Strategies for Mechanical Engine Simulations

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1 Abstract

In the development process of combustion engines two kinds of simulation techniques have been used successfully in recent years:

1. Thermodynamic and fluid dynamic simulations give information about combustion and gas exchange of the engine and help mostly to optimize the thermodynamic processes due to fuel consumption and emissions.

2. Mechanical simulations are important for understanding the parameters, that have influence on the durability of parts, the noise emission and the friction, which has an additional effect on the fuel consumption.

For the mechanical simulations, which are task of this paper, different numerical techniques are used, depending on the specific purpose. The most important tools used in this manner are:

1. Analytical solution of simple equations, often implemented as small programs,

2. linear and nonlinear Finite Element Analysis (FEA), including postprocessors for the evaluation of specific technical questions (e.g. vibrations, durability,...),

3. dynamic Multibody System Simulation (MSS) in time domain for the evaluation of the dynamic interaction between several parts.

Classically principle models have been set up and tuned individually, using results from simultaneous test rig investigations. The main purpose of these models is, to give the engineers an idea about the mechanical interactions.

With the increasing power of modern computers and the growing experience of the engineers it is possible today to create accurate results without model adaptation, that are exclusively used for design decisions. This is an additional and even more important purpose of simulation beneath its classical role, to help the engineer understanding a mechanical system. If Computer Aided Engineering (CAE) can partially replace expensive testing investigations, a large potential of cost reduction and efficiency will be used in development processes.

The main task for the calculation engineers is now, to find an efficient way to combine the calculation tools mentioned above. An MSS program as ADAMS delivers the most important preconditions to be the environment for this combination, because:

- the usage of USER-Subroutines is an efficient way to include analytical equations and
- the strength of linear dynamic FEA is available, using ADAMS/FLEX.

The full dynamic simulation of the "Virtual Powertrain" will be a combination of different simulation techniques, integrated into the MSS world of ADAMS.

2 State of the art

The reduction of costs and time to market without a loss of product quality are the most important targets of modern development processes. Using CAE these targets are approached by:

- understanding the physics of mechanical systems,
- come to quick design decisions,
- avoiding expensive and time consuming test rig investigations.

For mechanical simulations in the engine development process a wide range of simulation techniques is used. Especially in a very early design state concept tools, which are mostly engine specific small one-dimensional program codes, that require a lot of experienced engineering judgment to evaluate the results, deliver rough output before the first CAD data of the components is available. During the different further phases of the development process the degree of refinement of the used procedures is constantly increasing. The concept tools are more and more replaced by three dimensional CAE programs, that show more accurate results, but need much more effort for the model generation. The engineer's experience will, of course, never be replaced by simulation, so benchmarking is a necessary option in all project phases.

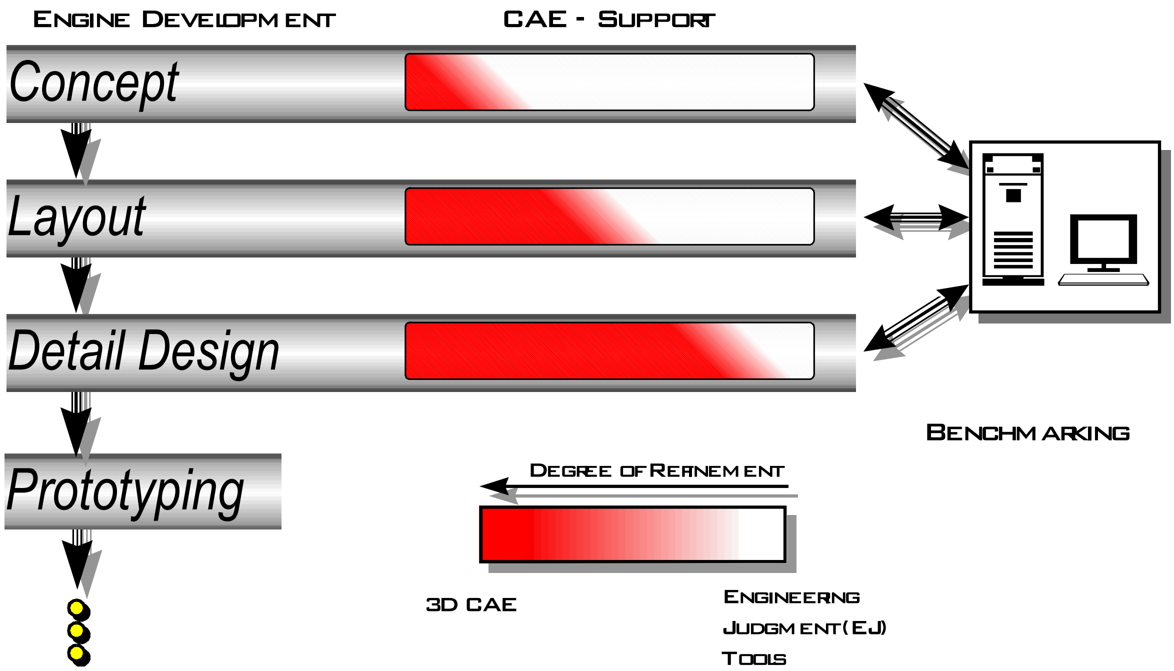

Fig. 1: CAE support in the development process, state of the art

Fig. 1 shows the relationship of several simulation techniques, having different degrees of refinement in engine development processes. Neither the easy and quick concept tools nor the high end accurate 3D programs are able to fulfill all targets on their own, because they perfectly complement one another. So the shown procedure is today the most efficient way to support the engine's design.

However, the strategy of combining different tools in one development process shows disadvantages as well. Due to the fact that the different codes have been developed by different persons having different specifications, compatibility cannot be expected. So all simulation models have to be set up individually. This leads to much redundant information in the CAE-World of engine development. Additionally, there are a lot of specialists required to work with the different programs. The exchange of model data between these people often leads to losses of information. The usage of different unit systems for example is a large error source in the communication.

Generally the wide range of CAE methods used in the engine development process is very efficient but has to be seen as a large quality risk.

3 Future Vision

This paper describes a concept for engine related simulation software based on FEV's know how in engine development and MDI's experience in the development of mechanical simulation software. The main target of the "Virtual Powertrain", which means a full engine simulation package, is the implementation of the strategy shown in Fig. 1 into the existing architecture of the new MDI product: ADAMS/ENGINE leading to the product: ADAMS/ENGINE powered by FEV.

The problems that appear using different techniques will be avoided, developing one product representing all methods mentioned above and their data exchange as shown in Fig. 2.

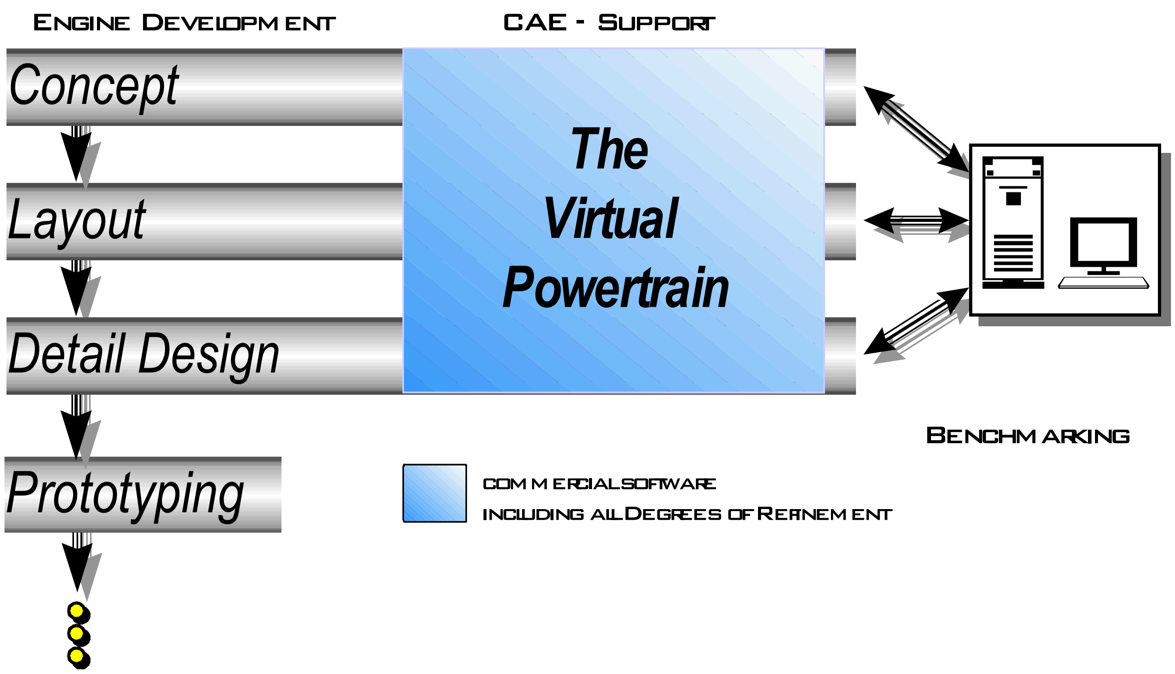

Fig. 2: CAE support in the development process, future target

3.1 Solution Strategy

The support of the engine development process by CAE takes place in several optimization loops using different tools in different project phases, as shown in Fig. 3. The requirements concerning initial data increase with the degree of refinement of the used tools. One of the most important duties of the "Virtual Powertrain" program is to carry the results of one optimization loop as initial data to the next one.

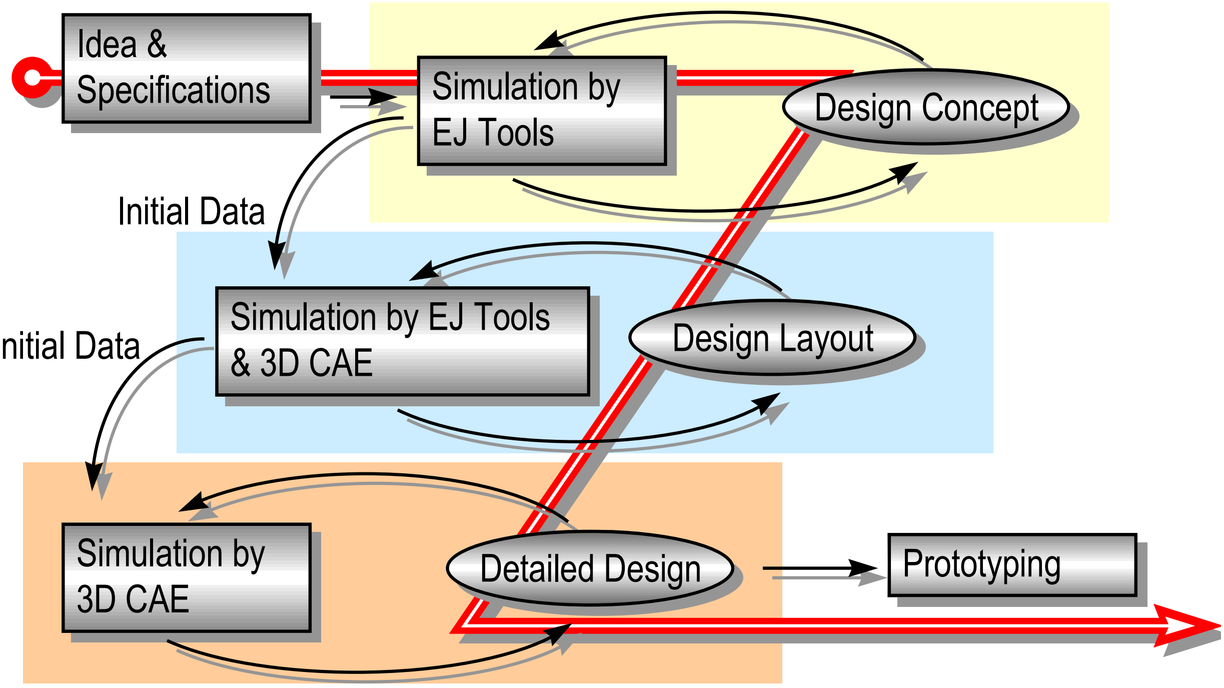

Fig. 3: Optimization loops and their interaction

Following this concept even very simple calculations using analytical equations may be included in the software. Conventionally the largest effort of these steps is not the calculation itself, but the documentation of the results and the error-free transfer to numerical codes. So a large potential of efficiency may be expected.

A large number of modifications is necessary to achieve a good design. Consequently all tools have to be as efficient as possible. This means, a strategy is necessary to evaluate whether effects have to be considered or not.

In general there are two different scenarios possible for the simulation of coupled problems. Fig. 4 shows the physical relations and the simulation strategies for these two possibilities. In the case of scenario 1 the physical effects are fully coupled. This means that they have an essential influence on each other and have to be simulated in closed loops.

On the other hand there are a lot of cases where backward influences may be neglected and it is possible to simulate the effects one after the other, using the results of the first calculation as input data for the second one. In Fig. 4 these cases are called scenario 2.

It is very important to evaluate whether it is necessary to apply a closed loop scenario 1 simulation or it is sufficient to work with scenario 2, because efficiency is the key to a successful design support by CAE: Only effects that have an essential influence should be considered at all.

A typical example for scenario 1 is the influence of the structural flexibility of an engine part on the dynamic behavior of the entire system and, the other way round, the influence of the global dynamic forces on the deformation of the part.

On the other hand the load and deformation status is a perfect input for the calculation of the local stress distribution, but local effects show almost no influence on the global deformation shape.

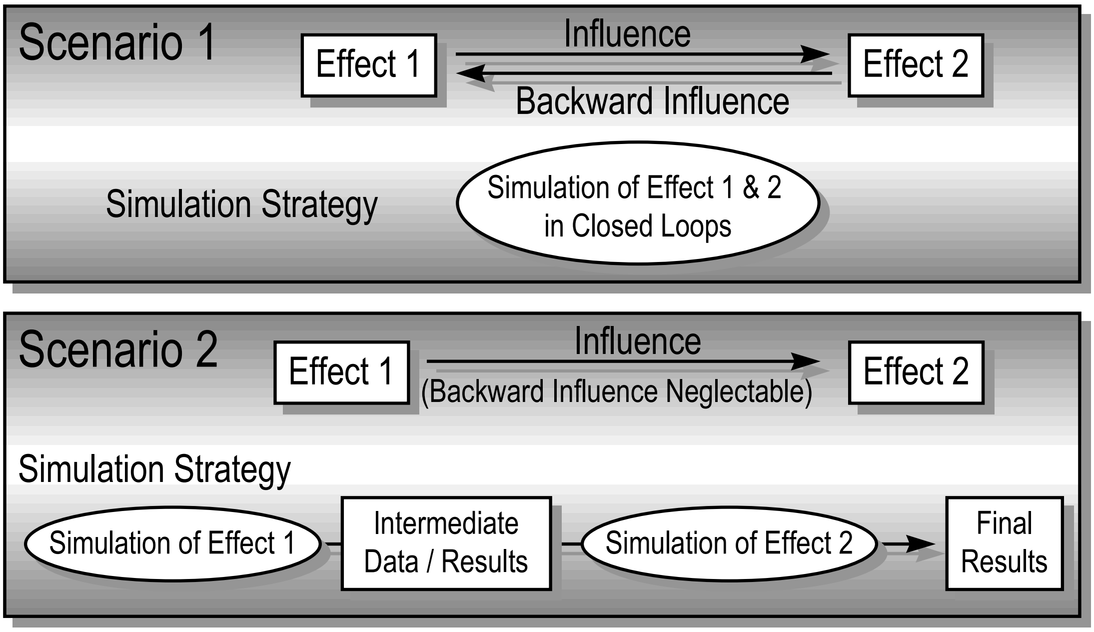

Fig. 4: Interaction of physical effects

The question, which scenario should be chosen, does not only depend on the physics of the subsystem, but also on the required results. Elastohydrodynamics (EHD), which is a typical example of scenario 1, is important looking at the bearings themselves and evaluating their durability in detail. Looking at NVH, the hydrodynamics of the bearings have to be considered, but the backward influence of the structural deformation on the local oil pressure distribution may be neglected. So a more simple and much faster Hydrodynamic (HD) approach will work in this case.

Looking at the total engine development process, it becomes clear, that for efficient CAE support steps both scenarios have to be possible in general. This is one of the main specifications of the "Virtual Powertrain": Simulation tools for each subsystem have to be available "stand alone", using fixed boundary conditions and "coupled", interacting with other subsystems.

Another very important demand is, that, as far as possible, common models should be used for several evaluation disciplines. Especially in the detailed design phase a lot of time can be saved, using this synergy. This means a global model is needed to show the general dynamic behavior of the powertrain which then may be used as boundary condition for detailed analysis of questions concerning durability, NVH or friction. Fig. 5 shows the detailed design optimization loop including a global MSS model and specific models for postprocessing. For the global model ADAMS is the perfect tool, because it is able to include all dynamic nonlinearities and delivers, with the load history feature, already the important interface for the detailed analysis to come to final results via scenario 2. The inclusion of flexible structures using ADAMS/FLEX is the most important scenario 1 process in this model. Other scenario 1 relations may be implemented using user subroutines.

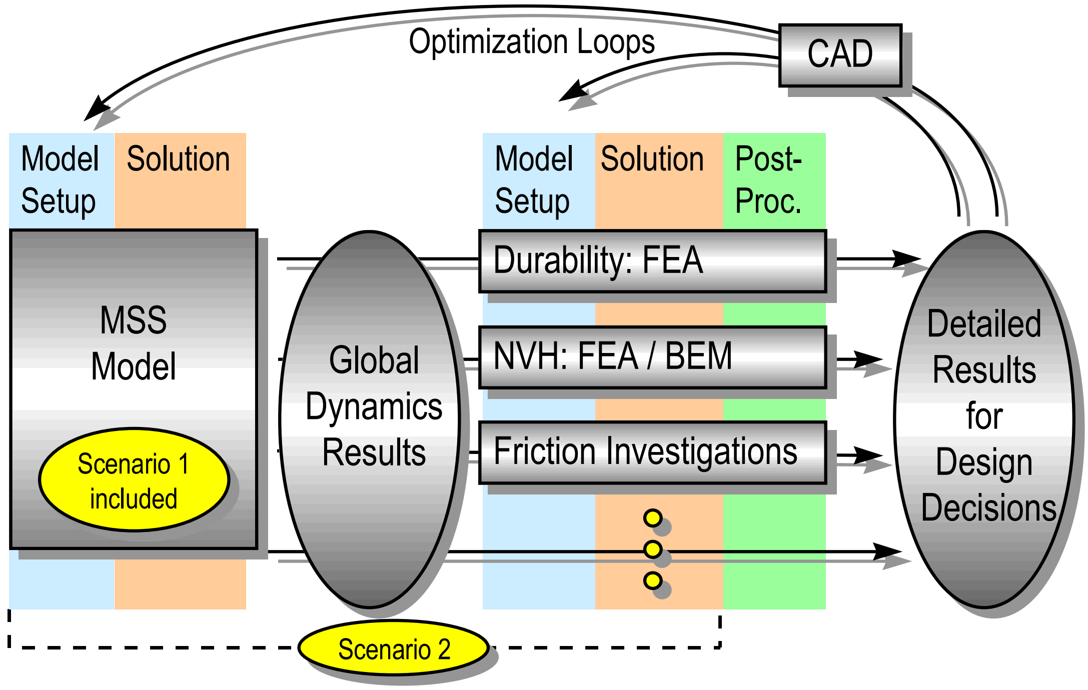

Fig. 5: Optimization combining Scenario 1 & 2

3.2 Modularization

The powertrain consists of several mechanical subsystems that have to be treated as simulation modules individually or combined (Scenario 1 or 2). Fig. 6 shows a possible modularization of the "Virtual Powertrain".

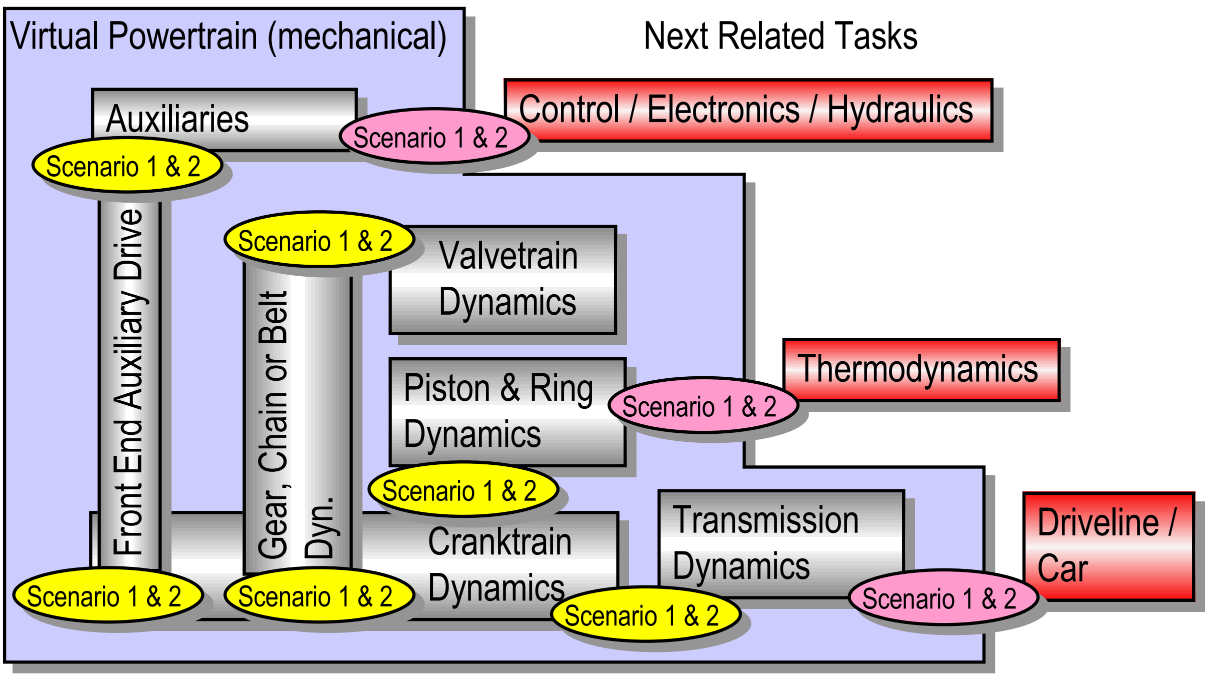

Fig. 6: Modularization of the "Virtual Powertrain"

At all interfaces between the modules scenario 1 or 2 will be possible. Scenario 1 means, that the two subsystems are combined to a common MSS model. In the case of choosing scenario 2 each module is simulated separately using pre-calculated loads or constraints and delivers time history results as input for the other module. The initial data to start with may be taken from measurement or from simulations of comparable engines.

The primary global loads and constraints for the mechanical powertrain are the thermodynamics of the combustion and the reaction of the driveline in the car. Additionally secondary boundary conditions, as the reaction of hydraulic pumps and the generator are getting more important in modern vehicles because more and more of the engine power is spent for the auxiliaries, driving an increasing number of additional electrical and hydraulical units.

For the "Virtual Powertrain" these interfaces should feed the powertrain model with boundary conditions (scenario 2) first. In a further vision of a the "Full Virtual Vehicle" these interfaces may also be implemented for full coupled analysis (scenario 1).

3.3 Controlling the "Virtual Powertrain"

Due to the large number of tools, included into the "Virtual Powertrain" the most important exercise is the data transfer from one simulation technique to the other one. Parameters preliminary fixed by conceptional engineering judgment tools have to be used by the further simulation program automatically without any additional effort for the user. To achieve this the tools have to be implemented under the roof of a global powertrain database that controls their interaction (see Fig. 7). It consists of all mechanical engine design parameters and all simulated time history results. The "Powertrain Meta Database" acts additionally as the interface to other development tasks as testing and benchmarking. For global design decisions and information exchange it will be accessed by the project management.

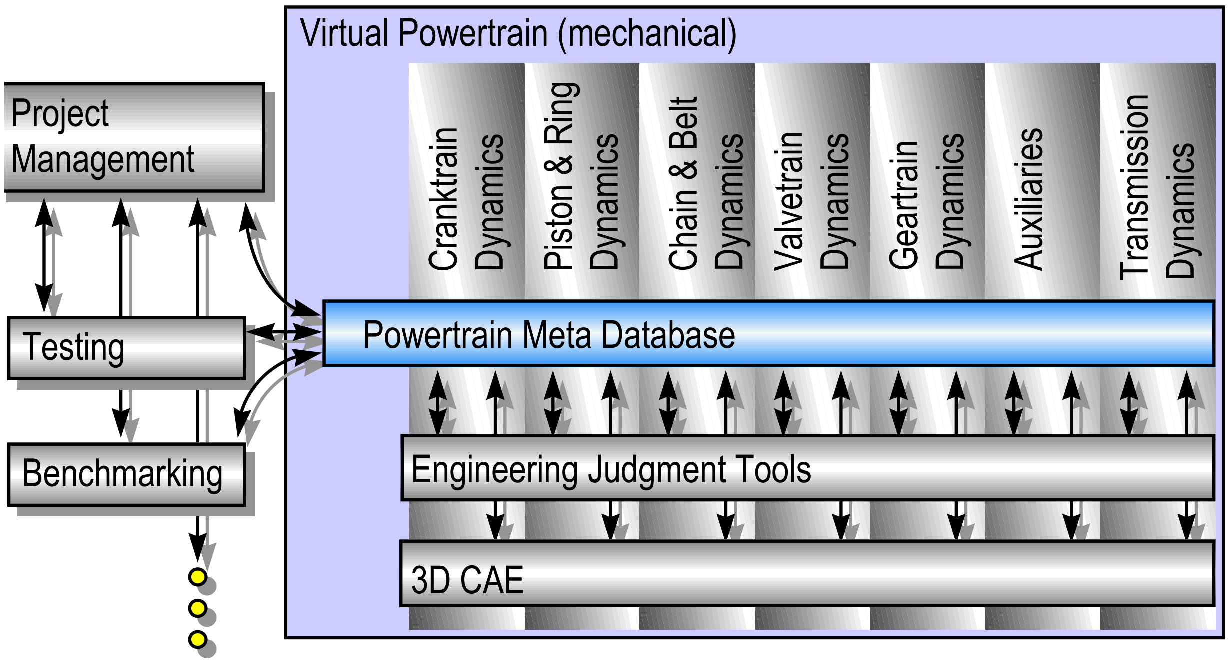

Fig. 7: Powertrain Meta Database

The resulting matrix structure, shown in Fig. 7, leads to a very efficient communication between the project management, that is responsible for the global engine specifications, and the technical specialists working on optimization steps at the several mechanical subsystems.

4 Summary:

For an efficient engine development support by simulation it is necessary to use tools having different degrees of refinement. Therefore the total range from engineering judgment estimations up to high level three dimensional CAE calculations have to be taken into the vision of the "Virtual Powertrain".

To come to efficient solutions it has to be checked carefully what kind of effects and backward influences have to be considered depending on the kind of physical problem and on the expected quality of the results. The "Virtual Powertrain" must therefore deliver both general possibilities for the simulation of coupled problems: with and without consideration of backward influences.

For the CAE support of the detailed design phase an MSS model including flexible structures and user subroutines is perfect for the simulation of the global dynamics of the powertrain. It delivers accurate boundary conditions for more detailed analysis on durability evaluations, NVH and friction issues. ADAMS shows all necessary preconditions to be the central software in this vision.

A global "Powertrain Meta Database" will be the connection of all the simulation tools used in the engine development process. It will additionally be the main interface for the project world outside the "Virtual Powertrain".

Starting with simulations of mechanical engine subsystems the "Virtual Powertrain" will grow to a full simulation package embedded into the vehicle simulation.