By Gregory Roth

Senior Engineering Specialist
Eaton Corporation Innovation Center
Southfield, Michigan

Analysis in Action: The Value of Early Analysis

Analysis in Action: The Value of Early Analysis

By Gregory Roth

Senior Engineering Specialist
Eaton Corporation Innovation Center
Southfield, Michigan

Eaton's major criteria in the selection of DesignSpace for evaluation was the ability to efficiently and accurately import complex geometries, such as this clutch housing model from CAD packages.

One of the driving forces in manufacturing companies is the continuing demand for reduction in product development time and cost to maintain profitability and competitiveness. Over the years, this requirement has prompted organizations in a wide range of industries to find different ways to make product development more efficient. Advancements in the entire spectrum of computer-aided design, manufacturing, and engineering (CAD/CAM/CAE) tools in particular have automated many design, engineering, and analysis tasks to shorten development cycles, mostly as labor savings to minimize overhead costs.

Progressive manufacturers are now investigating ways to further reduce design cycle time by evaluating and changing the product development process itself. The goal here is not so much economic savings in the engineering department but rather a broad business advantage in getting product innovations to customers faster, and thereby increasing a company's market share. Efforts at the Eaton Corporation Innovation Center, for example, are being directed toward studying the benefits of distributing analysis activities throughout product development instead of waiting to face design problems just before a product is released to manufacturing.

One approach now under investigation is called the interactive feedback CAD/CAE process, where basic analysis tools for first-pass studies are tightly coupled with CAD software. This allows designers and engineers to quickly iterate back and forth in performing basic conceptual "what-if?" studies to evaluate the merit of different ideas, compare alternatives, and filter out design weaknesses before more detailed analysis, prototype testing, and production planning.

Pilot studies are underway using tools such as DesignSpace® software from ANSYS, Inc. These tools are tightly associated with various commercial CAD packages normally run by designers and engineers. On-going studies have focused on components and assemblies manufactured by Eaton as a major supplier to the automotive industry, providing a wide range of mechanical products such as transmissions, differentials, and clutches, as well as complete mechatronic systems including those for air management, valve sets, and superchargers.

In a redesign of a heavy duty truck transmission, for example, engineers used up-front CAE to conduct basic stress studies to minimize stresses on the transmission housing. The program allowed for evaluation of possible design modifications of the gear mounts to weed out inefficient approaches quickly and validate correct ones before tooling was built. The analysis indicated that design changes originally proposed would not have solved the problem and enabled engineers to soon find a suitable gear mount configuration, saving the cost of tooling, testing, and another redesign cycle.

In another project, interactive CAE was used for analysis of a heavy-duty truck clutch housing to evaluate stress/strain concentrations prior to empirical testing. This process quickly identified problem areas early in the development cycle and enabled engineers to modify and verify the design before tooling was built.

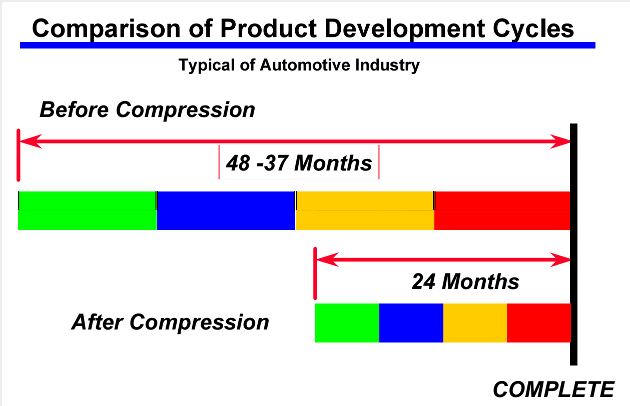
Work on the various pilot projects has shown impressive savings. Using the interactive CAD/CAE feedback process has resulted in time and cost savings ranging from 30 to 50 percent in the CAD/CAE/CAM phase of product development. Projects that formerly took eight weeks of design and analysis can now be completed in four to five weeks, for example. Moreover, greater savings can be achieved in the later stages of product development as designs pass prototype testing the first time, eliminating costly and time-consuming iterations to fix last-minute problems.

Streamlining the product development process using interactive feedback CAD/CAE is part of Eaton's continuing global strategic efforts to maintain its strong market leadership position by implementing the most advanced tools and processes for developing innovative, quality highly-engineered products. Eaton Corporation is a global manufacturer of highly engineered products that serve industrial, vehicle, construction, commercial, and semiconductor markets. Principal products include electrical power distribution and control equipment, truck drivetrain systems, engine components, hydraulic products, ion implanters, and a wide variety of controls. Headquartered in Cleveland, the company has 49,500 employees and 155 manufacturing sites in 25 countries around the world. Sales for 1998 were $6.6 billion.

Pressures on the Automotive Supply Chain

Manufacturers in nearly all industries traditionally have faced the same pressure to reduce time and costs while improving product quality and performance. Primarily to achieve labor savings, astute engineering managers and supervisors tried to squeeze all the work they could from their staffs to help the department bottom line. Shorter numbers of hours to create engineering drawings, complete design projects, and get the product released to manufacturing translated directly into lower costs. Similarly, initiatives with acronyms such as JIT, TQM, SPC, and CIM were used in manufacturing to minimize production time so companies could move finished products out the door as fast as possible. Generally in the past, these efforts were motivated by efforts to improve the return on investment (ROI) and increase profits by minimizing overhead costs.

A growing number of companies now recognize that, although running at peak operating efficiency is admirable, this alone does not guarantee success in the marketplace. Instead, a major factor now being focused on by many manufacturers is *time to customer*, since market share is so overwhelmingly determined by who gets to buyers first with product innovations and features. A growing number of manufacturers now recognize that being late in releasing products has a direct correlation with lost market share. This trend is especially strong in recent years with customer prefer-



ences changing so rapidly.

The impact of this trend has been felt particularly in the automotive industry for passenger cars as well as a variety of over-the-road trucks and off-highway vehicles, including construction equipment and agricultural machinery. The fiercely competitive nature of these markets means manufacturers absolutely must consider time to customer as a critical factor in doing business, all while maintaining quality of design and production. As a result, shortening the product development has become not just a matter of trimming time to save money but of finding major ways to radically compress the product development cycle for the survival of the company. Whereas automakers currently require as many as 48 months to develop a new car platform, for example, their goal is to compress this time to 24 months (see diagram above).

At the same time this movement is occurring, automotive OEMs are also changing the way they work with suppliers such as Eaton. Led by the major automakers, a growing number of companies in many industries are relegating increasing levels of design responsibility to suppliers that formerly made parts according to the OEM's specifications. Suppliers are thus being placed in the position of configuring geometry, selecting materials, analyzing stresses, evaluating reliability, and other aspects of product development of components, assemblies, and subsystems based on performance, function, and size. Allowing engineers at the Tier one and Tier two levels to focus on their areas of specialization while those at the OEM level concentrate on overall product integrity increases efficiency and improves designs.

This shift in design responsibility down through the supply chain presents supplier companies with tremendous business opportunities. But as more and more product development is relegated to suppliers, the pressure increases not only to create designs that work properly but also to meet increasingly strict standards and requirements. Moreover, deadlines for getting designs completed and products delivered are tightened to give OEMs time to review the suppliers' configurations and ensure they all fit together and function properly in the overall end product. As a result, the automakers' goal of reducing product development time for the overall vehicle by half means suppliers often must complete their work in less than 25 percent of the time formerly required to design a vehicle assembly or subsystem.

Tools for Product Development

Manufacturers have a wide range of computer-based tools available to support the product development process. Rapid prototyping systems quickly convert CAD models into physical prototype parts so users can hold, handle, fit together, and evaluate the appearance of components. Knowledge-based engineering captures technical standards, procedures, and other information in software to automate routine design tasks. Empirical testing systems utilize state-of-the-art, software-driven input equipment for duplicating real-world conditions, sensor technology for accurately measuring responses, and statistical methods for interpreting results. Solid modeling enables engineers to define parts and assemblies in 3D space and utilize this geometric and associated product data in a variety of downstream applications. CAE utilizes simulation and analysis technologies, such as finite-element analysis (FEA) used to study stress, deformation, vibration, temperature distribution, and other behavior in structures.

These tools do not act in isolation, but rather together in supporting the product development process, much like the underlying pillars of a bridge. Each has individual tasks and defined areas, but all are necessary for the total support needed. No single tool can effectively solve the entire problem; they all must be used in conjunction with one another to shave excess time and expense from the product development process.

So work performed with one tool must always be tailored in consideration of the others. Otherwise, efforts are often counterproductive, delays are introduced, and important benefits are negated.

The Traditional Design/Analysis Bottleneck

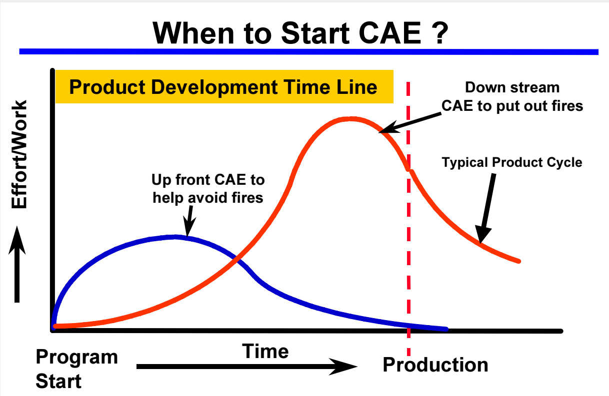
Of all the tools used in the product development process, FEA is one of the most valuable in analyzing structures to detect areas that might undergo excessive stress, deformation, vibration, or other potential problems. Since the early days of the technology in the 1960s and 1970s, FEA has become one of the most widely used methods for studying structural integrity.

FEA systems now have powerful graphical capabilities, automated functionality, and advanced user interfaces that make the technology considerably faster and easier to use compared to early programs. These improvements notwithstanding, however, full-blown advanced FEA still requires considerable time and the expertise of a dedicated analyst with the knowledge necessary to apply proper mesh densities, element types, and boundary conditions. These expert analysts also must know how to go about translating CAD geometry into the proper format for building the FEA model as well as correctly interpreting plots and other output information.

Because of the skills, training, and background required, experienced FEA analysts are generally in short supply and usually found in centralized groups that handle analysis tasks for an entire organization. Traditionally, engineers and designers develop part configurations and then throw the designs "over the wall" to the analysts, who then assign a priority to the project and get to it when they can after other work is completed. Days, weeks, or even months can pass before analysts are able to provide results and recommendations.

In most manufacturing companies, this exchange between designers and analysts is so slow and cumbersome that FEA is typically reserved for critical components with identified risks. For other components, it is applied in the final phases of product development, often only if hardware has failed some step of testing. Engineers then reconfigure parts and send the new design back through the cycle again.

Such traditional build-test-fail cycles expend considerable time and effort to modify designs, change drawings, issue engineering change documentation, and get the appropriate approvals. Also, designs may be far less than optimal due to quick-fixes inserted hurriedly to meet release-to-manufacturing deadlines. In many cases, parts may be overdesigned, resulting in added size, weight, and materials, not to mention increased manufacturing complexity. Solving isolated problems late in development also may detract from the overall design of the entire product.



Benefits of Up-Front Analysis

In efforts to shorten the product development cycle, many manufacturers are re-orienting the process itself so that analysis is performed much earlier in product development. This moves CAE forward into conceptual design, where changes are much easier and more economical to make in correcting poor designs earlier.

The experience of manufacturers in many industries has shown that 85 percent of the total time and cost of product development is committed in the early stages of product development, when only five percent of project time and cost have been expended. This is because in the early concept stages, fundamental decisions are made regarding basic geometry, materials, system configuration, and manufacturing processes. Further along in the cycle, changes get harder to make.

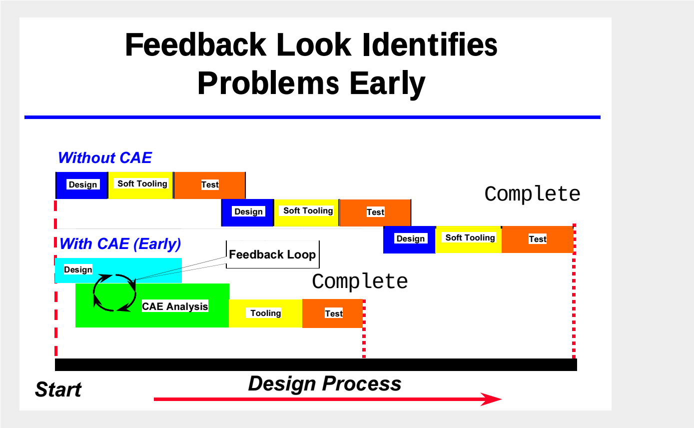
Essentially, the time and cost of correcting problems increase ten-fold with each step forward in the product development cycle: concept definition, detailed design, prototype manufacture, prototype testing, and production. So a relatively minor change to make in the concept definition stage, that would have cost a few dollars, may cost hundreds of thousands of dollars in the production stage, or millions if flawed products are actually shipped.

One analogy illustrating this might be that of going to the dentist. You can undergo a quick and relatively inexpensive early check-up and have routine teeth-cleanings, or you can wait until later when problems occur and go through the expense and pain of, for example, a molar extraction, or possibly even worse.

One of the major benefits of up-front analysis is the ability to perform “what-if?” simulations, which enable engineers and designers to evaluate alternative approaches and explore options early in the design cycle to arrive at a superior design. Through this process, engineers and designers can quickly investigate many design variations and evaluate numerous ideas that would not be practical to test in hardware. Moreover, computer analysis helps them find trouble spots that otherwise would be extremely difficult to isolate in the jumble of complex interrelated variables. Also, “what-if?” studies can show engineers the effects of making a design modification to correct a problem in an isolated area, so that such changes do not adversely effect overall product performance.

Because more resources are focused in the early design stages, costs during this phase will be higher than traditionally has been the case. Also, designs may take somewhat longer to release as concepts are being virtually proven-out up-front, rather than later by empirical testing. However, this added time and cost is more than offset later through savings in prototype testing and fewer engineering changes (see diagram - opposite page).

The use of up-front CAE supports the compression of the product development cycle by changing the manner in which errors are found and the design refined. A typical effort without CAE is an iterative cycle in which the design is created, prototypes are made through soft tooling, and tests are run. In most initial testing sequences, parts fail, resulting in another cycle of redesign, soft tooling, and testing. This can be repeated numerous times until satisfactory performance is reached. In using up-front analysis, CAD and CAE are jointly conducted in an interactive feedback loop up-front in product development. As soon as a basic CAD model is configured, a preliminary analysis is run and the CAD model modified and re-analyzed until it performs optimally. Ideally, the resulting prototype design passes all empirical tests the



first time (see above diagram).

First Pass Studies

To inject CAE up-front, some companies have attempted to dedicate a group of analysts to perform initial evaluation studies on designs in the early stages of product development. Generally, these are relatively simple linear-static analyses on individual parts that are done to find approximate “in the ballpark” answers. Basically, the intent at this stage is to filter out bad designs early. Then in the later stages of design, analysts perform more in-depth advanced analyses involving nonlinear multiphysics and dynamic studies.

The trouble with this procedure, however, is that analysts quickly become overwhelmed with performing these rough conceptual studies in addition to their already heavy workload of full engineering analyses. The resulting long delays defeat the purpose of early analysis, prompting many engineers to circumvent the system and forego up-front analysis entirely.

Eaton Corporation’s Innovation Center is piloting some solutions to this dilemma. Central to them is a relatively new class of first-pass FEA that is easy enough for designers and engineers to use themselves and is tightly integrated with their CAD software platforms. One promising software being evaluated for this work is DesignSpace® from ANSYS, Inc., whose full-function software, ANSYS®, is currently being used extensively.

The selection criteria included numerous items necessary to perform the first-pass studies. High on the list was ease-of-use, so that engineers and designers could readily learn and remember how to run the package. If a casual user had to read lengthy manuals each time they used the software, ultimately it would not be used. Engineers and designers, usually under such tight time constraints, could not afford to take time looking up software commands and procedures. Also, there would have to be a robust interface with a variety of CAD codes for users who have neither the time, inclination, or knowledge to resolve problems associated with importing solid models for analysis. Another key requirement would be that the system allow for simplification and less-than-perfect input for loads, boundaries, etc., while still providing useful results. Moreover, Eaton wanted a package that fit in with standard engineering and design processes and cultures, and could be used to communicate information readily so designers, engineers, analysts, and others throughout the enterprise could collaborate closely on projects.

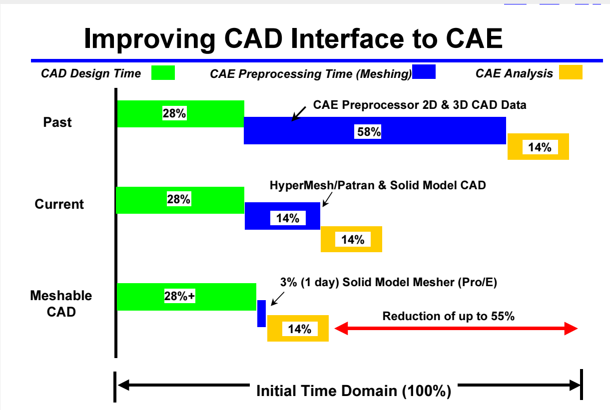
The pilot evaluations of DesignSpace demonstrate promising capabilities that can meet these needs. It allows for problem set-up, specific commands, and input/output requirements to be automated. Templates, defaults, controls, and preferences can be established for well-defined sets of problems. It has a robust CAD interface that associatively reads geometry directly from solid model CAD and supports geometry based on Parasolid and ACIS geometry kernels. The user is prompted for information about dimensional units, materials, loads, and supports, with built-in libraries of real-world conditions available for data such as bolt loads and pin supports.

Various wizards answer fundamental questions for the casual or periodic user such as: "What should it look like?" "Will it break?" "How will it deform?" and "How will it vibrate?" with "Go/No-Go" red or green flags indicating when predefined performance boundaries have been exceeded. These wizards provide step-by-step instructions guiding users through the process, thus simplifying training and providing valuable prompts to those who do not work with the software on a daily basis.

Automatic report generation provides a fully-formatted engineering document in HTML format that automatically captures material properties, environmental conditions, calculated results, and expected accuracy. The report can be issued as a printed document, posted on a Website for viewing, or transmitted via the Internet or a company's intranet. This allows designers, engineers, analysts, and managers to readily collaborate on projects.

Organizational Issues

The required process changes to shift first-pass analysis tasks up-front in product development and have engineers and designers perform their own studies are not made without addressing significant organizational issues.



For example, greater emphasis on early analysis means that more time is spent on the initial phases of product development, when engineers typically are accustomed to getting through conceptual design fairly quickly. Engineers and designers often are uneasy about delaying the release of the concept design for prototype and testing, since they anticipate significant amounts of time will be required downstream to iron out product problems and implement the associated engineering changes before the product is released to manufacturing. Hearing about and understanding the time-saving benefits of up-front CAE in the abstract is one thing, but having faith in the new process comes only after users have gone through actual projects and seen the value first-hand.

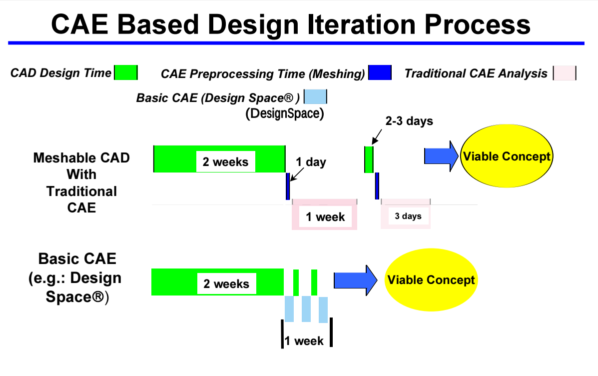
Often a tougher nut to crack in instituting these changes is convincing engineers, designers, and analysts to appreciate their new roles. Again, they must be involved in the transition first-hand to have faith that these changes will benefit the company as a whole and represent no threat or unfair burden to them personally.

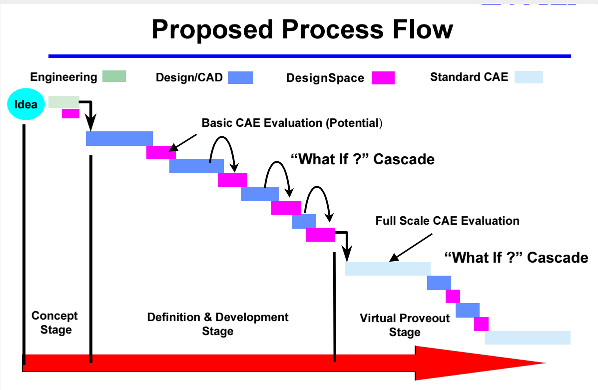
Over time, dedicated analysts realize that not having to perform routine basic studies frees them to concentrate on complex problems which take better advantage of their expertise. Also, analysts can serve as mentors to designers and engineers on particularly troublesome problems, teaching them which types of analyses to run, and how individual parts affect the overall system. Further, by collaborating with engineers throughout design, analysts have a greater opportunity to influence product development.

From the perspective of engineers and designers, the new tools at their disposal allow them to get results much faster than was possible previously. They can pinpoint problems early enough to easily correct them, and gain a greater understanding of part behavior and product performance. The end result is that they avoid the hassles and chaos of last-minute, all-night sessions to solve problems just before products are released to manufacturing.

Metrics Show Time Savings

Until recently, much of the work in reducing time for CAD and CAE centered on preprocessing technology to create the analysis model. In the past, models were built nearly from scratch, based on 2D or 3D wireframe geometric data. This labor-intensive process, in which nodes and elements were positioned manually, took more than half the total time required for design and analysis. Currently, improved preprocessors with semi-automatic mesh generators reduce model-building time to about 14 percent of the previous total. Nevertheless, considerable work was still needed, for example, in adding data stripped out in converting CAD geometry into a neutral format such as IGES for CAE model-building. Most recently, advances in meshable CAD technology have reduced CAE modeling time to only a few percent of the previous total, with analysis models developed within hours or





minutes once the solid model is available. With this meshable CAD technology, users are required only to provide minimal input such as general meshing density as a guide for the software in transforming the solid model into an analysis model. Moreover, variational and parametric systems allow the design and analysis models both to be changed more easily. In combination, these advancements have helped shorten overall design/analysis times by up to 55 percent (See diagram opposite page).

It should be noted that, although preprocessing time has been shortened dramatically over the years, the time required for CAD design has remained fairly constant (and even increased in some cases), mainly because advances in modeling efficiency have been offset by increased demands for greater levels of accuracy and additional information required for downstream functions driven by the solid model. Similarly, CAE analysis time has also remained constant, with computer processing speeds increasing, but users still must apply slow and relatively cumbersome methods when applying boundary conditions and loads, running postprocessing routines to display results, etc.

Using the interactive CAD/CAE up-front in the design process with codes such as DesignSpace can provide further efficiencies. Experience in pilot studies has shown that a typical project, taking eight weeks using meshable CAD with traditional CAE, can be completed in four to five weeks for a savings in the range of nearly 30 to 50 percent in design and analysis iteration time (see diagram, top of page).

New Process Flow

In the initial concept stage, engineers use a basic CAE system to provide a check on the proposed design concept, a "back of the envelop" determination to see if the idea has merit. At this point, the CAD model is only rough approximates and the part geometry is not very detailed. An automotive differential housing, for example, might be represented at this stage as a cylinder with a hole in the middle.

Once the basic design concept looks tenable, a definition and development stage follows, in which a designer adds details. In this process, a "what-if?" evaluation cascades sequentially to prove out incremental features before they are embedded in the design. In this way, the system guides the designer and ensures that the right direction is being followed in developing the model (see lower diagram, top of page).

After all details are added, the mature design is passed on to a dedicated analyst for in-depth, rigorous CAE evaluation. Design weaknesses that might cause major redesign in a traditional product development cycle have already been filtered out. At this virtual prove-out stage, a full-scale package such as ANSYS is used to perform more advanced CAE studies, including nonlinear, contact, fatigue, and multiphysics analyses. In addition, the dedicated analysts may also use tools such as DesignSpace to perform quick "what-if?" studies in resolving higher order issues such as overall quality, performance, reliability, or warranty.

In this entire process, tools like DesignSpace serve as filters to help keep the design going in the right direction. In the early stages, basic studies done by engineers and designers using the software are not expected to be the most accurate. In fact, most loads, boundary conditions, material properties, and other data are not fully defined or even known. Often, unit loads may be used to relatively compare different design proposals. The important point early on is to compare alternatives and eliminate bad ideas. Further along, details are added incrementally and evaluated at each step, with the "what-if?" evaluation cascade moving the design toward a winning solution.

In this way, the application of basic CAE capabilities early in the product development cycle enables companies to avoid process bottlenecks and take better advantage of the expertise of their engineers, designers, and analysts throughout the entire product development process.

ANSYS, Inc.
Southpointe
275 Technology Drive
Canonsburg, PA 15317

ansysinfo@ansys.com
T 724.746.3304
F 724.514.9494
Toll Free USA and Canada:
1.800.WE.R.FEA.1
(1.900.937.3321)
Toll Free Mexico:
95.800.9373321

Regional Offices:
North America
na.sales@ansys.com
T 724.514.3122
F 724.514.3115
International
int.sales@ansys.com
T 724.514.3086
F 724.514.3115
Europe
eu.sales@ansys.com
T 44.118.9880229
F 44.118.9880925

http://www.ansys.com