Model Quality: The Key to CAD/CAM/CAE Interoperability

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Abstract*. Today 3D CAD Models are driving a growing number of downstream CAD/CAM/CAE applications. When those involved in Finite Element Analysis, Rapid prototyping, Numerical Control, and Data Exchange functions can work directly with the original, clean CAD model the results are significant boosts to product quality, production costs, and time to market.*

Unfortunately a growing number of CAD models contain hidden errors or anomalies requiring the models to be reworked by the downstream user. Studies show that FEA users, for example, are spending as much as 70% of their time fixing CAD models. Similarly, other downstream users are wasting a significant amount of time correcting CAD model errors as well.

This presentation will discuss the Model Quality concept and demonstrate how these problems can be easily isolated and identified. It will show how implementing a Model Quality program can slash or eliminate the need for the downstream users to fix problem CAD files. We will detail how CAD/CAM/CAE users at any level can and should begin implementing such a program. While the presentation will provide a solid overview, it will highlight the CAE interests of the audience.

1. Introduction

In an effort to get products faster to market, at lower costs and with better quality, many manufacturers are implementing concurrent engineering practices that utilize 3-D CAD databases as master models for driving applications throughout the product development process. But hidden errors or anomalies in these database models can cause serious problems for Finite Element Modeling (FEM), Rapid Prototyping, Data Exchange, NC Programming, and other downstream applications that rely on the reusability and interoperability of these CAD models.

Obstacles that hinder interoperability are often caused by the CAD/CAM/CAE process. Such things as dissimilar software systems, lost data, inconsistent product versions and poor communication between design, engineering, and manufacturing can impede success. However, the predominate interoperability problems are due to CAD model quality problems. Unfortunately, many CAD models have unseen topological or geometric defects. Some of these flaws are inherent to the modeling software itself.

Regardless of cost or the vendor who developed it, every CAD system in use today is susceptible to producing invalid files when creating complex 3D surfaces and solids. At the same time, even the most experienced designer can occasionally create CAD models containing hidden errors or anomalies. The significance is that the CAD data cannot be effectively processed by downstream users. These bad CAD files can cause unprecedented levels of inefficiency, days of lost time and productivity, loss of design intent and ultimately inferior product quality.

Engineers doing Finite Element Modeling have long experienced their share of horror stories when performing analysis on problem CAD models. Hidden errors in these files represent a major obstacle for the Finite Element Analysis (FEA) process. Informal studies reveal that engineering analyst are wasting more than half of their time re-working CAD files before analysis can even begin. The bad news is that with the growing use and complexity of these models the situation will only get worse.

Over the past couple of years, the significance of reliable CAD model geometry has been garnering attention in the analysis community. This was aptly summarized in a recent presentation by Ted Blacker, Alla Sheffer, Jan Clements and Michel Bercovier at the 1997 Joint ASME/ASCE/SES Summer Meeting. *"The use of geometry based analysis requires geometries which are 1) topologically valid solids, 2) suitable for the analysis objectives and refinements required and 3) meshable using available algorithms. Modifications of the model are thus often a necessity as a precursor to effective mesh generation. Editing the geometry directly (e.g. surface redefinitions) is cumbersome, tedious, and expensive."*

Unfortunately, the tendency has been to look for ways of healing or modifying copies of the topology that comes from the CAD database as opposed to addressing the root cause of the problem, the original CAD model. Geometry healing or the use of alternate topology repair methods is sometimes referred to as "dirty" geometry clean up. These methods look to automating the otherwise cumbersome and time-consuming clean-up aspect of the finite element modeling process. Again, this philosophy only solves the immediate needs of the analyst. Interoperability is not achieved, and time is still lost performing the geometry fixes on a copy of the original model. Design intent can be lost because the changes are not communicated back to the original creator.   Occasionally, important model features can get treated as anomalies and are then refined, smoothed or mistakenly simplified out of the model.

Assuming that many designs are not static, even minor changes in a part design may cause secondary "dirty clean-up" and a sacrifice of the previous FEA modeling efforts. The good news is that ***Model Quality Testing*** now exists to help identify these problems in the master CAD model so that they can be rendered harmless before getting to the downstream analyst.

Model quality technology enables CAD designers to identify, locate and resolve model integrity problems ***before*** the file leaves the CAD system. Downstream model rework associated with bad CAD data can be virtually eliminated. When doing Finite Element modeling, the impact is that this leaves model simplification as the only requirement prior to preparing and FEA model for analysis.
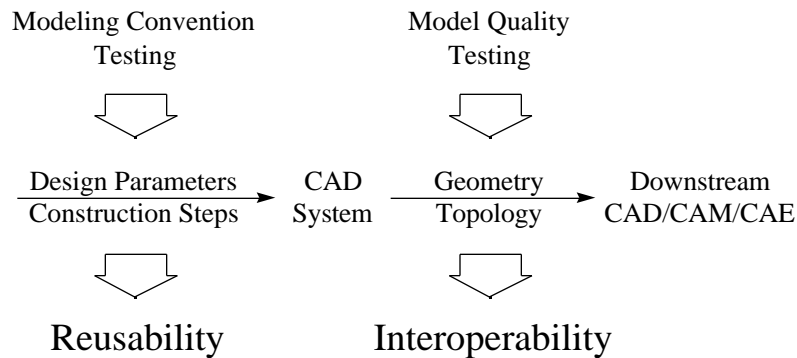

Figure 1 - Reusability and Interoperability

2. Impact of Model Quality Problems

International TechneGroup Incorporated (ITI) met recently with manufacturers throughout industry to determine the impact of model quality problems on the product development process. It was found that up to 70% of the man-hours were wasted correcting geometry problems in the Finite Element Modeling process alone. In addition, Rapid Prototyping, Numerical Control tool path generation, and Product Data Exchange functions had likewise similar amounts of their time respectively consumed reworking geometry problems. Because typical model defects do not surface until well into the downstream of design, this is presenting more than just minor inconvenience for those who receive them. CAD model problems can bring product development processes to a grinding halt as the corrupt model is shipped back to the designer to be fixed. A more common scenario, however, is that the downstream user is forced to make corrections or even reconstruct the model entirely. Obviously this practice can have a detrimental impact on altering design intent along with the obvious ramifications associated with lost time and cost over-run. With this in mind it is easy to see why CAD model quality issues have been identified as the biggest hurdle facing industry today.
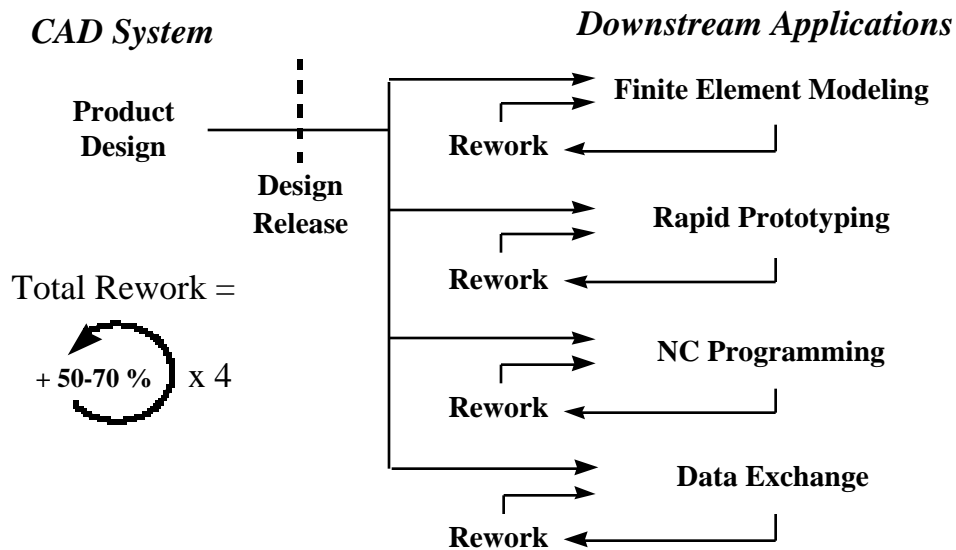
Figure 2 - The CAE Process without Interoperability

The Automotive Industry Action Group (AIAG) recently completed a Supply Chain Study which evaluated 18 first and second tier Automotive OEM supplier's product development practices in order to identify issues for their Supplier Chain Integrated Product/Process Development (IPPD) program. As a result of the study, five of the nine key issues identified are directly related or impacted by Model Quality.

AIAG Key Issues

1. *CAD Data Quality*

2. Inter-Company configuration management

3. *Ensuring good CAD data exchange*

4. *CAD data as the master model*

5. *Expanded use of CAD data*

6. CAD software version control

7. Changing roles of design staff

8. Clear communication of design changes

9. *Earlier involvement of second tier*

Figure 3 - AIAG IPPD Key Issues

3. Common Types of Model Quality Problems

As computer-aided design, engineering, and manufacturing tools continue to expand in terms of usage and complexity, downstream waste attributed to poor model quality will become an even larger problem. Such model quality problems can be generally categorized into three areas: *Structure*, *Accuracy* and *Realism*.
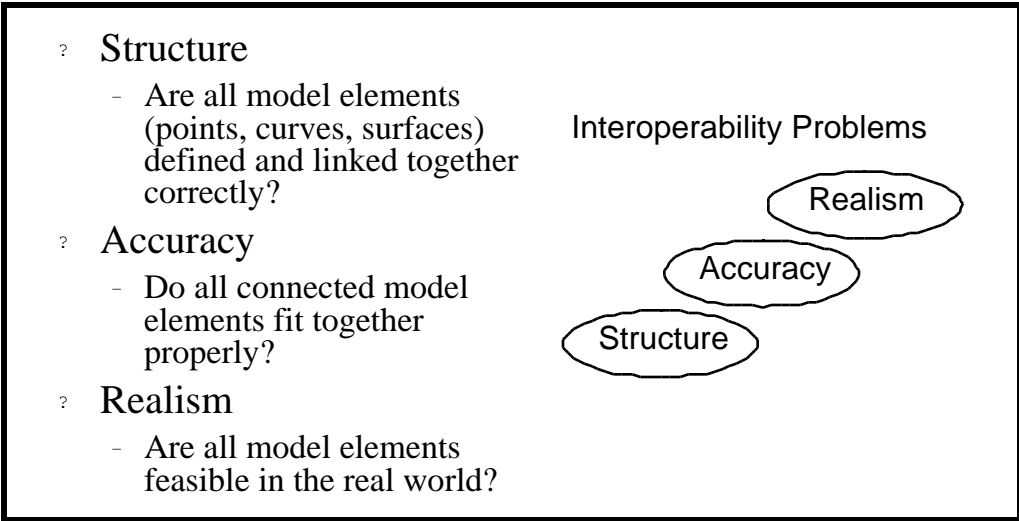

? Structure
  – Are all model elements (points, curves, surfaces) defined and linked together correctly?

? Accuracy
  – Do all connected model elements fit together properly?

? Realism
  – Are all model elements feasible in the real world?

Interoperability Problems

Realism

Accuracy

Structure

Figure 4 - Types of Model Quality Problems

5

Structure. Structural problems include loop orientation inconsistencies, missing geometry and self-intersecting geometry, among others. Structural errors violate the solid modeling application's own rules for what constitutes a correct model.

Structural errors can also cause modeling programs to crash without warning. Often this can occur far after the actual error has been made. Structural errors can cause programs for finite element mesh (FEM) generation, numerically controlled toolpath generation and intersystem translation software to behave unpredictably.

An example of a structural error is a face with an edge that isn't shared by another face. In a manifold solid volume, such edges shouldn't exist because they cannot physically be manufactured. They occur because some solid modeling programs allow non-manifold topology as a midpoint to creating complete volumes. If these errors are not fixed, manufacturing and analysis programs will reject the models.

Accuracy. Accuracy requirements place limits on gaps between geometric entities such as vertices, edges and faces that are adjacent. They can also limit the minimum sizes of trimmed entities such as edges, faces and regions.

Non-trivial gaps occur because intersections of curves between non-planar surfaces are approximated in most solid modelers. Approximations are used when the precise intersections between two geometric entities (faces, curves of intersection, vertices where intersection curves meet) are too complex to compute exactly. Solid modelers use different tolerances to compute the maximum deviation allowed between topological entities.

If the deviations between entities are too large, toolpath and finite element mesh generation programs can fail. They can uncover gaps in geometry that are too small to be seen in shaded or hidden-lines images of a model. The translation between programs can also fail if the maximum allowable tolerances between surfaces and edges in the exporting program are larger than those of the importing program.

All CAD modeling systems must balance the accuracy (precision) of the model with the amount of geometric information required to define them. Extremely precise models require complex and large data structures to define them. In general, the smaller the gaps, the smaller the edges and faces may become in complex models.

Realism. Realism errors render a part "unmanufacturable" due to physical limitations. Realism errors include transition cracks and sliver faces (see Figure 5).
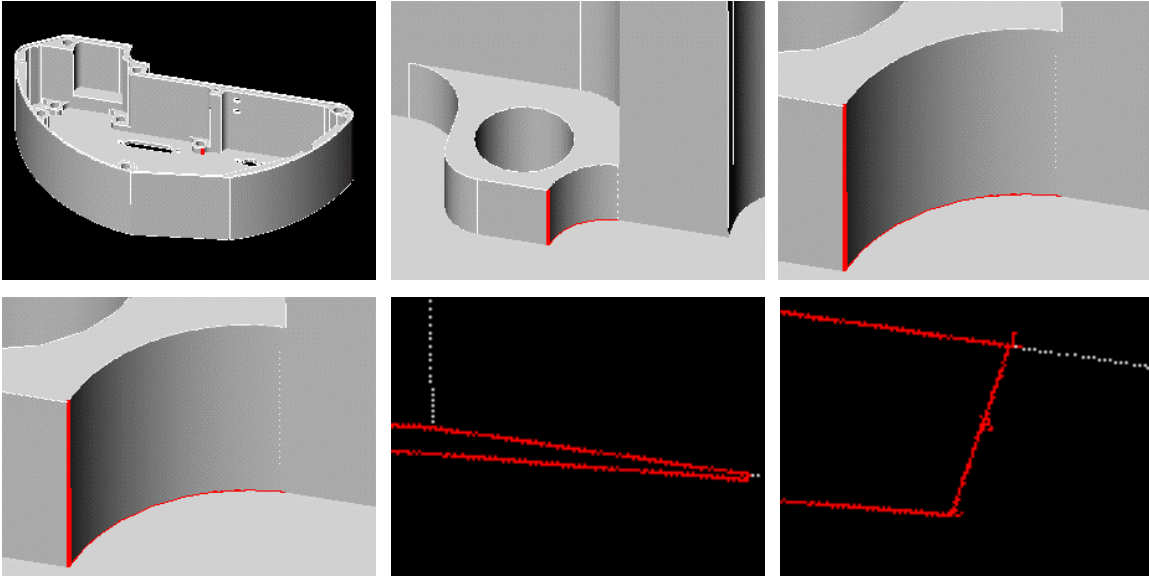
Figure 5 - Model Quality Software can identify sliver faces.

Transition cracks in solid models, like physical cracks in engineering materials, are nearly invisible gaps between features of the model. Like physical cracks, they may not extend completely through the object. Slivers are small, elongated faces that are generated by the system to patch between larger surfaces in a model.

Additional restrictions on the realism of model features are added by many concurrent engineering applications such as FEM, NC toolpath generation and rapid prototyping. For example, these tools are very sensitive to unrealistic features such as sliver faces, minute edges and very acute angles between edges at a vertex (see Figure 6).
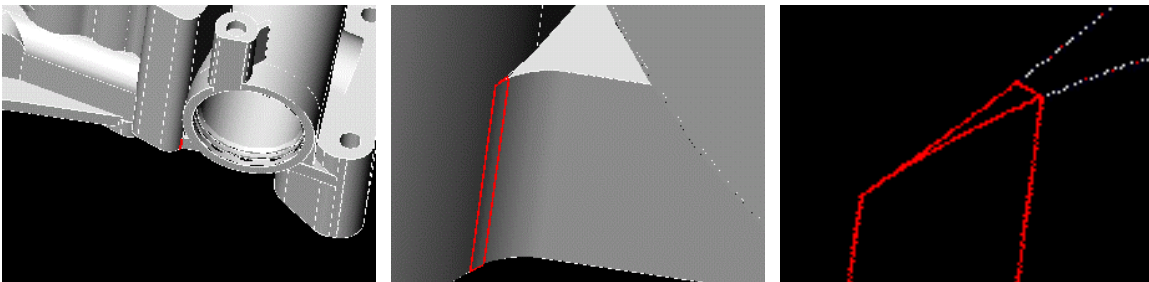

Figure 6 - Model Quality Software can identify sliver faces and minute edges.

4. Causes of CAD Model Problems

Obviously not every model has problems, but as you see, those models that do contain errors can cause significant delays and additional effort. Model quality problems are rooted in a variety of contributing factors that range from bugs in the CAD modeling system to data translation software errors. Additionally, modeling techniques that do not anticipate the needs of downstream shape-based applications can create anomalies. These human-error problems arise when CAD designers don't fully understand the geometric requirements of downstream applications nor do they have no efficient way to validate CAD models against those requirements to identify potential problems.

CAD model problems or anomalies are caused by a series of three factors:

• User Technique.

• CAD Applications Algorithms.

• Part Design and Manufacturing Requirements.

User technique can be the order in which you add a feature or create geometry. There are some commercial products that attempt to address this. In general, each company and type of product requires a unique set of rules. For example, a rule could be that the distance between parallel features for machined parts must be greater than 0.001 inch. This is great for machined bulkheads on airplanes, but not for microcircuits. So each company and each product has to have unique rules.

This same approach has been tried with electronic drawing checkers over the last 10 to 15 years. None of these products were very successful due to the expense of customization. Also, even when all rules are satisfied the anomalies can still occur.

Additionally, the CAD user can unintentionally introduce problems as a result of schedule constraints combined with last-minute design changes. These errors can easily go undetected and are allowed to be released in the model rather than run the risk of missing the release schedule.

A second factor contributing to these anomalies is the algorithms within the CAD applications themselves. This is especially true when the limits of the mathematics behind the CAD system are approached. For example, it's easy to understand how a round-off error can cause a gap between two lines that are supposed to intersect 10,000" out in space. One line might say the end point is 10,000.00001" and the second line might say the end point is 9,999.99999". The result is a gap of 0.00002". For an airplane or a skyscraper this is probably acceptable - for a microcircuit, it is not.

The third factor that contributes to these anomalies is the product design and manufacturing requirements. Sometimes a justifiable anomaly exists that prevents the use of a downstream application. This anomaly is necessary to support the intent of the design. An example could be a very small face to transition between two other features. In this case, the anomaly must exist in the design and may need to be removed in a secondary/reference model to support the downstream process. However, the removal or modification of geometry needs to be the product team's decision and not the decision of a single person in the process *(see Figure 7).*

Face Area		
Index	Id	Value (mm^2)
1	FcArea_172	1.48437e-005
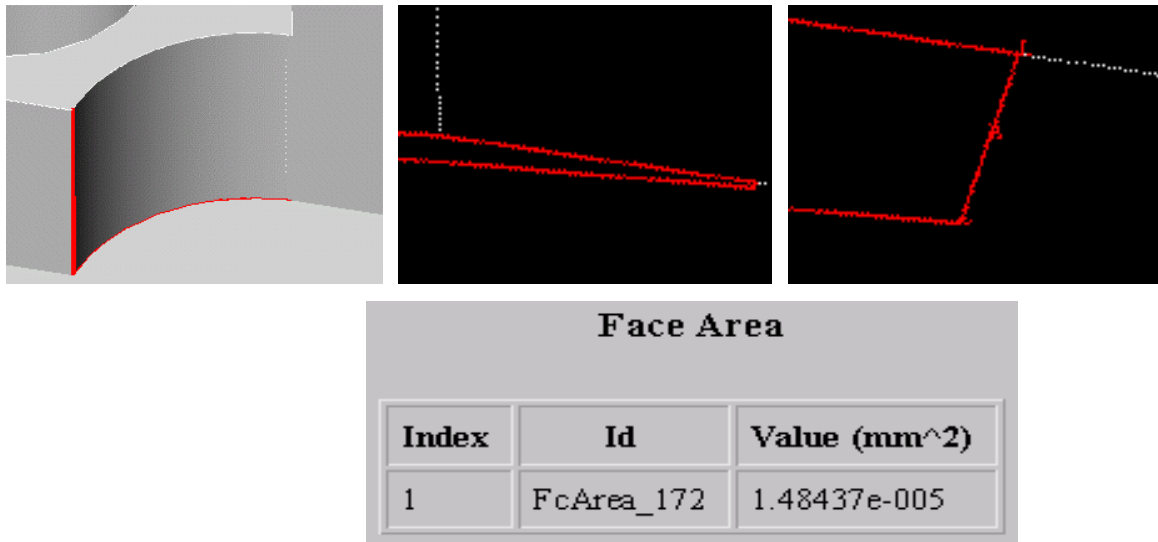
Figure 7. Model Quality software helps pinpoint a problem's magnitude and determine if a resolution is necessary, based on downstream use.

5. What's the Answer?

Regardless of the reasons why they exist, the fact remains that if model quality problems aren't effectively resolved, downstream process simply can't work. The solution is to implement a model quality program. Through such a program designers can better identify and resolve the source of these problems through a combination of improved modeling techniques, better software bug reports and "real world" user requirements for current research in this field.

Likewise the downstream software users should implement model quality as well. This will enable the recipient of the file to quickly analyze the model and locate problem areas before production begins. The file can then be returned to the designer with errors highlighted for quick turnaround. The downstream user may choose to make the modifications depending on the severity of the errors.

6.0 Model Quality Results

Implementing a model quality-testing program can yield breakthrough levels of improvement. Validating CAD files prior to release significantly reduces model rework time. ITI estimates that model rework time can be cut by 50 percent in downstream finite element, product data exchange and numerical control applications. This number jumps to savings of up to 80 percent for rapid prototyping functions.

As CAD models continue to take on a more significant role in the development of new products, it is naturally imperative that these files flow smoothly into downstream applications. Today technology exists to ensure the integrity, reliability and interoperability of CAD models throughout the product development process. By implementing a model quality program organizations can begin to reap the benefits of a tangible concurrent engineering environment.
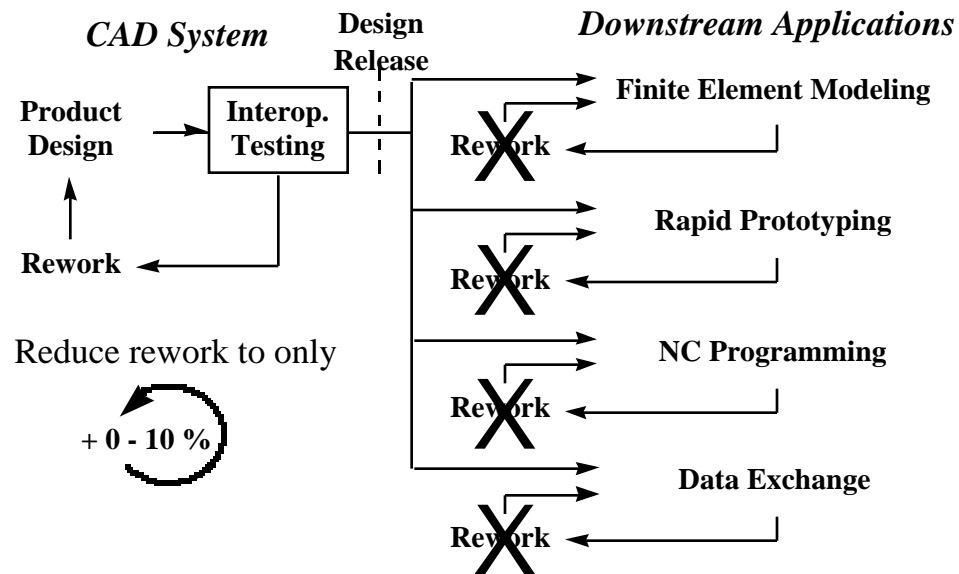
Figure 8 - Achieving Interoperability

7.0 Model Quality Tools

Off-the-shelf software now exists to make CAD model quality a reality. This technology analyzes CAD models, detecting problems that may prohibit a smooth flow into downstream applications. The *CAD-IQ* product from ITI, helps resolve CAD model quality problems, not CAD/CAM/CAE process issues. It comprehensively analyzes native 3D trimmed surfaces and solid models created by CAD systems, then graphically identifies any geometric & topological anomalies using 3D-edge and face geometry with diagnostic symbol overlays. Additionally, reports are generated that statistically summarizes the geometric quality of CAD models

Once identified, many of these problems can be resolved by a designer in the early stages of development, where changes can be incorporated quickly and at less cost with the full knowledge of the design intent of the part.

CAD-IQ can also be used to present to CAD/CAE system providers detailed reports pertaining to bugs in their software. Software bugs or translator induced errors, will require longer-term efforts by CAD/CAM/CAE vendors and researchers. Typically, these bugs or errors are communicated through customer support phone calls and hot-line reports. A comprehensive model quality control program can provide more detailed and valuable insight into identifying and documenting these problems.

It is important that these tools, like *CAD-IQ*, do more than just check models against "rules." They should provide the CAD system operator with the power and flexibility to analyze the model for conformance to a wide variety of applications *and* specific CAD/CAM/CAE system requirements. This allows the designer to anticipate system restrictions and ensure that models created will flow seamlessly into all downstream applications. In short, this allows unrestricted interoperability to be designed into the model.

8. Conclusion

While a solution for model quality is of obvious benefit to the designer and in fact holds value for all CAD/CAM/CAE software users throughout the product development process, those involved in analysis specifically stand to benefit from such technology.

Implementing model quality checks allows MSC/PATRAN and users of 3rd party finite element preprocessors who interface with any of the other MSC family of products to efficiently locate problems before analysis, significantly reducing model rework. By pinpointing problem areas, precise detailed information can be relayed back to the designer to expedite changes.

If the analyst or downstream application specialist is empowered to change the master model, they may make the necessary corrections themselves at a fraction of the time usually required. This provides a method to then recheck the model to ensure that the problem was corrected and that no new problems were inadvertently introduced into the design. Those employing the process today also find that such a program provides a means to better gauge the amount of time required for downstream functions allowing them to quote jobs more accurately.

Now, downstream software users can utilize CAD models with greater confidence and be assured of spending less time cleaning up bad CAD files. Proven model quality software provides a practical solution for CAD/CAM/CAE software users throughout industry and bridges the interoperability gap enabling CAD models to continue to take on a expanded role throughout the product development process.

Acknowledgments

References

Blacker, Ted, Alla Sheffer, Jan Clements and Michel Bercovier, Using Virtual Topology to Simplify the Mesh Generation Process, AMD-Vol. 220 Trends in Unstructured Mesh Generation, ASME, pp.45-50, July 1997

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