# Application of ADAMS/Car in Vehicle Development

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## 1. Introduction

Steyr-Daimler-Puch Fahrzeugtechnik (SFT) applies **A**DAMS**/Car** due to the program`s particular advantages for solving tasks in the field of automotive engineering, above all in

- (Elasto)kinematics / vehicle dynamics
- Cross-sectional forces calculation as input data for subsequent fatigue life estimation
- NVH calculation

This paper deals in detail with A/Car`s application in the first two fields, as well as with the systematic proceeding for MBS model checks that facilitate the rather sophisticated error identification and considerably improve the quality of the calculation results by means of a great number of plausibility checks.

## 2. A/CAR in vehicle development, general comments

For converting a 4x2 vehicle into a 4x4 vehicle, questions concerning packages, vehicle dynamics, operational strength and NVH must be dealt with. Apart from DMU and FEM techniques, the multi-body dynamics method is an essential tool to provide the designer with theoretical results during vehicle development.
If possible, one and the same MBS model is used for each work step. This cost-effective technique is supported by the modular structure of A/Car [1]. In SFT`s opinion, A/Car provides the following advantages:

- During the individual development phases, only the respective subsystems require maintenance.
- Quick generating of the complete vehicle model by means of these subsystems.
- Improved model clarity: engineers from the various special departments carry out the relevant calculations, i.e. that shortcomings of the model can be identified and corrected earlier than with other techniques.
- There is considerable potential to reduce costs due to the time-saving technique for generating the model and due to the central model maintenance.

The only slight drawback of this method is the fact that the basic principle of creating a model, namely „as simple as possible, as sophisticated as necessary“ cannot always be adhered to.

Figure 1 shows the application of A/Car for the various calculation tasks during the development phase. However, a distinction must be made between an axle model and a complete-vehicle model. An essential milestone in 4x4 development is the determination of the axle concept. Figure 1 shows that kinematics, elastokinematics, vehicle dynamics, cross-sectional forces and NVH calculations are available and serve, among other aspects, as decision aids. NVH calculations are not dealt with in this paper, see [2] and [3].

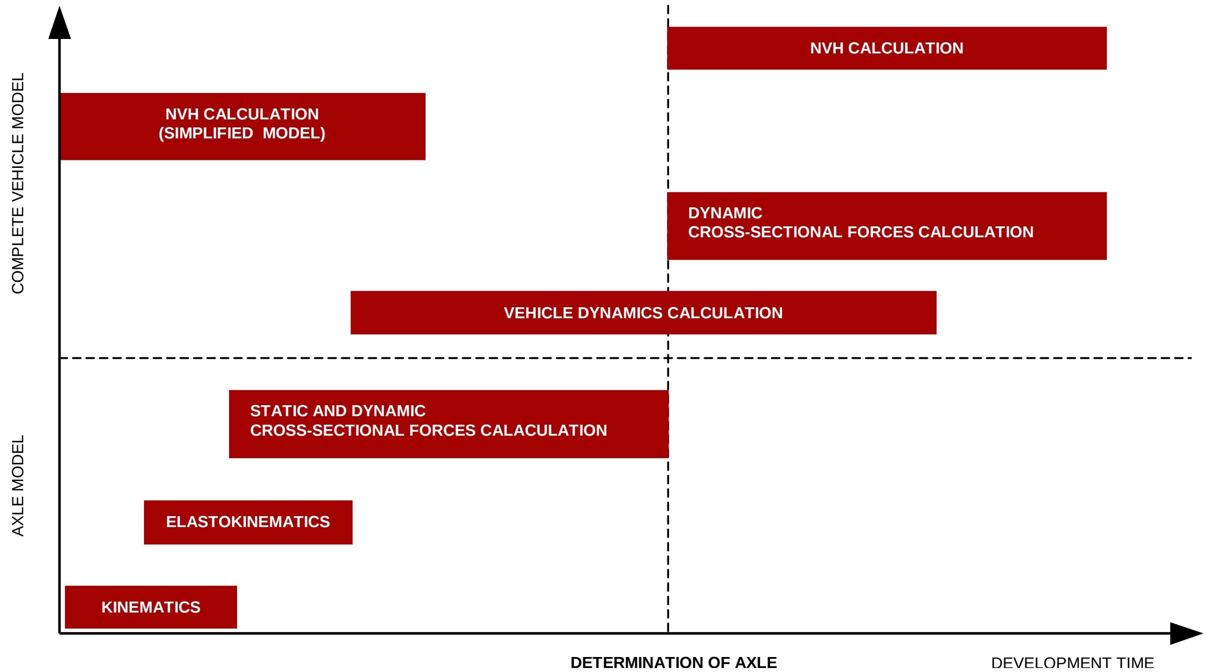


*Figure 1: Application of A/Car in the development process*

## 2.1. (Elasto)kinematics and vehicle dynamics

Figure 2 shows an example of a complete vehicle, in this case consisting of the following subsystems:

- Front axle
  - double-wishbone axle (36 DOF)
  - antirollbar (5 DOF)
  - steering (8 DOF)
- Rear axle:
  - multi-link suspension (80 DOF)
  - antirollbar (19 DOF)
- Body (6 DOF)
- Engine (6 DOF)
- Differential, front (2 DOF)
- Powertrain (14 DOF)

The individual rigid bodies of the MBS model are connected by means of kinematic and/or kinetic constraints. The number of the degrees of freedom of the whole system or subsystems is calculated by means of the equation (1)

$$DOF = 6 * n - q. \tag{1}$$

In equation (1), n is the number of rigid bodies and q the number of kinematic constraints.

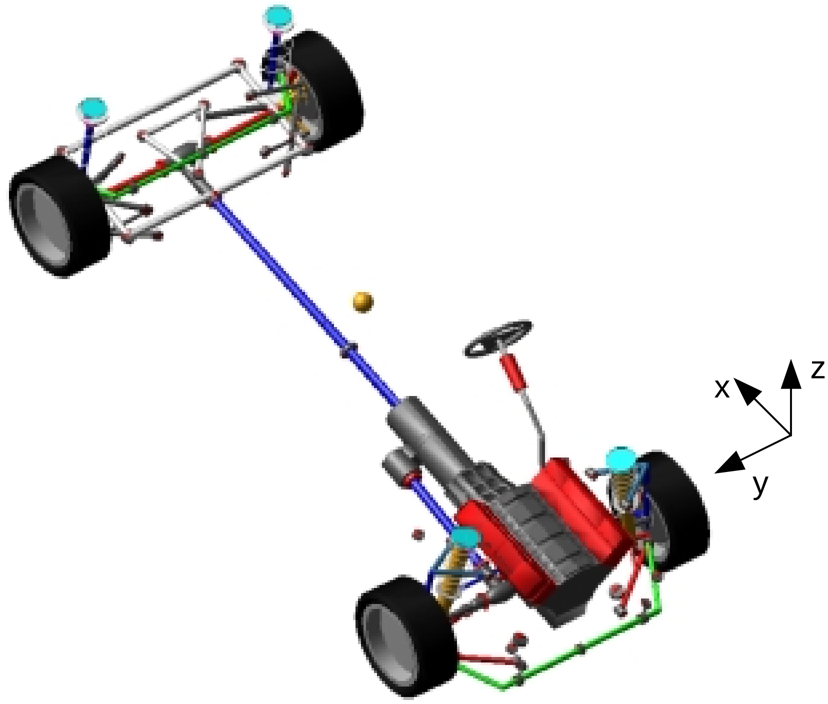


*Figure 2: 4x4 model of complete vehicle*

Above 4x4 model enables us to carry over the complete rear axle (multi-link suspension) and to adapt the front axle (double-wishbone axle) to the modified package. This requires a new design for the front axle with regard to kinematic, elastokinematic and vehicle-dynamic product performance specification criteria.
The kinematic quantities analyzed and dealt with in this case are: toe-in, wheel camber, ackerman error and roll center. The elastokinematic calculations are based on the loadcases shown in Table 1. Before vehicle-dynamic tests are carried out with the prototype vehicles, the vehicle is measured on the axle measurement rig. These measurements equal the loadcases of the elastokinematic calculation and serve as a means of comparing the measurement results with the simulation results.

| **Loadcase** | **Force input** |
|---|---|
| Braking | Forces in x direction; at wheel force application point |
| Transverse tension 2:1 | Forces in y direction; 30 mm behind wheel force application point |
| Drive-away | Forces in -x direction in wheel center |
| Shock | Forces in x direction in wheel center |

*Table 1: Elastokinematic loadcases*

Figure 3 shows the change in toe-in of the 4x2 and 4x4 vehicle under loadcase transverse tension 2:1 at the left wheel. It also shows the target range specified by the customer.

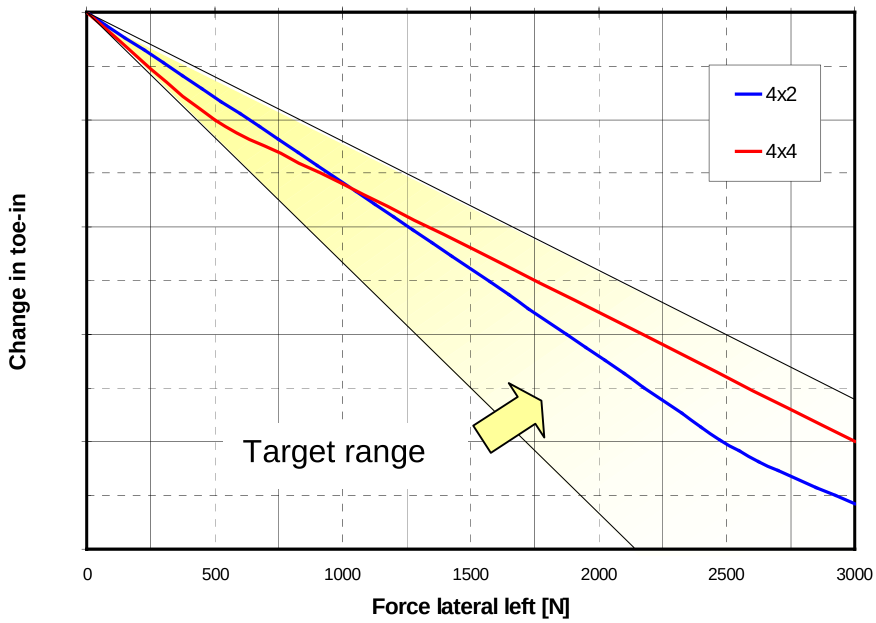


*Figure 3: Change in toe-in under loadcase transverse tension 2:1*

For the vehicle-dynamic tests, the configurations were as follows: 4x2 vehicle was rear-wheel driven, 4x4 vehicle featured a constant torque distribution in the center differential. The propshaft towards the rear is fitted with a rubber disk and mounted to the body by means of a bellow-type support. The driving maneuvers performed until the axle concept was determined had been constant radius cornering, step steer and swept sine steer. In Figure 4, the two vehicles` behavior during constant radius cornering is compared. Both vehicles are understeering, the 4x2 characteristic is slightly superior.

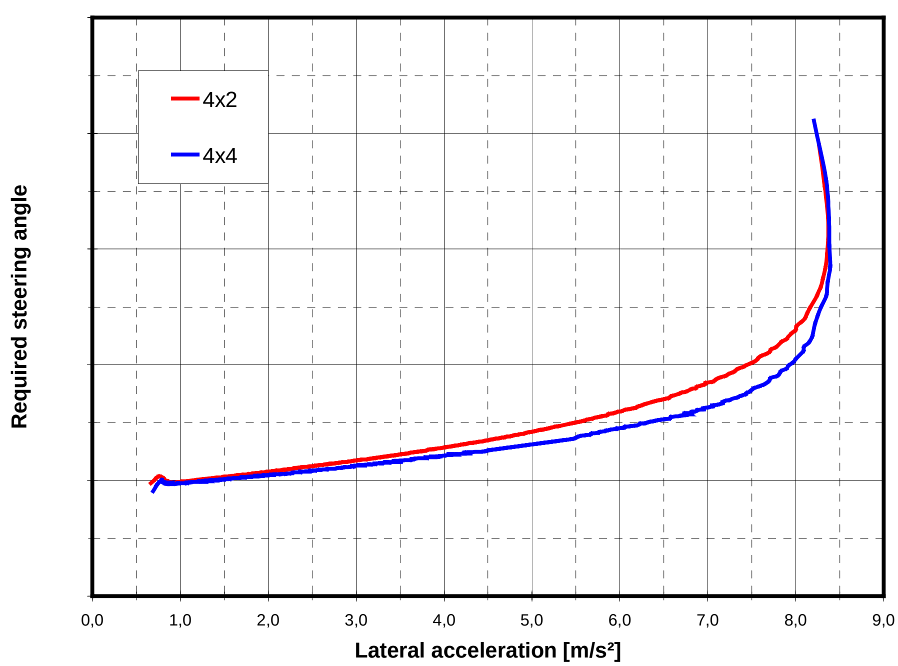


*Figure 4: Constant radius cornering, required steering angle 4x2 / 4x4 vehicle*

## 2.2. Cross-sectional forces calculation for fatigue life estimations

The cross-sectional forces calculation aims at determining the components` cross-sectional forces and torques in a body-fixed coordinate system. These quantities are the input data for the subsequent fatigue life estimation, [4]. The multi-body system technique is highly suitable for this process, since MBS models usually contain kinematic non-linearities (long wheel travel) and physical non-linearities (spring stop). Above all for determining the chassis` cross-sectional forces, these non-linearities are of utmost significance.
Depending on the development stage, see Figure 1, the cross-sectional forces are determined by means of reduced models (e.g. axle) or a complete-vehicle model. There is a difference between static and dynamic calculation. The static loadcases serve as a means of testing the MBS and FEM models for plausibility and of calculating the stress diagrams of the respective component. In Table 2, various static loadcases for the front axle are in part summarized. The loadcases differ from each other by their varying force and torque input.

| **Loadcase** | $\mathbf{F}_{XL}$ | $\mathbf{F}_{XR}$ | $\mathbf{F}_{YL}$ | $\mathbf{F}_{YR}$ | $\mathbf{F}_{ZL}$ | $\mathbf{F}_{ZR}$ | $\mathbf{T}_{YL}$ | $\mathbf{T}_{YR}$ |
|---|---|---|---|---|---|---|---|---|
| Design position | - | - | - | - | 1,0 | 1,0 | - | - |
| Cornering | - | - | 2,0 | - | 2,0 | - | - | - |
| Braking | 1,5 | 1,5 | - | - | 1,5 | 1,5 | $r_0$*$F_{XL}$ | $r_0$*$F_{XR}$ |
| Pothole | 1,5 | 1,5 | - | - | 2,6 | 2,6 | - | - |

$r_0$ . . . loaded tire radius

*Table 2: Calculated static loadcases at front axle*

After the static calculation, a dynamic analysis with a 4x2 load spectrum was performed by means of a reduced model. In this case, the force components ($F_{Xi}$, $F_{Yi}$, $F_{Zi}$) and torque components ($T_{Xi}$, $T_{Yi}$, $T_{Zi}$) measured by means of wheel force transducers are applied onto the right and left wheel center (i = R, L). Before determining the axle concept, this calculation is performed very often by means of a „half vehicle" fitted with the relevant 4x4 components

- body: half body mass
- elastically mounted engine/transmission unit
- front axle: double-wishbone axle, antirollbar and steering.

This simplified vehicle is elastically mounted on a reference body than can move freely in longitudinal direction. This kind of restraint prevents drift-away of the vehicle. Figure 5 shows, e.g., the $F_Z$-force – in a body-fixed coordinate system – acting between knuckle and lower control arm onto the wishbone during rough road driving. These quantities are the input data for the subsequent fatigue life estimation. In this case, the comparison with regard to cross-sectional forces and fatigue life between the 4x2 and 4x4 variant is also of utmost interest.

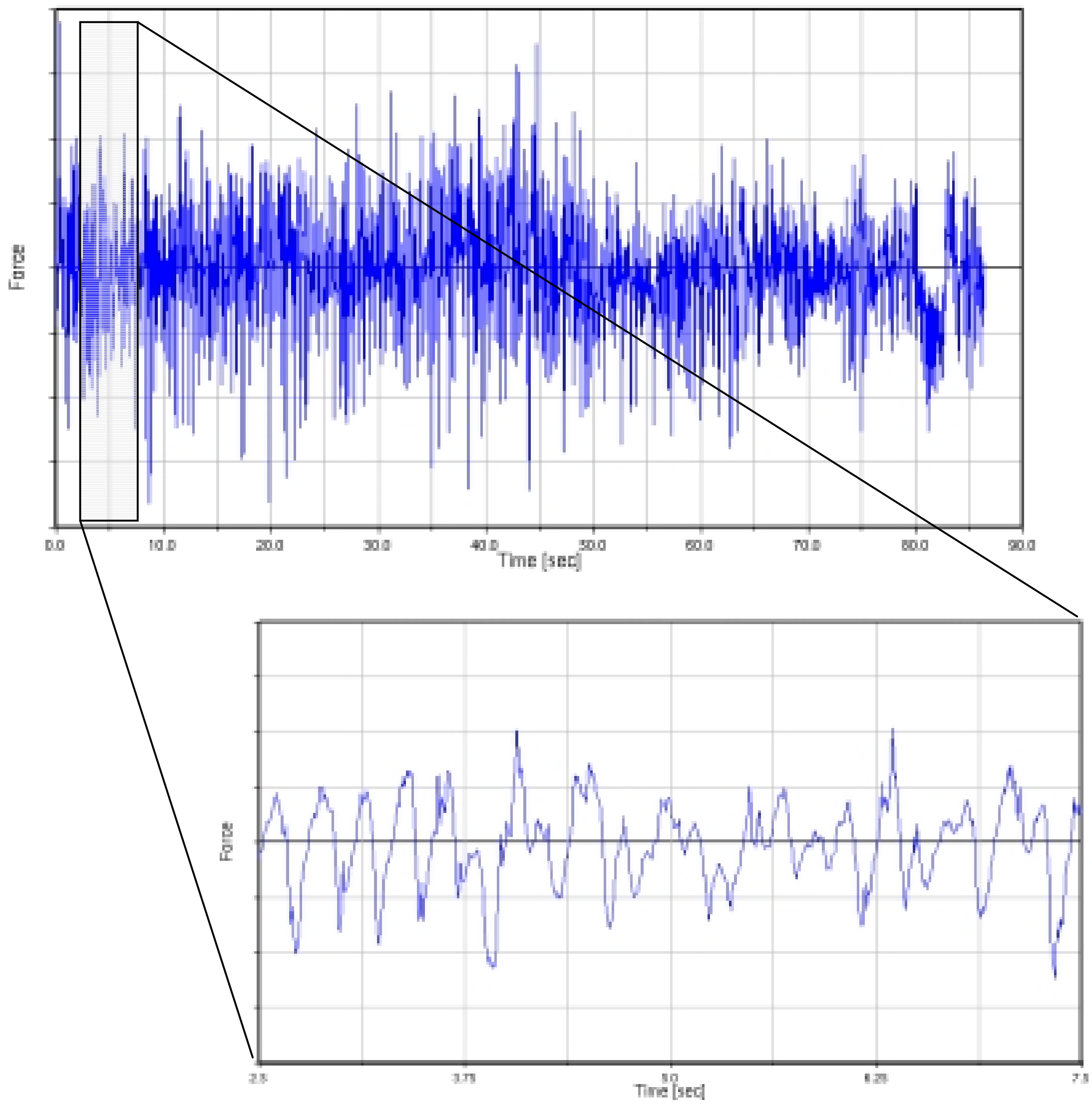


*Figure 5: $F_Z$-cross-sectional force acting between knuckle and lower control arm onto the wishbone*

The quality of the cross-sectional forces depends, among others, on parameters such as application points of tension/pressure stops. In such a case the experience and thorough acting of the calculation engineer is a decisive factor, since wrong input data result in faulty evaluation of the components with regard to operational strength.

After the decision which axle concept to use, these calculations are carried out for the complete vehicle. As a first approach, the torsional stiffness of the body can be taken into consideration by means of a revolute joint with a torsional spring that connects the front to the rear vehicle. Detailed results concerning the cross-sectional forces – above all those that act upon the body – are achieved when the body is taken into consideration by combining FEM and MBS. For a complete-vehicle simulation the measurement wheel hub forces and torques are applied on all four wheels. In this development phase, the measurement data are already based on 4x4 chassis load spectra measurements.

## 3. Systematic proceeding for model analysis

Due to the numerous process steps that are necessary to achieve proper simulation results, a great number of errors and misinterpretations may occur. For that reason it is absolutely necessary to adhere to a systematic proceeding for checking the MBS tasks. Basically, these activities consist of three groups, see Figure 6:

- Input data check
- MBS model check
- Result data check

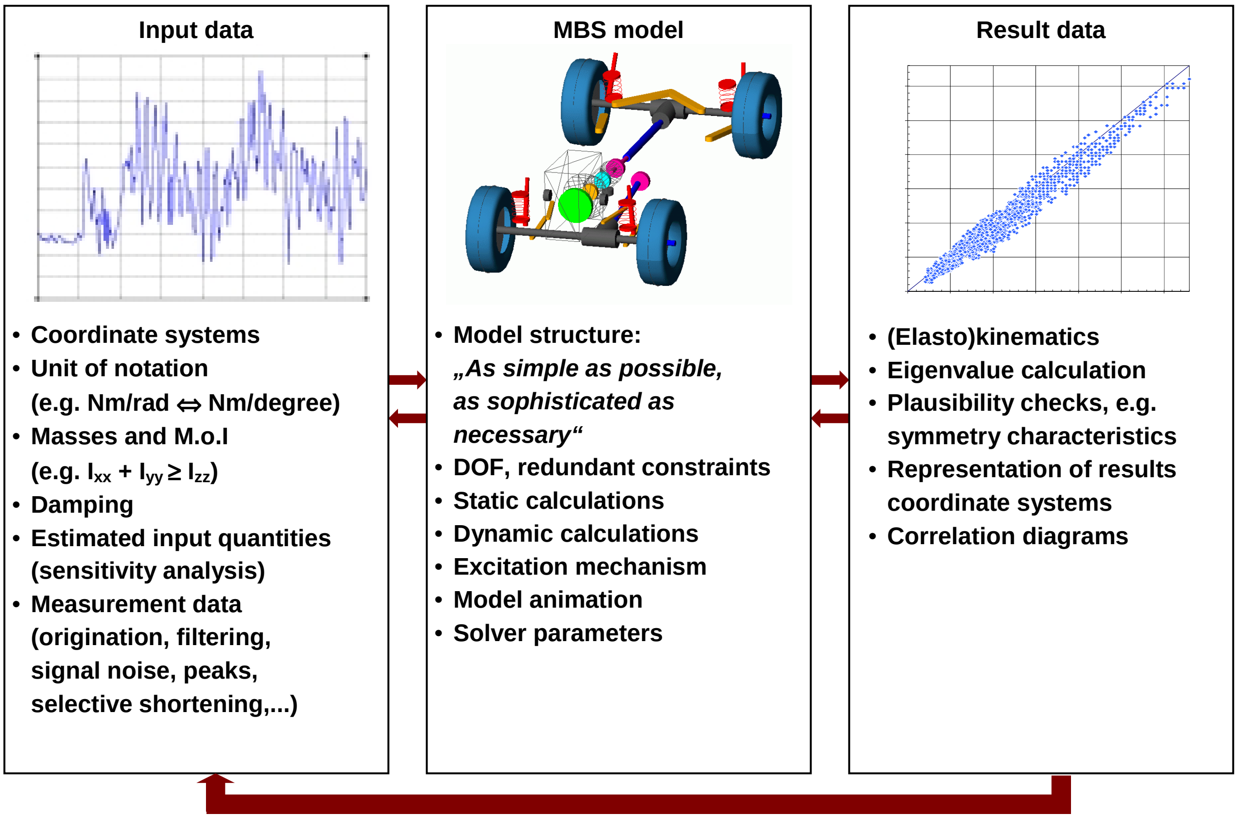


*Figure 6: Systematic MBS model check*

Usually, the input data are provided by test or design departments. A thorough and careful check by the calculation engineer is absolutely necessary, since numerous incorrect calculation results can be attributed to faulty input data. Wrong units of notation [Nm/degree] or [Nm/rad] as torsional input quantities for elastomer mounts, for example, can be identified by means of elastokinematic calculations as well as through eigenfrequency analyses.

In an early phase of vehicle development, during which, for example, the axle concept is determined, the theoretical support is of utmost significance for making decisions. Above all in this important phase the quality of the available input data is very often insufficient. Frequently, the calculations are carried out – and the conclusions drawn correspondingly – by using estimated input data which, of course are based on experimental values. The influence of these assumed data on the

calculation result must be either known or judged by means of relevant parameter variations.
The modeling depth of the templates provided by A/Car is definitely state-of-the-art. Such pre-defined structures very often lead to treating the question of model creation with insufficient consistency. The question whether to take the component elasticities into consideration by selective implementation of substitute stiffnesses or to choose the more exact but also more sophisticated way of implementing flexible structures must be permanently raised.
In the case of checking the output data of one and the same model, SFT basically strives for performing many tests in various special fields. The past experience showed that this procedure considerably improves the quality of the respective MBS vehicle model.
In the case of a result data check for the cross-sectional force calculation, clear distinction must be made between static and dynamic simulations, see Chapter 2.2. For static simulation the physical plausibility can be checked relatively simply by means of the force and torque equilibrium. Comparisons with the results of earlier projects should be made.
Checking of the dynamic simulation is considerably more sophisticated, since all load-time-histories must be checked individually in the time and the frequency range. Various tools are used [4] in order to check them in a time-saving and efficient manner. Extreme values and statistical characteristic values can be fetched immediately after availability of the results, and can be compared to the values of the static loadcases. One- or multi-dimensional Rainflow classifications serve as a means of comparing calculations of variants, and can be used for comparison of cross-sectional forces of other projects if these are similar as regards modeling depth and applied measurement hub quantities. In addition, analyses with regard to correlation of the load-time-histories are carried out, e.g. between wheel force application point and spring strut force. For checks in the frequency range, mainly FFT or PSD analyses are used. The frequency content as well as the amplitudes can be analyzed.
At SFT, the systematic proceeding in the field of MBS simulation has proved to be successful and is permanently extended and improved by the experience gained through current projects. Of course, some of the items of Figure 6 can be omitted if not required for the case at issue.

## 4. Final comments / Outlook

SFT considers A/Car to be a very good tool for vehicle development, however, some improvements must be made, e.g. the analysis Quasi-Static Maneuvers/Constant Radius Cornering with a 4x4 vehicle is not possible. Furthermore, it was rather sophisticated to create a static and dynamic test rig for the cross-sectional forces calculation introduced in this paper. This paper is also intended to serve as a means of specifying future demands of SFT on A/Car.
A short-term goal of MBS simulation is to drive with a physical tire model over defined obstacles and to compare the cross-sectional forces of defined components with the relevant measurement signals. In future, this process will be carried out prior to the chassis load spectrum measurement and serve as a means of checking the proper application of the measurement points.

A long-term goal of SFT is to drive with an MBS vehicle model over a digitized rough road track, which would above all at the beginning of a project result in better input data regarding the load spectrum and would allow to omit one or the other chassis load spectrum measurement.

## 5. Literature

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