An Explanation of Topology Building Algorithms used in MSC/XLfromCAD

by

Martin Jones
FEGS Limited
Oakington
Cambridge, CB4 5BA
UK

ABSTRACT

MSC/XLfromCAD provides functionality to build geometric topology (faces, solids) ready for meshing from 3D wireframe data. This paper provides background on the technology used to build this topology along with hints and strategies for the user in the use of these algorithms.

Introduction

MSC/XLfromCAD is a program which reads the geometrical description of a CAD model in IGES format and writes it out in a form suitable for input to MSC/XL, where the model may be prepared for finite element analysis by MSC/NASTRAN. At first sight, this may appear to be nothing more than a format translation, since the range of IGES entities supported correspond closely to entities within MSC/XL. In fact, simply writing out the entities read from IGES directly would produce a model of little or no use for analysis modelling. The name 'IGES' gives the game away - 'IGES' is an acronym for 'Initial Graphics Exchange Specification', and its initial objective was the transfer of **pictures** rather than **models**. More recently, IGES has been enhanced and extended to provide for the description of geometry far in excess of such an objective. Its usefulness as a medium for the transfer of actual models has been proven beyond doubt in the field. However, the fact remains that for an application such as analysis modelling a good deal of processing of the raw data received from IGES files is unavoidable.

Typically, the raw data received from an IGES file will consist of a disconnected wireframe model. In this context 'disconnected' means that each individual curve has its own start and end points, ie, there is no topological connection between curves which terminate at the same point in space. Such a model may look acceptable when displayed graphically, but is of little use for analysis modelling. The geometry as received from IGES must first be 'cleaned' to establish true topological connectivity between curves, and also to replace any representation of curves in terms of facets (short, straight curves) by a single curve representing, as closely as possible, the original single curve intended. Attempting such data cleaning by hand is an exceptionally tedious, error prone and time-consuming process. However, it can be seen that these processes are largely automatic, and therefore should be performed by the computer.

After cleaning we have a connected wireframe model. Sometimes, this is all we want to do with the received model, but often we can actually fill in this wireframe by automatically defining faces and solids. This process is known as 'building topology'. Unfortunately, there is no complete and foolproof algorithm to achieve this, and the ambiguous nature of a wireframe model is such that there can never be one. MSC/XLfromCAD employs a pragmatic technique which has proven to do a good job in many cases. Just how good a job MSC/XLfromCAD will do depends critically on what information is present in the IGES file - adding a few extra curves to 'guide' the topology building algorithms prior to transfer can have a dramatic effect on the model eventually received by MSC/XL.

Model Cleaning

Before we can carry out the search for faces and solids efficiently, we have to prepare the model from the 'raw' form received from IGES, which is deficient in three respects:

* Each curve has its own start and end points - there is no connectivity between curves.
* Curves may intersect, and may be duplicated.
* Curves may be faceted, ie represented as a sequence of short, straight curves.

MSC/XLfromCAD provides three commands to correct these deficiencies, **'CONNECT'**, **'REGENERATE'** and **'UNFACET'**.

The **'CONNECT'** command scans the points of the model and merges together those points found to be coincident to within a user-defined tolerance. MSC/XLfromCAD uses its own data structures for the storage of the model, and a curve is represented by reference to two point entities, one for the start and one for the end, together with additional information describing the path of the curve between the two points. The point merging process therefore effectively establishes the topological connectivity between curves which share a common geometrical end point. Clearly, the tolerance used to determine whether two points are considered coincident is of vital importance - too small a tolerance will leave points unmerged and therefore the model unconnected, whereas too large a tolerance will merge points that should in reality be considered distinct, causing the model to 'collapse'. Although the IGES file should contain a parameter to provide this tolerance, experience has shown the value is frequently unreasonable, or not present at all. Therefore it is left in the hands of the user to determine the value it should take. The tolerance is set by the MSC/XLfromCAD command **'PROC GTOL'**.

The **'REGENERATE'** command scans the curves of the model and detects pairs of curves that intersect. Both 'T' (where the point of intersection is at the end point of one of the curves) and 'X' (where the point of intersection is not at either end point of either curve) intersections are found, and corrected by creating a new point entity at the intersection (if one does not already exist) and splitting one or both curves there. The connectivity of the curves established by **'CONNECT'** is maintained by this process. Again, the tolerance with which the intersection detection is performed is of great importance, and is under the control of the user, using the **'PROC GTOL'** command. **'REGENERATE'** will also merge together any duplicate curves, guaranteeing that there is only one curve following a given path between a start and end point.

The final stage of the geometry cleaning process is using the '**UNFACET**' command to remove any chains of 'facets' - short, straight curves used to represent a single curve. Many CAD systems will write facets rather than a single curve, and MSC/XLfromCAD may also create them as a result of reading certain IGES curve entities. However, these should be replaced by a single curve as an MSC/XL face may be bounded by only a limited number of individual curves. Here, the '**PROC LLNG**' parameter is of importance, as it defines the length below which straight curves will be considered short, and therefore candidates for unfacetting. Setting this too low may mean that facets will remain, meaning that what should be single curves will continue to be represented by several, in turn meaning that some valid faces may not be found. Setting it too high will not in general do any harm, although it may mean that the command takes a little longer than it would otherwise as more facets are considered. A chain of facets may be replaced by either a straight, circular arc or spline curve. The '**PROC GTOL**' parameter should also be considered, as it determines the accuracy to which the single replacement curve will shadow the original path of the facets. It is a mistake to set this to an unreasonably low tolerance, as it will mean that curves which should be represented as straight or circular arcs will be represented as splines, so the value should be chosen carefully.

The effects of '**CONNECT**', '**REGENERATE**' and '**UNFACET**' are illustrated in figure 1.

Having performed '**CONNECT**', '**REGENERATE**' and '**UNFACET**', the model is a clean connected wireframe. These commands alone make MSC/XLfromCAD far more powerful than a simple IGES translator. However, having performed these commands, the user also has the option of allowing MSC/XLfromCAD to define automatically, as far as it can, the faces and solids.

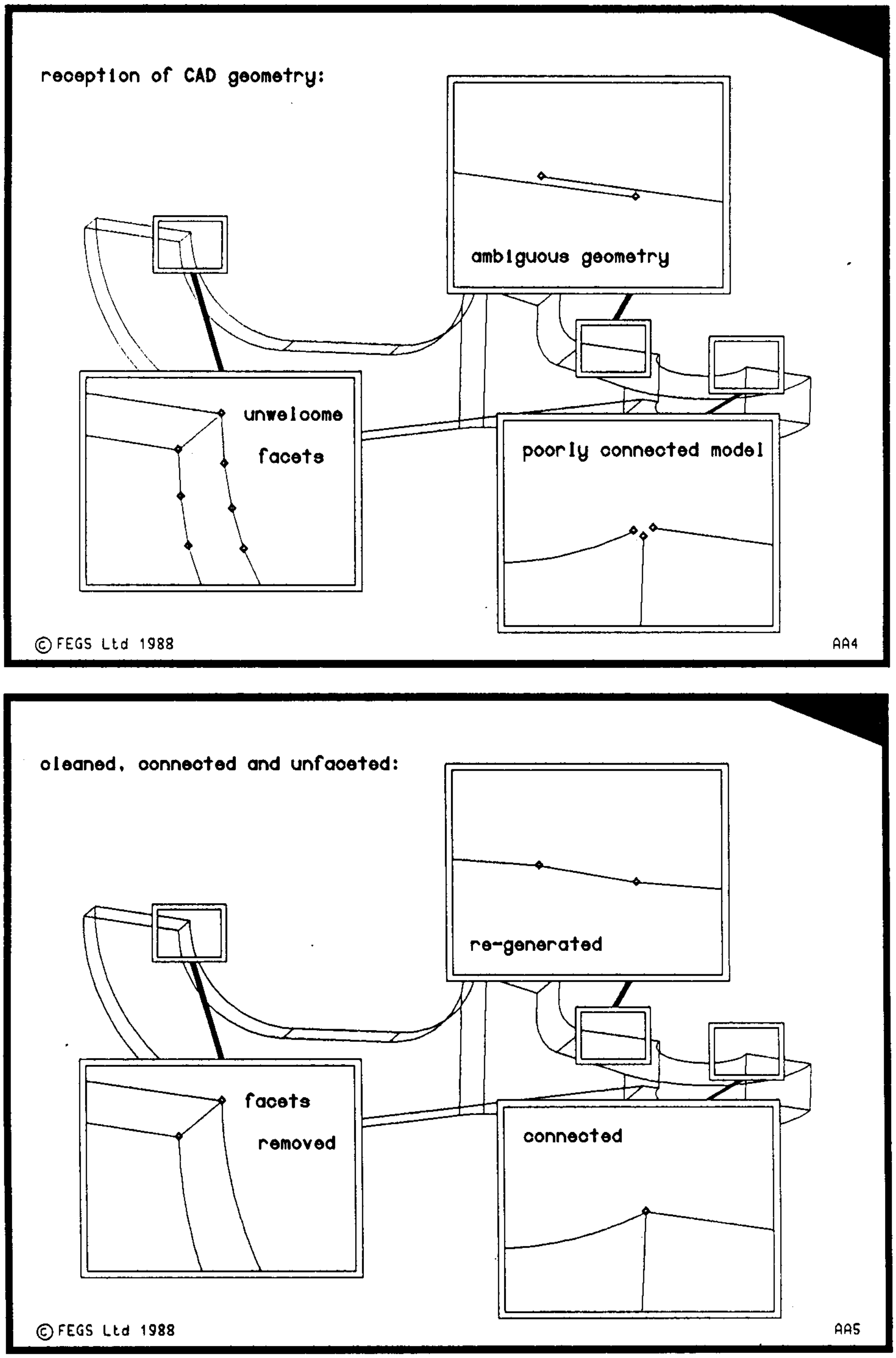

Fig. 1: The effects of '**CONNECT**', '**REGENERATE**' and '**UNFACET**'.

Building Faces

When a surface or solid model is reduced to a wireframe, information is lost. There is no method that can be guaranteed to redefine the faces and solids as originally intended. As an example, consider the 'hypercube' (a cube within a cube with corresponding vertices connected).

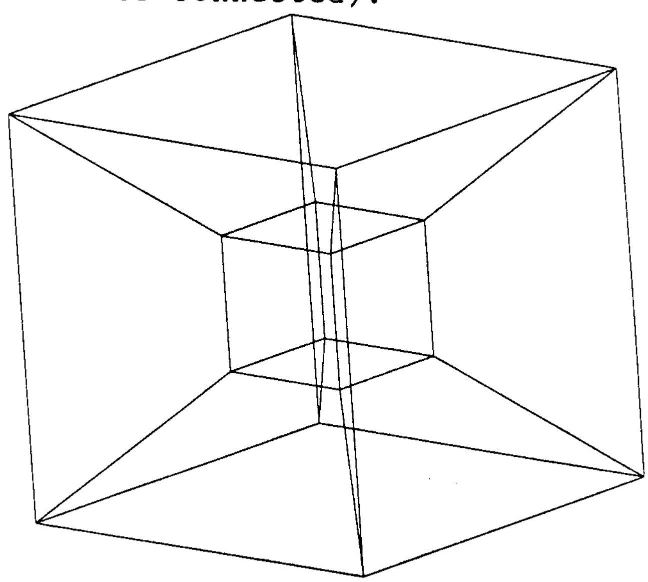

Fig. 2: The 'hypercube' wireframe.

Presented with this wireframe, what faces and solids should we define? Three possible alternatives are shown in figure 3 (solids are shown shrunken slightly towards their centroid for clarity).

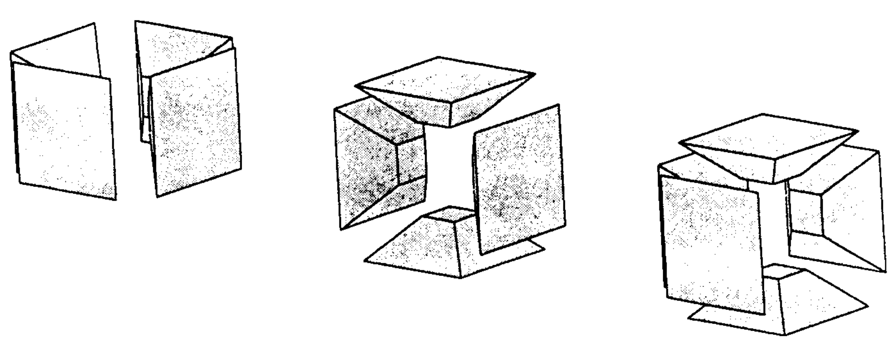

Fig. 3: Three possible interpretations of the hypercube wireframe

This wireframe is essentially ambiguous. Without further information it is impossible to tell which alternative is intended. Although this is a theoretical example, analogous problems of ambiguity frequently arise in real-life models.

Starting from a wireframe, we must first define the faces. This is a two stage process in MSC/XLfromCAD. The **'BUILD LOOPS'** command constructs an abstract topological representation of the model and scans within this for loops of curves which are potentially the boundaries of faces, storing these loops as sets within the MSC/XLfromCAD database. The **'BUILD SURFACES'** command then uses these sets to define the actual faces.

At its most basic, the process of finding loops is to start at a point and walk along curves, exploring the different alternatives at each branch, until we get back to where we started from. Considering the problem in this way, it becomes clear why it is essential to clean the wireframe received with the **'CONNECT'**, **'REGENERATE'** and **'UNFACET'** commands before 'BUILD LOOPS'.

For the purposes of the **'BUILD LOOPS'** command, the length of a loop is measured in terms of branch points, that is to say the number of points within the loop where three or more lines meet. The MSC/XLfromCAD parameter **'PROC BRAN'** controls the maximum length of loop that will be searched for. This parameter is set to 4 by default, but should be set to 3 when it is known that only triangular faces should be searched for.

Clearly, in order to be able to walk around a loop, and therefore detect it as a face, all the curves of the loop must be present. It is often necessary to add some extra curves within the CAD system so that the wireframe model written to the IGES file will contain all the curves which bound the required faces.

Similarly, because an MSC/XL face may be bounded by at most four curves, it is often necessary to split up more complex regions by adding curves in the CAD system. The precise position of the curves should be chosen to make the shape of the resulting faces as good as possible, for example, by avoiding sharp corners. Figure 4 gives a simple example of how a 5 sided region may be split into two 4 sided and one 3 sided regions by the addition of two curves.

The **'BUILD SURFACES'** command takes the sets containing loops of curves built up by **'BUILD LOOPS'** and defines faces using them where possible. A wireframe representation may contain loops within loops intended to represent holes, and the program cannot determine whether a loop found is intended to represent a face or a hole within a face. This can be rectified by adding additional curves so that MSC/XLfromCAD can work around the hole, as illustrated in figure 5. Notice that in this case the hole itself will be detected as a face (because it is a loop of length 4) as well as the 4 faces required. However, it is then a simple matter to delete this unwanted face interactively in MSC/XL.

'BUILD SURFACES' will ensure that no identical duplicate faces are defined, maintaining the 'cleanliness' of the model established by **'CONNECT'**, **'REGENERATE'** and **'UNFACET'**.

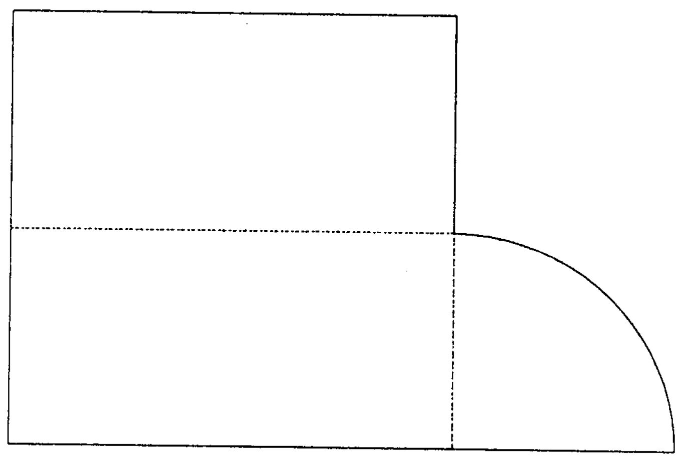

Fig. 4: Splitting a 5 sided region by the addition of two extra curves.

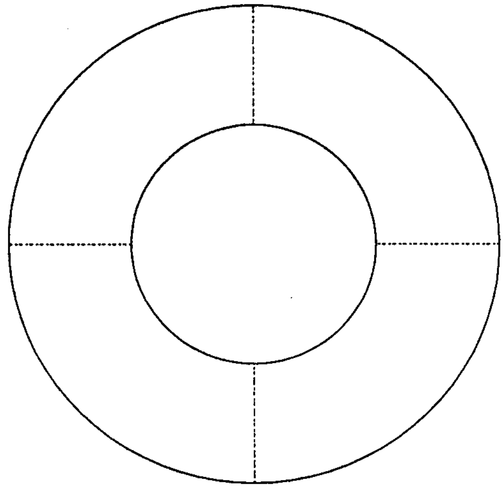

Fig. 5: Adding extra curves so that MSC/XLfromCAD can work around a hole.

Building Solids

After using **'BUILD LOOPS'** and **'BUILD SURFACES'** to detect the faces of the model, it is possible to use **'BUILD BODIES'** to detect the solids of the model. The technique employed for searching for solids is to scan the faces of the model to find 'tubes' of three or four quadrilateral faces. These tubes are then capped with two triangular or quadrilateral faces as appropriate to define the solid.

Since the searching for solids is performed entirely upon the faces in the model, the success of **'BUILD BODIES'** depends critically on the success of **'BUILD LOOPS'** and **'BUILD SURFACES'**. Therefore it is sometimes necessary to add extra curves to ensure that all the faces required to bound the solids can be detected.

As an example, figure 6 shows the extrusion of the example in figure 5 into three dimensions. The additional curves as added before ensure that the top and bottom faces can be found correctly, but it is also necessary to find the faces around the inside and outside of the required volume. This involves the addition of the extra curves as shown. Note that the central hole will now also be detected and transferred as a solid, but again it is a simple matter to delete this in MSC/XL.

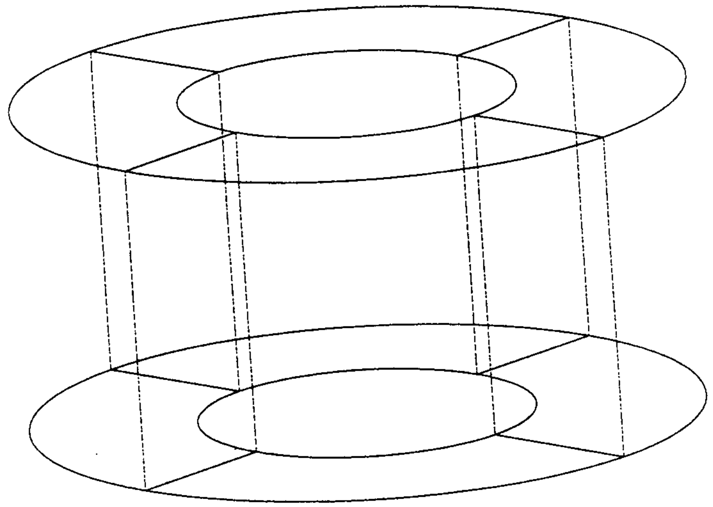

Fig. 6: Adding additional curves so that all faces required in the search for solids may be found

It may also be necessary to add extra curves so that faces are found to split up more complex solid regions into the pentahedral and hexahedral wedges that MSC/XLfromCAD will detect.

Preparation Prior To Transfer

MSC/XLfromCAD searches for simple triangular and quadrilateral faces, and pentahedral and hexahedral solids. In general, CAD systems can hold and manipulate more complex topology. For example, the number of bounding curves or faces may be much greater, or there may be holes in faces or solids. As shown in the previous sections, it is usually possible to add some additional curves in the CAD system to split up the more complex topologies into those that MSC/XLfromCAD can handle.

The model in figure 7 has been constructed to illustrate some of the problems which can occur in model transfer. A possible, but deficient wireframe representation is shown in figure 8.

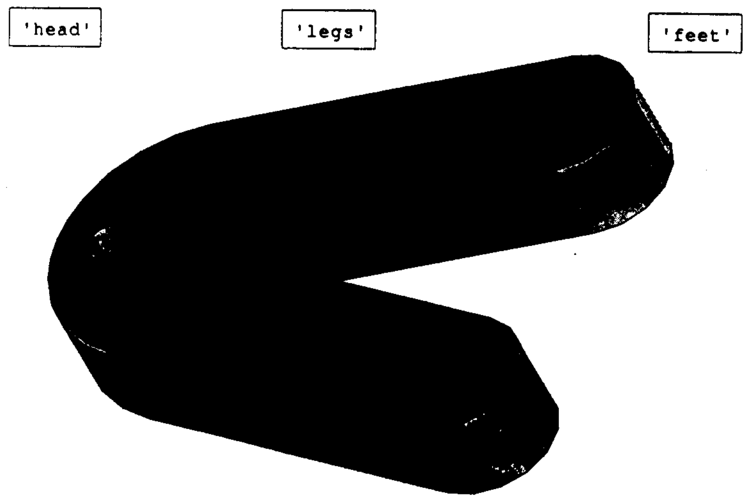

Fig. 7: Example model for transfer to MSC/XL.

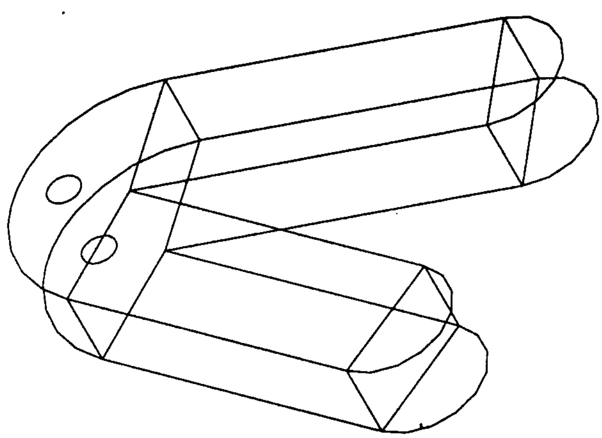

Fig. 8: Wireframe model.

However, this is deficient in several respects. MSC/XLfromCAD will be able to find the faces around the 'legs', but not the faces where the legs meet the 'head' as there is no curve joining the two points. Adding this curve (marked 'A' in figure 9) will allow it to find the legs correctly.

However, there is a hole through the head, which MSC/XLfromCAD will not be able to detect. We have to add some additional curves splitting the top and bottom faces of the head so that MSC/XLfromCAD will be able to find solids which work their way around the hole. The positioning of the first such split is defined by the new curve we just added where the legs meet, so we join from this curve to the hole on both the top and bottom face (the lines marked 'B' and 'C'). We must also add the curve joining the two points on the hole through the head as this will be needed in the definition of the faces around the hole (the line marked 'D').

To further split up the head, and bearing in mind the constraint that a face is bounded by at most four curves, we then add additional curves from the corners where the legs meet the body to the hole (marked 'E', 'F', 'G' and 'H'), and the appropriate curves on the face of the hole (marked 'I' and 'J'). To complete the splitting, we add a further 8 curves (marked 'L' to 'S').

The head and legs will now be found correctly. However, the 'feet' will not be since there are only two curves around each of the top and bottom faces (and only two faces around the tube of the solid). In order to find these correctly, it is necessary to add two additional curves (marked 'T' and 'U'). With these additional curves, the top and bottom faces of the feet are now triangular, and the solids are pentahedral.

This wireframe is now suitable for processing by MSC/XLfromCAD.

Figure 10 shows the model MSC/XL will receive from MSC/XLfromCAD, with the solids shown slightly shrunken towards their centroids to indicate the boundaries.

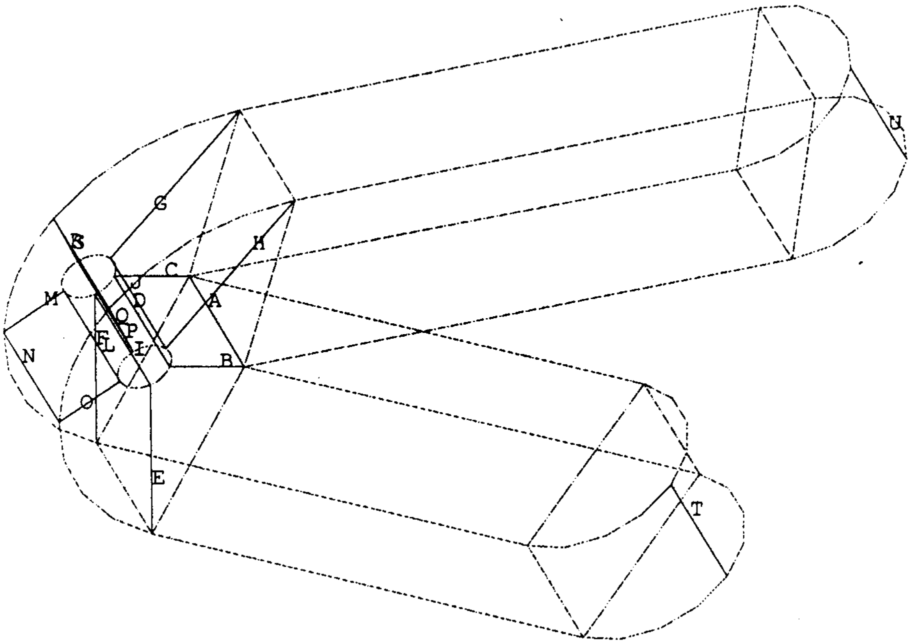

Fig. 9: Additional curves required in the wireframe for complete transfer

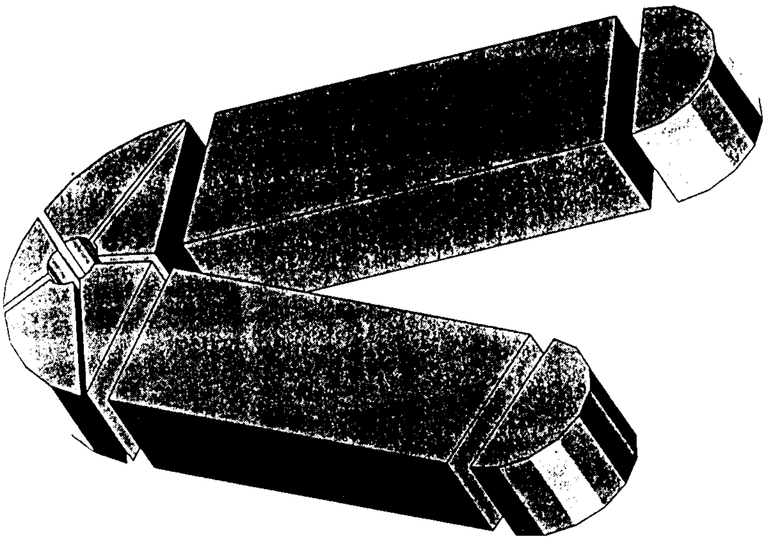

Fig. 10: The model received from MSC/XLfromCAD.

In this case, the hole has not been found as a solid because it is bounded by seven faces. Given the 'hypercube' wireframe mentioned earlier (figure 2), MSC/XLfromCAD will find every possible solid, as shown in figure 11.

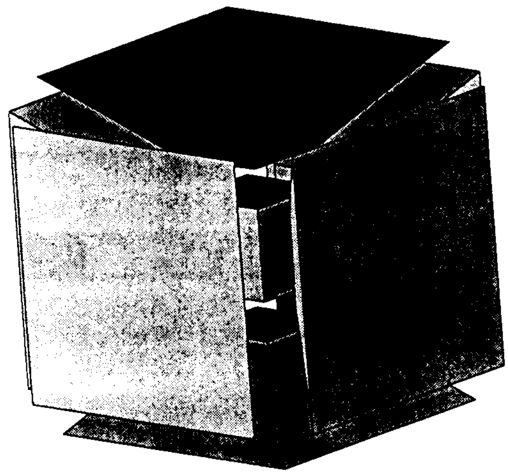

Fig. 11: Model received from the 'hypercube' wireframe

In addition the solid encompassing the whole volume (which appears equally valid to the algorithm) will be found.

Although this is almost certainly not what the wireframe was intended to represent, it is in fact the most useful model to pass to the user. Deleting an unwanted face or solid is far easier than identifying and defining a required one which has not been produced. Therefore, in such an essentially ambiguous situation, MSC/XLfromCAD gives the user too much rather than too little, allowing the user to make choices interactively in MSC/XL. It can be seen that either of the possible intended models illustrated earlier can be reached simply by deleting a few of the 'full set' of solids created by MSC/XLfromCAD.

Conclusion

Although there cannot exist a guaranteed perfect solution to the problem of redefining a surface or solid model which has been reduced to a wireframe, the algorithms within MSC/XLfromCAD provide a straightforward, pragmatic approach to rebuilding the topology. With some preparation prior to transfer, the results can require little or no modification before meshing. The effectiveness of the algorithms has been proved in practical use in MSC/XLfromCAD's parent product, FAMfromCAD.

IGES will remain in use as a medium for model information transfer for the indefinite future. However, it seems likely that other formats, such as PDES (STEP), which are capable of transferring complete manifold topology, will come to prominence. However, this cannot be utilised fully unless the receiving system is capable of holding and operating on such objects, including the definition of meshable faces and solids. The breakthrough will come when general topology can be used for meshing directly. Clearly there are great gains to be made by transferring the topology directly, rather than throwing it away and then attempting to build an equivalent representation.

The techniques used by MSC/XLfromCAD may, however, still be of great use within model building itself. By introducing more interactive control over the processes, they could be used directly to build up the faces and volumes from a wireframe sketched by the user.