OBJECT-ORIENTED CAD AND EXPERT BLADE DESIGN AT ROLLS-ROYCE

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Summary

Rolls-Royce (RR) is one of the world's three largest manufacturers of jet aircraft engines. It is somewhat smaller than its rivals General Electric and Pratt & Whitney, but this fact does not make the cost or time to develop a new engine any smaller or the job easier. It takes about 10 years and $1B, after a minimum of 6 years of preparing advanced technologies such as new materials. The development cost and complexity of new engines (and planes, too) is driving the major manufacturers into strategic alliances, possibly ending in mergers [See ref FT]. A practical result in design research and development is that Concurrent Engineering is already starting to spread beyond individual companies and involve teams from different companies working together. If the problems of merging cultures and data formats is not bad enough inside the same company, it will only be worse across companies.

RR is already dealing with multi-firm CE as it designs its new Trent engine for Boeing's 777. Boeing has declared that all engine data be transmitted in CATIA[1], and that several engine details be designed by Boeing. These include not only the obvious things like engine mounts but also some pumps and pipes on the engine's exterior. RR converts its CADDS data to flat CATIA files and sends them by satellite to Boeing. The designers communicate by phone a few times a week or send marked-up files back. RR also communicates electronically with dozens of vendors who make other components for the engine. RR keeps the master data and no problems over communication have occurred, mainly because new software is in use for managing assembly layout.

The most difficult assembly layout area of an engine is the outside of the fan and the core (the central tube containing the compressor, turbine, and combustion chamber) where hundreds of pumps, valves, wires and pipes are located. "Digital Preassembly" software (sometimes refered to as an electronic mockup) has replaced a full scale wood mockup for this task. Use of this software has evolved in unanticipated ways beyond making layouts to managing the CE process.

The digital preassembly model was built using Computervision's new Assembly Design software, a product that originally was meant to support creation of assembly drawings based on 3D models. It supports object-like definitions of models, including direct links between pipe or wire schematics and the associated geometric model. (Click on a line representing a pipe in the schematic and you see a picture of the pipe plus a list of the things it hooks to, the material, type of joints, etc.)

Use of this software has turned up some interesting facts. First, routing pipes this way takes just as long as using the physical mockup! However, making changes is much easier, many mockups for different versions of the engine can be built, and <u>many</u> man-years are saved when the documentation is produced.

More broadly, this software has awakened the company to assembly as a way to coordinate the design process. For example, using it brought out the need to have a corporate database and a formal configuration control process. Also, weekly meetings are held to identify future assembly problems early in design, many of which are found using the software.

Disassembly during maintenance is also extremely important; there are rules from the airlines concerning which systems can be disassembled at the same time, mostly based on safety. So interferences between pipes and identification of allowed disassembly sequences are of interest. No algorithms are presently in use for studying such problems. However, the designer can identify which items belong to which system using the object-designation capability.

The engine dressing model is apparently the first fully solid model RR has made of an engine assembly. Now the weight/balance control people have discovered it and are using it in place of cumbersome hand methods.

All this has flowed from a capability originally targeted at making assembly drawings. It is not clear if Computervision anticipated the main uses RR has identified for this product, and it certainly did not anticipate the size of RR's models. User feedback is thus of paramount importance in developing new kinds of design tools.

The problem for CAD vendors is satisfying all their customers at once, each with its own expanding requirements. A consensus on what design is clearly has not emerged, and both users and developers are continually discovering new needs and possibilities. This fact may partly explain the Japanese companies' decision to write their own design software. It definitely has contributed to the move to open CAD systems that permit users to add their own software.

Modernizing the Design Process

Before computers, mechanical designers drove the engine design process. RR began using computers to aid engineering analysis 35 ago, and the power of analysis grew until engineers drove the design process. In the last five years CAD has come into wide use, and the designers are now on a more equal footing with the analysts. Even though RR was unsatisfied with "electronic drafting" offered by the first CAD systems and wanted 3D capability, it decided to buy rather than try writing its own. It has standardized on Computervision's CADDS, but has had to write data convertors to CATIA and UNIGRAPHICS.
Even today, geometry, aerodynamics, and stress analyses are not completely linked. A high priority has been given to "key processes" whose execution is crucial to cost, design time, or engine performance. Key processes are end-to-end integrated paperless design and fabrication chains dedicated to individual items, such as compressor blades or turbine disks.

Mr John Cundy, Head of Propulsion Systems Engineering, notes that "we have learned a lot about design from our friends in manufacturing." He says they used to do design like a job shop and now they do it like a manufacturing cell. As in cellular manufacturing, the issue is to find the flows of information and organize the process around those flows.

Stress analysis, dynamics, and geometry of some parts are very tightly related, so people doing that kind of work are co-located. But generally, problems are so complex and the number of people needed to solve them is so large that co-located teams cannot be used in practice for everything. Instead RR has been more careful: In the last two years many processes have been studied with the aim of identifying exactly who should talk to whom and when. "Design is always a matter of identifying conflict and then achieving compromise." This means identifying the specific people, with name, phone number, and electronic mail address, who must work the problem out. The result is a virtual team, a "design cell." Since 75% by value of the engine is purchased, suppliers are members of many of these virtual teams.

Note that this is quite different from just putting everyone on the network and expecting them to find each other when problems arise.

As at other companies, RR has discovered that integration is a learning process that is separate from perfecting each of the steps. One discovers wide differences in assumptions, work style, data formats, and/or emphases in the groups that do each step. For example, different steps in blade design require different data point density: who is responsible for providing what to whom?

Digital Preassembly of an Engine

The most complex arrangements problem on an engine is placing the pumps, valves, electronics, pipes and wires on the outside of an engine. In the past, this was done with a full size physical mockup. The major components are placed first, then the pipes are routed, largest first, in groups related to a type of system. Equipment and pipe placement are limited by various rules. Among these are measures to hide key components on one engine from blades that might fly off another engine. Oil pumps are placed near their coolers since the intervening pipes are large.

This was a costly and time-consuming procedure, so costly that only one engine parts standard mockup was made even if several versions of the engine were under study. This led to errors as people designed pipes for components that were "not there" on certain engines.

Equipment layout takes so long that it must start before many other design decisions are finalized. Design changes led to piping revisions. Typically, a complete engine layout was repeated 2.5 times during the whole design cycle. While this may still be true, alterations are now much easier to make using digital preassembly.

This new model has been built on top of Computervision's recently released Assembly Design software. It permits a complete assembly tree to be written out, with a component model at each leaf of the tree. Component models are bought from the companies that make the component. Each component model is actually a fairly crude solid "keep-out" zone with accurate wireframe models for the pipe or wire attachments. These are placed on the engine using the numerical coordinates of mounting surfaces on engine and component. (A feature-based technique would be much easier.)

Linked to the assembly tree is a wiring diagram for electric power and actuating signals, plus a piping schematic. These are called "smart diagrams" and are filled with data about the individual items, such as their material, what they mate to, what kind of termination is used, and so on. To route a pipe between two components, the designer clicks a mouse on a line on the schematic; on the solid model, something like toothpaste appears to come out of the relevant components at the correct locations, avoiding any errors in attachment points. The designer then stretches and bends the toothpaste until it is satisfactory. Routing errors or other interferences are quickly but approximately checked by intersecting the surfaces of these models, not the solids themselves.

The system contains provisions for defining portions of the engine. These portions can be used as focus zones for closer looking or, more interesting, they can define keep-out zones for designers. That is, a designer can tell other designers not to route pipes through his region. Alternately, he can define a notify zone: if anyone else runs a pipe through it, he will be notified. These provisions are forerunners of more sophisticated tools that will be needed to help large teams work on the same item.

Expert System for Designing Internally Cooled Blades

This is a feasibility study to see if expert system technology can improve the quality and speed of engineering. A commercial program called WISDOM was used to build it. WISDOM permits geometric models and rule-based systems to be built and work together. The developer calls it an "intelligent product model" because in addition to geometry it contains design intent, it can highlight critical areas of the design, and it is feature-based so that portions of it can be easily split off when they are finished and sent to manufacturing for tooling design purposes.

Design begins with a given aerodynamic cross section shape for the blade and an external applied temperature. Blade material data associated with the shape include melting point, thermal conductivity, and so on. Different styles of internal cooling passage are available as features in a library. Each comes with the software to support thermal calculations. The designer chooses passages and places them inside the blade, separating them by supporting fins. In addition to satisfying the heat flow requirements, each passage must be possible to make by lost wax techniques, so an additional set of rules applies.

So far, the system is analytical. That is, if the passages cannot take away the heat, the designer is on his own to figure out what to do. As a first step toward supporting design, the developer has prepared a table that qualitatively links various parameters and their effects: heat flow, internal support for the blade, separation direction for making the wax core, and so on. Effects are classified as "strong," "weak," and "none."

Although this is only a feasibility study, test blades have been made using it, and the developer is confident that systems like it will win acceptance by the engineers.

Conclusions

Like the aerospace company Aerospatiale (see ESNIB article "Design-Build Teams at Aerospatiale"), RR sees the importance of assembly as a factor in product design and also sees the limitations of one of the first commercial products to address this area. Now that RR has begun to feed its experience back to Computervision, progress should quicken, and better tools should emerge. This will open the eyes of all the CAD vendors to assembly and hopefully make them more aware of the research that has been going on in this area for some time. This, in turn, should encourage researchers to do more in assembly, which has received much less attention in academia than other more conventional areas of manufacturing, such as metal cutting.

Reference

[FT] Financial Times of London, special section on Britain's aerospace industry, Wednesday, Sept 2, 1992.

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[1] CATIA is a solid modelling system marketed by Dassaults Systemes