INDUSTRY APPLICATION OF GEOMETRIC MODELING TECHNOLOGY

Major Future Issues and Some Challenges

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Abstract The present day geometric modeling technology plays a central role for making CAD/CAM systems effective in users' design and manufacturing preparation problem solving.
Though it provides a useful foundation for a variety of applications, there remain some issues which require further research or elaborate implementation.
The present paper discusses these issues with examples and describes challenges of resolving some of them by CADCEUS: Integrated CAD/CAM/CAE/CG system developed by Nihon Unisys, Ltd.(NUL).
Major focuses are pursuit of hybrid modeling in various senses, extension of parametric technology usage and major issues, effective use of non-manifold representation, use of geometric modeling technology for improving collaborative design, and several challenges of automated modeling. Curves and surfaces representation issue will also be mentioned.

Keywords curves & surfaces representation, non-manifold, hybrid modeling, parametrics, collaborative design

1 INTRODUCTION

Geometric modeling technology has played a central role for making mechanical CAD/CAM systems effective in users' design and manufacturing preparation problem solving. This paper tries, within limited pages, to extract

F. Kimura (ed.), *Geometric Modelling*

future issues of constituent technologies mainly from implementor's point of view, and introduces some challenges to resolve issues by CADCEUS*1. Investigation is mainly focused in automobile design and manufacturing applications where geometric modeling technology is most heavily used, and especially focused technology is parametrics. As for commercial CAD systems, PTC/Pro-E, SDRC/I-DEAS, DS/CATIA, EDS/Unigraphics, and NUL/CADCEUS are taken into consideration.

Representation issues are discussed in Chapter two. Chapter three discusses modeling issues, Chapter four parametrics issues, and Chapter five discusses the use of parametric modeling technology in collaborative design environment.

2 REPRESENTATION

2.1 Free Form Curves and Surfaces Representation

The author categorises applications which relate to curves and surfaces representation in the following three types by the difference of primary requirements.

1) Data exchange or visual presentation
2) Shape design like styling design of a car body
3) Shape modeling based on already designed curves or drawing

As for data exchange or presentation purposes, the primary requirement is wide most representation capability in order not to incur deterioration of data.

NURBS is widely used for this purpose and it is adopted in ISO/STEP and ISO/PHIGS. But, its use in STEP Part42(1): Geometric and Topological Representation is limited to as one of types of free form curves and surfaces representations different from its original claim that it can both represent analytical geometry and free form geometry. Major reasons we understand are that NURBS requires larger data storage to represent analytical geometry than its direct representation, and that increase of calculation time is not negligible.

As for shape design, the primary requirement is a representation which is suitable for use in an interactive shape design environment. It should enable easier establishment of human interface for controlling existing surface model so that deformation operation is intuitively accepted, easy and the result of deformation can be estimated for the user. Direct control of point on surface or curve on surface seem to be better than rather indirect method such

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*1: CADCEUS is the integrated CAD/CAM/CAE/CG system developed by Nihon Unisys. CADCEUS is adopted as the baseline system of Toyota's 'TOGO' system, and has many users especially in automobile industry.

as control of control points or NURBS weights. There has been rigorous research in this area such as Hosaka[(2)] and Higashi[(3),(4)].

As for shape modeling, Coons, Non-uniform polynomial B-spline, Bezier, Gregory representations and their extensions[(5)] has been used in wide area surface modeling and solid modeling.

Since major target of most of the commercial systems has been 1) and 3), they use NURBS for external representation, but they use more performance oriented internal representation such as a power series expansion for geometry processing.

In order also to include application type 2), re-evaluation of exact transformation among proposed representations is indispensable.

2.2 Non-Manifold Representation

In FEA area, coexistence of different dimensional entities for representing one analysis model has been natural requirement and many analysis packages support this requirement to some extent. The reason of the necessity of above coexistence is that there could be a drastic idealisation of the target shape within expected accuracy of analysis results.

In CAD/CAM area, since final target is actual manufacturing, and every manufacturable objects are manifold, adoption of non-manifold representation has not been aggressive.

But, in order to make a system very robust during modeling such as set operation, non-manifold representation is inevitable at least for representing intermediate result of modeling. There are more positive reasons why CADCEUS adopted non-manifold representation as explained in the followings.

As for non-manifold representation, K.Weiler's Radial Edge Structure[(6)] which aims at unified representation of manifold and non-manifold is well known.

CADCEUS represents a target model by a set of manifolds and allows the following three types of non-manifold connection.

Vertex vs. Vertex connection

Edge vs. Edge connection

Face vs. Face connection

The reasons why we adopted this method are to decrease data storage required, and to obtain good performance of data processing based on the experiences that most operations are closed within manifold.

Typical uses of non-manifold representation are automatic idealised shape model creation for use in FEM analysis by inactivating small holes and small fillets which do not affect analysis results, automatic rough milling model creation in the same meaning mentioned above, or upper die and lower die shape selection in view of press forming as shown in Figure-1. These applications require non-manifold representation at the boundaries of inactivated portion so that activate/ inactivate model modification is realised with easy data handling.

This activate or inactivate indication is easier to use in history based parametric modeling environment where the user has only to care about modeling history maintenance.

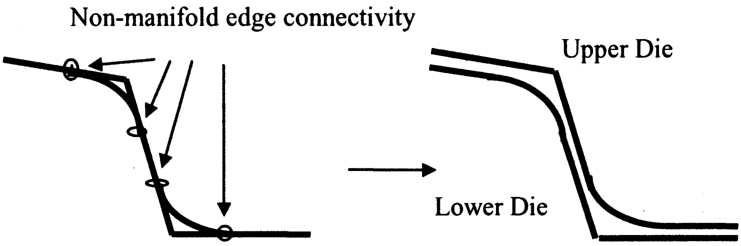


Figure-1: An application of non-manifold representation

3. SHAPE MODELING

3.1 Surface Quality

Requirement of high quality surface is expanding.

It is well known that styling design surface requires high quality surface. Not only local satisfaction of second order derivative continuity, but also global smoothness such as smooth highlight lines distribution and curvature monotonous are required.

But, requirement of high quality surface is gradually becoming a more general requirement. One of driving forces which gives rise to this requirement will be use of curve or circular arc NC path and high speed milling machine in sculptured surface machining area. It is estimated that surface quality is honestly reflected onto machined face in these circumstances. It means that development of high quality surface control technology on top of effective representations and satisfaction of required mathematical continuity is essential for supporting wide area surface and solid modeling.

3.2 Hybrid Modeling

It is crucially important to provide a modeling engine which enables flexible shape modeling environment, deformation of design object, and re-use of existing models. In order to satisfy these requirements, realisation of hybrid modeler in the following sense, as realised in CADCEUS, is regarded as a first step.

1) Arbitrary mixture of solid, surface and wireframe models is allowed for representing and manipulating a design model. This requirement naturally requires non-manifold representation.
2) Mixture of feature and non-feature models is allowed.
3) Mixture of parametric and non-parametric models is allowed.

As a reason of its necessity, consider ,as an analogy, the geometric constraint modeling case. Different from the expectation of the system, it is very rare that the user gives sufficient constraint conditions for the system to uniquely determine a target shape. Constraint conditions given are usually insufficient. There are cases that the user intentionally gives excessive constraint conditions. In order not to deprive freedom of design, it is the implementor's role to develop a constraint solver which can treat both insufficient or excessive constraint conditions cases.

The reason why 1) is important is that the user should be allowed any choice of shape model representation in view of design process and precision requirement of his design. This naturally requires implementors the provision of flexible modeling functions such as set operation between solid and surface, etc.

If 1) is realised, there is no need for the user to care about if his model is solid or surface. Body designer can freely refer engine data, and engine designer can also freely refer body data as necessary.

The reason why 2) is important is that design model suited for entire feature based modeling is extremely limited to some design process such as die structure design, and most of design models are suited for mixture of feature and non-feature models.

There is another discussion on the implementation of feature based modeler.

For simplicity of implementation, every commercial system treats any geometric entity such as a point or a curve as a form feature irrespective of feature semantics . Realisation of above mixture will result in correct implementation of features. Though feature modeling and shape parametrics are different technologies, implementation of feature modelers had better have parametric capability for ease of use and easier realisation of user defined features.

The reason why 3) is important is that there are many applications where current shape parametrics is not suited. For example, in styling design of a car body where trial and error is essential, simple accumulation of users all operations is not realistic nor meaningful. But, the next process, body design could be drastically improved by the effective use of shape parametrics. One thing to be noted in the realisation of mixture of parametric and non-parametric modeling is that there should be enough investigation on the appropriate mixture level in order not to incur confusion in its usage.

3.3 Automated Modeling

Automated modeling has been pursued for decreasing man hours required in each design process. Important points to be taken care are to provide a measure to judge the validity of the results from engineering point of view or mathematical representation point of view in order not to miss inappropriate result, and to provide easy means to supplement incomplete portions when automatic creation is not complete. This section discusses some results in two categories.

<Product Shape Modeling>

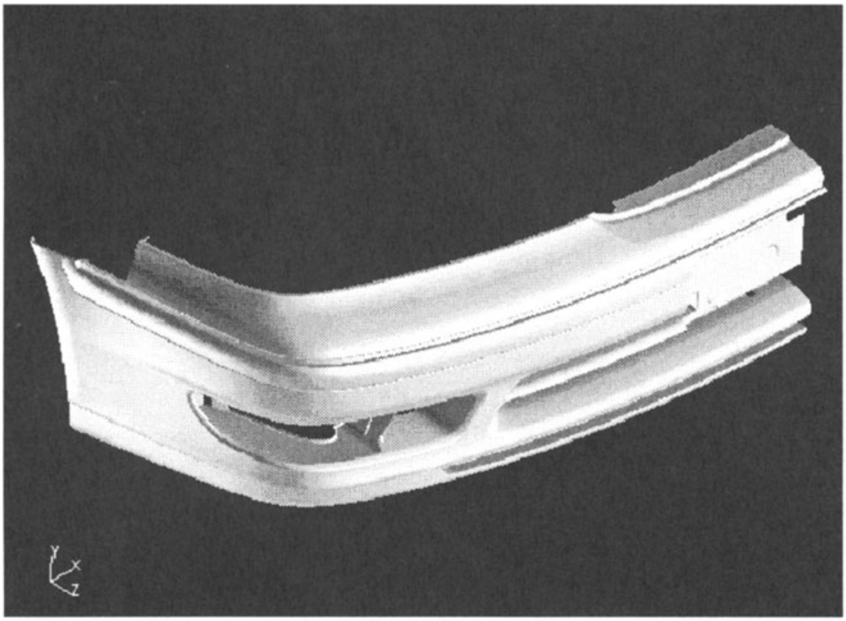
Figure-2 shows automatically created automobile bumper inner surfaces based on outer surfaces. Technology utilised here is an offset of a compound surface. After the completion of modeling outer surfaces as one compound surface (topologically connected surface), the user only specifies offset values at necessary locations. In the bumper example, variable offset is a crucial requirement.

Then, the system offsets outer surfaces and automatically resolves any topological and geometric inconsistencies which arise after offset. Total calculation time is below 20 minutes by HP/C180, and level of automatic creation is 95%. Remaining 5 % in this case is obvious open space and could be easily filled with usual surface modeling commands.

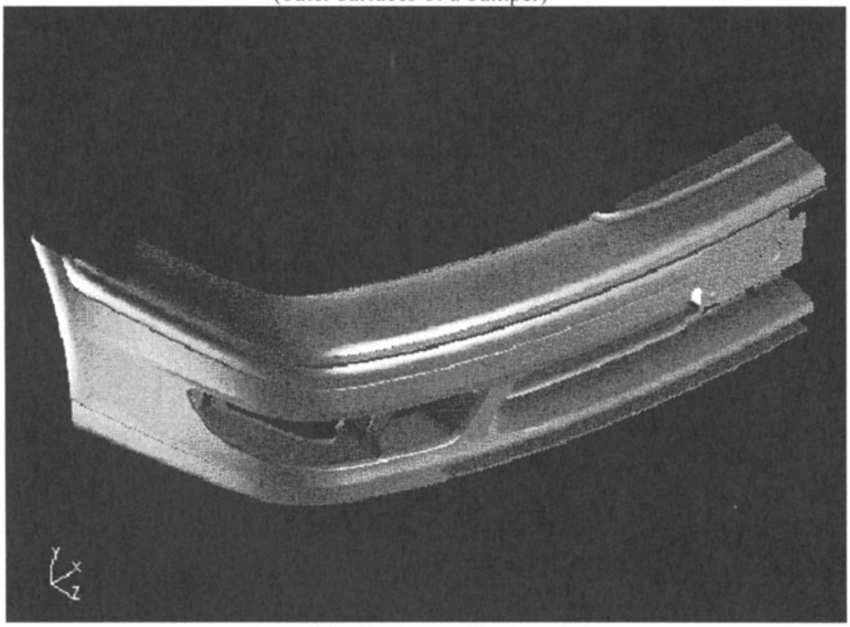
Figure-3 shows automatic creation of a surface model based only on a wireframe model. In this example, the system automatically recognises face loops and assigns plane or ruled surface or free form surface depending on the geometric characteristics of bounding curves. Calculation time with HP/C1800 is 2 minutes. Figure-4 shows automatic creation of fillet surfaces. The system automatically searches for edges where fillet surfaces should be attached, and creates and attaches fillet surfaces of prescribed radii there. Calculation time is around 1 minute.

<Product Shape Deformation in View of Manufacturing Consideration >

Most of commercial systems provide global deformation capabilities for considering manufacturability. ‘Over crown Estimation’ and ‘Spring Back Estimation’ are typical in press die area. Since pressed panel goes back by its elasto-plastic nature after press is completed, die shape should be deformed beforehand to take into account that behaviour so that pressed panel goes back to exact product shape. Though there are some challenges to directly attack this problem by the heavy use of FEM analysis, most CAD vendors approaches to this problem are experiment based geometric modeling approach. The user specifies parameters based on experiments and the system globally changes given die shape by prescribed algorithm. Mold area also has specific requirements such as under cut area detection, deformation in view of draft angle consideration or thermal effects consideration.

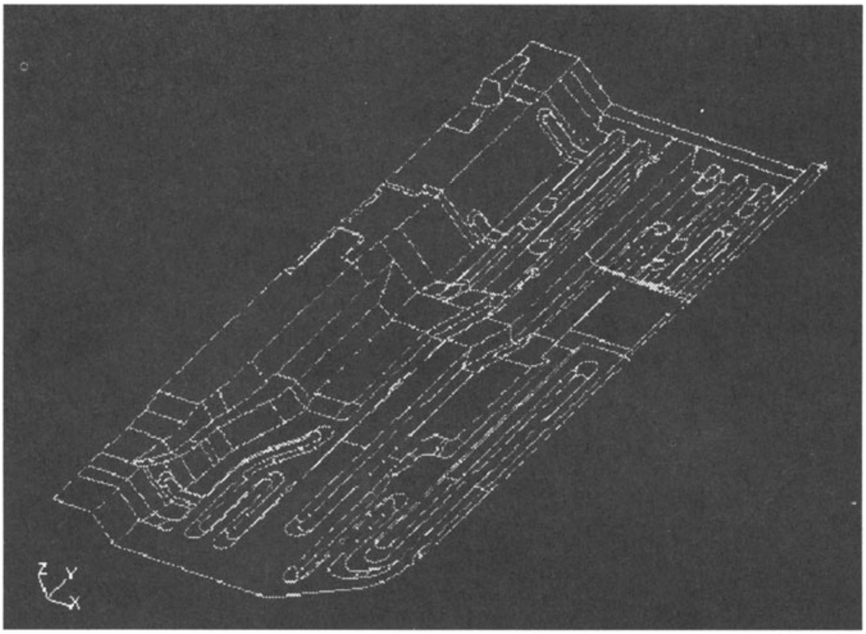


(outer surfaces of a bumper)

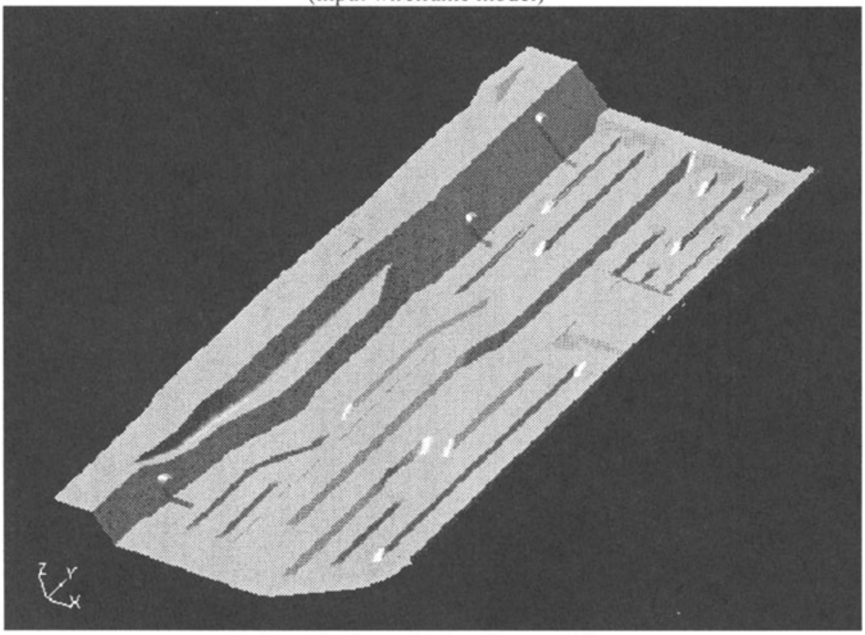


(automatically created inner surfaces)

Figure-2: An application of compound surface offset to bumper inner surfaces creation



(input wireframe model)



(automatically created surface model)

Figure-3: An example of automatic surface model creation

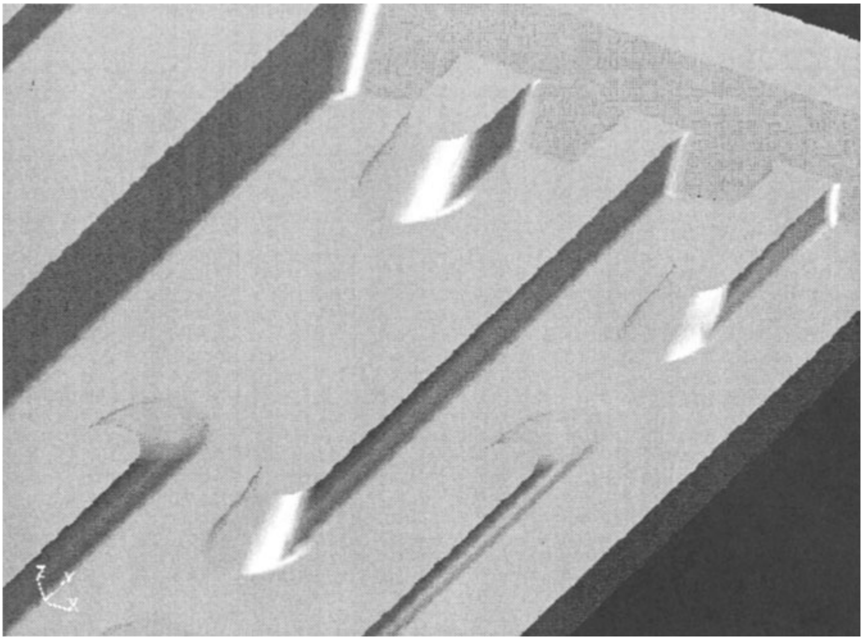


Figure-4: An example of automatic fillet creation

4. PARAMETRICS

Importance of solid modeling is well discussed and its effectiveness is getting points among end users. But, the author feels that parametrics is far more important technology than solid modeling. Solid modeling may improve design, but parametrics has a possibility to innovate design since it has a possibility to provide means to capture a design process and design constraints and transfer them to down stream applications.

Though implementations of parametrics of most commercial systems are solid model oriented, there is no reason that parametrics should be limited in solid modeling. As already realised in CADCEUS, it could be applied not only to a solid model, but also to a surface model, a wireframe model or their arbitrary hybrids. The facts that shape design of some design process is dependent on the shape of preceding design process, and parametric reconstruction based on reference change is practically available, show a strong possibility to drastically decrease total shape design period by the effective use of parametrics.

As is well known, current shape parametrics consists of the following three basic technologies.

1) Two dimensional geometrically constrained model representation
2) Three dimensional position constraints between parts
3) Operation history based representation[7]

1) and 2) have sound mathematical background and CAD system dependence there is quite small. On the contrary, 3) memorises users operation history and some other data and reconstruct whole shape model when some parameters are later changed.

Different from 1) or 2), 3) has no underlying mathematics, and CAD system dependence is quite big since the system memorises all the command parameters necessary for later reconstruction.

In all parametric CAD systems, 3) plays a central role, and 1) and 2) are combined with 3). A typical example of this combination is:

create a 2D profile of a boss(use of 1))
complete a boss by rotating above 2D profile(use of 3))
merge the boss into existing part model by the use of set operation(use of 3))

The shape or location and orientation of the boss could be easily changed ,even after the merger, by picking the boss, changing constituent parameters, changing set operation condition, and automatically reconstructing whole model.

Major remaining issues of operation history based representation mainly from standardisation point of view are as follows;

1) How to represent operations history itself. Hopefully, it should not be a honest copy of actual operations ,but should be some abstracted one so that it does not include CAD system dependence, and it is the sequence of meaningful design processes which includes obvious design intentions.
   Treatment of simultaneously working engineers' operations has also to be taken into account.
2) How to represent reference relation and interference relation among different operations included in the operations history so that robustness of reconstruction is guaranteed.
3) How to remove CAD system dependence of geometry manipulation capabilities, which are major contents of history information.
4) How to obtain high human readability of the operations history.

As for 2), there are some contributions from research side[8],[9] though further research is required for resolving practical problems. As for 3), see analysis of past challenges [10]. 4) which strongly concerns with issue-1) is quite difficult to resolve and requires further research.

5. USE OF PARAMETRICS IN COLLABORATIVE DESIGN ENVIRONMENT

In manufacturing industry, reduction of lead time through whole manufacturing processes and further improvement of product quality are still very important issues. For resolving these issues, thorough quality management by TQC(Total Quality Control)has been practiced ,and concurrency of manufacturing processes has been pursued.

As for the reduction of time required in each manufacturing process, major focus has been sophistication of CAD/CAM capabilities, and promotion of automation. It can be said that various challenges for reducing time necessary for product development has been tried on the condition that 'CAD/CAM system is a tool for single engineer's use'.

But, in view of the fact that two or more engineers are simultaneously concerned for the design of almost all large scale design objects, we can not essentially resolve the issue unless we establish a framework which directly support consistency management of two or more engineers simultaneous activities. In other words, evolution which makes CAD/CAM system 'a common tool for two or more engineers simultaneous use' is necessary.

Among issues for realising this goal, the following issue is geometric modeling technology related critical issue.

' Capability for announcing an engineer the change of other engineer's work which he is referencing is necessary. Revision of his model corresponding to the latest status of other engineer's work had better be performed with minimum operation.

In order to satisfy the latter half requirement of the above issue, CAD vendors are required to provide reference driven model reconstruction capability for a part model represented by a hybrid model mentioned before, and for an assembly model represented by combining those part models.

In what follows, collaborative design support implemented in CADCEUS will be presented(11).

Before going detailed explanation of developed capabilities, overview of CADCEUS data model is as follows. Hierarchy of data set is;

Work Space(WS) - Object(OBJ) - Group(GRP) - Entity(ENT)

Here, ENTITY is a minimum and leaf constituent of a product model, such as a geometric entity or a topological entity. Group is a concept to arbitrary summarise them. Object is a concept corresponding to a part, or an assembly, or a drawing sheet. Objects can have arbitrary hierarchy. Work Space is the highest concept among data set for representing a product model, and it corresponds to a design space. One Work Space can include any number of Objects. Work Space and Group are not allowed to have hierarchy.

(1) Realisation of Shared Work Space(SWS)

Fundamental requirement of collaboration support is ' to realise shared design space of related engineers satisfying maximum independence and efficiency of each engineer's work'.

In order to realise this requirement, we separated WS into two types, one is PWS(Private Work Space) for personal use , the other is SWS(Shared Work Space) for common use , and developed a SIM(Shared Information Manager) which manages transfer of data between SWS and PWS. Those information stored in SWS are fundamental design information(shape and constraints of the shape) common to all engineers, information which spans to two or more engineers, and objects which is disclosed to all engineers. Each engineer imports fundamental design information and other engineer's OBJ which is related to his design work from SWS. Then, he proceeds his design work independently. SIM always monitors information on SWS, and from what engineer the information on SWS is referenced. When some OBJ referenced by other engineer is updated on SWS, then SIM informs referencing engineer the fact and urges him to re-import the latest OBJ. When all the engineers finish their respective design and register their OBJs to SWS, then whole design is completed. The relation among SWS, PWS and SIM is as shown in Figure-5.

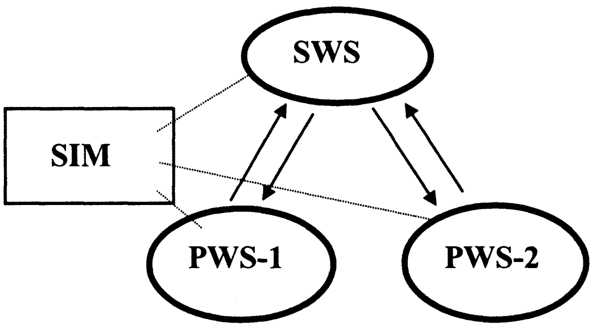


Figure-5: Fundamental structure of collaboration support.

In this mechanism, SWS is visible from all engineers but PWS is invisible from other engineers, which satisfy a requirement concerning independence of each engineer's work.

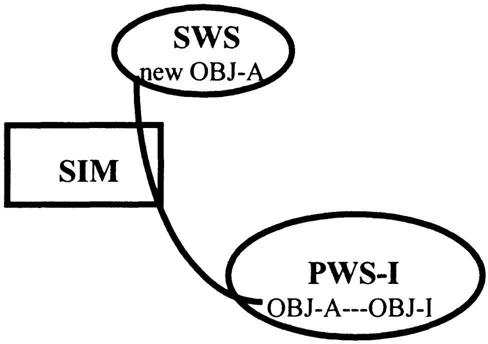
When the change of the other engineer's OBJ referencing occurs, concerning message is passed from SIM. What he should do ,at first, is to receive the latest status of the other engineer's OBJ from SWS. Then, he can automatically reconstruct his OBJ consistent with the newly received OBJ by the use of parametric capability described later.

(2) Update right control of OBJ

OBJs on SWS can be assigned update right by the use of SIM. Update right of one OBJ is assigned to only one engineer. One engineer may have two or more OBJs of which update right he has. Those OBJs of which update right are possessed by other engineer can be used and modified on PWS but can not be transferred to SWS.

(3) Consistency management of data model between engineers

'OBJ reflection capability' is prepared for revising referencing other engineer's OBJ to the latest status. This is a capability to transfer requested OBJ from SWS to requester specified work space via SIM. If the OBJ to be revised has any relation with other OBJs such as placement relation or reference dependency relation, SIM automatically recognizes the situation and urges the engineer to execute parametric reconstruction. History based parametric reconstruction capability by the change of references enables the engineer to obtain his reconstructed OBJ consistent with the latest status of other engineer's OBJs as shown in Figure-6.



automatic reconstruction of OBJ-I

Figure-6: Mechanism of consistency management among engineers.

(4) Common information

Every time OBJ is registered to SWS, a message called 'common information' is passed to all other engineers. This message inform which engineer has done what to what OBJ. Each engineer can judge its influence to his OBJ. If he judges the necessity of reflecting the change to his model, then he can do it by the use of previously described OBJ reflection capability.

(5) Global parameter

Global parameter is a user definable parameter mainly for sharing design parameters among engineers. By possessing various parameters defined in the fundamental design phase as global parameters, further detailed design could be simultaneously performed sharing design parameters. Furthermore, by changing some global parameters and by automatically reconstructing related parts, influence of parameter change can be easily reflected on the entire product shape. Global parameters are stored on SWS and therefore visible from all the engineers. Each engineer at first import global parameters onto his PWS, and performs his design consistent with global parameters defined in fundamental design phase by relating dimensions of his model with global parameters by the use of algebraic constraint definition capability. Global parameters may be changed on his PWS independently for investigating various design plan though the change can not be exported to SWS. These situations are illustrated in Figure-7.

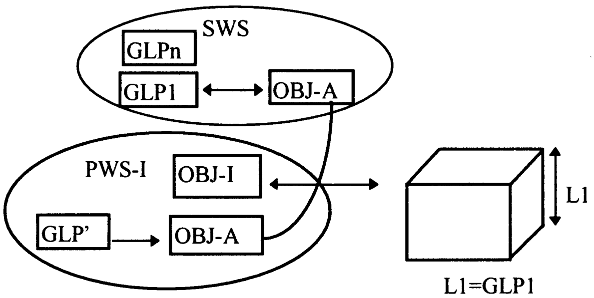


Figure-7: Global parameter.

(6)Example

This section examines the effectiveness of collaboration support capability developed on CADCEUS by using automobile engine design as an example. Supposed story is as follows. This story is also depicted in Figure-8.

1) There is only one fundamental designer. After he finished fundamental design, he registers fundamental shape(skeleton) and global parameters to SWS.

2) There are three detailed designers, one for exhaust port design, another for water jacket design, and the other for cylinder head design.

3) After receiving fundamental shape and global parameters, port designer proceed his design. When almost all shape is determined, he checks the design quality of his model by analysing distribution of sectional area, and finds out low quality portion where sectional area acutely changes as shown in Figure-9.

He then corrects base curve of the port and automatically reconstructs his model by the use of parametric capability as shown in Figure-10. The reader may understand the improvement of sectional area distribution. Finally, he registers his completed model to SWS.

4) Water jacket designer, when announced the revision of referencing port data, re-import new port data from SWS and reconstruct his model corresponding to the port data in the same way. Cylinder head designer may also reconstruct his model in the same way after importing latest port and water jacket.

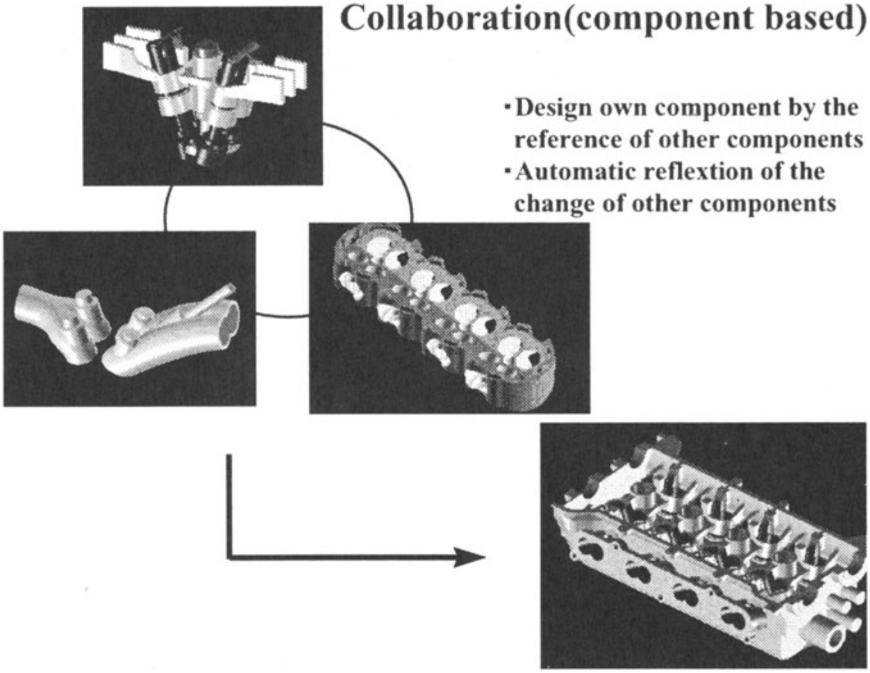


Figure-8: Supposed collaboration story

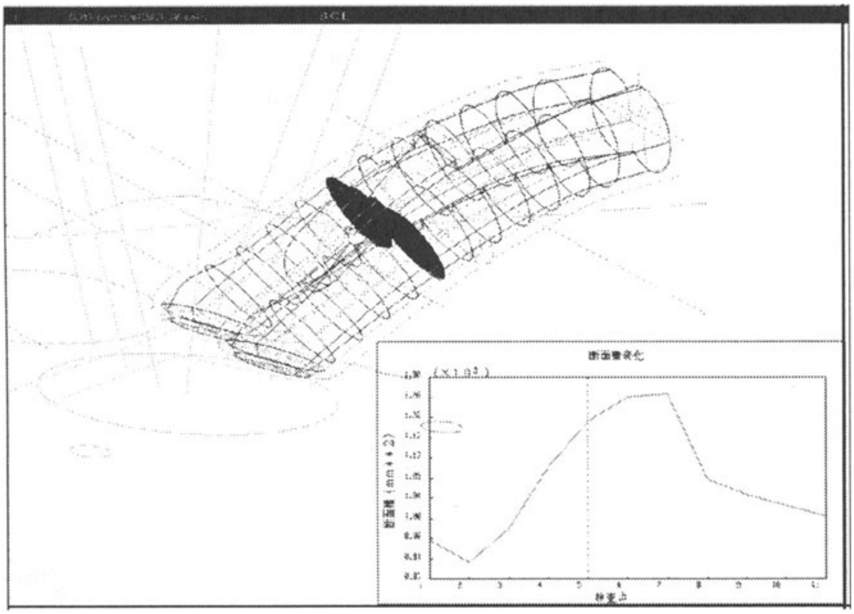


Figure 9: Quality analysis of a port.

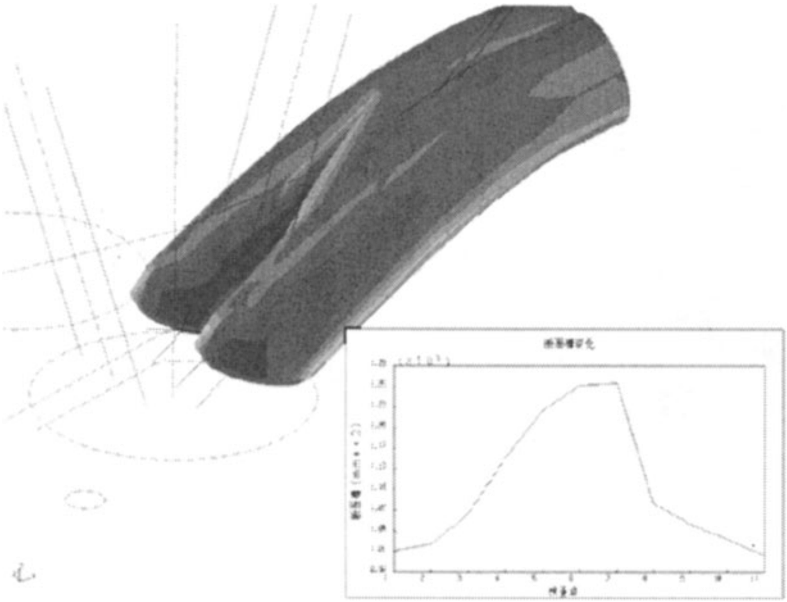


Figure-10: Reconstructed port.

6. CONCLUSION

Industry use of geometric modeling technology is reviewed from some applications in automobile design and manufacturing preparation with examples, and some future issues are discussed. Major issues are the followings.

(1) Re-evaluation of exact transformation among already proposed free form curves and surfaces representations is necessary, especially from the support of shape design point of view.

(2) Development of high quality surface control technology based on effective use of representations and satisfaction of required mathematical continuity is necessary.

(3) In order to provide users a flexible and powerful modeling environment, realisation of a hybrid modeler is critically important. Further investigation is required for knowing appropriate hybrid level.

(4) History based parametrics should be improved from CAD system independence point of view and strengthening of underlying technology point of view.

(5) Wireframe model, surface model, or any hybrid model should be allowed parametric behaviour.

(6) Effective use of reference driven model reconstruction should be further pursued for extending parametric technology usage, and for supporting

automatic shape model consistency management in collaborative design environment.

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