Recent Approaches of CAD / CAE Product Development. Tools, Innovations, Collaborative Engineering.

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Abstract:

In this paper, the latest approaches in the field of CAD-CAE product development are presented, as they are applied in industry. Innovations in the software tools are shown such as they arise from multi-physical simulation technologies. And the implementation of these processes in collaborative engineering is discussed. Because of the authors background in the portfolio of Siemens PLM Software there is a focus on these tools.

Introduction

In former times integrated CAD analysis tools were limited to basic applications only. These were mainly linear Finite Element Analysis (FEA, FEM) types for strength analysis and Multi Body Dynamics (MBD) analysis for kinematics.

The focus of these tools was the design- and not the analysis-engineer. Goal was easy setup of analysis models and fast responses to enable designers for A-B comparisons and decisions. Designer's analysis tasks are typically characterized by less abstraction techniques, so his 3D CAD models should not be modified or idealized very much for analysis. Consequently meshing for FEA was performed by simple tetrahedral elements which can well be automatically created on solid geometry. These element types have been designed in such a way that for the basic discipline of linear statics even poor quality element-shapes already led to relatively accurate results. Therefore adaptive meshing strategies and high-grade polynomials were developed in FEA shape functions. Still a problem for designers is correct validation of strength results, so decisions about strength are usually not done by them rather by analyst- or measurement engineers.

Analysts in former times never used CAD integrated simulation tools, because of their usual need for more abstraction and complexity in geometry and physics. Missing functionalities relate in particular to possibilities for non-linear simulation (contact, material and geometry), advanced material laws, advanced meshing techniques with shells, beams and hexahedral elements and the coupling of different simulation methods. Additionally in many cases there exist self-made software codes for individual problems which must be coupled or integrated to FEA or MBD systems to be efficient.

One more limitation in former systems was the focus on mechanical engineering only. Other engineering disciplines like electrical-engineering, control-engineering and system simulation were not supported.

The situation in today's large CAD software vendors is characterized by the fact that they more and more must satisfy needs coming from big OEM customers such as automotive and aircraft industries. This leads to large software vendors take over smaller companies that have specialized technologies and try to include these technologies into their major system. Competition around these specialized technologies is running and the question how to integrate all these technologies efficiently into the main system becomes crucial.

That's why more and more specialized high-end CAE software becomes integrated into major CAD systems. Analysis engineers now more and more do find their special functionalities that were missing in the past. This is one focus in this article.

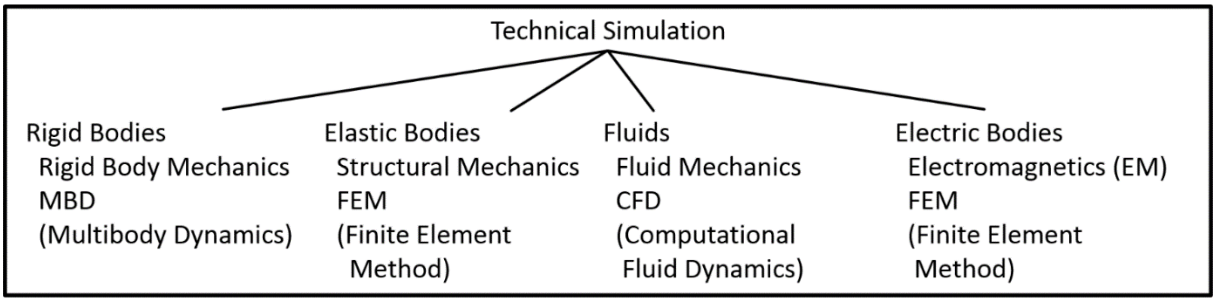

Figure 1: Disciplines integrated in CAD/CAE systems

Elementary disciplines that are integrated in most major CAD/CAE systems today are

- Strength Analysis computing displacements, stresses and strains through FEM,
- Dynamic Responses of Structures for free or forced vibration effects by use of FEM,
- Multibody Dynamics taking into account rigid body motion (MBD) to compute displacement, velocity, acceleration, joint-force and
- Thermal Analysis for thermal conduction, convection or radiation by FEM.

The following two disciplines are more advanced and currently at the beginning of becoming popular in major systems:

- Computational Fluid Dynamics (CFD) for pressure, velocity, turbulence through use of Finite-Volume-Method (FVM) and
- Electromagnetic Analysis (EM) for forces, eddy-currents and field-strengths computed by FEM.

Stand-alone tools of course are there and are powerful in their respective fields. But the challenge today for OEMs is the utilization of integrated CAD/CAE software that does allow for adaption to needs. Stand-alone tools must fit in this structure. So interfaces play an important rule.

Backbone for all of this is Product Data Management (PDM), what in area of CAE turns out as Simulation Data Management (SDM).

Multiphysics Solutions

While in the past solutions for those elementary disciplines mentioned above have been in focus today and in future there are more and more solutions for coupled problems needed. Following we describe some main types of those solution types, how they can be performed and in which industrial applications they are used.

Thermal / Structural one Way

One way thermal structural coupled analysis does first compute for temperature fields and then apply those temperature fields as loads to structural models. This is needed in all fields of strength analysis cases where thermal expansions plays a role. An example are motor housings.
Since mapping of temperature data from a thermal mesh to a structural mesh through interpolation methods is not very complicated this analysis type is not difficult to perform. It can be done in most integrated CAD/CAE systems today.

Thermal / Structural two Ways

A two way coupled thermal structural analysis is much more sophisticated. Temperature loads lead to structural deformation similar to the simple one way coupling described above. But the two way approach takes into account that deformed models may lead to different thermal conditions. This particularly appears if there exist contacts that – if closed - transfer thermal fluxes. Example applications for this are screwed container seals in nuclear plants.
This type of analysis is much harder to perform since iterations must be carried out and some convergence criteria must be controlled. Also meshes are needed that are good for the thermal as well as for the structural part. Because of those many iterations result mappings between different meshes should be avoided.
In todays integrated CAD/CAE systems this type of analysis is beginning to take place.

Thermal / Fluid two Ways

The combined analysis of thermal and fluid is carried out separately in rigid body regions and in fluid regions. At all interfaces there must be solved for heat transfer conditions. Example applications are cooling of electronic systems.

The analysis in rigid bodies is of simple thermal type. In fluid regions Navier-Stokes-Equations are solved by CFD. Since CFD is already an iterative solution that takes temperatures into account an application of rigid body temperatures is not very much more complicated.

Several systems today do have availability for this analysis type. But still this is not common for most of them.

Fluid / Structural one Way

Forces and pressures arising from fluid lead to deformations. These effects are taken into account by first analyzing for flow, capturing forces on walls from pressure results and transferring them to following structural analysis. Again mapping between different meshes must be carried out. Applications are stationary aircraft wing investigations.

Only some of the integrated CAD/CAE systems allow this analysis type.

Fluid / Structure Interaction (FSI)

The case FSI is fluid structural coupling in two ways. Fluid forces lead to deformations and those deformations lead to different fluid conditions. Applications are aircraft wings and turbine blades braking due to FSI oscillations.

FSI type analysis is currently not well established in the major integrated CAD/CAE systems.

Electromagnetic / Structural one way

Electromagnetic forces, for example Lorentz-forces, are computed in the EM solver and transferred to structural models to be solved for deformation, stress and strength. Applications are minimum air-gap studies in electric motors. This analysis type and all following regarding to EM, are possible in few systems only.

Electromagnetic / Thermal one way

Losses that result from electromagnetic eddy-currents and hysteresis effects, are computed in EM solvers and then used as thermal loads in following temperature studies. Application is electric motor thermal analysis. Few systems only allow this type of analysis.

Electromagnetic / Thermal two ways

Again losses are computed by EM and used to find temperature fields in the second step. But now those temperatures lead to different material-properties and back influence the EM result. Particularly the electric conductivity in electro-sheets of motors varies heavily with temperature. So common applications are electric motors again. Again, only few systems allow this type of analysis.

Control-System / Dynamic Response

For example in machine tools, vibration behavior is improved with controller circuits. For simulating these effects either control system models must be integrated into FEA or FE models must be integrated into control system models. Few systems only allow this type of analysis.

Solver Languages

All major FEA solvers today provide thousands of commands that allow analysis of very special problems. In common cases only small percentages of all commands are used in the analyst's daily work. User interfaces allow easy finding necessary commands for the daily work.

One recent approach addresses general ways how to implement new solver technologies in CAD/CAE systems. The need for this comes from the fact that more and more special technologies must be implemented in large CAD/CAE systems. This method utilizes so called solver languages and a neutral language for solvers. Currently this is developed for FEA solvers, but in future it may be available for other types like MBD too. Key idea is that all input data for any FEA solver can be classified by the following set of objects:

- Element Quality Checks: Special quality checks for the considered solver.
- Solution Class: Description of all solutions that characterize the solver, for instance Thermal or Structural or Electromagnetic.
- Sections: One-dimensional elements may need various sections.
- Elements: The various element types a solver can handle.
- Physical Property Tables: All physical properties like material data.
- Modeling Objects: Additional data blocks.
- LBCs: Loads, boundary conditions, constraints and related data.
- Solution: Detailed description of the physical solutions that the solver can perform.

By use of these solver languages companies can implement their own solvers with specialized capabilities into the commonly used CAD/CAE system. This increases collaboration effectiveness between different analysis groups in companies.

The software vendor has another advantage: He can easily and fast implement new solver technologies into the CAD/CAE system.

Master Model Approach

While simple analysis types – linear FEA and MBD Kinematics - became integrated into CAD systems some basic techniques were developed that allowed associativity between CAD and CAE data. These techniques resulted to be very successfully and today are still exploited by CAD/CAE systems. Of course the master model approach is used there basically. This means that all data for downstream processes is held in separate files being connected to the CAD master geometry. If the CAD geometry changes everything can update. Also this gives the basic possibility for engineers working concurrently on a digital product.

Designer / Analyst Collaboration

Next basic approach is the idea that CAE objects are linked to CAD objects. CAE Objects describe the CAE problem, such are forces, meshes, boundary conditions, material properties and others for FEA and similar links, joints, drivers, sensors for MBD. CAD objects are faces, edges, bodies and vertexes. While these CAE objects are connected to CAD objects fully automatic updates after geometry changes are possible. As an example you can imagine a CAE force object. The force object stores its magnitude and direction. The direction may be set to perpendicular to a CAD face. So if the CAD face changes because of designers work this force will update to a new direction. The following figure shows an example of MBD objects referencing CAD objects.

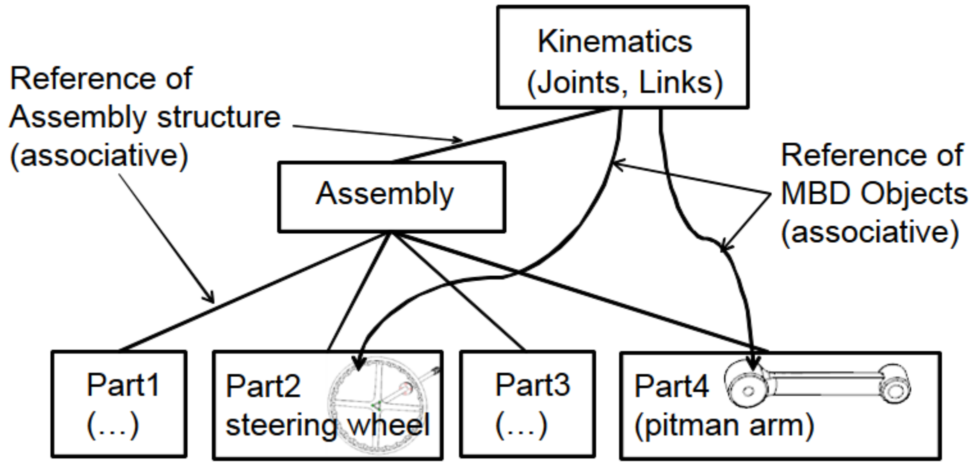

Figure 2: Associativity CAD to CAE

One newer approach supports concurrent engineering between CAD designers and analysts. In general also analysis engineers need to modify CAD models. Commonly there must be done simplifications, defeaturings, midsurfaces and other modifications. Therefore they need to modify CAD geometry but it is not allowed to modify the CAD master. So this approach offers an additional CAD model, we call it idealized CAD model, which is placed between the origin CAD master and downstream CAE files. Associativity between the origin CAD master and this idealized CAD model must be given by using associative geometry links. By this way changes in the CAD master lead to updates of CAE data. Nevertheless CAE engineers do have possibilities to modify geometry.

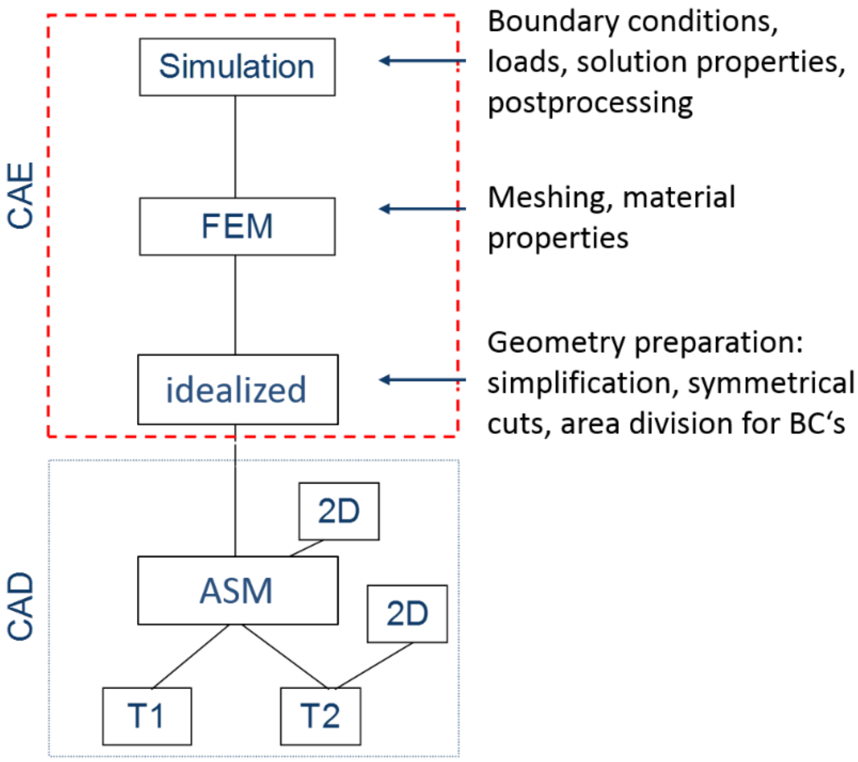

Figure 3: Idealized file and its integration in the CAD, CAE file structure

Design-Embedded Analysis / CAE-Experts Collaboration

A further approach for the support of concurrent engineering between design- and analysis engineers is given by the following. There are CAE software tools used by design-engineers and there are other tools used by analysis engineers. Both must have access to the CAD master so in the first step they simply can be placed parallel in the master model approach. But there are one or two additional data exchanges necessary because design-engineers may want to transfer their CAE models to analysis engineers to make it possible to see and check what is done there and maybe to use parts of it in more sophisticated simulations. This is the first additional data exchange and the second one, which is optionally only, allows improved models from analysis engineers to be back transferred to design engineers. These exchanges between design- and analysis engineers can be realized in various ways. An optimal solution would be if they both worked with exactly the same software, so all files could be shared. A good compromise is to use the same solver, so data exchange can be performed via solver input files. In many practical cases today there is still no digital data exchange between the two groups, models are set up multiple times and communication works via telephone or meeting-sessions.

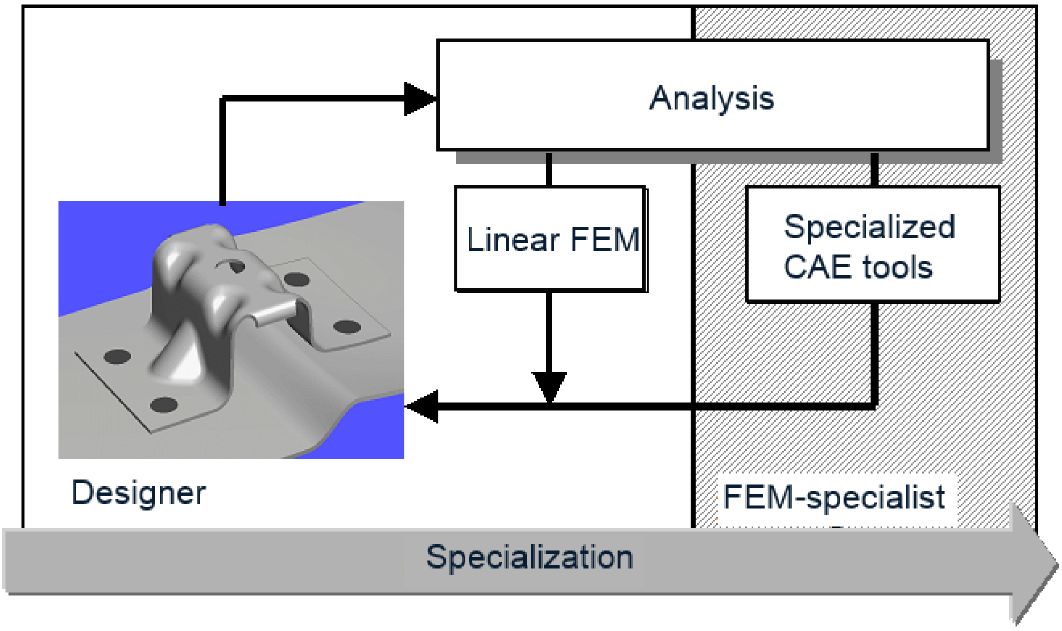

Figure 4: Design embedded Analysis / Analysis Experts Collaboration

Data Management

The management of analysis and simulation data aims to integrate analysis and simulation results in the workflow of virtual product development. For this purpose, this information is embedded in a PDM environment. Background information can be found in the recommendation [SimPDM]. An overview of the results of the SimPDM project group provides [Anderl3].

Most manufacturing companies today face the challenge of having to develop faster and more complex products. Design and simulation play a key role for the evaluation of product development results. What is new for many engineers is that simulation is gaining an increasing importance and for a higher development efficiency its integration with 3D product modeling is a critical success factor.

This linkage problem is characterized by the following properties [AnderlBinde1]:

- Personnel separation of modeling from the analysis,
- Many different CAE software systems,
- Many analysis variants,
- Lack of relationship of CAD to CAE models,
- Lack of process orientation,
- Inadequate data protection,
- Insufficient supplier integration.

In our following discussion, we restrict ourselves to the solutions of the PLM system Teamcenter from Siemens Industry Software GmbH and its CAE expansion modules, which are known under the name of *Teamcenter for Simulation*. These solutions now offer solutions for some of the above-mentioned problems or at least approaches to overcome them.

If in Teamcenter a standard CAE analysis is performed, the native files (figure 3: Simulation, FEM and Idealized) are assigned to the corresponding Item Revisions (CAEAnalysis, CAEModel and CAEGeometry) as references (see next figure). These CAE Item revisions can be revised independently. In addition, data is automatically provided with relationships. This data model and the relations - somewhat simplified - are shown in the following figure [TCSim].

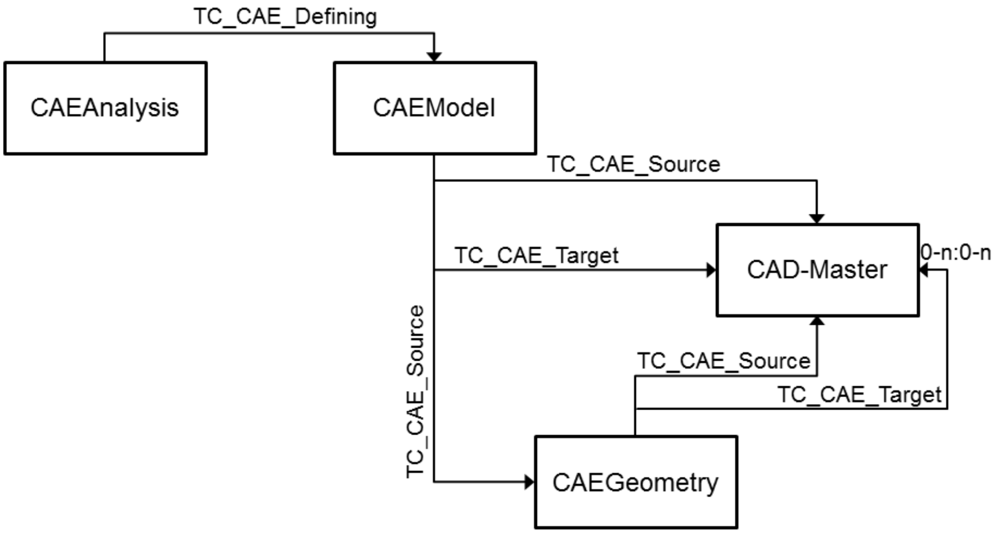

Figure 5: CAE Data Model used in Teamcenter

The relations have the following meaning:

- TC_CAE_Defining: Therefore relationship can be traced, which CAEModelRev is used by the CAEAnalysisRev, so which meshing is computed with a SIM file. For a CAEAnalysisRev there can be only one CAEModelRev, because there can be only one mesh for the computation.
- TC_CAE_Source: This relationship indicates from which item revision a model has been created, so what item revision was the source. It can be defined between CAEModelRev and CAEGeometryRev or between CAEGeometryRev and CAD Master revisions. In case that no idealized file is used, this relationship may also exist between CAEModelRev and CAD master. There can be only one source at a time.
- TC_CAE_Target: This relationship documents for which CAD-Master-Revision each CAE-Item-Revision applies (from CAEModelRev to CAD -Master-Revision, from CAEGeometryRev to CAD-Master-Revision). There may exist several TC_CAE_Target relationships in parallel. An example of multiple parallel TC_CAE_Target relations is the following: The simulation for a green part shall have validity for the identical blue, yellow and red parts.

Using this data model, the desired relationships between CAD and CAE are now available. Thus it can answer the questions: "Which CAD model belongs to which FEM model?" and “Are there new CAD revisions for my FEM model?”. Also the problem of a high variety of analysis variants is addressed. Additionally, these relations allow to automate approval processes between design and analysis.

Literature

[SimPDM] ProStep iViP Recommendation “Integration of Simulation and Computation in a PDM Environment (SimPDM)”. PSI 4, Version 2.0 2008

[Anderl3] Anderl R./Grau M./Malzacher J.: SIMPDM – a harmonized approach for the strategic implementation of simulation data management. NAFEMS World Congress 2009

[Anderl4] Anderl R./Malzacher J.: SimPDM – Simulationsdatenmanagement-Standard nach Maß. In: CAD CAM, Nr.1-2, 2009, Pg. 38-41

[AnderlBinde1]

[TCSim] Training documentation for Teamcenter for Simulation. Siemens PLM Software.