ADAMS/Car In The Chassis Development Process

A look at the new virtual prototyping tool at Volvo Car Corporation

11th European ADAMS Users' Conference
Frankfurt November 19-20 1996

Johnny Engström **Jan Hellberg**

Volvo Car Corporation

VOLVO Volvo Car Corporation

1 Abstract

In August 1994, a joint-venture project between Audi, BMW, Ford, Renault, Volvo and MDI was initiated in order to produce a user interface to ADAMS which was tailormade for the automotive industry. The new software product was named ADAMS/Car.

ADAMS/Car has now been developed to a state where it has been made possible to replace old software within Volvo Car Corporation.

In this paper we present how the current version of ADAMS/Car is used to enhance the efficiency of the chassis development process, including how a car's ride and handling properties will be developed.

Some models of varying complexity are presented, reflecting which stage of the chassis development they are used in. As an example of true virtual prototyping using ADAMS/Car at Volvo, a full vehicle model running over single-side dip is shown to give results that correlate very well with real testing.

2 Introduction

CAE is used extensively in the development of new cars at Volvo. Since Volvo is determined to remain among the leaders in passive safety, a lot of effort is made in crash simulation. In the last couple of years, the importance of "active safety" has been increasingly recognized. Therefore, a lot of effort is now done do simulate the handling/driving safety characteristics of the cars. One important tool in this area is ADAMS.

ADAMS has been used for various purposes at Volvo Car Corporation since 1986. There are presently about ten users, but in 1997 we expect this number to increase substantially.

3 Background

At Volvo Car, an in-house developed graphic user interface to ADAMS has been available since 1986. This GUI is called SUSAN (SUSpension ANalysis) and has up to now been used for the elastokinematic analysis of wheel suspensions.

As a preprocessor, SUSAN has a very simple user interface for generating ADAMS .adm files. As a postprocessor, SUSAN produces a number of standard suspension characteristic plots and gradients from 17 loadcases (vertical movement, roll, longitudinal and lateral forces) and is also used to run wheelhouse envelope studies.

In 1994, we realized that SUSAN needed to be replaced with new software in order to move from the mainframe environment to Unix, and to make the use of simulation tools more widespread within the Volvo chassis development organisation. Therefore a prestudy was carried out to investigate how this could be achieved.

The result of the prestudy showed that a very large amount of manhours was required to create a new software to replace the old functionality. This would also have meant a large maintenance cost in manhours every year, and difficulties in adding new functionality.

As a consequence, we started discussions with other car companies and MDI to see if there was a possibility to share costs in a joint-venture project. This lead to the initialization of the ADAMS/Car project.

4 The Adams/Car project

4.1 Consortium

In August 1994, a consortium consisting of the members Audi, BMW and Volvo was formed and the project was started with MDI being the software supplier. Renault joined the ADAMS/Car consortium in January 1995.

The project was divided in two subprojects A and B. Subproject A focuses on wheel suspension analysis while subproject B (which is still under development) focuses on full vehicle analysis. MDI has delivered new releases with regular intervals while the consortium has provided feedback continously during the project.

The consortium has also held regular meetings in order to present feedback and discuss development schedules et cetera.

4.2 Customization

Since every car company has its own specific way of developing cars, company specific customization of the standard ADAMS/Car product has been made at each of the consortium members. One important task of the project has been to ensure that customization can be done in a straightforward way. At Volvo we have tried to keep the customization to a minimum level to avoid as much in-house maintenance of code as possible. In order to replace the old SUSAN system, we have customized the standard version of ADAMS/Car in the following areas:

- Templates: a number of Volvo specific templates for suspension, steering, and antirollbar subsystems were built using the template builder in ADAMS/Car. Apart from the topology, the Volvo-unique features are the requests and the naming of the hardpoints.
- Loadcases: A set of 23 standard excitations for suspension analysis have been generated using the standard ADAMS/Car loadcase creation macros.
- Suspension characteristics plots: By adding our own requests to the suspension testrig model and defining plot configuration files, about 60 standard plots are autogenerated when the user runs the suspension in all 23 loadcases. The layout and text in the plots have been kept as close to the old SUSAN plots as possible, and also to the "reality" in form of the test rig results.
- Wheel envelope calculation: by making a "shell" around the standard MDI suspension analysis macro, the in-house developed envelope calculation program is automatically called when the actual ADAMS/Solver simulation has finished. The envelope calculation program exports a point swarm representing the outer envelope surface to CATIA, which is then used to create the wheel envelope surfaces.

In addition, some custom macros have been developed to perform steering column analysis, dynamic suspension analysis and full vehicle simulation.

5 The new chassis development process

5.1 Platform Strategy

As is well known, Volvo Car has decided to use platforms as a base for the development of the new cars instead of the previously used sequential strategy. The concept of platforms is very easily misunderstood: many people think that the platform is simply another word for the chassis underbody, and that all cars stemming from the same platform share the same chassis layout and components. This is not the case. Instead a platform

- encompass a family of clearly differentiated cars
- with a high degree of commonality in systems and components
- developed in the same module structure
- using commonality in work methods
- cooperation with a number of suppliers and
- manufactured in a common and flexible process

The difference between a platform strategy and a sequential strategy can be summarized in the following way:

Platform strategy: Commonality and differentiation between the cars is obtained by detailed planning in very early phases.

Sequential strategy: Commonality and differentiation is obtained by carry-over (or lack thereof) from earlier projects.

5.2 The process

The new platform strategy implemented at Volvo Car Corporation has meant new challenges to the development teams. Since the platform strategy requires such careful planning in the early phases, we must now be able to predict the characteristics of **all** the platform cars **early** in the development phase. As a natural consequence, the use of simulation has to increase.

Looking at the general process of developing a chassis (see Figure 1), new (platform) projects are in general initialized by marketing people 'looking into the crystal ball' to define which cars that are desired by the customers in the future. The marketing people's definitions of the new car will then be successively broken down into objective requirements for the complete vehicle as well as for the different systems. These objectives then serve as targets for the design engineers.

As the development proceeds, simulation models will become increasingly complex, in order to give the accuracy needed.

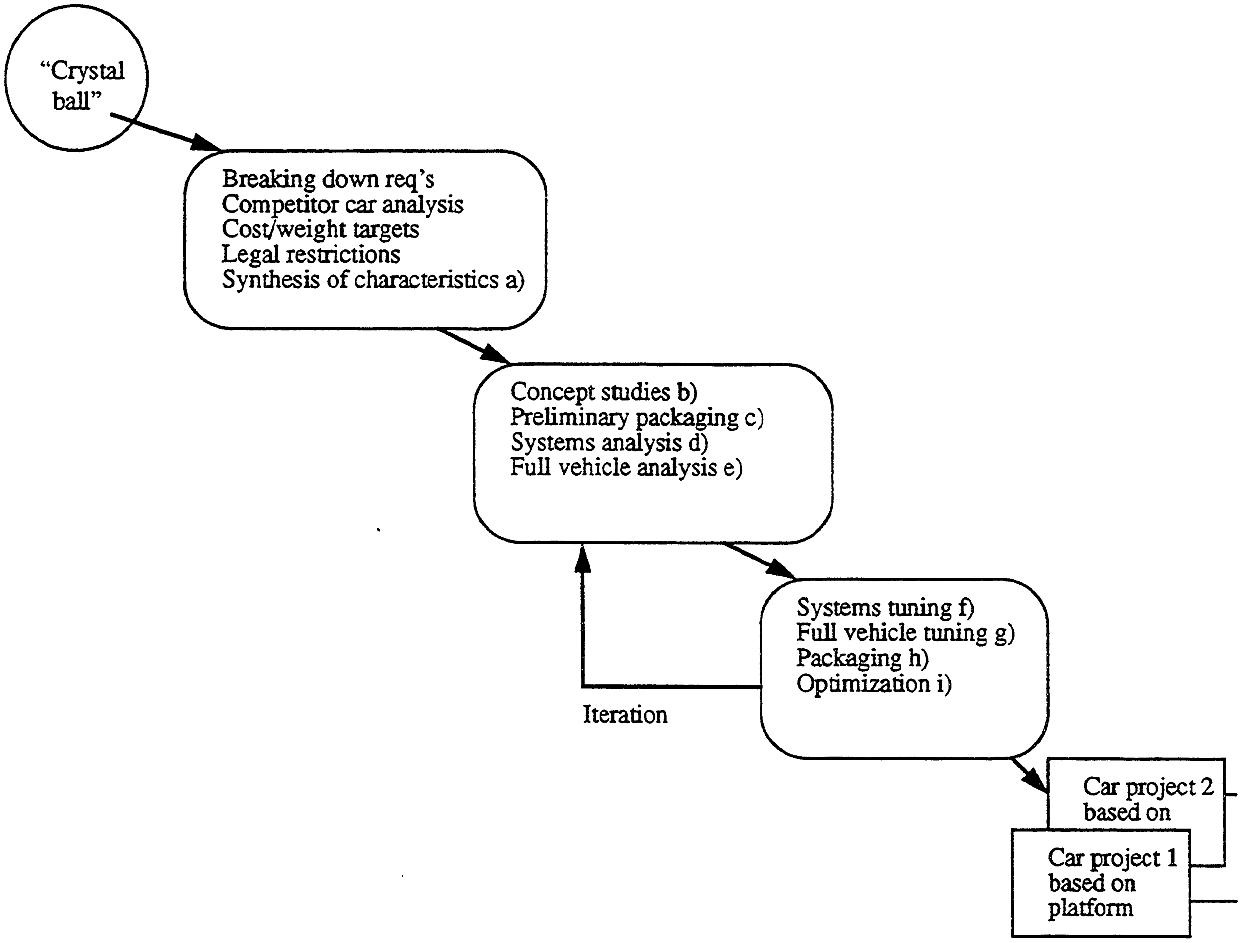


Figure 1: A brief overview of the chassis development process. Letters a) - i) denote activities that are explained in the text.

We will now explain some of the activities shown in Figure 1:

a) Synthesis of characteristics:

In the very earliest phases, one has to establish major parameters such as cornering compliance and vertical spring frequency. The process of using the desired characteristics as the basis for developing the solution is one of **synthesis** as opposed to **analysis**, in which one or more given designs are evaluated to determine their performance [1]. This is done using simple models in Matlab and ACSL.

b) Concept studies:

In the next step, it is important to very quickly assess for instance different wheel suspension concepts: what are their principal limitations and benefits? Potential for fulfilling requirements? Of course there are other issues as well: process adaptability, cost, weight et cetera. In ADAMS/Car, the characteristics of the subsystems and the full vehicle can be evaluated quickly. See also Figure 2.

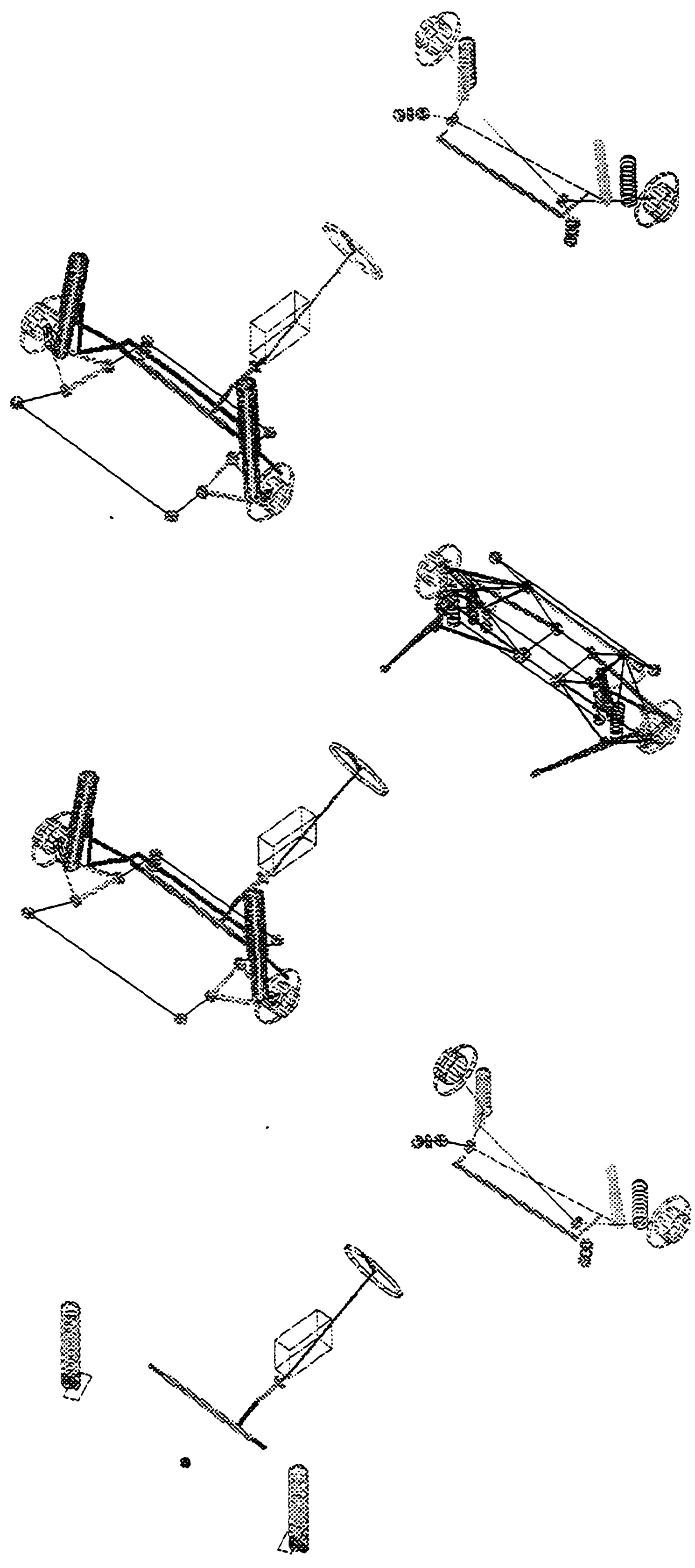


Figure 2: In ADAMS/Car, it is easy to swap subsystems in a complete vehicle model to perform what-if studies. E.g.: Which suspension will transmit least forces into the body?

c) Preliminary packaging

In order to make sure that everything will fit into the limited space of the car, early packaging studies must be performed. The wheel housing volume is one of the most important items to determine, since it imposes a limit on the turning circle, the engine bay volume and the interior space. For example, the result of these studies will determine which engines configurations that can be used.

At Volvo Car Corporation, we now use ADAMS/Car to create wheel envelopes. The space required by the wheel housing (the envelope) is obtained by imposing a vertical and (in the case of a front suspension) steering displacement on the suspension model. We call the combination of vertical and steering displacement the motion pattern area, see Figure 3. The spindle axis position at each combination of vertical and steering displacement and the wheel profile are then used as input to an in-house developed envelope calculation program, which generates a CATIA model containing a large number of points representing the outer surface of the wheel envelope.

A surface is created based on the point swarm. This surface serves as a limitation for e.g. the engine bay packaging studies.

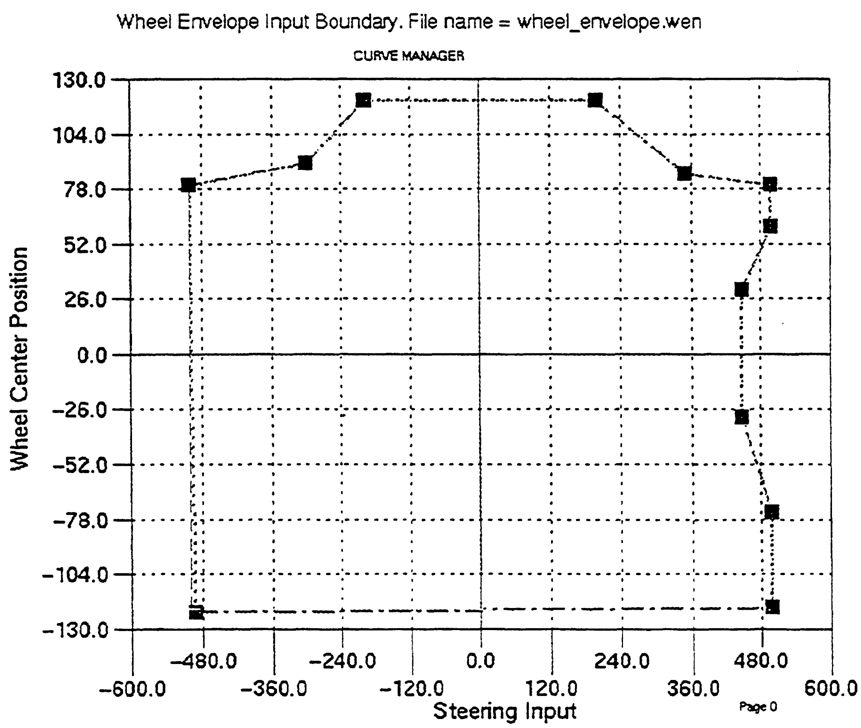


Figure 3: In ADAMS/Car one can use the curve manager to create the appropriate motion pattern area to be used in the wheel envelope analysis.

Performing wheel envelope studies is extremely important throughout the development. A lot of physical testing can be eliminated and thus a lot of time and money will be saved.

d) Systems analysis

When the major parameters of the car have been established through synthesis and concept studies, the system engineers can iterate to a suitable geometry in the suspension layout using the parameterized subsystems in ADAMS/Car. The system engineer submits a run of a number of loadcases and gets plots in a standard format. The user interface is streamlined in a way that people without previous ADAMS experience can use it.

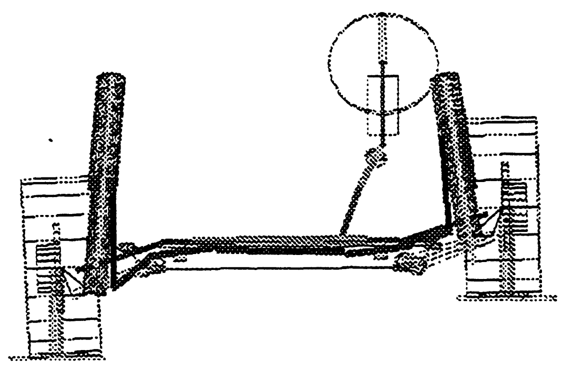


Figure 4: A front suspension assembly submitted to a roll analysis.

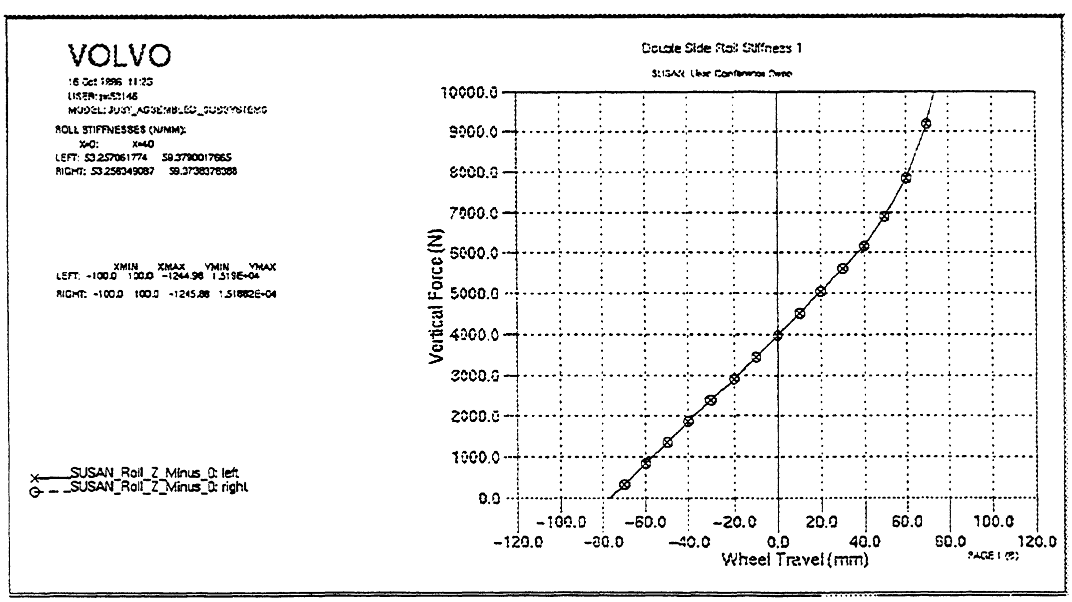


Figure 5: A typical standard suspension characteristic plot in the Volvo version of ADAMS/Car. The notes are generates by a custom macro developed in-house.

e) Full Vehicle analysis

As soon as the systems analyses have been performed, full vehicle models can be assembled and tested. If the results show that the full vehicle does not fulfill the requirements, we need to iterate to the systems analysis again.

In order to create a full vehicle in ADAMS/Car, the user simply chooses the desired subsystems and submits the analysis. Currently, a few standard manouvres such as Iso Lane Change and step steer analysis are implemented in ADAMS/Car, but with Volvo-specific add-ons, the goal is to run through all tests that are made on the real test track.

Not until we have come this far in the development process, we will build the first prototype to verify the suspension analyses performed in ADAMS/Car. If adjustments to the suspension models are necessary, looping back through activities c) and d) will in the end enable us to use the full vehicle analysis as a way to predict the characteristics of the car with confidence, thus eliminating a lot of expensive and time-consuming full vehicle testing.

f) Systems tuning

Later on in the development more and more factors influencing the characteristics of the car will be known. Therefore one can successively tune system characteristics such as NVH. Here the models get increasingly complex in order to provide the accuracy needed. As an example, a comparison between a MacPhearson suspension using only rigid components and one using a flexible damper rod is shown below. The flexible damper was created using a custom macro inside the Volvo version of ADAMS/Car.

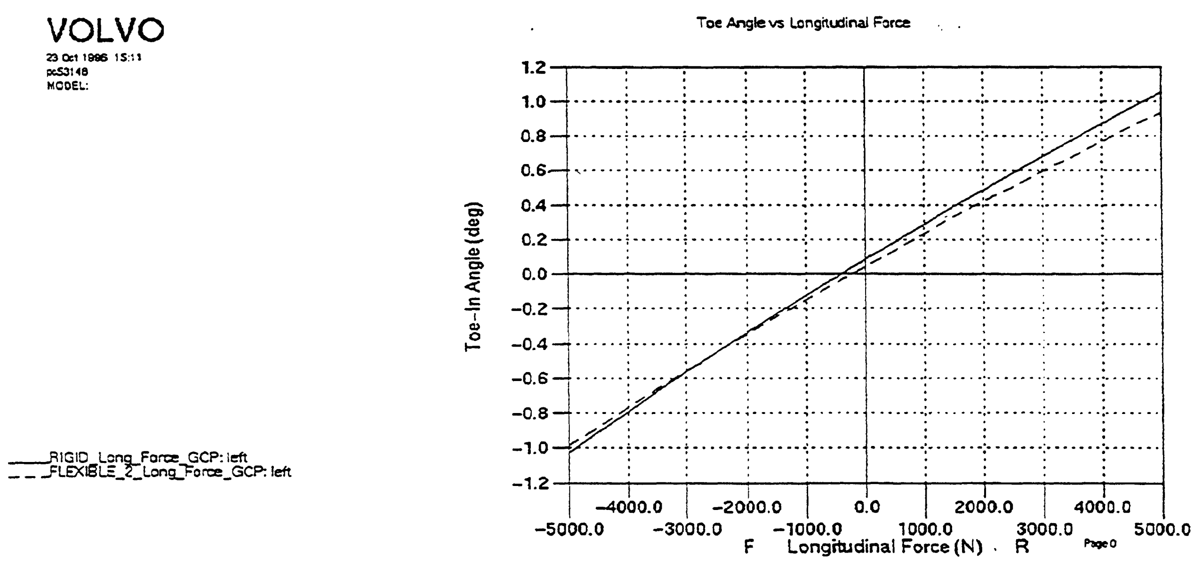


Figure 6: A comparison in toe angle characteristics between a rigid MacPhearson suspension and one using a flexible damper rod. The damper rod is modelled with BEAM elements, and is created in ADAMS/Car using a custom macro. The flexible damper rod gives less toe-in compensation at longitudinal braking force. Therefore the less complicated rigid model could give the systems engineer a false sense of security, leading him to belive that the stability of the car fulfills the requirements.

g)-i) Full vehicle tuning, Packaging, Optimization

Full vehicle testing on the test track is performed to verify that subjective targets are reached. The refinement of the simulation models continue to increase. The engineers iterate to the overall optimum solution (which is of course a compromize between conflicting requirements such as ride and handling characteristics), production tooling is manufactured, and so on.

As an example of how true virtual prototyping has been implemented in ADAMS/Car at Volvo Car Corporation, we will now describe a model being used in roll behaviour analysis.

6 Full vehicle model for roll behaviour analysis

6.1 Background

This work has been performed in order to develop a method that can be used to study the roll comfort of a car when passing over a single sided dip.

The aim of the model is to simulate roll comfort tests that can be carried out on a test track. The possibility to perform sensitivity studies has been applied as well, in order to attain knowledge about which parameters have a large influence on the roll behaviour.

This model of the Volvo 850 was first built in 1995 using a .adm-file, but in September 1996, the tyre subroutines were incorporated into the Volvo version of ADAMS/Car. This enables us to very quickly create the same full vehicle model in ADAMS/Car using the already existing suspension and steering templates. The tyre model allows the user to excite the vehicle with an arbitrary road disturbance.

The reasons for remaking the model in ADAMS/Car were twofold: firstly, to verify that real full vehicle analysis could be done in ADAMS/Car, and secondly to make it easier to use other suspensions from other cars with a minimum amount of work.

A typical single sided dip was measured on a common road to give input data of the road profile to the model.

The model has been validated against experimental results. Since the correlation between test and simulation results was satisfactory, new designs can be studied and optimization of specific configurations performed.

6.2 Description of the full vehicle model

The model consists of a rigid body, front suspension and rear suspension. Regarding the tyres, the Magic Formula is used to compute the forces in the ground contact plane but in the vertical direction there is a linear spring and linear damper.

The front suspension is a MacPhearson strut with coil spring, shock absorber, upper bearing, link arms and subframe (Figure 7). Non-linear bushings are modelled as splines.

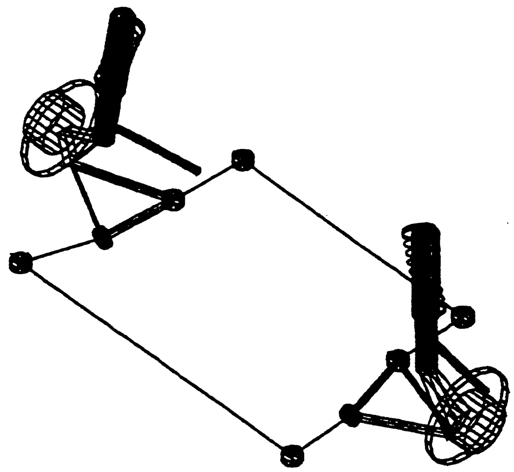


Figure 7: Volvo 850 front MacPhearson type suspension created in ADAMS/Car.

The anti-roll bar is modelled with beam elements in order to have a more detailed description of its elastic behaviour than the user can have with only two rigid parts connected with a torsional bushing.

The rear axle is a Delta Link with coil springs and shock absorbers (Figure 8). The non-linear bushings are modelled with splines.

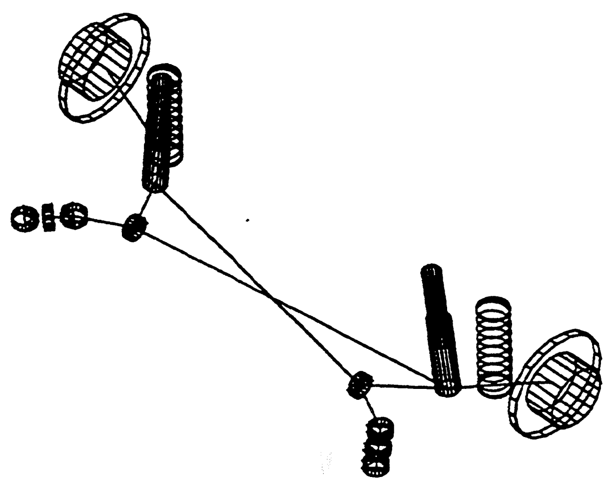


Figure 8: Volvo 850 Delta Link rear suspension created in ADAMS/Car.

The car body has been modelled with a single rigid part neglecting any elasticity in the structure. The mass of the engine and of the driveline is lumped together with the body.

As mentioned before, the tyre model consists of the Magic Formula for the ground contact forces and a linear spring in parallel with a linear damper for the vertical forces. This was in the old model implemented by the TIRE statement together with a user-written subroutine. In ADAMS/Car, the tyre model was implemented in the new TYDEX (TYre Data EXchange standard) compatible interface using the new TYRSUB.

6.3 Implementation of an arbitrary road profile

In order to induce a roll motion in the car, the method is to superimpose a desired road disturbance to a flat three dimensional road described in the Road Data File. (Figure 9a)

The desired road disturbance can be expressed with a vertical displacement from a defined horizontal plane (Figure 9a) and with the inclination in the lateral direction (Figure 9b). Mathematically these two characteristics can be expressed with analytical functions or with splines.

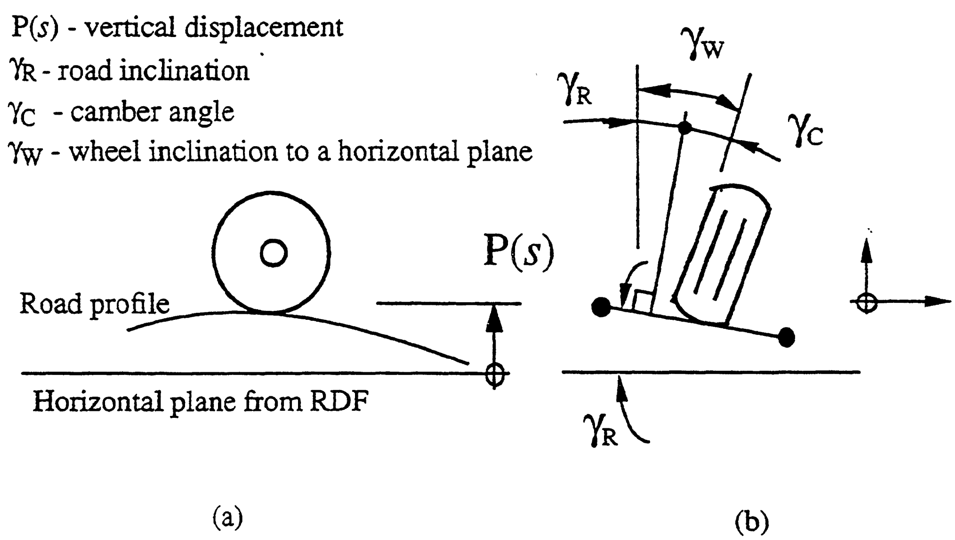
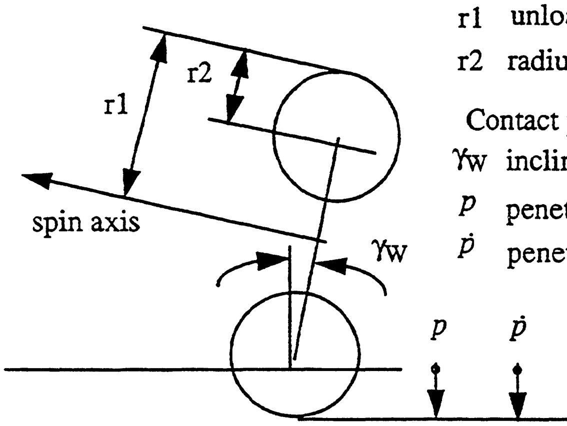


Figure 9: Road disturbance definition: a) in the vertical direction the disturbance is superimposed on the flat road surface definded in the .rdf file. b) in the lateral direction, the inclination of the disturbance is superimposed on the camber angle computed from the flat road surface.

Since ADAMS computes the normal penetration, the penetration velocity and the inclination of the tyre (camber angle) with respect to the flat surface, these contact properties have to be modified to take into account the influence of the road disturbance. The properties are described in Figure 10.



r1 unloaded radius of the tyre

r2 radius of the tyre carcass

Contact properties computed by ADAMS:

γ_W inclination angle (camber angle)

p penetration or tyre deflection

$\dot{p}$ penetration or deflection velocity

Figure 10: Definition of some tyre contact properties computed by ADAMS.

The road disturbance in the vertical direction is described by P(s) and the road inclination by $\gamma_R(s)$ as function of displacement. Therefore the user can excite the full vehicle model with this road description together with a flat road by modifying the expression for the tyre deflection, the deflection velocity and the camber angle as follows:

$$p_{tot} = p + P(s)$$

$$\dot{p}_{tot} = \dot{p} + \frac{d}{dt}P(s) = \dot{p} + \frac{d}{ds}P(s) \cdot \frac{ds}{dt}$$

$$\gamma_c = \gamma_W + \gamma_R(s)$$

Then the vertical force is calculated as

$$F_z = k \cdot p_{tot} + c \cdot \dot{p}_{tot}$$

Camber angle γ_c together with F_z are passed to Magic Formula to calculate the longitudinal and lateral forces in the ground contact plane.

With this method it is possible to apply different road disturbances to the left and the right side by using different expressions for the functions P(s) and $\gamma_R(s)$.

Finally it should be noted that when using a point contact model in the vertical direction the road profile must be fairly smooth since it does not give a realistic representation of a sharp obstacle.

6.4 Excitation with a predefined road disturbance

The test track used for roll studies was measured in terms of vertical displacement in the longitudinal and in the lateral direction. From these measurements it is possible to get a mathematical description of the road using spline functions. In Figures 11 and 12 the vertical displacement in the longitudinal direction is shown for left and right side tyres.

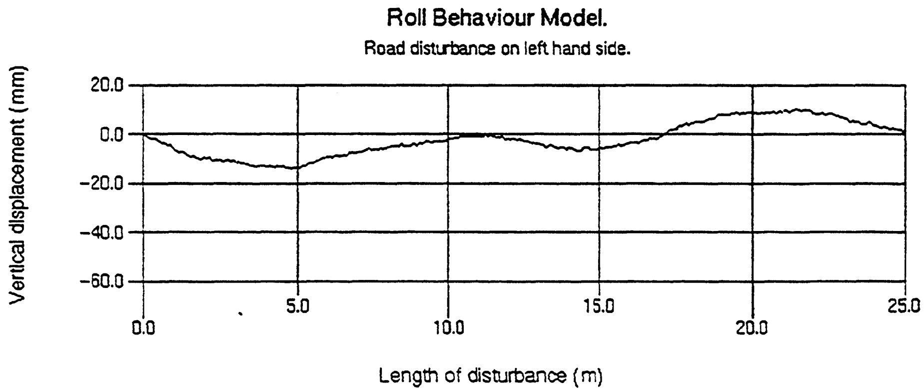


Figure 11: Vertical road disturbance for the left tyres. The plot shows the unfiltered measured vertical displacement signal. The road was measured with a sample rate of 25 points per meter.

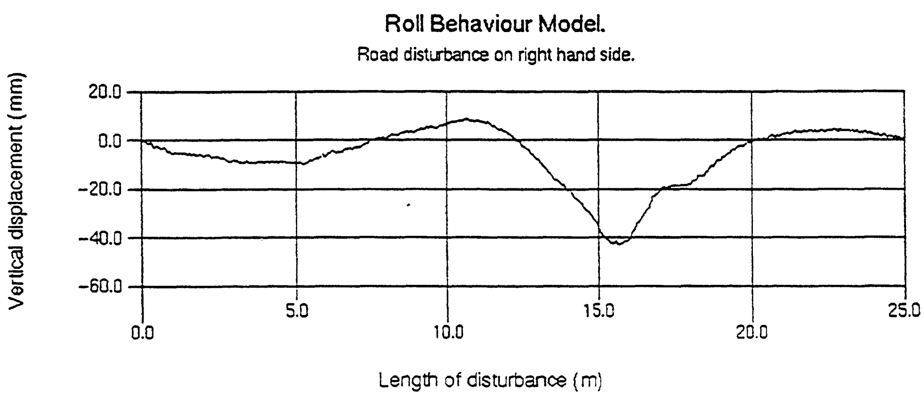


Figure 12: Vertical road disturbance for the right tyres. The plot shows the unfiltered measured vertical displacement signal. The road was measured with a sample rate of 25 points per meter.

6.5 Simulation results

The full vehicle model was updated with data corresponding to the test car: a Volvo 850 GLT.

During the ADAMS simulation, the acceleration was measured at two different points at the right hand side B-pillar, the same side as the dip: one point at floor level and the other one at ear level.

The model is driven at 70 km/h in the forward direction. Comparison between measurements in test car and simulation are shown in Figures 13 and 14.

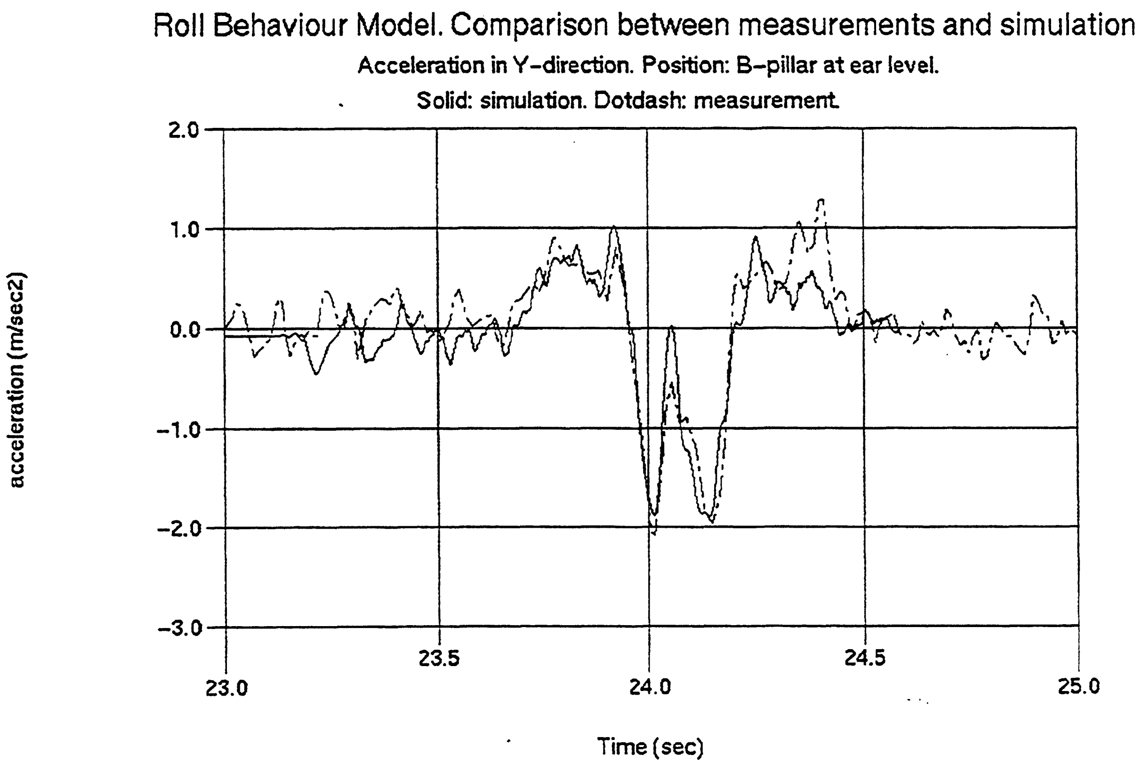


Figure 13: Comparison between measurements and simulation. The plot shows the ear level acceleration signal. The solid signal is the simulation result, and the dot-dashed signal is the measured one. As you can see, the correlation between simulation and real testing is good. The differences that still remain may be due to flexibility in the body structure and the fact that it is difficult for the test driver to follow the path simulated by the ADAMS model exactly.

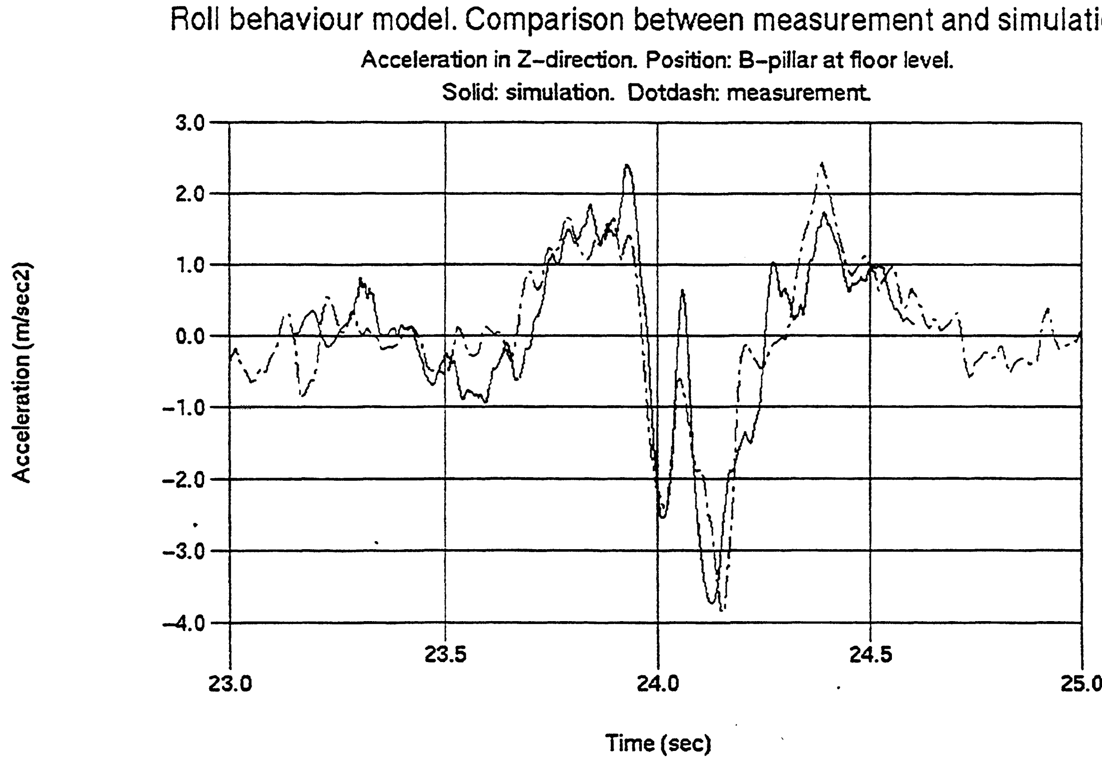


Figure 14: Comparison between measurements and simulation. The plot shows the floor level acceleration signal. The solid signal is the simulation result, and the dot-dashed signal is the measured one. Again you can see that the correlation between simulation and real testing is good.

6.6 Conclusions

A full vehicle model has been built in ADAMS/Car in order to perform roll comfort analyses and a method has been developed to excite this model by importing road data specifying a desired road disturbance.

- According to the sections above, it can be stated that the model shows good agreement with the measured response.
- It is possible to use the model in order to understand which parameters that control the roll behaviour so these issues can be highlighted in early design phases. Another important purpose is to perform sensitivity studies or Design of Experiments (DOE) in order to make the design robust.
- With this model our expectation is to reduce product development cost and time, while maintaining high quality.
- Full vehicle analysis can be made efficiently in ADAMS/Car.