Special reprint from CAD CAM 9-10/2008

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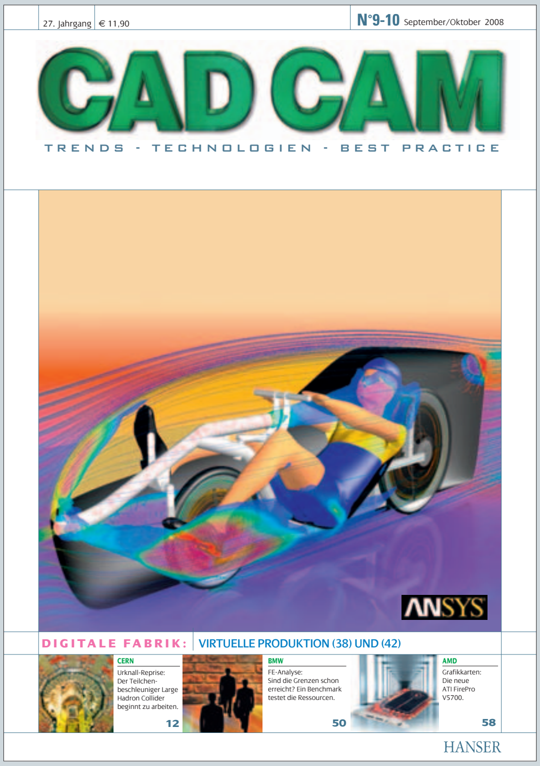
Reckoning With The Limits Of FEM Analysis



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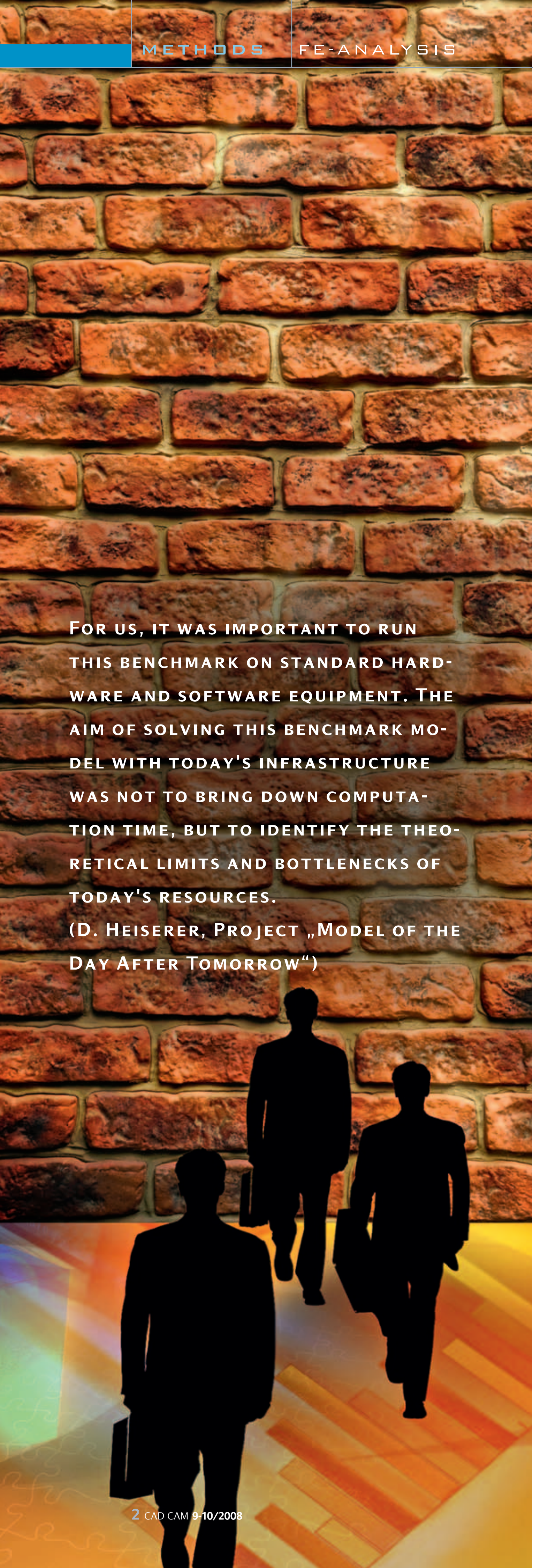


Reckoning With The Limits Of FEM Analysis

FEM analysis has become more complex and accordingly, the size and detailing of FEM models is continuously growing. Especially in the automotive industry this trend is obvious and the reason the German car manufacturer BMW asks the question, "How long can FEM programs cope with this growth?" The objective of a benchmark under the motto "Model of the Day After Tomorrow" was to stress the hardware and software to the limits it will face during the upcoming decade. MSC.Software and IBM have passed this test successfully.

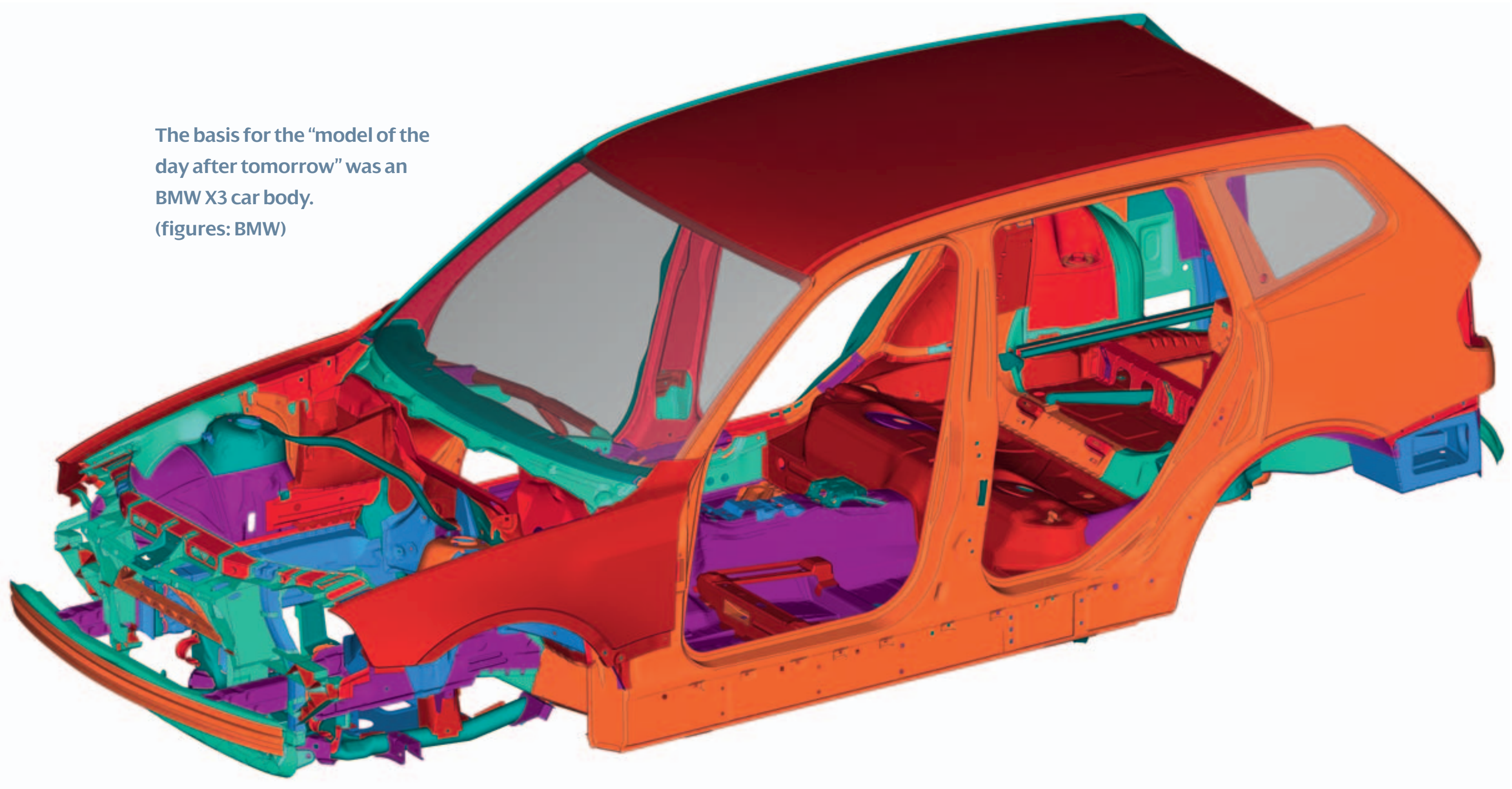
FOR US, IT WAS IMPORTANT TO RUN THIS BENCHMARK ON STANDARD HARDWARE AND SOFTWARE EQUIPMENT. THE AIM OF SOLVING THIS BENCHMARK MODEL WITH TODAY'S INFRASTRUCTURE WAS NOT TO BRING DOWN COMPUTATION TIME, BUT TO IDENTIFY THE THEORETICAL LIMITS AND BOTTLENECKS OF TODAY'S RESOURCES.
(D. HEISERER, PROJECT „MODEL OF THE DAY AFTER TOMORROW")

THINK BIG. Highly detailed meshes with several million elements and multi million degrees of freedom (DOF) have become common – and still the model size continues to increase. Due to the refinement of numerical methods and software engineering techniques the programs work with an increasing efficiency, the computing power increases constantly, and rapid advances in model creation and meshing software enable a relatively quick and convenient model generation. Some years ago several months were estimated for the meshing of an engine block. Today it is a matter of hours.

One of the companies which use and advance simulation techniques to a high extent is the German car manufacturer BMW. To shorten development cycles and to decrease the number of prototypes and tests at BMW, and at other manufacturers, complete car models are optimized on the basis of increasingly complex simulation models, ranging from stiffness evaluation via acoustic and comfort, to passenger safety and aerodynamics. On the numeric side this testing is carried out by launching both implicit linear based analysis and explicit transient analysis.

In early 2007 the computer assisted engineering process chain at BMW was reviewed in order to identify possible bottlenecks in the future caused by the increasing size of simulation models. Under the name "Model of The Day After Tomorrow" the group of functional design body and fitting developed the largest actual known FEM model for a system-benchmark.

Group member, Dr. Daniel Heiserer, stated that „For us, it was important to run this benchmark on standard



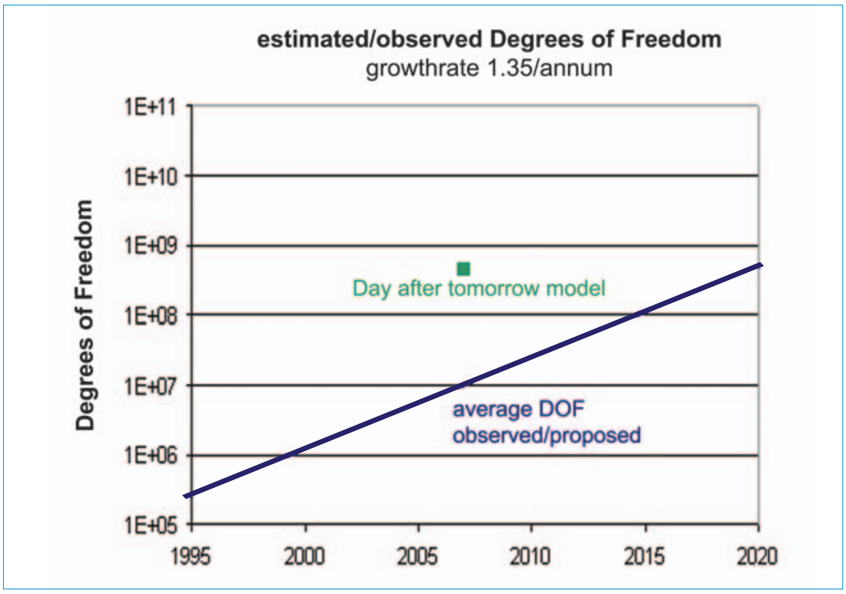
The basis for the "model of the day after tomorrow" was an BMW X3 car body. (figures: BMW)

hardware and software equipment. The aim of solving this benchmark model with today's infrastructure was not to bring down computation time, but to identify the theoretical limits and bottlenecks of today's resources. We concentrated on the pure calculation, because pre- and post-processing are subject to separate investigations."

The aim of the benchmark was to find out for a standard analysis (linear static with two load cases) up to what limits and in what time the fundamental steps of an FEM analysis can be performed:

- Read, sort, and tabulate the input data, consistency check
- Calculate element stiffness matrices and assemble a global stiffness matrix
- Compute displacements and stress data
- Output of the results

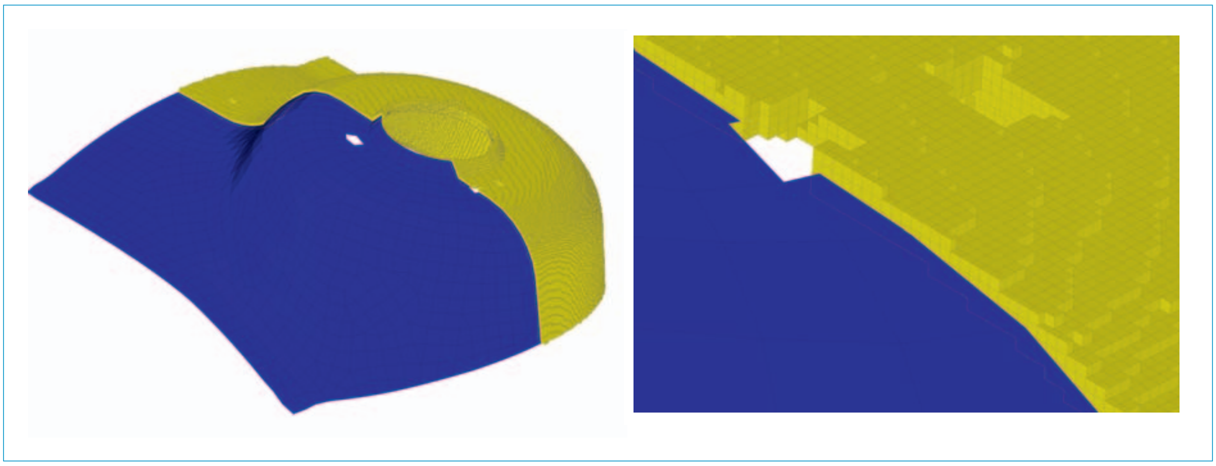
MSC.Software in cooperation with IBM was able to solve the problem within a few months. In a detailed report, which was used as the basis for this paper, the project members Peter Schartz and Gerald Himmler (MSC.Software), Dr. Daniel Heiserer (BMW AG) and Dough Petesch (IBM) describe their approach to fulfilling the ambitious requirements of BMW.



Observed average model size, including prognosis for 2020. Estimated/observed growth rate 1.35/annum. (figures: BMW)

Most established FEM programs have their roots in a time when the computing performance was not at its best.

In 1957 Ray W. Clough and his students developed what would become the Finite Element Method on an IBM 701 with just 16 Kbytes (16-bit) memory. Problems greater than about 40 equations required an out-of core solution logic, which means the outsourcing to a secondary storage medium. One decade later, when Nastran was developed, the requirements were similar. The customer NASA demanded a program for static and dynamic analysis of problems with at least 2.000 DOFs (Degree Of Freedom).



Shell model of shock tower of X3 model (blue), MODAW volume representation (yellow). (figures: BMW)

Today this seems to be history. As CPU speed and efficiency increased as well as memory sizes, the power demanding fundamental operations, like generation and assembly of the Finite Element matrix, can be computed without "out of core" operations.

Even the modern MD Nastran reflects the software design considerations from that early period, for example conservation of computer memory and efficient use of disk I/O subsystems via "out of core" or "spill" algorithms. Those attributes were extremely helpful for the generation of the global stiffness and mass matrix for the project.

The used computer system IBM p5-595 2.3GHz POWER5+ (figures: BMW)

The Model BMW X3

The basis for the model generation at BMW was the Body in White of the BMW X3, model year 2004, which refers to the basic sheet metal body design without trim components. For the size of the model the engineers orientated themselves at the extrapolation of empirical values, which predicts approximately 800 million DOFs for the year 2020.

The meshing program was developed by Dr. Heiserer and uses the Raw Meshing Technique (RAT), which allows an extremely fast HEXA-meshing of complex geometries, even on the basis of inconsistent or erroneous CAD-geometry. Disadvantages of RAT modelling are that the models are extremely large and that only basis stiffness properties can be simulated meaningful.

The final model for the benchmark with a maximum edge length of 1 mm contains 151 million grid points, nearly 95 million HEXA elements and 911 million global degrees of freedom. Removing rotational degrees of freedom yields a problem size of 455 million equations to be solved.

To ensure praxis-oriented conditions and to limit costs to a manageable size the test should be run with commercial programs and on single-processor computers. An appropriate computer for the FEM-symptomatic I/O and memory requirements was found in the American benchmark centre of IBM in Poughkeepsie/New York. The computer system used was an IBM p5-595 2.3GHz POWER5+ with 512 GB memory and a 6 TB scratch file system striped across 48 physical disks with a capacity of 146 GB each. For the optimal utilization of the available memory the ILP-64 Version of MD Nastran was used. To factorize the global (assembled) stiffness matrix a sparse direct multifrontal-algorithmm with a nested dissection reordering was employed.

The global stiffness matrix is the assembly of ca 95 million element stiffness matrices. The resulting factor matrix contains 5.7 1011 terms (more than 4 TB of data) to be solved at an estimated maximum front size of over 100,000. Nearly one CPU-year would have been necessary to calculate the solution. Because that much time was not available, the decision was made for an iterative solution with the included PCGLSS Iterative Solver, which needs significantly less memory and disk space and is highly effective especially for models composed of solid (3-D) finite elements. The analysis job was submitted requesting a memory amount of 50 GB, and an additional 10 GB memory segment for Modular I/O (MIO).

MIO is a smart I/O cache developed by IBM. It uses a relatively small amount of memory to asynchronously pre-fetch data during

I/O intensive operations that are common in MD Nastran.

To handle the huge amount of data a number of modifications and settings of system-parameters and Input-data had to be made, e. g. the runtime parameters for the internal maximum number of Grid-Point ID were increased to 160 million {standard: 100 million} and parameters for the PCGLSS solver were modified due to the size and kind of the used memory.

At the Input data the Grid Point Weight Generator output request was removed, as well as the generation of the mass matrix. The time and I/O savings were 22 min/226 GB and 1.4 hr/450 GB. Because of the restricted computer resources the second load case was not calculated.

Analysis Results

After 22 hours and 17 minutes the calculation of the analysis in serial mode was finished. The number of used CPU-seconds was 76,254; the CPU utilization was 95%. The analysis of the second load case would have increased the total calculation time by 15 hours (53,786 seconds) up to a total of 37 hours.

The total amount of scratch disk space required was 2.27TB. The analysis did 7.8TB of disk I/O. The binary output file for post processing was 99.9GB in size and contains the undeformed geometry and output for one load case (displacements and stress).The PCGLSS solver converged to a tolerance of 9.9803e-05 in 149 iterations and acquired approximately an additional 230 GB of memory. The total memory used was approximately 300 GB (60 GB MD Nastran, 10 GB MIO cache, 230 GB PCGLSS solver).

The project was based on the BMW X3 Modell 2003

Despite the extreme memory, disk, and I/O-requirements the calculation was executed on a standard hardware platform with standard software. Due to its “Out of Core” capabilities the MD Nastran analysis software is well positioned for the computation of extremely large problems. Besides the high efficiency of the software, the IBM POWER5-architecture, which features large memory with uniform efficient access speeds, proved essential for the fact that the calculation could be run in a sufficient time frame.

Translated by MSC.Software GmbH

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