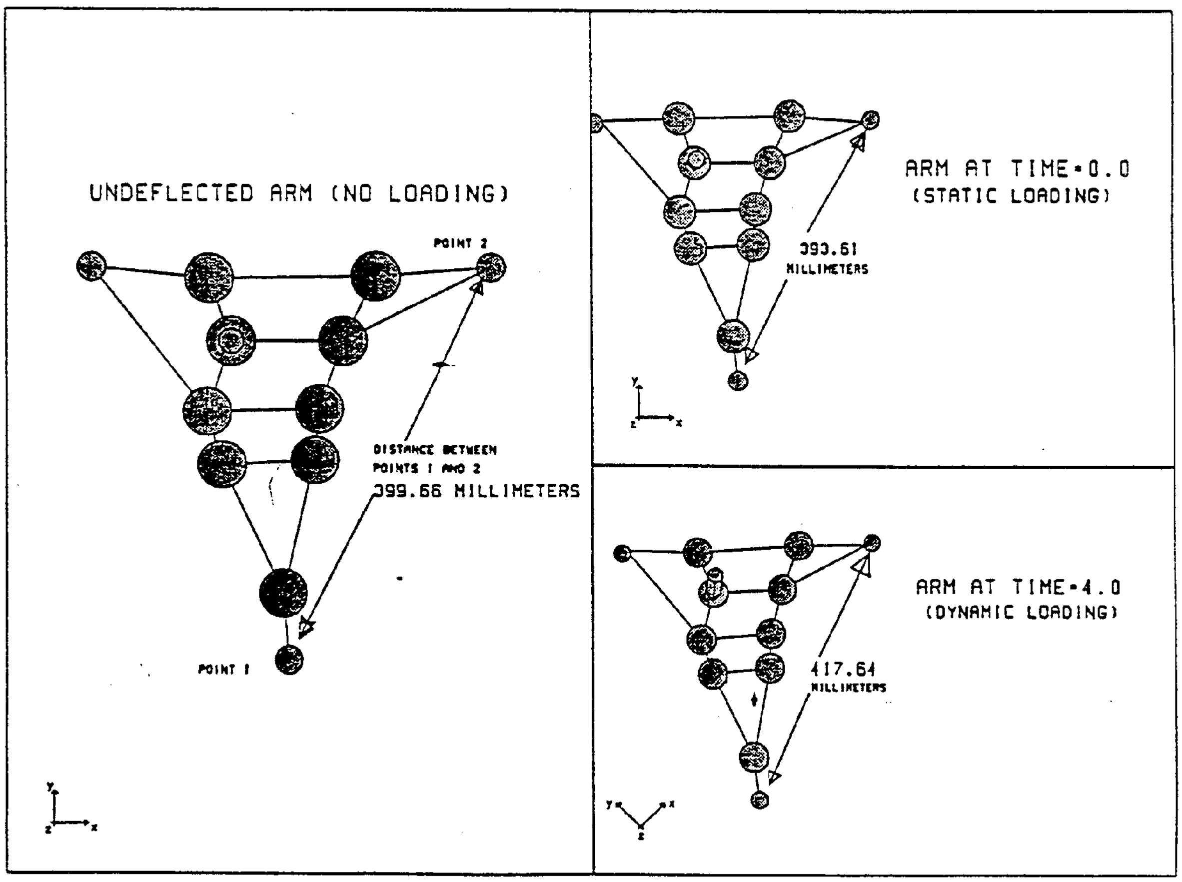

Figure 6 Deflection of the Upper Control Arm During the Maneuver.

Figure 7 displays the left and right wheel camber angles during the simulation. As can be seen in this curve, each wheel behaves relatively symmetrically for the lateral force increase during cornering. The differences in the camber curves between the left and right wheel are attributed to the non-uniformity of the maneuver (steering and speed).

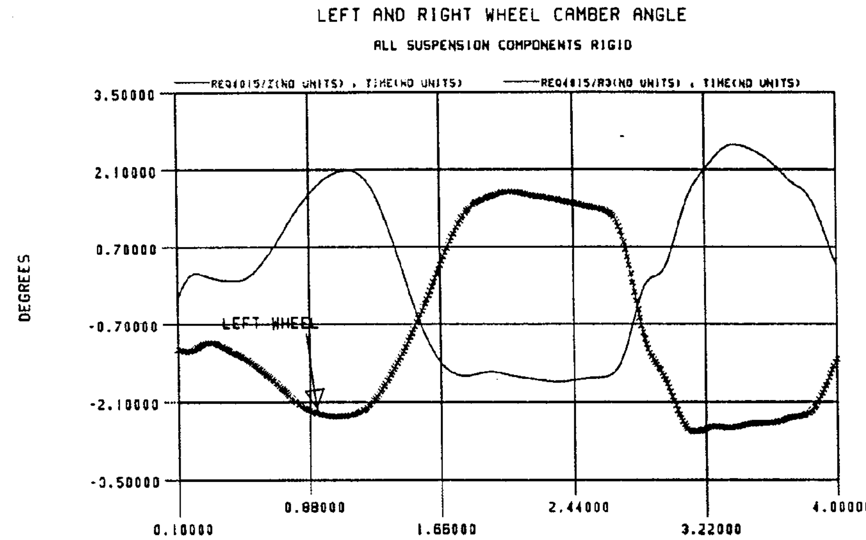

Figure 7 Left and Right Rear Wheel Camber Angles for the Rigid Control Arm Model.

Figure 8 displays the left and right rear wheel toe angles during the simulation for the model with the rigid control arms. As would be expected for this suspension, the toe angle is somewhere in the numerical "noise" level but still exhibits the same type of symmetry as in figure 7.

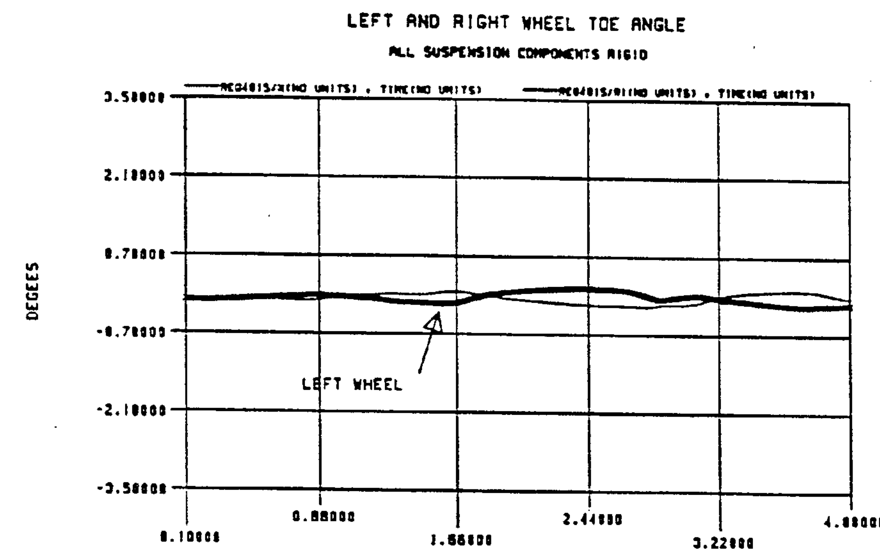

Figure 8 Left and Right Rear Wheel Toe Angles for the Rigid Control Arm Model.

Figure 9 shows the camber angle effect of the added compliance of the upper and lower control arms in comparison to the rigid control arms. It can be seen that the flexibility has the effect of absorbing energy and exaggerating the camber angle of the vehicle, especially during the events where the lateral forces are the greatest. The greatest difference being an angle of 3.4 degrees for the flexible simulation versus 2.4 for a difference of 30%.

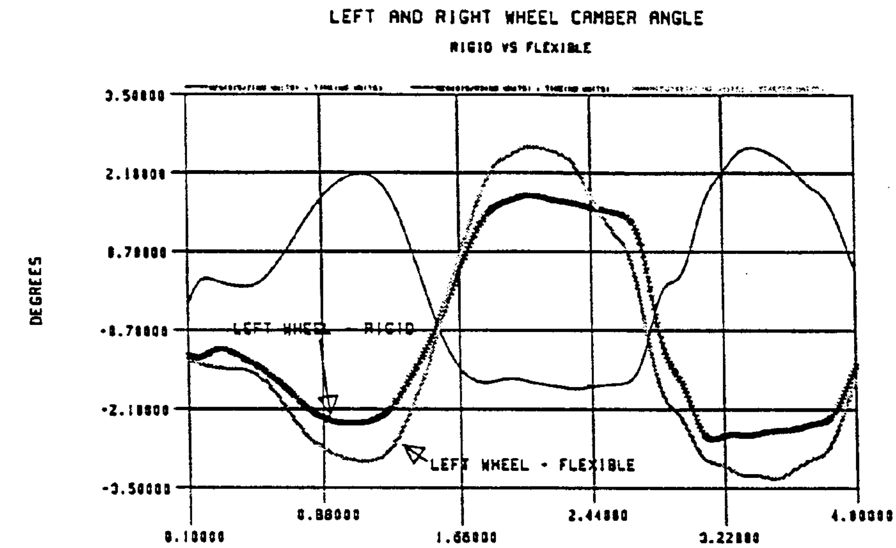

Figure 9 Comparing the Camber of the Rigid Model to the Flexible Model.

Figure 10 compares the effects of the added compliance on the toe angle. Again, this plot hovers in the numerical noise level, however the flexibility is shown to have an exaggerating effect of toe.

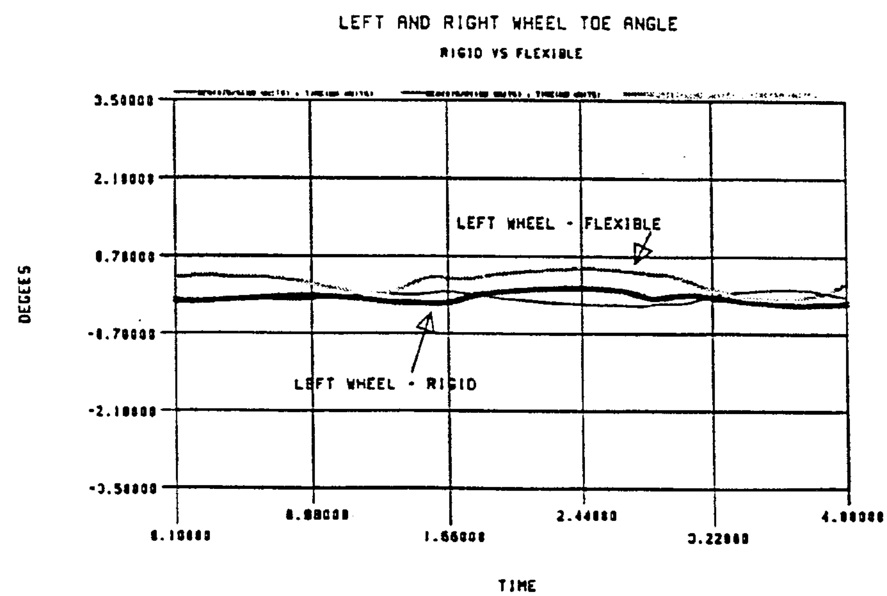

Figure 10 Comparing the Toe of the Rigid Model to the Flexible Model.

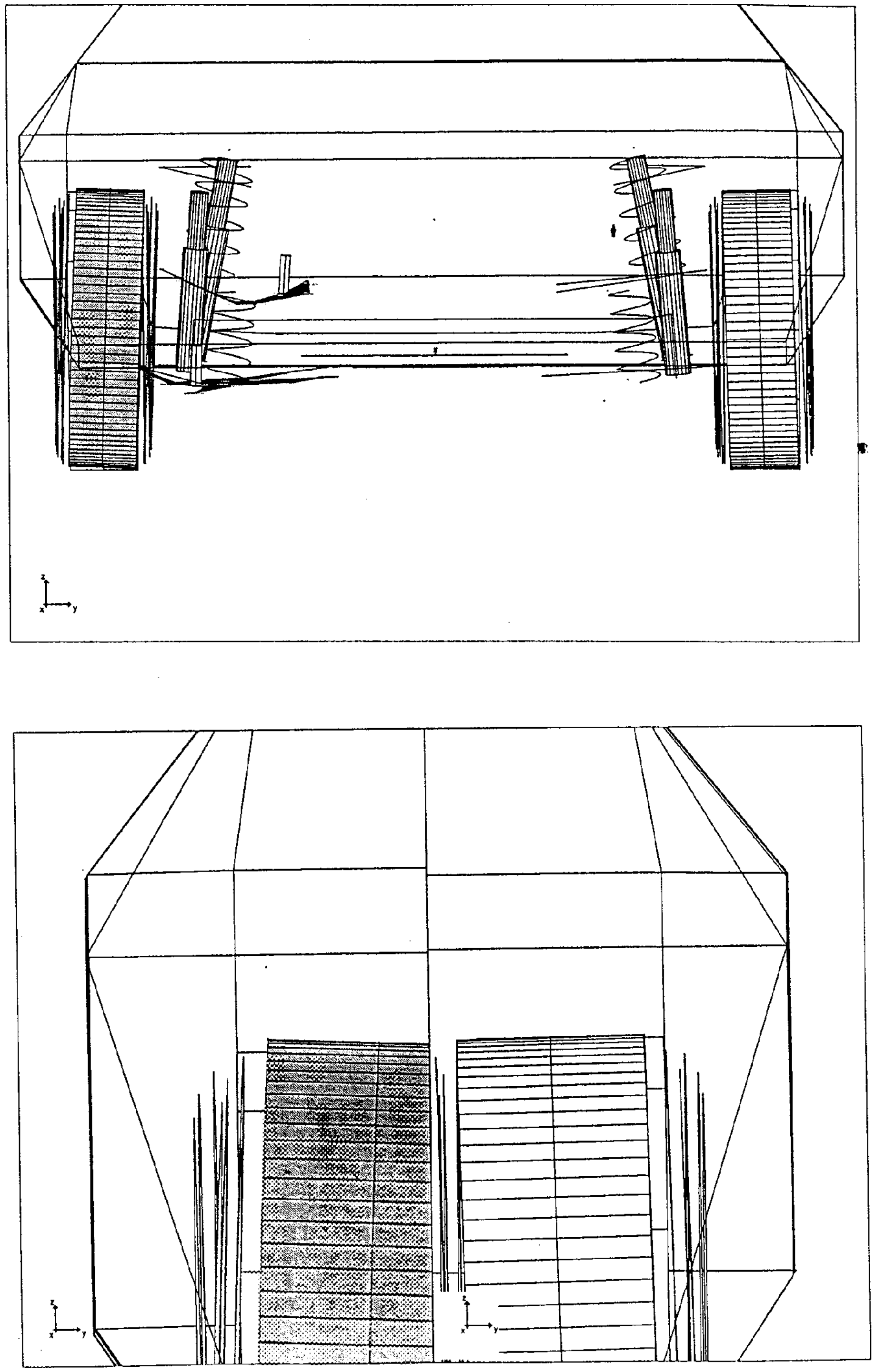

Figure 11 Comparison of the Camber of the flexible (left) and the rigid (right) suspensions at 60 mph (no steer).

Figure 11 provides a still frame of the subsequent vehicle animation to display the camber angle difference between the left (flexible) and the right (rigid) suspensions.

XI CONCLUSIONS

Upon completion of steps one and two in the inquiry plan, it has been determined the compliance of the suspension components, sub-frame and body should be included in the analytical model. This will account for their deflection effects on suspension geometry and to aid in correlation with objective results.

The numerical results covered in this paper are directionally correct and are mainly considered as an incentive for further investigation. In order to accurately model the vehicle suspension system the flexibility of all components affecting wheel position should be considered.

By modeling components and body structure as compliant, their flexibility effects on vehicle dynamics can be quantified and used to achieve stiffness targets for future designs.