

# Practical Examples and Future Directions for CAE-Based Development for Automobile Transmissions by Designers

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## ABSTRACT

Three-dimensional (3D) CAD systems have been used for design and development of automobile transmissions for several years. These systems have been improved to the point that they can be used to design sand castings, which have the precision equivalent to that mass-produced from die molds. Since automatic meshers for CAE analysis have improved so much, it has become increasingly common practice for designers to use, as is, the 3D models of prototype parts and mass products in CAE analyses to make decisions on the detailed specifications of components. The next step in this revision of CAE systems is to re-create them as a more designer-friendly environment, and allow designers to use these systems to perform CAE analyses not only of individual components, but also of assemblies, a much more difficult task.

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## 1. Introduction

Recent years have seen developments in design using 3D CAD systems, and it is becoming normal design procedure to use 3D methods from the beginning of the design process, rather than creating 2D drawings for conversion into 3D models. It is also increasingly customary to use 3D models including detailed fillets and draft angle (hereafter 3D detail modeling) for design investigations of die molds for manufacturing engines, transmissions and other forgings<sup>(1)</sup>. It has also become possible to use 3D detail models directly for CAE analysis<sup>(2)</sup>. This has made it a simple matter for the designers themselves to carry out design investigations employing CAE analysis. Here, some examples will be provided to show how effective 3D design methods are for development of automotive transmissions and to indicate directions of future developments in CAE as it will be used by designers.

## 2. 3D Detail Modeling and Precision of Prototype Parts

Mass production of components such as transmission cases and engine cylinder blocks is by forging with die molds, but initially, small lots of prototype parts are produced with sand molds to investigate specifications. Before the 3D detail modeling-based development shown in Fig. 1 came into use, the sand molds were produced by hand on the basis of 2D drawings. This often resulted in some discrepancies between the designers' intent and the shape of the actual parts. One of the reasons for this is that the designers' intent could not be completely expressed in 2D drawings. Another was that the designers themselves sometimes failed to provide complete specifications of the shape of the mass-products from die molds forging in their 2D drawings. Due to these factors, it sometimes happened that prototype parts were of different shapes than the intentions of the designers and than the mass-

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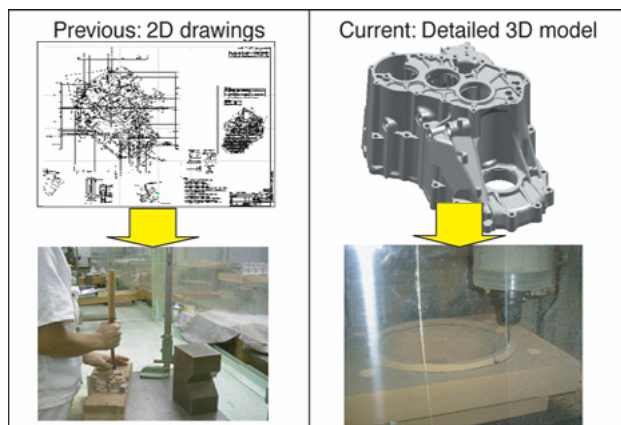


Fig. 1 Comparison of designing methods for sand mold manufacturing

products. Currently, since the design process at the leading manufacturers is based on 3D detail modeling, from the early stages of development to mass production, prototype parts are constructed with vastly improved precision. This is because it is possible to capture the intent of the designers and the full benefit of the ideas and experience possessed by the manufacturing department in specifications at the early stage of design and to represent them directly as complete 3D detail models<sup>(1)</sup>. As shown in Fig. 1, the shape of the prototype cast in a sand mold made with numerically controlled (NC) equipment according to the 3D detail model is nearly a 100% match with the intentions of the designers and the experience of the manufacturing division.

Figure 2 shows the result of a comparison of estimated weights (design weights) and actual weights of a sand-mold prototype made in the traditional method and of a sand-mold prototype made in the 3D design process. The vertical axis is the amount in percent by which the design and actual weights differed.

Conventional sand mold castings weighed about 10% more than the design weight, but those made from sand molds formed in NC equipment on the basis of the 3D detail models weighed within  $\pm 2\%$  of the design weight, a very close correspondence to design. Thus, 3D detail models enable creation of forged components at the prototype stage with weights and shapes virtually identical to those mass-produced from die molds.

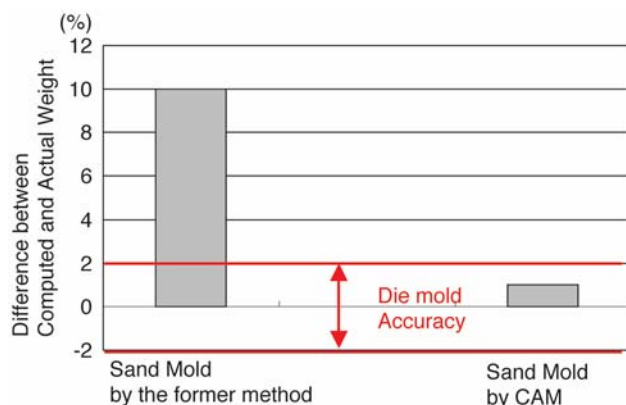


Fig. 2 Comparison of error in prediction of casting Weight

### 3. CAE Analysis of Single Components in 3D Detail Models

Formerly, both CAE analytical software (hereafter a CAE solver) and a technology for creating a CAE model compatible with the CAE solver were necessary in order to carry out analysis. Besides designers and test development engineers, there is a third specialty called 'CAE experts'. CAE experts used the 2D drawings or 3D data provided by the designers to create CAE models incorporating fillets, draft angles, bolt holes and other features, as shown in Fig. 3, and carried out analysis with these models. Also, at times, CAE experts acted in place of the designers in assessing the results of the analyses.

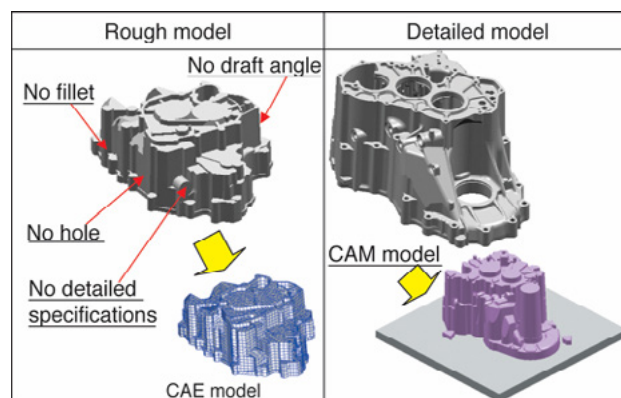


Fig. 3 Definition of rough & detailed models

One goal of simplification of model shape was to minimize the size of the CAE model in order not to exceed the capacity of the computer. Therefore, hexahedral elements, which provide comparatively high precision in calculations, have always been used to obtain the best precision in results with the smallest possible number of elements and nodes. Shell elements, which can provide acceptable precision while reducing solving time, were also incorporated in parts of the models to reduce the labor time of the CAE experts<sup>(3)</sup>. These measures were necessary in order to extract the most effective possible results, within the limits of the computers. Thus, it was necessary for CAE modeling technology to not only allow specialized operations and settings for analytical conditions but also to account for the calculation capacity of the host computer. This was an obstacle to the use of CAE analysis as a numerical tool aiding designers in design specification decisions.

Figure 4 shows the flow from development to mass production, using a transmission as an example. CAE techniques are generally used to investigate specifications during the development up to creation of the prototype. As explained in Section 2, now that a sand-cast prototype can be obtained with nearly identical precision to that of mass products from die molds assessments based on tests employing these prototype parts are of the same level of confidence as assessments from tests of mass produced parts. Shape adjustment based on the test results requires the same level of precision as direct revision of mass production parts

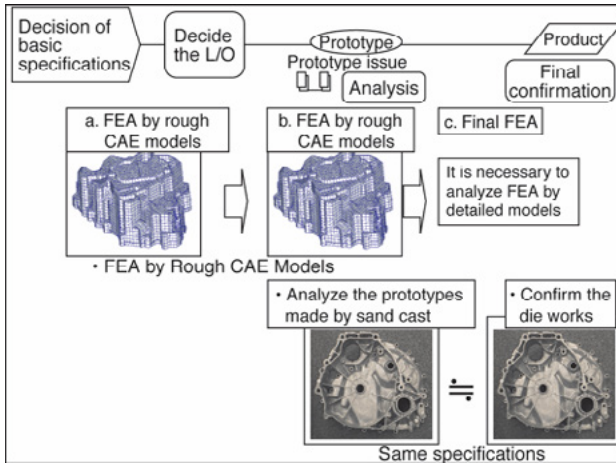


Fig. 4 Transmission development flow and models

do. “Final FEA” in Fig. 4c indicates that it is not possible to assess the influence of component shape details by analysis of the simplified CAE models made by the CAE experts. Full, un-simplified models must be used. It is concluded that the more precise the prototype becomes, the stronger the demand becomes for precision in the shape of CAE models after prototype testing.

### 3.1. Aim of 3D CAD-CAE

An automatic meshing (automesh) function capable of inserting meshes into fine details is necessary for finite element (FE) analysis of 3D detail models. The automesh function has been described in previous reports<sup>(2), (4)</sup> so no explanation will be given here.

Thus, for the effective use of CAE analysis at the development stage, fast FE analytical functions must be incorporated within the same 3D design tool to be used during the design process with 3D model. Figure 5 shows how the functions allow CAE analysis while providing a 3D representation of the designer’s intent.

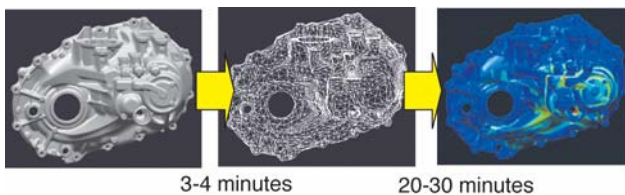


Fig. 5 The detailed model and the result

### 3.2. Examples of Stress Analysis by Designers

Here, some examples of actual use of component automeshing and stress analysis performed by designers are provided<sup>(2), (4), (5)</sup>.

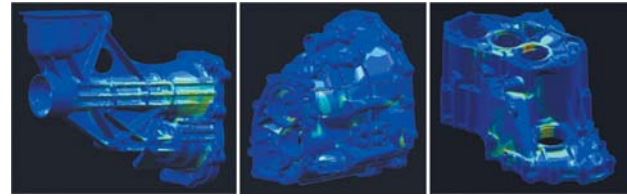


Fig. 6 Examples of FEA in detailed models

Figure 6 shows an actual stress analysis. There was absolutely no simplification of the component, such as elimination of fillets or shape revision, before the FE analysis. The 3D detail model also allowed application to die molds, including die mold draft angle.

The model consisted of about 90,000 2nd-degree tetrahedral elements with 150,000 nodes.

Formerly, a CAE expert would have required over 80 man-hours to perform only the manual meshing of the transmission case with about 2,000 nodes without fillets. To perform the analysis of this 3D detail model, it took about 10 minutes to apply the boundary conditions, and the analysis on a workstation, including automeshing, required about 30 minutes. The meshing task only required 3 – 4 minutes.

### 3.3. Examples of Eigenvalue Analysis

Here are some examples of the 3D detail model applied to eigenvalue analysis<sup>(5)</sup>.

Tests of this component revealed intense 2.3 kHz radiation noise, which would considerably degrade noise from the vehicle. Based on the noise test results, CAE analysis of a 3D detail model of the component was employed to examine the effects of the ribs and other features on the eigenvalues, as depicted in Fig. 7. The 2.3 kHz eigenvalue was raised to 4.1 kHz, resulting in a large improvement in radiation noise.

CAE was already employed for eigenvalue analysis, but it was not possible for designers to use 3D detail models as is, including draft angle for die molds, for CAE models.

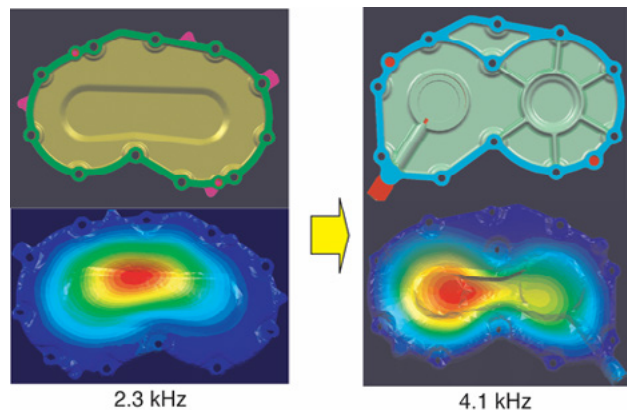


Fig. 7 Modal analysis by FEA

Figure 8 displays examples of the usefulness of CAE analysis by designers during transmission development. The number of design modifications was cut to about 1/3 of its previous level by the direct use of 3D detail models as CAE models.

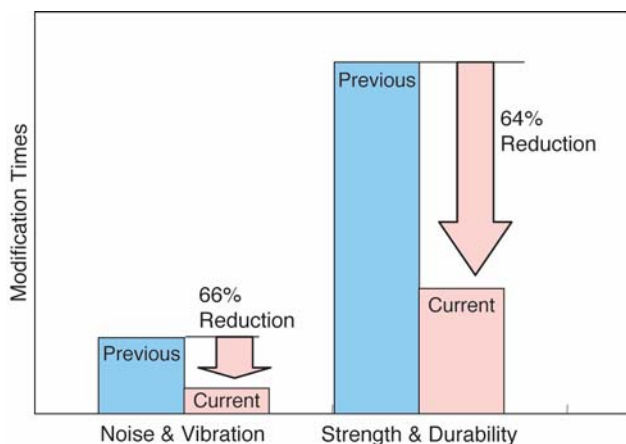


Fig. 8 Revised specifications of the transmission die mold parts at start of production

#### 4. CAE Analysis of Assembled Models by Designers

##### 4.1. Aim of CAE Analysis of Assembled Models

Section 3 described examples of decisions on single component specifications made by designers and test-development engineers after their own CAE analyses of components for strength, stiffness and eigenvalues.

The biggest concern in functional assessments of single components at the designer's desk is the selection of analytical conditions. These are set on the basis of the design requirements and the results of past tests. These analytical conditions are usually considered not on the basis of a single independent component, but on the assembly of several components. For example, the load applied on each bearing or other component and its direction are calculated from the input transmission torque; this sets the analytical conditions for each component. There is much controversy about CAE precision, but the investigation of precision in the analytical conditions is usually left up to the analyst. There are not many research papers or reports which serve as references on the subject. Originally, designers themselves calculated the loads applied to each component and the resulting deflections, and used previous examples to set design specification. The better the designer was at accurately predicting the forces applied on the component, the lighter and more compact he could design it. CAE analysis will allow all designers the ability to investigate analytical conditions in order to make more precise choices of conditions. However, in new L/O design and design of components with new functions, it is difficult to predict the forces on the component. Sometimes, CAE experts were summoned to create very roughly meshed CAE models for analysis of simplified assembled models in order to estimate analytical conditions such as forces on individual components. These models were also used for investigations of analytical conditions for single components,

using the forces estimated from the assembly models. If it is possible to perform CAE analysis of assemblies using 3D detail models, very high precision can be obtained in analytical results such as strength and eigenvalues for components while taking the analytical conditions of single components into consideration.

For example, when finding the stiffness of a transmission case, CAE analysis of the case itself is easy, but one of the analytical conditions which must be taken into account is the load on the joint between case halves. If it is possible to carry out a CAE analysis of an entire transmission unit, the load on the joint will be available as one of the analysis results. Of course, CAE experts have always been employed to carry out these large-scale, time-consuming analyses of assembled models. Transmission analyses are common as examples of CAE analysis. However, it was extremely rare for designers to use this at the design stage with assemblies using 3D detail models, due to high-precision CAE analytical techniques and the time needed for analysis.

Thus, one of the next steps in this technology will be construction of a CAE analytical environment for assembled models. This will enable rapid analysis of 3D detail models by designers in the design stage.

##### 4.2. Examples of CAE Analysis of Assembly Models and Their Effectiveness

Practical testing of CAE packages allowing analysis of assemblies of multiple components began just as CAE analytical methods were becoming available for analysis of single components by designers. An example is provided in Fig. 9.

This transmission had two outer cases which were fastened together. A CAE analysis of the assembled model was carried out with separately created cylindrical gears and gear shafts. This kind of analysis was already the established method for CAE experts. The great difference between the earlier analysis and the new analysis was that the several hours required for preprocessing items such as contact definition was cut by a factor of about 10 through use of the CAE solver. With CAE analysis software embedded in 3D CAD systems (hereafter CAD-CAE systems), the simplified preprocessing and the fact that it is all performed on the same CAD system results in great reductions of man-hours. Design investigation by designers by CAE analysis of assembled models has entered the realm of possibility.

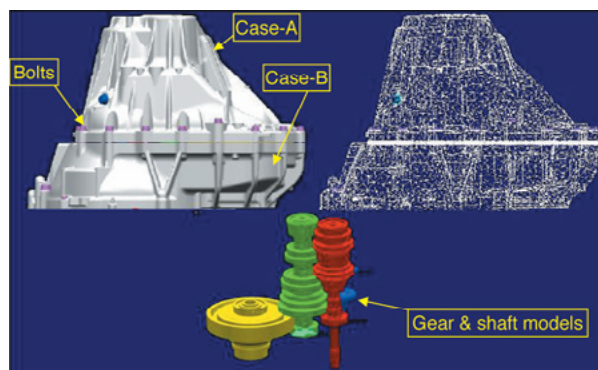


Fig. 9 Assembled models

Figure 10 presents the results of designers' investigations of eigenvalues with CAE analysis of the transmission assembly in order to reduce radiation noise from the case. Figure 11 shows some additional details of the countermeasures. The designers were able to assess the effects of details of shapes of some of the components in a coupled situation, without the help of specialists.

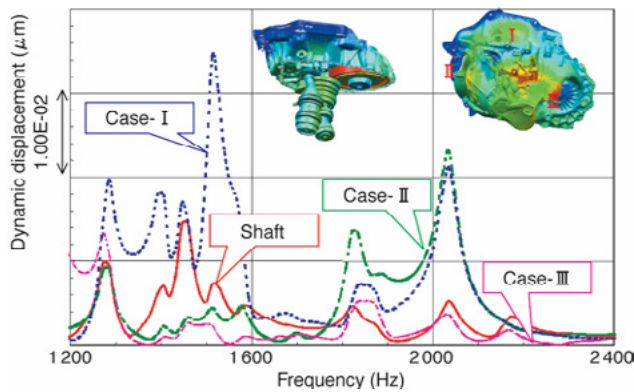


Fig. 10 Dynamic displacement of an assembled model

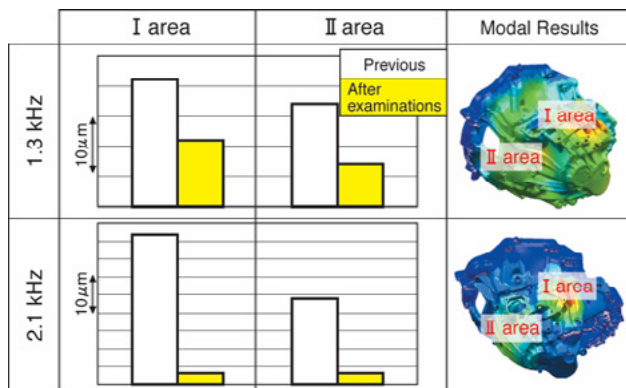


Fig. 11 Results of countermeasures

#### 4.3. Future of CAE Analysis of Assembly Models by Designers

CAE analysis of assembled models with CAD-CAE systems is expected to spread throughout the industry, just like the CAE analysis of the single components explained in Section 3, due to the convenience of using CAD models directly as CAE models and the much more user-friendly

definitions of contact conditions than in previous CAE solvers. It is believed that the labor involved in using CAE in the next generation of CAD-CAE systems will be greatly reduced, requiring only about one tenth the time necessary in current CAD-CAE systems. While designers have seen the utility of CAE analysis of assembled models with their own eyes, demands have naturally grown for greater capabilities in modeling of details in gears, shafts and similar components, as described in Section 4.2. Due to the huge size of the files involved and the current numerical capacities of computers and CAD systems, it is not yet possible to prepare 3D models with the shape details of every component in an automobile for CAE analysis of an assembled model. Also there are certain differences between systems, so it is impossible to give a 'correct' value for the calculation limits of currently used CAD-CAE systems, but a plausible estimate for current analytical models is 1 million degrees of freedom and 2,000 – 3,000 contact elements. Further improvements to systems and to CAD-CAE software will be necessary in order to carry out the CAE analyses of assembled models that designers, including the authors, would really like to carry out. The authors are certain that all designers share a desire for stress-free, easy calculations for this region.

## 5. Summary

The following advances have been made, thanks to the development of 3D detail shape modeling.

- (1) The precision of sand-cast prototype parts was improved to that of mass products with die molds.
- (2) Since the precision of prototype parts allows nearly the same confidence in assessments of the test results as after tests of mass products, it is necessary to develop CAE analysis employing 3D detail models that allow assessment of details in CAE analysis of prototype part tests.
- (3) Designers are now able to use CAE analysis employing 3D detail models during the design process.
- (4) Designers now realize that they are able to use CAE analysis of assembled models, a task formerly entrusted to CAE experts, during the design process.

## 6. Afterword

Thanks to the development of 3D detail models, not only has it become possible to incorporate manufacturing technologies in the early stages of the design process, designers themselves can also use FE analysis. The tools of FE analytical techniques have been placed in the hands of designers. Thus, technologies and information formerly available only to manufacturing technologists and CAE experts have been provided to designers at the early stages of product development, allowing them to assess products and make adjustments to specifications. Now that CAD-CAE operations have been simplified so that designers can employ CAE analysis, it is clear that the next step will be to provide CAE analysis capabilities for assembled models. The obstacle to this is the limitations on model size in CAD-CAE systems. The key to future developments in design technologies will be the sharing of this issue by CAD vendors and designers and the rapid improvement of CAD-CAE analysis environments.

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