Design Research at Cranfield Institute of Technology

by Daniel E. Whitney

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INTRODUCTION

Cranfield Institute of Technology (CIT) is one of Europe's premier technological teaching and research institutes. It is located in Cranfield, Bedford, United Kingdom (U.K.), and is unusual in having on campus 27 separate research organizations [called Centers of Excellence (CoE)] and 12 commercial enterprises that formerly were CoEs. All once were departmental research laboratories and typically are staffed by former faculty and/or students. Most are small. Many retain direct connections to academic departments and provide research assistantships to Cranfield students.

Cranfield itself thus represents an interesting design; it contains on campus some of the elements of technology transfer and maintaining flows of information and people up and down the transfer path. It is more than a university, more than a technology park.

Cranfield participates in many EC-funded projects because of its excellence in aerospace engineering, artificial intelligence (AI), and CAD/CAM (computer-aided design/computer- aided manufacturing). This article discusses two of the projects and results from interviews with Professor Alan Morris, Head of the Aerospace Scien-ces Department. The projects have to do with using AI and high-speed communications to aid complex design processes: critiquing designs for manufacturability, and linking many designers so that they can pass subsystem definitions and interface specifications back and forth.

The topic of most interest concerned a new EC-sponsored project on collaborative design using broadband communication networks. The high speed of the network (144 MB) is not as interesting as the focus of the project, namely, trying to ra-tionalize interfaces between complex engineering subsystems. One quickly discovers that some very basic questions need to be answered:

1. When a description of an object is handed across a boundary, exactly what information needs to be transmitted?

2. What constitutes an adequate description of the objects being handed across?

3. How should variability be described (variability includes tolerances and freedom for revision)?

4. How can really useful diagnostic messages be generated? "It doesn't fit" is not very helpful.

5. In the era of computerized design, with designers widely separated from each other, what will be the nature of the well- known interface control document (ICD)?

These questions could be applied to any designed object or system, not just to interfaces, which is why the project has broad interest and potential impact. The Navy impact is clear: every large system designed and built for the Navy involves prime contractors and many subcontractors and suppliers. The interface control document is a basic part of the development of these systems. It may seem like a humble, even bothersome, document, but Prof. Morris makes clear the technical opportunities available from making it the focus of a deep research project.

Prof. Alan Morris: Two Novel Design Research Projects

Professor Morris has specialized in the past on computational aerodynamics, but our topic of discussion was design and computer aids for design. He agrees that today industry leads in creating computer design tools, even though 20 yearsago one might have been able to get useful code from universities. For example, today no university can afford to produce commercially interesting finite-element codes.

Industry's offerings are nonetheless limited. No one commercial system does everything. He notes that inside Boeing one can find large CATIA installations as well as in-house software. I pointed out that it may depend on the program manager who, in many companies, controls the facilities budget for his program. In the case of the Boeing 777 aircraft, Boeing has chosen CATIA "because it comes from an aerospace company (Dassault Aircraft), which means that one can directly link surfaces to aerodynamic calculations," he says. He also believes that Boeing has added a large amount of its own software to CATIA. Another reason Boeing chose CATIA is that "electronic mockups" of interiors and interfaces to purchased items like engines can be made. Problems can be found early, different cockpit or passenger interiors can be compared, and communication between designers can be eased.

He contrasted Boeing and Dassault with the British aerospace industry which, he says, has not done its own research and development of design tools. British Aerospace was strong in this area 30 years ago, but now they buy commercial software. Dassault apparently felt, like the Japanese companies I visited last summer,[1] that it could not buy what it needed.

Before the age of computers, stress specialists participated early in the design process, according to Prof. Morris. When computers arrived, they were able to analyze only bits and pieces of the airplane, so the stress people waited until detail design was well under way before doing their evaluations. When they found problems, the design was seriously delayed. Dassault now has a computer system that is geared to permitting rough stress calculations and identifying places in need of evaluation early in the design process. Enough computer power is now available to look at the whole plane, and specialists "now have their proper role—advising at an early stage."

Dassault has also done a good job of linking geometry, aerodynamics, and flight control software, thereby permitting several varied parts of the design to be done in a coordinated way.

Professor Morris also had interesting comments to make about the history of concurrent engineering in aerospace. The walls came down 20 years ago when carbon fiber composites began to be used. The new material presented a wide range of problems: how should one design, analyze, manufacture, and certify aerospace structures? These issues concern all the major interested parties, including government (because it contains the regulatory agencies). Everyone has to work together. When aluminum was the only material, the designer was king and everyone did what he said.

Then he drew my attention to two EC projects he is involved in that are quite unlike conventional CAD/CAM/CAE.

1. EC Project on Computerized Design Critics

This project is called IKADE. Several universities and companies in EC countries are involved. The goal is to develop a design critique system that can help a designer determine basic manufacturability issues. Apparently the goals are fairly basic: is there a machine in the shop that can make this workpiece, or this feature on this workpiece?

It appears that the researchers originally thought this was a fairly meaty problem, but they have now realized that commercially available software packages can handle it, at least at the level they are aspiring to. Two packages have been chosen, leading to some confusion in his opinion but perhaps a nice side-by-side comparison. The two are ICAD and WIZDOM, both U.S. products with quite similar capabilities. They permit geometry to be entered and rule bases to be constructed. As a result, simple design protocols can be built that capture repetitive decisions and capabilities. An example is "If load on beam X exceeds Y then use steel." General Electric (GE, U.S.) has spent several years packaging such problems into software. It calls them "purchase order engineering," meaning modifying existing designs to meet new customer specifications. According to GE, 85% of its design effort corporation-wide falls into this category.

The interesting point here is Prof. Morris' opinion that academia could not easily have created the capability that ICAD and WIZDOM have.Yet it should be noted, as above, that the aspirations of this project are not great. A more ambitious project could quite possibly have exceeded any commercial package. This opinion is based on papers given at last year's International Conference on Artificial Intelligence. This conference contained a special session on AI applications, including several design aids. These were quite sophisticated and were not likely to be within the capabilities of the commercial software.

Two companies are participating in this project: Lucas Engineering of the U.K. and Roneo, a Spanish furniture maker. Lucas makes highly engineered products, whereas Roneo's desks and filing cabinets comprise standard components, simple shapes, low mechanical stresses, easy tolerances, and so on. Morris says that he and others worry that they have been biased in their work by the simplicity of the furniture.

I raised the question of how much/how detailed geometry information is needed for some DFM studies and when is some nongeometric information of more importance. He felt, as expected, that it depends on the product: aircraft surface shapes are quite important, and small changes can render them unmanufacturable by available machines. This is not true of the desks, whose shapes are so simple and noncritical that almost anything the designers can think up can be made in the existing shop.

By contrast, in Japan I saw the camera companies going through an upheaval as they tried to adjust to cameras with sculptured surface exteriors. The car companies have had 20 years to develop software and methods for this kind of design,
but the camera companies have had to climb the learning curve in only 3 years. This shows how a change in product style or production technol-
ogy can invalidate existing design methods and software, as well as existing production equip-
ment. When might sculptured-surface office furniture become stylish, and what will happen to design then? The Spanish may be the ones to do it, too.

Despite the strong AI component in this project, Prof. Morris is not optimistic about the ability of AI to significantly aid the design process. They are thinking about how to add it, but at the moment he is more intrigued by the idea that vivid graphic displays can strongly couple the humanexpert to the problem, permitting real synergy and progress on a design. Stacks of printouts contain the same information in principle but can't be interpreted.

2. EC Project on Broadband Communication

The other project Morris described, called EDID, is new and much more technically challenging. It is about distributed design in the anticipated future environment of really high-speed communication:

> How will design be done by groups of geographically separated designers who have access to 114 megabit/s communications?

Several universities and companies are involved, including IBM U.K., British Telcom, Alcatel, and Aerospatiale. The project has focused on an interesting subset of design, namely checking interfaces between designed elements or subassemblies, detecting and identifying mismatches, and negotiating resolution of the mismatches.

The project is funded by RACE (Research and Development in Advanced Communication Technologies in Europe). The subject is broadband communication. (He says the EC has an amazing array of acronymed programs. This one is not part of BRITE or ESPRIT.) It originated from a rather vague call for proposals recognizing the impending availability of broadband communication, asking for proposals on how to get companies and universities to think about what it would mean and how to use it. One gets money from these organizations by putting consortia together and proposing specific things that read on the RFP. Concurrent Engineering and Distributed Design seemed like an obvious target.

This is a fascinating project because it raises several basic issues that apply to much more general design problems:

1. When a description of an object is handed across a boundary, how should the recipients be prepared for what they are to receive, what should they expect in the way of technical content and information structure, how are they to find the information they need, etc?
2. Regarding the objects themselves, what constitutes an adequate description?

- geometry? pictures? simulations?
- geometry plus some sort of functional description?
- "features?" variability? (see next item)

3. How should variability be described (variability includes how the interface might deviate within tolerances as well as how it might be altered within specifications should a mismatch be detected).

This list could be applied to any designed object or system, not just to interfaces, which is why the project has broad interest and potential impact. It also brings to the surface some questions raised above: is geometry the main kind of design data, and if not, then what else is needed and how can it help? Virtually all existing CAD, CAM, and CAE deal exclusively with geometry.

Professor Morris used hydraulic pipes as an example. Suppose pipes must be joined across the interface and suppose positioning errors between the pipes are to be detected. One wants to be able to say more than "they don't fit up." One wants to be able to suggest a fix, but to do so requires other information. For example, if the errors are lateral, are the pipes flexible enough that the errors can be fixed just by shifting them sideways a little? If the errors are longitudinal, are strain relief bends designed into the pipes that can be flexed a little? On which side of the interface is it easier to put these bends? Is the pressure in these pipes so large that no flexing should be attempted? Etc.

At present, there are two ways of handling interface problems: the physical mockup and the interface control document (ICD). The mockup is satisfactory for nondistributed design when there is plenty of time and money, but these ground rules are withering away. The ICD is a really huge document that is administered by a prime contractor who resolves all conflicts, not only between itself and subcontractors but also between subcontractors. Resolutions take a long time and require very knowledgeable people who understand the re-lationships between subassemblies and the systemwide impacts of suggested resolutions.

The project as it is presently shaping up seems to assume that both the ICD and the resolving role of the prime

contractor can be replaced by a proper computer aid, high-speed communications,
participation of the designers, and design protocols. In particular, a decomposability assumption seems to have been made, namely, that each interface mismatch can be resolved across that interface independently, without reference to other interfaces or the internals of the system as a whole.

It is a matter of conjecture whether this assumption is true or not, in my opinion, and I did not detect that testing it was part of the project. However, he notes that Aerospatiale originally argued that its usual mode of operation should be maintained in the new setup: all interface discussions are held one-on-one, with Aerospatiale being one of the participants. Thus no subcontractors can talk directly to each other. This apparently is the "French style." He contrasted this to the U.K. style, where any box that can really be isolated (he cited avionics as a candidate) can be dealt with by the subcontractors themselves. In this project, a compromise has been reached, in which any pairs can talk as long as Aerospatiale joins in.

Since the approach is young, the approach is still evolving. As Prof. Morris describes it, it fits the mold of an object-oriented database in which each subassembly or interface specification is an object with a set of attribute slots. (No implementation has begun and, in fact, the basic issues are still being explored.) Things that must be slotted include the items listed above plus some sense of "stiffness": some things are negotiable while others are not, or not unless certain identified costs are acknowledged, such as money, time, or performance. If such information is provided, it opens up the typically closed ICD-dominated situation in which the prime contractor often acts dictatorially. Morris anticipates that designers will enter the negotiation directly, enhancing their role and making the process more creative and efficient. Of course, people do not always make their negotiating positions known, so either the system would require some changes in behavior or it might not work.

The project represents a big step forward in sophistication in several areas, not just in ICDs. The EC sponsors have come to realize very quickly that merely transmitting geometry or pictures will not solve the problem. This means that they are climbing the learning curve very fast compared to many others who confront similar problems. Many new issues are emerging. He agrees that these problems go way beyond broadband communications, but he was reluctant to say that broadband communications was just a vehicle for what they were really interested—just that he was
quite aware that other research goals would be served.

The companies, too, are finding their preconceptions under attack. At first they thought the result of the project would simply be an "electronic ICD." They do not want to upset their current methods very much—they do work, after all!

CREATE Ltd

While at Cranfield I also visited CREATE Ltd. This is a 20-person consulting company that spun off from Cranfield Institute of Technology in 1979; it was 1 of about 12 such spinoffs that evolved from Centers of Excellence on campus. Other centers are still in operation.

At present, more than 25 other Centers of Excellence. CREATE was purely a design consultant until 3 years ago when the current deputy managing director, Colin MacMillan, took over. His background is in manufacturing, and he extended the firm's reach to include making factory automation equipment. However, few clients with design problems ask CREATE to design their manufacturing equipment. "Clients usually know how to make their product." Companies come to them when they have run out of ways to solve a hard problem, or when they want a fresh look.

My visit here pointed up the challenges faced by a small company that sees different engineering and design problems regularly rather than repeats of the same problem. There is little commercial computer support for them beyond commodity CAD drafting and a few finite-element codes. They get by on 386 personal computers, operate on their wits and ability to formulate a quick but accurate mathematical model, make drawings and, possibly, numerical-control (NC) tapes, and build prototypes. Until now they have not been able to field a product of their own design or conception. "We are totally customer-driven." Also, they work to fixed price quotes.

CONCLUSIONS AND DISCUSSION

The design research activities described by Prof. Morris, especially the one on interfaces, suggest several lines of research:

_ do we know what an adequate description of a product (equivalently, a designed item) is? That is, to what degree must the description hold information that supports or is even about the design process itself rather than just about the product— how it will be made and used, and so on? This is a new wrinkle, in my opinion.

_ do we know the difference between "communication" as a supporting activity and communication as an active element in the design process? For example, the EDID folks are depending on negotiation to be facilitated by high-speed communication. But it is known that negotiation is central to concurrent engineering, and that skilled negotiators have several agendas and tend to hold back information during the negotiation process. An important reason for holding back is that the ability to meet a specification may depend on the availability of design resources such as people or test gear, rather than just on ingenuity or the state of engineering knowledge. "I'll solve your heat flow problem if you give me Joe from your group" is a typical negotiating position.

_ do we really know what to expect of artificial intelligence as an aid to the design process? This question is only tangential to this report, but it is stronger in other reports. (See especially articles on design research in Berlin and several U.K. universities.) That is, AI holds a lot of promise, but we need to recognize the current status: only simple rule checking seems feasible now; the amount of serious and deep knowledge that needs to be codified is huge; deciding how to codify and interlink it may be equivalent to re-packaging all of engineering. When people attempt something serious, such as AI that suggests an improvement to a design or converts a high-level functional specification into a lower level physical implementation, only the most trivial realizations are achieved.

_ do we appreciate the strong links between the way design processes work and the way businesses operate? The French and U.K. styles of dealing with subcontractors and ICDs illustrate the point. The Japanese car industry provides another regional contrast. Recent research shows that Japanese car builders have cultivated a multilevel supplier industry, arranging long-term contracts, flowing design and manufacturing technology down, and encouraging lower level suppliers to build and nurture their own chains.[2] Rapid, two- way flow of design data, costs, constraints, and production requirements is a strong ingredient of such a system. Thus what we think of as "design tools," the familiar finite-element packages or solid modelers, merely scratch the surface of the kind of tools peoplewill need in the future. The example also shows that we must begin thinking about designing infrastructures to support concurrent design and distributed design, equipping these infrastructures with the right decision tools.

An interesting example of such infrastructure design can be found in MOSIS, the DARPA-sponsored electronic network that permits custom integrated circuits (ICs) to be made to order. A standard design language was created by Carver Mead and Lynn Conway[3] that permitted designs to be described and communicated to a family of vendors. These vendors would then piggyback the ICs onto their existing production activities. But there was a hitch in this process that required human intervention and judgement.[4] This was the requirement to check the designs to be sure they conformed to a set of design rules and to sort the designs according the rules they obeyed in order to match them to the capabilities of the vendors. This sorting and matching is part of what DARPA has come to call *brokering* in its new application- specific electronic module (ASEM) program. The implication is that even the most apparently paperless and systematic design-build process needs help at critical points.

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Points of Contact

Professor Alan J. Morris, Head of Department College of Aeronautics
Aerospace Sciences Department
Cranfield Institute of Technology
Cranfield, Bedford, MK43 0AL
United Kingdom
Phone: +44 234 752779

Colin MacMillan, Deputy Managing Director
CREATE Ltd (Cranfield Engineering and
Technology Enterprise)
Cranfield, Bedford, MK43 0AL
United Kingdom
Phone: +44 234 752710
Fax: +44 234 750054

Dr. Ip-shing Fan (works for Prof. Peter Sackett) The CIM Institute
Cranfield Institute of Technology
Phone: +44 234 752773
Fax: +44 234 75085
e-mail: isfan@cim.cran.ac.uk