Title:
CAD/CAE Associative Features for Cyclic Fluid Control Effect Modeling

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Introduction:
Interfacing CAD and CAE tools is widely recognized as a technical gap without a general solution. There are two commonly applied approaches to establish the integration: one is to develop an integrated system with both CAD and CAE modules equipped, for which the feature-based techniques are supposed to maintain the semantic information during model conversion [1]; the other is to develop a unified feature model incorporated with both CAD and CAE information, with which both CAD and CAE views could be extracted and the information consistency could be easily sustained. In this extended abstract, CAD/CAE associative feature is proposed to manage the geometric and semantic associations between CAD and CAE models based on the well-established associative feature concept [7]. In addition, CAE boundary feature is put forward as a robust tool to maintain information consistency during the conversion. CAE effect feature is introduced by extracting the sensitivity information from the CAE results which are necessary for guiding the design modification properly. By utilizing these new concepts, a new CAD/CAE integration framework has been developed, which covers both the forward and reverse integrations and supports the automated cyclic product development.

Main idea:
Associative feature concept [7] is used to interface the CAD and CAE tools, which synchronizes the different application models and guarantees the consistency. The overall CAD/CAE integration scheme is shown in Fig. 1.

CAE boundary feature can be defined as a class of features that contains the mapping relations of geometrical dependencies between CAD entities and their associated CAE mesh representations, e.g. grids and tetrahedrons, as well as non-geometrical dependencies, such as inherited properties, like names, tags, constitutional structures, and conceptual constraints to apply CAE boundary conditions.

In order to realize the automatic interpretation of the CAE result, the concept of CAE effect features is defined as a class of features that represents the unique characteristics of interested measure changes for a physical behavior in the context of a CAE analysis scope. How the proposed feature concepts interact in the integration is shown in Fig. 2.

In hydraulic systems, components such as valves and pumps can be modeled by parameters. Parametric modeling can be achieved by the library in CAD module. Fluid space is abstracted from the established geometry by Boolean operations. Because surface IDs in CAD system may differ from that in another system [8], the IDs of fluid space surfaces will be assigned specific tags with attributions and boundary conditions attached. The information of entities with tags is stored in database for later processes. Tab. 1 shows the mechanism how information is transmitted between different module, in which m, n, p and q are the numbers of corresponding faces in CAD model.

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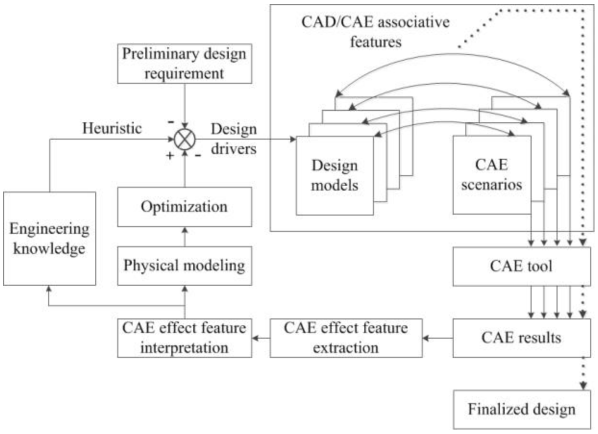

Fig. 1: CAD/CAE integration scheme.

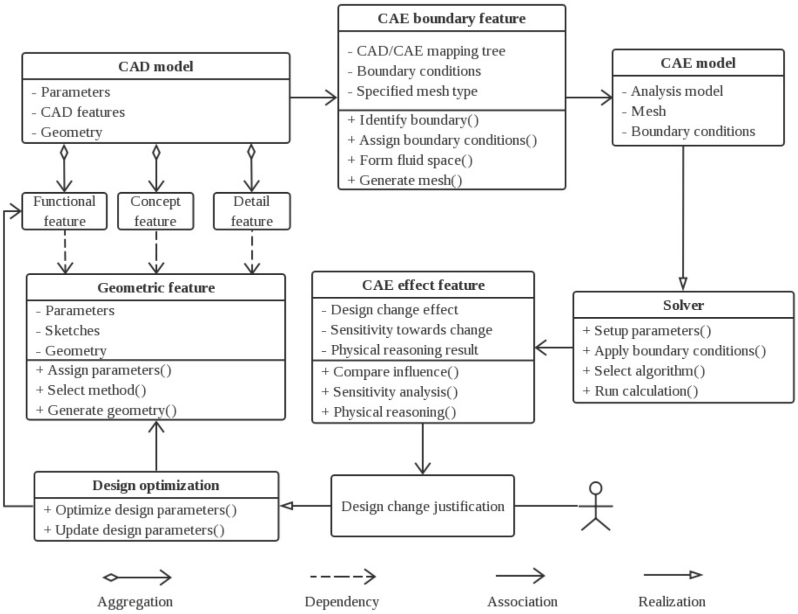

Fig. 2: Semantic associations in CAD/CAE integration.

Tag	*Attribute*	*Boundary condition*
$I_1, I_2, \ldots\ldots, I_m$	Inlet	Velocity or pressure inlet
$O_1, O_2, \ldots\ldots, O_n$	Outlet	Velocity or pressure outlet
$W_1, W_2, \ldots\ldots, W_p$	Wall	No-slip wall
$S_1, S_2, \ldots\ldots, S_q$	Symmetrical plane	Symmetry

Tab. 1: Information transmission in CAD/CAE conversion.

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Based on the design of a valve, Fig. 3 shows the detailed CAD/CAE integration mechanism. The valve can be parameterized by the dimensions in both axial and radial direction. According to empirical formula, forward physical reasoning can be achieved, which will be useful in the optimization process. CAE boundary features are identified to establish the links among geometry surfaces, corresponding boundary conditions and specific mesh generation. Surfaces such as inlet, outlet, wall and symmetrical plane with unique tags will be invoked from the database and assigned names with the type of boundary. Solver in CAE module will automatically recognize the boundary with such kind of names and assign boundary conditions correspondingly if applicable. Later in meshing stage, CAE boundary features also direct the mesh generation and refinement. For example, mesh inflation is applied along the wall boundary in order to obtain more accurate result. In this process, the non-geometrical parameters remain unchanged.

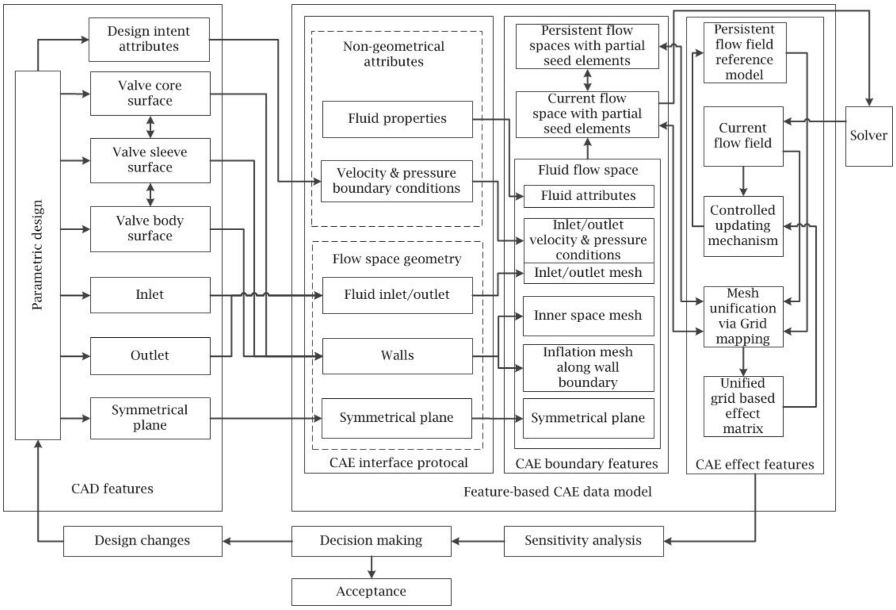

Fig. 3: CAD/CAE integration mechanism.

In the meshing stage, it is important to remove the irrelevant geometric details within the error limit providing precondition for steady calculation. Ferrandes et al. [4] put forward a method not only evaluate the error of simplification but also repair the model if the simplification triggers unacceptable error. Simplification features concept [6] was proposed to identify the details to be simplified and maintain consistency between CAD model and FEA model. The assessment and control of simplification will increase the robustness, accuracy and efficiency in cyclic integration.

With the meshing done, Finite Volume Method (FVM) is applied to solve the flow field because it is usually the most efficient for flow simulations. Optimization will be needed if the original design does not meet the requirement. Both of the CAD and CAE features will be modified after the modification of the design parameters, such as the valve core diameter. In remeshing stage, a 3D automatic remeshing method [5] is well suited for remeshing models with small design parameters change. With the remeshed CAE model, analysis will be processed again. CAE effect features which are the differences of different rounds of the analysis results will reveal the sensitivity towards design change. This will provide the backward physical reasoning. The physical reasoning of a phenomenon will figure out the method of modification and thus propel the iteration. Therefore, the CAE effect features support the CAE to CAD process and further help establish the CAD/CAE integration loop in which consistency

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maintenance [2] is used to update the feature model in different view. The process iterates until an optimal design is obtained.

As shown in Fig. 4, the proposed system mainly consists of a CAD module, a CAE module and a post-processing module. CAD module and CAE module can be commercial software which is capable of complex geometry and analysis. Most commercial CAD systems employ design by feature (DBF) method [3]. There is a feature library in the CAD module to support model creation with DBF. Under the associations, CAD model is converted to analysis model which can be processed by CAE module. In post-processing module, CAE effect feature are extracted with different CAE results. Physical reasoning gained from CAE effect feature is sufficient for the optimization of design parameters which will be updated in CAD module. Users can get access to all the modules through user interface.

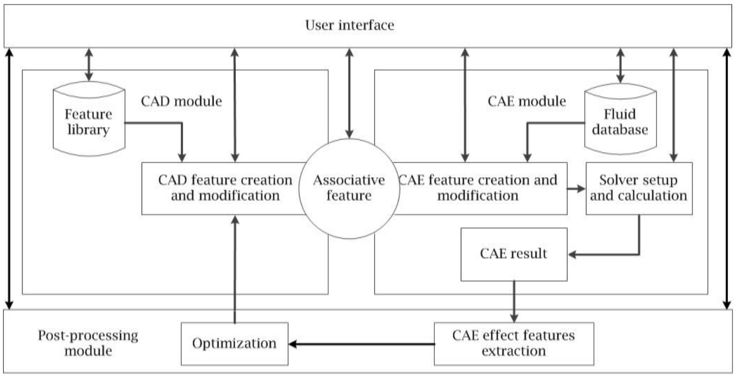

Fig. 4: Prospective CAD/CAE integration system framework.

The development of a valve is illustrated to show the effectiveness of this method. The conceptual design is shown in Fig. 5 (a). The P-A fluid space with tags assigned, which is shown in Fig. 5 (b), is studied to check whether the maximum velocity exceeds the allowance. The mesh is generated as shown in Fig. 5 (c). Fig. 5 (d) shows the result of the analysis. It is obvious that the maximum velocity is approximately 34 m/s, which exceeds the limitation of 27 m/s. Hence, optimization is needed.

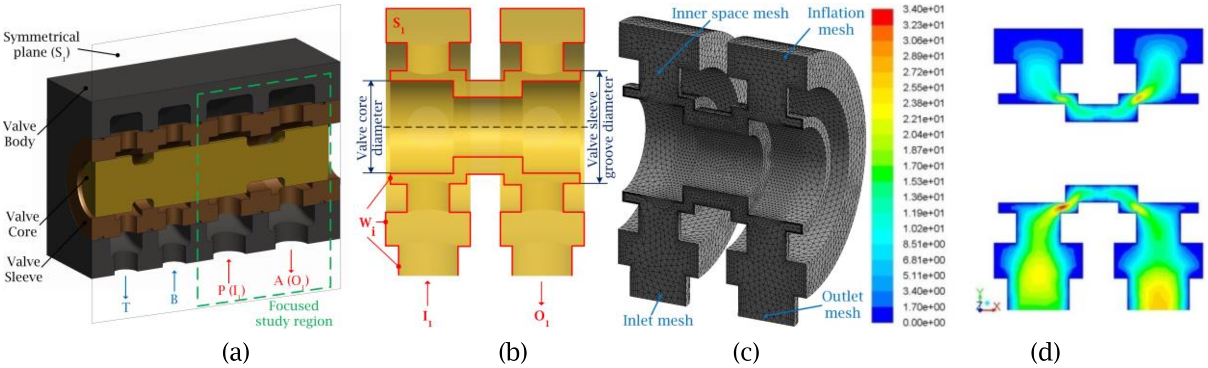

Fig. 5: Case study of a hydraulic valve: (a) Valve structure, (b) Fluid space abstraction (Sectional view), (c) Mesh generation, and (d) Velocity distribution.

In design optimization process, the valve core diameter is increased by 1 mm per step. The developing trend of maximum velocity is shown in Fig. 6 (a). In order to obtain faster decreasing rate, the valve

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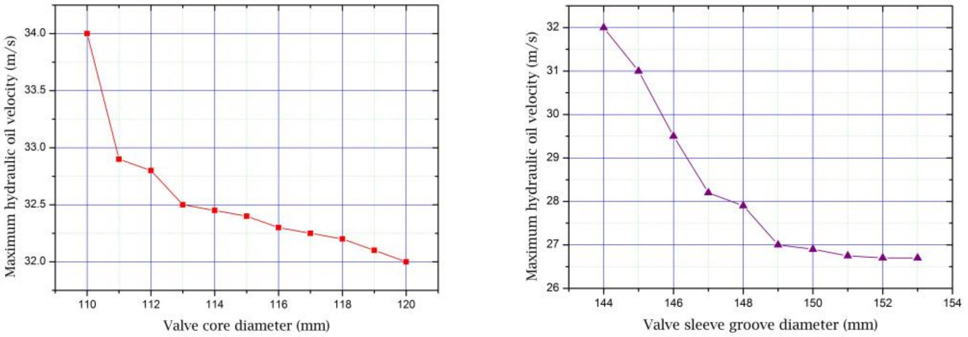
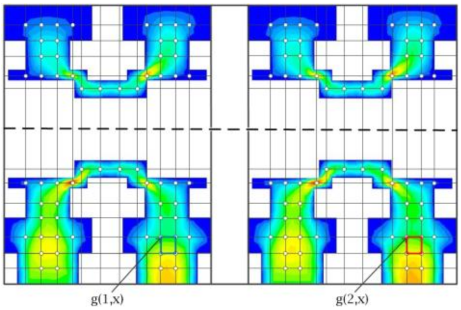
sleeve groove diameter is increased 1 mm per step at constant valve core diameter. As shown in Fig. 6 (b), the maximum velocity falls below 27 m/s leading to the convergence.



(a) (b)

Fig. 6: Maximum velocity: (a) with different valve core diameter, and (b) with different valve sleeve groove diameter.

CAE effect feature demonstrates the effect on the whole fluid domain by grid mapping method. A set of characteristic points are assigned to the locations where interested, which is shown in Fig. 7 (a). The difference in the velocity of corresponding points is calculated after the first modification. Divided by the change in valve core diameter, the velocity change rate can be derived further, which is shown as the matrix in Fig. 7 (b). Consequently, each point's sensitivity towards the change of valve core diameter is reflected by the value, which is of great significance to the further optimization.



(a)

$$\frac{\partial V_x}{\partial D_c}=\begin{bmatrix}
-0.08 & -0.08 & -0.08 & -0.08 & & & & & -0.08 & -0.20 & -0.20 & -0.08\\
 & -0.25 & -0.25 & & & & & & & 1.33 & 1.33 & \\
 & -0.25 & -0.40 & & & & & & & -0.45 & -0.40 & \\
-0.03 & -0.08 & -0.36 & -0.70 & & & & & -0.95 & -0.40 & -0.08 & -0.03\\
 & & & & -0.40 & -0.40 & -0.40 & -2.06 & & & & \\
 & & & & -0.55 & -0.45 & -0.40 & -2.10 & & & & \\
-0.08 & -0.19 & -0.45 & -1.05 & & & & & 2.45 & 1.3 & -0.14 & -0.08\\
 & -0.50 & -0.50 & & & & & & & -0.40 & -0.40 & \\
 & -0.50 & -0.50 & & & & & & & -0.40 & -0.40 & \\
-0.20 & -0.60 & -0.60 & -0.20 & & & & & -0.20 & -0.40 & -0.40 & -0.20\\
 & 1.00 & 1.00 & & & & & & & 1.05 & 1.05 & \\
 & -0.65 & -0.65 & & & & & & & -0.70 & -0.70 &
\end{bmatrix}$$

(b)

Fig. 7: CAE effect feature extraction.

Conclusions:

This extended abstract explores a mechanism of CAD/CAE integration based on the concept of associative feature. The concept of CAE effect feature is proposed for the first time, enabling the realization of the integrated loop of CAD/CAE sessions with effect comparison over the changes. The consistency and accuracy of integration is maintained by introducing CAE boundary feature. A case study is implemented to show the effectiveness of the method. Currently, the authors are not aware of any limitation of the proposed approach so long the optimization space keeps the similar topology. In the future, prototyping of automated functions is to be carried out to provide implementation proof.

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