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SPECIAL FOCUS

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Toulouse '92—International Conference on Wavelets and Applications: An Eclectic Interchange of Theory and Practice

by Robert D. Ryan, a mathematician currently serving as Liaison Scientist for Mathematics and Computer Science at the Office of Naval Research European Office. Dr. Ryan is on leave from the Office of Naval Research, Arlington, Virginia, where he is Director of the Special Projects Office.

KEYWORDS: multiresolution analysis; signals and images; medical applications; turbulence; coding

INTRODUCTION

Toulouse '92 (June 8-13, 1992) was an outstanding conference. It was well organized; the speakers presented an excellent selection of the latest results; and applications spanned an impressive range of science and technology. I know of no other field of modern mathematics where the interaction between applications and theory is so rich. This report reviews the high points of some of the latest results.

Toulouse '92 is properly considered the third conference of a series. The first two were the First International Wavelets Conference, Marseille, December 1987, and the Second International Wavelet Conference, Marseille, June 1989. Proceedings of these conferences are noted as Refs. 1 and 2; proceedings from Toulouse '92 will also be published.

By my count, there were 12 invited talks (each 1-1/2 hour), 59 shorter talks, and 30 posters. The shorter talks (25 to 50 minutes) were divided into: Industrial Applications, Medical Applications, Earth and Universe Sciences, Fractals and Turbulence, Signals and Images, Statistics, Wavelets and Multiresolution, Coding, and Mathematical Physics.

With proceedings promised, I will limit myself to a selection of notes and comments, mostly—but not exclusively—about the invited talks.

INVITED TALKS

Alex Grossmann and Yves Meyer

I had looked forward to meeting and hearing J. Morlet, who was scheduled to give the opening talk, "Les ondelettes ont déjà 10 ans!" Regretfully, illness prevented Morlet's attendance. Our disappointment was compensated by a pair of talks on the history of wavelets: the first by Alex Grossmann (in English) and the second by Yves Meyer (in French).

Grossmann told us about Morlet's early work, noting that in 1963 he was the first person in Europe to organize a system of numerical treatment for seismic data. Later, the Fast Fourier Transform became the analytic method of choice, but its inadequacies in this context are well-known. The precise problem that led to wavelets was the problem Morlet faced in trying to "separate" the different scales in a returned seismic signal. This was a signal that originated as a "wavelet" and had then traveled through a complex dispersive media. R. Balian referred Jean Morlet to Alex Grossmann because Grossmann worked at "unraveling" things in phase space.

At this point, Grossmann turned the floor over to Yves Meyer, who began by pointing out the contributions of Grossmann and Morlet. As he does in his latest book,[3] Meyer noted that by rediscovering Calderón's identity, Grossmann and Morlet gave it new life and a new interpretation in terms of coherent quantum states. He also mentioned the contribution Grossmann and Morlet made by suggesting that wavelets might be useful for analyzing nonstationary signals. Meyer went on to comment on a broad range of wavelet topics and history. Following Benoit Mandelbrot, he mentioned the complexity of the world and the need for tools to describe it. The point is that wavelets help us *describe* things rather than explain or interpret them. He mentioned briefly the mathematical pathways, beginning with Haar in 1909, that have led to what we now call wavelet theory. Meyer emphasized the role of signal processing in this history, particularly Galand's work on quadrature mirror filters. Wavelets and multifractal objects, and wavelets and numerical analysis were also mentioned. Meyer concluded with remarks on "beyond wavelets": optimal development of a signal in the time-frequency plane, optimal development of a signal in time-frequency "atoms," and wavelet packets.

Bruno Torresani

Bruno Torresani talked on "Some aspects of continuous wavelets." This was a review of the time-frequency (or position-momentum) aspects of the continuous wavelet transform. It focused on the issue of measuring local frequencies of signals. Torresani reviewed the 1-D case, including the "Ridge and Skeleton" method. He discussed the wavelets of R. Murenzi in connection with the 2-D generalizations of the "Ridge and Skeleton" methods, in which case the "ridge" becomes a surface. The last part of the talk concerned the bandwidth problem, the need to adapt the bandwidth of the analyzing "wavelet." For this Torresani introduced a family of analyzing functions that blend (interpolate) wavelets and Gabor functions. The new analyzing function is the product of the continuous wavelet $W(a,b)$ and a complex exponential exp $[iw(x - b)]$, with the additional condition that the scale parameter a is a function of the frequency w, that is, $a = f(w)$. This seems to be an interesting general formalism. Although results were only sketched, is seems clear that reasonable assumptions on the function f will yield results on the analysis and synthesis operators.

David Donoho

In his talk, "Restoration of noisy images and inverse problems," Donoho described work that he and Ian Johnstone have been doing on solving linear inverse problems by using their Wavelet-Vaguelette Decomposition (WVD). The WVD is an alternative to the Singular Value Decomposition (SVD) for a class of inverse problems. This class includes numerical differentiation, Able-type transforms, certain convolution transforms, and the Radon transform. Donoho outlined the WVD method and compared it to SVD. He pointed out that the SVD optimality theory, which is based on stochastic arguments, excludes (as having measure zero) some of the most interesting practical problems. He illustrated the WVD method with some examples (integration, the Radon transform). Donoho mentioned that, theoretically, the nonlinear WVD method achieves faster rates of convergence than the SVD method in the case of recovering spatially inhomogeneous objects. David Donoho is conservative in his claims for the WVD method, and I have not heard him say that it is always better than traditional schemes. However, from what I have seen, I would strongly encourage anyone doing inverse problems to take a serious look at the WVD decomposition.

Patrick Flandrin

Flandrin's talk, "Analyses temp-échelle et processus autosimilaires," was an overview of his and other's work on using wavelet transforms to study self-similar stochastic processes, the characteristics of locally self-similar structures, and the time dependence of the scaling laws for these objects. Flandrin used fractional Brownian motion (Fbm) to illustrate these ideas. In previous work, he had expanded Fbm in a wavelet basis and analyzed the correlation properties of the wavelet coefficients

$$d_j[n] = 2^{-j/2}\int_{-\infty}^{+\infty} B_H(t)\psi(2^{-j} - n)dt,\ j,\ n \in \mathrm{Z}.$$

Here, H is the familiar parameter $0 < H < 1$ for the Gaussian zero-mean nonstationary stochastic process $B_H(t)$. When $H = 1/2$, B_H is ordinary Brownian motion. Flandrin's analysis showed how the correlation $E(d_j[n],\ d_k[m])$ depends on $H,\ j,\ k,\ m,\ n$ and the number of vanishing moments of the wavelet.[4] Two developments in this field should be mentioned: At the end of Flandrin's talk, Yves Meyer said that Guy Ruckebusch had found an expansion for fBm in a bi-orthogonal wavelet basis that gave decorrelated coefficients. (I have not seen this work.) Albert Benassi and Stephane Jaffard have a similar result as a special case of a more general theory. They expand the process in an (ordinary) orthonormal wavelet basis for a Hilbert space associated with the process.

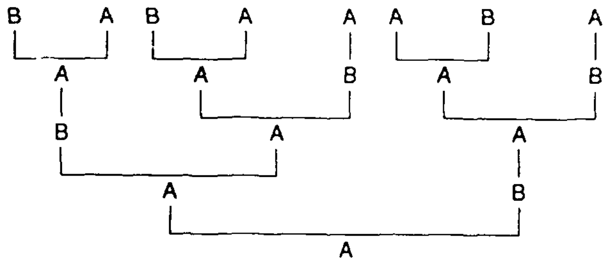
Alain Arnéodo

I am not sure which title Arnéodo used for this talk: the one in the abstracts, "Uncovering Fibonacci sequences in the quasi-fractal morphology of DLA clusters with wavelets," or the one I have in my notes, "Toward a statistical thermodynamics of Laplacian fractals." Both titles contain key words, which will be explained. The motivation is to understand fractal growth phenomena in certain physical and chemical systems, like viscous fingering and electrochemical deposition.

These are too hard to attack directly so a common limiting case, the Stefan problem, is examined instead. This is a diffusion problem (for the pressure or electrochemical potential), with boundary values specified by a moving interface whose local velocity is determined by the normal gradient of the Laplace field. The direct solution of this problem is still too hard. An alternative, and the one studied by Arnéodo and his group, is to simulate the diffusion-limited aggregation (DLA) model introduced by Witten and Sander. Computer simulations of the DLA model generate delicate tree-like structures radiating from the initial center-point attractor. Here again, despite the simple rules governing the simulation, the DLA model remains largely a mystery. Is there order hidden in the seemingly disordered DLA structure? Is the complex geometry of DLA clusters due to the randomness in the growth process? Or is it due to the proliferation of deterministic tip-splitting instabilities?

Arnéodo and his group have subjected the DLA clusters to extensive analysis by using the wavelet transform as the analyzing instrument. The first result is the existence of an intrinsic five-fold symmetry that governs the branching. Not all branching angles are 36 degrees, but the histogram of screening angles at bifurcations as represented in the wavelet transform have a definite, single maximum at about 36 degrees. This observation is corroborated by a statistical analysis of DLA growth in different geometries, for example, in linear and sector-shaped cells.

The next result, again revealed by wavelet analysis, is the existence of Fibonacci sequences associated with the branching process. This is hard to see without a picture, but imagine the following: At a given scale, the wavelet transform yields a picture of the branching (of a "dead" section) of the process. This picture looks like a flat, 2-dimensional tree. Label the "branch points" A or B depending on whether it really branches (an A) or it is does not branch (a B). A typical section looks like this. Not all sections look like this, but they do look like this statistically.



The number of branches at each level, counting from the bottom, are 1, 2, 3, 5, 8, ..., and this is the Fibonacci sequence. The ratio of the terms in this sequence tends to $(1 + \sqrt{5})/2 = 1.618 \ldots$, which is the golden mean.

Arnéodo and his group have confirmed that the generalized fractional dimensions are equal to the fractional dimension which, by various means, has been measured to be 1.60 ± 0.02. This is very close to the golden mean and, in fact, Arnéodo has conjectured that they are equal.

The point of all this is that there seems to be a relation (as yet unexplained physically) between the five-fold symmetry and the Fibonacci branching in these processes. Furthermore, Arnéodo has proposed interpreting the geometry of DLA clusters as a "quasifractal" architecture. Conceptually, this architecture lies between the well-ordered fractal structure of snowflakes and the disorder of random aggregates. This notion of "quasifractal" is offered in the same spirit as the recent notion of "quasicrystals" in solid state physics.

Victor Wickerhauser

Wickerhauser's talk, "Computation with adapted time-frequency atoms," had three parts: periodized wavelet packets, image compression, and matrix sparsification. The work on periodized wavelet packets will appear shortly in *C.R. Académie des Sciences*. In this section, Wickerhauser described a decomposition of $L^2(R)$ into an orthogonal direct sum of copies of $L^2(T)$. This decomposition (actually a whole class of decompositions) maps smooth signals into smooth periodic signals. By using a different arrangement of the same operators, a smooth periodic function (smooth periodic basis) is transformed into a smooth, compactly supported function (smooth, compactly supported basis). A key ingredient for these decompositions is the "local cosine trick" that has appeared in the work of Malvar (1990) and Coifman and Meyer (1991). Recall that this involves a smooth function $b(t)$ that increases from 0 to 1 on $[-1, 1]$, is 0 for $t < -1$ and 1 for $t > 1$, and has the property that $|b(t)|^2 + |b(-t)|^2 = 1$ for t in $[-1, 1]$. By using b, Wickerhauser defines the folding operator U (around the point $t = 0$) by

$$Uf(t) = b(t)f(t) + b(-t)f(-t), \text{ if } t \geq 0,$$
$$Uf(t) = b(-t)f(t) - b(t)f(-t), \text{ if } t < 0.$$

The adjoint of U is defined by

$$U^*f(t) = \overline{b(t)}f(t) - \overline{b(-t)}f(-t), \text{ if } t \geq 0,$$
$$U^*f(t) = \overline{b(-t)}f(t) + \overline{b(t)}f(-t), \text{ if } t < 0.$$

Then, $U^*U = UU^* = I$ since

$$|b(t)|^2 + |b(-t)|^2 = 1.$$

These may be the ingredients, but it is the clever way that Wickerhauser puts them together that makes it all work. In particular, going from a smooth function to smooth periodic functions involves segmentation, two foldings, restriction, periodization, and unfolding (U^*). It is this last operation that puts it all together.

Note that this construction does not give wavelets on an interval, in the way that this problem has been approached (and solved) by Y. Meyer, A. Cohen, I. Daubechies, B. Jawerth, and others.

Wickerhauser listed the following applications for his constructions:

- Segment a smooth acoustic signal into smooth periodic pieces without introducing artifacts or redundancy. This allows more efficient transform coding.

- Use periodized wavelet packets for local best-basis expansions.

- Construct smooth orthonormal "windowed" Fourier bases in spite of "Balian-Low."

- Use the coherent signal extraction (or "denoising") algorithm of Coifman, Mallat et al., on smooth periodic segments of a signal. This allows "local" denoising.

- Construct smooth, compactly supported orthonormal bases on certain smooth manifolds.

In the second part of his talk, Wickerhauser presented highlights from the Yale-FBI fingerprint saga. This must be counted as one of the true wavelet success stories; here is a very condensed version. The FBI is faced with storing a huge amount of data in the form of fingerprints. In addition, they wish to code fingerprints, to transmit them to offices around the country (and the world), to reconstruct the fingerprint image by using desktop computers, and to have an image that is good enough to be identified by an expert. Yale and the FBI have shown that this task can be done, with a compression ratio of 20 to 1, using a wavelet-based approach. To achieve this result, it was necessary to seek a "joint best-basis" by examining the best-basis for many fingerprints and creating a "hand-tuned" algorithm.

In the last part of his talk, Wickerhauser showed how adapted image compression algorithms give new matrix sparsification algorithms. This is a continuation of the now-famous Beylkin-Coifman-Rokhlin work on fast wavelet transforms and numerical algorithms and a contribution to the theme that says image compression equals matrix sparsification.

Nadine Aubry

Nadine Aubry is at the Levich Institute for Physico-Chemical Hydrodynamics, City College of the City University of New York. Her talk, "Spatio-temporal affine groups in turbulence," dealt with work done jointly with R. Guyonnet, R. Lima, and W. Lian. The following is paraphrased form Aubry's abstract.

She used the space-time scaling invariance of the Navier-Stokes equations, in the limit of infinite Reynolds number, to derive the spatio-temporal structure of fully developed turbulence in the homogeneous and inhomogeneous, incompressible and compressible cases. This structure consists of a hierarchy of spatial and temporal modes that are related to each other through a dilation-translation symmetry group. The analysis uses bi-orthogonal decompositions that decompose the flow into spatial and temporal modes, which are in one-to one correspondence (by means of a dispersion relation $U\varphi_n = A_n\psi_n$; φ_n, ψ_n being the bi-orthogonal basis). This analysis permits the derivation of spectrum laws that coincide with Kolmogorov's $k^{-5/3}$ power law when the flow is homogeneous and incompressible.

Ingrid Daubechies

Ingrid Daubechies spoke on "Wavelet bases on the interval and fast algorithms." This is joint work with A. Cohen and others that will appear in Ref. 5. An outline of earlier work on this problem can be found on the last few pages her new book.[6] The issue here is that one would like to have all of the structure (multiresolution analysis, efficient algorithms, wavelet coefficients reflecting function behavior, etc.) that exists for the whole real line carry over to the finite interval $[0,1]$. If you are content with the Haar basis and L^2-theory, all is well. But (modern) wavelet analysis is, among other things, about having "good" bases for other function spaces. In her talk, Daubechies first showed that naive approaches, like restricting the analyzed function to $[0,1]$ and setting it to 0 outside this interval, fail completely. This, and the slightly less naive idea of periodizing the function or the analyzing wavelets, introduce discontinuities, and these discontinuities produce large coefficients at fine scales.

The first successful attack on this problem was made by Yves Meyer.[7] This is complex business (Ref. 7 is more than 15 pages long, and Meyer is hardly known for being long-winded), so I will give only brief hints at how things go.

To fix ideas we work on $[0, \infty]$, where we deal with only one end point. Let φ be the scaling function for an analysis on $[-\infty, \infty]$, and let $\varphi_{j,k}$ be the basis functions for the subspaces V_j of the standard multiresolution analysis. Suppose that φ has support $[0, 2N - 1]$. Meyer's construction goes like this: Define the functions $\tilde{\varphi}_{j,k}(x) = \varphi_{j,k}(x)$ for $x \geq 0$ and 0 otherwise; define $\tilde{V}_j$ as the closed span of the $\tilde{\varphi}_{j,k}$. The functions $\tilde{\varphi}_{j,k}$ are 0 for $k \leq -2N + 1$, and $\tilde{\varphi}_{j,k} = \varphi_{j,k}$ for $k \geq 0$. Thus the only new functions that are actually cut off at 0 are the $\tilde{\varphi}_{j,k}$ for $k = -1, -2, \ldots, -(2N-2)$. The fact that make this construction works (and which was very difficult to establish originally) is that these $\tilde{\varphi}_{j,k}$ for $k = -1, -2, \ldots, -(2N-2)$ are independent of each other and of the $\tilde{\varphi}_{j,k}(x) = \varphi_{j,k}(x)$ f or $x \geq 0$. Having established this, it is possible to orthonormalize the $\tilde{\varphi}$, define the spaces $\tilde{W}_{j,k}$, and define the corresponding wavelets. The wonderful thing about this construction is that is does the job: The bases that fall out are not only bases for $L^2[0, \infty)$ but they are also unconditional bases for the Hölder spaces restricted to $[0, \infty)$, and this includes the coefficients properly reflecting the behavior of the analyzed function at the boundary.

Ingrid Daubechies and her collaborators have a different construction, which also does the job, and more. Again, she keeps the "interior" functions $\varphi_{j,k}$, $k \geq 0$ and constructs "edge" functions so that they, along with the interior functions, span the polynomials up to a degree $N - 1$. The process moves from polynomials to vanishing moments, and on to the construction of spaces $\tilde{V}_j$ and the whole multiresolution analysis. A key point is that this construction involves only N "edge" functions, whereas Meyer's construction involves $2N - 2$. This has implications for computing the filter coefficients for applications.

The applications for "wavelet on the interval" include image processing, adaptive time-frequency tiling, wavelet packets on the interval, and numerical analysis. To merely list these is a bit of an understatement, for I believe these ideas will find widespread application—fully as rich as we see today for other parts of wavelet analysis—once they have filtered down to engineering practice.

Stephane Mallat

Mallat talked about work he has done with Zhifeng Zhang, which is published in a paper entitled "Local time/frequency multilayer orthogonal transforms." The problem (an old one dealt with by Gabor, Ville, and others) is to provide a decomposition for a signal that is well adapted to detect and localize transient phenomena. The difficulty increases with the proliferation of very different kinds of local behavior. Detecting and characterizing transients is closely related to decomposing the signal into waveforms or "atoms" that have a "tight" energy distribution in the time-frequency plane. Mallat described a nonlinear process that decomposes a signal into atoms in such a way that the total energy of the signal is equal to the sum of the energy of the individual terms. Of course this is to be expected for a linear transform with orthogonal atoms, but in this case the atoms are not orthogonal. The ingredients are a Hilbert space H and a "dictionary" of unit vectors e_i, $i \in I$, that are dense. Think of H as $L^2(R)$ and the e_i as the Gabor functions

$$g_{s,u,a}(x) = \frac{1}{\sqrt{s}}\, g\left[\frac{x-u}{s}\right] e^{iax},$$

where g is the Gaussian. These functions are well localized in time and frequency. The trick is to choose atoms among this continuum that "best" represent a function f in $L^2(R)$. The nonlinear algorithm Mallat described does this in a sequence of steps that preserves energy. At each step, the energy of f squared ($\|f\|^2$) is equal to the sum of the squares of the terms already chosen plus the energy in the "remainder." The numerical results for a complex function (different behavior at different places) were very impressive.

Ronald Coifman

Coifman reviewed wavelet packets and best-basis analysis in "Adapted waveform and wavelet packet analysis." He described how, from the first days of wavelet research, the Yale team (in collaboration with Meyer and others) had realized the shortcomings of windowed Fourier transforms and wavelets, and how this led via quadrature mirror filters to wavelet packets. Unfortunately, despite the flush of initial enthusiasm, wavelet packets were not well localized at high frequencies, and so the search for bases that were better localized continued. In this connection, Coifman described the local basis with smooth windows of the form

$$w(x)\sin[(k + 1/2)(x - a)/L],$$

where window functions w, v have the now-familiar property that $|v(x)|^2 + |w(x)|^2 = 1$ where they overlap. Then for two adjacent windows, A and B, with $A + B = C$, it turns out that the span of functions in A plus the span of functions in B is equal to the span of functions in C. This being the case, it is possible to have an algorithm that picks the "most efficient" combination of windows. This and schemes described by Mallat and others are leading to a set of algorithms that look, in outline, like this: Start with a large collection of orthonormal bases, one that is rich enough to match all the types of "transient" behavior you expect to encounter. Then represent different "pieces" (both time pieces and frequency pieces) of the function being analyzed in terms of different basis elements, where the choice is governed by some nonlinear criterion, typically involving entropy or energy, or perhaps a min-max criterion from decision theory.

Gregory Beylkin

Beylkin was touted to speak about "Multiresolution representations using the autocorrelation functions of compactly supported wavelets," work which he has done with Naoki Saito. This work has some elegant theoretical aspects, and it would have been nice to hear a live exposition. Although the dilations and translations of these autocorrelation functions do not form an orthonormal basis, this analysis is shift-invariant, the analyzing functions are symmetric, there is a reconstruction algorithm, and there is a noniterative reconstruction from zero-crossings and slopes. I hope that the proceedings will contain a paper on this.

Beylkin did speak about "Fast algorithms for multiplication of functions in a wavelet basis," showing why, if you want to take a large inner product, it is better to do it in a wavelet basis.

BRIEFLY MENTIONED

There were so many interesting papers on such a broad range of topics that the most I can do here is to whet your appetite for the proceedings. I'll just skip through the talks that, for one reason or another, caught my attention.

J.-M. Morel, of image processing fame, spoke about the application of wavelets to the mathematics of economics and finance, which is a field of research mentioned in the CNRS (Centre National de la Recherche Scientifique—National Center for Scientific Research, France) Strategic Plan for 1991-1993.

The talks on medical applications included reports about wavelet analyses of mammograms, EEGs, and cardiac potentials and multiscale reconstruction of tomographic images.

A paper by G.G. Walter and G. Davida described the use of wavelets for encryption. One can only speculate on how far this technology has actually been developed.

Astronomy was well represented by the people from the Nice Observatory (A. Bijaoui, E. Slezak, P. Bury) and by the folks from the Observatoire Midi-Pyrenees (A. Lannes, S. Roques, and others). The subjects ranged from the galactic structure to satellite image restoration.

Other topics in the Earth and Universe Sciences included atmospheric turbulence, analysis of satellite images with applications to geology, and numerical models of the Gulf Stream. There was a poster on the study of the Himalayan relief with wavelets, and there was one on the relationship between interseasonal variations of the length of day and the El Nino events using the wavelet transform.

Cormac Herley gave the latest report on the work he and Martin Vetterli have done on wavelets and filter banks. From what I have seen, they have explored every conceivable relation between these two constructs: think of a property for filter banks and they will tell you how it is reflected in the associated wavelets, and conversely.

The work on multiscale stochastic models by Benveniste and Willsky was presented, as was the latest work by Istas and Laredo. The stochastics section was rounded out with Benassi's presentation of the work he has done (with Jaffard and Roux), which, among other things, generalizes the famous results of Levy and Kahane on Brownian motion.

Gerald Kaiser presented work that he and R.F. Streater have done on what they call the "Analytic-Signal transform" (AST). This work originated in relativistic quantum mechanics, where it involves extending functions from R^n to C^n in a semi-analytic way. The AST and its generalizations reduce to continuous wavelet transforms in dimension 1, while in the general case they retain properties of the wavelet transform.

Finally, I wish to note again the work of Pascal Auscher and Philippe Tchamitchian on differential operators. They are tackling some hard, long-standing problems by using wavelet-based techniques and ideas. I'll not discuss the details of this work, but I will use this, or more precisely, a couple of Auscher's comments to introduce an idea and the closing remarks by Yves Meyer.

Auscher notes in discussing the work on differential operators that "the usual wavelets are ineffective, and it is necessary to modify them by adapting them to the operator." This reminded me of a passing comment Pascal made to me last March when we were at Stéphane Jaffard's habilitation. He said something like, "Wavelets are dead, but using them often leads us to the heart of the problem." I'm sure this is not quoted correctly, it may have been, "Wavelets don't work, but..." In any case, the idea is clear: wavelets may not solve the problem, but by "trying wavelets" new ideas are being uncovered and progress is being made.

YVES MEYER—CONCLUSIONS AND PROSPECTS

Meyer began by noting that wavelets had become fashionable for both right and wrong reasons, the wrong one being that these techniques could "solve any problem." He then emphasized the theme that wavelet tools were often leading us to the "true difficulty," and that one of the successes had been in clarifying problems. (I suggest that Auscher's work is an example.) He continued by suggesting that in addition to giving pointers to difficulties, wavelets had inspired new problems and new viewpoints. He cited the work of Benveniste and Willsky as an example.

In another direction, Meyer spoke of the trend to "rebuild and reshape the wavelet" and to "make the wavelet fit" the problem, inside the multiresolution framework. He cited the work on unfolding signals, the ridge/skeleton algorithms, and the Yale work on packets and best basis.

Meyer ended by emphasizing the importance of both using and checking the new ideas and algorithms that had been presented at this meeting. He said that these must be carefully checked to discover their strengths and limitations. He praised the strong interdisciplinary nature of the community and, as on other occasions, noted the very productive feedback in both directions between theory and applications.

Finally, said that we should wait 2 years before having the next conference. The point being that he felt that it would take that long to properly test all the ideas currently in the air.

MY COMMENTS

I certainly subscribe to the notion that "wavelet research," interpreted broadly and liberally, is leading to a wealth of both applied and theoretical results. I count the fact that wavelet theory (as we know it today) has unified and interpreted so much mathematics (and signal processing), going back to Fourier (1807) and Haar (1909) and continuing right through the results presented at Toulouse '92, as a pure success. Wavelet theory is not the "polywater of mathematics," as was once suggested to me.

But wavelet research has an almost unique position in modern mathematics: I know of no other field where the interplay between applications (real and potential) and theory is so rich. And this is a new phenomenon that did not exist when Grossmann and Morlet did their original work. The interest in applications (and perhaps the economic aspect of some applications) lend a spicy (if not unique) dimension to wavelet research. Following Yves Meyer, I would encourage the community to resist any moves that might tend to split this eclectic community.

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Computer Science

NATO Advanced Research Workshop—Cognitive Models and Intelligent Environments for Learning Programming

by Albert T. Corbett, Department of Psychology, Carnegie-Mellon University, Pittsburg, Pennsylvania

KEYWORDS: Abstraction; writing code; retrieval mechanism; debugging; goal poster

THE MEETING

The NATO Advanced Research Workshop on Cognitive Models and Intelligent Environments for Learning Programming provided a representative cross section of research in the field. The workshop was held in Santa Margherita, Ligure, Italy, March 17-21, 1992.

This report briefly describes the topics raised in the presentations. A collection of the workshop papers is being published by Springer-Verlag under the NATO Advanced Science Institute Series, Subseries F: Computer and Systems Sciences. Enrica Lemut, who organized the workshop, is the editor. Professor Lemut can be reached at:

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PROGRAMMING

Perhaps the chief point of consensus is a growing appreciation of the complexity of the cognitive processes involved in learning to program. Programming can, of course, be decomposed into three major subskills: comprehension, generation, and testing/debugging. However, a number of talks focused on a further analysis of these skills.

The task of writing code, for example, can be decomposed into multiple phases, essentially problem representation, design, implementation, and maintenance. A consequence that follows is that different students may be working in different problem spaces. In programming a solution to a real-world problem, the student may opt to solve the problem in the real-world domain and translate to the programming domain, or translate the real world given to the programming domain and then solve the problem.

This complicates the task of cognitive modeling, although a unified cognitive model is being developed. Moreover, the nature of each subtask may vary in subtle ways. For example, the nature of code comprehension processes depends on whether the programmer is trying to understand code that is assumed to be correct or assumed to be buggy.

ABSTRACTION

A recurring and problematic issue in the workshop is that of abstraction, as exemplified by the distinction between design and implementation. This distinction assumes that students can plan programs in an abstract space and translate them into a specific language.

Novices, in particular, may have an impoverished cognitive design space, however. Novices face the simultaneous tasks of learning the syntax of a language, a model of the notional machine reflected in part by this syntax, algorithm design, and (for that matter) a general understanding of what programming is.

As a result, programming knowledge is likely to be tied closely to the programming language in which it is couched, rather than in an abstract planning space. It was argued that there is no psychological reality to abstract plans. As a result, the structure of the language may have a substantial impact on students' cognitive activities. The issue of abstraction was also addressed in relation to data structures, code debugging, and reasoning by analogy. An explanation-based retrieval mechanism for retrieving analogous examples during problem solving was described. This mechanism, developed for an intelligent tutoring system, performed slightly better than ARCS (analog retrieval by constraint satisfaction) models in retrieving structurally appropriate analogs.

In debugging, abstract code evaluation (essentially proof of program correctness) can be contrasted with pragmatic evaluation (identifying and trying critical test cases). There may be fundamental individual differences paralleling this contrast, between students who think relationally (in terms of static formalisms) and those who think functionally (in terms of dynamic operations).

In learning to program, the student needs to develop both a model of the programming environment and cognitive processes for manipulating the environment. Since these are both unobservable constructs, a recurrent concern in the field is reification of the notional machine and program behavior and of cognitive processes. The intrinsic difficulty in each case is that the student is required to learn a second formalism (the reification) in addition to the primary formalism (the programming language).

COGNITIVE PROCESSES

This is particularly problematic in the case of cognitive processes, since the student is typically required to both generate and comprehend the formalism in order to specify goals, plans, state, etc. A system was described that attempts to reify goal states while avoiding the generation problem. Instead of requiring the student to post goals, the system posts its interpretation of the student's goals as the student generates code.

This goal poster represents implicit feedback, since uninterpretable (and unpromising) actions map into general (vague) goals, and provides a structure the student can actively explore. It will be interesting to see whether students use this goal information to construct an organized understanding of the problem-solving episode.

The issue of transfer will also be interesting, since it seems possible that students may adapt their problem-solving behavior to use goal poster cues that are not ordinarily present in the programming environment.

APPROACHES

Workshop presentations reflected two longstanding characteristics of the field. First, although a general consensus exists on the complexity of cognitive processes in learning to program, a traditional diversity of opinion remains on how to structure learning environments to foster learning. There are two general approaches to the complexity of learning to program.

One approach, particularly strong in England, emphasizes the traditional human-computer interaction (HCI) approach of putting development effort into the interface and fostering discovery learning. It recognizes both the difficulties of student modeling and the importance of students exercising control over learning and the development of metacognitive skills.

The other approach emphasizes the traditional intelligent learning system(s) (ITS) of tailoring instruction to the individual student. The efforts in this workshop tended to emphasize intention-based diagnosis for the sake of individualized feedback.

Only two of the systems described maintain a model of the individual student, allowing curriculum as well as feedback to be tuned to the individual student. Of course, a correlation does not need to exist between interface optimization or even cognitive modeling and pedagogical strategy. Nor does a sharp dichotomy need to exist between discovery learning and traditional tutoring. Some researchers are pursuing both. An interesting challenge for a tutoring approach is to bring tutoring techniques to bear on metacognition.

Empirical evaluation of the systems is still insufficient. A variety of talks presented empirical data on students learning to program and many described computer-based learning environments, but only a handful described empirical evaluations of learning environments.

CONCLUSIONS

The issues raised during this conference were generally familiar ones from the last five years of research in learning to program, and I wouldn't characterize any of the presentations as revolutionary breakthroughs. Rather the workshop reflected a healthy, evolving field. Healthy, in that there seemed to be a general consensus on the nature of learning to program, but a diversity of ideas on how to structure environments to foster this process.

Engineering

The 37th ASME International Gas Turbine and Aeroengine Congress and Exposition

by Robert J. Hansen, Applied Research Laboratory, Professors A.H. Epstein, E.M. Greitzer, and B. Lakshminarayana of The Pennsylvania State University.

KEYWORDS: turbomachinery; active control; machine diagnostics; monitoring; cost/benefit analysis

THE MEETING

Each year, the American Society of Mechanical Engineers (ASME) International Gas Turbine Institute sponsors a major congress and exposition for the exchange of information on research, development, design, manufacture, and operation of gas turbines and related equipment. The 1992 meeting, held in Cologne, 1-4 June 1992, was the largest in the history of the International Gas Turbine Institute, both in terms of number of technical papers presented (439) and exhibitors participating in the exposition (228).

On the evening preceding the Congress and Exposition, an awards banquet was held honoring the authors of the best papers published by ASME in the gas turbine area during 1991. The work reported in one of these papers, "Active Control of Rotating Stall in a Low Speed Compressor," by Prof. J. Paduano et al. of the Massachusetts Institute of Technology (MIT) Gas Turbine Laboratory was supported as part of the Office of Naval Research program on active control of complex physical systems.

ACTIVE CONTROL

The area of active control continues to be of interest in the turbine engine community. Particularly noteworthy were the papers by Ffowcs Williams et al. of Cambridge University and Simon et al. of MIT. The former reported the demonstration of active control of surge in a small working engine; the latter gave a new methodology for quantifying the performance of alternative approaches to active control in a gas turbine engine. More generally, as described in an overview of the subject of active control given by the present author, it is now clear that active control can be successfully used to favorably impact surge, rotating stall, and combustion efficiency at laboratory scale. A primary issue in scale up for applications will be achieving improved control authority by the combined use of better active elements and better control algorithms.

AFFORDABILITY AND MAINTAINABILITY

One major theme of this year's meeting was enhanced affordability and maintainability of gas turbine equipment through manufacturing processes, materials, and diagnostic techniques. Harman Lanser of KLM reported the use of engine-condition monitoring, particularly exceedances in exit-gas turbine temperatures, to monitor high-pressure turbine blade damage in one class of commercial aircraft. Before initiating this program, the percentage of engines in this class that had to be removed at regularly scheduled shop visits by KLM aircraft had climbed to 30. Condition monitoring reduced this percentage to less than 10.

CONDITION MONITORING

J. Jakobson of Phillips Petroleum Norway described condition monitoring of large turbines on North Sea platforms. A satellite link is used to transmit the data being gathered to a central site for analysis and action as warranted. This capability has proved critical for effective North Sea operation. P. Nayaf of Dow reported the positive results realized from implementing condition monitoring on both large and small machines. Of particular interest is the cost/benefit analysis of their recent experience with small machines: the cost to implement condition monitoring represented 28 percent of the estimated first-year savings in maintenance, and the operation of the monitoring system cost only 5 percent of the estimated annual savings on an annual basis.

Although the experiences of users to date are encouraging, the need for prognostic rather than diagnostic capability was identified. More specifically, they would like to see the development of improved modeling to provide information that would complement that from sensors, improved sensors, and improved decision-making capabilities.

EMISSIONS REDUCTION

Another topic of increasing importance addressed by a number of papers is the reduction of NO_x emissions from aircraft engines. One example was the work reported by Sturgess et al. of United Technologies, in which a new combustor design methodology was described for reducing NO_x emissions while keeping that of other pollutants (e.g., carbon monoxide and unburned carbons) suitably low as well. The methodology combines measurements of emissions from an experimental engine and computational fluid dynamic results to optimally modify the combustor stoichiometry distribution. Worthwhile NO_x emission reductions were accomplished with minimal impact on combustion section pressure loss and combustor outlet temperature distribution.

TRANSFER PHENOMENA

A number of benchmark-quality experimental studies of the complex fluid dynamic and heat transfer phenomena associated with compressor and turbine flows were reported. For example, Manwaring and Wisler of GE Aircraft Engines described an experimental study of the unsteady pressure imposed on turbine blades by incoming gusts. The data pointed out deficiencies in classical linearized treatments of this problem but showed the ability of Euler code predictions to capture the forces imposed on the blades. Stauter of United Technologies Research Center reported comprehensive LDV measurements in the tip region of compressors, with the somewhat surprising result that a clearly defined leakage vortex does not exist.

Prato and Lakshminarayana of Penn State University reported experiments on the relationship of wake structure to blade loading, finding a substantial effect of blade loading only in the near wake structure. Abhari and Epstein of MIT made time-resolved measurements of heat transfer in a short-duration, transonic turbine facility. Film cooling was shown to have a large effect on the time-averaged heat transfer from the blade suction surface but relatively little effect on that from the pressure surface.

A transient facility was also used by Dietz and Ainsworth at Oxford to make detailed measurements of the unsteady pressure on the surfaces of a rotating turbine blade. The high spatial density semiconductor transducer arrays mounted on the blade permitted detailed measurements of unsteady wave propagation, allowing distinctions to be drawn between phenomena propagating at fluid flow and at acoustic velocities. This data set will be particularly helpful in testing predictions of compressibility effects made with various computational and analytical methods.

NEW METHODS

Finally, the conference included a number of new methods for and applications of computational fluid dynamics to turbomachinery. Dawes of Cambridge University reported the adaptation to turbomachinery flows of an adaptive grid technique that has already been successfully used by NASA Ames for external flows. Kunz and Lakshminarayana of Penn State described a new embedded grid technique that they used with both Navier-Stokes and Euler solvers to study tip clearance flows.

Choo, Liu, and Rodi of The University of Karlsruhe (Germany) reported improved capability to predict unsteady heat transfer in turbomachinery lows. A team of investigators from Allison Gas Turbines, MIT, and NASA Lewis described the numerical simulation of compressor flows in the presence of casing treatments. They focused on the type of grooved endwall that has achieved marked increases in the stable low range. The simulation was aimed at unraveling the mechanism of casing treatment operation. The paper makes clear that such treatment is successful in suppressing rotating stall for two reasons:

- it introduces suction of the low total pressure, high blockage fluid at the rear of the passage; and
- it energizes the tip leakage flow, particularly in the core of the leakage vortex.

CONCLUSIONS

This conference highlights the continuing attention being given to improved turbomachinery in the United States, the European Community, and the Pacific Rim countries. It shows, as well, the continuing interest in traditional areas of turbomachinery research and development (such as numerical and experimental studies of flow and heat transfer phenomena) and the growing attention to newer areas (such as active control, advanced maintenance methodologies, and pollution control).

PROCEEDINGS

Proceedings of the conference will be available from:

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Manufacturing

Perspectives on Artificial Intelligence in Design

by Daniel E. Whitney, former Liaison Scientist for Manufacturing, Office of Naval Research European Office. Dr. Whitney is at the Charles Stark Draper Laboratory, Inc., Cambridge, Massachusetts.

KEYWORDS: knowledge base; traditional engineering tools; ICAD; mechatronic; Interface Control Document

SUMMARY

This article brings together different views on possible roles, applications, and limitations of Artificial Intelligence (AI) in design. The views described here were given independently and frankly during recent visits to European and United Kingdom (U.K.) research laboratories. The opinions offered were not solicited, and I did not challenge them or ask any speaker to comment on the others'

views. In each case, the views were offered in the context of ongoing projects.

The issues raised are:

- can Artificial Intelligence really contribute significantly to design and, if so, in what way?

- are AI's existing methods adequate, and if not, what improvements are needed or what other methods should be added or substituted?

It can be concluded from what follows that AI is earning a place as a training aid or an expert-simulator that can duplicate what good designers do now on design problems that fall into a previously defined class of a given object. However, new kinds of designs of such objects cannot be tackled. The exact limits of "new" have not been well-defined. Communication between designers and knowledge engineers is weak; the result is that deep knowledge is not obtained. It is possible that the inability to get deep knowledge is a symptom of weakness in basic engineering models rather than or in addition to weakness in the methods of knowledge engineering.

The researchers do not deem existing knowledge representation schemes adequate to capture what designers do. Possible explanations include the fact that designers do not explicitly know and use rules, that their thinking processes are not strictly linear, and that they do not in fact know some basic engineering or perform necessary and feasible analyses. Instead they may copy their own or others' procedures. AI methods may not be able to escape these limitations until they are combined with analytical methods based on first principles.

The article that follows considers three AI-design projects, two at Cranfield Institute of Technology in the U.K. and one at the Technische Universität Aachen. It then offers for comparison some design methods based on first principles of engineering mechanics and thermodynamics.

1. "Regarding knowledge bases and rule chaining for aiding designers, the methods are weak but the knowledge of designers is pretty shallow, so for now the methods are adequate."

This trenchant comment was gleaned from discussions at Cranfield with AI researchers associated with the College of Aeronautics. The AI Unit was formed about two years ago because its members had been so consistently successful at getting both U.K. and European Community (EC) research funds. "There is a lot of money for research in AI applications if you pick the right projects," said Dr. Jaz Saggu. AI has important opportunities in aircraft design, manufacturing system design, and design for manufacture, he says.

The Unit's general approach is to regard AI as creating an environment that contains an array of tools useful to the designer. Some of these will be traditional AI tools, while others will be traditional engineering tools. The designer should be able to apply any tool that is needed without being an expert in its use. AI should also provide a front end with an explanation facility so the designer can see why a decision or recommendation was made. The group does not develop new AI methods and is not committed to one style or approach. Example projects they have worked on include:

- critiquing designs for manufacturability;
- preparing designs for FEM, or recommending which parts of a design should be subjected to FEM;
- designing safety-critical software; and
- structural optimization.

Are existing AI methods and commercial offerings adequate for such applications? Part of the answer was quoted above. In addition, Dr. Saggu cited the problems of linking knowledge engineers and designers. The two clearly talk different languages and lack understanding of each other's fields of expertise. Selling designers on the usefulness of an AI aid is difficult. In addition, tools for helping engineers create their own knowledge and rule bases are very primitive. In his opinion, these factors combine to make the resulting knowledge bases shallow.

The group has tried using the commercial package ICAD. The application was a mechatronic designer's aid that helped arrange components (like motors, gears, bearings) to achieve a function while keeping the total weight down. The methods used included numerical calculations, rules, and constraint processing, together with some geometry. The missing element in ICAD was an explanation facility based on reasoning about the design, which the Unit's researchers had to create.

Saggu also gave his view of the EDID project (see Ref. 1 on the Cranfield Institute of Technology, where Prof. Alan Morris' view is given). This project involves using AI methods to merge two versions of the same design and detect mismatches. Part of the AI component will be to combine two people, a rule base, and an agent to negotiate the mismatches. "Why use an agent?" I asked. "Well," he said, "we want to explore agents; we really don't know if they are good for anything."

The project will also generate a new kind of Interface Control Document (ICD). It will have a hierarchical structure as well as several data classifications or views: geometry of parts, minutes of meetings, lists of mismatches, and so on. The hierarchical tree arrangement will list the systems and subsystems of the item being designed (a communications satellite) and the subcontractors are expected to choose what to work on by making reference to this tree.

2. "AI-design folks think they are in the home stretch providing tools for design."

This equally trenchant remark came from an engineering-oriented researcher at Cranfield who is studying design for assembly by using both AI and other approaches. Mr. Graham Jared is in the School of Industrial and Manufacturing Science at Cranfield. Together with Prof. Ken Swift of the University of Hull, Jared is working on various approaches to design for assembly (DFA). His background is in computer-aided design (CAD) and geometric modeling. Before coming to Cranfield he worked with Ian Braid at Cambridge. (Braid developed the CAD modeler that is the father of ASIS, now commonly used by many research and industrial laboratories.)

Jared apparently bases his opinion of AI in design in part on his experience trying to build rule-based DFA (design for assembly). The work is an outgrowth of Swift's work with Lucas Engineering, a large mechanical engineering company. Swift built a software-based DFA system similar to the famous one made by Prof Boothroyd. Both systems ask the designer a series of questions about each part in a product design (is the part easy to pick up; is it symmetric—thus easy to feed automatically to a robot—and so on). From the answers, the computer computes a score that predicts how long assembly will take or indicates whether the part should be redesigned to make assembly easier. Based on geometric and materials properties, the software can also detect the opportunity to make two adjacent parts into one. This is important because superfluous parts raise cost without much benefit.

Swift found, to his and Lucas' disappointment, that the computerized system did not create results any faster or better than answering the questions with pencil and paper, a result others have found. Also, the method seemed incapable of helping design really new things or of handling situations not anticipated when the questions or scoring method were developed. Finally, they found that the users did not really understand the questions and often answered optimistically when asked to judge ease of assembly. They were not neutral judges but were evaluating their own designs.

So Jared and Swift determined to automate or assist the DFA evaluation process; for this they needed a geometric model and a set of rules and AI methods for doing the evaluation. Some of the required information can be located and identified as features, as long as these are identified in some way. For example, chamfers (bevels) around the rims of holes are known to make peg-hole assembly easier. Checking for the existence of chamfers can be easy if the CAD data are properly organized.[2]

It turns out, however, that they knew only some of the features that would be the "knowledge-carriers" relevant to DFA evaluation. Only some of these are geometric. Other kinds of relevant information do not show up in CAD data bases: smoothness of surfaces or likelihood that there will be oil on the surface during assembly (both fundamental to ease of assembly of rubber seals, for example, or to the likelihood that a person might drop the part), amount of resistance force that might oppose assembly (such as in spring-loaded parts), and so on. Jared and Swift informally estimate that 70 percent of the information needed to fire the DFA rules could be found in properly structured CAD data. They have not yet gotten far in their project, however, so the 70 percent estimate is unverified. They stress the amount of "lore" that they must get out of the designers at Lucas and other participating companies.

In addition, there is a built-in conflict that arises from using CAD as the source of the data for the evaluation: companies would rather have the evaluation done on a concept, not on a fully developed CAD model. Such models take a long time to build and can be hard to revise. No way out of this conflict has been devised. You cannot do geometric reasoning without some geometry or a workable representation of the geometry that contains the necessary information. Defining "necessary information" is the challenge, since some of what we now deduce from geometry might be expressed another way if we knew what it was and how it would be used. An example is the mutual direction of assembly of two parts. This can be deduced by geometric reasoning about the shapes of the mating surfaces. Alternately, the designer can create mating surfaces by picking them out of feature libraries as data objects (pegs, holes, slots, chamfered holes,...). These objects can contain the mating direction as a numerical/text attribute.

So the question is not just whether AI methods can help but also what information must be available before AI methods can contribute to their best advantage. This issue is well illustrated by the problem of implementing more sophisticated part-count-reduction algorithms. The current method of detecting the opportunity to eliminate parts operates by having the designer answer three questions about adjoining part pairs:

- are the parts made of the same material?
- is the method used to join them permanent?
- is there some important reason why it should be possible to separate them after assembly?

If the answers are YES, YES, NO, then the two parts should be considered for consolidation into one. The first two questions can be easily answered from properly structured and augmented CAD data, but the third one requires real knowledge: it concerns the product's function, intended use, failure modes, repair methods, modularity, and so on. The third is, in fact, the only really interesting question, and it is more than just difficult to answer. Like the question of how to choose tolerances, the required knowledge can be said to reflect the entire design process. It is not general knowledge but rather specific information about the product. Is it reasonable to expect future product data models to contain such information?

3. "When we tried to determine the designers' rules for machine tool spindles, we found that there were far too many for an efficient rulebase. The designers could not verbalize many of them. Also, many steps in design do not seem to follow a logical path. So we turned to neural nets instead to capture what the designers were doing."

This comment is an evaluation of the limits of AI methods and indicates a novel use for neural nets as a substitute. It was made by Mr. Baer, a Dr-ing. candidate at the Technische Universität Aachen. He is building an aid for designers of machine tool spindles. A machine tool spindle is a shaft with typically two sets of bearings. At one end is an attachment for the drive motor; at the other end is an attachment for a cutting tool. Both motor and tool apply large loads to the spindle, and both must be taken into account during design.

The design system being developed covers many phases of spindle design, such as basic requirements, types of machining it will do, geometry, choice and placement of bearings, stress analysis, and design evaluation and redesign. The neural net has been built for the evaluation and redesign phase.

Several conventional AI techniques suffice to aid parts of the design process. Rule bases are used to hold information about the amount of friction or types of failure modes of different lubrication methods (grease is stiff and can dry out, but it takes high loads). Design requirements are expressed as fuzzy categories like "the load is high but the speed is low." A set of precalculated decision tables is used to combine the requirements and the rules and to present the designer with a prioritized set of solutions to choose from. "Duplex greased roller bearings are the first choice. Their cost is X."

Other parts of the system use interesting geometry descriptions to put together shaft shapes. Many spindle designs were studied, and characteristic regions were identified: the tool mount end, the step-down from the tool mount to the first bearing region, the bearing regions themselves, and so on. Each region can have a variety of shapes, which are modeled with adjustable parameters. A geometry description language was developed to generate these regions and hook them together. An example statement in this language is "The step is next to the mount. The step is on the same axis as the mount and the first bearing region." A rulebase looks at this description and the requirements and tries to find what type of region should be picked from the available ones in the library. The designer can substitute his own choices if he does not like the computer's.

Evaluation is the step that could not be captured by rules. Two large neural nets are being tried instead. One creates an evaluation while the other suggests design changes. A large number of designs were studied, and designers' revisions of them were recorded. These before-after pairs were used to train the net. Each net has three layers. The evaluation net has about 50 inputs, 30 elements in the hidden layer, and 25 outputs. These 25 plus 125 constraints make up 150 inputs to the second net, which has 80 outputs. Some of the inputs are continuous variables scaled to the interval [-1,1]. Others are logical variables that capture distinct attributes which are coded as discrete numbers like -1, 0, or 1.

This large and ambitious neural net is still under development. Recurring issues are how many hidden layers to use and how many neurons to put in each layer. Too few layers or neurons will cause the net to fail to capture the desired nuances; too many will cause the training session to fail to converge. Neural nets are rare in design software, so there is not much experience to go on.

Taken as a whole, the spindle design aid has occupied Mr. Baer and others for four years. He says it can do well on types of spindles it has "seen" before but not on ones that are new. Variants of standard types are the easiest. It is a great training aid, and it permits a student to design an acceptable spindle in about a day. An experienced designer takes an hour. A designer with 20 years' experience can design a better spindle without the computer aid, however.

COMMENTS

Expert systems appear to be primarily empirical. They are often applied when the developers conclude that there is no hope of an analytical solution. A classic case is that of medical diagnosis. It is clear in this case that the resulting expert system is a model of the doctor, not a model of the sick person. Many expert systems hoping to capture design are similar.

There is no doubt that systematic attempts to model processes bring large rewards. Asking doctors to think about their diagnostic methods revealed an underlying structure that had not been taught explicitly in medical school. Work reported in other articles (about Volvo,[3] for example) shows that trying to model design processes (by AI or other methods) reveals important opportunities for improvement.

It is also worth reconsidering the conclusion that evaluation of spindle designs, for example, cannot be couched in analytical form. What we can tell is that the designers who were questioned did not use analytical methods. This in itself is not really sufficient proof that an analysis is impossible, but only that one has not been attempted, or has not been pursued with enough vigor, or that the designers questioned were not aware of existing or potential analyses.

A counterpoint to AI in design is provided by researchers studying design methodology. Examples include Professor Beitz' systematic design and Prof Nam Suh's design axiomatics. Here I would like to discuss the work of Prof. Michael French of Lancaster University in the U.K. In a recent book[4] he uses a series of examples and first principles in mechanics to bring out a number of considerations that designers often use implicitly. He says that these can be made explicit and, in line with the above argument, can be dealt with analytically. Examples of these design considerations are:

- *Disposition.* The essence of many design problems is to identify a key commodity, such as space or energy, whose allocation dominates the problem. Once the commodity has been identified, the allocation can often be made analytically.

• *Combination or Separation of Functions.* It is often efficient in terms of space or weight to make one item perform several functions. A classic counter-example is James Watt's invention of the separate condenser for steam engines. Prior designs used the piston cylinder as the condenser, making it too hot to be efficient as a condenser and too cold to be efficient as a driving element. A thermodynamic analysis was not available to Watt, but one can be done and the advantage of making the separation can be calculated.

• *Structural Efficiency.* J. C. Maxwell proved that the integral of force times distance over a stressed elastic structure depends only on the pattern of applied loads, not on the geometry of the structure. French calls this integral "pertinacity." Efficient structures have minimum pertinacity, and the designer obtains it generally by maximizing the tensile loads and minimizing the compressive loads inside the structure. Minimizing the pertinacity will reduce the amount of material required to support a given set of loads. The designer will try to reduce the material until every element is stressed to its safe limit. By using first principles, French shows that efficient structures are also stiffer than inefficient ones.

French says in the book's preface that it is likely that good designers create such structures but it is not obvious that they are aware of pertinacity or that they calculate it explicitly. My questions are: If they do not, what do their "rules" for designing structures look like? Could something like pertinacity be deduced from their designs? Is that the right way to discover pertinacity?

CONCLUSIONS

AI methods obviously have a lot to contribute to design. The limitations of AI acting alone are becoming clear, however. They assume a type of thinking process that designers may not use, or may not use exclusively. Designers may not have clear enough or analytical enough views of their work to make rule-based or neural net methods efficient or to permit these methods to innovate in a meaningful way.

For the time being, fruitful approaches appear to combine all of the methods we know of: rules, mathematical and geometric models, extended data models, object-oriented descriptions, calculations, numerical searches, and so on. Only a few laboratories are pursuing such a combined strategy, and none are using a large number of methods together.

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From Functional Specification to Concept Design—Strengths and Weaknesses in Some Current European Approaches

by Daniel E. Whitney

KEYWORDS: computer-aided design; concept design research; data representations; WZL; element modeler

SUMMARY

Most commercial computer-aided design (CAD) is not really design software. Instead, it generally supports either two-dimensional drafting or three-dimensional geometric modeling, with added text representing dimensions, tolerances, process notes, and so on. The most advanced commercial CAD software permits geometry to be parameterized by numerical or symbolic arguments, with some equality and inequality constraints on these variables. However, such software mainly supports creation of geometry at a detailed level and does not directly permit engineering, exploration of rough concepts, or discovery of conflicts and tradeoffs. Moreover, when commercial CAD companies and their customers speak of "concept design," they usually mean exploration of geometric shapes, often rather creative shapes. In other cases they mean exploration of space allocation, typically involving packing components inside a given skin.[1]

Researchers have taken note of these gaps and are trying to create CAD that will help designers explore nongeometric concepts and create rough realizations from loosely stated design goals and required functions. This article reports on several European [including United Kingdom (U.K.)] laboratories that are working in this area. Their approaches include one or more of the following:

- scripts or design procedures that guide the designer from specifications to classes of realizations in terms of known elements
- diagramming methods that permit the designer to hook elements together in different data views
- engineering-oriented approaches that permit the designer to think functionally about groups of predetermined elements, with the computer providing some engineering knowledge or constraints.

Behind all of the research projects reported on here (and most others in this area that the author is aware of) is the assumption that "product design" consists more or less of a set of steps that one engages in and passes through successively, while establishing and refining information. This relatively clean view contrasts sharply with what many in industry actually experience: superimposed on (and often dominating) the set of steps, there occurs sharp conflict, wide gaps between specifications and possible realizations, and a constant struggle to predict future problems and costs, understand the needs of other designers, and so on. No laboratory visited or known to me represents design as a struggle to identify and resolve conflicts or bases its research on such a view. Yet this view describes real design better than existing research or teaching paradigms and implies great needs for computer aids of a type that no one is trying to create.

A summary sense of the state of these efforts can be gained from the following generic anecdote. Each of these research groups showed me points in their software at which a conversion was made between a more abstract representation and a more concrete one (from the statement "convert energy" to a diagram of a motor-generator set, for example). In every case, when I asked "Did the computer do that or did the designer?" the answer was "The designer."

I believe the fair thing to say at this time is that this software plays a role similar to that of

personal computer (PC) software of a type called "productivity enhancers." Such PC software claims to help stimulate and organize ideas for writers and other creative people. One can brainstorm into the computer, diagram links between ideas, and so on. But such software cannot respond to the command "Write me an intelligent paragraph summarizing important research topics at this university." (Significantly, fewer products of this type are now for sale than were a year ago.)

Similarly, concept design research software at this time can be characterized as "inspired sketchpads," capable of generating and searching structured lists, constructing graphs that connect elements in various ways, or, occasionally, accessing rules or tables to help evaluate performance of elements. Good graphical user interfaces are being developed to support these activities. But little has been done so far to exploit the structures thus created in a systematic way, such as checking for correctness and completeness. Nor has anyone taken the obvious step of converting a correctly constructed graph into any existing systematic dynamic simulation modeling methods such as Bond Graphs, although most say they plan to do so.

In all of the above respects, the laboratories visited show remarkable similarity.

Except for focused situations, which essentially constitute redesign of an existing item by using the same kinds of fairly simple elements, the bottom line is that not very much progress is being made on systems that really aid the designer (other than bookkeeping). The reasons for this situation may be lack of basic engineering knowledge, lack of a mature concept of a product data model that can link form and function, and/or lack of a mature concept of the "product design process."

The article that follows reports on the following universities and laboratories:

- Technische Universität Aachen (two projects)
- Lancaster University (two projects)
- Technische Universität Berlin [summary of material in the article "Design Research and an Industrial Application of Systematic Design Methodologies," *ESNIB* **92-06**, 293-301 (1992)]
- University of Leeds (summary of material in the article "From Geometric Modeling to Product Data Models: Collaboration Between Engineering, Computer Science, and Industry at Leeds University," *ESNIB*, this issue).

TECHNISCHE UNIVERSITÄT AACHEN

The Werkzeugmaschinenlabor (WZL) (machine tool laboratory) at the T-U Aachen is one of the world's great mechanical engineering research centers. It is allied with the Fraunhofer Institut für Produktionstechnologie (IPT) next door that works with industry in similar areas. Both are devoted to a range of production technologies, the required research, and associated industrial consulting and technology transfer. The WZL and IPT occasionally step on each others' toes, since WZL wants to have contracts with industry while the IPT wants to work in some of WZL's research/applications areas. But the problems are small since the directors of the five main laboratories in both institutes are the same people. One feature of the division of labor between the two organizations is that IPT does not deal in issues relating to design of machine tools. That is done only at WZL.

Interestingly, WZL's technology and research are far ahead of anything the German machine tool industry can absorb. "The companies are proud if they have one PC with AutoCAD," said one researcher. So while the name says "machine tools," the reality is that the best work is supported by and done for the automobile and aerospace industries.

Two design projects concerning conversion of requirements into a design are going on at WZL. One of these aims at permitting a designer to hook a set of machine elements together to form a system, analyze them, design them by CAD, and so on. The other is more conceptual and is intended to permit a designer to think up new configurations of functions and parts and look at them from the point of view of assembly.

Machine System Design

This project is being carried out by Mr. Repetzky, a Dr.-ing. candidate. He calls it computer-aided engineering (CAE) of the future. The goal is to integrate all of the tools a designer needs for designing a complex machine: CAD, dynamics, simulation, FEM, machine elements like gears and bearings, hydraulics, controls, and so on. He has been at work on it for a year.

A major goal is to combine the different kinds of data that a designer would need to attack such a problem, and store the data in a unified representation. This would be more like how designers think of things, he says, as opposed to the different kinds of data representations that present-day software uses. His approach is the object-oriented method.

The project is an outgrowth of the general problem of putting functional design capability into conventional CAD. His view of function in machine system design is that each machine element responds to inputs and delivers outputs. So his first efforts have gone into defining data objects for the elements and placing calculations (methods) into the objects that define the input-output relationships. A major problem for him is to decide when he has described an element in enough detail. For helical gears, for example, must he include the helix angle? Another issue is to design the software and the user interaction so that calculations will be launched when they are needed. It is not clear if he understands message-passing or events. I am not an expert in these either, but I believe that he would benefit from having more sophisticated computer science help in his research.

The software at present supports a mouse-menu interface that permits the designer to extract objects from a library, put them on the screen, and hook them together. The elements have the required hooks on them already, and a design is not complete until all the hooks have been connected to something. For example, a drive motor has a hook for fastening it to the ground and another for fastening it to a rotating shaft on another element. A bearing has a rotating element that can be hooked to a shaft and another that can be hooked to a housing. The hooks are each responsible for fixing one or more degrees of freedom (DOF), and the software will eventually be able to tell if all DOFs have been accounted for. On the hookup screen, the elements are represented by icons and do not have any particular geometry. They just have the mathematical properties described above.

If Repetzky hooks together a motor, a shaft, some bearings, a gear reducer, and a load, he can calculate the shaft torques on both sides of the gearbox. He could add tooth load calculations to the gear object but has not done so yet.

He has considered using Bond Graphs as a way to link these hookups to simulation. I believe Bond Graphs could help because they easily calculate the above-mentioned torques. In addition, they are designed to model hybrid systems, such as electro-hydraulic, using the same symbols and math throughout. In addition, the Bond Graph method contains a number of internal consistency checks that prevent some kinds of basic modeling errors, such as failing to conserve energy or attempting to define both the force on, and the velocity of, a moving object. Bond Graphs are based on lumped parameter modeling and assume discrete elements like torque sources and inertias, so they are suitable for modeling what he wants to represent.

Combining the consistency checks of Bond Graphs with the DOF accounting he now plans would give his system some capability for evaluating the correctness and completeness of a model. I think this would be an important property for a modeling system to have. No researcher I have visited has given this kind of thing high priority. In some cases, designers can draw what they want and computers will try to model it.

Mr. Repetzky also wants to connect his element modeler to a CAD system so he can draw the real shaft, for example, and tell the system that it is the same shaft as the element in the hookup. Also, he would like to be able to optionally begin part of the design in CAD mode and cut/paste pieces back into the hookup. He feels that a major problem will be to propagate design changes consistently from one representation to the other, and he worries that it will not be possible to accomplish this automatically. I feel sure that without the consistency checks mentioned above, reliable change propagation will be difficult to achieve.

Assembly-Oriented Design

Mr. Baumann, another Dr.-ing. candidate, described a system called DEMOS, on which he and others have been working for many years. It supports design of mechanical items and has several objectives. First, it seeks to bring assembly issues to the concept design phase. To do this, it permits the designer to describe the product in terms of graphs that link parts without the geometry of the parts being specified. Second, it allows the designer to study the design and improve its assembleability. This, however, is done after geometry is defined. A commercial solid modeler (EUCLID from MATRA Datasystems) and a commercial data management system have been combined with WZL's own rule and databases and user interface to create this system. Future plans include converting to the ACIS modeler, a product of Spatial Technologies, Inc., and an object-oriented data representation.[2]

Nominally, the design process supported by the system begins with a functional description that is admittedly not very abstract; it merely permits the designer to link functional needs to individual mechanical parts. The system's strongest features deal with development of two data structures: the function structure and the assembly structure. The designer inputs both of these, and the software supports the process by keeping track of all the parts, logging the designer's choices for connection or assembly methods that link parts, later accepting the shape of each part, and finally performing Design for Assembly (DFA) analyses. By ordering the process this way, Ba~mann hopes to encourage assembly-oriented thinking by the designer before the geometry is completely described, even though the last steps require geometry. The sequence also adheres to the German design standard VDI 2221.

Both the function structure and the assembly structure are hierarchical graphs in which nodes are single parts or subassemblies, while links indicate some kind of relationship (Fig. 1). In some cases, the relationship is that of assembly. In others, it represents some functional aspect of the design. So in the functional graph of a gearbox, the top node is the *gearbox*, and lower nodes represent *input*, *output*, and *housing*. *Output* has subnodes such as *shaft*, *gear*, *bearing1*, *bearing2*. In the corresponding assembly structure, the top node is again the *gearbox*, but the next level contains a two nodes: a *subassembly* of *housing top* and one *bearing cap*, and *all the rest* of the gearbox comprising, at the next lower level, a *subassembly* for *housing bottom* and the other *bearing cap*, plus *subassemblies* for the *input* and *output shaft-gear-bearings* sets.

Once the assembly structure has been drawn up, the system attempts to generate an assembly sequence. To do this without knowing much geometric data, the system uses several heuristics. For example, the part with the most connections to it is selected as the "base part" onto which others are added (the upper housing or lower housing would be chosen in this example). Parts with lots of connections to each other are candidate subassemblies. The system seeks to create as many independent subassemblies as possible by using such rules. The designer can edit or alter the suggested assembly sequence.

Once the assembly structure and assembly sequence are determined, the designer can assign types of part mates to the assembly links. Library features like bearing seats can be called forth, including dimensions if the designer wishes. Last,

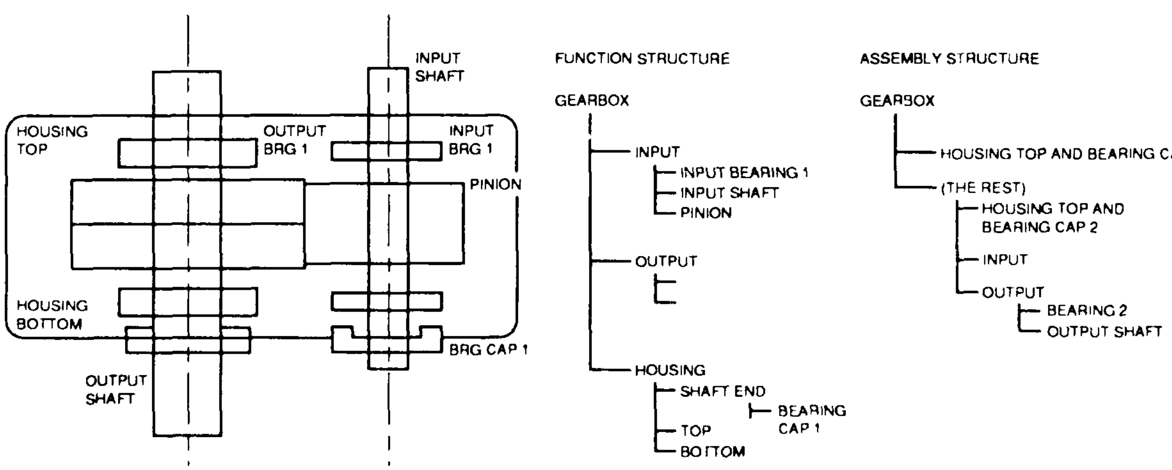

Fig. 1 — Structure relationship

the designer uses the CAD module to make up the actual shapes of the parts that contain these part mates. When the system has all the geometry and assembly structure information, it carries out a DFA analysis and suggests places where part count can be reduced. Tables from the Boothroyd method are used for this purpose.

Mr. Baumann contrasted this work with that of Mr. Repetzky by indicating that DEMOS seeks to support design of completely new things, whereas Mr. Repetzky was trying to model systems made up of standard components. The distinction is not clear to me, especially in view of the fact that a gearbox clearly can be built up of standard items. My comparison of the two projects is as follows:

Mr. Repetzky is facing the problem of converting specifications and functional requirements into physical realizations, whereas Mr. Baumann is facing the problem of helping the designer think of the product as something to be built rather than just something that works. The two methods, or descendants of them, will obviously have to be merged in order to create more complete design support systems.

Side Comment

The assembly sequence strategies used by the DEMOS software raise some interesting questions. For example, it is not obvious that maximizing the number of subassemblies is always a good idea. The reasons for doing or not doing this may depend on information from marketing or assembly machine experts, for example. Some of the considerations are discussed in the *ESNIB* article on Telemechanique (this issue), where product modularity is the driving consideration. Other researchers [see "Robotics in Theory, Robotics in Practice: 1992 IEEE Robotics and Automation Conference," *ESNIB* **92-05**, 241-254 (1992), special symposium on assembly planning] deal with these complexities by permitting the designer to impose other subassembly strategies or even to generate all feasible assembly sequences and choose among them. However, these methods require the part geometry to be defined. The type of mates also influences these choices, but in DEMOS the assembly sequence is chosen before the part geometry and mate type.

The larger issue is whether significant design decisions can be made without the specific geometry having been defined. Assembly decisions illustrate the question here, but it comes up in many other contexts. DEMOS is a bold effort to create an environment where decisions can be made without geometry. At present, however, it seems to me that many of those decisions are destined to be revised later.

The next question is whether the design is better anyway, even if the decisions were redone, just because the designer had to think about assembly much earlier than would normally be the case. No one is thinking about design processes this way: revisions are usually thought of as a sign of waste or inefficiency in the process.

LANCASTER UNIVERSITY

The two concept design projects described here are under the direction of Professor Michael French, who established the Mechanical Engineering Department at Lancaster 24 years ago. French is an experienced mechanical designer who returned to academia because he felt that design was not as well taught as it could be. His approach is to be as analytical as possible but to attempt at the same time to articulate "design principles" that go beyond analysis and describe what designers do. Example principles are:

In general:

- provide clarity of function (know what each component does, ensure that it does it well and simply, and is not compromised by trying to do other things);
- achieve matching (symmetry, equal sharing of functional responsibility, sharing out loads equ ally, etc.); and
- take care in investigating alternative nesting orders for things (the nesting order of typehead and paper movement in old-fashioned and ballhead typewriters is completely different).

In structural engineering:

- use short direct force paths; and
- use single rather than multiple force paths.

French realizes that not all of design can be made analytical, but he is skeptical of some "received wisdom" (the "expertise" that expert system builders try to capture). He suspects that trends seen in designs could be given an analytical explanation and foundation but simply have not. An example is his observation that in double-track vehicles (cars) the steering function is nested between the wheels and the springs; in single-track vehicles (motorcycles) the springs are between the wheels and the steering function. Asking designers why it is this way does not yield satisfying answers, but a serious explanation is probably possible, based on kinematics, dynamics and, possibly, manufacturing considerations.

The two projects described are funded by the U.K. government under the Engineering Design Centre program. French's project is aimed at mechatronic design, that is, design of mechanical systems that contain computation, measurement, and control, as well as familiar kinematics, dynamics, fluids, strength of materials, and so on.

Schemebuilder

It is like Mr. Repetzky's system in many respects, with similar aims but perhaps a more analytical underpinning. It is written entirely in the commercial expert system shell KEE. There are two windows: a "building site" and a "model library." The building site is like Repetzky's hookup window and functions in basically the same way. The example here is mechatronic, in keeping with the theme of the Centre: an autopilot for a yacht. A compass provides a control setpoint for a servomechanism that will drive the boat's tiller to correct a heading error.

Two kinds of elements can be called forth: those capable of transmitting power, and those dealing only with signals. These can be joined in ways similar to those provided by Bond Graphs, including keeping track of causality. But the full force of Bond Graphs has not been utilized in the sense that no generic components (inertia, compliance) have been defined. Instead, each element represents an individual physical type of thing (tiller with rotational inertia, boat with translational inertia...).

Design begins by calling forth specific elements, such as the yacht's tiller. These elements are described only qualitatively, such as noting that the water will exert a force on the tiller in one direction while the steering motor will exert a force the other way. The motor will act through an Acme screw, whose function is described qualitatively as converting rotational input to translational output. Quantitative descriptions are going to be added later in the project.

Each element has hooks that permit restricted kinds of connections to be made. A browser is available in the model library that helps the designer find suitable elements for a given hook type. For example, to provide translational power for the tiller, the list could include electric or hydraulic actuators but would not include things incapable of driving a load. However, the list presently also includes solenoids, which are too small to drive yacht tillers, an indication that qualitative factors dominate the system at the moment.

Several extensions of the current system are planned. One deals with design concepts like function and advice/warnings to the designer. The other deals with linking the concept to a CAD system so that space can be allocated for each of the components as it is placed in the building site.

Curiously, Prof. French does not feel that the warnings and advice feature should be based on making the software understand engineering fundamentals. He feels that would be appropriate for design of really new things, whereas here he is dealing in some sense with hookups of already designed and understood things. Instead he would like to link the advice and warnings to a more sophisticated formulation of function as it relates to the elements selected from the library. He uses the term "function structure" to describe statements of functions, perhaps at a semantic level, to which the system would respond with solution types built of library components that match the description. Once a pattern of solutions began to emerge for a given problem, the advice might draw on the existing design. For example, if some hydraulic components have been selected by the designer, the system might select more hydraulic components to mechanize other functions in order to exploit the hydraulic power supply that is already required.

No approach to providing this semantic facility has been identified as yet.

System for Improving Mechanical Assembly Design

This piece of software is a model editor for assembling cylindrical things with a single rotational axis of symmetry. It is a deceptively simple context—and a brilliant one—because its simplicity forces certain basic issues into sharp focus while keeping side issues from clouding the discussion.

One type of assembly is involved, namely placing gears, turbines, bearings, spacers, and their required fasteners onto stepped shafts. The designer must create the stepped shape and indicate the steps onto which the bearings will rest. Each set of parts, starting from a step and proceeding along the shaft through bearings and spacers to a fastener, is called a "stack." The system has been programmed to recognize stacks and to understand some of their inherent constraints. For example, a stack with no fastener is incomplete.

The system understands several geometric facts about such assemblies. For example, it can recognize stacked stacks: a step followed by a bearing, a spacer, another bearing, another spacer, and finally the fastener. It can also recognize the opportunity to create a stacked stack out of two serial stacks by responding to the command "Reduce number of fasteners." Finally, it knows when assembly is impossible because a step is too high to permit a bearing to pass over it on the way to another step. This error can occur if the system discovers that a step is too short to support the bearing assigned to it and attempts to make the step higher.

However, the system is unaware of some basic engineering facts that would seem to be naturals for it. For example, it does not really understand the concept of load path, that is, the idea that the fastener is going to push the spacer against the bearing, which will in turn push against the step, trapping the bearing with a compressive force. At present when the designer places a bearing near a step, the system will not place the bearing against it in anticipation of the direction the force will ultimately point. Instead the designer must move the bearing with the mouse until it visually coincides with the step on the screen.

An extension of this idea is to recognize when axial forces must be resisted. Helical gears generate such forces. Alternately, angular contact bearings require preloads. In such cases a load path to a fastener is needed, and the design is incomplete until this path is provided. All such paths comprise loops through the structure, with alternating loop segments in tension and compression, all adding up to zero net force around the loop. This is another case where "correctness and completeness" could be checked systematically. The student who is writing this software does not seem to want to add such understanding to the system but instead prefers that the designer realize it.

The potential benefit of adding it to the system is that this provides an opportunity to study in a simple but nontrivial context the question of how to link geometric design to real engineering (elements cause loads that have to be supported by using steps and fasteners). It would be very satisfying to see a system of this type developed as a counter-example to other research where such physical facts are deduced as "rules" used by designers.

RELATED WORK AT OTHER UNIVERSITIES

In other articles I have described in some detail work along these lines. Rather than repeat this here, I summarize it briefly and refer the reader to the detailed article.

Technische Universität Berlin

The work of Professor Beitz and his students also consists of providing a computer interface to concept design in the form of linking elements on a computer screen. Each element comprises physical and logical properties that can be exploited in various ways. The user can make legal hooks between elements and can construct a "system" that the computer will ultimately be able to link to a simulation. As the design proceeds to more and more detail, the computer support becomes more substantial and the element descriptions become more physical. At the lowest level I saw (how to fasten hubs to shafts) there is an extensive rule base and some fundamental engineering calculations. However, constraint satisfaction is up to the user. ["Design Research and an Industrial Application of Systematic Design Methodologies," *ESNIB* **92-06**, 293-301]

University of Leeds

Professor Neal Juster and his student Jim Baxter are trying to define functions provided by mechanical parts. Example functions are "provide support," "locate position," "stop leaks," and so on. A graphical representation is being tried, in which all the items that perform the same function are linked into a graph. Some syntactic checks are possible. For example, if the "support" graph is disconnected, it means that the design is in error since some of the parts are in fact unsupported. An engineering check could also be made: if the same part provides both fastening and location to another part, the design is a poor one, especially if both functions are to be provided by a screw. In good designs, location is typically provided by separate locating pins, spigots, steps, or other specific geometric features independent of the fasteners. ["From Geometric Modeling to Product Data Models: Collaboration Between Engineering, Computer Science, and Industry at Leeds University," *ESNIB*, this issue]

COMMENTS

After reviewing the above projects, it is tempting to ask why all this seems to be so difficult. One researcher I visited spoke wistfully of gate synthesis in electronic logic. This was a "done deal" at least two decades ago. Algorithms exist that will convert a given Boolean algebra or truth table representation of a desired logic function into the minimum number of logic gates and their required hookup. Why is this possible?

There may be a good mathematical answer to this question, but I do not know it. This researcher and I surmised that logic gates have certain basic properties that mechanical elements just do not have, and these make the difference:

- each gate is discrete;
- the gates do not back-load each other but instead behave as a one-way logical cascade;
- a gate's behavior is dominated by logic; any physical behavior (heat, thermal expansion) is secondary to its behavior and does not affect it except catastrophically); and
- each gate does exactly one thing, does it purely with no side effects, and does it so repeatably that tolerances are not an issue.

Typical mechanical and mechatronic elements simply do not have these simple properties.

CONCLUSIONS

Each of the projects described above is attempting to tackle a genuinely difficult problem, one that often has been left to "creativity" and deemed too unstructured for systematic attack and computer aids. So far, it appears that the problem is living up to its reputation. There may be some underlying reasons for this.

The most likely one is that the problem is indeed too difficult because reducing requirements to a concept requires too much knowledge; furthermore that knowledge is not well structured. In a recent paper,[3] Professor French lists the following knowledge areas that a designer must encompass to greater or lesser degree:

1. engineering science combined with physical insight;
2. ability to model a problem analytically, including when to simplify;
3. ability to organize work and proceed step by step;
4. ability to recognize key decisions in a complex problem and link them together;
5. invention (!);
6. aesthetic judgement, enabling the designer to distinguish good solutions from bad ones;
7. possession of a wide repertoire of methods and solved past designs; and
8. "received wisdom" about accepted practices in one area of expertise.

Of these, he feels that research is feasible in areas 2, 3, 4, 7, and 8. In omitting 1, I believe he feels that the basic facts about statics, dynamics, and so on are already well understood. The task is to extend modeling to the repertoire and received wisdom areas and raise the latter two above the current level of "rules."

Thus I return to the theme of "Perspectives on Artificial Intelligence in Design" (*ESNIB*, this issue). The weakness in current approaches is at least in part due to insufficient understanding of the underlying engineering facts or insufficient effort to model them (the load paths in this article, or the machine tool spindle in the AI article - also involving load paths). The designers are the wrong people to ask since their approaches are too intuitive. In the near-term it may not help to continue trying to build design aids that use graphical interfaces, word searches, rule bases, or neural nets because they stand on a weak foundation in the engineering fundamentals. Instead, thought should be given to identifying areas in engineering science that could be recast in terms of analytical design principles. Design of machine elements is clearly a candidate where enough work may already exist to permit researchers to skip the expert systems and go straight to the theory.

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From Geometric Modeling to Product Data Models: Collaboration Between Engineering, Computer Science, and Industry at Leeds University

by Daniel E. Whitney

KEYWORDS: geometric modelers; PDES/STEP; simultaneous engineering; product data model; numerical control

SUMMARY

The Computer-Aided Engineering Unit in the Mechanical Engineering Department at Leeds University has built its expertise on increasingly sophisticated geometric modelers over the last 15 years. From this base, two main trends have emerged. The first is increased sensitivity to the need for structured data to represent products as a whole, not just their geometry. The second is a broadening view of design beyond creation of geometry to include concurrent engineering.

[Concurrent engineering (CE) is a recent and evolving technique for designing products. The Japanese are probably its best practitioners, although companies world-wide recognize its advantages. Its goals are to include more manufacturing and field use issues early in the design process than has typically been done. The "nonconcurrent" approach resembles an assembly line, in which each department (design, engineering, manufacturing, sales, etc.) does its work on the design and then passes the work on to the next department—along with a host of problems that could have been mitigated by mutual consultation. CE presents a wide range of intellectual problems because it requires explicit and rational resolution of highly complex and interacting conflicts between the various departments. Data and algorithms for resolving these conflicts are scarce or nonexistent. Most of the companies and some of the research laboratories I visited in Europe are addressing one aspect or another of CE. (A good example of European industry's efforts in CE is discussed in "Dramatic Reductions in Lead Time at Volvo Based on Restructuring the Design Process and Introducing Computers," *ESNIB*, to appear).]

In both cases, the Unit has established strong ties with the Computer Science Department and has also hired individual staff who combine engineering and computer science backgrounds. These ties give the Unit's research a quite different character from that of most other computer-aided design/computer-aided engineering (CAD/CAE) laboratories, especially the German ones. Most research here has industrial partners; the test cases they provide are "really challenging."

Some results from this laboratory have had practical consequences. One is an institute devoted to standardizing data formats and promoting data interchange. The other is active participation in the PDES/STEP (Product Data Exchange Using STEP/Standard for Technical Exchange of Product Data) process; a member of the Unit is the editor of STEP Part 41, which defines product configuration data.

Recent research has focused on a product data editor. This is an interactive software tool for designing product data descriptions. The implication is that product data represent a generic need but each product will require its own structure. An important issue is how to define the appropriate structure in each case. At the present time, the editor creates essentially elaborated, hierarchical parts lists with links to important design algorithms and references to relevant data. The structures contain information about single parts but no information about assembly or other technical interrelations between parts other than set membership. STEP Part 41 has the same character.

New research with United Kingdom (U.K.) government and industry funding is dealing with defining product data models that will support concurrent engineering. Both fabrication and assembly will have to be dealt with. The work is just starting, and no definitive results are available.

The Unit's past and current research is strongly influenced by industry and by long-term government funding patterns. University budgets are now based in part on matching funds from industry. Research projects in manufacturing must be structured like concurrent engineering activities: the users of the research must be part of the research project from the planning stage to the time when the "results" are "delivered." The Unit's director, Prof. Alan de Pennington, has had a key role in advising the U.K. government on design and manufacturing research policy. In the mid-1980s he was a Program Director in the National Science Foundation Division of Design and Manufacturing. Because of the sweeping influence of these funding patterns on universities at large as well as on manufacturing research, I have written a separate article discussing these trends. (See separate *ESNIB* article, "Government Funding Policy for British Universities and University Research," where these topics are discussed in detail.)

BACKGROUND

Professor Alan de Pennington is the director of the CAE Unit, still colloquially called the Geometric Modeling Project for historical reasons. He is one of six professors in the Mechanical Engineering (ME) Department, the others being mostly in traditional ME areas like tribology and fluid mechanics. Before coming to Leeds, de Pennington was at the Philips Production Automation Department at Eindhoven, The Netherlands. There he met Professor Herb Voelcker, a pioneer in solid modeling, and took inspiration to develop CAD models. He has been at Leeds since 1979 and is now a leader in this field as well as a member of several influential U.K. government committees that plan research. He therefore offers interesting perspectives on such matters as

- how funding trends and reorganization of the U.K. university system affect what research topics are pursued as well as research projects' balance between basic research and research that must be transferrable to industry within the life of a single research project;

- how computer science can be combined with engineering and design and what kind of research emerges; and

- how each of these issues is reflected in the balance between "top-down" and "bottom-up" in design research.

History of the CAE Unit's Research

The first of a series of geometric modeling projects began in 1979. These resulted in commercial CAD modelers and (in phase II) some computer capabilities in numerical control based on solid models. Spurred by some of its industrial partners, in 1983 the Unit began to work on CAD data interchange. The CAD/computer-aided manufacturing Data Exchange Technical Centre, an industry-funded consortium, is one result. de Pennington feels that phase II was somewhat ahead of its time for both the researchers and the industrial partners. The ideas of concurrent engineering were in the future, and the partners did not understand the potential of solid modeling to capture important design and engineering information. In particular, they resisted his attempts to include assembly modeling in the project because they thought assembly was not itself a cost-driver for manufacturing. Also, the researchers did not produce a modeler with a good user interface, preventing the users from appreciating it. Yet the users blocked Leeds from working on Ultrasonics International, thinking there was no research issue there.

By 1987 the Unit stopped direct work on solid modelers, since very good commercial ones were becoming available. Instead, it launched phase III of the GMP with an effort to provide Information Support Systems for Design and Manufacture. The result of this project, in collaboration with the Computer Science Department, was the product data editor, about which more below.

Starting this year (1992), the group is working on "Exploiting Product and Manufacturing Models in Simultaneous Engineering." It is just starting up and has not produced any firm results. The goals are to extend the idea of product data, addressing such questions as

- what is a specification for a product?
- what is an assembly data model?
- what is a manufacturing model?
- how can conflicts between specialists on concurrent engineering teams be resolved?
- how can different specialists' models be harmonized?

The industrial partners include a high-tech systems house, a food packaging machine maker, and a materials handling equipment maker. This mix is intended to provide a variety of products whose data needs are different.

THE PRODUCT DATA EDITOR

"Product data model" is new terminology since the mid 1980s. While the Unit's appreciation for such data goes well beyond geometry, in practice the research deals mostly with geometry. In that context, a product data model organizes geometric data, provides a hierarchy for it, and provides hooks for applications that will work on it. Typical applications check for intersections between solids, define or check relationships between entities (e.g., parallel to...), annotate drawings with dimensions and tolerances, calculate tolerance stackups, plan inspection programs for coordinate measuring machines (actually plan the approach path for the inspection probe), and plan numerical control machining.

The goal of the product data editor is to permit creation of organized and coordinated data structures that allow the applications to get the information they need from one central database. This contrasts with current commercial capabilities in which data are created and structured during the design process by the CAD software. The resulting data structure suits the CAD process but not much else. The data must often be massaged or converted to a new form before a new application can work on it.

While recent object-oriented data structure efforts have produced hierarchical trees, the Leeds structure editor creates directed graphs. To support recursive structures like {products contain parts or subassemblies which contain parts or subassemblies}, the graphs can be cyclic. They thus can support a "part" that is actually an assembly of parts.

In other respects, the Leeds structures resemble objects: they can contain slots with attributes or methods. ["Objects" are data structures that exist independently of each other. Objects are organized as a set of "slots," each of which may contain data, algorithms, or other objects. Data are sometimes called "attributes" because they provide information about the object. Algorithms are sometimes called "methods." They describe how the object is to behave when executed.In "object-oriented programming," software may consist entirely of sets of objects. Substructures can be generated as instances of master structures. These are called patterns. Some of these patterns can be generated with parameters that will get their values later, thus permitting decisions to be deferred.]

Given the capability to define arbitrary structures, the question becomes: what kinds of structures and patterns would best support product descriptions? Several of these patterns have been identified:[1]

{**name** | **attributes** | **comments**}

{**name** | **abstraction** | **comments**} (abstraction is just a collection (COL) node in the graph onto which other nodes are hooked)

{**specification** or requirements | **definition** or design seeking to meet the requirements | **actual** or as-made instances of the design}

I was shown the proposed general structure based on these patterns, a portion of which appears in Fig. 1). Three data structures with major similarities are outlined. At the top is the most general structure, which describes the product. Below are two dependent structures describing assemblies and individual components. The arrangement and content of each of these structures is the same, except that, at key points, the word "assembly" or "component" is used in place of "product."

Interestingly, the structure contains "Finite Element Analysis" (FEA) as one of a collection (COL) of nodes fairly near the top of the hierarchy, indicating that a finite-element model was presumably needed at the "product" level. This is quite unusual. (Note in this figure the repeated occurrences of FEA analysis at the "assembly" and "component" level.)

It is necessary to point out that this structure was carefully made and not arbitrary, but it did not represent a tested model of a real product. Yet the inclusion of the FEA node at this unexpected place provides an irresistible opportunity to ask where such structures might come from in the future. All the previous data models I have seen in industry are in some sense mimics of a product design/development process. Hence they contain essential elements of time and logical precedence, indicating data that are needed first, then second, and so on, plus the data flows as inputs and outputs.

The Leeds structures are not typical time-based models of design processes like PERT/CPM diagrams (and of course they need not be). Instead they are something else, but it is not clear what. They are not just descriptions of the product because they have references to engineering analyses high in the structure. These references correspond to a time relationship in the design process: when an assembly model is available, do an FEA on it.

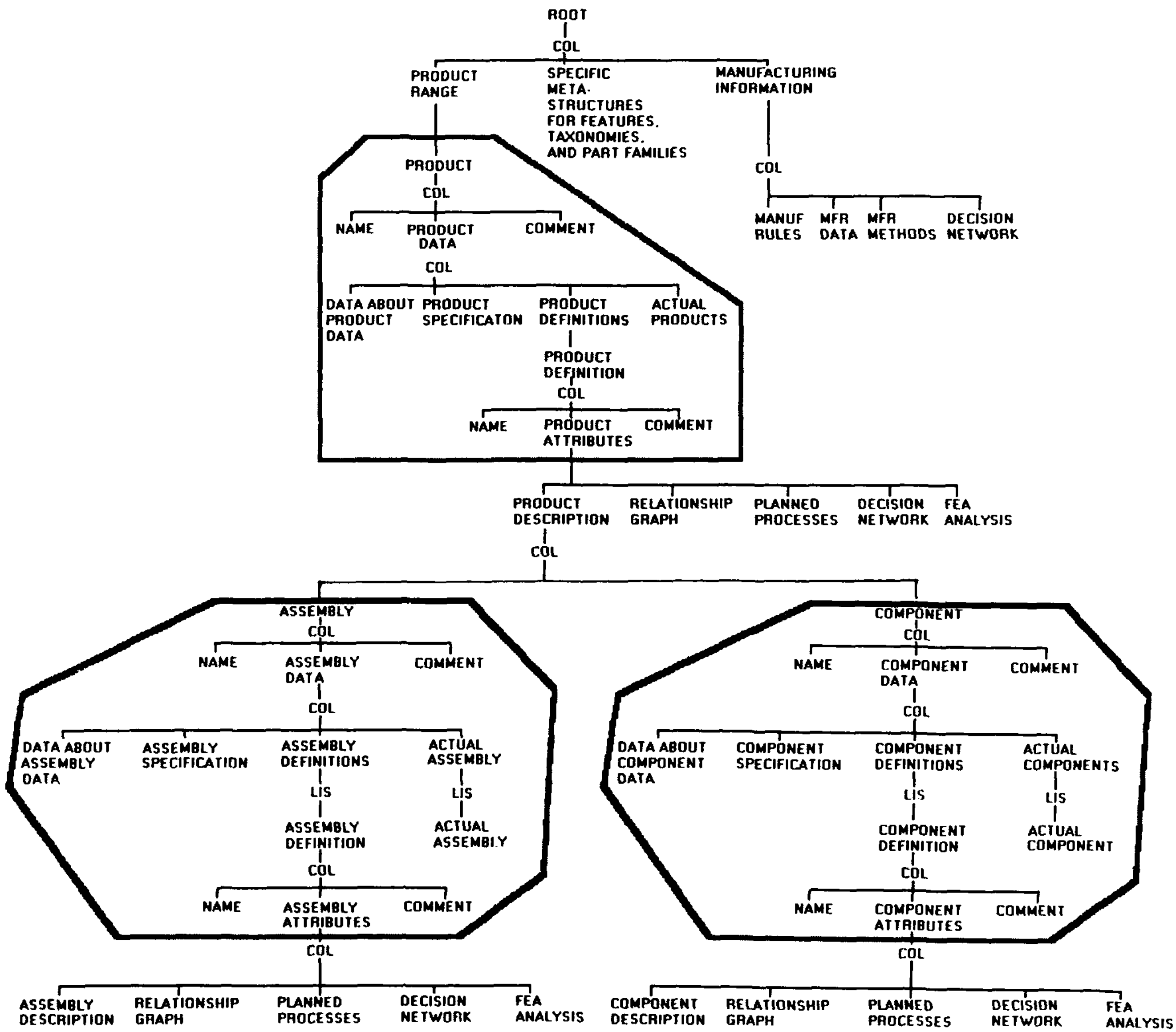

Fig. 1 — Portion of hierarchical product data model developed at Leeds University

Why are these FEA references there? How did someone decide that they belonged there? What is the relationship, in other words, between this structure and its creator's image of the time-based design process? de Pennington and his colleagues quite openly agreed that this was an issue, that the structure simply evolved from their internal debates and industry input, and that a methodology for constructing such structures is needed.

This discussion also points out, again, the fact that data can be included in a "product" data model that actually support or even describe the design process rather than the product itself. This is an important and perhaps paradoxical point. It may be an admission that there is no such thing as pure product data. A similar point is made by Prof. Voelcker:[2] 50 years ago designers annotated drawings with notes like "drill and ream." That is, the designer put process planning instructions on the drawing. In more recent times, the ideal has been to separate design from process. The designer states the tolerances required, but a process planner decides whether or not reaming is needed to achieve the tolerances. The choice may hinge on what machines are available or how many of the part are needed. This is a nice ideal, but it plays a big part in separating *design* from *design for manufacture*. The disadvantages of this separation are now clear, but there is still no agreement on whether designers should resume saying "drill and ream." Similarly, product data designers are investigating whether, when, or on what part sets FEA analyses should be done.

Many people familiar with electronic product design and manufacture VLSI (very-low-spacing integrated circuitry or very-large-scale integration), for example, point out that one of the main reasons why VLSI has advanced so rapidly is that designers need not concern themselves with process issues. The process limitations are represented by design rules that can be expressed purely in geometric terms (minimum radii, minimum line width and separation, etc.). These rules can easily be checked and enforced by the computer. Furthermore, most elementary functions in VLSI are represented by standard cells of basic devices and interconnects that the designer can lift from a library. This leaves the designer free to think almost completely in terms of functions.

If the Leeds work is a harbinger, then it adds evidence that mechanical product design will never be accomplished as pure data manipulation at the function level the way VLSI design is.

A final point: this research clearly shows the influence of sophisticated computer science, provided not only by collaborators Prof. Peter Dew and David Holdsworth from the Computer Science Department but also by staff members Susan Bloor and Alison McKay who combine engineering and CS backgrounds. Dew spent several years working on VLSI data architectures and automated design methods. None of the German CAD research observed during my visits in Europe contains anything like this level of CS participation or sophistication.

PRODUCT FUNCTION MODELING

Professor Neal Juster and his student Jim Baxter are starting a project to add function modeling capability to the product data model. They began with some interesting "false starts" that, in their opinion, were too geometric. The first of these was assembly fit modeling, similar to what assembly planning researchers do. That is, relations between parts were modeled with the "fits" and "against" relations pioneered in the 1970s by the artificial intelligence group at Edinburgh. Then they tried the 4×4 matrix relations first published by Gossard and Lee.[3] Neither of these can capture function. To fill that gap, they tried naming the relations more specifically, such as gear mate and screw mate, hoping to mimic the thought process of a designer who wants to mate gears or fasten parts together with screws. They are not satisfied with this approach either, although they presently have another student at a company trying to represent a design process for a product in terms of information that ultimately impacts its assembly.

In the meantime, theoretical thinking is proceeding along the lines of graph representations of functional relations between parts. Baxter has analyzed a gearbox and tried to characterize each of the joints in terms of some function or functions it performs. Examples are

- support,
- seal against fluid leaks,

- transfer torque,
- attach,
- locate geometrically,
- permit motion,
- prevent motion,

and so on. Graphs are then made by linking all the nodes that perform the same function.

Some obvious logical checks can be made by inspecting the resulting graphs. For example, if the graph made by connecting the "support" nodes is disconnected, then parts of the product are floating free and unsupported. As another example, if the definitions of the functions are made carefully enough so that, for example, "attach" is never confused with "fasten," then if an attach graph and a fasten graph ever share a node, a classic design error might be detected: by using a screw to provide geometric location. This is inadvisable since screw threads do not provide high-quality surfaces for providing location.

This work is still in the early stages, and no definitive results are available. It looks interesting, however.

CONCLUSIONS

This article deals with two related topics: future strategies and patterns of U.K. research funding for manufacturing and design, and one university's response to it. The government strategies are becoming decidedly short term—3 to 5 years to obtain results—but the researchers are able to carry out fairly generic research anyway. It is quite strongly focused in industry because real case studies are continuously being carried out.

Cross-disciplinary research is proving to be not only intellectually important but institutionally important, too. Collaborators may have higher survival rates. In U.S. universities, tenure usually goes to people who prove they can survive alone. It's an interesting contrast.

Finally, the particular collaboration illustrated by this laboratory appears especially promising, giving the professional level of the computing aspect of engineering design research that is not often seen.

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Design-Build Teams at Aerospatiale

by Daniel E. Whitney

KEYWORDS: design-build; modeling; integration; sequencing; entity relation

SUMMARY

With 37,000 employees, Aerospatiale is one of the largest aerospace companies in Europe. The Aircraft Division, located in Toulouse, France, has 14,000 employees. It designs and performs the final assembly of the Airbus family of commercial aircraft. Other divisions make helicopters, tactical weapon systems, and space systems. This article focuses on the Aircraft Division.

Aerospatiale has used computers in the aircraft design process since 1977; it had launched the "design-build team" concept two years before. Since then, the emphasis has been on using computers to integrate the design process, not simply to make drawings of parts. Today, almost all of the A340's parts are designed by computer.

While design of individual parts is now well under control, M. Bernard Vergne (who is responsible for aircraft definition capabilities) says that modeling and planning assembly is their biggest problem. He has been seeking computer tools to aid this process "for 20 years" and only now has the first one appeared, the Assembly Design program from ComputerVision. It helps with configuration control but is not useful enough for predicting assembly problems. (See "Object-Oriented CAD and Expert Blade Design at Rolls Royce," *ESNIB*, this issue, for another view of this software.)

Another important area is sheet metal forming. Folded parts represent 40 percent of all parts on their aircraft, and no tools exist for accurate design that takes account of springback and bend radius. As a result, it is difficult to provide the shop with flat versions of these parts and specific bending instructions. At the moment, Aerospatiale is looking at using artificial intelligence (AI) methods to attack this problem.

HISTORY OF CAD/CAM AT AEROSPATIALE

Computer-aided design and computer-aided manufacturing (CAD/CAM) began at Aerospatiale in 1977 in the lofting shop, where metal patterns for sculptured surfaces had been laid out by hand in the past. Later CAD was extended to the drafting department. Since the beginning, ComputerVision's CADDS software has been the standard. CADDS 4X is currently in use. (At the helicopter division, Dassault's CATIA is used).

CAD was introduced slowly by applying it to part families identified by group technology methods. The main families cited are: "folded" (bent)—40 percent by part count; flat—20 percent; rotational—10 percent; the rest—everything else, of which many are pipes and wires. Since the majority of these parts have simple shapes, the 2.5D and surface capabilities of CADDS 4X are sufficient. No switch to solid modeling will occur until the consequences for manufacturing are thoroughly investigated. About 80 percent of the parts are made by outside contractors. The French data exchange standard SET (Standard Exchange and Transfer) is used to exchange data with design-build contractors, but contractors that just design parts for Aerospatiale (or other contractors to make) must use CADDS 4X.

CAD/CAM was introduced into an environment in which "design-build teams" had already been operating for two years. That is, the reorganization of the design process began first, and then computers were introduced. Design-build teams (a method recently adopted by Boeing for the 777 aircraft development program) seek to collocate design, engineering analysis, manufacturing, and inspection people so that they can anticipate problems during design.

While the process of integrating design and manufacturing and then computerizing them is still continuing, the sequence (reorganize, then computerize) was important. Top management drove this process and put it in the hands of engineers, not information technology people. The goal was to integrate the process from the beginning, not just to prove that computers could help design or manufacturing separately. At least, that is how the history is viewed now, after many years of pursuing the goal.

The implementation has two main parts: the geometric modeling software (provided by ComputerVision) and the database (designed by Aerospatiale). M. Vergne says they have spent twice the cost of their commercial software on their own developments, which include several kinds of analysis programs in addition to the IGES (International Graphic Exchange Standard) database.

Despite the computerization effort, much of the knowledge needed to integrate design and manufacturing is still in the heads of experienced people. This experience is concentrated at Aerospatiale by the strategy of focusing each manufacturing facility on just one of the types of part family.

Because the Airbus is a consortium of many companies in many European countries, Aerospatiale has had access to their design methods. Some of the things they saw surprised them, including disorganized databases and manual design methods transferred to computers. At one company, designers cannot find the information they need quickly, especially information about manufacturing constraints. "Their problem is that they don't know anyone in the manufacturing department." At another company, CAD drawings of pipes are still in the three-view format of manual drawings with many cross-sections, whereas modern CAD permits pipes to be shown in realistic views with selected cross-sections and component lists where needed.

"THE DATABASE IS OUR ART"

Much of Aerospatiale's computer effort has gone into their database, which unifies the design and production processes. M. Vergne says, "It's not a storage place but rather an industrial plant," where information is coordinated, checked, altered, plotted, and so on. The basic structure of this database is entity-relation; it is not an object-oriented database.

It contains not only the geometric data, but allowed lists of components (pipe fittings, electrical parts), tool information, surface finishes, and so on. The capabilities of the specialized factories are also available, although I got the impression that most of the detailed information is kept by people in their heads. So the computer is often used to exchange information between people rather than to just look it up.

M. Vergne noted that the average time to make a CAD drawing is still the same 50 hours that it was when manual drafting was used, but the comparison makes no sense because a "drawing" today contains so much more information. Production information and process plans are the main addition, and many loftmen and process planners are no longer needed. In addition, there are standard quality sheets, technical directives for standardizing processes, and lists of allowed components. The database is designed in such a way that the production people can easily find these data.

PROBLEMS AND FUTURE NEEDS

M. Vergne cited three main problem areas:

- assembly,
- fabrication of folded parts, and
- data exchange and data persistence.

Assembly

Current CAD systems support the design of single parts but not of assemblies. ComputerVision has recently introduced a product called Assembly Design, which permits users to create assembly drawings (drawings that show several parts in their correct relative positions and orientations.) Strictly speaking, this is *assembly drawing design*, not assembly design, since none of the essential tasks in assembly planning are supported: interferences between parts, sequences, access for tools or assembly people, disassembly for maintenance, and so on.

The present way of designing things consists of converting a preliminary design into single parts and then into subassemblies. When assembly problems are discovered, the single parts must be redesigned. M. Vergne wants to be able to validate assembly before single parts are designed, but there is a paradox in this hope: many assembly problems are caused by very small details on the parts. Checking assembly at a preliminary design stage will therefore not catch all the problems. However, major interferences, sequences, and access issues can be addressed. "You don't want to put an air conditioning duct where it might drip condensate onto a computer."

To encompass assembly properly, the database will have to be revised. Several views of parts and assemblies will be needed, including several degrees of detail and stages of subassembly. Also, a new kind of person will be needed, the assembly checker. Such a person may be needed for each main engineering system (air conditioning, for example). The subcontractors will have to be involved in this as well, and by remote access from various parts of Europe.

Experience from the A340 aircraft program is being collated and fed back to ComputerVision.

Folded Parts

Folded parts represent a different kind of challenge since process and material properties are involved, whereas assembly is mostly geometric and logical. The issue is to standardize all the knowledge concerning different materials and machines and to create a drawing of the flat part plus instructions on how to fold it into the desired final shape within tolerances.

The CAD companies, in Vergne's opinion, are presently in no position to produce software like this. They do not have the resources or the experience with manufacturing. But he feels that the companies are trying to offer this kind of service anyway since they have found that they cannot make money on either hardware or graphics software anymore.

When I asked if Aerospatiale would join with other aerospace companies to solve problems like this in the future, he said that many of their Airbus partners do not even see the strategic value of standardized data exchange.

So an entirely new kind of CAD/CAM is needed, of which both assembly and folded parts are examples. They focus squarely on the interface between design and manufacturing and involve a different kind of data and knowledge than the standard procedures and parts lists that Aerospatiale has been able to put in its database so far.

Data Exchange and Data Persistence

Aerospatiale apparently recognized the need for standardized CAD data exchange several years ago but, as noted above, has not been able to bring its partners along. SET is being used because IGES does not work reliably and PDES/STEP (Product Data Exchange Using STEP/Standard for Exchange of Product Data) has not emerged yet.

Even if data exchange is solved, data persistence still looms. By persistence, he means the ability of CAD systems 25 years from now to read the data that were created last year or 5 years ago. Aerospatiale is not waiting for outside solutions but has written its own database in such a way that future CAD systems will be able to access it. This is accomplished in a way that is analogous to pseudocodes and cross-compilers in software: every time a new CAD system is adopted, a new interpreter is written so that it can read the database. He hopes that the U.S. program CALS (Computer Aided Logistics Systems) will help, since CALS is aimed at similar problems.

RESEARCH IMPLICATIONS

Two main issues appropriate for future research stand out here, although they can be seen at other companies as well. The first is the idea of the product data model (PDM) and what it should contain. The second is the question of providing early information to designers about future fabrication and assembly problems.

The PDM at Aerospatiale clearly is a mix of geometry and text, with the latter containing notes and information that all designers and engineers, including production people, can access and comment on. However, it does not contain much knowledge or many explicit process models. Although folded parts are the example given, many others undoubtedly occur, either here or at other companies. The problem is that they appear at present to be specific to each company (its knowledge, its machines) or to an industry. This means that the CAD vendors will have trouble creating a critical mass of resources and support to attack each one separately. Either the users must join together, or else the apparent differences between, say, airplane folded parts and automobile folded parts, must be removed by research into the basic processes and machines.

Predicting future problems in fabrication and assembly during concept design runs straight into the paradox cited above: small details can have big effects. This fact eliminates strategies that depend on scaling laws and forces one, sooner or later, to track down all the details. Thus a triage of problems needs to be carried out, so that those that really can be handled during concept design receive researcher's attention while the others are left aside.

On this basis, a priority list of problems to attack might look as follows:

1. detecting gross incompatibilities between assemblies in terms of function, malfunction, proximity, and so on (moisture, heat, flying parts due to engine failure, human access during normal operation, diagnosis, or repair);

2. finding access for routine things like original assembly or scheduled maintenance (requires database annotations indicating items that need regular maintenance);

3. finding access routes for interconnections between things, including approach paths to the items being connected;

4. establishing the general "layering" of things: what's on the outside, what's next, etc.; and

5. detecting incompatibilities between single parts.

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Peugeot's Manufacturing Technology Challenges EC Assumptions

by Daniel E. Whitney

KEYWORDS: robotics; mechatronics; concurrent engineering; concept design; technology transfer

SUMMARY

Peugeot-Citroèn is Europe's third-ranking automobile maker with 13 percent of the market (33 percent in France). According to M. Jean-Serge Bertoncini, Director of Information and Informatique, Peugeot has more than 2100 robots in its plants and has automated as many types of automotive assembly operations as advanced Japanese plants have. Example capabilities include, beyond the usual robot spot welding: installing all five wheels, windshield, rear window, dashboard, front and rear seats, and doors, plus performing portions of engine and gearbox assembly. These

activities were developed inside Peugeot-Citroèn and used their own software and optimization techniques.

After repeatedly hearing Michel Carpentier, the director of EC Research Directorate XIII (the ESPRIT program), say that Europe was behind, Bertoncini brought Carpentier by corporate jet to Peugeot's best plant and showed him what Europe can do. Needless to say, Carpentier was impressed.

PSA, the parent of Peugeot-Citroèn, is still in the process of merging Peugeot and Citroèn, and this process reveals new wrinkles in concurrent engineering. Different cultures, locations, engineering areas of expertise, and types of computer systems had to be joined gradually without upsetting the ongoing design of cars. Even now there are different design styles in some areas. A somewhat involved concept and advanced design procedure permits each division to design its own cars while drawing on common expertise in advanced development program management plus various engineering and manufacturing areas. In addition, PSA has learned to use the same component (e.g., engines) in both brands while tuning them differently to appeal to each brand's traditional market. A company with a single product line or that grew internally rather than by merger would not have seen the same problems and evolved the same solutions.

André Rault, with a 1966 Ph.D. from the University of California at Berkeley in controls, joined PSA three years ago. His goal was to bring a more systematic approach to its design methods, especially for mechatronic components like transmissions and brake systems. He has brought in software called CAMAS from the University of Twente that permits hierarchical Bond Graph models to be built. Several quite accurate models of complex items have convinced the engineers that this is a valuable method. Rault has now launched an ESPRIT project to create a library of proven Bond Graph models of common mechatronic components, together with their geometry (a link not supported by CAMAS) so that systematic Bond Graph modeling and design of complex mechatronic things can be done more easily in industry.

CAD AND PRODUCT DEVELOPMENT

As a relatively small automobile company, PSA has not had the resources for CAD that larger firms have. But PSA has moved faster than most large firms to implement new techniques in both design and manufacturing—recalling the case of Volvo, another small but innovative firm. PSA has implemented its own robot off-line programming system based on CAD solid models of both automobile bodies and robots, and has installed its own trajectory optimization and task-planning optimization methods. It has also carried out a careful but still incomplete study of cost savings from both the robotics work and several CAD and artificial intelligence (AI) applications. Some of the benefits were unexpected:

- first design takes as long by solid modeling as by hand, but modifications and computer-aided manufacturing (CAM) are done much faster;
- robot task optimization can often reduce the number of robots needed by 10 percent (FF1.7 million per robot if the surrounding equipment is included).

M. Bertoncini challenged the notion of companies developing their own CAD tools, as the Japanese have. "Too few people have the skill, the art really, to develop an architecture like you find in CATIA or CADDS. We know we don't have it, and we suspect the Japanese don't either." (CATIA is the solid modeling software sold by Dassault Systemes; CADDS is similar software sold by ComputerVision.) But PSA's reliance on outside vendors has pushed it to take a possibly suboptimum approach to the ubiquitous problems of data incompatibility between commercial CAD systems and difficult data transfer from one stage of design to another. It has chosen one vendor for each of its "lines of design:" CADDS for styling and body engineering; CATIA for mechanical design; MEDUSA (drafting software sold by ComputerVision) for factory layout and equipment design; and so on. This prevents easy merging of the different lines and may not be a long-term solution.

In their terms, they now have in place "new tools for doing design the old way." Now they must develop new ways. Whether their CAD strategy up to now will support the new ways is not clear. They have not done the intensive design process studies that Volvo has. Only in the last two years have strong connections built up between design and manufacturing.

IMPROVING THE SYSTEMS APPROACH IN CAR DESIGN

Dr. Rault noted that PSA, like other French companies, is short on systems mentality. Thus he found that little analytical skill existed in Citroèn's critical hydraulic suspension system group, and that tolerances were little understood because the French educational system does not teach random variables to engineers. He was assigned to improve both of these situations.

As an example, Peugeot recently did a competitive teardown of several models of a Japanese luxury car. They were surprised to find the same wiring harness in each, despite different wiring needs. This strategy results in slightly more weight and much lower fabrication, installation, and test costs, plus fewer errors, compared to using separate harnesses for each model. Only a systematic analysis can reveal the benefits of one strategy over the other. A more systematic approach to such problems can be expected at PSA in the future.

Rault has also brought Bond Graph modeling[1] to PSA, utilizing software called CAMAS. CAMAS is like the original Bond Graph simulation system ENPORT in many ways. It supports hierarchical models of complex hybrid systems. In an X window one can have a model with two nodes: ENGINE and TRANSMISSION. Clicking on one of these nodes reveals a more detailed model, and clicking on its nodes reveals even more detail. At each level, the graph obeys the Bond Graph notation rules. At any level, explicit mathematical statements can be substituted in a Fortran-like language called SIDOPS to handle nonlinearities and other details. CAMAS automatically converts the Bond Graph model into a set of SIDOPS statements and evaluates them numerically.

CAMAS has been applied to modeling of automatic transmissions. (In the Computer Systems Department at the Ford Motor Company, a similar model has been built. At the research level, there is frequent communication between the two companies.) These are good examples of mechatronics because they have either hybrid or all electronic controllers as well as many gears, clutches, shafts, friction elements, and inertias; Bond Graphs are amply equipped to model such systems. The first model, while still approximate in some areas, accurately predicts that PSA's current transmissions jerk the car somewhat while shifting. A previous analysis of manual transmissions correctly identified gear backlash as their main source of noise. These successes have impressed the engineers, making further applications likely. A complete automobile and suspension system model is being built. Rault has also launched an ESPRIT project to harden and commercialize Twente's software.

CAMAS in its present form is really for modeling and simulation, and does not support design directly. It has no link to geometric models, and it has no way of helping the designer improve the design. The fast Fourier transforms and other classical analysis techniques that Rault would like added will not really fill this need.

However, the EC project mentioned above will address several other gaps, including providing links to geometry and the finite-element method (FEM). More importantly, it will create a library of elements that combine proven Bond Graph models and the elements' geometry. This will be called the Open Library for Mechatronics Components.

Once this project is well underway, Rault expects that a methodology for mechatronics can be developed.[2] He sees it as a person with a controls background would: as a systems problem of simulation, control system design, failure mode analysis, and engineering analysis—all carried out in a concurrent engineering environment. The hierarchical nature of CAMAS will be essential for this.

CONCLUSIONS

Rault is bringing new research into Peugeot's design office and showing that it is ready to do real work. Apparently this is happening on his own initiative. It reinforces the point that companies must search out research and speed up the technology transfer process. The Japanese have shown that they are very good at this.

The EC project Rault has started will not only create a useful tool but will contribute to generic knowledge of use to many industries. The project is (potentially, at least) a good example of what can be done when a university and a company work together.

I note in another article[3] that most academic researchers on concept design have not taken the Bond Graph method seriously. It deserves more attention because of its ability to model hybrid systems and to check a model for internal structural and physical consistency. This added sophistication is being brought to bear in concept design by an *industry* researcher, a point to ponder.

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Systematic Design of Modular Products at Telemechanique

by Daniel E. Whitney

KEYWORDS: MRP; computer-aided design; part commonality; subassembly; modules

SUMMARY

Telemechanique (Paris, France) designs, builds, sells, and uses internally a wide variety of automation equipment plus the associated controls and software. This article focuses on problems and methods in the design of multipart electromeelectromechanical items that are made in a wide variety. How does one control the design process so that an easily made product emerges? How does does one assure high quality and low defects while switching effortlessly from one version to another in unpredictable batch sizes? What rules are needed to make sure that the design process is systematic, that the number of parts does not grow uncontrollably, and that the varieties available meet the needs of customers without strangling the manufacturer?

BACKGROUND

Telemechanique is a large manufacturer of industrial controls and automation equipment. The company has more than 15,000 employees worldwide and FF 10 billion (approximately $2 billion) of annual sales. More than half the sales and almost half the employees are located outside of France; these fractions are growing.

Its products are similar to those of Allen Bradley (Milwaukee, Wisconsin): programmable controllers, factory communication systems for control and data acquisition, electrical distribution and motor control, contactors, relays, manual motor starters, pneumatic controls, and so on. All of these are sold separately and are being integrated into the newer business of providing computer-integrated manufacturing systems. They are generally highly engineered and made in wide varieties. Thus they have some characteristics in common with Nippondenso's products. Design and manufacture in the face of technological change and wide product diversity is a major concern as well as being the focus of my visit.

Because the products it sells are used in automation systems that make similar kinds of items, Telemechanique is often in the interesting position of being its own customer. It is able to simulate the business conditions and technical requirements of its external customers, to learn about them by looking at itself, and to learn about itself by looking at them.

RESEARCH AND DEVELOPMENT CENTER ACTIVITIES

The Center's 150 employees work on a wide range of projects; several are funded by the European Community (EC) and involve other companies and universities. Examples of these projects include robotics and assembly, semiconductors, power transistors, scheduling algorithms, and environmental problems. Recent projects include high-speed robot control with KUKA, robot installation of windshields at Citreon, washing machine assembly in Italy, fuzzy logic methods of tuning servos, and software for analyzing plastic molding processes and sensors for monitoring them. Telemechanique developed the sheet metal computer-aided design (CAD) software that MATRA (France) sells.

Product Design for Variety

Mr. Morelli, Director of Automation and Productivity, is a thinker who has tried to systematize Telemechanique's product design methods. He describes his methods as in the spirit of Nam Suh: study and implement the functional requirements. As an anecdotal example, he cites his group's study of contactors (relays that switch motors on and off): when looked at properly, a contactor is a subset of a *reversing* contactor, in both parts complement and function. Even though contactors are sold in much larger quantities than reversing contactors, the main design constraints are on the reversing contactor. So, to take advantage of parts commonality, the reversing contactor must be designed first; otherwise, the contactor will have to be redesigned. Telemechanique did not originally design them in that sequence.

He also has tried to get product design to begin with a business scenario for the product. This is similar in spirit to Nippondenso's idea: Toyota is their main customer and demands high variety, unpredictable order mix, and 24-hour delivery. So Nippondenso has designed its products to meet this environment. It is significant that the manufacturing technology for these products is not unusually high tech, although the logistical control undoubtedly is. Most of the innovation is in the design.

The same is happening at Telemechanique. In the case of a new line of contactors, the business scenario is to create a small sample of a model to show to customers. Based on their response, varieties can be made on short notice in larger quantities.

More generally, Morelli has developed an approach to designing high-variety products that encompasses several strategies:

- Functional decomposition
- Modularity
- Definition of subassemblies
- Reduction in apparent variety by part commonality
- Design for automatic assembly.

Functional decomposition (conversion of functional descriptions into specific lists of parts) is a familiar step that appears in most design methodologies. It requires experience so that the functions are represented by an economical number of parts. This step is complicated when the product must be made in many varieties because some functions (and thus their respective parts) may be in some varieties but not others. Whether to make these as separate parts or merge them with their neighbors is a constant challenge.

A similar challenge occurs when parts must change identity, shape, or composition at various points along the spectrum of varieties. Increasing product size along the spectrum is an example reason. Can a scaled-up version of the smaller common part be used or must a new configuration be created? Where along the spectrum should the transition occur? Etc.

An example is given below that shows how fabrication, assembly, cost, and market demand all must be taken into account. No systematic design tools exist for such decisions.

Modularity involves making up a function by combining several identical or related parts. It is relevant to products with repeated internal structures that implement repeated functional requirements (*N* contacts, where *N* can be chosen by the customer, for example.) The design choice is between assembling the repeated parts or designing special parts that contain the required number of elements. Significantly, Morelli is not uncritically in favor of modularity; he recognizes its drawbacks as well as its advantages. Modularity brings flexibility but requires more parts, more careful attention to tolerances that build up when these parts are assembled, and more effort in logistics to muster those parts needed for each order. The choice is also influenced by the cost of making molds and the influence of production volume of the different types of the product.

Consider the case where motor control protectors with three or four poles (contacts) must be made. Table 1 table shows four different ways they might be designed. The assumption is that the cost, complexity, and design/build time for a mold for making the parts will increase with the number of cavities in the part for holding poles. Each different design alternative is intended to generate both varieties of the product.

Designs 1 and 4 are not likely to be economically viable alternatives if 4-pole units are low-volume sellers while 3-pole units are high-volume sellers. Designs 2 and 3 are more feasible in this case, but it is not immediately obvious which is the best.

The net effect of this example is that designing the product properly requires a good model of the market, plus the ability to predict the cost of the associated molds and the tolerance buildups in the alternative assembled units, and the ability to model the cost structure of the product as a whole: how costs are distributed over materials, logistics, fabrication, inspection, assembly, and test. Since there is some probability that the market might change (e.g., increasing the demand for 4-pole units), a statistical decision theory approach might be taken. Researchers have studied this method, but Morelli did not mention Telemechanique doing this.

More generally, one must be careful not to offer so many modules that the customer becomes confused. One way of selling offers the customers the chance to "design their own" by choosing from a catalog of the modules. Part of marketing such a product is the ability to direct the customer right to the variant needed. So, the spectrum of needs

Table 1. Comparison of Different Strategies for Conceiving a Modular Product

Number of Poles	Design Alternative			
	Design 1	Design 2	Design 3	Design 4
3	a special 3-cavity piece	3 single-cavity modules fastened together	a special 3-cavity piece	3 single-cavity modules
4	a special 4-cavity piece	4 of the same single-cavity pieces as above	the above 3-cavity piece plus one of the single-cavity pieces	a special 4-cavity piece

must be understood and the modules must be constructed so that it is easy for the customer to see what modules to combine.

One must be careful not to confuse the designers either. When a large number of varieties must be encompassed and some common parts are involved in each variety, a design change in one part can cascade changes throughout the design in unpredictable ways. A strong database is needed to keep track of such interrelationships. I doubt that one exists because it would need to know about related part features on different parts at a geometric level, as well as about sets and relations between part families at the module level. This lends additional richness to the idea of a "product data model:" another example of a model that contains data to support the design process, not merely to describe the product.

"Subassemblies" could be different from "modules." This is a new distinction for me, since I have used the two terms interchangeably in the past. Modules, as stated above, may be related to the customer's or salesman's needs. Subassemblies are directed only to the manufacturer's needs. These include integration of made and bought parts or the maintenance of mechanical stability and control during assembly. For example, it may be useful to fabricate two parts near each other and assemble them immediately. This will establish their relative position tolerances while they are under complete control and keep them from being damaged or jostled out of their desired orientations during transport to another assembly point. Many other criteria for defining subassemblies exist but were not discussed at this meeting.

The next consideration is seeking commonality. Morelli drew a table that placed many product varieties in columns next to each other. The rows represent the various functions. Each entry in the table represents a way of realizing a function in a model version. If the same realization is used in all versions, the row reads the same all the way across. Deviations from this desirable pattern can be seen immediately. Then the reasons for the deviations are sought: lack of design oversight, carelessness, change in conditions in the product requiring a different realization, historical evolution, and so on.

Another basic step is design for automatic assembly. Here again, the impetus and approach are similar to those seen in other companies, but a lot of care has gone into certain key concepts that deserve mention. The main one is the concept of the reference surface. Every item handled by automation must be gripped at a reference surface; such a surface is then toleranced to all the other internal features that must be dealt with by the automation. These are places where other parts are attached or manufacturing operations are performed. This is not a new idea, but it takes on added significance when a variety of parts might be handled by the same automation.

An example is electric contacts. These come in four generic shapes, each suited to a desired amount of current and thus a required amount of contact force. To pack the contacts into a small space, designers have created different spring shapes to store the energy that creates the contact force. There are no design rules for choosing the correct shape in each instance, and no standardized way to define the required reference surfaces. Morelli is in the process of defining this problem and getting the rules out of expert designers. These rules will ultimately be linked to parameterized geometric models. "When we have all of this in place, then we will have CAD," he says.

Once the main functions have been realized in terms of common and different part sets at a conceptual level, detail design begins in consultation with tooling designers. Manufacturing process design also begins, in consultation with assembly system designers. Cost analyses are done and redesign needs are discovered. When the parts are satisfactory, then shop floor equipment is designed.

Example Product Designed by These Methods

Morelli described a product that had been designed this way and is now assembled in a computer-controlled factory at Dijon. It is a miniature motor circuit breaker with an innovative arc-breaking mechanism. At least 72 varieties are made. Each unit has 76 parts, of which 28 are common to all varieties. It was designed and put into production over a period of 4 years ending in 1988, partly with French government funds. The objectives were similar to those of Nippondenso, Allen Bradley, General Electric, and several others who have sought to use design to make high-variety manufacturing easier: flexible production, easy changeover from one version to another, 100% test and zero defects, optimized production costs, and real-time computer management and control. An integrated product-process design team approach was taken, set up in a "skunk works" with top management support and special shielding from top management interference.

The assembly equipment consists of standard modules made by Telemechanique. Some provide transport; others are the foundations for either manual or automatic assembly workstations. The modules plug together so that mechanical, electrical, electronic, and pneumatic connections are made automatically. All interfaces to higher level communication networks are also made automatically. Several wide and local area networks are available as standard Telemechanique capabilities.

Parts are delivered with automated guided vehicles (AGVs). In his opinion this is a mistake. The main reason is that the vehicles cost so much and carry only a few low-cost parts. The tracks also take up a lot of floor space. They do not save much money because a person still has to unload the parts onto the workstation.

Design Data Management Software

Dr. David Pherson, former student of Prof. Boothroyd at the University of Massachusetts, described software he is developing to help manage design data. In this, his effort has much in common with that of Dr. Schacht at Siemens. That is, a lot of designs exist, and no one knows how to organize and sort the data about them. Even the MRP (Manufacturing Requirements Program) data for different varieties in the same family cannot be compared or checked because each is represented by a 6-inch-thick printout.

He is trying to use the MRP bill of materials (BOM) for something that perhaps it is not suited for. At any rate, he can show it graphically as a tree structure. At the leaves are the parts and their manufacturing processes. He can invert the tree and branch it out from common processes, to see what production capacity in each process he needs. He can also combine the BOM with the assembly sequence and figure out how much assembly plant capacity he needs, or how many instances of a kind of equipment are needed. In this way, the production impacts of design decisions in high-variety design can be readily determined.

CONCLUSIONS

M. Morelli is an interesting designer, researcher, and teacher who should be visited periodically. His methods present an interesting counterpoint to those of Nippondenso, another company whose systematic design methods I try to follow.

Topics for future research that emerge from this visit are:

1. Organization of design of products with many varieties. A great many products fit this description, perhaps the majority. However, only some have regular internal structures like relays have. Thus such products might present a useful subset on which to focus research. Later, products with less internal structure might be tackled. In either case, some of the issues involved include

- how to map the required functions across the spectrum of varieties so that a top-down design approach to the entire set can be undertaken (M. Morelli's table of varieties vs functions is an example of such a "map");

- how to design something for "upward compatibility," that is, with the knowledge that the above map will be incomplete and that additional versions will be needed later, will they fit in smoothly.

2. Composition of the product data model. As mentioned above, designing products with many varieties means designing a set of products at once rather than designing each member of the set individually. What inter-variety data are required in the PDM? In the report an example was made of capturing the functional and physical relationships between parts so that design changes can be propagated. Here, again, the content of the PDM reflects the needs of the design process and does not merely describe the product in a functional/physical way. Another PDM question concerns what kind of cost and process data are needed so that the module/part/subassembly tradeoffs can be made.

3. Communication between designers. In theory, if one person designs the entire set, this person will also be able to keep track of all the varieties and their implications. The "map" mentioned above would help. Keeping track may be more difficult when several designers are working, especially if a hierarchical approach is taken, that is, successive subdivisions of functions into subfunctions, etc. As the hierarchy gains levels, each lower level will have more elements in it, requiring more designers. These designers can stumble over each other unless some cumulative method for monitoring their work is put in place, especially if each level has more than one designer.

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Object-Oriented CAD and Expert Blade Design at Rolls-Royce

by Daniel E. Whitney

KEYWORDS: concurrent engineering; interferences; disassembly sequences; CAD; digital preassembly

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 does not make the cost or time to develop a new engine any smaller or the job any easier. It takes about 10 years and $1 billion, after a minimum of 6 years of preparing advanced technologies such as new materials. The development cost and complexity of new engines (and aircraft, too!) is driving the major manufacturers into strategic alliances, possibly ending in mergers.[1] One practical result in design research and development is that concurrent engineering (CE) 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 were not bad enough inside the same company, it will only be worse across companies.

Rolls-Royce is already dealing with multi-firm CE as it designs its new Trent engine for Boeing's 777 aircraft. Boeing has declared that all engine data be transmitted in CATIA and that several engine details be designed by Boeing. (CATIA is a solid modeling system marketed by Dassault Systems.) These include not only obvious things like engine mounts but also some pumps and pipes on the engine's exterior. Rolls-Royce (in the U.K.) converts its CADDS data to flat CATIA files and sends them by satellite to Boeing (in the

U.S.). [CADDS is ComputerVision's 3-D computer-aided design (CAD) system.] The designers communicate by phone a few times a week or send marked-up files back. Rolls-Royce also communicates electronically with dozens of vendors who make other components for the engine. Rolls-Royce 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 referred 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 for managing the CE process.

The digital preassembly model was built by using ComputerVision's new Assembly Design software, a product that originally was meant to support creation of assembly drawings based on three-dimensional (3-D) 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 many 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 by 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 by 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-and-balance control people have discovered it and are using it in place of cumbersome manual methods.

All this has flowed from a capability that was 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 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. Rolls-Royce 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 not satisfied with the "electronic drafting" offered by the first CAD systems and wanted 3-D 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 that 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 the geometry of some parts are very tightly related, so people doing that kind of work are collocated. But generally, problems are so complex and the number of people needed to solve them is so large that, in practice, collocated teams cannot be used 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, by name, phone number, and electronic mail address, who must work the problem out. The result is a virtual team, a "design cell." Since 75 percent 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. Although this may still be true, alterations are now much easier to make by 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 by 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 interestingly, 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 by using it, and the developer is confident that systems like it will win acceptance by the engineers.

CONCLUSIONS

Like the aerospace company Aerospatiale (see "Design-Build Teams at Aerospatiale," *ESNIB,* this issue), Rolls Royce 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.

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Materials

Third European Conference on Diamond, Diamond-like, and Related Coatings

by Max N. Yoder, Electronics Division, and Lawrence Kabacoff, Materials Division, Office of Naval Research; James E. Butler, Chemistry Division, Naval Research Laboratory; Kathleen Doverspike and Jaime Frietas, Electronics Division, Naval Research Laboratory; and M. Marchywka, Space Science Division, Naval Research Laboratory.

KEYWORDS: research directions; thermal conductivity; diamond defects; tribology; sensors

INTRODUCTION

The Third European Conference on Diamond, Diamond-like, and Related Coatings was held in conjunction with the Third International Conference on the New Diamond Science and Technology in Heidelberg, Federal Republic of Germany (FRG), 31 August through 5 September 1992. With 662 registered attendees, it was the largest diamond conference ever held. This record-setting attendance can be attributed, in part, to the combination of the two conferences. It also was a result of the rapidly increasing importance of artifact diamond technology in Europe—as shown by the 119 attendees from the FRG; this is more than double the number of German attendees from last year. The U.S. with 99 attendees sent the second largest delegation; this was followed by the U.K. with 58 and Japan with 50 attendees. There were 30 attendees from the former U.S.S.R. Presentations in the opening plenary session described diamond progress by region. "Diamonds in Europe" was presented by I. Buckley-Golder of Atomic Energy Authority Technology, Didcot, Oxfordshire, U.K.; "Diamond in the U.S." by one of us (M. Yoder); "Diamond in Japan" by Y. Sato of NIRIM, Ibaraki, Japan; and "R&D on Diamond Films in the former U.S.S.R." was presented by B. Spitsyn of the Institute of Physical Chemistry, the former U.S.S.R. Academy of Sciences, Moscow. These papers described representative recent progress; in the case of the U.S., they described new research directions as well.

OVERALL HIGHLIGHTS

The thermal conductivity of visually transparent polycrystalline diamond films can approach that of natural single crystalline diamond at room temperature or higher if the crystallite size exceeds 100-micrometer (μm) diameter. Room-temperature thermal conductivities as high as 24 W/cm-K were reported. These findings were typified by J. E. Graebner et al. of AT&T Bell Laboratories, Murray Hill, New Jersey. Polycrystalline diamond films synthesized specifically for thermal heat spreading applications can now typically be grown to 1-mm thickness and 10-cm diameter (G. Lu et al., Norton Diamond Films, Northboro, Massachusetts). Numerous poster papers addressed the issue of thermal conductivity as a function of crystallite size, but these generally were qualitative rather than quantitative. In what may be the largest current market for chemical vapor disposition diamond, heat spreaders for diode lasers, A. Katz of AT&T Bell Laboratories and colleagues described the fabrication and requirements of the laser submounts.

When diamond films are nucleated on carbide-forming substrates and on materials in which carbon readily diffuses, a period of time is required to saturate the substrate material with carbon before diamond will nucleate. This saturation mechanism is most prevalent in nickel. When used as interfaces in diamond-coated tools, carbide-forming intermediate layers should be relatively thin and backed by a carbon diffusion barrier. Results of this nature were typified by R. Haubner et al., Institute for Chemical Technology of Inorganic Materials, Technical University of Vienna, Austria. Closely related to these findings was the growing evidence that non-diamond forms of carbon films may be transformed into diamond. In fact, evidence shows that most diamond films grown today are deposited as non-diamond carbon; they are subsequently transformed into diamond in a continuous manner during the growth process. Although hydrogen appears to play a critical role in this process, details remain unresolved. This transformation was typified by O. Baybars et al. of the Max-Plank Institute of Stuttgart, FRG.

In what was perhaps the most interesting paper of the conference, X. Jiang and C.-P. Klages, Fraunhofer-Institut fur Schicht-und-Oberflaechen-technik, Hamburg, FRG, reported the growth of highly oriented diamond films on {100} silicon substrates. Even though the free-surface energy of diamond is 6 J/m^3 vs the 1.5 J/m^3 for silicon and the lattice constant is 34% smaller for diamond than for silicon, 80 to 90% of the diamond nuclei were oriented with {100} vertical axes and their {110} axes parallel to the {110} axis of the silicon substrate. At 3.6-μm thickness, the diamond "nuclei" were 10 μm across and spaced on 10-μm centers. The appearance was that of a checkerboard; however, individual diamond "squares" were not of equal height, implying that nucleation time varied among the various nucleation centers. Although the nucleation and growth process was not disclosed for proprietary reasons pending patent application, it was widely rumored that the silicon surface was treated with a light (shallow) patterned anisotropic etch prior to plasma-enhanced diamond deposition.

DEFECTS IN DIAMOND

Two oral sessions and numerous poster papers addressed defects in diamond. S. Dannerfaer, University of Winnipeg, Canada, described a novel approach to characterizing diamond. Positron lifetime analysis was used. It is based on the fact that positrons are trapped for different periods of time as a function of the defect type or vacancy. By using this approach, they were able to demonstrate that diamond impurity doped with boron at concentrations of 500 ppm exhibited no carbon vacancies and that without the boron, carbon vacancies exist in clusters. G. Davies, King's College, London, U.K., discussed the vacancy complexes that resulted after annealing radiation damage in type Ia and Ib diamond. After irradiation, both Vo and V- defects were found; after annealing, both vacancies capture N and form H3(N-V-N) complexes. The most interesting result was that from analysis of the production rate of Vo and V- and the decay of Vo and V- during annealing; it appears that there is an unexpected preferential creation of vacancies near nitrogen impurities.

A trans-Atlantic team of J. Freitas and U. Strom, Naval Research Laboratory (NRL), Washington, DC, and A. Collins, Kings College London, U.K., revealed a new vibronic defect band (with zero phonon line at 2.395 eV.) Although this band has been previously observed in natural diamond, it was found to be much more intense in HPHT diamond. A new red band centered at 1.9 eV and observed in artifact semiconducting diamond is believed to be associated with recombination involving boron acceptors and a deep unknown donor. Photoluminescence and cathodoluminescence were both used in the characterization.

Perhaps the most sensitive, but also time-consuming measurement of defects in diamond is the well-know X-ray topograph. Three papers described X-ray topography in diamond. M. Moore et al., Royal Holloway College, University of London, Egham, Surrey, U.K., described the use of a synchrotron to provide intense monochromatic beams, which significantly reduces measurement time or improves sensitivity. Another significant paper by D. Black et al., National Institute of Standards and Technology, Gaithersburg, Maryland, demonstrated that artifact diamonds of type IIa are almost always superior to commercially available natural material.

GROWTH

There were 14 presentations on diamond growth, 4 on c-BN growth, and more poster papers on this subject than on any other. M. Nunez-Regueiro, Centre Nationalde la Recherche Scientifique, Grenoble, France, demonstrated that fullerenes could be transformed into crystalline diamond at a pressure of 15 GPa. Unfortunately, the method (although of academic interest) appears to have no advantages over conventional HPHT processes and uses more expensive starting material.

The carbon-hydrogen-oxygen phase diagram for the growth of diamond at subatmospheric pressures was originally defined by P. Bachman as being in the form of a wedge. P. Bachman et al., Philips Research Laboratories, Aachen, FRG, further delineated the phase diagram It is no longer thought to be wedge-shaped, but is now thought to be more like a hemisphere. According to the diagram, it should be possible to grow diamond by using C_2H_2 as the hydrocarbon source, but in their high-power microwave system they encountered much difficulty. They concluded that nitrogen impurity in the gas must be responsible for the low-quality films that they obtained. They were, however, able to use the same C_2H_2 feedstock to obtain high-quality diamond by using the combustion technique. The effect of nitrogen on the quality appears to be very different in the two systems. Growth/no growth near the $C/C+O = 0.5$ ratio is very abrupt. On the carbon-rich side of the equation, delineation between diamond and DLC is less well-defined.

The highest substrate temperature growth (1200°C) for microwave plasma-enhanced diamond grown films was reported by A. and T. Badzian, Penn State University, University Park, Pennsylvania. Not only was this the highest temperature ever reported for growth in such a system, but the film quality as measured by Raman spectroscopy was also the best ever reported (FWHM of 1.7 cm^{-1}) for diamond films.

New nonmetallic catalysts were reported by M. Akaishi, NIRM, Ibaraki, Japan, for the growth of HPHT diamond. These included Li, Na, Mg, Ca, and Sr and their hydroxides. These are very electropositive elements and have previously been suggested as donor impurity dopants for diamond. This is the first known attempt to synthesize n-type HPHT-grown diamond with these impurities. In separate theoretical work in the U.S., J. Whitten, North Carolina State University, Raleigh, North Carolina, has theorized that the subcutaneous presence of electropositive elements such as these and/or hydrogen will predispose carbon atoms attaching to the diamond "seed" surface to bond in sp^3 (diamond) rather than sp^2 (graphite) configurations.

K. Doverspike et al., NRL, presented work introducing a new method of impurity doping films grown by the open oxyacetylene torch. The impurity doping was achieved by injecting aerosol droplets (produced by an atomizer) containing the dopant species into the premixed torch gases. Results confirming the activation of silicon and boron doping were presented. The photoluminescence spectra of B-doped films show the same spectral features previously observed in HPHT B-doped diamonds (i.e., green and red bands.) This technique will soon be investigated for n-type doping.

Cubic boron nitride (c-BN) is an interesting material in its own right, but for this conference its potential as a substrate for single crystalline diamond was of greatest importance. For this reason, four papers relating to its synthesis were presented. Unfortunately, progress is not significant, and the synthesis of c-BN remains more difficult than that of diamond.

An interesting new correlation of diamond film quality with optical emission spectroscopy of the growth plasma was made by J. Lewis and R. Dillon, University of Nebraska, Lincoln, Nebraska. They found that the lower the ratio of CH emissions to hydrogen alpha emissions, the better the films quality. They also found that diamond films synthesized from CO gas sources were of better quality than those produced with equal atomic concentrations of CH_4 and O_2.

The fastest diamond film growth rates ever reported by diffusion-dominated microwave plasma reactors—15 μm/hr—were reported by E. Sevillano et al., Applied Science and Technology Inc., Woburn, Massachusetts. The increased growth rate is attributed to a 5-kW power source and improved flow dynamics of the ASTEX reactor.

Reflection Electron Microscopy (REM) as a new real-time characterization tool was briefly described by M. Yoder, Office of Naval Research, Arlington, Virginia, in the plenary session. H. Kawarada and H. Sasaki, Waseda University, Tokyo, used the REM to examine the effects of boron during diamond growth. Here it was found that surface roughness and free-surface energy was considerably reduced by the presence of boron. Boron also was observed to improve the surface mobility of carbon atoms and carbon precursors on the growth surface.

Electromagnetic coupling to hydrogen plasmas with a parallel plate configuration is known to be notoriously poor. Nevertheless, the first report of diamond films by this method using RF (not microwave) excitation was given by Y. Shimada et al., Tokyo Denki University, Tokyo. A 50-nm thick iron film was used over a silicon substrate to significantly enhance the nucleation of diamond.

The first reports of diamond growth by supersonic jets were made at this meeting. In addition to the brief tutorial given in the plenary session, "Diamond in the U.S." (M. Yoder, ONR), two papers addressed the issue. These two papers, however, were plasma assisted, and the monoenergetic control (of the growth species impacting the substrates) of the supersonic jet approach was lost. Nevertheless, this is an area in which considerable progress is expected in the next year. S. Girshick et al., University of Minnesota, illustrated the dramatic effects of controlled amounts of kinetic energy on the growth surface. Kinetic energy was used to control the effective thickness of the boundary layer and could be used to change between diamond and graphite deposition. The kinetic energy was imparted by adding argon through the injector (along with H_2 and CH_4) into an atmospheric pressure induction plasma. The addition of argon increased the momentum, reduced the boundary layer thickness, and appeared to widen the window for diamond growth.

TRIBOLOGY AND WEAR

Hydrogen-terminated diamond is known to have a coefficient of friction equivalent to that of teflon; as such, four papers were devoted to friction and wear of diamond. The most interesting of these was by Y. Tzeng, Auburn University, Auburn, Alabama, and accompanying authors. They reported that in ultra-high vacuum the hydrogen termination of the surface is not replaced during friction, and that without the surface termination, frictional values become very high. In contrast, with water termination, the lowest frictional values ever reported for diamond were given: 0.001.

SENSORS

Strain causes a splitting of the degeneracy of the heavy and light holes in the valence band of diamond. This leads to a piezoresistive effect; the light holes exhibit a greater mobility than do the heavy holes, and their relative abundance is controlled by strain. M. Tamor, Ford Motor Company, Dearborn, Michigan, described experiments wherein he determined that the gauge factor for diamond exceeds that of all other known materials. Although it is 20 times that of silicon at room temperature, its relative figure of merit improves with temperature.

TOOLS

Diamond-coated cutting tools are expected to soon gain widespread use. The biggest technological problems have to do with adhesion of the diamond film to the tool base. Because of the proximity and potential magnitude of this market, a special session was devoted to Tools and Mechanical Properties. Although much characterization of adhesion was reported, the particular methodologies used to adhere the diamond coatings were largely omitted as proprietary.

OTHER FINDINGS AND APPLICATIONS

Diamond-like carbon (DLC) films appear destined for protective coatings for infrared detector windows, radomes, and similar applications. Approximately 50 DLC papers reported nominal progress on understanding the growth and properties of these films. This is a maturing technology; there appeared to be no significant advances in this area.

J. Bade et al., Kobe Steel, Research Triangle Park, North Carolina, presented work illustrating the use of polycrystalline diamond films for high-temperature thermistors. Although the diamond was well-behaved and stable at temperatures to 500°C, much work remains to be accomplished with ohmic contacts to the diamond.

L. Pan et al., Lawrence Livermore National Laboratory, Livermore, California, presented work on charge carrier mobility in polycrystalline diamond films grown by Crystallume. He described a record room-temperature mobility of 4000 cm^2/V-s as measured by photoconductivity (e.g., combined electron + hole mobility). This compares to 3500 cm^2/V-s for the best recorded measurement for natural type IIa diamond. They have also found that charge carrier lifetime in the artifact films can be as much as 50 percent greater (measured values to 1 nanosecond) than that found in natural diamond. These results bode well for the use of these materials as ultraviolet photodetectors. M. Landstrass et al., Crystallume, Menlo Park, California, also compared the mobility for doped and undoped films. Mobility was shown to be strongly dependent on impurities (500 and 200 cm^2/V-s for phosphorous and boron doped polycrystalline films respectively.) Many of the unusual photo-response characteristics previously found in HPHT diamond were observed in these polycrystalline films.

Unlike silicon and germanium, H. Maeta and K. Haruna, University of Tamagawa, Tokyo, found that diamond does not exhibit a negative thermal coefficient of expansion at cryogenic temperatures.

V. Ralchenko et al., General Physics Institute, Moscow, the former U.S.S.R., found that iron, nickel, and platinum (in that order of efficacy) have a catalytic effect in etching diamond films. When these metals were deposited as films of fractional to 10-μm thickness on diamond and exposed to molecular hydrogen at 950°C, they clearly etched the diamond underneath without being consumed. The carbon beneath the films diffused through the films to the upper surface, whereupon it was methanated by the hydrogen. Etch rates of 10 μm/minute were obtained for iron films. J. F. Prins, University of Witwatersrand, Johannesburg, South Africa, described implantation-assisted etching techniques. Annealing at various times before and after etching produced different effects and can be used to determine the origin of "bumps" sometimes seen in the etched regions.

PERSPECTIVE

Although the advances reported by U.S. organizations still appear to lead those of European groups, the European R&D base is growing at a faster rate; their productivity is expected to exponentially increase in the next two years. A new surge in Japanese work is anticipated as Japan announced a new five-year, $16M program at the NIRIM facility.

Oceanography

Overview of Articles on Former Soviet Union

by J.P. Dugan and Larry Jendro. Dr. Dugan is an oceanographer currently serving as a Liaison Scientist for Physical Oceanography for the Office of Naval Research European Office. Previously he formed and directed the Field Measurements Department for Arete Associates. Earlier, he was at the Naval Research Laboratory, Washington, D.C. Larry Jendro was the Liaison Officer for Oceanography and Environmental Systems at the Office of Naval Research European Office. Following his retirement from active military service, he currently is Chief, Science Branch, Ice Operations Division, U.S. Coast Guard Headquarters.

KEYWORDS: joint studies; unknown literature; organizational differences; liaison visits; funding

INTRODUCTION

This article introduces a series of contributions to *European Scientific Notes Information Bulletin* (*ESNIB*) that concern relations with oceanographers in the former Soviet Union (FSU). We feel that it is important to understand how these scientists work and how their institutes operate. In these articles we hope to facilitate the entry of these scientists into the world scientific community.

We have organized a series of articles in this and following issues of *ESNIB* that are about FSU oceanographic institutes, the scientists, and their research and activities. This introductory article reviews our organization, our goals, and the tools available to us.

ONR European Office

Objectives of the Office of Naval Research European Office include discovery of new advances in European/Middle Eastern science and technology, reporting this to the U.S. scientific community, facilitating direct communication between U.S. and European scientists and organizations, and even initiating collaborative U.S./European research projects. The geographic area of responsibility, though not the specific goals of the organization, has been extended to include Central Europe and the former Soviet Union.

This extension of coverage toward the East is timely because many scientific activities, organizations, and personnel are not well known in the West. There really are a number of good reasons to do this. Specifically, it will open communication channels that might permit us to:

- evaluate novel techniques,
- use unique assets and infrastructure,
- explore possibilities for possible joint studies,
- access previously inaccessible territory, and
- access unknown literature.

Even before entering this effort, we have been aware that Russia in particular has unique capabilities that U.S. oceanographers can only admire. Specific examples are very capable ice breakers, strong infrastructure for maintaining ice camps in the high Arctic, and research vessels designed from the keel up for underwater acoustics research.

The Office has made scientific liaison visits to scientific institutes in the FSU for many years; this has intensified in the last five years. Liaison scientists and naval officers have attended numerous technical meetings, participated in and reported meetings, and written a number of meaningful technical assessments of their findings in such diverse fields as structural acoustics, solid state physics, power physics, atmospheric electricity, biotechnology, and efforts to market technology and scientific products and services supporting oceanographic research.

These visits have had significant impact because they have provided comprehensive assessments of the science and technology by highly regarded scientists from the ONR European Office. In addition, they have significantly expanded scientist-to-scientist contacts with this community. Many of these contacts have resulted in further contact with scientists and scientific managers in Navy, Army, and NASA laboratories, and in U.S. universities.

At present, the discipline of oceanography has been under-represented in these assessments. This is a strong discipline in the FSU with many institutions and numerous highly regarded scientists, and it is appropriate at this time to emphasize this area. The opportunity is available now; there are numerous contacts among present ONR European Office scientists and naval officers and oceanographers in the FSU.

This effort simply is an extension of liaison duties toward these new countries. Unfortunately, we have only a few tools at our disposal. These tools are scientific visits to these institutions by ONR European Office staff and communicating to the U.S. through our publications the information that is found to the U.S. We also can provide financial support for workshops in Europe and travel by foreign scientists to research institutions in the U.S. The articles that follow in *ESNIB* are part of the communication efforts in all these areas. A complementary part of the communication of findings to the U.S. scientific community is the *ONR European Office Oceanography Newsletter*.[1]

Before introducing the articles, some of the problems that make it difficult to accomplish the forementioned goals should be reviewed. First, substantial cultural differences in the organization and funding of various scientific organizations in the FSU creates an entirely different approach to science activities and reporting of results. In the West, scientists are involved in obtaining support from sponsors of their research; in the East, this typically has occurred through the structure of the institute. Thus, the responsibility of the individual scientists for determining the future of the work and communicating it to others is lost within the institute. In addition, since there has been no perceived competition, there has been no importance placed on assessments of the state of the art on a national or international level. Thus, there has been no motivation for communication between institutes on either a managerial or scientist-to-scientist basis.

We think this has resulted in technical papers that are so short and uninformative as to make any realistic assessment of the value of the work almost unattainable. This has been made more difficult because of the notable lack of capability, resulting from both language and facilities, of communicating with Western scientists.

SUMMARY OF ARTICLES

The first article in the series is contributed by Dr. Robert Heinmiller who is the founder and owner of the OMNET communications network that is so well used by oceanographers on an international scale. Dr. Heinmiller was the U.S. Executive Manager of the U.S.-Soviet POLYMODE oceanographic project in the 1970s and early '80s and, as such, was responsible for coordination and plans. This included the very important area of communications, that at the time was very difficult in the Soviet Union. Dr. Heinmiller and Dr. Curt Collins, who was the U.S. National Science Foundation sponsor and currently is with the Naval Postgraduate School, recently published an excellent article reviewing the relations between American and Soviet oceanographers during that project.[2] The present article that Dr. Heinmiller has written at our request concerns recent relations and communications with FSU scientists, and he includes his recommendations on how to improve them.

The second article is an assessment by one of us as a result of a liaison visit to the Arctic and Antarctic Research Institute (AARI) in Saint Petersburg, Russia. The work of this institute is especially interesting because it is not generally well known, even though AARI is the lead institute in Russia for research, operations, and forecasts in the Arctic. The article provides an overview of the history and organizational structure of the institute and in-depth reviews of the work of several departments and laboratories.

Two additional articles are included in this issue. One reviews the NATO Advanced Study Institute on Acoustic Signal Processing for Ocean Exploration, which drew significant interest from FSU scientists. The other describes wave research being conducted at two Institutes in Nizhny Novgorod, Russia.

Articles scheduled to follow in upcoming issues of *ESNIB* include institutional assessments as a result of visits to four other major oceanographic institutes in Moscow and Sevastopol. In addition, one article already published[3] concerns an international program involving Russia, Crimea, Bulgaria, and Romania. In that article, Dr. Aubrey and his colleagues on the Steering Committee of the Cooperative Marine Science Program for the Black Sea have provided the plans and successes to date for cooperative oceanographic work by the five countries surrounding the Black Sea, namely Turkey and the four from the former Soviet Union enumerated above.

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2. Curtis A. Collins and Robert H. Heinmiller, "The POLYMODE Program," *Ocean Development and International Law*, Vol. 20, 391-408 (1989).

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Scientific Collaboration and Communications with the Former Soviet Republics

by Dr. Robert Heinmiller, founder and president of OMNET Inc., which is the international electronic mail facility most used by oceanographers. He was previously the Executive Manager of the bilateral U.S. — U.S.S.R. POLYMODE physical oceanography program.

KEYWORDS: POLYMODE; data network dial-in nodes; OMNET; bulletin boards; mailboxes

PAST AND PRESENT

With the disintegration of the Soviet Union has come a heightening interest and an increased ability to work with earth scientists from Russia and the other republics of the former U.S.S.R. Ironically, this interest comes at a time of great uncertainty for their science and scientists. But, perhaps this makes it all the more important to lay the groundwork now for future collaborations. As the old adage reminds us, the best time to plant a tree was twenty years ago. As an aside, everyone, including scientists, are wrestling with the problem of how to refer easily to the country or countries that used to be the Soviet Union. "The republics of the former Soviet Union" doesn't roll off the tongue, while "Commonwealth of Independent States" somehow doesn't seem to be a useful reference, even though the U.S. Department of State refers to this area both ways.

Although the scientific system in Russia and the other former Soviet republics is changing, it is not at all clear yet if the new system will be better (or even a system at all), but change surely is occurring.

There is no denying that much past experience in U.S./Soviet collaboration was difficult and unsatisfying.[1] But, the past difficulties generally arose from technical and systemic problems, not from lack of scientific expertise or interest.

POLYMODE

The author was U.S. Executive Manager of POLYMODE, a U.S.-U.S.S.R. bilateral program in physical oceanography from the mid-1970s to the mid-1980s. In POLYMODE, concerns about security and complicated bureaucratic procedures, for instance, would block communication, sometimes indefinitely, thereby seriously impeding research efforts. Early in the program, it took two years to come to an agreement to install telex machines to facilitate POLYMODE program-related communications.

Even after the machines were installed at the Massachusetts Institute of Technology (MIT) in the United States and at the Shirshov Institute in Moscow, it often took two to three weeks for turnaround of information. The telex medium was too inaccessible to the scientists. It required (on both sides) the intervention of an expert operator to send or receive information. In addition, it was site-specific: one did not send a message to Scientist A; one sent a message to a physical machine, regardless of where Scientist A happened to be. When, or if, Scientist A got the message depended on where he was, the energy, good will and expertise of the telex operator, and, often, office politics, or worse.[1]

COMMUNICATIONS TODAY

Today, however, communication is perhaps the fastest changing technical area within that part of the world, and the implications for scientific collaboration are enormous. Although it is difficult to get through on the few international telephone lines into these countries, fax machines are becoming common. Western export restrictions on computers and peripheral equipment, such as modems, have eased.

Western communications companies are installing facilities within these countries. For example, Sprint International has commercial data network dial-in nodes in Moscow and St. Petersburg.

Also—to varying degrees in each republic—we are witnessing the rise of a new entrepreneurial class eager to speed the introduction and implementation of new technologies. (OMNET has been approached by people interested in developing cooperatively and selling databases, packet-switching networks, consulting services, satellite terminals, communication channel time, and even precious metals and commodities.)

ELECTRONIC MAIL

Several electronic mail options are available within the country. Some research institutions have had access to Fidonet or Bitnet for years. Internet connections between Russia and Western Europe are spreading. The nonprofit San Francisco-Moscow Teleport (SFMT) operates video and electronic mail services to promote understanding between the two countries.

During the aborted coup attempt in August 1991, although it was difficult to communicate via telephone since the lines were constantly tied up, electronic mail communication with the outside world exploded as Westerners fed news reports to people within the U.S.S.R. and received and relayed updates of the resistance. On SCIENCEnet, we received reports of the overnight construction of barricades in St. Petersburg, for instance.

OMNET's SCIENCEnet service has had subscribers in the Soviet Union with the ability to communicate with restricted groups since 1988. Since 1990, SCIENCEnet subscribers in the U.S.S.R. (now Russia and the other republics) have had open communications with all people on SCIENCEnet, reading and participating in all public bulletin boards and discussions, exchanging messages with scientists on other networks, and accessing authorized database information.

Presently, SCIENCEnet has mailboxes in Moscow, St. Petersburg, Kharkov, Kazan, Tomsk, Obninsk, Sevastopol, and other locations. The way in which mailboxes are used varies. Some communication is individual one-on-one personal communication from a particular Russian scientist. Some mailboxes are used for all individuals in a single department, or an entire institution or facility. In other cases, mailboxes have been set up for data exchange or agency communications rather than for personal communications. For example, the World Data Center B in Obninsk exchanges information with the National Oceanic and Atmospheric Administration in the United States.

THE NEEDS

Easy access to Western scientists and information will pull Russian scientists quickly into the mainstream of international earth science. Even without funds and resources to travel widely, they can have easy access to information about the most current research and on-going programs. Without needing to literally "be there," they can, in fact, begin to observe and participate.

There are still formidable technical obstacles to overcome. The internal phone system is primitive and marginal. There are no comprehensive internal data networks. Personal computers and modems are still too few, and it is still difficult to obtain training, parts, and service. Hard currency to buy Western equipment and services is scarce.

On the positive side is the enthusiastic attitude with which scientists have embraced the idea of communication and joint cooperation with earth scientists elsewhere. Network access to earth scientists in the West is the least expensive and fastest way to incorporate Russian, Ukrainian, and other former Soviet researchers into the world's earth sciences research community.

But, more support from the West could be provided.

Western agencies or individuals can supply equipment. It does not have to be expensive or sophisticated. A 2400-baud modem attached to what many might see as an outmoded personal computer is a window to the world for a Russian scientist, his department, or even his whole institute.

Communications funding support saves valuable hard currency resources. Woods Hole Oceanographic Institution has funded mailboxes at two laboratories in the Ukraine, and has also helped to provide the basic equipment necessary to use the mailboxes. Lamont Doherty Geophysical Observatory is considering doing the same.

Scientists in Russia and the other republics want meaningful scientific collaboration with individuals, agencies, and programs in the West. Recently, a plea was posted on a SCIENCEnet bulletin board from a Russian oceanographer in St. Petersburg. Messages had been posted asking about sending food and medical aid. The response was: "ONLY Russians can save Russia, but if some American scientist can collaborate with a Russian colleague — please do that!"

THE FUTURE

The development of a strong political, economic, and technologically appropriate infrastructure will take many years, and not until stability is reached in those areas will we be able to expect complete involvement and participation by Russian scientists with the rest of the world's research community. The explosion of communications capabilities within the country, and easy access to international research networks, will greatly hasten that process.

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What is the Present and Future for Arctic Research in Russia?

by J.P. Dugan

KEYWORDS: Arctic; sea ice; oceanography; marine meteorology; forecasts

INTRODUCTION

The Russian oceanographic institutions are among the largest in the world, and the single Russian institute responsible for all polar operations and research, the Arctic and Antarctic Research Institute (AARI) in St. Petersburg, is no exception. As is the case with other oceanographic institutions in Russia, AARI and its scientists are presently struggling for their continued existence.

This article provides a broad introduction to AARI and a detailed assessment of some of the work in the research and forecasting departments. In doing so, it provides a current picture of the working conditions of scientists in northern Russia. The plight of the scientists has been well publicized in the U.S. over the last year, but the real impact on the present work and future plans have not been known to us. In addition, since many scientists of this Institute have not published in literature easily available in the West, this provides an opportunity to find out what they have done in the past, to get some insight into what they do well at present, and what their plans are for the future. Specific areas covered include ice mechanics, forecasting of ice conditions, air-sea-ice interactions, physical oceanography, marine meteorology, ship model testing, and expedition support.

AARI is one of 23 laboratories administered by the Committee on Hydrometeorology, now called the State Committee for Hydrometeorology and Monitoring of the Environment, which is in the Ministry of Ecology and Natural Resources of the Russian Federation. AARI is responsible for all scientific and operational activities associated with the polar regions. Included in this broad charter are observations and forecasts in support of operations on the Northern Sea Route, operation of research vessels, supply and operation of Antarctic stations, and research in both polar regions. The Institute is located in St. Petersburg near the Primorskaya Underground station in close proximity to the Gulf of Finland in the northwest part of the city. It is situated in a large six-year old building that looks much older and worn down because of lack of ordinary maintenance.

The Director of AARI is Dr. Boris A. Krutskikh, but he apparently is rather old and was not available during my visit. He has traveled in the West, so is known to some scientists in the U.S. The Deputy Director for Research is Dr. Yevgeny Nikiforov who has previously been involved in the International Arctic Buoy Programme, so he also is known on the international level. Dr. Nikiforov provided an overall briefing about the Institute, including its history and present organization, and made arrangements for visiting several laboratories in the Institute. All interactions with non-Russians are handled by Sergey V. Karpekin, the Deputy Director for Foreign Relations, and he actually made the detailed arrangements for my liaison visit. He is aided in this by Sergey Pryamikov, Head of the Department of Science Cooperation. The two remaining senior administrators are Dr. Nikolai A. Kornilov, Deputy Director for Expeditions, and Andrey P. Dogonov, who is a Deputy Director without portfolio.

HISTORY AND GENERAL OBJECTIVES

The history of AARI is directly connected with the Soviet history of exploration and development of the Northern Sea Route. A predecessor institute was established in 1920 to help solve important practical needs of cargo and passenger transportation along the Siberian coast; this was important for developing the natural resources in the Russian (then Soviet) North. It was renamed the All-Union Arctic Institute in 1930, with a major goal of preparations for the first complete voyage across the Northern Sea Route between the North Atlantic and North Pacific in one summer season. This was successfully completed in 1932, and emphasis was shifted to studies of Arctic natural wealth and development of meteorological and marine forecasts to support navigation on the Northern Sea Route.

In 1956, the Soviet Union joined the Antarctic Treaty nations in studies of Antarctica, initially by participating in the International Geophysical Year efforts, and the Institute was renamed shortly thereafter to accommodate the extension of its charter to the Southern Ocean and Antarctica. It was brought under the Committee for Hydrometeorology in 1963, and it now is experiencing an accelerated rate of change as a result of the recent changes in the national government. The present charter continues to be very broad, but a major element of the ongoing activity is research and development to extend the navigation season on the Northern Sea Route to year-round activity.

Over the many years of work in the north, AARI has developed observational and forecasting capabilities to support large developmental activities, including shipping along the coast and up the rivers. A strong capability has been developed for planning, logistics, and research associated with lengthy polar expeditions, with many successful Arctic drifting stations to their credit. Present studies include polar oceanography, hydrophysics of polar and inland waters, meteorology, air-sea interaction, geophysics, physical and mechanical properties of sea ice, glaciology, physiology, hydrochemistry, hydrology of river deltas and water resources, ecology, ship interactions with ice, and polar medicine.

GENERAL ORGANIZATION

According to Dr. Nikiforov, the efforts of the Institute fall into four general groupings: science, the science research fleet, Russian Antarctic Expedition, and ice information. Departments and their present heads are listed in Table 1.

As an organization, AARI is a combination of many departments that are only marginally dependent on one another. The organization is very complex, causing more than a moderate amount of difficulty in determining just what each department does and how it fits into a simple picture of the whole organization. AARI is a forecasting center that in some ways is equivalent to the Navy-NOAA Joint Ice Center in Suitland, Maryland. In addition, it is a research center similar in some ways to the Naval Research Laboratory (parts of all three locations), other government laboratories (Cold Regions Research and Engineering Laboratory,

Table 1. AARI Departments and Heads

Department	Head
Arctic Regional Hydroecology	Alexander,P. Grayevsky
Estuaries Hydrology and Water Resources	Ing. Vladimir V. Ivanov
Geography of Polar Countries	Vladimir N. Petrov
Geophysics (Upper Atmosphere)	Oleg Troschichev, Lev Metlyaev (deputy)
Ice and Ocean Physics	German A. Lebedev, Peter D. Korobov
Interactions Ocean/Atmosphere/Ice	Henrikh V. Alexeyev
Long-Range Weather Forecasts	Nikolay D. Vinogradov
Meteorology	Andrey P. Nagurny
Murmansk	Vladimir P. Ulyanov
Oceanography	N.V. Mustafin, Vladislav I. Zhukov (deputy)
Polar Medicine	Valery P. Klopov
Polar Atmosphere Energetics	Vladimir F. Romanov
Research and Development of Hydrometeorological Stations	Rudolf A. Balakin
Science Expeditions	Nikolay A. Kornilov
Sea Ice and Sea Ice Forecasting	Albert A. Romanov
Ship Performance in Ice	Vladimir A. Likhomanov
Arctic and Antarctic Museum	Nikolay G. Yagodnitsyn
Centre of Sea Ice and Marine Meteorological Information	Anatoly L. Sokolov
Laboratory for Geochemical Monitoring and Analytical Chemistry	Sergey A. Melnikov

Arctic Submarine Laboratory, etc), and numerous Office of Naval Research and National Science Foundation contractors in universities, and industry. It is an instrument-development laboratory similar to many of our instrumentation companies. Finally, it is a logistics center like the combined effort of our Naval Support Force Antarctica, the Polar Science Center of the University of Washington, Polar Associates, Inc., as well as others.

In total, there are about 2000 employees including the crews of the six ships operated by the Institute, so it indeed is a very large organization. In reality, though, it probably is not much larger than the combination of all the U.S. organizations, only a few of which are enumerated above, involved in polar activities.

ACTIVITIES OF THE DEPARTMENTS IN MAJOR AREAS

Sea Ice and Ice Forecasts

Sea ice is a major physiographical feature that dominates all operations in the polar regions, and it therefore receives considerable attention. Primary subjects of importance include its variability in space and time, its interaction with our climate, and its effects on human activities. Logically for Russia, the focus of work on the effects of sea ice on human activities is on the efficiency and safety of transportation.

Additional subjects that seem to have recently joined the above short list is the effect of man on the environment and the interaction of the Arctic with world climate.

The primary activities supporting these subjects are research and its practical applications. These applications include periodic forecasts of sea ice distribution and properties, manuals and instructions, reference material, and recommendations. These activities are undertaken by the Department of Sea Ice and Sea Ice Forecasting and the Centre of Sea Ice and Marine Meteorological Information. The forecasting center is of much interest to us because AARI has long had high confidence in their forecasts for ice conditions. As is well known, they make forecasts into the future for short range up to 30 days, long range up to 6 months, and super long range, for a full season or even several years. They make these forecasts on the basis of all information, including archived data and recent observations. The details of how they do this, and how accurate they really are, remain subjects of high interest. The answers to questions to date have been largely unsatisfactory, because they have not been in a form that can be judged objectively or duplicated.

Briefly, the forecasters appear to rely heavily on statistics available from their data archives. These departments have at their disposal unique archives on the distribution of sea ice properties. Much of it has been obtained from long-term time series at specific locations, namely Arctic and Antarctic coastal stations including ones on the meteorological network. In addition, considerable amounts of data are available from the many drifting research stations (total of 75 station-years for the North Pole stations), automatic drifting buoys, shipboard observations, aerial reconnaissance, and satellite imagery. The shipboard observations are made from icebreakers and cargo ships of opportunity. The specific data are statistical and probability indices that characterize the state of sea ice at any location and time. The number of data types is very large, including the location of the ice edge and of ice islands, ice extent, number of floes, age, thickness, concentration, degree of ridging, mechanical properties, snow depth, and freezing and melting dates.

The forecast products include ice charts and text messages, with specific recommendations as to the best ship route and alternatives, estimated difficulty, and best speed. In addition to the statistical models used for forecasting, there apparently are operational products based on mathematical models of ice evolution that simulate the fields of drift, strains, thickness, and concentration. I was not actually provided results from an operational forecast, although I asked to see them.

The Department of Sea Ice and Sea Ice Forecasting has five laboratories and about 70 employees. It is headed by Dr. Albert A. Romanov, who is an expert in Antarctic navigation. The laboratories are:

- Laboratory for Numerical Methods (I. Appel)—10 people using PC-level machines for developing forecasting models

- Laboratory for Long Term Ice Forecasting (Igor Carillon)—statistical approach, from 1 to 6 month forecasts

- Laboratory of Antarctic Studies (A. Romanov clearly leads the work)—includes all but numerical methods. This laboratory ran the Weddell Sea experiment over austral summer 1991/92

- Laboratory of Ice Regime (Ivan Frolov, Head of Working Group on Ice Cover of World Meteorological Organization (WMO), that is responsible for nomenclature and operational reporting)—goal is to "generalize" all previous observations, by producing charts and a data bank. Works with World Data Center B in Obninsk

- Laboratory of Study of Ice Conditions for Navigation—estimates of ship speed as function of ice conditions; involved in the Northern Sea Route Program.

I had the opportunity to have a very long discussion with Dr. Igor Appel, Head of the Laboratory for Numerical Methods. He is unusual in my brief experience with Russian scientists in his persistence in attempting to market the research by his Laboratory to any and all potential sponsors. One area in which his group obviously is very strong is research in methods to improve the Institute's support of shipping on the Northern Sea

Route. This research is a combination of oceanography in shallow water, northern coastal meteorology, ice mechanics and thermodynamics, and forecasting methodology. When this research is combined with the specific region of application, namely the Russian northern shelves where they have unique experience, this subject clearly must be of high interest to ONR and the U.S. Navy. I highly recommend that discussions of collaboration in this specific area be pursued as soon as it is possible to do so.

Department of Ice and Ocean Physics

This Department is headed by Dr. German A. Lebedev who is an expert on hydroacoustics, which is the Russian term for acoustics in the ocean. He was ill during my visit so I was not able to meet him. I did talk with Dr. Igor Popov of the Laboratory for Acoustics and Optics of the Ocean. Ostensibly, this Department, and this Laboratory in particular, is especially short of funds at present because of the loss of Soviet Navy support of their research. The Department has about 60 scientists. This is significantly less than the number of about 100 several years ago. The laboratories in this Department are:

- Laboratory for Physics of Ice (Dr. Victor N. Smirnov)—wideband vibrations of sea ice, instrumentation, 16 scientists

- Laboratory for Radiophysics (Dr. Spitsyn)—radio location of ice, measurements of thickness, temperature, and all other characteristics; uses IR, optics, and microwave

- Laboratory for Acoustics and Optics of the Ocean (no present head; Dr. Gusev has emigrated to Germany and a new head has not yet been appointed)—this lab is down to 10 people, apparently due to lack of funds

- Laboratory for Improving Experiments (Dr. Gavrilo)—development of methodology for experimental techniques and instruments

- Laboratory of Crystalline Structure of Ice (Dr. N.V. Cherepanov)—located at branch on Ladoga Lake 100 km distant; ice structure and growth in laboratory only.

This Department has had a long history of collecting data on the physical properties of sea ice and snow. They have been very strong in describing the morphology and physical (mechanical, acoustic, thermal, electric, and optic) characteristics of sea ice. This has included polarization characteristics, radio emissions, and radar backscatter characteristics. These observations have been helpful in developing algorithms for interpreting UHF signals measured by an airborne laboratory and of IR images obtained from satellites. Much of this work has been published in numerous manuals and reference books, many of which have been available in Russian and some of which have been translated in the past.

The Department also has done considerable research on the icing of ships and marine structures in polar regions. They also have been active in the determination of ice loads on structures, and have experience in building and maintaining ice bridges and cargo platforms on sea and fresh water ice.

The Head of the Laboratory for Physics of Ice is Dr. Victor Smirnov. I had previously met him at a meeting at the Scott Polar Research Institute of the University of Cambridge.[1] We have a lot in common because of our previous research on the natural vibrations of sea ice. Presumably because he knew me personally, he attended to my accommodation, meals, and transportation needs while in St. Petersburg, a feat that is difficult to convey in a few words if one has not recently visited a Russian city.

Dr. Smirnov and I spent considerable time talking about his research in vibrations on sea ice. He expanded on my previous knowledge about the history of his work, including his discovery of low-frequency vertical motions of sea ice as a result of internal gravity waves propagating in the thermocline below the ice cover. This work is observational, and although less well known in the West, has been amply published in Russian scientific literature. There has been a significant amount of theoretical work supporting it by others, in particular, Professor Leonid Cherkesov of the Marine Hydrophysical Institute in Sevastopol. Dr. Smirnov also provided details and reprints concerning his discovery of self-excited oscillations on sea ice. This work continues to be very good, but poorly described (in my opinion) in their literature, and therefore almost unknown in the West. I had stumbled across it years ago simply because I was convinced that AARI was doing something important on all those long-term drift camps that they maintained in the Arctic.

And so they were, in ice motion measurements at least, as I found important articles on the subject in the USSR Academy of Sciences Journal and in the AARI Proceedings. The self-excited oscillations occur near a frequency of 1 Hz. They are not fully understood even now many years after their initial discovery. Their theories are associated with a combination of stick-slip effects at boundaries between floes and/or cracks in a floe. The resulting waves that are generated are modified by the specific modes of propagation as they propagate across the ice cover to the locations of the instruments. Dr. Smirnov invited me to write a joint paper with him on these results, since they are complementary to some measurements previously analyzed and published by my former group at Arete Associates. We talked about this possibility at some length, and concluded that more analyses should be performed, but made no specific plans.

The scientists in Dr. Smirnov's Laboratory have many reports, monographs, and papers that are not available in the West. I found interesting studies of ice motions due to internal waves, ocean swell, calving of glaciers, tidal motions on landfast ice, underwater acoustics, and instrument development. I learned how they make their measurements with sensors they call seismometers, tiltmeters, accelerometers, strain gauges, stress meters, and pressure sensors. Again, much of their knowledge in this area is not known in the West. I believe they have done more in this specific area of research than the rest of the world all together. Dr. Smirnov showed me the manuscript for a monograph entitled "Elastic and gravity waves in ice" that is scheduled to be published in Russian later this year.

Dr. Smirnov mentioned several other topics that are interesting and worth relating here. He feels he was the first scientist to use explosives to send acoustic waves from one ice camp to another, up to 1200 km apart at the time, and measured the results with seismometers on the ice. I believe this work was done from the North Pole-20 camp in 1977. The results were judged spectacular for the quality of the received signal in a center frequency of about 10 Hz, and they were published in 1990 in the Academy of Science Journal *Soviet Oceanology*. He gave me a copy of the paper in Russian, but *Soviet Oceanology* has been translated since 1980, so it is available in English. He mentioned several other publications associated with this work, but I did not actually see the results. He concurred with Dr. Popov that loss of Russian Navy interest in scientific and technical development activities at the present time comprises part of their funding difficulty. It is not clear to me whether they received funding directly from the Navy in the past, just as Office of Naval Technology contractors might in the U.S., or whether the Navy's influence at the Ministry level was enough to affect the AARI budget provided by the (former Soviet) Committee on Hydrometeorology.

Oceanology and Air/Sea Interactions

AARI is the responsible Russian institute for oceanography of the polar seas, both the Arctic and Southern Oceans. In principle, this includes all areas of oceanography, but it seems to be focused on the physical aspects, much of which has been rather descriptive in the past. The work is described as being important to the future of climate. The Department of Oceanology is headed by Dr. N.V. Mustafin and the Department of Studies of Air/Sea Interaction by Dr. Henrikh V. Alexeyev.

Research in the past has included analyses of water masses and their variation, the thermohaline structure, heat and mass transport, and description of frontal zones in the Central Arctic and marginal seas. It has also included descriptions and statistics of sea level variations, swell, currents, tides, and divergence, the latter impacting the forecasting of ice cover. The Department has wave and surge forecasting capabilities that advertize 1-3 day accuracy for the former and 5-6 days for the latter. Finally, they have many manuals, instructions, and recommendations for ship routing and construction of marine structures.

Department of Estuaries Hydrology and Water Resources

This area is regarded both within and outside Russia as an important one because the Siberian rivers are a major source of fresh water in the Arctic, and this directly affects the circulation on the very large Siberian shelves. AARI has collected almost 70 years of hydrological and hydrochemical observations on the rivers and estuaries for many purposes. The most important application has been for shipping on the Northern Sea Route, especially the data on freezing and melting dates and on freshwater flow. These data are now getting extra attention because of issues associated with water quality and the effects of man on the environment.

Meteorology and Climate

Two departments operate in this general area. The Department of Meteorology is headed by Dr. Andrey P. Nagurny and the Department of Long-Range Weather Forecasts is headed by Dr. Nikolay D. Vinogradov, both well known and senior scientists in the field. These departments produce, use, and distribute the typical products of weather centers worldwide. They do research in the area and produce regular weather forecasts, both for the northern hemisphere and for the Arctic proper.

Some of the research is of a climatic nature, with publications typically being statistical summaries of weather for all sea and air transportation routes and sites along the northern coast. Included are statistics of temperature, winds, snow, clouds, and icing conditions. These typically are in the form of atlases, maps, tables, and annual summaries, but there also have been learned texts on polar atmospheric energetics. In addition, the Laboratory of Polar Atmosphere Energetics headed by Dr. Vladimir F. Romanov performs quantitative diagnostic studies of circulation based on observations and numerical modeling. This includes calculations of energy exchange between the atmosphere and ocean/ice and land and calculations of the kinematics and dynamics of circulation from regional to global scale and from synoptic to annual and interannual periods.

There are a few special-purpose research results that are of interest, including algorithms for calculation of wind loading on structures, calculations of snow drift, icing and frosting, and estimation of optical characteristics including illumination, aerosols, trace gases, and opacity.

Regular weather forecasts are made four times per day for all northern areas but, as in the ocean and ice areas, long-range forecasts are made for polar regions up to one year in advance. The long-term forecasts are updated every three months. These include mean monthly air pressure and temperature fields and anomalies, directions of prevailing air flows, and coastal winds. The short-range forecasts are for all Arctic sites and are from 24 hours in advance to 8-10 days in advance. They have a new forecast product that is a one-month forecast for Antarctica.

Based on their experience and capabilities, they believe they can make a number of climate predictions. However, it seems to me these really are just probability characteristics based on previous observations of means and variances.

Department of Ship Performance in Ice

This department is headed by Dr. Vladimir Lickomanov, who has many years of experience in ship operations in ice and testing of same. The main objective of the work in this Department is to evaluate the capability of ships and engineering structures to be used in ice conditions. This includes the ability to overcome resistance of floating ice and operate at speed, ability to avoid damage from ice, and the ability to maneuver or perform other normal operations in ice.

The Department has 25 personnel and more than 400 m^2 of staging area for preparing samples for their four cold tank facilities. These have been in operation for only one year in the present building. However, the Department apparently has much experience in their use, having built the first ice tank facility in the world (Lickomanov claims) in their older location in St. Petersburg in the late 1950s.

The largest tank is impressive; it is 38 m long, 5 m wide, and 2-7 m deep, and it has a large towing carriage. It can test models of up to 1:15 scale, and examples of these are evident all over the laboratory spaces. The models can be either towed or self propelled. They all are icebreaker or ice-strengthened designs (both hull and thruster) of one or another exotic shape. Apparently, the Department sets all requirements for icebreaker designs in Russia, whether the ship actually is (or was) built in the country. The ice in this tank can be up to 15 cm thick, and its properties are controlled carefully (he claimed) by spraying frozen crystals on the water and controlling the air temperature and water salinity. The temperature can be lowered to -25 degree Celsius; it can be controlled by an enormous layer of cold coils both on the walls and the ceiling, and additional movable coils that lower on panels to almost the water level. Finally, the tank has a number of observation windows on the sides and the bottom.

There are additional cold tanks, one which is deep and another which contains a wind tunnel, and several cold rooms where they often run personnel and equipment cold-adaptation tests. They currently are testing magnetic recording tapes for behavior in the cold.

They also provide expert opinions on the designs of others that are not actually tested by them. Included in this is an "ice passport" that contains specific recommendations for safe navigation regimes under various ice conditions for any type of ice-strengthened transport. These apparently can be in tabular form or in software for use on ships' computers. Finally, the department claims to have a capability to undertake full-scale trials of ships in any season or navigation route to evaluate their ice characteristics.

Department of Science Expedition

This department has a very wide range of responsibilities for all expeditions, including drifting ice stations (North Pole camps), high-latitude airborne reconnaissance, visual and instrumental aerial sea ice reconnaissance along the Northern Sea Route, research and research/cargo vessels, and other expeditions along the Siberian coasts and Antarctica. The range of observations for which it is responsible includes all major parameters of the atmosphere, ocean, sea and shelf ice, rivers, glaciers, magnetosphere, and ionosphere. Included also are studies of human, plant, and wild life and their adaptation to the polar climate.

The Department advertises their capability to support the North Pole camps, although they are not doing so presently because of lack of a sponsor. This support is for all logistics and services necessary to live and work on the ice, including accommodations, electric power, medical service, radio communications, food, transportation to and on the ice, and cold weather clothing. Dr. Nikiforov would like to continue the North Pole camps and is interested in collaborative work in this area.

The Department operates six well-known ships. The *Academik Fedorov* is about 17,000 tons, the *Mikhail Somov* about 14,000 tons, the *Professor Zhubov* and *Professor Vieze* about 7,000 tons, and the *Academik Shuleykin* and *Professor Multanovsky* about 2,000 tons. The *Fedorov* is an icebreaker; it supported research in Antarctica during the austral summer of 1991/92. The *Fedorov* has numerous laboratories and individual cabins for all scientists, and all ships have ice-strengthened hulls and stabilizers. The four larger ships have upper air sounding capability, and all have oceanographic measurement capability. The ships have satellite communications, although Western scientists have had difficulty contacting Russian colleagues when they are on expeditions on these ships. In all, though, a very capable fleet.

Individual scientists have mentioned that AARI is having difficulty maintaining these large ships at present because of lack of hard currency for fuel and support in foreign ports. Sergey Vasiljev, who holds the title of Senior Expert with the International Cooperation Department of the State Committee on Hydrometeorology, with offices in Moscow, told me that the difficult financial position of Russia is forcing the Committee to attempt to sell most of their 30-odd ships. (Note: this number does NOT include the Russian or Ukrainian Academies of Science ships.)

As administrator of the Russian Antarctic Expedition, AARI has supported seven permanent stations in Antarctica in the past, but these now have been reduced to five. Apparently there is serious discussion in Moscow regarding the future of even this level of activity because of the cost. They already have difficulty with resupply by aircraft because of strained relations with the Ukraine, where apparently specific organizations are instrumental in maintaining the large resupply aircraft they used previously. AARI is depending on an agreement with our National Science Foundation to help supply some of their bases with the Hercules LC-130 aircraft operated by U.S. Navy Squadron VXE-6.

PAST AND PRESENT PROJECTS

AARI has been involved in a number of projects that are of considerable interest. A very-long-term project has been the North Pole drifting stations that have been maintained for many years. The really impressive part of this was the enormous effort required to set up, supply, and maintain these camps anywhere in the Arctic basin so that they could be used as bases for scientific observations. These stations are typically referred to in the West as the NP stations. There were 31 of these camps with an average 2.5 years per station, encompassing 75 station-years. The success of this program is a laudable testament to the sheer strength and determination of AARI, but the accompanying expense makes it difficult to continue in the present financial and political environment.

The Soviet-Norwegian Oceanographic Programme (SNOP) that is winding down included numerous joint moorings and conductivity-temperature-depth lines in the Barents Sea. One specific part of this project that is especially interesting was undertaken by Dr. Bjorn Erlingsson, who is a research fellow in the Geophysics Department at the Norwegian Polar Research Institute (NPRI). He was the first Western scientist (to his or my knowledge) who has spent considerable time on one of the North Pole camps. This was organized as part of SNOP, and he went onto the NP-31 ice camp with the logistical help of Andy Heiberg of the Polar Science Center of the University of Washington (PSC/UW) when it was 100 miles north of Prudhoe Bay in the spring of 1991. At that time, it was about 2.5 years old, had a crew of 23 men, and was being supplied by Antonov-24 aircraft from Eastern Siberia. This apparently was at the limit of the range of that aircraft and at the end of a very long logistics train.

Dr. Erlingsson was really impressed with the effort it must have taken to build and maintain the 1100-m long runway. It was built up from water pumped onto the ice, and kept smooth with heavy equipment. Oceanographic observations were mundane, being weekly conductivity-temperature-depth (and bottle) casts. Also, weekly ice maps were prepared from satellite images. In addition, though, the synoptic meteorological observations included good radiation measurements and twice daily upper-air soundings, including velocity (apparently very similar to our rawinsonde). I agree with the opinion of both Dr. Erlingsson and Roger Colony, also of PSC/UW, that this latter data set must be unique. The interest from AARI in hosting the joint observations apparently was the chance to get joint measurements with a combination of AARI and Scott Polar Research Institute ice-motion sensors that previously had been deployed by Dr. Smirnov's group. Dr. Erlingsson spent two weeks on the ice and left his instruments and a working computer system so that the observations would continue in his absence. The camp broke up later that summer season, as it was drifting into the melting zone north of Alaska, and he has not seen any of the data to date. These measurements are continuing presently during the joint United States-Former Soviet Union (US-FSU) drift camp in the Weddell Sea in the Antarctic.

AARI is a partner with NPRI in the Ice Data Acquisition Programme; there is oil company support of NPRI for tracking icebergs by using Argos drifters (often in the Russian Economic Zone). They also are partners with others in the Northern Sea Route Project. This latter project is in the planning stages, with only preliminary studies to date. The only reports available are a preliminary environmental assessment written by a Norwegian scientist and a summary of a multinational meeting that discusses the results from Phase I of the Project. AARI scientists tell me they are preparing a report that presumably is a complete review of all areas of environmental interest along the northern Russian coastal region, including oceanography, meteorology, and ice conditions. I think it will provide a convenient measure of their knowledge concerning the physics of the ocean, ice, and meteorology in this important geographic area. I have a copy of the table of contents, and the whole report is expected to be available in a matter of months (although I find their estimates on dates such as this one much too optimistic).

FUTURE PROJECTS

Roger Colony has had considerable experience working with scientists at AARI. He has three projects in the planning stage that involve scientists at AARI, and two of them are part of proposals to the Global Change Program at NOAA. In the first planned project, the two institutes plan to jointly analyze the temperature field of the Arctic by using the archived AARI surface temperature data set. The purpose is to address greenhouse warming issues. This work is with Dr. Igor Appel of AARI, and it is to be done as a subcontract from the University of Washington to AARI. This is an important topic; it is clear that Arctic temperatures are crucial to world climate, and the Russians have the only good long-term data set that includes many observations over many years in the central Arctic basin. There have been many recent temperature observations made with drifting buoys by western scientists, but the temperatures reported by these buoys are considered to be unreliable.

In the second project, the plan is to form a collaboration with PSC/UW, AARI, and the World Data Center for Glaciology in Boulder, Colorado, and to generate a CD-ROM of all data from the North Pole camps. The data set includes station position, air pressure, surface temperature, wind speed and direction, radiation (purportedly unique and very good data), snow characteristics, and cloud data in some instances. The goal is to include all 75 station-years of data in the set. The AARI contact in this case is Dr. Ivan Frolov, who is the Chairman of the World Meteorological Organization (WMO) Sea Ice Group.

The third project involves reporting and analyzing the Soviet DARMS (Drifting Automatic Radio Meteorological System) data. This data set also is unique, as it is from drifting buoys that the Soviets deployed from 1953-1972 on their wide Arctic shelves. There were more than 350 such buoys. They reported surface meteorological data via high-frequency radio, and their positions were triangulated from direction-finding stations on the shore. Roger Colony has previously worked with the position data from these buoys, and he feels it is accurate enough for monthly positions, but the meteorological data have not been available so their completeness and accuracy remain undetermined.

GENERAL COMMENTS

AARI is much like other large scientific institutes I have visited in Russia. There is strong central control, with little interaction of individual scientists with researchers at other institutes either inside or outside Russia. Sergey Karpekin is a central point of contact with all outsiders.

The institute personnel have received about a factor of four increase in salary in the time period June 1991 to June 1992, but this lags inflation by almost an order of magnitude, so the scientists are experiencing a "big problem," a term they often use, with meeting their cost of living. As is well-known, there is an exodus of top scientists, but many of the older and more established scientists are optimistic for better days and seem to be patiently waiting it out. I am of the opinion that most scientists at AARI intend to stay, but many of them are working other jobs in parallel with their work at AARI. Apparently, they continue to draw their salaries at AARI, as there is no accounting mechanism for charging time per project as we are used to doing (more on this below).

The administration is not presently planning to downsize their personnel, although it is not clear to me why not. I find this interesting because of their large size (AARI is only one of 23 branches of the Russian Committee on Hydrometeorology), especially because these laboratories are now supported financially by Russia alone.

While at AARI, I received two short briefings about the commercial organizations related with AARI. Because of the financial situation, there are various organizations associated with the Institute and the personnel so that they can make enough income to support their families. INTAARI is a company that essentially includes all the AARI personnel, but it was organized to be able to accept contracts outside the Hydrometeorology Ministry. It is a commercial joint enterprise of AARI, INTERA Information Technologies in Canada, and NPRI. It is almost impossible to separate INTAARI from AARI, because of the commonality of personnel, including directors.

The second enterprise that I received information about directly is a small group of scientists from the Laboratory for Numerical Methods. It is called "IceInform," and is made up solely of the personnel in Dr. Appel's Laboratory. Its director is Nikolai Senko, a scientist in the Laboratory. They have a long list of commercial products and services that they are willing to provide at a price. Again, I have the list if there is further interest. The amazing aspect of this is that they do not separate themselves from AARI. Apparently, they will contract to do this work at the laboratory during regular hours using laboratory equipment.

Clearly, this is an unusual way of doing business compared with U.S. practice. I suppose it can be attributed to "any port in a storm," especially when there are no financial controls at the Institute or within the country to speak of. Unfortunately, between the Institute and the multiple enterprises, it leads me to wonder just who I am dealing with during any specific conversation.

Finally, communications with scientists at AARI are especially difficult. There are no telemail addresses, and the telephones and faxes are very unreliable. The only reliable means of communication is by telex. Unfortunately, this goes through one terminal at AARI, and it is centrally controlled. (I think all communications both ways are cleared by Karpekin.) The individual scientist is not encouraged to use this link, so it will not enable normal scientist-to-scientist interchanges in the near future. Unfortunately, I suspect this situation is as much by design as due to the lack of facilities, so I do not expect it to change very quickly.

AARI's address is:

38 Bering St.
199226 St. Petersburg
Russia
Phone: 352 03 19
FAX: 352 26 88
Telex: 121423 NILAS SU

REFERENCE

1. John P. Dugan "The Music of Sea Ice—Ice Vibrations Seminar at Cambridge University," *ESNIB* **91-06**, 35-39 (1991).

Acoustic Signal Processing for Ocean Exploration and the "Third Dimension"

by Peter N. Mikhalevsky, Vice President, Science Applications International Corporation, McLean, Virginia, and CDR, U.S. Navy Reserves, assigned to the Office of the Chief of Naval Research, Science and Technology Headquarters Unit 106.

KEYWORDS: underwater acoustics; signal processing; matched field processing; ocean; Russian

INTRODUCTION

The "Acoustic Signal Processing for Ocean Exploration" conference was sponsored by the NATO Scientific Affairs Division as the most recent in a series of Advanced Study Institutes (ASIs) in acoustic signal processing. These conferences have been held every four years since 1964 to disseminate advanced knowledge not yet in university curricula and to foster international scientific contacts through high-level teaching courses. In notable contrast to earlier ASIs, there was significant interest from scientists in the Commonwealth of Independent States (CIS); with the encouragement and support from NATO, four Russians ultimately participated in the conference.

The conference title, "Acoustic Signal Processing for Ocean Exploration," also reflects a growing trend in underwater acoustics, namely, the use of sound as instrumentation to explore and understand the ocean and its processes. The fact that this work is commanding greater interest from defense researchers is indicative of two developments, also evident at this conference. The first is the growing interest and popularity of ocean acoustic tomography and matched field processing, about which more will be said below. The second is the realization that the defense budgets are shrinking and applications of underwater acoustics and signal processing to scientific research that can be related directly to ocean research, fisheries, and environmental issues is an area where future funding may be found.

The fact that much of the world's best expertise in underwater acoustics and signal processing has been veiled in secrecy has limited the development of acoustic methods for purely scientific ocean research. This tremendous capability is now slowly being focused on these issues. The significant lowering of tensions as reflected in the Russian participation in this conference is the operative factor in these developments, and this NATO ASI provided clear signals of these new trends.

The future of this series of Advanced Study Institutes in acoustic signal processing is in some doubt. Although plans are being made to organize the next meeting in France in 1996, it has not been confirmed that NATO will continue their support. As stated in the objectives of the NATO Science Programme... NATO has, in addition to its better-known political and military dimensions, a "Third Dimension," which seeks to encourage interaction between peoples, to consider some of the challenges of the scientific potential of Alliance countries. Underwater acoustics and acoustic signal processing have always had a very large military dimension with far-reaching political impact over the years. However, it is a field with a unique potential for contributing to this "Third Dimension."

While Russia and other CIS countries are not yet members of NATO (and even that may soon change), the interaction at this conference with its emphasis on ocean exploration in a small but palpable way is a start toward refocusing the prodigious Russian/CIS defense infrastructure in underwater acoustics on peaceful applications. At this juncture in time, the opportunity to continue the process of creating a more stable world through such interactions is unprecedented. I hope that NATO will continue and even expand its support for this program.

The technical presentations were grouped into eight general areas: the ocean environment and propagation; matched field processing; array processing; localization and detection; acoustic imaging and mapping; recognition; underwater vehicles/communications; and computational methods. A preliminary Proceedings was available to conference attendees at the start of the conference. The final Proceedings will be published by Kluwer and will be available at a price of $40/copy. Points of contact are listed at the end of this article.

In the following paragraphs I briefly discuss the first three technical areas with which I am most familiar. Sixty-six papers were presented, and a comprehensive review is beyond the scope of this format.

THE OCEAN ENVIRONMENT AND PROPAGATION

Finn Jensen (SACLANT Undersea Research Center, La Spezia, Italy) provided a very well organized and comprehensive review of the basics of underwater acoustic propagation modeling. The discussion included wavenumber integration methods including the Fast Field Program (FFP), normal modes, and the parabolic approximation (PE). Acoustic propagation modeling has achieved a level of sophistication that even the most complex environments can be modeled with exceptional accuracy. The current limit on predictive modeling is the input data required to drive the models, i.e., accurate sound speed data, bathymetry, and acoustic properties of the bottom. The modeling sophistication is also the result of the high-speed computational capabilities that have developed over the past 5-10 years. This ability to accurately model both amplitude and phase of the acoustic field has been one of the key factors in the success of matched field processing.

A very new area of ocean acoustic modeling research was touched upon by Finn Jensen. This is transglobal acoustic propagation—over distances of tens of thousands of kilometers in the ocean. This was expanded upon by William Kuperman [Naval Research Laboratory (NRL)] and Arthur Baggeroer [Massachusetts Institute of Technology (MIT)] in a later paper. They discussed a famous experiment conducted in 1960 when underwater explosions were detonated off Perth, Australia, and recorded in Bermuda halfway around the world. They also discussed the recently completed Heard Island Feasibility Test in which signals were propagated from Heard Island in the southern Indian Ocean to receiving hydrophones and arrays in the Atlantic and the Pacific. By using a global 3D sound-speed database on an ellipsoidal earth, impressive agreement between data and modeling results was obtained. Measured travel times from the Perth experiment were modeled remarkably well by computing horizontal rays for each mode separately. High-order mode content of received energy from Heard Island was modeled by using a high-angle PE projected onto local normal modes. These results portend the application of long-range acoustics as an instrument for measuring ocean climate that has been proposed by Walter Munk at the Scripps Institution of Oceanography.

The use of simulated annealing in underwater acoustics to invert received acoustic pressure field data to determine source parameters and ocean environmental parameters has received recent attention in the acoustics literature. A good summary of the principles of simulated annealing was included in a paper given by S.E. Dosso, J.M. Ozard, and J.A. Fawcett (Defense Research Establishment Pacific, Victoria, Canada). The method is being applied to inversion problems in which the number of possible states that would have to be searched to minimize some cost function far exceeds existing computational resources that use a straightforward systematic search procedure.

Array Processing

Norm Owsley (Naval Undersea Warfare Center, New London, CT) reviewed and compared array processing techniques, including high-resolution adaptive methods. He defined a Standard Test Case (STC) as a benchmark for comparison. Norm Owsley is careful to make the distinction between processing that is optimal for parameter estimation (direction finding) and detection (what he prefers to reserve the term *beamforming* for). Some high-resolution direction finders such as MUSIC require a priori knowledge of the number of sources in the field for optimal performance. In practical applications this limits their utility. The minimum variance distortionless response (MVDR) adaptive beamformer requires no a priori knowledge but does require a stable estimate of the sample covariance matrix. This means that care must be taken when applying this beamformer with real data.

It has been our experience that the number of independent snapshots of the covariance matrix must be at least two to three times the number of elements in the array. Norm Owsley discussed his Enhanced MVDR beamformer, which uses the signal subspace idea of MUSIC, combined with diagonal stabilization (using an estimate of the single sensor noise), which makes the MVDR robust to mismatch effects. The exploitation of adaptive processing in beamforming, for its good resolution (parameter estimation), sidelobe rejection (parameter estimation), and noise rejection (detection) properties is the issue here.

Matched Field Processing

Matched field processing, as the name implies, involves using knowledge of the ocean environment (i.e., the sound speed structure) to predict the complex pressure field on an array as a function of important parameters like the source range and bearing. These predictions are then compared to the actual received complex field by using normalized correlation processing and adaptive versions such as MVDR. At this conference Art Baggeroer (MIT) and Bill Kuperman (NRL) presented a comprehensive tutorial and summary of open-literature work in matched field processing. This included a lengthy list of references, which would be very useful for those interested in the area. From the conference it is evident that a lot of work is also going on in this area in Canada, the SACLANTCEN in La Spezia, Italy, and recently in Portugal. From the references in the Baggeroer and Kuperman paper as well as discussions with the Russians, it is also clear that matched field research is an active area in Russian acoustics. V.V. Borodin (Andreev Institute of Acoustics, Moscow, Russia) was scheduled to present a paper on source coordinate estimation using matched field processing. The paper was in the preliminary proceedings but was not presented when Dr. Borodin was unable to attend.

In beamforming, matched field processing provides the "best" possible match to the signal structure, maximizing signal gain. If matched field replicas are used as the distortionless constraints in an MVDR processor, mismatch degradation can be minimized. Successful application of matched field processing requires accurate array element locations. Two papers from the Defence Science and Technology Organisation, Salisbury, South Australia, were presented on estimating the array shape of towed arrays by using acoustic and nonacoustic methods.

As discussed above, one of the practical considerations in using MVDR involves obtaining a stable estimate of the spectral covariance matrix. This can put some practical limitations on the coherent integration time that is used. If this coherent integration time is too long, the total amount of time required to obtain a stable covariance estimate may violate the stationarity assumption (e.g., resulting from changing target and noise dynamics). One is tempted to make the coherent integration times short for the purpose of covariance estimation, but there is a tradeoff here as well. The coherent integration time cannot be so short that the time of flight of the acoustic energy across the aperture is a significant fraction of the integration time. A general rule of thumb for negligible losses at all angles including endfire is to make the ratio of time of flight to integration time 10 or greater.

Because the time of flight is a function of steering angle one way around this problem is to time steer the array prior to covariance estimation. It is an easy calculation to compute the loss as a function of time of flight and integration time, since the former is directly related to the difference between time steer angle and other look angles. This defines angle wedges such that the loss is less than some desired value and the number of steer angles required is then the ratio of the total angular search area to the angular wedge size. Time steering in azimuth is straightforward. In a very interesting paper Jeff Krolik (MPL, Scripps Institution of Oceanography) and G. Niezgoda (Concordia University, Montreal, Canada) have devised a method for essentially performing time steering in the vertical. The processing is intensive because it requires the application of focusing matrices at each search point. However, this approach could be promising, particularly for applications in which the tradeoffs mentioned above are particularly onerous (such as arrays with a large number of elements).

Matched field processing requires the use of the sound speed structure explicitly in the signal processing. While a significant amount of research has been focused on identifying source parameters, given a receiver location and measurements of the environment, the analog problem of using a known source and receiver and inverting for the sound speed structure or other properties of the propagating medium is self evident. Traditional ocean acoustic tomography has used wideband pulses to separate multipath in time. By identifying particular raypaths and the parts of the ocean through which they travel, inversions can be performed to determine ocean sound speed and temperature. Matched field processing with arrays is a coherent spatial analog of this problem. In regions of the world's oceans where paths or modes overlap in time, spatial processing could provide the capability to identify paths and modes that could then be used in the same inversion processing.

I am confident that the interest generated at this conference in matched field processing is going to lead more researchers into this field. With its traditional applications in beamforming, new possibilities in ocean acoustic tomography, the mature state of propagation modelling (discussed above), and the availability of advanced high-throughput computing, matched field processing has become an attractive and powerful acoustic signal processing method.

CONCLUSIONS

The content of this conference was extremely informative and interesting to me in the areas that I have mentioned above. I would hazard to say that those with special interest in the areas that I did not cover in this short article would find many of these papers stimulating as well. This particular series of the NATO Advanced Study Institute, I believe, is especially topical today, not only in terms of the traditional goals and objectives of NATO, but also in the dimension of scientific interchange at a time when such an interchange could have profound influence on the future direction of the world. The fact that the research has such potential in applications relating to nondefense issues while perhaps being a side benefit today, could emerge in the future as the most important development in the underwater acoustic signal processing community.

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Dynamic and Stochastic Wave Research in Nizhny Novgorod, Russia

by Paul Barbone, a Research Associate in the Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge, U.K. His research activities focus on analysis of problems arising in structural acoustics, including acoustic wave propagation in fluid/solid waveguides and acoustic scattering.

KEYWORDS: radiophysics; nonlinear waves; radio astronomy; acoustics; structural acoustics

INTRODUCTION

The Radiophysics Faculty of the University of Nizhny Novgorod, Russia (formerly Gorki) sponsored an "International Scientific School—Seminar on Dynamic and Stochastic Wave Phenomena," 1-4 June 1992. In addition to the Radiophysics Faculty, I visited scientists at the Institute of Applied Physics, the Institute of Architecture and Civil Engineering (both in Nizhny Novgorod) and the Acoustics Laboratory in the Physics Department at Moscow State University.

I begin with a description of the structure of the University of Nizhny Novgorod. Because it is impossible to distinguish between the work done at the University and the work being performed at the closely associated research institutes, I summarize together all the research in Nizhny Novgorod that I found interesting. In describing research, I have tried to include references that are in English, that are easily available in the U.S., and that will give the interested reader an idea of the level of work being performed. My own area of interest and expertise is structural acoustics, particularly in analytical methods, and so I may inaccurately judge the quality of other work I am reviewing.

I next describe the Acoustics Laboratory, Faculty of Physics, Moscow State University, and highlight some of the research being performed there. The article closes with a few observations and generalizations on the trends in Russian science.

The research review is presented at several levels. In the first place, the strengths and interests of the departments and faculty are described. This is followed by a discussion of the emphasis of the research in each area, and its principal motivating application. Finally, highlights of current research being performed are given.

UNIVERSITY OF NIZHNY NOVGOROD

Here I explain the structure of the University, its industrial connections, and then go into detail about the make up of the Radiophysics Faculty and its closely associated Institute of Applied Physics.

Background

Universities in Russia are divided into faculties the way universities in the U.S. are divided into departments or colleges. Each of the faculties is then divided into chairs, which contain several professors all working on the same general topic. A chair most closely corresponds to a laboratory group in an American university, except that chairs are more independent and may be much larger organizations.

The University of Nizhny Novgorod was founded in 1918 by a group of refugee academics from Warsaw Polytechnic University. It has since grown to its present status as one of the largest universities in Russia, with 9,500 students, 2,000 research associates, and 800 teaching faculty spread among 14 faculties (departments).

Structure

The city of Nizhny Novgorod was a scientific and industrial center for Soviet defense. Because of this, it was closed to outside visitors until late last year, and visitors were allowed into the city by invitation only. This prevented prying eyes from seeing the local submarine construction facility or the new MiG 29s leaving their assembly plant. Encircling the main factories at the center of the city are many supporting plants producing the necessary smaller components (e.g., electric motors and controllers).

The technological requirements of the city's industries are met by the many scientific institutes in Nizhny Novgorod. The University's strong ties to these institutes has disproportionately developed its science faculties. These include three physics faculties, two mathematics faculties including the first computational mathematics faculty in the country, and perhaps the strongest chemical faculty in Russia.

The structure of the three physics faculties betrays the degree of interaction between the industrial research institutes and the university. Members of the Radiophysics Faculty, for example, were active in founding the Radiophysics Research Institute and the Institute of Applied Physics. The Faculty of Applied Physics and Micro-Electronics is housed in the center of the city, closer to its industrial collaborators. Finally, the newly formed and elite School of General Physics, which accepts only 25 students per year, is officially part of the Institute of Applied Physics and the Russian Academy of Science.

The largest of the physics faculties is the Radiophysics faculty; the Institute of Applied Physics, its close associate, is the largest of the research institutes. The Radiophysics Faculty consists of 34 professors in 10 chairs, with a corresponding number of research associates and students (I was not given a precise number). (The Appendix provides the name of the head of each chair.) The Institute of Applied Physics is home to much of the research performed by members of the Radiophysics Faculty. It has more than 30,000 m^2 of laboratory and office space, which is occupied by 183 Ph.D.s, 24 D.Sc.s, 4 members of the Academy of Science, and 1 Academician. These researchers are aided by more than 800 engineers and technicians as well as some 500 other support staff.

Approximately 100 km due west from Nizhny Novgorod is Staraya Pustin. This is a radio astronomy observatory run by the Institute of Applied Physics. The centerpiece of Staraya Pustin's data acquisition ability is a synthetic aperture array consisting of three 4-m dish antennas, spaced 50 m apart. This array has the singular attribute of being the only one of its kind located so far north (to the best of my knowledge).

As mentioned previously, it is impossible to distinguish between the research interests of the members of the university and those of the members of the institutes. For this reason, I attempt no distinction in the following research review.

SCIENTIFIC RESEARCH IN NIZHNY NOVGOROD

Following is a brief description of the more (personally) interesting research in Nizhny Novgorod to which I was exposed. The primary source of this exposure was, of course, the summer school. Through a fortunate set of circumstances, however, I met some people doing research in structural acoustics who were not connected with the summer school.

The subjects discussed below include ocean acoustics (and waves in random media), nonlinear waves, and structural acoustics. In each case, a short description of general research interests is given; this is followed by recent notable contributions of the local scientists.

Ocean and General Acoustics

Interests in this area include signal processing, propagation in random media, and tomography. The emphasis in tomography was either implicitly or explicitly on shallow water applications. Professor Sergei Gurbotov, Head of the Acoustics Chair in the Radiophysics Faculty, has written a proposal to any interested parties for collaborative development of a "through-ice sonar".[1] (Preliminary calculations pertaining to the through-ice sonar also assumed relatively shallow water.)

Drs. A.G. Nachaev and A.I. Khil'ko (IAP—Institute of Applied Physics) concentrate on diffraction tomography using modal expansions. His calculations rely on the ability to use so-called "natural modal shadowing" (as might be provided by the continental shelf). References 2 and 3 describe some of their recent contributions.

Wave propagation in random media is one of the strongest areas of research in Nizhny Novgorod. Virovlyansky (IAP) and Kosterina (UNN—University of Nizhny Novgorod) describe extensions of concepts like Fresnel zones in the context of ocean waveguide modes.[4] Efim Pelinovsky (IAP), known for his book on nonlinear wave propagation, discusses conditions under which mean and typical response can differ. He demonstrates an asymptotic method by which the typical shape of a nonlinear random wave can be obtained.[5] Finally, Dr. V.V. Tamoikin (RRI—Radiophysical Research Institute) combines the Bobolybov-Mitropol'sky method of averaging with the WKB approximation to problems of parametric wave decay and nonlinear wave interaction.[6]

Nonlinear Waves

The physical applications of work in this area range from waves in plasmas and quantum mechanical waves, to turbulence and large-amplitude acoustic waves. The overall interest in this area of research in Nizhny-Novgorod is too large to review completely.

Clearly, Pelinovsky and Tamoikin (see section above) could be included in this category because of the nature of their work. Besides these two, V.V. Ostrovsky (IAP) and A.I. Smirnov (IAP) are doing excellent work. S.N. Gurbotov (UNN), the conference organizer, is gradually gaining recognition in the West for his expertise on nonlinear waves. References 8-11 describe research at Nizhny Novgorod on nonlinear waves that is representative of that being performed. Reference 7, for example, contains a notable analysis of singularities in solutions of the nonlinear Schroedinger equation. L.A. Ostrovsky (IAP) has recently published some interesting work on the nonlinear elastic properties of complicated composites.[8]

Structural Acoustics

Research in this area is concentrated on radiation from inhomogeneities.[11] The analytical work has often been performed neglecting fluid loading and expanding the vibration field in modes. Statistical methods seem less common, but are nevertheless present. Otherwise, where fluid loading is considered, impedance concepts were heavily exploited. Noticeably absent were any numerical methods.

Of interest is the work by P.I. Korotin and A.V. Lebedev who discuss the general characteristics of the effects of dissipation on sound radiation by an inhomogeneous object. This work is complemented by that of D.M. Donskoi and A.E. Ekimov, who seem to combine a variant of Statistical Energy Analysis with an asymptotic expansion in frequency space near resonances. R.A. Dudnik (IACE—Institute of Architecture and Civil Engineering) has published considerably on the effects of a concentrated inhomogeneity on the radiated sound field.[12] His coauthors include E.A. Fiyaksel, A.B. Mol'kova, and V.V. Tamoikin (same as above.)

The experimental effort in structural acoustics research in Nizhny Novgorod include optical holography, active vibration control, and direct surface vibration measurements.[11] The single experimental acoustics facility that I saw in Nizhny Novgorod was an office in the Institute of Architecture and Civil Engineering. Here, measurements were made of sound radiated by a cylindrical shell excited at resonance. The data were taken late at night with the windows open to reduce reverberation and background noise. An ultrasonic Doppler surface velocity meter, developed at IAP, was used to measure the surface velocity of the shell directly. The meter has a sensitivity to displacements of tens of microns, and so is not useful except for resonance measurements in air.

ACOUSTICS CHAIR, FACULTY OF PHYSICS, MOSCOW STATE UNIVERSITY

The Acoustics Chair in the Faculty of Physics, Moscow State University, is big enough to be called a department in the United States. It contains more than 70 research scientists (including technicians), and has its own teaching curriculum for its 15-20 new graduate students each year. The Appendix lists the main faculty and their general interests. During my visits to the chair (once on a general tour, once by appointment), I observed three major strengths in their research program: nonlinear wave propagation in general, ultrasonics, and inverse scattering.

Ultrasonics

The person at the center of the ultrasonics group appears to be Associate Prof. Igor Yu. Solodov. His interests and specialties include nonlinear acoustic phenomena at crystal surfaces.[13] Applications of his work include nondestructive evaluation and second harmonic surface acoustic wave generation. His laboratory has measured third harmonics and are looking for fourth.

Nonlinear Acoustics

Professor Oleg V. Rudenko, head of the Acoustics chair, is also one of the most active contributors to the nonlinear acoustics literature in the department.[14] He has recently published on nonlinear absorption of sound,[15] thermal self-focusing of wave trains,[16] and sound excitation in fluid flows.[17]

Inverse Scattering

Associate Prof. Valentin A. Burov is respected by the head of his chair for his outstanding work in inverse scattering theory. The focus of his efforts in the past has been on iterative methods based on the T-matrix approach and the Lippman-Schwinger equation.[18] He has since extended such techniques to very strong scatters.[19] More recently, he has been studying functional-analytical methods, long used in the context of 1-D quantum scattering, and applying them to multidimensional scalar inverse scattering.[20]

DISCUSSION AND CONCLUSIONS

The greatest strength of this scientific community seems to stem from their greatest weakness: no (greatly restricted) computational power. Since numerical solutions are often impossible, many of these analysts turn to asymptotic methods to evaluate solutions. These asymptotic results are beginning to find themselves at the heart of extremely fast and efficient special-purpose computer codes, which use more general "standard" numerical techniques only when necessary.

Perhaps the best conclusion that we can draw from this insight is that the single best method of solving any particular class of problems is usually an intelligent combination of many solution methods.

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Appendix

FACULTY OF RADIOPHYSICS, UNIVERSITY OF NIZHNY NOVGOROD

Head	Chair
V.I. Talanov	UHF Electrodynamics
A.N. Malakhov	Statistical Radiophysics and Bionics
V.P. Dokuchaev	Radiowaves and Radioastronomy
V.A. Zverev	General Physics
A.A. Andronov	Quantum Radiophysics
B.D. Shalfeev	Oscillation Theory
S.V. Gaponov	Semi-Conductor Devices
S.N. Gurbotov	Acoustics
G.A. Utkin	Mathematics

ACOUSTICS CHAIR, MOSCOW STATE UNIVERSITY

This is a list of "scientific group leaders" within the Acoustics Chair of Moscow State University; the subject following the name is the field in which the group is working. Professor Oleg V. Rudenko is the head of the Chair.

O.V. Rudenko	Nonlinear Waves
V.A. Krasilnikov	Physical Acoustics
L.K. Zarembo	Magneto Acoustics
I. Yu Solodov	Acoustic Waves in Crystals
V.I. Pavlov	Ocean Surface Waves
O.S. Tonakanov	Ocean Acoustics
V.A. Burov	Inverse Problems
V.A. Gordienko	Vector-Phase Measurements in the Ocean
A.I. Korobov	Solid State Devices
P.N. Kravtchun	Noise and Vibration
E. Ya Tagunov	Nonlinear Hydrodynamics

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Physics

Critical Currents Conference, Vienna, Austria

by D.H. Liebenberg, Physics Division, Office of Naval Research, Arlington, Virginia

KEYWORDS: superconductivity; critical currents; transport current; magnetization loops; theory

THE CONFERENCE

For bulk material applications of high temperature superconductivity (HTS) and for some film applications, a high critical current and critical current density is essential. To bring together specialists from major international groups to share information on this specialized subject, the third Critical Currents Conference was held in Vienna, Austria, April 22-24, 1992. (The first Critical Currents Conference was organized by Dr. A. Clark of the Office of Naval Research European Office, London.) During the six years since the first announcement of superconductivity above 30 Kelvin, the critical current density of bulk materials has increased at nearly one decade per year. Films of HTS have reached values more than sufficient (10^6 Å/cm^2) for device applications. Bulk materials have reached critical current densities, J_c of $2 \cdot 10^4$ Å/cm^2, that are within an order of magnitude of that needed for early applications for transmission lines and bussbars. This conference was notable less for any single breakthrough than for agreement that earlier gains can be reproduced in many laboratories; the underlying pinning mechanisms that control critical currents are being investigated both theoretically and experimentally with enthusiasm and innovation.

FIRST DAY

Early theories for homogeneous isotropic superconductors were summarized by Prof. John Clem (Iowa State University). He examined the modifications of these theories, especially the Ginzburg-Landau theory for the anisotropic case. In this case, the vortex can be viewed as a pancake in the copper-oxygen planes of the HTS. However, the coherence length is less in the *c*-axis direction than the spacing of the Cu-O planes. Thus, the Lawrence-Doniach model must be used, which leads to a concept of pancakes connected by magnetic strings. Consequences of this picture were discussed under conditions of weak and strong pinning and when the field is applied in different directions. For a tilted applied field, the spacing is determined by the component perpendicular to the Cu-O layers; there is no quantization for the case of the penetration depth approaching infinity—the case near T_c. Thus, there would be no Josephson-type coupling of the vortices. These coupling conditions can be varied experimentally by using a multilayer system of superconductor and insulator or normal inhomogeneous superconductor. This presents additional difficulties for theory, although such defects modify the critical current behavior drastically. Professor Clem's model has been successfully applied to a wide variety of experiments, which were discussed at this conference.

Overuse of the Critical State Model

Dr. Ron Goldfarb (National Institute of Standards and Technology, U.S.) was expected to speak about ac susceptibility measurements but instead discussed the overuse of the critical state model—frequently called after C. Bean (then at General Electric, Schenectedy, New York), although modifications by various people have brought confusion to the use of the term "Bean Model." The critical state model attempts to relate magnetization M to the critical current J_{cm} as $J_{cm} \sim M/a$, where a is a dimension of the sample; this frequently is the grain size. A variation of the ballistic galvanometer magnetometer was described that included the capability of passing a current through the sample during the magnetization vs field H measurements. The magnetization loops (M vs H) were discussed, the general tilt of the loop being due to the background diamagnetism. At higher fields the magnetization pinches off as a signal that critical current density has been reached. Dr. Goldfarb suggested that the irreversibility line could be identified by using this technique, where the pinch-off of the magnetization loops is not quite complete. The samples used had only very low values of J_c—100 Å/cm^2.

Magnetization Measurements

Dr. Mas Suenaga (Brookhaven National Laboratory, U.S.) discussed dc magnetism measurements. Experimentally, a small ΔM loop must be greater than the variation of magnetic field across the sample. The Hao-Clem theory is useful when the field increase gives a linear shift in the resistivity curves, but this generally is not the case for HTS materials where these resistivity curves spread with increasing field. His results are based on earlier work where correlation decreases with field and fluctuations become more important. Various elements substituted in YBCO have been studied for their irreversibility temperatures and a general relation found: $H = a[1\text{-}(T_r/T_c)]^n$ where T_r is the irreversibility temperature and $n = 1.5$ fits his data. Proton radiation causes large J_r change, but the change does not reach to irreversibility line temperatures. Heavy ions produce a greater change. He also discussed the applicability of the Bean Model to give critical current density values that compare with transport measurements. In the HTS, the power law fit, $J \sim E^n$ frequently gives small values of n. When n is <5, the Bean Model does not give results comparable to transport measurements. The flux creep and pinning potentials must be included with the time variation, as well as material inhomogeneity. The Anderson-Kim model is not adequate for this situation.

Intrinsic Pinning

Intrinsic pinning, where the intrinsic plus extrinsic pinning determine the critical current, was discussed by Professor M. Tachiki (Tohoku University, Sendai, Japan). He develops the Ginzburg-Landau model for both weak and strong pinning and vortices at a boundary. He obtains the angular dependence for a horizontally and vertically oriented vortex. For angles near $H \| a,b$, a critical angle separates regions where no vortices cross the a,b planes and where vortices begin to cross. Thus, in addition to the angular dependence that peaks J_c at $H \| a,b$, he obtains a spike at this angle that extends only to the limit of the critical angle he derives. Such peaks, he stated, have been found by H. Adriaan.

Nearly 60 posters were presented each day so it is not possible to discuss those results in any detail. On the last day, I was presenting a poster and thus did not have an opportunity to visit posters of that day. I also did not review posters that primarily addressed susceptibility determinations of critical currents. Although these techniques are interesting to determine intra-grain currents, transport measurements are necessary to validate bulk critical current density improvements. Delegates had come from about 26 countries, including many eastern European countries, and a wide range of accomplishments was displayed.

Magnetics

V. Sirenko (Kharkov, Russia) showed the increase of trapped magnetic flux with increased strain. N. Nakamura et al. (ISTEC Laboratory, Japan) reported $4 \cdot 10^8$ Å/cm^2 at 77 K, 0 T, with a steep fall off above 3 T for YBCO melt-powder melt growth (MPMG). In a second poster from this group, H. Fujimoto et al. described angular measurements that showed a double peak in the magnetization of bulk YBCO similar to what I observed in the MIT Professor Cima samples. They interpreted this peak as being due to twin boundary pinning—different from the Clem picture I applied to the data.

T. Francavilla et al. (including this author) reported the magnetic field dependence for high critical current (>300 Å) samples from the Texas Center for Superconductivity (R. Meng). At 1 T, Ic = 225 Å and J_c = 1070 Å/cm$_2$. Y. Yang et al. (University of Southampton, U.K.) achieved J_c = 50,000 Å/cm^2 at 67 K, 0 T, in a neutron-irradiated melt-textured YBCO. K. Kimura et al. (Nippon Steel) gave a value in melt-processed YBCO of

J_c = 10,000 Å/cm^2 77 K, 10 T. For Bi(2212), J. Bock and S. Elschner (Hoechst), values of 1000 Å/cm^2 at 77 K, and currents up to 500 Å have been carried in a length of 15 cm. At 5 K, J_c = 55,000 Å/cm^2. H. Kliem et al. (RWTH, Aachen) investigated the change in slope in the log V vs log I curves to indicate different pinning energies in YBCO. Anomalous torque behavior was studied by J. Martinez et al. (Leiden, the Netherlands) in Bi(2212) single crystals. A maximum in torque for $H \| a,b$ decreases linearly with T; at about 1 K below T_c, a second smooth maximum develops at higher angles—about 15 degrees. This is interpreted as core trapping between weakly coupled superconducting layers.

An unusual result by M. Riessner et al. (Vienna and Orsay, France) for $H \| a,b$ was reported for aligned powder YBCO. A sharp minimum is seen for $H \| a,b$, and a secondary peak seen for $H \| c$. Measurements to 6.7 T were obtained. A torsion wire magnetometer developed by F. Steinmeyer et al. (Walther-Meissner Institute, Germany) was applied to single crystal Bi(2212). For orientation of field near $H \| a,b$, anomalies were found that they related to lock-in transitions of flux lines between the Cu-O layers. Another report was given by S. Brongersma et al. (Free University of Amsterdam, the Netherlands) that used Nb/Cu multilayers and magnetization measurements; a critical angle of the field related to the periodicity of the layers is found. D. Zheng et al. (Cambridge, England) investigated a thallium (1223) phase superconductor to obtain J_c = 10^5 Å/cm^2 at 77 K, 0 T, although his was a magnetic measurement. Proton irradiation raised the critical current in thin YBCO layers by about a factor of 50 in work reported by G. Castagno et al. (Physics INFM, Torino, Italy). Ion irradiation of single crystal Bi(2212) showed improved magnetic properties according to A. Zhukov et al. (Moscow State University, Russia). M. Wacenovsky et al. (from H. Weber's group, Atominstitut, Austria) measured the influence of fast neutron radiation on samples by Murakami of melt-textured YBCO. An enhancement of a factor 4 was found at low temperatures.

SECOND DAY

Invited papers on the second day emphasized critical current density enhancements by irradiations of various types, by melt texturing, and (in one paper) by switching to a thallium-based system. Fast neutron radiation effects were studied by the Weber group; F. Sauerzopf (Atominsitut) described atomic displacements in response to >0.1 MeV neutrons. T_c decreases with dose while J_c increases as pinning centers are increased, although finally the reversible defects decrease J_c. The effort has been to distinguish the defect classes and to examine the way in which defects cluster. For the Bi(2212), an increase in the irreversibility line occurs with increased dose. The high-energy neutrons produce isotropic defects: the sample is put into the core of the reactor so the radiation is isotropic and the energy absorption results in isotropic energy deposition. For radiation dose of 10^{21} cm^2 a factor of 10 increase in J_c is observed at 3 T; the difference reduces to zero near 9 T.

Dr. H.-W. Neumüller (Siemens) discussed results of 0.5 GeV iodine ions into Bi(2212) single crystal. For a $5 \cdot 10^{11}$ ion/cm^2 dose and thin crystals, 5-10 μm homogeneous damage is observed. J_c is $1.3 \cdot 10^7$ Å/cm^2, determined magnetically. No angular dependence is observed on the magnetization at 1 or 2 T. Above 60 K there is no correlation of J_c with iodine radiation. An earlier irradiation with 0.4 GeV oxygen gave no increase in J_c.

Radiation Effects

Neutron and proton radiation effects in YBCO were discussed by Dr. M. Kirk (Argonne National Laboratory). About 10^{16} cascades result from $2 \cdot 10^{17}$ dose. J_c increases linearly in this fluence regime. The strain field has a size 1-5 nm and is about twice the defect size, as determined from atomic resolution microscopy. These defects are stable for a year at 20 °C and for 8 h at 300 °C. They don't always produce pinning enhancement. The protons show more damage along the a-axis, which suggests shifts in the Y,Ba atoms in the a direction. Kirk also discussed electron radiation effects. The enhancement of J_c is similar to neutrons, but 10^{16} dose produces 10^{16} defects. The weak pinning model gives $J_c \sim n^{3/3}$ where n is the density of pinning sites. Here the displacement of copper atoms in the Cu-O plane is suggested; clusters of size less than 2 nm can form. The irreversibility shift is observed to be small and doesn't show up in all crystals.

MPMG Processes

Dr. Murakami (ISTEC, Japan) discussed flux pinning in melt-processed melt-growth (MPMG) and melt-growth processes. Inclusions of 211 material has been developed by him to increase J_c. Although the particle size is large compared to the coherence length of the vortices, he believes the pinning occurs at the boundary of the 211 particles in the YBCO(123). He showed very sharp boundaries between 211 and YBCO(123) material. The J_c is stated to be proportional to the defect volume V_d. The color of the optical microscopy changes when oxygen deficiency occurs in the material. The earlier material of Salama and Murakami showed an angular dependence of J_c with a peak at $H \| c$, which they interpreted as grain boundary or twin pinning enhancement. Values of $J_c \sim V_a/d$ indicate that the area of the inclusions is important (hence the boundary pinning model), and values up to 38,000 Å/cm^2 are shown. Magnetic "snapshots" show the uniform ingrowth of magnetic flux for the better material.

Dr. K. Aihara (Hitachi) discussed work with T1(2223) and T1-Sr-Ca-Cu-O(1223), T_c = 100 K, bulk samples; he presented results for single crystal and sheathed wire. The time decay factor for magnetization was less for T1(2223) than for T1(1223). Their T1(1223) contained 0.44 or 0.47 Ba and 0.45 Pb (atomic percent). For $H \| a,b$, a more standard curve is found. Wire drawing and rolling of the T1(1223) material resulted in a T1 layer thickness of >70 μm and near random orientation. Values of J_c were 75,000 Å/cm^2 at 77 K, 0 T and 1,000 Å/cm^2 at 77 K, 5 T. The microscopic pinning centers are not yet identified.

Collective Pinning

Dr. V. Vinokur (Argonne National Laboratory) described theoretical work in collaboration with others and a development of the H vs T parameter diagram for vortex glass, vortex liquid, and the melting line. Collective pinning was discussed and a modification of this parameter diagram suggested. He stated that no increase in J_c can result from point defects since vortices are line-like. Line defects are effective, provided they match the vortex dimensions. Various relations between J_c and the pinning energy for types of defects were displayed. A cross-over is expected when the spacing between vortices is similar to the coherence dimension. He develops a theory for the critical length of vortex distortion needed to give a nucleation of a new vortex line, analogous to critical droplet formation. Variable hopping range ideas are introduced to discuss the current-voltage relation.

Papers on pinning, including melt-grown, planar defects, and radiation damage, were described during the second poster session; magnetic properties were also discussed. Wire of Hi(2212) by the powder-in-tube (PIT) method reached 13,000 Å/cm$_2$ at 4 K, 0 T and stayed at 5,000 Å/cm$_2$ up to 10 T. This work was by J. Johle et al. (ETH, Switzerland). Silver-sheathed wires and ribbons were prepared by P. Regnier et al. (Saclay and Orsay, France). A J_c = 1,000 Å/cm^2 was obtained at 77 K, 0 T for thicknesses of ~10 μmand going above 10,000 Å/cm^2 at 4 K. A 3-dimensional array of Josephson junctions was considered by S. Pace (University of Salerno, Italy). This array may describe the granular nature of weakly connected grains in HTS. Multiple processing steps (5) were used to obtain 4000 Å/cm^2 at 77 K, 0 T in Bi(2223) by V. Plechacek (Institute of Physics, Prague, Czechoslovakia). R. Jenkins et al. (Oxford University, U.K.) obtained high J_c values across short lengths of Bi(2212) tape, J_c = 60,000 Å/cm^2 for 4 K, 0 T. At 1 T, J_c = 30,000 Å/cm^2 for $H \| a,b$ and 4 K. For $H \| c$, they find J_c > 10,000 Å/cm^2. The Bi(2223) silver-sheathed tapes by S. Cassidy et al. (Imperial College and University of New South Wales, Australia) gave J_c = 8,000 Å/cm^2 at 77 K, 0 T but showed a rapid drop for 1 mT. They report a non-power-law I-V behavior at low currents. Another paper from New South Wales by Q. Hu et al. measured tapes and multifilaments of the Bi(2223) and found no secondary peak in the angular dependence. J_2 = 27,000 Å/cm^2 at 77 K, 0 T for single filament and about 1/2 that for a multifilament wire were reported. Thick YBCO films (0.2 mm) were shown to have J_c = 8,000 Å/cm^2 at 77 K, 0 T, but this drops rapidly at 10 mT. This work was reported by K. Fischer et al. (Institute of Solid State Materials Research, Dresden, Germany.)

Thick Film Measurements

Another thick film measurement was reported by M. Day (University of Birmingham, U.K.), with 10 percent silver added. Film thicknesses were not given, J_c = 2,000 Å/cm$_2$ at 77 K, 0 T. Composite wires of Bi(2223)/Ag were shown to have J_c = 10,000 Å/cm^2 at 77 K, 0 T, by Y. Huang et al. (University of Zaragoza, Spain). Similar values were obtained by D. Brauer et al. (Wuppertal, Germany); at 1 T the value was J_c = 1,000 Å/cm^2. These authors show variations with ceramic thickness on J_c. A similar tape gave K. Hautanen et al. (Canadian Superconductor Technology Consortium) a value of J_c = 9,000 Å/cm^2 at K, 0 T. I was interested in the report from W. Knaak (Asea Brown Boveri, Heidelberg, Germany) who used a Faraday-effect measurement to visualize vortices. The role of low-purity materials of Bi(2223) was emphasized by S. Shukla et al., (National Physical Laboratory, New Delhi, India) where J_c > 10,000 Å/cm^2 is obtained and Ic = 25 Å for high-purity material, although the purity level was not given. The role of carbon in decreasing J_c was shown by N. Buffer et al. (Stuttgart, Schaebisch Gmuend, and University of Tennessee).

FINAL DAY

The final day brought thin films into the invited paper sessions. Professor Ø. Fisher (University of Geneva, Switzerland) described the ability of layer-by-layer deposition of thin films with one unit cell containing a yttrium core and the next layer of one unit cell thickness containing a praseodymium core (1.2nm/1.2nm). These superlattices can be used to modify the coupling interaction, which is already anisotropic in the HTS materials. For the superlattice above T_c = 50 K, reduced from 92 K of the pure YBCO, the coupling is shown to vary little after the conditions of (2.4/9.6) nm Y/Pr superlattice is reached. He suggests that strong coupling results for pure YBCO. A stiff rod model for vortex lines is thought to exist for thin films up to 26.4 nm. The response to magnetic fields is determined, and much of the data can be fit by a relation for the pinning energy U, the thickness d, and the field B; $U/d \sim a \cdot \ln(B) + b$. Proximity effects are also investigated by substituting a normal metal layer for the Pr. Such coupling is found across 12-nm normal metal layers.

Professor Jack Evetts (Cambridge University, U.K.) discussed critical currents in thin films from the perspective of complexity. He also discussed the pitfalls of putting too much emphasis on any one model at this time in view of the variable conditions, say, of defect structures, that exist and are not yet controlled.

Superconducting Wire

A series of three talks by manufacturers of superconducting wire were given as the final part of the invited program. Dr. H. Krauth (Vacuumschmelze/Siemens) described Bi(2212) and Bi(2223) phase materials on silver. The role of silver in aiding crystalline alignment is not fully understood. J_c values of 10^5 Å/cm^2 at 4 K, 0 T, and >10,000 Å/cm^2 at 4 K, 10 T were given for Bi(2212). At 77 K, the Bi(2223) gave 40,000 Å/cm^2 in a 0 T field. Angular dependence showed no indication of a secondary peak for $H \| c$.

Dr. K. Sato (Sumitomo Japan) described the Bi(2223) composition carefully $Bi_{1.8}Pb_{0.4}Sr_{2.0}Ca_{2.2}Cu_{3.0}O_x$ (this is similar to that used by other groups). Rolling gives a thickness of 0.1 - 0.2 mm and widths of 2.5 - 5 mm. At 4.2 or 20 K the J_c values are nearly the same at 10(5) Å/cm^2 in fields up to 25 T. A factor of 3.7 reduction results for the field oriented normal to the tape. Cyclic bending was investigated; for 0.18 percent, little change is seen while for 0.48 percent, a decrease by 30 percent is found. Lengths to 100 m have been reported with good quality along the length. One such length (114 m) gave J_c = 9700 Å/cm^2 at 77 K. Bundling of the filaments was discussed. Although too much silver is required for use in current leads between high and low temperatures, they have passed 2,300 Å through one such bundle in one direction and 1214 Å in a return path configuration. A pancake wound and measured in a field of 20 T at 20 K could produce 0.25 T (I believe he said). Silver makes up 80 percent of the wire to date.

Dr. Michael Walker (IGC, Guilderland, New York) spoke about their Bi(2223) phase wires. Lengths of 80 m show full superconductivity. A multiple rolling gave J_c = 29,000 Å/cm^2 (compared to 24,000 Å/cm^2 for a less rolled wire. At 4 K, 5 T he reported 70,000 Å/cm^2, and at 20 K, 20 T the value of 50,000 Å/cm^2 is obtained for fields parallel to the tape.

CONCLUSIONS

Thus, I conclude that by several applications criterion these wires are about ready to be considered for applications—beginning with transmission lines, bussbars, current leads to low temperature magnets, etc. The similarity of results at present suggest that a plateau has been reached. It is perhaps this perception that has brought so much attention back to the need for understanding the basics of flux pinning mechanisms. As one manufacturer remarked, "We are depending on you (basic researchers) to give us the innovations we need to engineer improved bulk materials and wires." And many papers at this conference were getting into microscopic detail as to the nature of pinning centers. In later talks with Professor M. Flückiger (University of Geneva), we noted the sustained effort in Japan by large companies compared to the small entrepreneurs in the U.S. He remarked that the stability of funding in most of the European programs is crucial for developing the breadth of information—from phase diagrams to analytic physics tools and theory—that is needed to address the very subtle problems of flux pinning. This conference provided an excellent discussion of the significant progress that has been made within the last year and the issues that need to be addressed by further research.

Papers from the conference will be published by Butterworth-Heinemann in *Cryogenics*. The first part has been published as Vol. 32, No. 11 (1992).

POLICY

Government Funding Policy for British Universities and University Research

by Daniel E. Whitney, former Liaison Scientist for Manufacturing, Office of Naval Research European Office. Dr. Whitney is at the Charles Stark Draper Laboratory, Inc., Cambridge, Massachusetts.

KEYWORDS: strategy; triage; multidisciplinary research; Leeds University; SERC

BACKGROUND

Until five years ago, British universities had line-item budgets from the government that were based on "planned" enrollments. If enrollments fell short of the plan, the universities kept the extra money. This has been changed; funds are now based on actual enrollments. The government also gives funds that match industry contributions and contracts. The slack in the old system must have reached 25 percent in places, so the squeeze has been hard.

On a recent visit to Leeds University, I had a wide-ranging discussion of changing research funding strategies in Britain with Professor Alan de Pennington of the Mechanical Engineering Department. This article summarizes these discussions. (Technical aspects of this visit are described in

Ref. 1.) Additional insight to the topic in this article is provided in Ref. 2.

APPROACH

Leeds and other universities have had to cut staff and turn departments and research units into "holding companies" (more aptly called "profit centers"). This trend has forced research into a more applied mode to capture industry support. It also has tended to tilt the research more toward bottom-up efforts, in the sense that particular processes or design steps must be emphasized, even if there is a generic goal in the minds of the researchers.

Another change that is affecting universities is a triage by the government. The result of the triage will be three classes of universities:

- those that have broad curricula and unrestricted research opportunities;
- those that will revert to teaching only; and
- a group in the middle that will have both teaching and limited research topics.

(The same triage is happening in Germany.) The Vice Chancellor at Leeds has determined that Leeds will be in the first category. He apparently sees multidisciplinary research as one way to cement this position. He recognizes that traditional departments do not encourage such research but that manufacturing and design not only do encourage it but thrive on it.

Professor de Pennington also described the changing nature of government funding for design and manufacturing. The two sources, SERC (Science and Engineering Research Council, like our National Science Foundation) and DTI (Department of Trade and Industry, like our Department of Commerce) have different goals, funding sources, and management techniques.

SERC's effort in design research[2] is currently a single program, not an ongoing process with a recurring budgetary line item. DTI, on the other hand, funds more broadly defined manufacturing research through its line item for the ACME (Application of Computers to Manufacturing Engineering) directorate within SERC.

A joint DTI-SERC steering committee [the Advanced Manufacturing Technology Committee (AMTC), of which de Pennington is a member], oversees the ACME program. AMTC operates in a sort of contract mode rather than a grant mode. It establishes milestones and work is frequently reviewed. AMTC can stop a project if it is not making progress, and it often does so. Since its founding in 1984 ACME has spent £40 million.

The November 1991 edition of the ACME Strategy booklet[3] defines the committee's strategy. The main components of this strategy read like an "industrial policy" and appear to me to be

- declaration of a mission to use research funds to help British manufacturing;
- recognition that something beyond "basic" research is needed to help manufacturing;
- identification of classes of research and industries;
- conscious allocation of projects and resources to some of these classes;
- recognition that manufacturing spans technical, social, and financial domains, and that spanning research is needed;
- a *time-line* structuring of each project from idea to product so that suppliers and users of potential results are part of the project from initial planning stage to conclusion (the concurrent engineering of research projects?);
- a *cross-disciplinary* structuring of the projects to require collaborators fromdifferent backgrounds, companies, and universities; and
- rejection of collaboration or diversity for its own sake.

Careful study of the strategy book indicates that:

- overall, research funds in manufacturing will shrink over the next three years;

- since several university centers of excellence have emerged over the last few years, it is they who will get the bulk of the remaining funds, while others will be squeezed out;

- funding for robotics and textile manufacturing will be reduced, while funds for management and planning research and for manufacturing processes will rise; funds for CAE, integration methodologies, and advanced production machines will remain the same (integration was boosted significantly last year);

- compensation for the funding falloff will be sought from industry;

- projects will be actively monitored; and

- the entire portfolio of projects and research topics will be reviewed in two years.

This strategy reflects increasing pressure on researchers to emphasize the applicability of their research and to get more money from industry. Only some of the researchers can meet this challenge. And because of the recession, not many companies have the money to provide significant support.

CONCLUSIONS

The strategy described is an activist one that does not depend on the workings of the market or other natural mechanisms to make technology transfer happen. It attempts to prescribe a definite-structure for academic research in manufacturing so that relevance will be enhanced and transfer more likely. The National Science Foundation is currently conducting a study to see what steps might be taken to encourage the same effects in the United States. The U.K. strategy should be looked at as part of that study.

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THE EMBASSIES: TECHNOLOGY ROUNDUP

SPAIN

For further information on Spain items, contact Mr. Robert G. Morris, Science Counselor, American Embassy, Madrid, APO AE 09642-8500.

Materials Science at Zaragoza: One of Four Institutes on a Quest

Spain seeks to break into materials science for its putative key to technological development. The Institute of Materials Science of Aragón, Zaragoza, is one of four such institutes recently set up by the government around the country. These institutes are devoted to fabrication and study of new technological materials including magnets, composites, superconductors, liquid crystals, and catalysts.

Materials science, like microelectronics and biotechnology, is a quest for a philosopher's stone by science and technology (S&T) planners in all industrialized countries, a "secret key" to technology development and economic growth. In Spain the hope of riches through materials development also runs high. Although the country has a competent tradition in physics and chemistry, two of the traditional bases for materials studies, it had no major program in materials science before the mid-1980s. At that time the National Research Council (CSIC) began founding institutes of materials science now located in four cities: Madrid, Barcelona, Seville and Zaragoza. This article covers work at the Materials Science Institute of Aragón in Zaragoza (Instituto de Ciencia de Materials de Aragón—ICMA).

Zaragoza, the capital of Aragón, is a city of 600,000, with 22,000 students attending its university. Of transcendent importance in Spanish history, it was of course Aragón that joined with Castile, under their two monarchs Fernando and Isabel, to form what became Spain. With a small industrial base, Aragón educates most of its scientists and engineers for positions elsewhere in Spain.

ICMA is of the "mixed" variety of institute, meaning that it is operated jointly by CSIC and the university. Its staff consists of 90 researchers, 20 technicians and support personnel, and 50 students on research scholarships and grants. Fifty eight percent of the staff are connected with the university and 42 percent with CSIC. The current director is Víctor Orera Clemente, a physicist appointed by CSIC. The deputy director, Carlos Cativiela Marín, is from the university. In a mixed institute, CSIC and the university share the direction in this way and rotate their representatives in the two positions.

By nearly every index, ICMA has demonstrated rapid growth since its founding in 1985, including budget, staff, and research articles published for example. Doctoral thesis output has been flat, with graduate assistantships falling in 1991, and 1990 levels have not been regained so far this year.

The 1991 budget was about $5 million, not including salaries which were a similar amount, for a total of around $10 million. The research budget goes for:

Infrastructure	$2.2 million
Overhead	0.3
Projects for EC	0.2
National projects	1.3
Contracts	0.7
Administration	0.1

The source of all these funds is not evident from the categories shown, except that projects and contracts depend on the EC, the national government, industry, and local government.

In 1991 ICMA researchers published 131 articles in international journals on results from

58 projects, and they guided 30 thesis projects below the Ph.D. The level of Ph.D. thesis output has ranged between five and ten each year since 1987 when the first ones were awarded.

Dr. Orera asserts that the prime goal of ICMA is "to perform good science." "The science has to be motivated by novelty more than for immediacy of applications." The goal is "a search for new concepts, new effects and new technologies," he went on, "rather than just a repetition ad nauseam of old strategies leading to small and irrelevant alterations of present knowledge."

"But," he emphasized, "our research is quite expensive. This means," he said, "that he and his colleagues have to convince society that their research is useful as well as good; society has to believe that today's science will support tomorrow's technology."

Choosing good subjects and assuring that the work is good is the main job of Orera and the leaders of the institute's seven groups. In addition to being institute director Orera is leader of Group IV, Spectroscopy of Solids. Deputy Director Cativiela heads Group III, Liquid Crystals. Carried on the roll of Group II, Polynuclear Compounds and Homogeneous Catalysis, is Luís Oro, well-known to U.S. policymakers as the Secretary General of the National Research and Development Plan and Chief Executive of the Interministerial Commission for Science and Technology (CICYT). Oro was a professor at Zaragoza before entering the government. The seven groups are:

- I. Organometallic Compounds
- II. Polynuclear Compounds and Homogeneous Catalysis
- III. Liquid Crystals and New Organic Materials
- IV. Spectroscopy of Solids
- V. Low-Temperature Solid State Physics
- VI. Magnetism of Solids
- VII. Physical Properties of Materials of Technoiogical Interest

Research programs and individual projects underway generally involve more than one group. These programs and a few examples of projects are:

- Magnetism (compounds, permanent magnets, superlattices)
- Molecular chemistry (organometallics, catalysis)
- Molecular materials (liquid crystals)
- High-temperature superconductors (fundamental properties, applications: magnetometer, wire production by laser floating zone method)
- Materials for optical applications (heavy metal halide glasses for optical fiber amplifiers, insulating crystals)
- Conventional superconductors (metrology, power storage)
- Materials engineering (carbon epoxy composites, mechanical properties)
- Theory (many-body quantum systems)

An example of the participation in programs by the different groups is given for the high-temperature superconductivity program. Four of the seven groups are involved in this program: IV, V, VI, and VII. Magnetism draws support from Groups III, V, VI, and VII.

A walk through the laboratories revealed a good supply of modern equipment. The equipment was somewhat crowded into part of the physics department in the Faculty of Sciences building on the main campus in Zaragoza's university city. Another part of the institute is located across the Ebro River on the six-year-old engineering campus. Equipment includes electron microscopes, scanning microscopes, a microsample calorimeter for temperatures down to 2 millidegrees Kelvin, a magnet producing fields of 30 teslas for 1.5 seconds, and laser floating zone monocrystal and polycrystal fiber growth apparatus developed and built in the institute.

The institute personnel dream of being united in the spacious and uncrowded newer buildings of the engineering campus. The current separation is obviously a handicap. The electron and scanning microscope facility is across the river and all samples are prepared there, including those made by laser floating zone—no matter for what work. All the composite materials studies and work on physical properties and phase transitions are carried out there as well, under the overall direction of Rafael Navarro Linares, a veteran of years at Los Alamos. Like Navarro, Orera also worked professionally in the U.S. at Oak Ridge.

Like the other three materials science institutes, ICMA is subject to review by an international advisory committee headed by Manuel Cardona of Stuttgart. IBM's E. E. Méndez is an American member of the group, which tries to establish international standards at the four institutes and guide them into fruitful areas. Use of such groups is not common in Spain.

Collaboration with foreign laboratories has included formal projects with

- The Institut Laue-Langevin in Grenoble
- The Daresbury, U.K., synchrotron radiation source, along with the British Council (rare earth amorphous intermetallic compounds)
- Italy's CNR (polynuclear metal complexes)
- Université Pierre et Marie Curie and CNRS (intercalated magnetic compounds)
- Université de Maine (bimetallic magnets)
- Würzburg University (catalysis)
- Paderborn (lasers).

Orera serves on the editorial committees of *Magnetic Resonance Reviews* (U.S.A.) and *Journal de Physique Appliquée*, while a colleague serves on the board of the *Journal of Materials Chemistry*.

Visits that have come from or been made to the United States include: the University of Michigan, University of Georgia, University of Colorado, and the University of Texas.

Some activities (by group) are listed below. The projects in organometallics, liquid crystals, low-temperature solid state physics, and magnetism stand out.

I. Organometallics: synthesis and characterization of organic compounds containing nickel, palladium, platinum, gold, ruthenium, rhodium, iridium, and others; close interaction with catalysis group

II. Polynuclear compounds and catalysis: work on many of the compounds listed above, plus clays and zeolites

III. Liquid crystals: nonlinear and ferroelectric liquid crystals; high-performance polymers

IV. Spectroscopy of solids: organometallics; applications to solid state lasers; halide glasses for optical fiber amplifiers

V. Low-temperature solid state physics: high-temperature superconductors; superconducting magnetometer that operates at liquid nitrogen temperature (77K); resistance standard utilizing the quantum Hall effect; voltage standard applying the Josephson effect; fabrication of superconducting wire and coils (not high-temperature superconductors); calorimetry of superconductors, liquid crystals, and magnets temperatures down to 2 millidegrees Kelvin (the institute has its own liquid helium facility).

VI. Magnetism: compound magnets with neodymium, iron, and boron as one example; magnetic semiconductors; rare earth magnets; magnetic polymers; superlattices; magnet of 30-tesla field strength, 1.5-second pulse.

VII. Physical properties of technological materials: superconductors of families like Bi-Sr-Ca-Cu-O; basic studies like flux pinning in superconductors; superconducting fibers by the laser floating zone method; carbon epoxy composites.

Good Science But No Big Payoff Yet

Spain's materials effort is yielding good science, as shown by the prodigious output of research papers. But Spain, no more than any other country, knows how to turn good science into big bucks quickly and surely. The danger is that the country will grow impatient, forsaking the progress already made. Ten years is a long time for any government to wait for a program to mature. In science, waiting is necessary. With less experience in science than many countries, Spain may not stay the course. Government expenditures on S&T declined in 1992 after a rise averaging 23 percent a year from 1983 to 1990. The pressure on the Spanish government to reduce spending, because of a public sector deficit hovering over 5 percent of GDP and to fight stubborn inflation, may lead to further cuts in S&T. Additionally, the new areas just being developed, like materials, will suffer first and the most.

UNITED KINGDOM

For further information on United Kingdom items, contact Mr. Jeffrey Lutz, Science Counselor, American Embassy, London, PSC 801 Box 38, FPO AE 09498-4038.

U.K. Launches a Program for Higher Degress Through Industrial Partnerships

One hundred of the United Kingdom's (U.K.) brightest research students will achieve their higher degrees through industrial partnerships under a new scheme launched in June 1992 by the Department of Trade and Industry (DTI). The scheme, jointly managed by the DTI and the Science and Engineering Research Council (SERC), will lead to conventional M.Sc.s and Ph.D.s in a wide range of industrial disciplines. These include process engineering, information technology, materials, and biotechnology.

Industry Minister Tim Sainsbury announced the DTI initiative on 4 June, encouraging students to study for higher science degrees through this scheme. The DTI has allocated £2 million a year (as of August $1.89 = £1.00) to five postgraduate training partnerships with industry. The five partnerships will each enroll 10 students in academic year 92-93 and 10 students in academic year 93-94. Each postgraduate student will receive a SERC stipend starting at £7,000 per annum (1992-93), which may be supplemented by the industrial partner.

"Industry and academics must work even more closely together in Britain — as they do in our competitor countries," Sainsbury said. "We want more of our best researchers to see their natural careers in industry; this scheme is part of our wider efforts to make this key cultural change. If successful, these pilots could be expanded further." This stand-alone scheme recognizes the importance of increasing the flow of people from academe to industry and increasing the industrial relevance of postgraduate research.

The partnerships are a pilot program for the Faraday Centers promised by ministers before the general election. They were also recommended in the Prince of Wales' Working Group on Innovation final report in May. The partnerships will be:

- BHR Group Ltd. and Cranfield Institute of Technology
- EA Technology and the University of Manchester Institute of Science and Technology (UMIST)
- Sira Ltd. and University College, University of London
- BTTG (British Textile Technology Group) and the University of Leeds
- WRC plc (Water Research Center) and Imperial College of Science and Technology, University of London

Sainsbury said: "I was delighted with the enthusiasm with which this initiative has been greeted. A total of 58 applications were submitted for consideration and standards were very high. I look forward to hearing of the progress made by these postgraduates and I am sure that the experience gained will provide a very useful contribution to the wider debate, currently in progress, on the role of intermediate organizations in technology transfer."

This pilot scheme was announced by Ministers for the DTI and the Department of Education and Science (DES) on 19 February 1992. Following the government changes after the April 1992 election the Office of Science and Technology (OST) will now take on the former DES interest in this scheme. SERC will be representing OST.

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