Manufacturing
New CAD Software from Dassault Systems: Starting to Combine Design and Engineering

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SUMMARY

This article describes recent developments and prototype software that will extend the range of the three-dimensional (3D) modeler CATIA. CATIA started out as an aerospace industry product but recently has made major inroads in the car industry. New software plans include providing object-oriented databases; using free-form 3D sketchers; providing the ability to manipulate constraints, engineering equations, and tolerances; and modeling assembly processes. A new and quite large European Strategic Programme for Research and Development in Information Technology (ESPRIT) project on assembly has just begun. It's a turning point in computer-aided design (CAD) capabilities.

GENERAL BACKGROUND

Dassault Systemes (DS) is one of the major suppliers of CAD/CAM (computer-aided manufacturing) software. It was founded in 1981 as an offshoot of Dassault Aircraft and has grown from 15 employees then to 1000 today. Annual sales are usually about FF 1 million per employee, year after year. Several years ago, DS formed a broad strategic alliance with IBM—selling it a minority interest, buying CADAM (a 2D CAD package) from it, and obtaining marketing, software, hardware, and maintenance services world-wide. As a result, DS is well supported with the means to write and sell CAD/CAM software on both workstations and mainframes.

Their major product is a 3D modeler calledCATIA, which originated in Dassault Aircraft. A practical results is that, unlike most other CAD vendors, DS's evolution has been from 3D to 2D, rather than the reverse. In the past, when CATIA was DS's only product, DS's capabilities were strong in surface modeling (suitable for aircraft) but weak in conventional 2D drafting and solid modeling (suitable for automobile engines); again, this is the reverse of many CAD vendors. These differences are gradually being corrected by the purchase of CADAM and the addition of 3D solid modeling to CATIA. Among the improvements are those aimed at enabling a designer to convert a fully dimensioned and toleranced 3D design into conventional 2D drawings for transfer to manufacturing.

CATIA currently consists of about 5 million lines of FORTRAN comprising the geometric modeler and an infrastructure of data management and other facilities. In addition to this infrastructure, there are an additional 8 million lines of applications code (apps) and other infrastructure. The apps include various CAE software (finite-element codes, kinematic analyses, the beginnings of tolerance representations, etc.) plus communications capabilities to make concurrent engineering easier. The infrastructure makes it easier for third-party developers to insert and check their own ap-plications. Apparently much of this development has been driven by the customers. "It's pretty hard to keep up with them," says Dominique Florack, Manager of R&D Strategy.

Another technique for strengthening DS has been to hire people from engineering organizations,including Dassault Aircraft, so that new developments will be more focused on the needs of current and new customers.

DS is also interesting in the way it develops new capabilities. According to Florack, half of their internal R&D projects are co-funded with one or more industrial partners. These partners will have a two-year exclusive opportunity to use the results before they are sold generally.

DS now has 3000 customers representing more than 19000 seats, with twice as many seats being mainframe-driven as workstation-driven. The customers are distributed as follows:

- 50 percent Europe, 25 percent U.S., 25 percent Asia;
- 40 percent automobile, 30 percent aerospace, 30 percent other.

Recent and well-publicized sales have been to Boeing, for the 777 program, and Chrysler, which adopted an "all CATIA" strategy about two years ago. The sale to Boeing has blocked DS from selling to Aerospatiale, but the sale to Chrysler has not blocked sales to German car companies. Here, another national style difference emerges: the

German car companies are working together on several fronts, including standardizing databases for dealing with suppliers' CAD systems. Cooperation at this level, including using the same design software, is deemed important for survival of their industry. (See next report about Volvo and Volkswagen.) Finally, DS has made headway with the engineering services industry, notably Bechtel, a designer / builder of nuclear power plants, oil refineries, and public works projects. CAD / CAE for these customers includes piping layout, buildings, steel structure, and so on.

Other regional differences affect DS's long-term strategy. The U.S. customers are demanding an open architecture, presumably because they hope to add applications from other vendors. They also think that openness will help them overcome incompatibilities between data formats in different programs, permitting them to keep more of their installed base of older software. Boeing and Japanese customers are starting to ask for shared screens—the ability for two or more designers to work on the same design at the same time. (This contradicts my finding a year ago that the Japanese are not looking forward to substituting computer communication for face-to-face communication.) The Japanese are also asking for open architecture, but so they can add their own software rather than that of other vendors. (This is consistent with my finding that each Japanese company wants to tailor its CAD software to its distinctive "working style.")

The new capabilities DS is adding comprise the maturing of a drawing package into an engineering and enterprise management package, a trend ongoing at other CAD companies as well. This is stretching DS as well as the old software technology on which CATIA is based. Gradually FORTRAN is being replaced by C, but DS would rather use C++ because of its object-orientation. O-O is seen as vital for more powerful databases, groupwork, versioning, event notification, and other aspects of highly interactive and integrated engineering. Unfortunately, there is no C++ standard for workstations and no C++ at all for mainframes. Object-orientation is not the answer to everything either—it's too slow in many applications—so it is not clear how CATIA and other CAD products will evolve over the next few years.

NEW DEVELOPMENTS

Pascal Lecland, Manager of New Technologies and Research, and several of his staff discussed and demonstrated new projects that will ultimately appear as CATIA capabilities:

- a free-form design sketcher for solid objects
- representation of constraints and parameterization in engineering design
- representation of tolerances
- the ESPRIT-funded SCOPES project in assembly modeling.

These are discussed in turn. They are interesting in part because they represent topics that are being worked on at several university research laboratories. Either technology transfer is starting to happen very rapidly, or the universities are not very far ahead of some applications. Both may be partly true, and in some cases I think the universities are behind. In others, DS's capabilities will be quite modest in these areas at first.

Free-form Design Sketcher

This project was described by David Bonner, a recent Massachusetts Institute of Technology (MIT) graduate and new hire. Bonner developed the sketcher as his Master of Science thesis under Professor Mark Jakeila of the MIT Mechanical Engineering Department. The research was originally sponsored by Nissan. The sketcher permits one to input a solid elongated shape and then distort it systematically into a desired shape. Both large- and small-scale deformations are possible. The object maintains certain shape constraints while deforming, such as keeping slope or second derivatives continuous everywhere, and keeping the surface closed.

Extensions Bonner is working on for DS include the ability to tie the shape to certain curves imbedded in the surface (what the car designers call feature lines) and then cause the surface to deform when these curves are deformed. So far, no attempt has been made to relate the surface deformations to explicitly written constraints (keep the volume = 500, make the left end half the diameter of the right end, etc.)

(Although Bonner and Lecland said that no other modeler could presently do what this one does, I saw a similar capability at Volvo. The software is called ALIAS, whose surfaces are built on Bezier curves. The designer can pull on a curve and the whole surface will deform smoothly. In this way, Volvo has converted several of its clay model car stylists into computer-based stylists. Compare this to Toyota's method of having a computer person attempt to convert stylists' sketches, then sit with the stylist and correct the model.)

Representation of Constraints

The goal here is to improve the ability of CATIA to support engineering, as distinct from drawing. This project and SCOPES (below) represent major departures from typical CAD. I believe the constraints project is just beginning, although such work has been ongoing at several universities for some time.

The basic issue is to find a good design for a problem that is primarily defined by sets of simultaneous nonlinear equations and inequality constraints, some of whose parameters also define geometry in a solid model. General solution methods do not exist, and DS is not trying to find such solutions. A multi-prong attack is being used, comprising elements of artificial intelligence (AI), mathematical programming, constraint propagation, and numerical solutions.

The AI approach appears to be rule-based and similar to ICAD.[1] The math programming approach is hard to generalize since such algorithms typically must be carefully constructed specifically for each problem. For the time being, Lecland appears satisfied to present the designer with a family of solutions obtained any way possible, including successive numerical search, and let the designer choose.

Three possible applications/illustrations were given:

1. 2D and 3D equipment layout to meet constraints. For example, place machines on a factory floor or so that trip distances between them along typical process routes are shortest. (Several classic operations research or mathematical programming approaches to this problem exist; some AI methods have also been tried.)
2. Advise designers on selecting equipment or parts from catalogs to meet constraints presented by the designer or the design. The goal is to support "fuzzy requests," presumably avoiding the need to describe the needed item explicitly. (Two forms of this problem have been identified. One selects single items, which is not too hard. The other tries to select sets of items that will be connected to each other. This is a lot harder. Allen Ward at the University of Michigan did his Ph.D. thesis work on this.)

3. Study the problem of allocating space, such as between the front wheels of a front-wheel drive car. (This is a striking coincidence, since I use this very example in speaking about how Japanese car companies organize design projects. This allocation is a crucial one; the way different companies deal with it says a lot about how the companies organize their design processes.) The approach

suggested by Lecland was to vary the parameters systematically, redrawing the layout in real time so that the designer can see a lot of alternatives one after another.

For the long term, he envisions a "full concurrent design approach" that combines freeform sketching and constraint-based design.

Features and Tolerances for Parts and Assemblies

This was described by Philippe Dufosse. DS is working on these topics at several levels, not only upgrading existing software but also developing new capabilities. These were described and shown as prototype demonstrations later in the day.

Dufosse divided the topic into mechanical design modeling (kinematics), assembly modeling, assembly process design, and tolerancing of both parts and assemblies.

He described and then demonstrated a 3D mechanism sketcher based on features. The features supported are plane faces, cylinders, and cylindrical holes. One can sketch simple solid shapes and link them with the features. Planefaces can be placed against each other. Cylinders can be located on the object via the object's coordinate frame and some simple commands. Cylinders and holes can be aligned via their centerlines; the surface contact between peg and hole is then detected automatically and the kinematic degrees of freedom are noted in the model. When the model is finished (here a simple slider-crank mechanism), it can be animated. The designer deals at the level of shapes and mutual constraints between them. The design is unscaled, and the designer can add actual dimensions later.

Assembly modeling is going on at two levels. One level merely places parts on the computer screen in the correct mutual locations. This creates a data model that tells what parts are present and where they are. The other level models (actually will model when the SCOPES project is done) the processes by which assembly would occur in the factory. This model is hierarchical in that it defines subassemblies recursively; the minimal subassembly has one part.

A nearer-term use for assembly modeling will be to allow designers to access catalog parts and place them correctly in a design along with drawn parts. Another potential use is to search for existing designs described somehow (types of parts in them?). This was not clear but is obviously useful and not easy to accomplish.

Functional dimensioning and tolerancing is also going on at several levels. For single parts, the goal is to provide enough information to program coordinate measuring machines and compare the results to the design. Current methods of assigning tolerances in CAD usually mean adding some text annotations to 2D drafting. There is little connection to the geometry itself. Lots of errors are made, every designer assigns tolerance types and values his own way, and the design can't be checked.

The new approach is based on work by Professor Andre Clement, who has developed a conceptual model of tolerancing based on kinematic concepts.[2] A tolerance describes or constrains one or more kinematic degrees of freedom, such as a point, a line and a point, and so on. These are called geometric reference elements (GRE). If a hole is to be located relative to two surfaces, the constraints involved are two planes and a line. Such constraints are added directly to a 3D model. At present, the related surfaces must be identified by the designer; although I got the impression that DS thinks this can be done automatically, I am not sure how they will do it. A possible way is to look at the surfaces as part of named engineering items like "bearing seat." Standard ways of dimensioning and tolerancing such items could be stored in a database. So far they are not taking this approach.

In the demonstration, I saw what they are doing now. A user makes a fully surfaced model and then begins to associate surfaces. For example, a part that will hold a caster wheel has two cylindrical bearing surfaces on a shaft and a flat face at the root of the shaft. The designer wants the first cylinder perpendicular to the face, so he clicks on these two surfaces and clicks on "perpendicular" in a menu. The software offers several choices for geometric dimensioning and tolerancing notations, from which the designer chooses one. He then fills in the numbers representing the degree of perpendicularity he wants. Similarly, he makes the two cylindrical surfaces concentric. When this process is complete, the designer can ask that a three-view conventional 2D drawing be made, containing all the tolerances and dimensions in the right places.

Next year they plan to extend this capability, exploiting the fact that the GREs provide a way to relate the dimensioned and toleranced surfaces to each other systematically. Possible extensions include computing tolerance chains by both worst-case and statistical methods to check for the possibility that parts will not fit; synthesizing tolerances based on minimum cost; and understanding how tolerances propagate through assemblies of parts. Over-dimensioned parts and inconsistent tolerances may also be possible to detect.

Professor Clement observes that all of the surface selection done by the user now could be done automatically by using his methods. He feels this might be necessary because so few designers really understand tolerances—how to select the right surfaces, or how to choose the numerical values for the tolerances.

In my opinion, such automatic selection and numerical assignment cannot be done until the engineering content of the geometry is captured by calling it a bearing seat, for example, and referring to a database for additional information aboutbearing seats. This approach will work as long as design consists of reusing old things or basing new ones on defined concepts. But not every concave cutout in a part is destined for an established and documented use. Thus higher level descriptions are also needed, such as "capture a substantially rigid convex shape and hold it against forces and torques of XX magnitude in the YY and ZZ directions."

The SCOPES Assembly Modeling Project

Boubker Badr, DS's program manager for the SCOPES project, described it. This 3-year, 67.7 man-year project sponsored by ESPRIT III is just getting started. The partners are DS, Telemecha-nique, Mandelli, and four research laboratories, including the CIM Institute at Cranfield. Teleme-chanique[3] is a French company that builds industrial controls for automation systems as well as automation systems themselves. Mandelli is an Italian machine tool and automation systems builder.

The main structure of the project is divided into two parts:

- the "offline design" of a multipart product and creation of the assembly plan for it, including concept design of the assembly plant; and
- the "online design" of the details of the factory and its real-time control system.

DS is the task leader for the offline part while Telemechanique leads the online part. Both Telemechanique and Mandelli will be user test sites during the project. A planned demonstration will consist of designing a product and a robot assembly cell for assembling it, then designing the control system for the cell, then building and operating the cell at Telemechanique's research and development laboratory. No software will be delivered as part of the project. Instead, DS will judge the success and usefulness of any software it develops and decide later if it will be added to CATIA.

This project, as stated above, represents a totally new direction for CAD. Assembly is the first really new CAD/CAM application since numerical control, and assembly brings totally new issues to the surface. Among these are

- dealing with several parts at once;
- understanding all the ways those parts will interact;
- exploiting the integrative character of assembly to help tie the design process together; and
- understanding assembly as both a process that occurs in the factory and as a way that parts provide "engineering services" to each other (support, location, sealing, heat transfer, retain fluid...) and then connecting those "services" to the assembly constraints inherent in individual part mates (slide in, fit against, glue together, fasten with screw, compress O-ring,...).

In more detail, the project has three segments: offline, online, and the offline-online interface. These are described briefly below:

Offline

This will consist of three activities, namely product redesign or design for assembly (DFA), assembly planning, and resource planning.

Redesign will actually involve the designer using conventional DFA rules and other criteria such as properties of different assembly sequences iteratively to arrive at a suitable design.

Assembly planning, part of the above iteration, will consist of generating the possible assembly sequences for the product based on geometric properties of the CATIA model, and evaluating them according to criteria such as the ability to support model variants of the product, least use of fixtures and tools, and management of subassemblies. These criteria are similar to those being investigated in the assembly planning research community,[4] and techniques from research laboratories will be used.

Resource planning will consist of identifying "logical" resources such as generic tools, people, or robots that are described parametrically by size, speed, or load capacity. These will be matched to the required assembly sequence by methods not made clear to me. However, researchers have created some applicable methods. These logical resources will be laid out on a factory floor while obeying facility constraints such as avoiding pillars and minimizing flow path lengths.

Significantly, the project does not include estimating assembly cost. In my opinion, resource planning depends crucially on resource cost and speed, so cost is not separable from resource planning. Fabrication cost is also absent, yet it is well known that redesign based on DFA criteria sometimes increases the cost of parts. A more complete design system would therefore permit these important tradeoffs to be evaluated.

Offline/online Interface

This part of the project will be jointly managed by DS and Telemechanique. Its main component will be a detailed but conventional discrete event simulation of the planned assembly system. The issues to be explored in this interface are scheduling the system, controlling material flow, and recovering from errors. The simulation will exist at three levels of detail: each workstation, cells of several stations, and the whole assembly system.

Online

In this part of the project, the system will be designed and built. In particular, the system control software, communication links, sensors, monitoring, user interface, diagnostics and error recovery, scheduling, and statistical quality control will all be specified, designed, built, and tested. Control, scheduling, and error recovery algorithms derived during the simulation phase will be used, and the operation of the actual system will be monitored by the simulation. Methods for designing these system elements will presumably be developed, but I have no information about this.

This is obviously an ambitious and important project, perhaps too big for the time allowed. It will not directly address the larger issues listed above but it will open the way for such issues to be addressed in parallel or in the future.

Software Demonstrations

In addition to the demonstrations of kinematic sketching and tolerancing described above, I saw one on a prototype for a new mouse-menu-icon user interface that included shared screens and other support for concurrent engineering. Thissystem is based on a version of X Windows called XCAD. As such, it supports multitasking, which in this case means supporting several CATIA applications running at the same time on the same or different geometric models.

Several features are supported. The simplest permits a user to send a model to another user, although not yet by simply clicking on an icon that represents that user. The next permits a user to launch a CATIA application by dragging the icon for the model onto the icon for CATIA. This act launches a message from one data object (the model) to another object (CATIA), causing an instance of CATIA to be created to run that model. The third facility keeps a journal of all the de-signer's actions (a little recording tape icon) that can be replayed later or used to create a variant of the model.

The last and most ambitious capability is groupwork. This permits several levels of cooperative work. The lowest level permits a user to look over the shoulder of another user. The next permits him to launch a CATIA instance on the other person's screen. The highest permits both to modify the same model "at the same time" in the sense that either one can modify it without asking permission from the other. This is called "debate mode." I think DS recognizes the need to reconcile databases that result from two or more designers working on the same model, but no mechanism has been identified for doing so. This is a potential showstopper for groupwork, and several researchers are studying it.

CONCLUSIONS

DS is moving CATIA from a geometry modeler to an engineering design support system. It appears to be actively seeking recent research results, not only by following the literature but also by hiring recent graduates who have done such research. At present CATIA is still primarily geometry-oriented, and the hard engineering capabilities have only recently been considered. But this is the long-term trend, and other CAD companies are moving in the same direction.

The kinds of research that DS and other CAD vendors' work still need include

_ better and faster databases for managing really large and complex designs;

_ object-oriented (or other content-driven) approaches for manipulating design data and relating geometry to engineering;

_ better user interfaces for creating and manipulating solid models;

_ ways of modeling design processes so that CAD systems can help companies create and optimize such processes as well as manage them; and

_ more understanding of assembly processes and their relation to engineering: both the engineering of the assembly actions themselves and the assembly implications/
descriptions of engineering functions accomplished by groups of parts

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