# A CAD / CAE Integration Framework for Simulation Driven Design

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**Abstract**

Simulation driven design (SDD) requires the support of CAD/CAE seamless integration platform. In this paper the functional requirements of SDD on CAD/CAE integration platform is firstly discussed, upon which a new CAD/CAE seamless integration framework is proposed to make integrated CAD/CAE platform have the abilities of effectively generating the analysis oriented geometric model, achieving the interaction between CAD and finite element mesh (FEM) models, and allowing designers to use mesh generation and CAE capabilities easily and efficiently during design process. The core components of the integration framework include analysis oriented geometric model generation with evaluation, analysis feature model generation by feature mapping, rapid generation of feature-based multi-resolution FEM model, fast remeshing of modified solid models through mesh re-use, synchronous modification of a FEM and its corresponding CAD model based on semantics, and direct FEM editing through CAD operations. The implementation of the proposed integration framework with the preliminary results is given.

**Key words:** CAD / CAE integration, Simulation-driven design, FEM, CAD, CAE

## 1. Introduction

It is well recognized that CAD and CAE are two key technologies of digital product design. Historically, each of them was developed independently and forms the independent software tool on its own. As CAD and CAE activities are interrelated and need to interact in the process of product design, CAD/CAE integration becomes imperative.

The existing CAD/CAE integration approaches can be divided into two categories. One is simple integration, the other is seamless integration. The simple CAD/CAE integration, i.e. directly transferring CAD models from a CAD system to a CAE system, is achieved by importing CAD models created in a CAD system into a CAE system based on the standards of STEP or IGES. This kind of integration has been widely used. However, it is difficult to effectively support the associations and interactions between CAD and CAE activities during design process.

The CAD/CAE seamless integration which supports the intelligent conversion from CAD models to CAE models and the associations and interactions between CAD and CAE activities is the advanced CAD/CAE integration that industries really require. The related work on CAD/CAE seamless integration includes: Shephard et al. [1, 3] presented an approach that makes finite element modeling within an integrated geometric modeling environment. Remondini et al. [4] proposed a generic data structures dedicated to integrated structural design. O'Bara et al. [5] developed an attribute management system for engineering analysis. Lee et al. [2] proposed a CAD/CAE integration approach based on feature-based multi-resolution and multi-abstraction modeling techniques. Liang et al. [6] put forward an integrated model based on STEP AP209 [7] which gives the standard presentation of the data required in the process of design and analysis. In general, current developments on CAD/CAE seamless integration[8-12] are still quite preliminary and there is still a long way to go in addressing the needs of simulation driven design.

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According to the requirements of SDD, a CAD/CAE integration framework that is CAD system centered is proposed in this paper which aims for realizing CAD/CAE seamless integration.

## 2. Framework Architecture

### 2.1 Functional requirements analysis

In the process of product design conducted using SDD approach, designers need to evaluate and optimize the design concepts and results in different design stages utilizing integrated analysis tools to ensure that the design is in the right way from the early beginning. And the simulation driven design has the following functional requirements on CAD/CAE integration platform:

1. CAD/CAE seamless integration should be CAD system centered. This is because: 1) designers mainly use CAD systems to conduct product design; 2) the design modification according to analysis results must be done in CAD system; 3) CAD model serves as the common basis of various CAE models.

2. To evaluate the design concepts and results rapidly and make the design process easy and smooth, the generation of the analysis oriented geometric model and finite element mesh model should be quick and simple.

3. To speed up the design modification and re-analysis, direct editing on finite element mesh model according to analysis results and propagating the changes being made on the FEM model to the corresponding CAD model should be supported.

### 2.2 Overview of the Framework

According to the above functional requirements analysis, we propose a CAD/CAE integration framework which is intended to effectively support simulation driven design. Fig. 1 shows the architecture of the framework which consists of supporting modules, core function modules, CAD/CAE system interfaces and user interface.

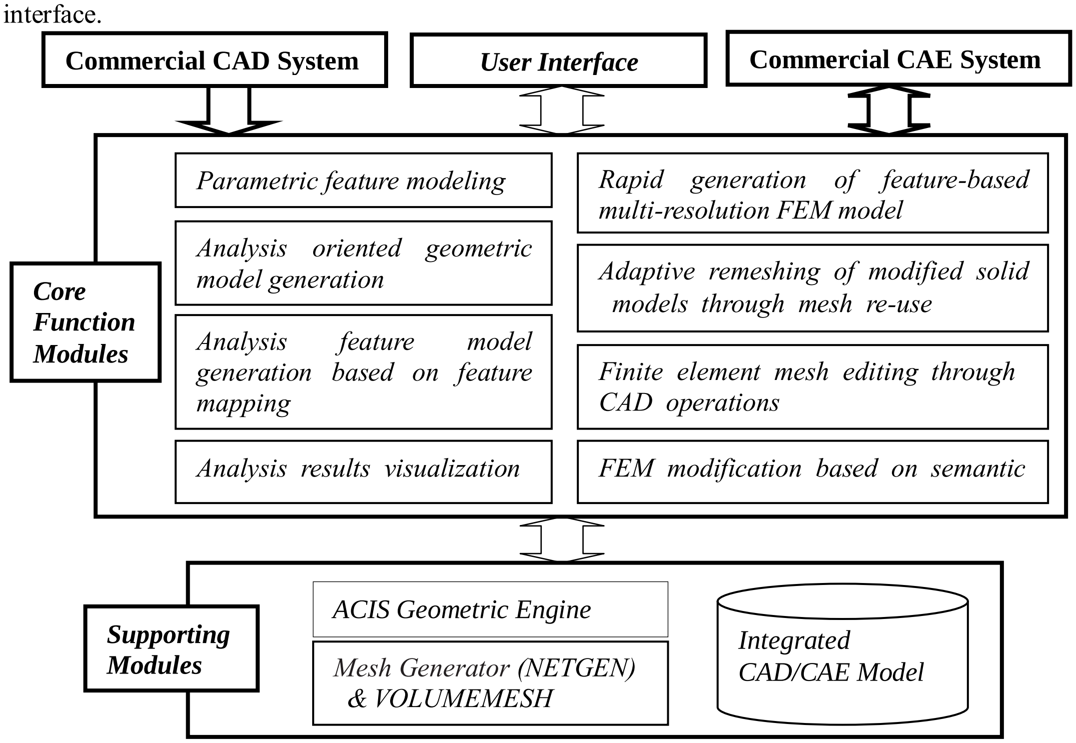



Fig. 1. Framework architecture.

1. Supporting modules, including ACIS geometry engine, mesh generator NETGEN [18] and VOLUMEMESH, integrated CAD/CAE model, and so on.

2. Core function modules, consisting of parametric feature modeling, analysis oriented geometric model generation[17], analysis feature model generation based on feature mapping[13, 14], rapid generation of feature-based multi-resolution FEM model[16], adaptive remeshing of modified solid models through mesh re-use[15], direct FEM editing, etc. The design and implementation of each core function will be described in the third section.

3. CAD/CAE system interfaces, which include the ports of importing CAD models from commercial CAD systems, exporting the generated analysis models into commercial CAE systems to perform analysis computation there, and getting back the analysis results from CAE systems to visualize them in the CAD/CAE integration platform.

4. User interface.

# 3. Design and Implementation of Core Function Modules

## 3.1 Analysis oriented geometric model generation

This module provides the capability of analysis oriented geometric model generation through model simplification and idealization with their impacts on the final analysis results considered. Firstly, the regions that need to be simplified or idealized are determined by automatic recognition or interactive definition; then, the quantitative impact of each region simplification or idealization on the final analysis results is assessed using a new evaluation index based on the principal of virtual work and reciprocal theorem; finally, the regions whose impacts are within the given tolerance are suppressed or dimensional reduced and the analysis oriented geometric model is generated. In order to reduce the accuracy loss caused by model simplification and idealization, some additional boundary conditions are added on simplification model.

The analysis oriented geometric model generated using the above approach can guarantee the required analysis accuracy because the region simplification and idealization are based on the quantitative evaluation of their impacts on the final analysis results.

## 3.2 Analysis feature model generation based on feature mapping

This module provides the capability of automated conversion from a design feature model to an analysis feature model. Firstly, the design model is decomposed into a set of remnants of additive features, each of which represents the part of an additive feature's volume that remains in the final volume of the design model; then, the remnant of each additive feature is decomposed into swept bodies and non-swept bodies; after that, the thin regions of each swept body are effectively recognized using its sketch information; finally, the analysis features are created according to the real thin and thick regions together with the interfaces between them, which forms the analysis feature model. By using a sketch-based method to recognize the regions suitable for dimensional reduction from the swept bodies involved in the remnant of each additive feature, the algorithm efficiency is greatly improved.

## 3.3 Rapid generation of feature-based multi-resolution FEM model

This module provides the capability of rapid generation of feature-based multi-resolution FEM model corresponding to different levels of analysis accuracy. Firstly, the interfaces between every two features of the model are determined; then, the mesh model of each design feature or analysis feature is generated by taking the related interfaces as constraints; finally, the corresponding features' mesh models are selected to compose the multi-resolution FEM models at a special level of resolution. By composing multi-resolution FEM models directly with design features' mesh model instead of generating each resolutional FEM model from scratch makes the approach fast and effective.

## 3.4 Adaptive remeshing for modified solid model through mesh re-use

This module provides the capability of effectively generating adaptive mesh model of the modified solid models. Firstly, the destruction zone of the original mesh model is determined and mesh elements of destruction zone are removed; then generate the variation mesh to form the final mesh of the modified model. Here the variation mesh is the new mesh section that composes the final mesh model of the modified model together with the retained unchanged mesh. As parts of the original mesh model are re-used to avoid unnecessary mesh generation for unchanged geometry, the time of remeshing after solid model modification is much reduced and thus the efficiency of analysis on modified model is improved.

## 3.5 Direct Finite Element Mesh Editing

**1. Finite element mesh editing through CAD operations**

This module provides the capability of direct editing on FEM models through CAD operations. Firstly, Sweeping operation and Boolean operation are used to construct the new geometry on the mesh model according to the modification requirements, taking the mesh elements as the reference of the operations; then, mesh geometry fusion is conducted, which makes the related mesh elements aligned with the intersection lines between the original mesh model and the newly added geometry through node repositioning; finally, mesh elements for the newly added geometry are generated and optimized. Through CAD operations, complex editing of FE mesh model can be achieved and the efficiency of editing can be improved by limiting the remeshing to the modified region.

**2. FEM modification based on semantic**

This module provides the capability of allowing analysts to change FEM models by modifing design features' parameters with the corresponding CAD model being modified accordingly. Firstly, we establish the association between topological entities of the feature based CAD model and mesh elements in the mesh generation stage; then, deform and optimize the relevant mesh elements according to the changed design feature parameters; finally, CAD model is updated accordingly. As direct modification on mesh model is supported and CAD and mesh model are changed in a synchronized way, the efficiency of the design modification and re-analysis can be greatly improved.

## 4. Implementation and Results

We have preliminarily developed a CAD/CAE integration platform based on the proposed seamless integration framework. It is implemented with Visual 2008 under windows operating system using C++ as development language and HOOPS as model rendering tool. The input of the system can be the CAD models directly created by the feature modeling function of the platform, or SAT files from other commercial CAD systems. The platform can export the generated mesh model with the other related information into ANASY system through APDL files, and can import the analysis results from ANASY and visualize them. In addition, importing and exporting finite element mesh models are supported. Figure 2 to 10 show the preliminary functions of the developed platform.

Figure 2 shows the module of feature modeling.

Figure 3 shows the module of adaptive remeshing for modified solid model. In the figure, the upper left window shows the original mesh model of the engine; the upper right one shows the modified engine CAD model; the lower left one shows the remeshing result of the modified region; and the lower right one shows the modified engine's whole mesh model generated.

Figure 4 and 5 show the module of multi-resolution FEM model generation. Figure 4 shows the mesh model of the part without any feature suppressed while Figure 5 shows another resolutional mesh model with some features suppressed.

Figure 6 to 8 show the module of FEM modification based on semantics. Figure 6 shows an original mesh model. Figure 7 shows the modified FEM generated by changing the radius parameter of a boss. Figure 8 shows the updated CAD model.

Figure 9 and 10 show the module of mesh editing through CAD operations. Figure 9 shows an original mesh model, and Figure 10 shows the modified mesh after two sniffers being added by CAD operations.

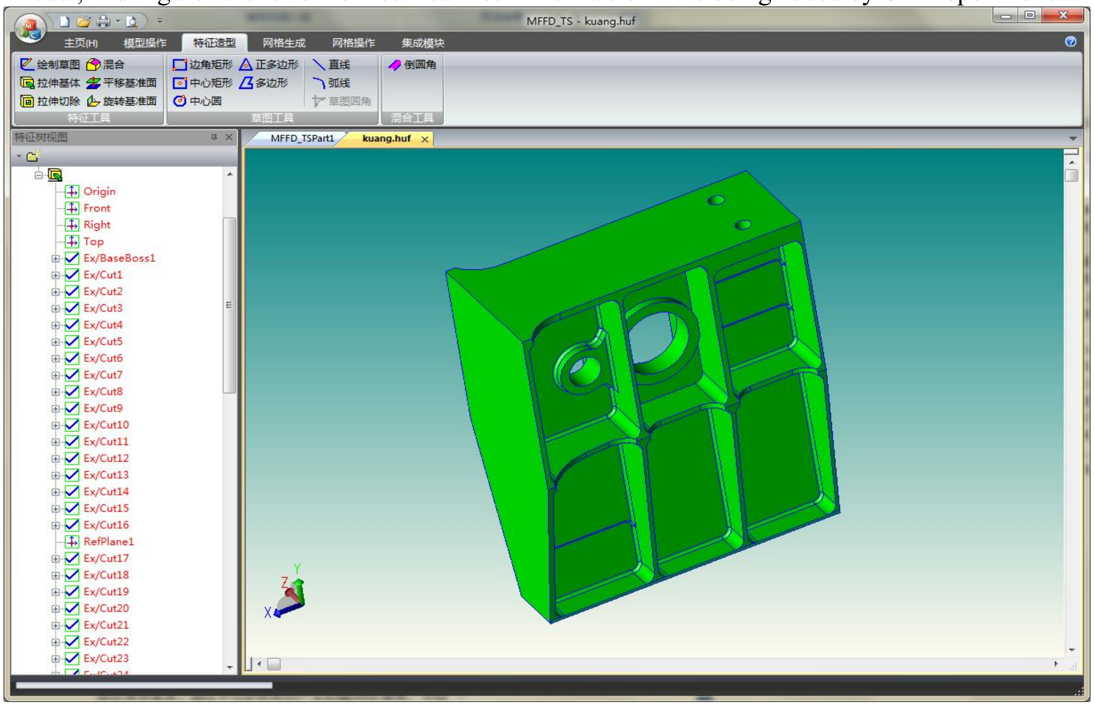



Fig. 2. The module of feature modeling.

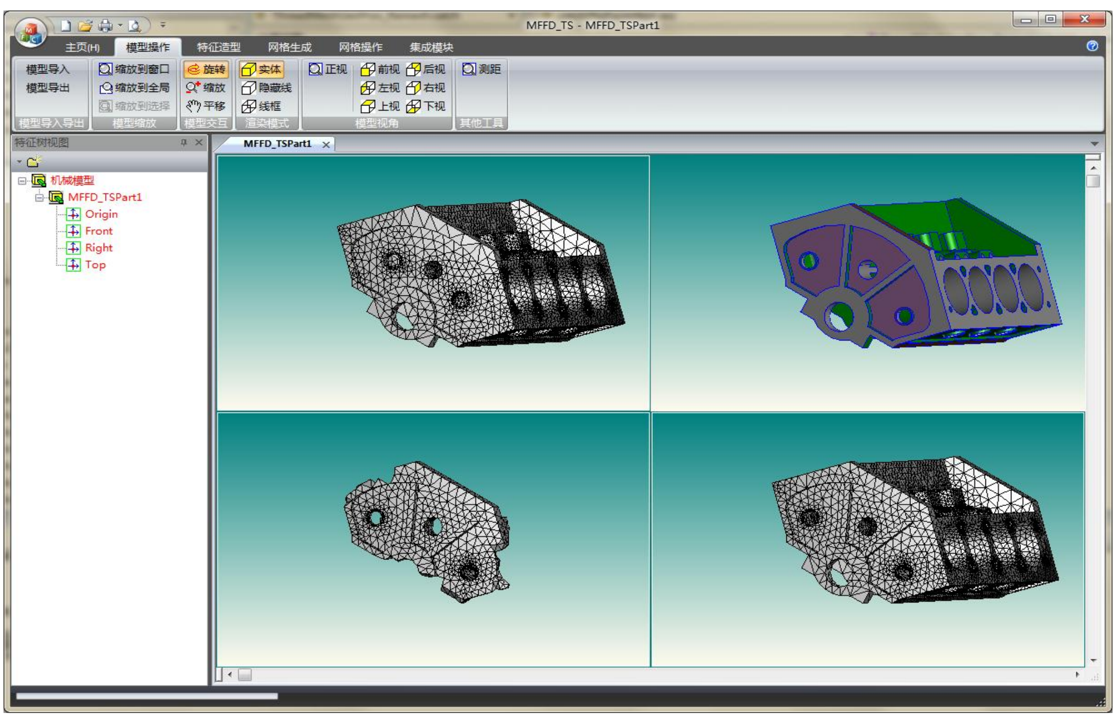
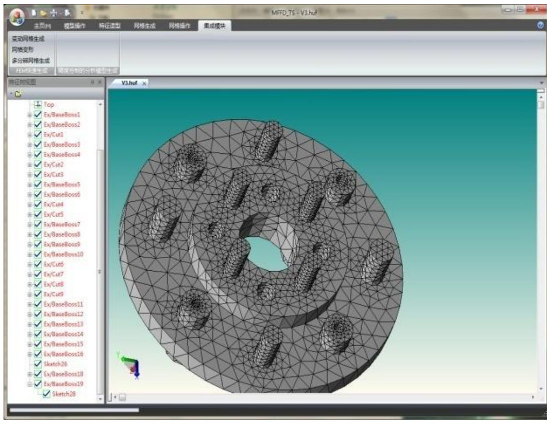



Fig. 3. The module of adaptive remeshing for modified solid model.



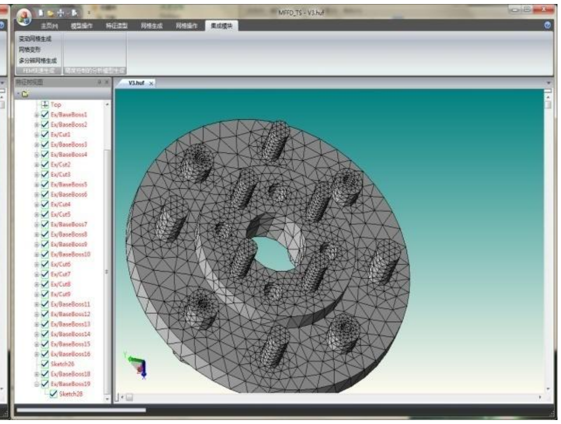


Fig. 4. The multi-resolution mesh without features suppressed. Fig. 5. The resolutional mesh with some features suppressed.

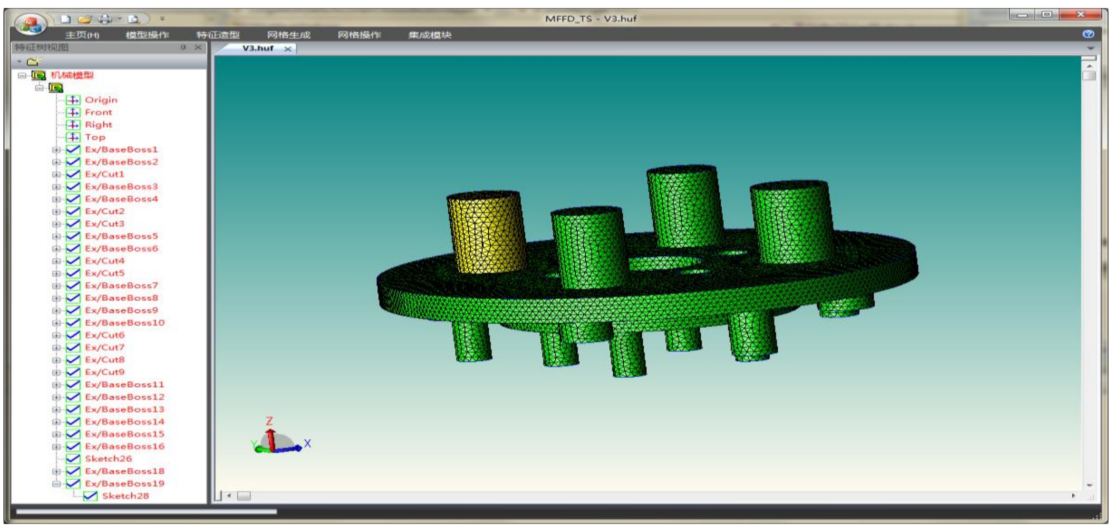
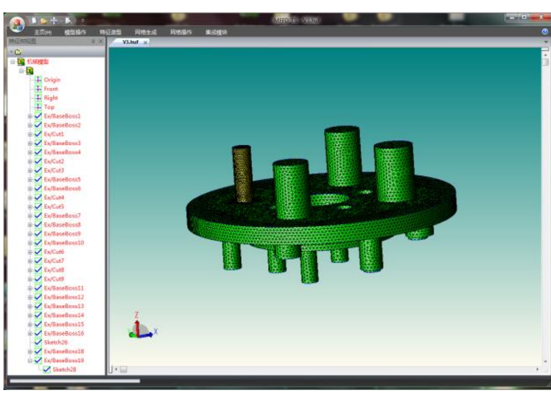



Fig. 6. The original mesh model.



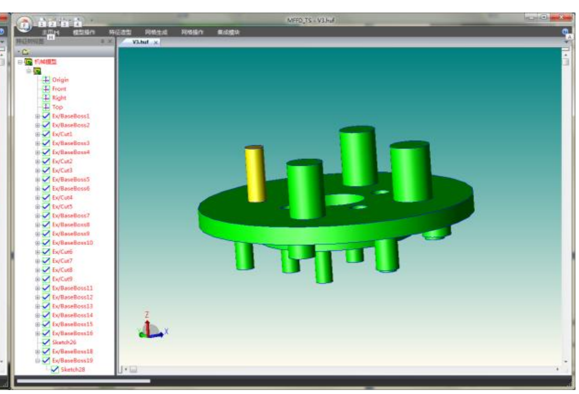


Fig. 7. Deformed mesh after radius parameter changed. Fig. 8. The updated CAD model.

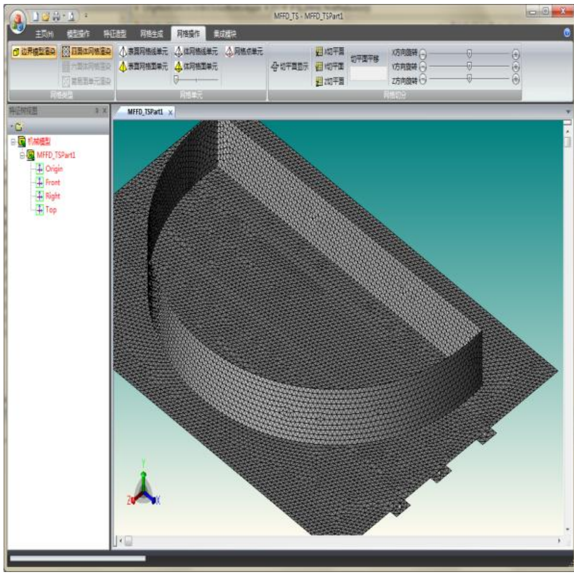


Fig. 9. An original mesh model.

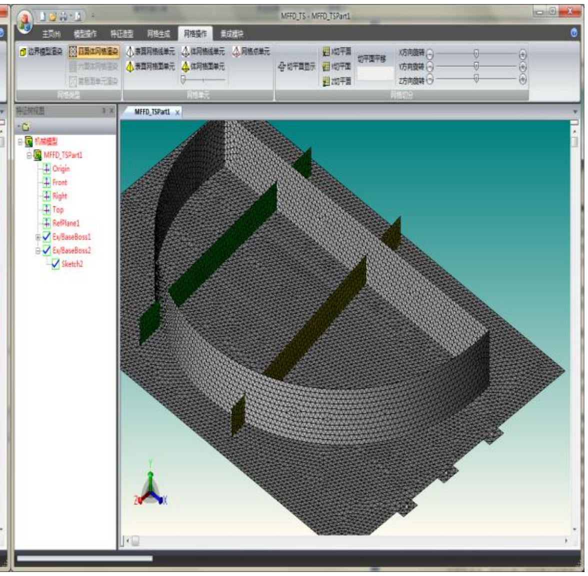


Fig. 10. The modified mesh after two stiffeners being added.

## 5. Conclusions and Future Work

According to the requirements of SDD on the CAD/CAE integration, we put forward a seamless CAD/CAE integration framework. It has the following characteristics:

1. Centered on CAD system and based on an integrated CAD/CAE model, which enables designers to use the mesh generation and CAE capabilities easily and efficiently during design process.
2. Intelligent conversion from CAD model to analysis model through model simplification and idealization is supported, and the impact on the final analysis results caused by model simplification or idealization is evaluated to make the analysis accuracy under control.
3. Direct FEM editing through CAD operations or based on semantics is supported, which makes the efficiency of the design modification and re-analysis improved.

Currently, the implementation of integration framework is still preliminary. Complete implementation of the system with high quality is our next step.

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