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Cut the Scrap

FEA software helps manufacturers reduce scrap.

In a perfect world, all drawings would be clear, every part would be machined within tolerance and no one would make mistakes. Because we live in an imperfect world, however, a certain percentage of parts end up as scrap.

In most cases, parts are scrapped because they do not meet some critical specification on the drawing. If this causes a problem with components fitting together, rework is usually the only way to salvage the parts. But if the specification is for performance or durability, then the parts may be usable without rework—if you can prove they still meet the overall goals.

Simulating a part's behavior with finite element analysis is a fast, accurate way to determine whether an out-of-print part is usable "as is" or needs to be reworked to meet specifications. Design teams typically use a combination of tests, calculations and FEA to determine the optimal geometries and construction materials that will allow a part to perform at its best for a given period of time.

For parts that do not meet initial specs, FEA allows a design team to predict the effects of such factors as stress, temperature, displacement and harmonic frequencies. This capability informs them how these parts would behave in the "real world."

So far, the turbomachinery industry has led the way in applying FEA to evaluate out-of-print parts. That's not surprising, considering a single component can cost up to $50,000.

One area where FEA is widely employed is in the manufacture of fan blades. The geometries of these tall, thin structures are directly related to their aerodynamic performance and operating life. It's fairly common to find a batch of inaccurately machined blades. The airfoil may lean too much to one side, for example, or be too thin or the fillet at the airfoil's base may be too small. Any one of these flaws can shorten the blade's operating life.

However, some rejects may not threaten equipment performance or durability. A relatively simple FEA can help determine how out-of-print parts might be used most cost-effectively, allowing these manufacturers to utilize costly titanium hardware that would have remained on the scrap pile.

Cost-Effective Tool

Not long ago, taking advantage of FEA required a company to employ a staff of engineering specialists. This put FEA technology beyond the reach of most small-to-medium-size companies. Recent hardware and software advances have "democratized" the technology, however, allowing almost any manufacturing organization to employ FEA.

Three critical advances have made FEA more accessible:

Dramatic increases in computing speed and capacity. Since the FEA method essentially converts geometries, loads and constraints into one huge mathematical matrix that must be solved, the technique requires significant CPU time, memory and disk space. Today, these commodities are less expensive than ever, and even complex problems can be solved affordably on a standard-issue PC. In fact, most of today's home computers outperform the multimillion-dollar mainframes that FEA professionals used in the early days.

Improved 3-D parametric solid modeling. This factor has had a huge impact on the entire design-to-manufacturing process. Instead of re-creating geometry in the context of the FEA software, geometries can be imported directly from various CAD programs. In many cases, associativity to the parameters in the solid model can be maintained. For evaluating out-of-print part geometries, parameters can be easily used to modify the solid model to match the as-manufactured configuration. Existing FEA models need only to be updated, rather than be created from scratch. This reduces the time required for a simulation from days to hours.

More accessible user interfaces. FEA software vendors still employ an army of specialists to develop and refine subroutines for handling exotic materials, esoteric loading and ever-larger models. However, these specialists have also focused on creating more user-friendly software. As a result, more FEA tools leverage computer and CAD advances, and the tools include interfaces that help guide the user through the analysis. One such software package is Workbench Environment, from ANSYS Inc., Canonsburg, Pa.

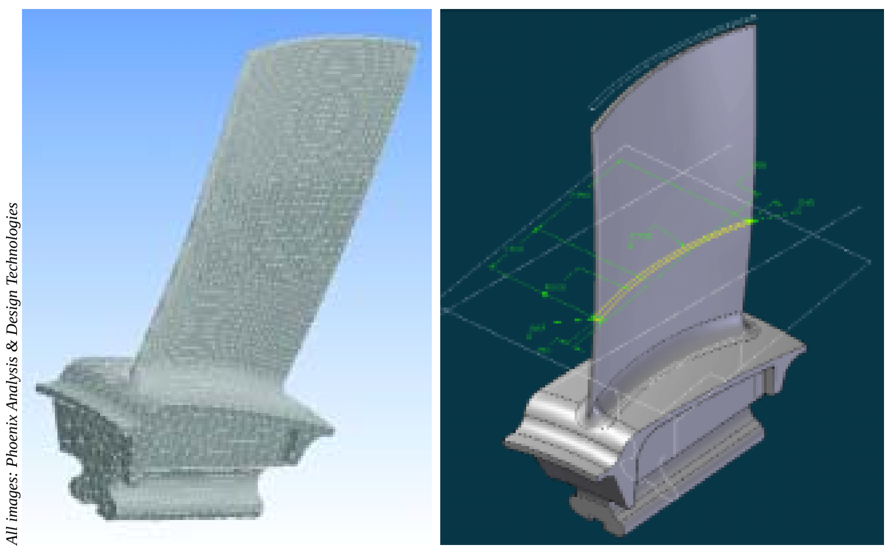

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Figure 1 (left): A parametric solid model of a fan blade. Figure 2 (right): FEA software was used to create a modified version of the fan blade's geometry.

The Analysis Process

When evaluating out-of-print parts with FEA, the first decision is who should perform the analysis. The ideal person is the design-team member most familiar with the part and most comfortable working with both FEA and CAD software.

If no one possesses these skills, then the manufacturing team should consider training the best-qualified candidate. If production volume and scrap costs are high, it pays to develop in-house expertise.

In other situations, however, it may pay to outsource the analysis. When doing so, choose a vendor with solid CAD skills and experience with the types of parts being studied. The company should also have a high-end FEA package, not the low-end software typically used for quick, preliminary analyses. Such "down-and-dirty" software tools may be acceptable at the beginning of a design project, but not when a part is undergoing detailed evaluation. When determining whether or not a part will fail, it is essential to use the most accurate tools available.

The next step is to calculate the deviations in the part's as-manufactured geometry. A drawing or sketch should be created that shows how the part varies from the configuration specified in the engineering drawing. This information then can be used to modify the existing specified geometry to match that of the manufactured parts. In the best-case scenario, only a few parameters will need to be changed to modify the geometry.

If an FEA model already exists and an asso-

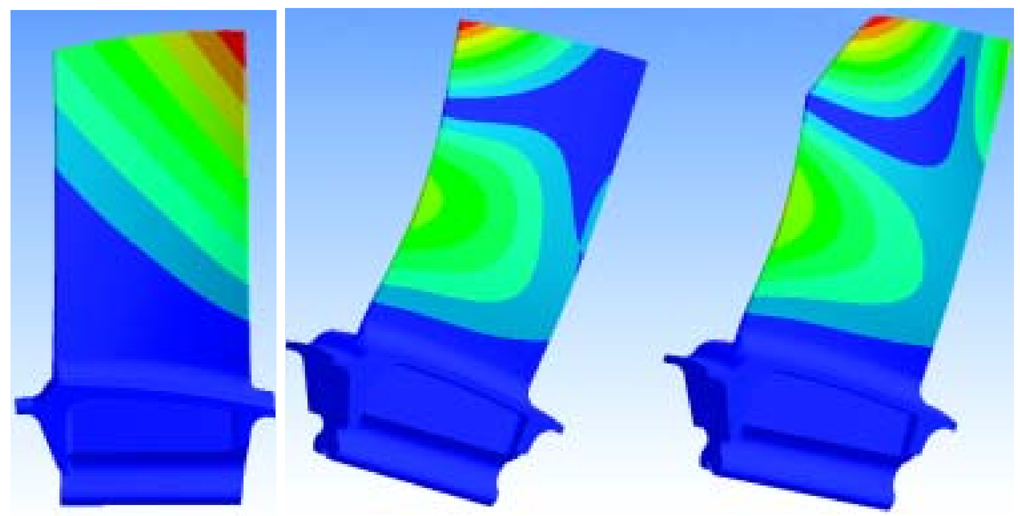

Figure 3 (left): Analysis showed that blade thinning would not cause a frequency problem. Figure 4 (right): What the vibration response would be before and after a corner of the blade was clipped to shift frequencies.

ciative-type program is used, then the model will only need to be updated with the new geometry. If an FEA model does not exist, though, one must be developed.

Once a model is obtained, applying the proper load is critical for determining whether or not a part is acceptable. The analyst must work with the entire product team to establish which loads the part was designed to withstand.

Finally, the FEA model must be solved. The predicted stresses, displacements, frequencies or temperatures resulting from the analysis must determine whether or not the part will be acceptable. The results must hold within acceptable limits, and proper documentation must be created to justify using an out-of-print part.

If the analysis shows that the part cannot be used as is, then the team must decide whether it can be made usable through rework. Again, FEA, particularly software with associative- and parametric-modeling capabilities, offers a practical approach for determining the kind of rework needed.

The FEA method

Engineers developed the finite element analysis method because they needed to predict the behavior of objects that were too complex to represent with a simple equation. Because of their complex designs, analyzing buildings and aircraft delta wings were some of the first applications.

What FEA does, essentially, is to take a complex object and break it into a collection of blocks, or elements, that can be described with simple mathematical equations. For example, to determine stress and deflection, you would use the relation of force to stiffness times deflection.

For stress analysis, FEA software breaks any geometry up into these blocks in a process called "meshing." The resulting mesh, or collection of blocks, is then converted into a large number of equations, one for at least every corner of every block. The equations are then assembled into a large matrix.

How the part is held, and what forces act on it, are represented as vectors in the matrix equation:

F = KU,

where F is the force vector, K is the stiffness matrix, which is made up of the assembled equations, and U is a vector that contains any fixed displacements on the geometry.

Since the force and displacement at most element corners is not known, the matrix equation is numerically solved for the unknown forces and displacements. These calculated values are then used to predict deflection, stresses and reaction forces. A similar process is employed for thermal, vibration and electromagnetic analysis.

To learn more about the FEA method, visit www.nafems.org.

—E. Miller

FEA in Action

FEA was applied to determine whether or not an out-of-print fan blade could be used and, if so, the amount of rework that would be necessary.

Typically, a blade's thickness determines which excitation frequencies will cause it to vibrate. (Excessive vibration can cause a blade to quickly fail.) When a blade is inspected and found to be too thin or too thick, the first concern is whether its natural frequency has shifted into an "excited" range.

An FEA program was used with a CAD package to determine if a thinner-than-specified blade would be acceptable (Figure 1). Since an FEA model already existed, the first step was to change the parameter that sets the thickness of the airfoil. This was done in the FEA package; the solid model was updated and a modified model was created (Figure 2). Loads and material properties were verified, and a natural-frequency simulation was conducted.

After the simulation ran about 20 minutes on a laptop computer with a 1.8GHz Pentium 4 processor and 1GB of RAM, the first six frequencies were calculated. A review of the first frequency showed that blade thinning did not shift the frequency into an area that would cause problems (Figure 3). Once this information was properly documented, the team could release the part for use.

If the analysis had indicated a problem, then the FEA method would have been used to determine whether a reworked blade would be acceptable. A common way of reworking a fan blade to shift the frequency is to clip a corner of its tip. Figure 4 depicts what the blade's vibration response would be before and after rework. Investigating this modification took less than 4 hours.

Without FEA, an expensive vibration test would have been required. This expense would have included the cost of the design team, test engineers, technicians and usage of a test laboratory. In addition, the entire process might have taken from 2 to 5 days, depending on the part and personnel and facility availability.

Gone are the days when finite element analyses required mainframe computers and took 6 months to complete. New computer and software technology have made FEA faster, more accurate and easier to perform.

About the Author

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