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Multibody simulation in product development at systems supplier ZF

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Abstract

ZF Friedrichshafen is a major systems supplier for the automotive industry as well as for general driveline applications. This paper focuses on the application of multibody simulation in product development at ZF using ADAMS, mainly with regard to the development of suspension systems and drivelines for commercial vehicles. ADAMS is used for suspension kinematics, compliance calculations, collision checks and simulation of vehicle handling. In addition, driveline kinematics and dynamics are determined using ADAMS. This paper presents a range of typical ZF applications. Finally, the advantages of ADAMS customization for ZF are shown.

Introduction

ZF provides the automotive industry with driveline and chassis systems. These include manual and automatic transmissions, power steering systems, axles and independent wheel suspension systems. ZF products can be found in cars, buses, coaches, trucks and off-road machinery. Furthermore, ZF also supplies driveline components for rail, marine, aircraft, helicopter and industrial applications.

With a 33 000-strong workforce, worldwide ZF Group sales exceed DM 8 billion per year. Product development involves more than 2 200 engineers in 5 divisions, all of whom are supported by the Corporate Research and Development Center located in Friedrichshafen on the banks of Lake Constance.

ZF operates as a "tier one" supplier. Applications worthy of particular emphasis include the ZF-made front and rear axle independent suspension systems for the new Mercedes M-class

MPV. We are worldwide leaders in drop-center axles for low-floor buses. On top of that, a whole host of coaches feature ZF axles and steering systems in their designs.

Growing demand has forced ZF to intensify multibody simulation, primarily in the development of suspension systems. Last year, ZF started using ADAMS for four main reasons: it is an all-purpose MBS tool, it is an automotive industry standard, it has a CAD interface and it is customizable. The following two sections deal with ZF applications of ADAMS virtual prototyping.

Suspension kinematics and vehicle handling

The first application aspect to be discussed is coach handling. ZF supplies various customers with hubs, live axles, power steering systems and complete suspension systems. An important ZF task involves assessing the handling and comfort levels offered by ZF axles in different customer coach configurations (with regard to weight-split, center of gravity height, roll stiffness, steering kinematics etc.).

ZF's Off-Road Driveline Technology and Axle Systems Division in Passau has a test coach with typical suspension system in operation. This coach represented the "real" counterpart of an ADAMS virtual prototype, figure 1. The coach has a double wishbone type front suspension. The spindle is connected to an upright by means of a kingpin. Steering is via a Pitman arm which is connected to left and right tie rods. The rear live axle is connected to the chassis via four links: two lower trailing links and two separate upper A-arm links. The coach features air springs with level control on all wheels, with a stabilizer bar available as an optional extra.

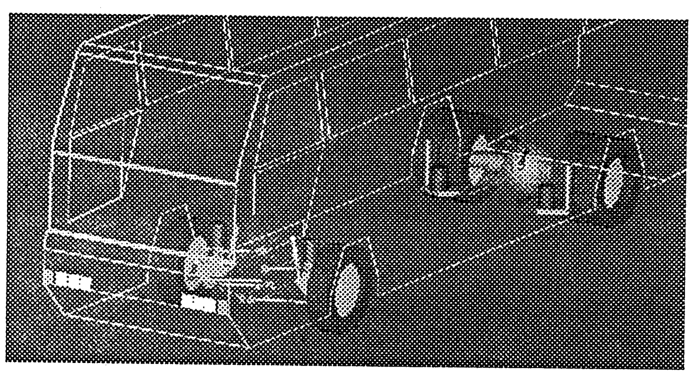

Figure 1: ZF-coach full vehicle model

The coach was transferred to an ADAMS multibody model with 57 degrees of freedom. Bushings were included where necessary. Six tyres were modeled with TINA using the Magic Formula 89 model. Simple velocity control was added, plus steering control for steady state cornering. Results with regard to steering wheel angle, lateral acceleration, roll angle or yaw velocity were all generated using ADAMS/Solver variables.

Theoretical examinations of the influence of the rear axle suspension on coach handling and safety were performed. Because of the high rear mass distribution – typically about 60 – 65 % – handling manoeuvres are strongly influenced by the rear axle kinematics and compliance. These characteristics are determined by the link geometry together with the bushing stiffness. Lemförder, also a division of the ZF Group, supplies links and bushings for coaches of various designs.

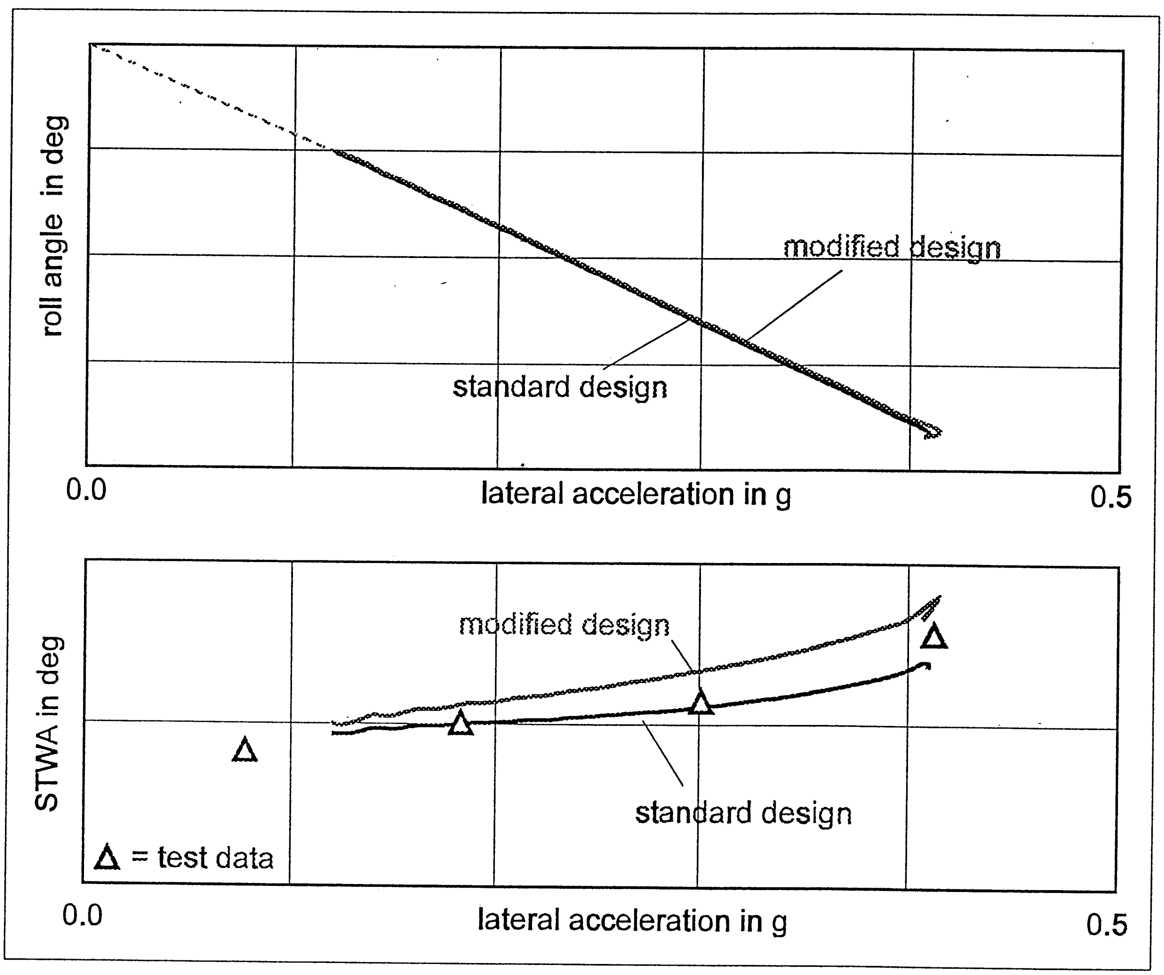

Figure 2: steady state cornering results

The rear axle only was analyzed on a virtual kinematics & compliance rig. Different settings were generated and analyzed. Above all, roll stiffness, roll steer gradient and lateral force steer were evaluated. Following this, a group of full vehicle models was assembled, featuring the different rear axle settings. Using these models, several tests were carried out, including steady state cornering and single lane changes in open loop mode.

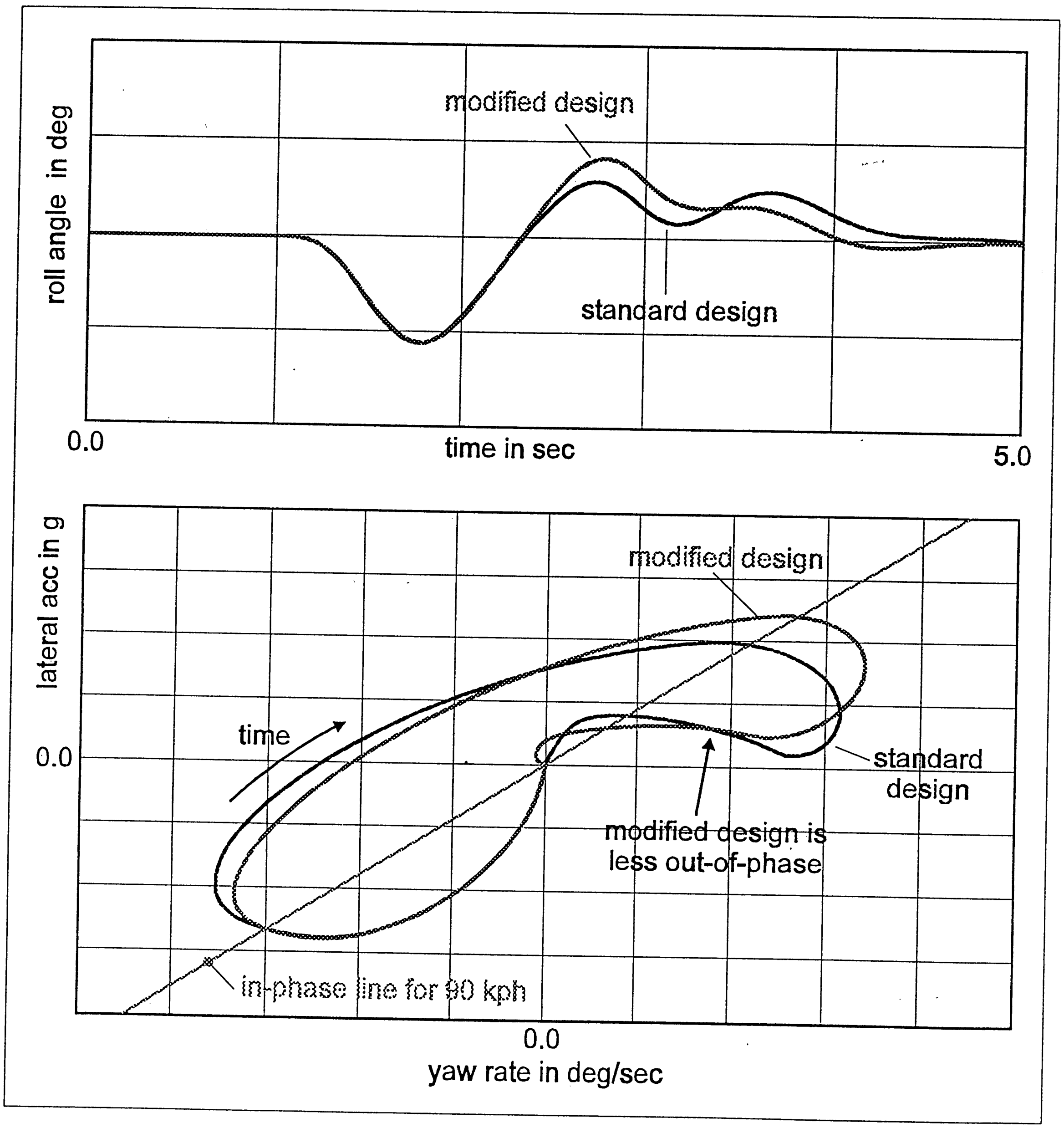

Figure 3: lane change results

The assessment of the different settings is based on understeer gradient (for steady state) and phasing between lateral acceleration and yaw velocity (for lane changes). Roll angle was also monitored. Figure 2 shows the results for the current rear suspension design and the optimized proposal for steady state cornering. Both maximal lateral acceleration and roll gain are more or less the same. The understeer gradient is slightly higher for the new design. However, with 90 kph medium lane changes (figure 3), a clear improvement in phasing can be observed. This goes along with a more symmetrical roll angle time history.

The subjective assessment from test engineers and customers was good. The modified suspension makes the coach more responsive. Objective tests are to be carried out soon in order to confirm the validity of the simulation.

In the case of low-floor city bus front suspension, flexible bodies also had to be taken into account in order to study certain dynamic effects. A good correlation between the simulation and the tests was achieved for the standrad design using ADAMS beams since the main flexibility was in parts with a beam-like shape. Subsequently, ADAMS analyses helped to pinpoint a modified design.

The examinations mentioned above are performed by a vehicle dynamics analyst at ZF using ADAMS/View. Another important task is the collision check for new designs. This task is carried out directly by the ZF designer, using Mechanism/Pro. Due to customer confidentiality, all we can mention is the fact that we used Mechanism/Pro to pinpoint a collision-free design for a newly-developed bus suspension system.

Driveline applications

This section discusses applications of ADAMS for driveline dynamics and kinematics.

ADAMS was used to determine critical loadcases for a 3-axle, all-wheel driven vehicle whose complete driveline (transmission, differentials, propeller shafts and sideshafts) is developed by ZF. The designers had to determine the internal loads on sideshafts etc. "Simple" calculations of drive torque cannot be applied to a 6x6 vehicle since the wheel loads, and therefore the tyre drive torques, depend on the body pitch angle. Therefore, springs and dampers have to be taken into account. ADAMS multibody simulation was then used for 2 loadcases in longitudinal dynamics: idiot start and 60% hill climbing.

The appropriate 2D model features body, propeller shafts, wheels and 3 sprung axles with a total of 10 degrees of freedom. The suspension systems were kinematically linearized as translational joints, but with nonlinear springs and dampers. In both loadcases, the differentials were locked.

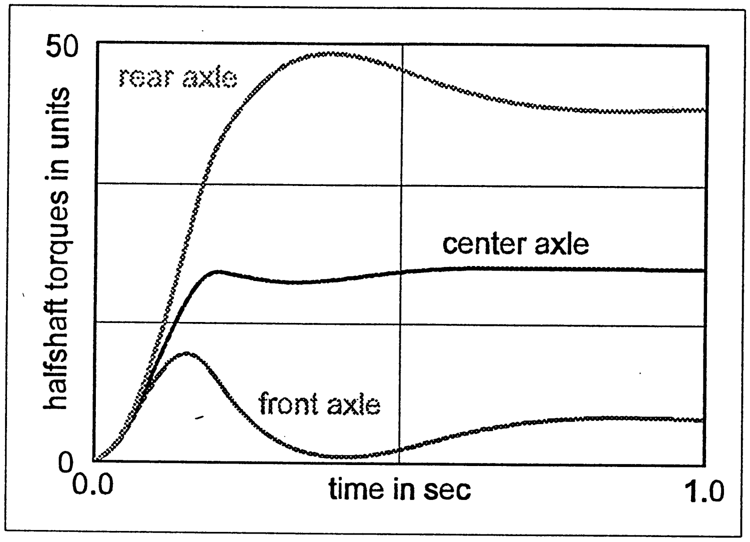

Figure 4: "idiot start" results

Figure 4 shows the results of the "idiot start" simulation and figure 5 the results on the 60% hill. It can be seen that the sideshafts of center axle and rear axle have the highest load.

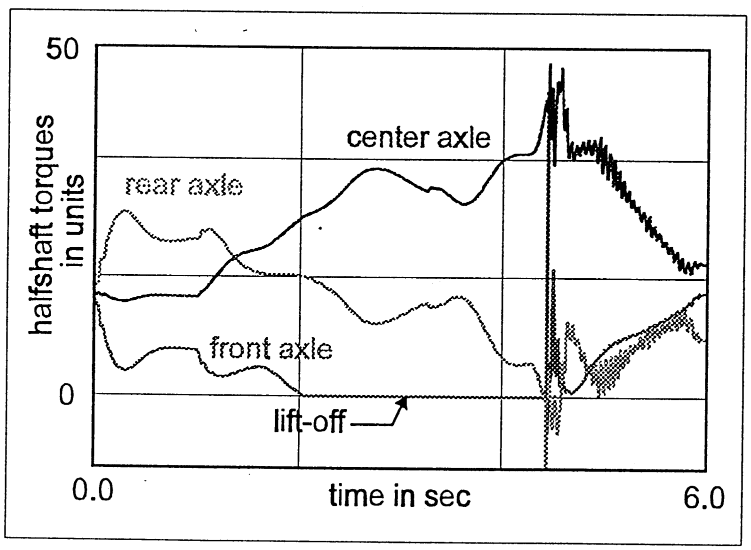

Figure 5: 60%-hill ramp-up results

The second example deals with driveline kinematics. For a driven double-wishbone front suspension, the constant velocity joints (CVJ) had to be specially selected. Therefore, the designer has to know – among other specifications – the maximum working angles and plunging length of the sideshaft CVJs. A kinematic model of the complete suspension system including steering and driveshafts was set up in ADAMS. From a combined ride and steer loadcase, the relative joint motions were determined, figure 6. The plot shows the envelope of plunging length vs. working angle for all possible vertical wheel travel and combined steer motions.

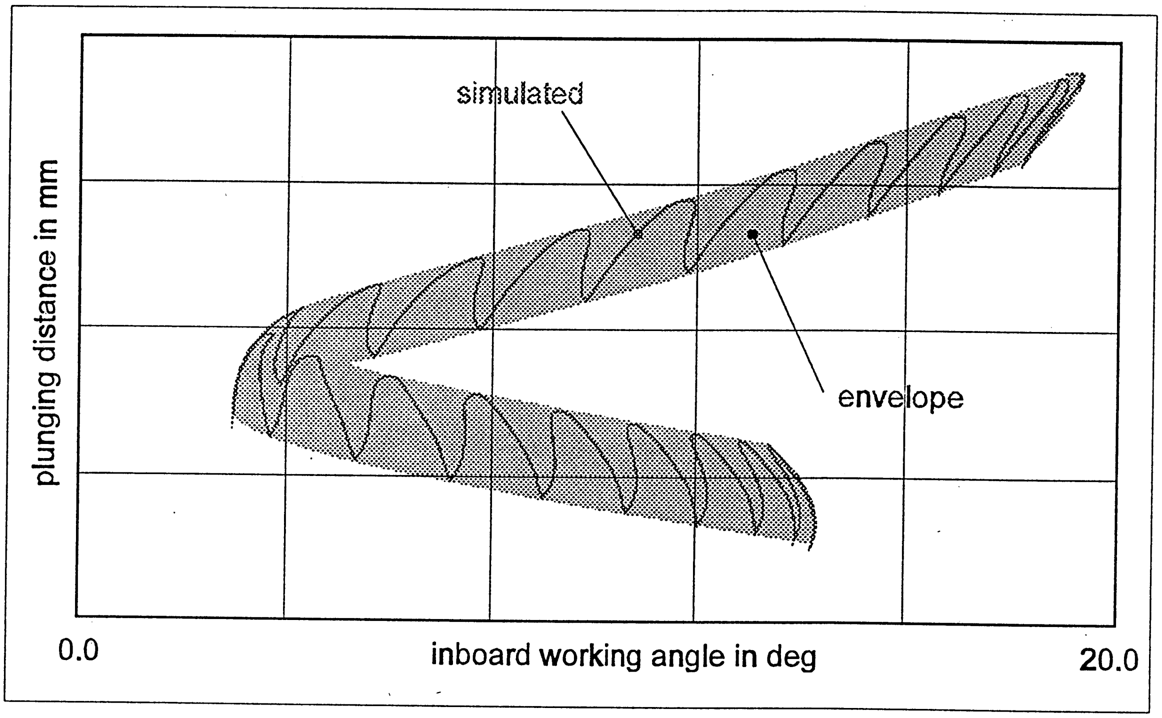

Figure 6: CV joint relative motions in ride and steer

Parametric modeling and customization

Although the new axles are now designed using Pro/Engineer, the suspension kinematics and handling simulation is carried out separately in ADAMS/View. This is because several entities (such as jacks, tyres, controls etc.) necessary for the simulation cannot be completely generated using Mechanism/Pro. On the other hand, the transferred model (from Mech/Pro to ADAMS/View) does not feature a suitable parametric design.

The ADAMS/View parametric modeling functions are widely used in the axle and full vehicle models at ZF. The model setup is based on a special philosophy which allows quick changes to the axle models such as new hardpoints or compliance characteristics (bushings, stabilizer bars etc). This feature is essential for ZF since our large number of customers requires the simulation of many different axle designs. Customized panels ease the variation of geometry, see figure 7. Furthermore, the parametric models allow switching between kinematic and bars etc). This feature is essential for ZF since our large number of customers requires the simulation of many different axle designs. Customized panels ease the variation of geometry, see figure 7. Furthermore, the parametric models allow switching between kinematic and compliant models or unladen and laden vehicles thanks to the group function. Topological changes, if necessary, are carried out using the basic modeling functions of ADAMS/View. In our experience, these methods work very effectively.

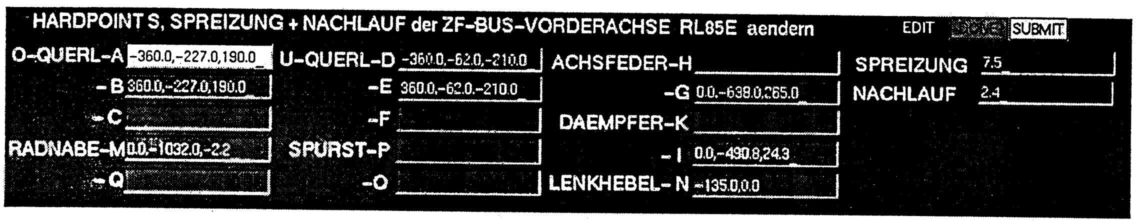

Figure 7: hardpoint parameter panel for ZF coach front axle

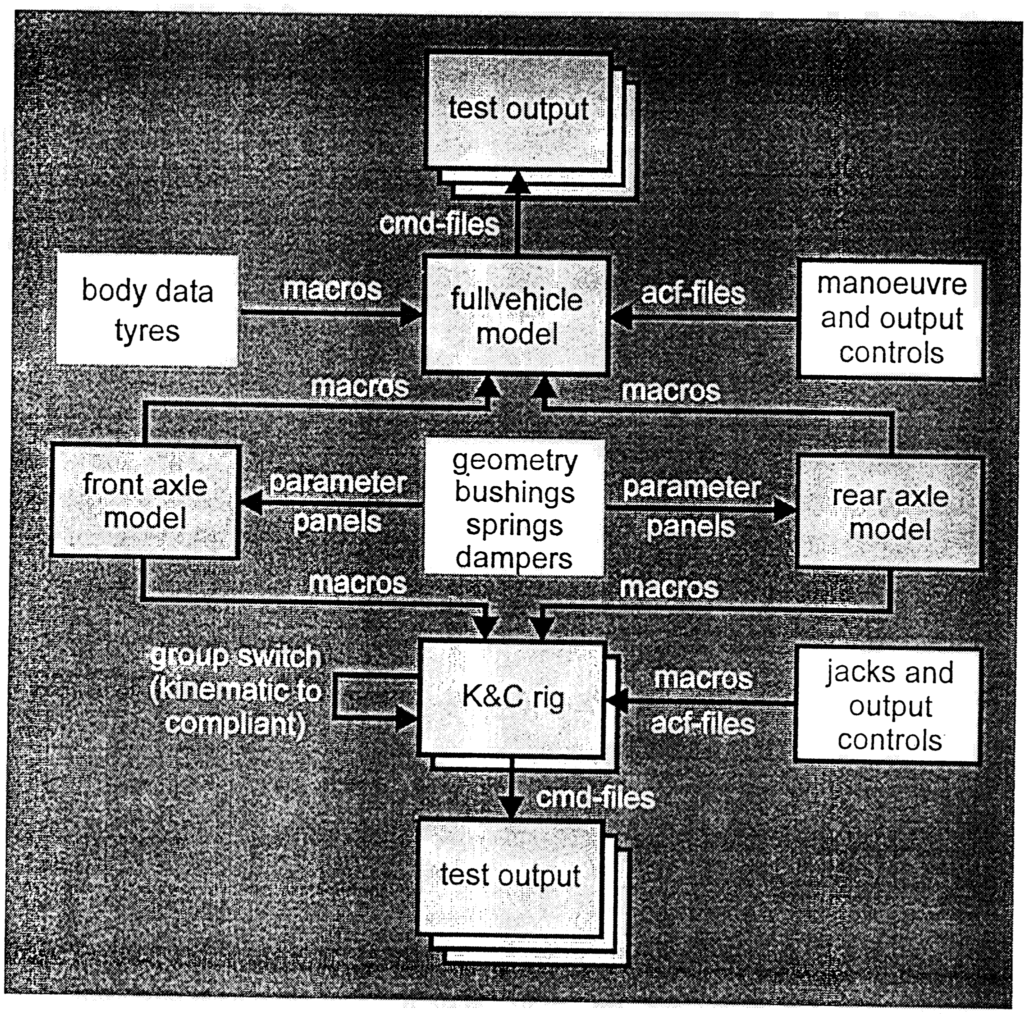

Figure 8: ADAMS flowchart

using macros. This is the only possible procedure which guarantees consistency between axle and full vehicle models. The powerful acf-file feature of ADAMS/Solver is also used for "programmed" analysis tasks. We are happy that ADAMS 9.0 includes this feature in the graphical user interface. Figure 8 summarizes the model setup and analysis procedure.

Consequently, a ZF-specific model template and macro pool was set up in order to assure the fastest possible response to customer requests.

Summary and outlook

ZF uses multibody simulation in the design of suspension systems and driveline components. ADAMS has been successfully used for over a year now. Some typical applications from our Axle Systems Division have been discussed. Using ADAMS, simulation results can also be presented to customers in a very effective way. As our experience grows, ADAMS will be used in other ZF divisions also. ZF is prepared to fulfill every customer need with regard to multibody simulation.