# A Feature-Based CAD-CAE Integration Model for Injection Molded Product Design

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**Abstract.** One prominent characteristic of product design for injection molded parts is that design and analysis (e.g. flow simulation) go hand-in-hand to ensure that the design is manufacturable by the injection molding process. Despite the wide use of CAD and CAE systems, it is known that communication between the two processes is poor. In this paper we propose a feature-based *CAD-CAE integration model* to tackle the problem. The model comprises a hierarchy of CAD-CAE features that incorporate information necessary for both design and analysis. Based on this model, a prototype system for injection molded product design has been developed. The system consists of four layers: a CAD and CAE platform layer, a CAD-CAE feature layer, a model layer and a GUI layer. A design case study was also conducted to illustrate the proposed model and the system framework.

**Keywords.** Constraint; Feature-based design; CAD-CAE integration model

## 1. Introduction

There are a few prominent characteristics of injection molded product (plastic part) design, one of which is that design and analysis go hand-in-hand to ensure that the design can be manufactured by the injection molding process. For this reason, both CAD and CAE systems are now widely used in practice. However, despite the great achievements of applying CAD and

CAE technology in injection molding design, it is known that communication between the two processes is poor. One example for this is that designers cannot specify their design intent for CAE analysis using current CAD design software. For example, assume that a designer has created an initial design model (a solid model) by using a certain CAD package. Out of an esthetic or functional consideration, the designer may have a design intent of assigning no-go areas for weld lines, sink marks and vestige marks from gates. These types of constraints must be entered manually during CAE data input, because current CAD models do not have the facility to allow the designer to specify this information. Hence it cannot be passed to CAE analysis process automatically. Obviously, lack of this information shall lead to unnecessary large search space during CAE simulation and optimization, which in turn lowers the computational efficiency of the analysis.

There have been a number of research works on establishing links between design and analysis. The earlier work is on idealization of CAD model for CAE analysis and automatic mesh generation. Although model idealization still requires human interference because of its nature of subjectiveness, automatic mesh generation has achieved great success and is now well-established within various CAE applications. In fact, almost all commercial CAE packages (and some CAD packages as well) provide such functionality.

However, model idealization and automatic mesh generation only support transformation from CAD model to CAE model in geometric aspect. The derived idealization model (either with or without mesh generation) still needs to be provided with information such as material type, manufacturing process or physical behavioral process, boundary conditions, and so on. That is, the model still lacks information relating to CAE analysis.

A more complete research aims at integrating the two processes. There are in general two approaches in doing this. One is through development of an integrated environment with built-in

CAD/CAE functionality. For example, Kim (1985) developed an injection molding synthesis system, which integrates both design synthesis and melt flow analysis, where melt flow analysis is used as a design evaluation tool. Irani et al. (1995) developed a framework for integrating CAE and iterative design/redesign of injection molding feed system. Kagan and Fischer (2000) have developed an integrated mechanically based CAE system by using a B-spline finite element model for both design and analysis stage. This system is a more integrated approach than the above systems because both the design and analysis use the same representation model - there is no need to transfer the design model to the analysis model. However, all these systems achieve CAD/CAE integration on condition that they are within an integrated computational environment. Obviously this approach has its limitations, given the wide applications of those sophisticated standalone CAD and CAE packages at present time.

Another approach looks more promising: developing a comprehensive design model that can incorporate necessary information for CAE analysis and also to provide mechanism for easy incorporation and manipulation of this information. Arabshahi et al. (1993) have attempted to incorporate analysis information in a design model. They propose a scheme for automated CAD-FEA transformation. The scheme consists of a robust and comprehensive product description system (PDS), a semi-automated means for transforming PDS data into an attributed, abstracted, and (possibly) subdivided model ready for finite element mesh generation, as well as some other features found in the general CAE environment. A set of tools were also suggested, such as an *attribute editor* to allow the users to attach attributes (material properties, analysis type, loads, constraints, etc.) to the features of the design model, a *detail editor* to allow the users to partially automate the abstraction and idealization of PDS data to form a suitable CAE analysis model, a *dimensional reduction aid* to reduce the feature dimensions, thus to reduce the cost and complexity of the analysis. The paper, however, did not provide information regarding how the proposed PDS can be formalized, hence it is not clear how the different types of attributes (non-geometric data) are related with each other and how they are related to the geometric model itself.

In this paper, we propose a feature-based *CAD-CAE integration model* to tackle the problem. This is an enhanced product model compared to a conventional one, in that it captures design intents for the analysis directly in the design model. Our ultimate goal is to develop strategies and tools for the integration of CAD plastic part design and CAE analysis, so as to automate the whole design-analysis process.

In the next two sections, we elaborate on the proposed CAD-CAE features and the feature-based CAD-CAE integration model. Section 4 discusses the implementation strategies of the model, where a prototype injection molded product design system is presented. A simple design case study is described in Section 5 to illustrate the concepts and the design framework before concluding.

## 2. CAD-CAE Features

Feature-based design technology has been demonstrated as very effective in capturing non-geometric information in a geometric design model. There are quite a number of feature-based design models that support incorporation of both geometric and non-geometric design information. However, the focus of current research in this respect is on design for manufacturing and integration of CAD and CAM processes (Yueh & Miller, 1995; Kim & O'Grady, 1996; Chen & Wei, 1997). Hence, the non-geometric data is not oriented to engineering analysis.

Based on the findings from the literature review, we propose in this section a novel feature ontology, which consists of a number of CAD-CAE features. These features represent not only the geometric information of a plastic part, but also the design intents oriented to analysis.

(1) Part feature. This feature contains the overall product information of a plastic part.

(2) Wall feature. The wall features form the basis of a plastic part.

(3) Development feature. The development features are those developed from the wall features, such as rib features, boss features, hole features and so on.

(4) Treatment feature. This feature is used as treatment of other features, such as chamfer features, round features and fillet features.

(5) Sub-wall/development feature. This feature is used to allow the designer to specify analysis-oriented information (mostly constraints) on a sub-area of a wall feature or a development feature. The sub-area could be a face, an edge, part of a face, segment of an edge, or even a point on the corresponding feature. For example, the designer may wish to specify part of a wall face or segment of a wall edge to be no-go area of a gate location. For brevity, this feature is also referred to as a sub-feature.

(6) Gate location feature. This feature is used to allow the designer to specify injection point for analysis. The geometry of this feature is a marker called ‘gate location marker’, which could be a circle, a cross, and so on.

Each of these features contains design and analysis related data, which are called feature attributes. The part feature has attributes such as part identifier, part thickness, part material, constraints, analysis type and the relevant boundary condition and processing condition data. The part thickness is the overall thickness of the part, which is inherited by wall features and some development features. The part material includes material information that can be used to retrieve material properties from material database within an analysis package, e.g., material type, its manufacturer and trade name. The constraints relating to a part refer to the relevant analysis optimization criteria. Boundary condition and processing condition are related to the specific analysis type. For example, the boundary condition for filling analysis is the injection gate location, while its corresponding processing condition includes mold and melt temperature, injection time, and so on.

The wall feature has attributes such as wall identifier, wall thickness (in case the wall has a different thickness from the overall part thickness), wall geometry as well as constraints. In this paper, constraints on a wall specifically refer to the gate location constraints, which act on the faces and edges of the wall geometry.

The holes, ribs and bosses have similar attributes except that holes do not have thickness, and these features all have an attribute of suppressibility. Suppressibility is used to characterize whether a feature can be suppressed or not for analysis. This is an important part of model idealization work. It is noted that in this paper hole features include any general cutout features on the wall, rib and boss features, that is, they are not just of cylinder shape. Similarly, boss features include any outstanding parts from wall and other development features.

Treatment features are commonly used in the conventional CAD/CAM system. However, it is necessary for the designer to specify whether they can be suppressed during CAE analysis. Hence they have an attribute of corresponding geometry and an attribute of suppressibility.

The sub-feature has the attributes of its corresponding geometry as well as the relevant analysis information. In this paper, we only consider the gate location constraint as the analysis information.

The gate location feature has an attribute of its corresponding marker geometry. With pre-defined routines the designer can easily determine the coordinate of the gate location from this attribute, e.g., the center of a circle (if the marker is a circle), the intersecting point of a cross (if the marker is a cross).

Besides the above specific attributes, there is also relation information between the features with which the features can be combined to form the design model (integration model). The part feature has the attributes of pointers to all the wall features. The wall feature has the attributes of pointers to its embedded development features and treatment features. The development feature has the attributes of pointers to its corresponding treatment features. All of these features have the attributes of pointers to their embedded sub-features and gate location features.

In the reverse direction, all the features except the part feature have the attribute of pointers to their respective parent features. Figure 1 illustrates the feature attributes and the relationships between these features.

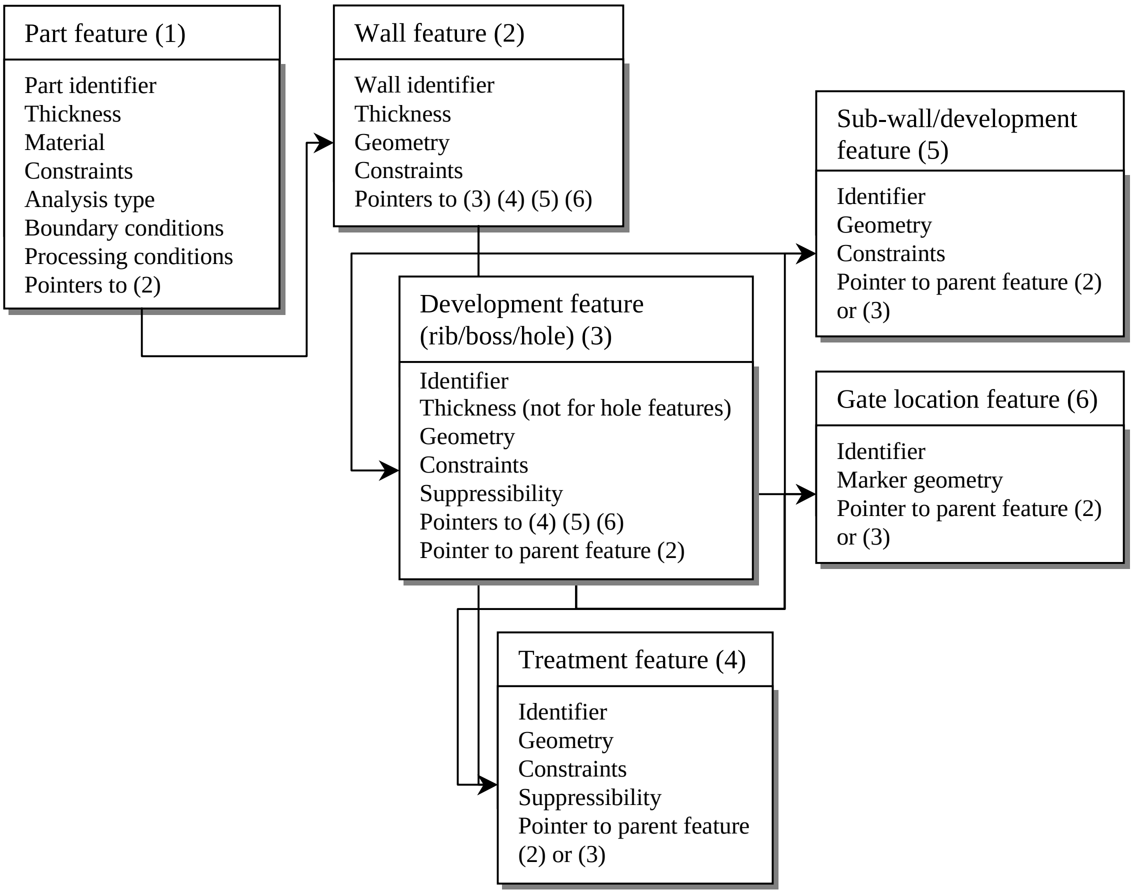


**Figure 1. Attributes of the CAD-CAE features**

# 3. CAD-CAE Integration Model for Design-Analysis Process

## *3.1. Constructing the integration model*

The integration model is constructed from the defined CAD-CAE features. This includes constructing the geometry of a plastic part by Boolean operations, as well as establishing relationship information between the features. If a CAD system supports automatic Boolean operations during geometric feature creation, then only the second task is required. For example, in the Solid Edge® environment, the creation of a "Cutout" feature will automatically invoke the Boolean "Subtraction" operation between the created feature and the base feature. Other CAD systems, such as AutoCAD®, require users to manually activate Boolean operations during the model construction process.

The relationships between the CAD-CAE features form a hierarchical structure of the integration model. At the top of the hierarchy is the part feature. The second level consists of a number of wall features. Development features and treatment features are at the next level of the hierarchy. The lowest level includes sub-features and gate location features. Following the relationships between the features the hierarchical model can be easily constructed. The designer or a pre-defined routine (this has been implemented in the prototype system to be discussed below) can check the part feature first to get all wall features. Then each wall feature is examined to get its embedded development features and treatment features, if any. The process is continued until all features are retrieved and constructed. Figure 2 shows a flowchart of this process.

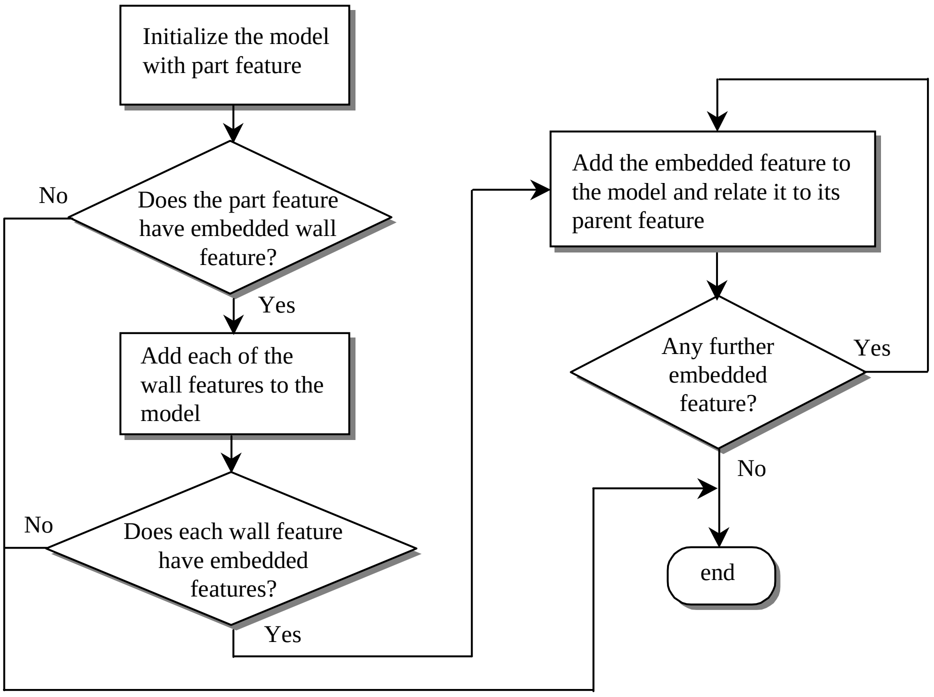


**Figure 2. Constructing integration model from CAD-CAE features**

### *3.2. Integration of design-analysis process*

The integrated design-analysis process starts from creation of the required CAD-CAE features and construction of integration model. After that an analysis model is abstracted for the desired CAE analysis. The abstraction process involves abstracting an idealized geometric model (idealization) and abstracting non-geometric analysis information, such as material type, boundary conditions, processing conditions and constraint information. The idealization involves simplifying the geometric model to suppress non-significant features (suppressible features).

With all the information available from model abstraction, the underlying CAE system can be activated to conduct a CAE analysis. The analysis results are then examined to check whether any of the pre-defined criteria – which are in the form of part feature constraints in the integration model – is violated. If any criteria are violated then the CAD-CAE features need to be modified. After modification, a new integration model will be constructed and analysis model abstracted, so that another CAE analysis can be activated. The process iterates until all criteria have been satisfied.

If the design requires optimization of some parameters then designers need to have a predefined optimization routine. This routine can take full advantage of the integration model. For example, if a designer needs to search for an optimized gate location over a restricted area of the plastic part, the optimization routine will only need to change the gate location attribute of the part feature in the integration model for each iteration process. Furthermore, the gate location constraint of the corresponding wall feature can be utilized to reduce the optimization search space.

## 4. Implementation of a Prototype Design System

Based on the proposed integration model, we have developed a prototype system for injection molded product design. The system consists of four layers: a CAD and CAE platform layer, a CAD-CAE feature layer, a model layer and a GUI layer. The CAD platform provides modeling tools and algorithms for specifying geometric information of the plastic part, while CAE platform provides analysis routines for the CAE analysis. The feature layer comprises predefined features and user-defined features based on the above feature definition. The model layer is used to develop the integration model and to extract the required CAE analysis model. The GUI layer provides the facilities for the user-system interaction.

We propose to use existing CAD/CAE systems as the CAD/CAE platform. By using these existing systems, a lot of software development efforts can be saved. In the implemented software prototype, Solid Edge® is used as the CAD platform, while Moldflow® is used as the CAE platform.

Because Solid Edge supports ActiveX automation, the functionality of this system can be easily accessed by the outside programs. Figure 3 shows the GUI of the developed prototype system. The upper panel shows the system menus and tool bars and the lower-left panel shows the feature tree of the plastic part being designed. The underlying Solid Edge system is shown in the lower-right corner. To create CAD-CAE features, designers need to create the relevant geometry by using Solid Edge geometric modeling functionality first. After that, analysis information is specified while the created geometry is assigned.

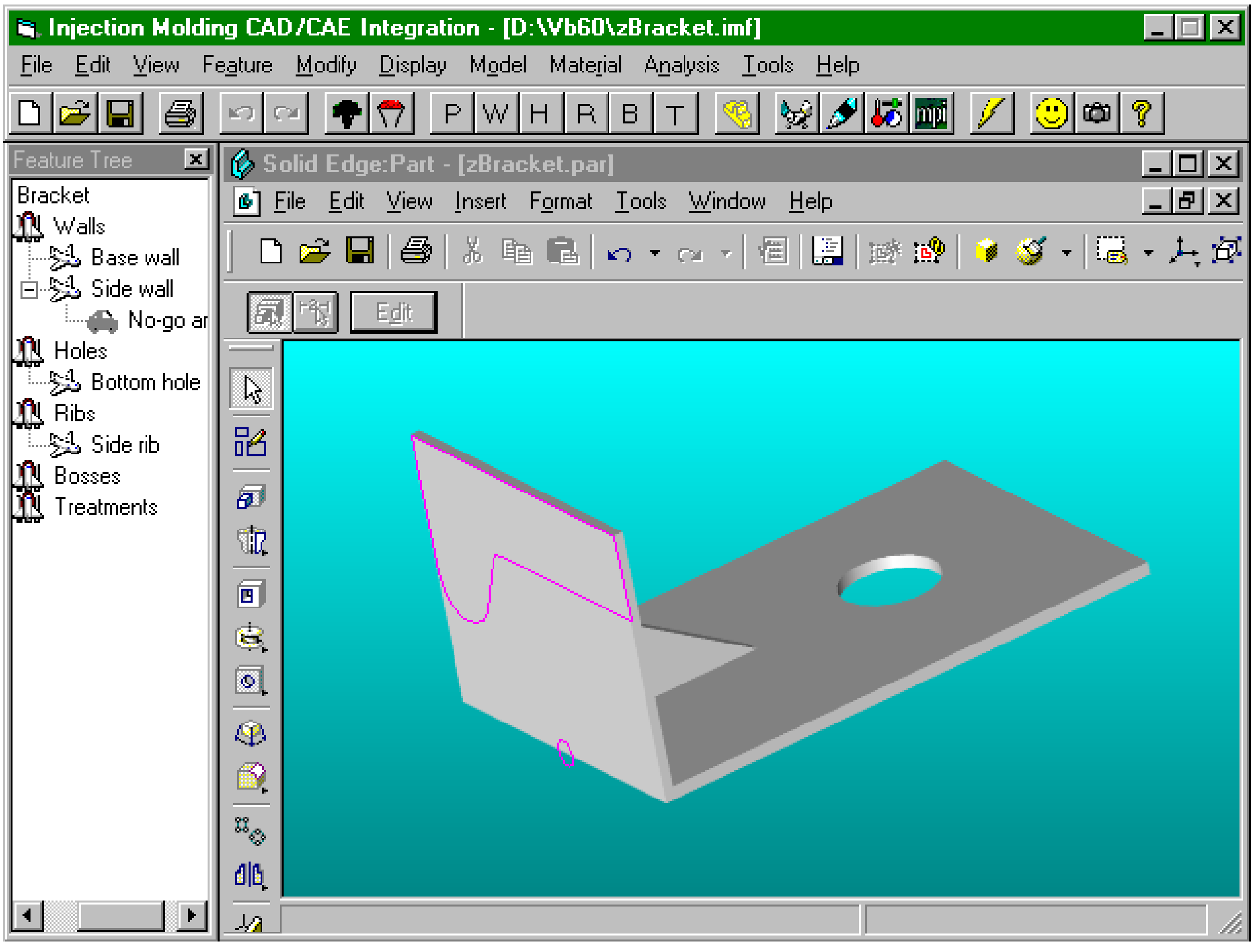
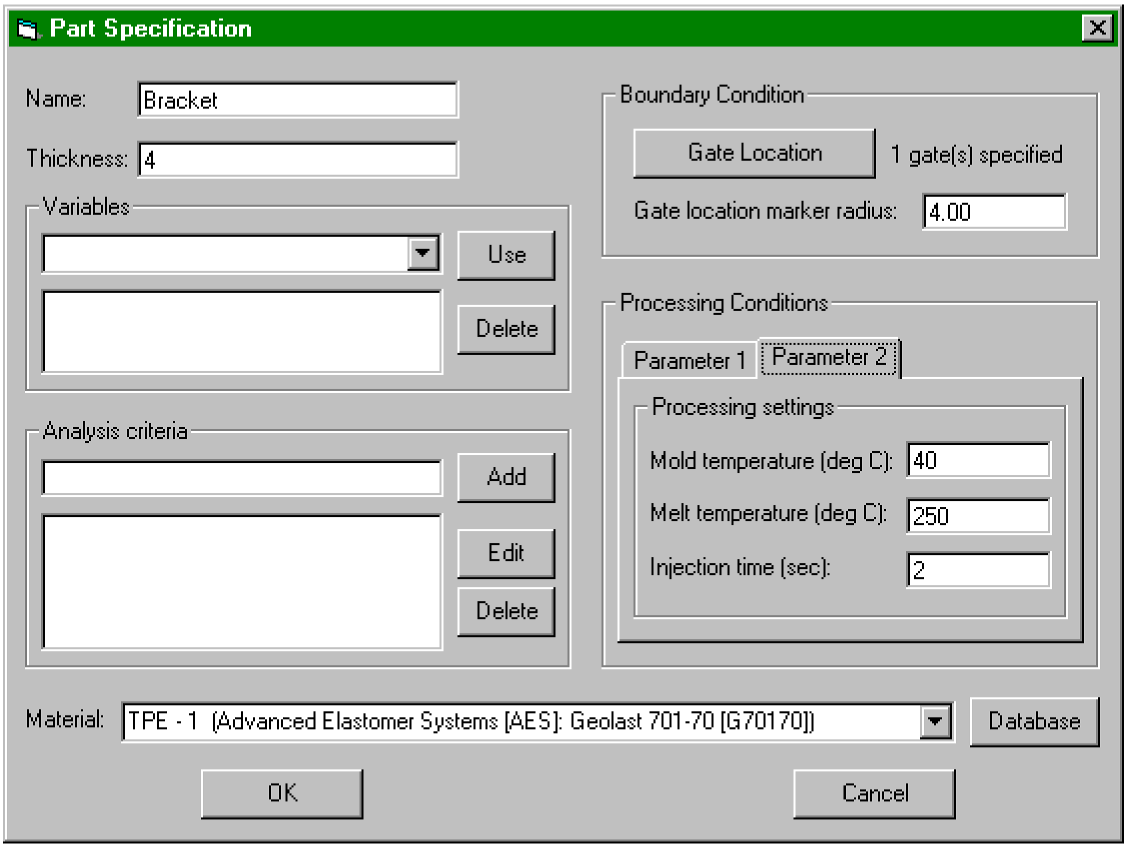


**Figure 3. Graphical user interface of the developed prototype system**

Figure 4 shows the user interface for specifying the part feature. If the designer wishes to specify gate location at the part design stage, he or she should create gate location feature first. By clicking 'Gate Location' button within the part specification user interface, the system will automatically access Solid Edge system and allow the designer to assign the created gate location marker, thus create the corresponding gate location feature. This is achieved by using the exposed ActiveX objects of the CAD system. Multiple gates can also be specified. The system uses circle as the gate location marker, where the center of the circle is retrieved as the gate location. In Figure 3, the small circle on the left-bottom edge of the part represents a specified gate location. Figure 4 also indicates this by the text ‘1 gate(s) specified’.

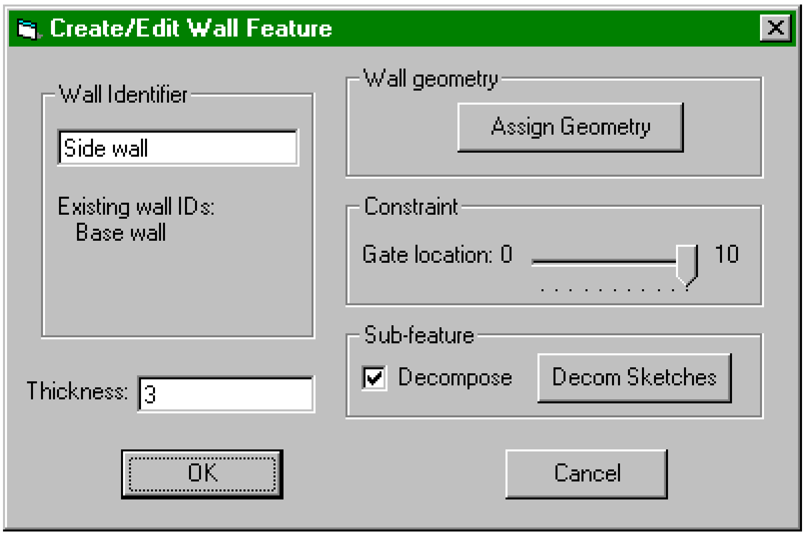


Name: Bracket
Thickness: 4
1 gate(s) specified
Gate location marker radius: 4.00
Mold temperature (deg C): 40
Melt temperature (deg C): 250
Injection time (sec): 2
Material: TPE - 1 (Advanced Elastomer Systems [AES]: Geolast 701-70 [G70170])

**Figure 4. User interface for specifying part feature**

The other aspects of part information can be specified as well. The designer can specify the material type, its manufacturer and trade name as the material information. This information serves as an index to the material properties within the Moldflow environment. The system has a material library to allow the designer choose his or her desired material from the library. The constraint information is specified by the relevant design variables and analysis criteria expressions (this information is not specified in Figure 4).

Figure 5 shows the user interface for creating a wall feature. The designer should create the wall geometry first and then click ‘Assign Geometry’ button to select the geometry from the CAD environment. The ActiveX objects corresponding to the selected geometry shall be used as the geometry attribute of the wall feature. These objects incorporate not only all the geometric entities of the feature, but also the topological relationships captured by the CAD system.



Wall Identifier: Side wall

Existing wall IDs:
Base wall

Thickness: 3

Gate location: 0 … 10

☑ Decompose

**Figure 5. User interface for specifying wall feature**

The designer can also specify the gate location constraint of the wall feature by dragging the slider (see Figure 5) to specify a value between 0 and 10 for the weight of the gate location. The value 0 indicates a gate is not to be located on this wall feature, while the value 10 indicates that the wall feature is highly desirable for locating a gate.

If the designer wishes to specify different constraints over part of a wall feature, he or she can create a sub-wall feature. Again, the geometry needs to be created first. Designers can then click button ‘Decom Sketches’ (see Figure 5) to select the geometry for the sub-feature. Figure 3 shows an example of this feature over the outer surface of the ‘Side wall’ feature. This is a sketch in the Solid Edge environment. Note that the sub-feature can be created over any geometric entities of the part geometry, hence is not restricted to a wall feature or any other feature alone.

Other features can be created and specified in a similar manner. The designer can use menus and tool bars provided by the system to activate relevant functions. Alternatively popup menus can be activated under the feature tree window to achieve the same functionality.

After all CAD-CAE features are created the system will automatically construct the integration model of the design. Since the model has incorporated suppressibility information over relevant features, the model geometry can be automatically idealized to abstract the analysis geometry. This should then be used to develop finite element mesh (FEM) model for CAE analysis. Moldflow system supports three types of mesh model: midplane model, surface model and 3D model. Of the latter two types, the idealized geometric model can be directly used. However, a conversion from the idealized geometric model to the midplane model should be conducted for the first type. The designer can choose to achieve this either under the Moldflow environment or a CAD environment that has such functionality.

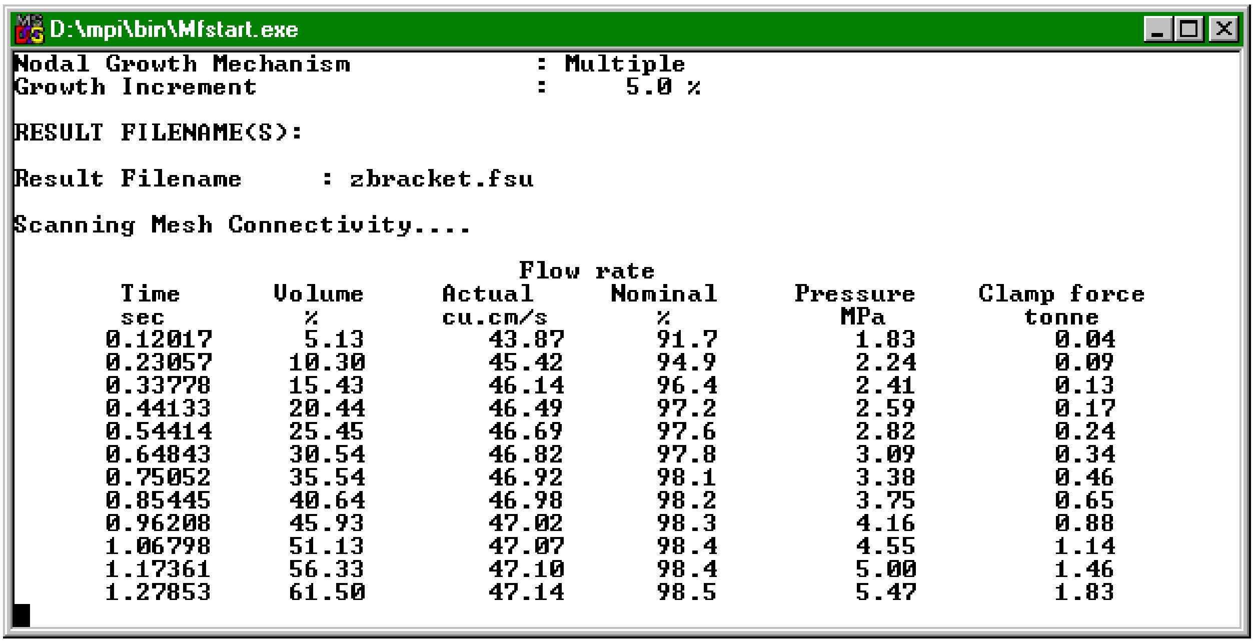
Besides the geometry information, the non-geometric information should also be abstracted from the integration model. The system will automatically generate the boundary condition file using the specified gate location information. After that, a Moldflow 'analysis inputs file' is generated, which incorporates information such as material data, processing conditions, pointer to the boundary condition file, and so on. With this file, the system can automatically activate the relevant Moldflow routines for the intended CAE analysis.

## 5. Case Study

A plastic part design case is studied to indicate the proposed integration model and its application in transferring non-geometric information from CAD environment to CAE environment. This is an L-shape bracket, shown in Figure 3. By using the predefined features from the prototype system, the designer first creates two wall features: 'Base wall' and 'Side wall'. All design and analysis information relating to these walls is specified. GUI tools are used to assist the process of specification. Assume that the designer wishes to specify that part of the outer surface of the 'Side wall' feature is not allowed to have gate location mark. A sub-wall feature is thus created.

After this, all development features are created, including a rib feature on the 'Base wall' feature and 'Side wall' feature, as well as a hole feature on the 'Base wall' feature. If there is any treatment feature that needs to be suppressed during CAE analysis, the designer should also create it and specify it as suppressible.

With all the features created and their relevant information (geometric and non-geometric) specified, an integration model is constructed. Note that Figure 3 only visualizes the geometry of the model and its feature tree. After that the designer can use the tools provided by the system to abstract analysis geometry, create mesh model and generate Moldflow analysis inputs file. The relevant analysis routines can be activated subsequently. Since all necessary information is within the integration model, this process can be carried out easily.  Figure 6 shows the running process of the Moldflow filling analysis.



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Nodal Growth Mechanism                  : Multiple
Growth Increment                        :      5.0 %

RESULT FILENAME(S):

Result Filename      : zbracket.fsu

Scanning Mesh Connectivity....

                                    Flow rate
       Time       Volume      Actual      Nominal      Pressure     Clamp force
       sec          %         cu.cm/s        %            MPa          tonne
      0.12017      5.13        43.87       91.7          1.83          0.04
      0.23057     10.30        45.42       94.9          2.24          0.09
      0.33778     15.43        46.14       96.4          2.41          0.13
      0.44133     20.44        46.49       97.2          2.59          0.17
      0.54414     25.45        46.69       97.6          2.82          0.24
      0.64843     30.54        46.82       97.8          3.09          0.34
      0.75052     35.54        46.92       98.1          3.38          0.46
      0.85445     40.64        46.98       98.2          3.75          0.65
      0.96208     45.93        47.02       98.3          4.16          0.88
      1.06798     51.13        47.07       98.4          4.55          1.14
      1.17361     56.33        47.10       98.4          5.00          1.46
      1.27853     61.50        47.14       98.5          5.47          1.83
```

**Figure 6. Running process of Moldflow filling analysis**

Figure 7 shows two filling analysis results: fill time and pressure. If any specified criteria are not satisfied then the integration model can be modified and the whole process be carried out again. In this case study no optimization criterion is specified hence no iteration is necessary.

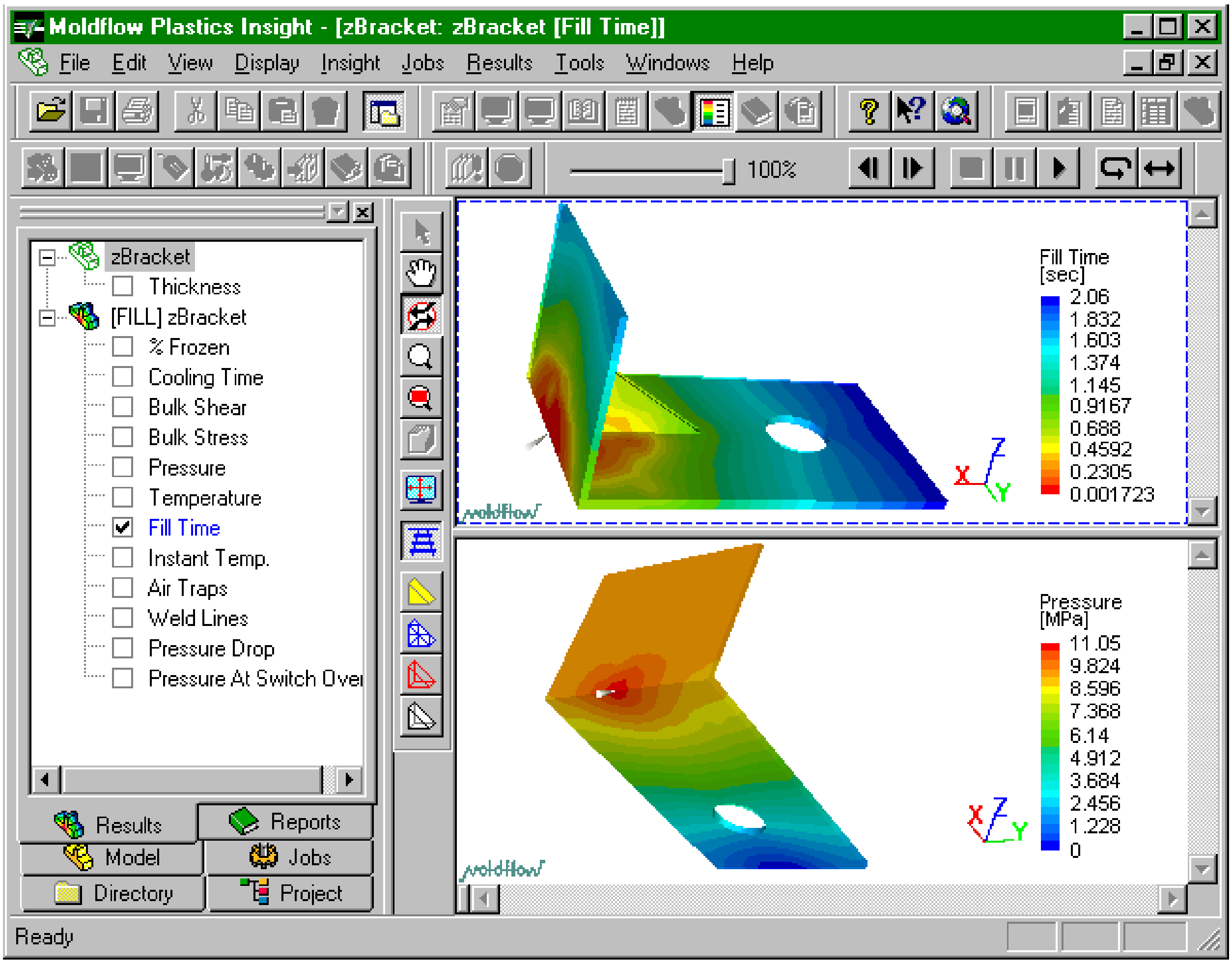

**Figure 7. CAE analysis results: fill time and pressure**

## 6. Conclusions

The goal of this research is to develop a CAD-CAE integration model which can provide more than geometric information to CAE analysis, thus assist the analysis information transfer between plastic part design and analysis. To this end, we have presented a feature-based integration model, which consists of a number of CAD-CAE features. The attributes of the features include both geometric and non-geometric information necessary for CAE analysis. A four-layer system framework was presented for developing a prototype design system. A number of tools were developed to assist the design process.

Future research will enrich the CAD-CAE features and devise self-configurable CAD-CAE features so that they can be tailored for the specific application environments. We shall also investigate how an automatic interpretation of CAE analysis results can be achieved based on pre-specified criteria, so that an automatic modification of the integration model and an iteration of CAD-CAE process can be achieved as well. By doing these we intend to minimize the requirement of human expertise both in transferring a CAD design model to CAE analysis and in interpreting CAE analysis results for proper modification of the CAD design. In short, our long-term goal is to achieve a maximum degree of CAD-CAE integration for the injection molded product design.

## Acknowledgments

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