White Paper: Conceptual Engineering

CAD Tools that Promote Invention

Executive Summary

Today's mechanical engineers are challenged to produce new products in less time than ever before. Over the past ten years, new design technologies have contributed to lower cost, higher quality products. Feature-based, parametric, associative CAD systems have streamlined engineering by enabling concurrent design of detailed models of all engineering deliverables that drive the design-through-manufacturing process. These deliverables include solid and behavioral models of components and assemblies, structural, thermal, and dynamic analyses, manufacturing models such as molds, tooling, and CNC cutter paths, and detailed drawings and electronic documentation of those models. Data management software enables concurrent engineering and workflow control by allowing anyone involved with a project to specify changes to these deliverables and participate in any facet of the design process. Yet most of the participants of the detail design process base their work on conceptual designs generated by engineers before the core design-through-manufacture cycle ever begins.

New CAD technologies have automated design through manufacture.

While state-of-the-art CAD systems have dramatically decreased the time required to move a new concept from design through manufacture and production, there are few tools that specialize in driving that process at the earliest phases of design. Conceptual engineers, who specify the design criteria that drives detailed design, need new tools that emphasize engineering rather than the core detailed design-through-manufacture process.

Engineers need innovative engineering tools to increase their productivity during conceptual engineering.

The conceptual engineering design methodology differs from traditional detailed design. Detailed design typically commences after the design criteria are known and involves modeling every nuance of the final product and documenting it accordingly. The design criteria used to initiate detailed design are the detailed specifications of individual components and mechanisms. These specifications include design rules and other engineering intelligence that govern the mechanics of the product and constraints derived from the components' interfaces and assembly, such as range-of-motion envelopes and packaging considerations. It is during the conceptual phase of development that these criteria are refined from the general product requirements.

The requirements of conceptual engineering users differ from those of traditional designers.

Conceptual engineers create design criteria, not detail models.

Conceptual engineering software must foster a conceptual engineer's creativity to turn marketing requirements into product concepts. To satisfy that need, a CAD tool should have the following characteristics and capabilities to be considered for conceptual engineering:

The following are the facilities needed for conceptual CAD:

- *Ease of use and learning.* Most engineers are casual users who do not have time for training and must become productive rapidly without learning specialized skills

Ease of learning

- *Reuse of existing data.* Various CAD data and analysis results drive conceptual designs. Engineers need to leverage this information directly on the concept model. Conceptual CAD tools must be able to import a diverse set of CAD data and use results of engineering analyses.

Data reuse

- *2D drafting and layout tools.* While most engineers do make detailed drawings, they need tools to quickly layout and sketch new concepts. Drafting tools should encourage rapid idea capture and provide the flexibility to move from rough sketching to exact sizing.

2D sketching

- *Simple yet robust skeletal and solid modeling.* Many engineers would like to explore the benefits of parametric solid modeling but have found current technologies to be inaccessible. A strong conceptual engineering tool must include powerful 3D design capabilities but not sacrifice ease of use. Top-down skeletal modeling tools are needed to allow the specification and design of complex assemblies. Solid modeling
- *2D and 3D kinematics.* Often conceptual designs include the specification of mechanisms. Engineers must be able to invent and validate mechanisms prior to detailed design. Kinematics studies
- *Compatibility and migration path to detailed CAD.* Once the conceptual design is complete, its data must be directly reusable in the production CAD system used by the detail designer. Integration with production CAD

While most of this functionality is available in high-end systems, no single product offers all these facilities as a cohesive solution designed for conceptual engineering. This paper outlines the conceptual engineering process in detail and further enumerates the required functionality of such a product. No single product is designed to meet these requirements

Introducing Conceptual CAD

The conceptual engineering process occurs when a product is first being conceived. Engineers must reconcile assorted specifications and design constraints and from them create models that will eventually be passed along to detail design. Traditionally, when engineers are devising ideas they would start by sketching thoughts “on a napkin,” and revise to accommodate specifications until the production design criteria are known and the work can be thrown “over the wall” to a detailed designer. The engineers make decisions such as the overall layout and assembly structure of the design, study basic kinematics and range of motion, and annotate the drawing to convey other important design information such as material and process considerations. Some version of this process occurs in almost every company within the mechanical design industry.

While the tools for writing specifications, performing analyses, and drafting are now electronic; many engineers are using inappropriate 2D drafting programs or simple modelers to accommodate this workflow. Not considering themselves CAD users, engineers often gather incompatible authoring, analysis, and drafting tools to get their job done and delivered to detailers. Very few software products cater to the needs of mechanical engineers. A truly useful tool for conceptual CAD must have the ability to work with diverse design input, allow rough 2D sketches to be refined into 3D assemblies, and provide a viable path to the core detailed design process through the specification of design criteria.

These design criteria are the files the engineer passes on to detailed design, and contain a diverse set of data that encapsulate engineer’s design intent. Skeletal and solid assembly models consisting of sketched curves, critical dimensions, and datum information are the basis of the design. In addition, the model should be annotated with key names and indicators of assembly and component interface details not explicitly defined by the model itself. Envelope, space claim, and range of motion information are also critical to ensuring well-specified and accurate detailed design.

One important requirement of conceptual CAD is that it be easy to learn and use. Most engineers are only casual users, and do not have time to be trained on high-end systems. These tools should foster an environment where engineers can explore different design possibilities, and not be hindered by the need to build design intent before it is known. The system should not require specialized hardware, but should run on a standard desktop computer or laptop.

By adopting a conceptual CAD tool that works with their high-end system, engineers gain additional productivity. Not only do they gain access to design tools that are tailored meet their unique needs, but they gain the ability to work with process tools such as data management systems that help control and streamline the design-through-manufacture cycle. These tools allow everyone who participates in the conceptual engineering phase to provide feedback before detail design commences. Detail designers can also provide feedback while they are working. In addition, if the conceptual and detailed CAD systems are associatively interoperable, users' designs are automatically updated based on the iterations the entire team has initiated.

Inputs to the Conceptual Design

To produce design criteria, the engineer must accommodate disparate specifications, constraints, and design data, including:

- *Specification documents:* general descriptions of the product's requirements, typically existing as word processor or HTML documents.
- *Parametric and tabulated data:* dimensional values that drive the size of the design. These data are typically contained in spreadsheet documents, and could be the results of engineering analyses or listings of the dimensions of a family of related products. For example, an engineer might use a spreadsheet to calculate critical dimensions of an engine based on the power requirements and thermodynamic cycle.
- *Raw numerical, calculated data:* raw data that directly drive the geometry of the design, typically from proprietary analysis systems. For example, data points that drive the shape of an airfoil could be used as a rotor blade cross section.
- *2D and 3*D *CAD data:* existing solid models and drawings. For example, a design detail used on other designs could be reused or a standard enclosure could be adapted as the basis for the design.
- *Graphical images:* bitmap data such as an artist's concept drawing, a competitor's product, or a scanned hand-drawn sketch. These could be used for reference and documentation only, or traced over using drafting tools to create 2D or solid models.
- *Existing conceptual engineering files:* other conceptual design data or proprietary design standard documents to be reused.

Any software being considered for conceptual engineering should provide the ability to contain and link to these data. Additionally, it should provide the ability to integrate directly to the parameters and results of analyses, so that data can be used to help to construct the models.

The Conceptual Engineering Process

With these specifications and constraints in hand, the engineer must invent mechanical solutions. Typically an engineer will complete several design iterations, converging on a reasonable solution. During that process, the engineer may also pause to consider other possibilities, storing the one concept while exploring others. To develop these ideas, a conceptual engineering solution should provide the following facilities:

- *Freeform and parametric sketching tools*

While most engineers don't need a full-featured drafting solution, they do have basic sketching and drafting needs. 2D drawings are the basis for creating layouts, rapidly capturing ideas, and creating reusable geometry. Standard 2D drawing functionality such as the ability to move, copy, group, and stretch entities is needed. These tools should be tailored for mechanical design, as opposed to diagramming or architecture. To designate layout geometry as different bodies, engineers also need the ability to change line color and font, fill regions with shading or hatching, and name and annotate bodies and cross sections. Using these organizational tools, engineers can draw their concepts, but to further improve their process, engineers need more sophisticated functionality aimed at creating design criteria.

Parametric sketching tools improve on traditional drafting tools by allowing sections to be dimensioned and resize as the design progresses. Most systems only employ parametric tools for solid modeling and do not provide these abilities on drawings, where they could be used to drive layout. Using parametric tools, engineers can commence sketching by roughing out the overall design. As sizes become known, engineers can apply parametric dimensions to the sketched geometry, updating the overall design and bringing it closer to the finished product.

· *Integration of 2D and 3D modeling capabilities*

While many mechanical designs can be adequately conceptualized in 2D, most are inherently 3D. When visualization becomes difficult, most engineers turn the design over to detailers who eventually observe clearance and interference problems on the detailed models. To prevent lengthy iteration loops, engineers should have 3D functionality available in their design tool, but should not be forced to use 3D when 2D workflow is more natural or 2D drawings are sufficient for specifying the design criteria. While many solid modelers provide the ability to document 3D designs, almost none provide an integrated path from 2D sketches to 3D solids. Conceptual CAD tools should be able to create 3D designs that directly leverage the 2D work. If an engineer starts work in 2D and then decides that some 3D content would be useful for specifying design criteria, the engineer should not be forced to start over.

For a conceptual engineering system to be adopted, the 3D capabilities as well as the 2D tools must be easy to learn and must work together. In 3D, engineers should be able to continue working until satisfied that the design criteria are sufficiently complete for detailing to commence. Often, wireframe skeletal construction geometry is sufficient for specifying these criteria, yet most modern mechanical packages concentrate on solid modeling and de-emphasizing simpler skeletal modeling. Work initiated in 2D should be reusable as the basis of a 3D skeleton.

When necessary, engineers should be able to use solid modeling features along with construction tools. While not focused on building the detailed model, solid modeling tools are helpful to designate individual components, check for general fit, and visualize the overall product. Solid features should be an extension of the drafting capabilities: freeform and dynamic for concept modeling, yet parametric when design intent is better known.

· *2D and 3D kinematics analysis*

Many conceptual designs are focused on devising mechanisms. Engineers creating designs with moving parts need tools to analyze assemblies as they would behave in production. Kinematics analysis is necessary in both 2D sketches, during the preliminary sketching phase, and on 3D solid assemblies that mock up the final design's geometry. In 2D, engineers should be able to group selections of 2D lines as bodies that can be moved together. When creating solid parts for better visualization, engineers should also have access to kinematics. With 2D or solid bodies, engineers should then be able to dynamically add joint definitions and drivers to visualize the range of motion. From this information, the engineers can then designate space-claim information used downstream in the detailed design and specify dynamic analyses to be performed by specialists.

· *Migration to the production mechanical design automation (MDA) system*

Detail designers can prevent rework by reusing the data coming from conceptual CAD tools, but many engineering organizations have no electronic hand-off from engineering to detailing. Those that do often rely on import and export translations to third party standards that can omit data or change geometry. Due to the inaccuracy of these formats, the translation document rarely contains reliable, reusable content.

To be useful, the transfer should include all the design criteria the engineer needed to specify to enable detailed design. All 2D and 3D geometry, joint definitions, annotations, and datum information must transfer seamlessly. Ideally, the critical dimensions and parameters specified in the design criteria should be able to drive the detail model associatively. Emerging standards are beginning to make this integration possible.

Summary

Conceptual engineering is an important phase of the development process, in which rapid idea capture is paramount. Mechanical engineers would benefit from specialized CAD systems developed for conceptual engineering, yet have the ability to feed the core design-through-manufacture system. Although many different tools have the functionality engineers require, few single solutions are satisfactory. Emerging conceptual CAD products offer conceptual engineers similar productivity benefits that parametric, feature-based CAD provides detailed design.

Source: Blake Courter, Product Line Manager, Parametric Technology Corporation, 1999