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CAD/CAM and • au Canada

As a result of advances in computer technology the cost of computation is decreasing approximately tenfold per decade. In the manufacturing industries this is fostering the development of widespread changes in design and manufacturing techniques, referred to as Computer Aided Design and Computer Aided Manufacturing or CAD/CAM, at an unprecedented rate. This presents both a challenge and an opportunity for manufacturing companies to maintain or advance their relative positions as suppliers of manufactured goods of virtually all kinds.

In terms of long-term growth and job creation, the manufacturing industries are one of the most important sectors in the Canadian economy. In this context, the rapidly emerging use of Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) technology is of special significance.

Industry, Trade and Commerce
JULY 12 1983
Library

With the advent of CAD/CAM, it will become increasingly evident in the 1980s that the design of an up-to-date plant is just as important as the design of the product. Developments will lead increasingly to the marriage of both Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) into highly integrated design and production systems.

Productivity will be especially important to Canadian manufacturers in the 1980s. During this decade, tariff protection will be lowered, competition from external sources will undoubtedly increase. At the same time a new worldwide wave of industrial automation, based on a rapidly increasing use of computers in design and manufacturing, is occurring.

Interest and activity in CAD/CAM by Canadian companies has increased substantially since 1977 when the first reprint of 15 articles was made available by the Department of Industry, Trade and Commerce to encourage a wider interest by Canadian industry. It is expected that this second and expanded reprint of more recent information will be equally useful to those wishing to gain an appreciation and introduction to this important technology.

Copies of this publication, and a companion Directory of Companies providing CAD/CAM products and services are available from:

The Business Centre (34/2)
Department of Industry, Trade and Commerce
235 Queen Street, Level 01
Ottawa, Ontario
K1A 0H5

Par suite des perfectionnements dans la technologie de l'informatique, le coût de l'informatisation diminue, et de façon très perceptible à chaque décennie. Dans les industries de fabrication, cela permet de faire de grandes et rapides innovations dans les techniques de design et de fabrication; c'est ainsi qu'on a vu la naissance du design informatisé et de la fabrication informatisée. Ceci représente un défi pour les entreprises de fabrication et leur donne en même temps l'occasion de maintenir ou d'améliorer leur position à titre de fournisseurs de presque tous les produits manufacturés.

Si l'on considère la croissance et la création d'emplois à long terme, les industries de fabrication figurent parmi les plus importants secteurs de l'économie canadienne. Dans cette optique, le recours au design informatisé et à la fabrication informatisée revêt une importance spéciale.

Dans les années 80, on se rendra compte de plus en plus que le design des installations de fabrication est tout aussi important que le design du produit. Les réalisations allieront d'une façon croissante le design informatisé et la fabrication informatisée pour donner lieu à des systèmes hautement intégrés.

Au cours de la prochaine décennie, la productivité revêtera une importance spéciale pour les fabricants canadiens. La protection tarifaire diminuera et la concurrence étrangère augmentera. Parallèlement, il y aura une nouvelle vague d'automatisation des industries dans le monde entier, basée sur la croissance rapide de l'utilisation des ordinateurs dans le design et la fabrication.

Depuis 1977, on enregistre une progression sensible de l'intérêt des compagnies canadiennes à l'égard du design et de la fabrication informatisés. En effet, à ce moment-là, le ministère de l'Industrie et du Commerce publiait 15 articles sur le sujet, pour y sensibiliser l'industrie canadienne. La présente ré-impression, plus volumineuse, contient des données plus récentes qui devraient s'avérer tout aussi utiles à ceux qui désirent être initiés à cette importante technologie ou en connaître davantage.

Vous pouvez obtenir des exemplaires de la présente publication, ainsi qu'un répertoire des compagnies utilisant le design et la fabrication informatisés, en vous adressant au:

Centre des entreprises (34/2)
Ministère de l'Industrie et du Commerce
235, rue Queen
Niveau 01
Ottawa (Ontario)
K1A 0H5

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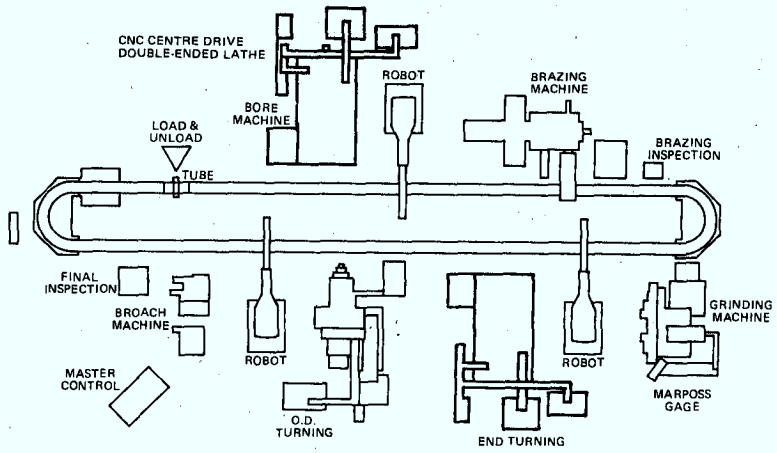
This block diagram shows the location of the two CNC centre-drive double-ended lathes in the machine set-up around the conveyor in the automatic machining line in which transfer is done by robot



NC turning points way to larger production volumes

The following has been adapted from a paper by W. H. Maddock, vice-president engineering and sales, Standard-Modern Tool Co. Ltd., Toronto, presented at the Numerical Control Seminar of the Japan Trade Centre last month. The original title was "Opportunities for NC in High-Volume Production."

In the production of shafts or chucking parts, "high volume" can be defined as anything from a four-minute cycle down to a 24-second cycle. On a two-shift basis this would be approximately 50,000 parts per year up to half a million parts per year. This is the equivalent of 15 to 150 parts per hour.

This total annual production can be a single part or it can be a family of similar parts. Nevertheless, volume is volume, and the application of NC, or rather CNC with microprocessor controls, and the electro-servo drives that are now available, make the power of numerical-control turning attractive because of its versatility, reliability and manageability.

One often hears comments such as: There is no way I will have NC in the production line; there are too many breakdowns; we only have one tool operating at one time; I can't afford it — and so forth.

Consider some facts as published in the SME 1977 Delphi Report on the future of metalworking in the next ten years; it is not a complete list, but it is very appropriate to the subject at hand, and forecasts that by 1982:

- Accuracy and finish will become as important as high rates of metal removal for 95% of all material, removal operations;
- Ten percent of existing NC machines will be connected to a dispatch or control computer;
- Twenty percent of the equipment failures will be instantaneously detected and diagnosed with on-line software;
- Computerized capacity planning and shop floor control systems will be used by at least 10% of the plants in the manufacturing industry;
- By 1984, machine cutting speeds other than for grinding will be increased to between 20 and 30 metres per second, which is equivalent to 4000 to 6000 surface feet per minute;
- By 1986, the production of NC and computer controlled machines will reach 50% of the value of total metal cutting machine tools produced. Fully self-optimizing adaptive control machines will be developed and in wide use;
- By 1987, the application of NC will exceed 33% of the machining output in plants employing less than 30 workers;
- Non-contact, high-speed, high-accuracy inspection systems will be in use for 100% inspection in-line, with closed-loop feedback to machine control.

The Delphi Report is a consensus of opinions of a large number of manufacturers in the U.S., and clearly indicates the move towards improved control systems for production machine tools.

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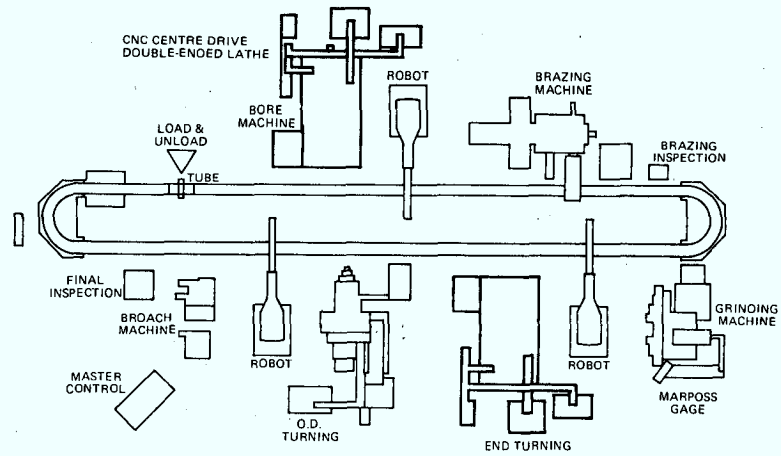

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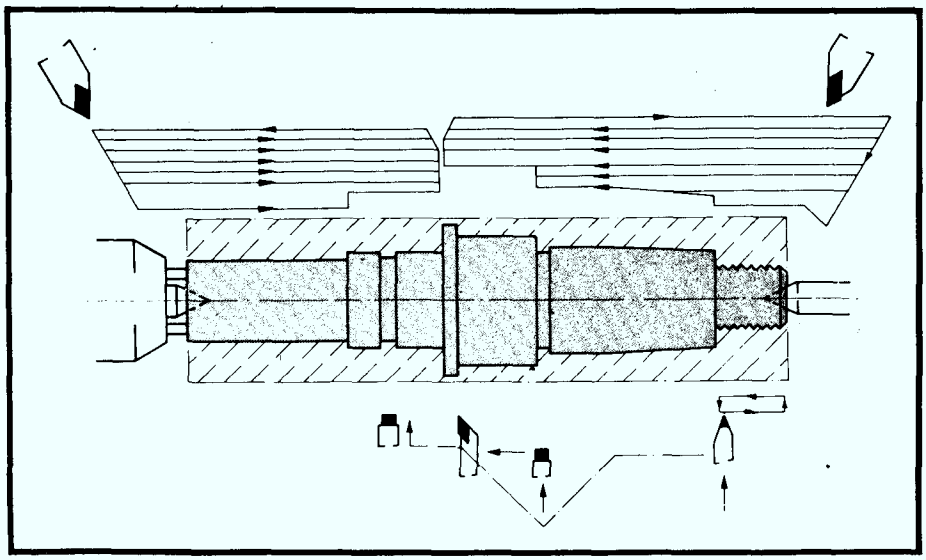
CNC Turning goes into production (cont.)



This example shows a shaft workpiece being machined in a double-ended lathe having three slides. The lower slide having a six-tool turret provides grooving, facing and threading tools. Overhead slide, rear slide and bottom slide tools can operate simultaneously

It is increasingly clear that the demands of competition and the need for management computers to interact with machines is becoming mandatory in our every-day production activities.

The real question is: Can you justify **not** using numerically controlled machines?

The following will give examples of typical components, and of their rates of production, and indicates some philosophies of using CNC for larger volumes, with ideas for hardware — both real and futuristic.

"The application of CNC with microprocessor controls make numerical control turning attractive because of its versatility, reliability and manageability."

Two of a family of nine distributor housing castings have been produced at the rate of 1 min per part with an annual volume of approximately 200,000 total. Both the shaft and the housing have been made on dedicated NC machines of the very simplest variety using fixed tools.

In the case of the shaft, one operator takes pre-heat treated stock, runs a facing and centering machine, loads the component into the NC machine, which automatically clamps the part and actuates the tailstock and produces one end in 2 min. The machine stops and the operator turns it around to complete the other end.

Only three tools are employed: a rougher, a finisher, and a threader. Two cutting speeds are necessary. While a contouring control is necessary, with today's technology and microprocessors all that is needed is memory to store one program all year. A tape reader and extra capability are not required. This would be the cheapest package possible.

The distributor housings use three dedicated fixed tools turning from the right and from the left, and a grooving tool. One fixed set-up of tools and chuck jaws is sufficient to produce all components, and the only additional requirements is a different tape for each.

Again, the very cheapest machine that can be produced, with a microprocessor control and memory capability for nine short programs, is all that is required.

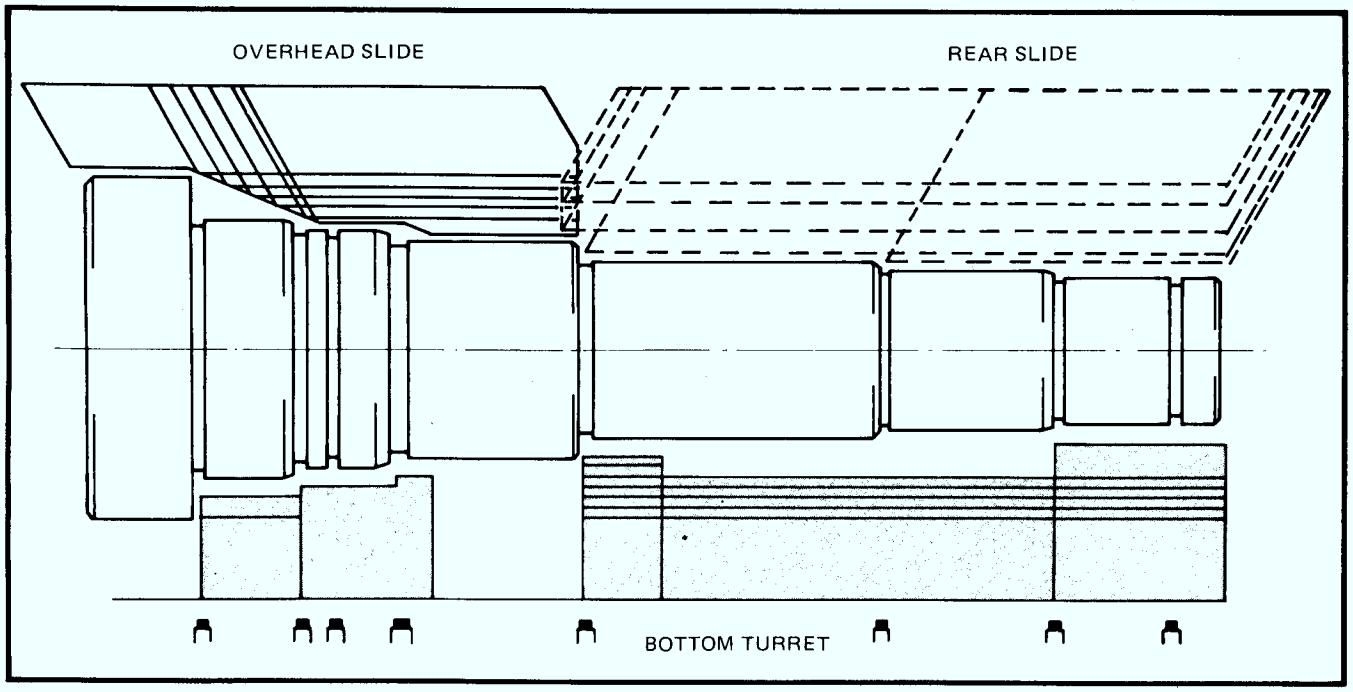
Another example is that of a rocket shell produced on two machines — one for doing all external work between centres, and the other for doing inside work.

If we consider the external portions of this shell, it is obvious that maximum production could be realized by having at least three tools in operation simultaneously — one from the thread end, one coming from the nose end and another a threading tool. This is all possible on a new machine that has three sets of machining slides and combines micro-processor control with tracing slides. A vertical and a horizontal tracing slide operate from each end and are placed in such a way that no tool interference will occur. From below, a six-station turret under full NC control is capable of threading as well as many auxiliary grooving and profiling operations.

With this kind of machine one can now start to think in terms of higher volume, for it is possible to incorporate the advantages CNC, i.e. stored programs, tooling offsets, etc., with three tools operating simultaneously.

The cost of this equipment is less than two slant bed type machines, and it has considerably more output.

Various kinds of thinking are taking place in the U.K. and the United States that are very exciting. For instance, automobile companies traditionally set up multiple lines of dedicated tracers and other types of



This is an example of how a shaft workpiece is machined on a double-ended CNC centre-drive lathe using three cutting tools operating simultaneously in three machining slides

threading machines, and so forth, to produce single components. Of course, any one machine going down shuts down one of the lines.

In addition, if a production requirement goes up by 20%, it is necessary to buy another line.

Current thinking suggests that machines that can produce the total component and can also produce several different parts of a family, can be arranged in paralled and feed an assembly line, so that any one machine going down only reduces the production by that increment.

Other philosophies suggest that a pool of these machines could be available to augment existing dedicated tracer lines to take care of cyclical production increases or to step in where major breakdowns occur.

The philosophy of multi-tool machining is the key to increasing volumes above the 100,000 compounds per annum.

There are components being manufactured for the copier industry, known as fuser rolls, consisting of a copper barrel with a stainless steel hub braised into the barrel to form a roller. These components must be produced at a production rate of 1 min. per part with an annual volume in the order of 125,000.

This component is being manufactured on a fully automatic robot-fed work centre. This CNC-controlled and managed work centre completely handles the part and controls diameters by feeding back information from electronic gauges to the computers to adjust offsets automatically.

Here again, multiple tooling is in evidence and interaction with a management control centre provides adaptive and management control.

To take a quantum jump to production of one and a half million components per year requires more sophistication and more tools to accomplish a 24-sec. cycle.

A machine has been proposed that could be used to produce a family of thirty disk brake components for automobiles. The machine is constructed in the form of a centre column machining centre with an index table and eight live spindles mounted around. Six micro-processor controls operate two axis slides with full contouring capability at each station and with dedicated individual dc drives.

The load station provides for automatic chucking and unchucking, and station 5 would be provided to turn the component over so that work could be performed on the opposite side.

A machine of this configuration is entirely possible with microprocessor technology and reliability, and controls would take the form of small individual micro-processor packages at each station, with central computer supplying all of the program storage and management and maintenance data. Redundancy would be provided to maximize up time.

"The philosophy of multi-tool machining is the key to increasing volumes above 100,000 components per annum."

In summary, the age of microprocessors is upon us, and to remain competitive with an ever-shrinking world we must take advantage of better management techniques to improve production.

The ability of CNC machine tools to perform a variety of tasks, controlled from a management level, can reduce inventories and shorten batch reduction. Production machines will be developed and will become a reality in our every-day lives within a very short time. ■

National Research Council Canada
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DIVISION OF MECHANICAL ENGINEERING

computers

VOLUME 7, NUMBER 2, JANUARY 1978 OTTAWA, CANADA

A PRINTING PRESS ORDER SEQUENCING AID

A.W. Chan, Analysis Laboratory

Background

As part of a technology transfer program, the Division of Mechanical Engineering at NRC collaborates with Canadian industries in performing experiments and studies on industrial productivity. In the spring of 1976, such a project was initiated and jointly supported by R.L. Crain Ltd. and NRC to study the scheduling function at R.L. Crain Ltd. with the objective of improving productivity in the press department. It was decided that as a first phase, an interactive sequencing aid would be developed to "stream" customers orders, as streaming constitutes one of the key scheduling functions. The first phase of the project was completed in the fall of 1977. This newsletter describes the sequencing aid and the results obtained from a 6 month in-plant trial period.

Objectives and scope

The Ottawa plant of R.L. Crain Ltd. produces a large variety of business forms ranging from blank perforated forms to multi-copy multi-colour forms with interleaved carbon paper. The work flow in the plant is schematically represented in Figure 2.

The scheduling of customers orders for the pressroom consists of the assigning of print orders to one of the many continuous forms presses in the plant and to a specific print week. For each of these assignments, the sequence in which the orders are to be produced during the week must be determined by a procedure called "streaming". There are numerous print order characteristics pertinent to the scheduling activity, the more

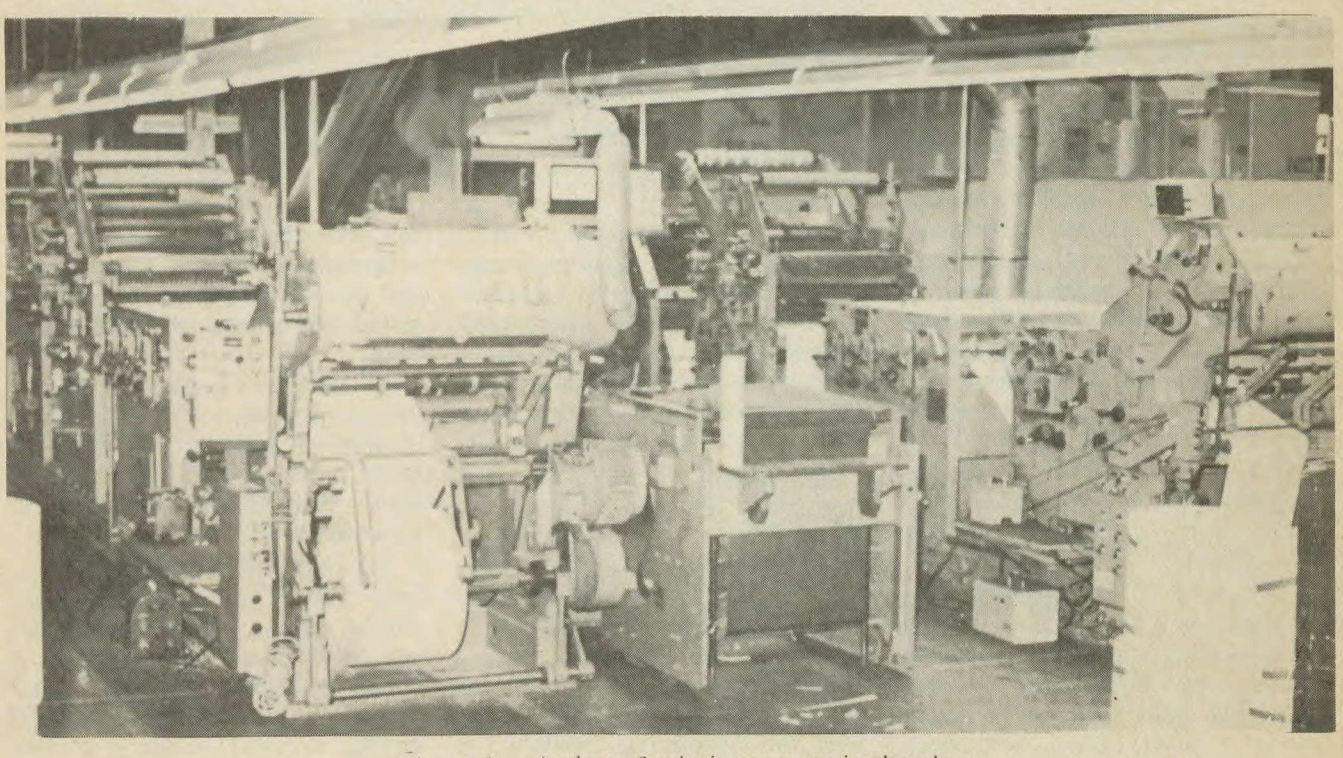


Figure 1 -- A view of printing presses in the plant.

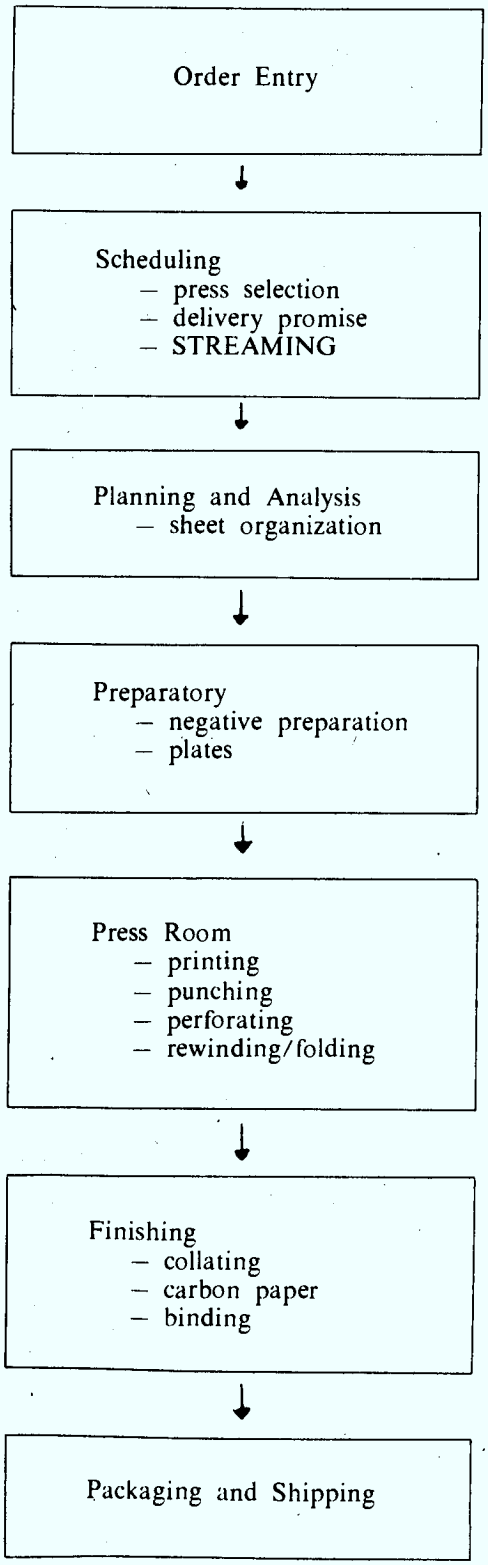


Figure 2 – Work flow diagram.

important ones being form depth and width, paper stock, production quantity, number of colours, colour details, numbering requirements and special requirements such as perforation and punching. These characteristics may restrict the selection of a press for a particular order. The priority and delivery date of the order determine to which print week the order should be assigned. As the orders assigned to a given press for a given week can have a range of characteristics, the press change over effort from one order to the next can be considerable, and the setup time is a large proportion of the total production time. Since the setup time for each order depends on the condition of the press after the last order, the total setup time can be significantly reduced by using the "correct" sequence. These considerations dictate the streaming portion of the scheduling activity.

Currently the scheduling of print orders is handled by two press-coordinators who, based on guidelines and experience, juggle the orders whose characteristics are coded on small strips on schedule boards. However, with the large number of alternative schedules and the occurrences of rush orders and last minute changes, the press-coordinators usually find that they have little time to investigate different sequences in order to select the most efficient one. An interactive sequencing aid is desirable.

The overall objective of the first phase of the project was to develop a self-contained interactive computer program to serve as a sequencing aid which would allow the press-coordinators to devote more time and effort to the other major aspect in scheduling, namely, the allocation of orders to presses and print weeks. During a subsequent phase of the project, an order allocation program can be developed and incorporated to construct an even more versatile scheduling aid.

Approach

The computer program stores the characteristics of a set of printing presses and provides for the entry of a list of print orders with their relevant characteristics. It also provides for entry of groups of orders assigned to a particular press in a certain week. It checks the order characteristics and the press capabilities and warns the scheduler of any incompatibilities. An algorithm is incorporated into the program for computing a "suggested" or best sequence for a given assignment. First, by comparing the differences in characteristics between each pair of orders in the assignment, a time matrix containing the setup times between every such pair of orders is constructed. For any specified sequence, the total setup time is the sum of the corresponding elements from the time matrix. The problem is to find the order sequence for which the sum of the setup times between orders is a minimum. This problem is equivalent to picking a set of elements from a square matrix such that exactly one element is picked from each row and each column and such that their sum is a minimum and a valid sequence is formed. This optimization problem is known as the travelling salesman problem in which a salesman must visit each one of a number of cities (with

SPECIFIED SEQUENCE FOR PRESS X PRINT WEEK MAY 12

	ORDER NO.	SETUP	RUN	ORDER	CUMUL.
1	186542	4.6	1.9	6.5	6.5
2	186827	6.1	1.7	7.8	14.4
3	186814	5.9	15.9	21.8	36.2
4	185872	6.2	6.8	13.0	49.2
5	186585	7.8	3.1	10.9	60.1
6	186556	5.9	13.7	19.6	79.7
7	187056	7.3	8.3	15.6	95.3
8	187777	5.1	2.8	7.9	103.2
9	187290	7.2	4.6	11.8	115.0

TOTAL SETUP HOURS = 56.1 TOTAL RUN HOURS = 58.9
TOTAL HOURS = 115.0

SUGGESTED SEQUENCE FOR PRESS X PRINT WEEK MAY 12

	ORDER NO.	SETUP	RUN	ORDER	CUMUL.
1	186542	4.6	1.9	6.5	6.5
9	187290	6.1	4.6	10.7	17.2
7	187056	5.7	8.3	14.0	31.3
8	187777	5.1	2.8	7.9	39.1
6	186556	5.4	13.7	19.1	58.2
5	186585	6.2	3.1	9.3	67.5
3	186814	5.2	15.9	21.1	88.6
2	186827	5.7	1.7	7.4	96.0
4	185872	5.8	6.8	12.6	108.7

TOTAL SETUP HOURS = 49.8 TOTAL RUN HOURS = 58.9
TOTAL HOURS = 108.7

Figure 3 – Example order sequence.

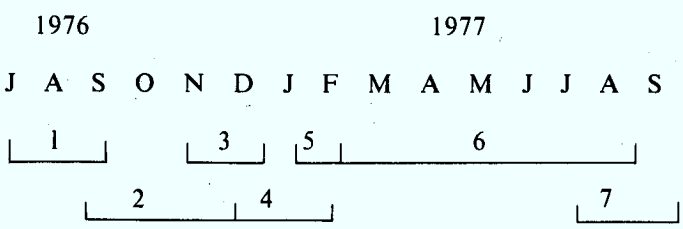
the inter-city distances given in a square distance matrix) once and only once, his objective being to minimize the total travel distance.

How the sequencing aid is used

The interactive program serves as a sequencing aid by performing two main functions. The first function is the computation of a run sequence called the "suggested sequence", which, while not necessarily the optimum sequence, is reasonably good in terms of the total setup time. The second function is to provide for the entry of any externally "specified sequence" and to compute a table displaying the run, setup and total times, which can be used as a basis of comparison among alternative sequences.

In a typical session, the scheduler is expected to delete orders which have been processed, add new orders, assign these orders to specific presses and print weeks, ask for "suggested sequences" and if necessary, modify these sequences by supplying "specified sequences" until he has a satisfactory sequence which can be adopted in the pressroom. In addition, the aid can be used to accommodate last minute changes and rush orders. The scheduler can add or delete orders from a print week or transfer orders from one press to another or from one week to another.

A hypothetical example of print orders is shown in Figure 3 to illustrate a possible comparison between a "specified sequence" and a "suggested sequence".



Major Activities

1. Data collection and system definition.
2. Program development and validation.
3. Test runs at NRC.
4. Study of implementation alternatives.
5. Rental arrangement with NRC computation centre.
6. In-plant trial period.
7. Evaluation.

Figure 4 – Project time table.

History

Figure 4 outlines the major activities and time history of the project. The interactive computer program was written in FORTRAN and developed on the IBM 360 in the NRC Computation Centre. Test runs were made on NRC terminals by the Industrial Engineering personnel and the press-coordinators from R.L. Crain Ltd. Alternatives for implementing the sequencing aid in the plant were studied and R.L. Crain decided to rent a computer terminal linked to the NRC computing facilities for the in-plant trial period. The terminal was installed in the production control department at the Ottawa plant and was used by the press-coordinators to "stream" 4 presses for 6 months.

Results

During the in-plant trial period, the press-coordinators used the interactive program as a sequencing aid to stream print orders on 4 presses. They were receptive to the idea of a sequencing aid, and made suggestions for changes to some interactive features of the program, mainly to simplify its use. In general, they found the computer program convenient to use. While the "suggested sequences" were not always adopted, they provided a starting point for investigating alternative sequences. On occassions, the sequences supplied to the pressroom, while deemed feasible by the coordinators, could not be followed for reasons such as:

- late proof return;
- inability of support departments to provide supplies such as plates, paper ink, etc.;
- distruptions due to rush deliveries.

After the trial period, an evaluation was made based on data on the actual setup times for the 4 presses. A comparison was made of the setup time per order before and during the trial period and between a similar group of 4 presses which had not been "streamed" using the sequencing aid. Due to the difficulty in maintaining a set of identical control conditions under operating conditions, mainly qualitative conclusions can be drawn. For 3 of the presses, there were changes in the operating policies and the types of orders run on the presses before and during the trial period. While the setup time per order appears to have decreased for these presses, it is difficult to derive quantitative results from the evaluation. However, for one of the 4 presses, the comparison was made under reasonably constant conditions. Data from the months before and during the trial period indicate an average reduction on the setup time per order of approximately 10%. Comparison of similar presses during the trial period also indicates a definite improvement in the average setup time per order using the sequencing aid and confirms the reduction at approximately 10%.

In summary, an interactive program has been developed which has proved useful as a sequencing aid. If closer attention is paid to other supporting functions in the plant, so that less "disruptions" in press operations are experienced, even more effective use can be made of the program. The trial results indicate that a 10% reduction in setup time may, reasonably, be expected.

With the completion of the first phase of the project, the cost-effectiveness of system implementation is being considered together with plans for the next phase of the project which would incorporate the order allocation aspect in the overall scheduling process.

Participants

Many people have contributed to this project. The participants from NRC have been Albert Chan, Udo Graefe and Leo Nenonen of the Division of Mechanical Engineering. Neil Olorenshaw and Keith Galloway of the Industrial Engineering Department have been the main contributors from R.L. Crain Ltd. and K. Baker, B. Lathem, B. O'Connor and W. Biene of the Production Control Department have supplied helpful suggestions during and after the test runs at NRC and the in-plant trial period.

Newsletters are published in the broad fields of Transportation, Manufacturing Developments, Energy, Computers, Control Systems and Human Engineering, Standards and Standardization in the Engineering Industries and Medical Instrumentation.

Other Publications by the Division of Mechanical Engineering include the more technical reports of the work done by the various laboratories and also an annual report which describes briefly the various on-going research and development programmes within the Division. Enquiries in general including requests for further information, technical reports, visits to the laboratories of the Division of Mechanical Engineering in Ottawa, etc., should be directed to the Director, Division of Mechanical Engineering, National Research Council of Canada, Montreal Road Laboratories, Ottawa, Ontario, K1A 0R6.

Cette publication est aussi disponible en français sur demande.

Optimizing the production of electronic designs

Ken Blais
Bill Clipsham
David Pearson

The circuit pack system provides computer-aided design software to improve the efficiency of the design and documentation processes for electronic printed circuit packs.

In many complex electronic systems — including telecommunications products — a basic unit of design and manufacture is the printed circuit pack. Consequently, the processes of printed circuit pack design, documentation and manufacture have a definite impact not only on product cost and quality, but also on overall corporate success. To simplify and speed up these processes, a computer-based circuit pack system has been developed and successfully put into production use at Bell-Northern Research.

Following five years of development and trial use of the system, 1978 has seen several very significant targets being achieved. Early in the year, a comprehensive production version of the system was released to the user community of printed circuit pack designers at BNR, Ottawa. In mid 1978, BNR INC in Palo Alto, California, successfully installed the system and became its first user outside Ottawa.

This year also saw us offer the circuit pack system for licence to customers outside the corporate family. It appears that no equivalent system exists on the open market anywhere in the world and therefore our product has received widespread customer interest.

But, before we look at the details of the system and the experience of using it, we need to examine the benefits of developing systems like this.

From paper-based design to computer-based design

A key element in the success of a supplier of electronic systems is product cost. To keep the cost competitive, the process of development and manufacture must be continually examined and amended. Since product designs are continually improved, the ability to incorporate design changes as a system is built and tested is crucial. Also needed is an effective method to transfer product design information from the development to the manufacturing organization.

The basis for improvement in these areas is the automation of the process of creating and using product information, which represents essentially a change from paper-based design to computer-based design. That is, records are no longer stored on paper but in computer files. The customer optimized product engineering system[1] (Copes), developed by BNR's advanced development systems department, brings the power of the computer to bear on the creation, documentation, transfer, and updating of product design information.

The circuit pack system is a major component of Copes. It supports and controls the entire lifecycle of BNR's printed circuit pack products, from design conception, through field maintenance, to final replacement. Its automated facilities ensure that the processing and recycling of pack designs are achieved quickly and efficiently. In the context of the Copes family of design aids, the circuit pack system is complemented by the data storage system so that product information can be stored and updated and reports generated using comprehensive data management facilities.

The production of printed circuit packs is a complex activity involving many diverse groups of people. The process is both time consuming and error prone.

The Copes approach unifies the storage and maintenance of design data and offers a uniform and universal environment within which each contributing group has access to a common pool of information, and an appropriate set of tools to perform its function. This imposition of order on what looks suspiciously like chaos is shown in Figure 1.

The benefits of this system are ultimately reaped by customers of Northern Telecom. Products are less expensive, more reliable, better documented and much better supported. Added benefits are the more rapid introduction of new products and the extension of existing ones.

What is the circuit pack system?
The main functional modules of the circuit pack system are shown in Figure 2. They communicate with each other, and with the data storage system, by means of a central design file, one for each printed circuit board design. The modules can be considered to be a set of tools which are used either independently or in combination to provide the desired support of the circuit pack development process. Let us look in a little more detail at each of the modules.

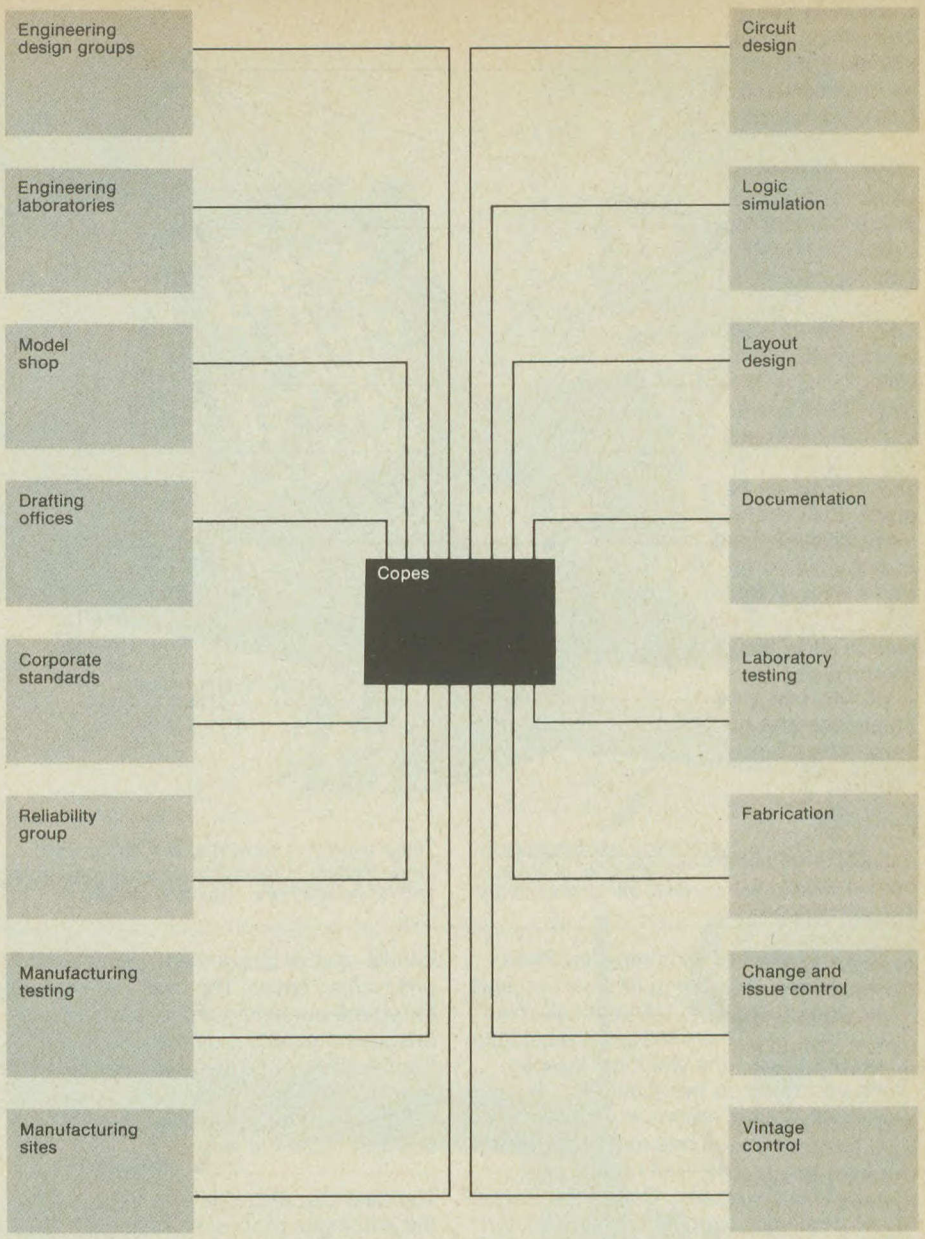


Figure 1. Many different groups within the design and manufacturing organizations (left hand column) are involved in the process of creating printed circuit packs. Important functions are represented in the right hand column. Conventionally, groups interact independently with functions, making for an extremely complex communications pattern that uses paper to convey information (grey lines). The solution adopted by BNR (designer) and Northern Telecom (manufacturer) is represented by the computer-based Copes, or customer optimized product engineering system. This system simplifies the overall communication process (coloured lines). Besides acting as a central repository of circuit pack designs, Copes is a central collection of tools for creating and modifying designs, and a standard interface for transferring information between design and manufacturing organizations. The circuit pack system described in this article is a major part of Copes.

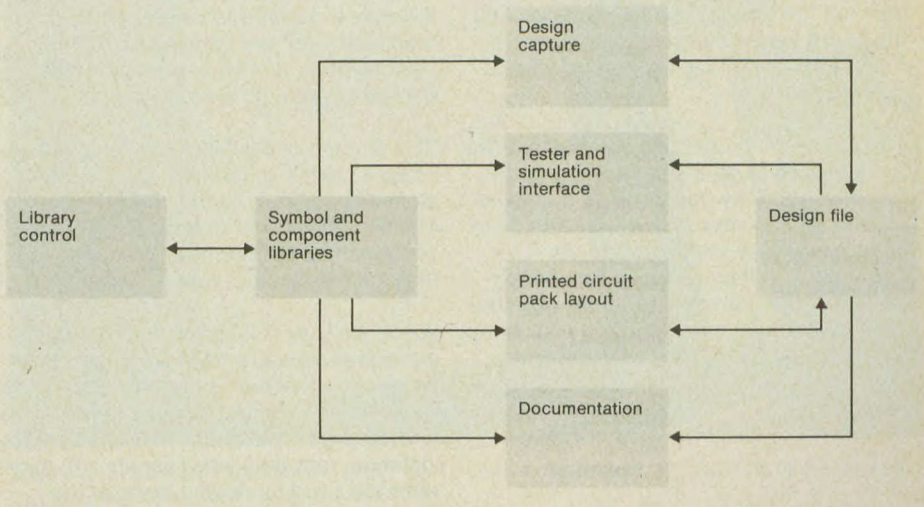


Figure 2. The objectives of the circuit pack system, whose main modules are shown in grey, is to prepare a complete circuit pack design and to allow for easy updating of the design, as necessary. The modules add to, or act on, information in the design file. A schematic design is entered into the computer using the design capture module. The intended design function can be verified by accessing a variety of test and simulation packages through the tester and simulation interface. The layout module is used to create a physical layout for the circuit pack, transforming the electrical connections between the logic gates into printed wire connections between components on the pack. The documentation module transforms the information in the completed design file into the forms — such as stocklists, drill tapes, and component insertion data — required by the manufacturing process. The symbol library contains graphical and electrical descriptions of symbols used in the design process, while the component library holds graphical, electrical and physical descriptions of valid components. A library administrator prepares new entries and enforces corporate standards for the use of symbols and components. Design files are retained in the data management subsystem of Copes.

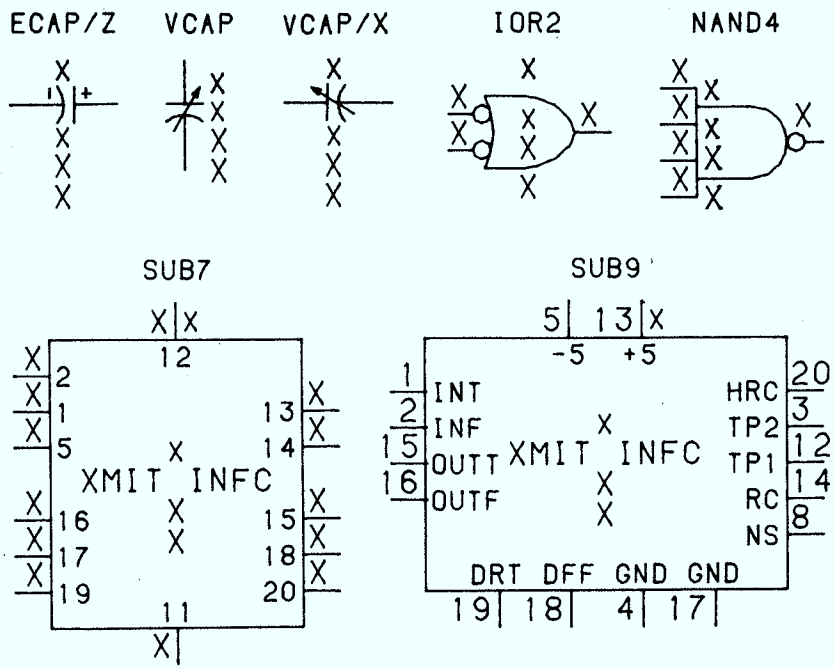


Figure 5. Graphical and electrical descriptions of symbols available to the designer in preparing schematics are stored in the symbol library. These examples show (top line, left to right) three discrete components and two logic gates, and (lower line) two integrated circuits.

When the system has completed these three stages, the routing module can take over. Its purpose is to automatically plan the paths that the printed wires must take in order to make the electrical connections described on the schematic. Sprig has three distinct routers to achieve this; the user selects the one most appropriate for the changing state of routing as it appears on the screen. One router is used at the beginning to cover an initial 'pattern' on the board, the second is used later to handle the random logic present and then, as the design nears completion and the board becomes congested, a maze router can be used to lay out the final optimal paths.

The automatic processes described above are intended to do the bulk of the work for the user. They handle large quantities of data and achieve in relatively little time what would take many days to do manually. But they cannot be made to handle all special considerations required by designers. As a result, Sprig equips the user with a set of editing commands to handle special assignment, placement and routing cases. The user can choose to run the automatic processes first and then use the editing commands to make the necessary changes. Alternatively, the user can first take care of the special cases and then have Sprig's automatic facilities finish the work.

The user can also interact directly with the automatic processes to guide them appropriately. For example, between stages of the automatic routing process, the user is allowed to delete, add or modify any printed connection, to move devices around or re-assign logic gates if these operations are needed.

This amount of flexibility is most useful when a design is updated. Only those elements affected by the change need be modified. For minor changes, this facility prevents useless reruns of the board through the whole layout process.

When the user is satisfied with the Sprig-generated layout, a verification and post-processing function is performed to check for short-circuits and other violations. The final step is to 'clean up' the board by, for instance, rerouting small sections to minimize the need for drilling holes in the board, and to increase the space between printed wires wherever possible.

The design file is the key

On completion of the clean up process, the design file is passed to the documentation module which can extract the necessary information to produce stocklists and other printed reports and to generate the outputs required for final printed circuit board manufacture. Figure 6 shows some of the items included in the documentation package. The tester and simulation module translates the information from the design file into a general data format that can be used by the various logic testers and simulators employed by BNR and Northern Telecom. Hence, a considerable amount of effort is saved by not having to prepare data for these test and simulation systems separately. New modules may be added to the circuit pack system, extracting from the design file the information they require without disturbing the operation of other modules. Thus, the design file is the key to the modularity and extensibility of the circuit pack system.

Maintaining data integrity and validity

An important improvement over manual methods is the ability of the circuit pack system to validate data when they are entered, and to check for consistency in the design. For example, cross checking is done between symbols and components when they are entered in the libraries; schematic symbols used in Loki are validated to ensure correct mapping into physical components; and a layout can be checked to ensure that there are no manufacturing tolerance violations.

Transition to the circuit pack system

The major user of the system in BNR is the engineering design services department. Its function is to organize and provide design documentation to product development departments.

Prior to the circuit pack system, both schematic drawings and printed circuit board layouts were prepared manually. Completed layouts were digitized and captured in computerized form. Paper plots could then be generated, as well as tapes to drive photoplotters for preparation of layout masks, paper tapes to drive drilling machines, and other manufacturing information. However, changes in logic or layout required repetition of the complete process, with considerable loss of time and money.

Capturing design data
The design capture module provides facilities for computer entry, validation, and modification of circuit pack designs. Design data can either be coded for offline computer entry using the circuit capture facility, or entered interactively using the graphics system, Loki. The circuit capture facility provides a circuit description language which permits concise coding, by a clerk, of an engineer's hand-sketched schematic diagram. Loki is designed for interactive capture and manipulation of graphical information. Using Loki, a schematic diagram can easily be constructed at a graphics terminal by a design engineer or draftsman with perhaps only a very rough sketch from a laboratory notebook as a guide. Loki's powerful editing functions make possible fast modification of schematics entered originally using either Loki or the circuit capture facility, see Figure 3. A paper plot can be requested at any time to allow the engineer to check his design, see Figure 4.

The schematic symbol and component libraries are integral and vital parts of the circuit pack system. Graphical and electrical descriptions of all symbols available to the designer for the construction and maintenance of his logic schematics are held in the symbol library, see Figure 5. The component library contains a complete description of all components available to the circuit pack system user. There is full referencing between the component and symbol entries. The library control module provides editing facilities which allow a library administrator to create, modify or delete entries and control symbol and component issues. Through administrative and authorization procedures both libraries are used to enforce pre-determined usage standards on all components.

Designing a printed circuit pack
Automatic and interactive assistance in designing a printed circuit pack layout is provided by Sprig[2] — a system for placement and routing using interactive graphics. Sprig works on the initial design file that was created by the design capture module. The first stage in designing a layout is assignment, a process in which logic gates from the schematic are assigned to physical components selected from the component library. The next stage is placement, in which the selected devices are distributed over the board in a manner which maximizes the proportion of required electrical connections between components which can be physically realised (routability). Following placement, the automatic optimizer re-examines the logic gate and component pin assignments to further increase routability.

Figure 3. Peter Ward, of the engineering design services department, uses the graphics editing functions of the design capture module to update a schematic.

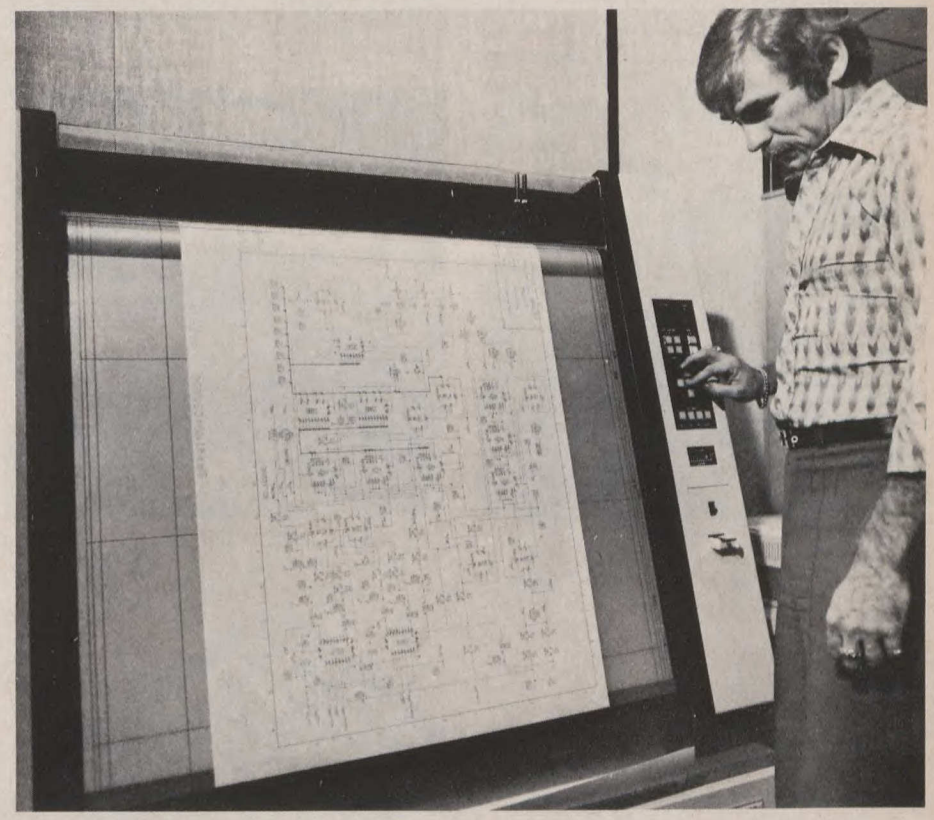
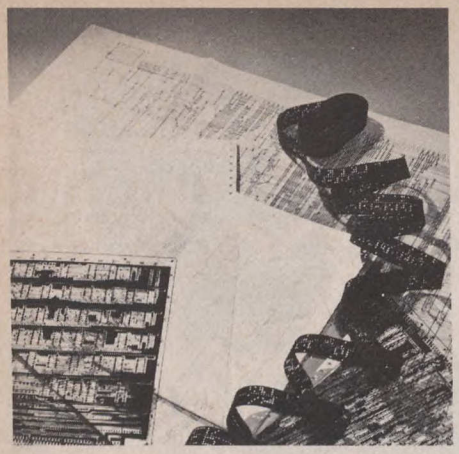


Figure 4. A completed schematic is drawn by a digital plotter, operated by Gerry Tolle of the same department, for checking by the designer.



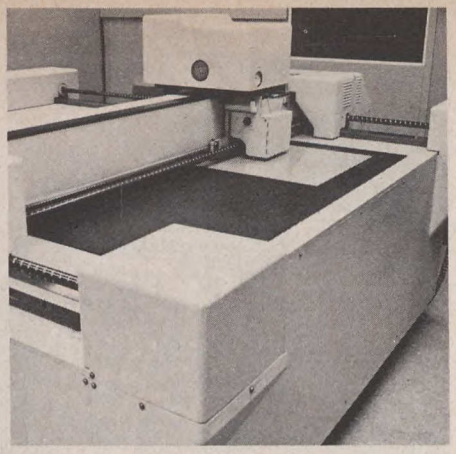
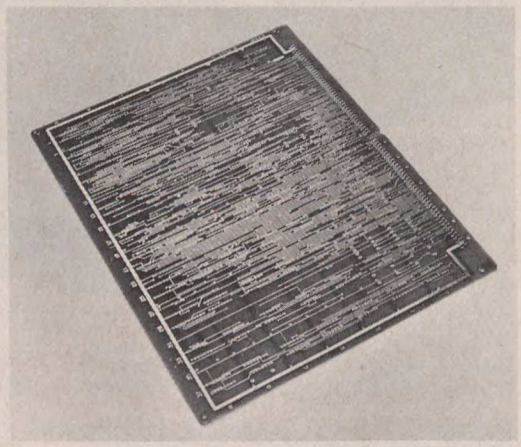


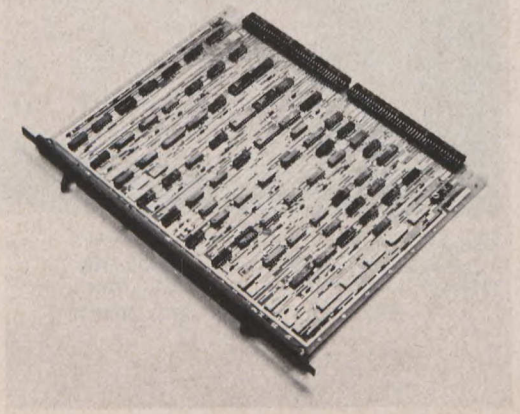
Figure 6. This sequence shows how the outputs of the circuit pack system are used in the manufacture of circuit packs. The manufacturing information produced by the system (far left) includes punched paper tape to drive drilling machines, stocklists, and automatic insertion data for electrical components. The photoplotter (left) automatically prepares photographic masks used in the manufacturing process from this information.



The printed circuit board, on which copper tracks or interconnections have been formed with the aid of the photographic masks, is now ready for drilling and insertion of electrical components.

Working from a paper tape created by the circuit pack system, a drilling machine (far left) automatically makes holes in the board in the correct places to accept the components.

Once the board has been put in position, this computer-controlled machine (left) inserts components in the board using the data from the circuit pack system.



The finished printed circuit board, with all components in place, has its connectors and faceplate attached, and is now ready for use.

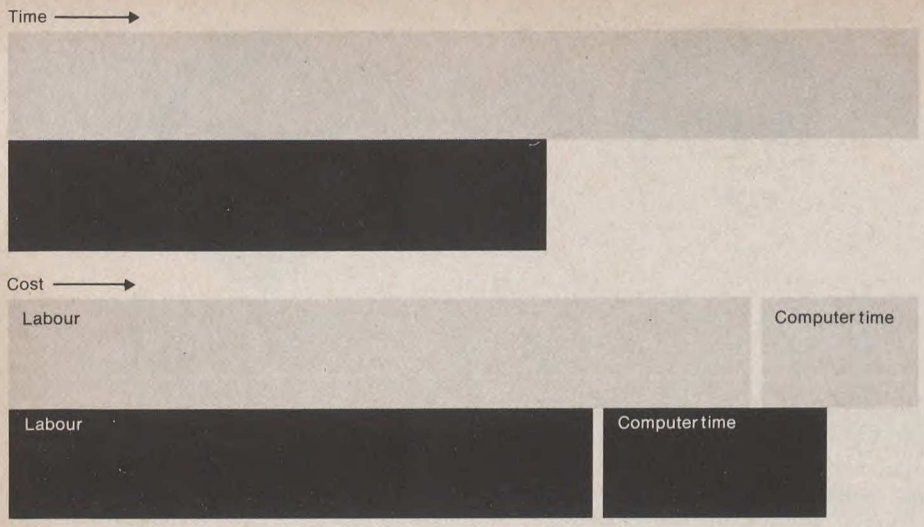


Figure 7. Time and cost savings attributable to the introduction of the circuit pack system are illustrated (colour), compared with the conventional manual process (grey). For a typical circuit pack of moderate complexity, the system reduces by over 30 percent the time (top) to carry a design from inception to the complete manufacturing information package. Labour costs (bottom) are reduced by about 30 percent, for a small increase in the cost of computer usage. Moreover, the output from the circuit pack system includes a finished schematic, advance parts ordering information, and other outputs for automated manufacture that are not included in the conventional method.

During 1977, use of a prototype version of the circuit pack system provided experience on which to base full conversion to the new production software, planned for introduction early in 1978. Careful planning and management were required for the switchover. Some of the key aspects were: organizational restructuring, evaluation of machine resources, scheduling, conversion of existing databases and software assessment.

Planning the transition from a manual to a fully computerized environment also required careful consideration of the human element. Because of the magnitude of the change and the large number of people involved, the potential for counter-productive emotional responses was high. In BNR, engineering design services users, hardware designers and software developers operated as a team with shared responsibilities for plans, progress and problems. This division of responsibility provided the individual involvement and motivation necessary to achieve and maintain positive attitudes.

A necessary part of the transition was the restructuring of engineeering design services into two distinct functions: database administration and production. Administration groups manage libraries of schematic symbols, logical functions and physical component information, while production groups use Loki and Sprig to prepare schematics and layouts. These latter groups have full responsibility for scheduling and performing design documentation functions. They no longer depend on other service groups for production of support documentation such as schematics, stocklists and other reports and can therefore be more responsive to their customers' priorities.

The first production users were chosen to form a balance between drafting personnel with experience in printed circuit layout and volunteers interested in being part of the new service. Initial training was provided for one month, followed by on-the-job training for an additional three to five months. At the end of this time, users had a good understanding of the system and a high level of competence in the new process.

Selection of product data administrators was based primarily on knowledge of production and manufacturing requirements. They required a somewhat longer training period to become familiar with all database functions. Preparation of the symbol and component databases had to begin well in advance of production use to avoid delaying users while a large volume of new component data was entered.

No system as large as this one is initially without software problems. Nor can it remain static; new features are continually required to satisfy more of the diverse, complex parameters of printed circuit pack design.

Regular user group meetings were introduced as a vehicle for ensuring common understanding between the user and the development group regarding problems and new requirements. To ensure quality and stability a formal release mechanism was set up by the development group. Each release fixes certain problems and introduces new features. In addition, the development group provides a schedule for future releases well in advance of the release date.

Time and cost savings

In the short time that the system has been used in full production, its effectiveness has become very evident. Automatic placement and routing is performed on approximately 60 percent of BNR designs. Simple designs may or may not be automatically routed. Complex designs require some manual layout with partial or complete digitizing, depending on design category.

Productivity results to date have shown considerable time reduction and cost savings, as demonstrated in Figure 7. Using a typical moderately complex digital design to compare the old and new ways, some noticeable features have been:

- reduced design time
- reduced design cost
- complete package of output information readily available
- reduced frequency of errors and changes
- reduced labour

The data available in the circuit pack system offer a complete computer-generated information package for manufacturing, with the exception of the assembly drawings. Assembly drawings are currently generated manually to show mounting features of faceplates, etc, and their associated component parts. By the end of 1978, completion of a 'handbook' of mounting features will supersede this manual drawing, thus providing total machine transfer of information.

Transition to the circuit pack system in the engineering design services department has not only proven an efficient means of producing documentation, but has introduced an entirely new environment for processing and controlling design information. The old 'drawing office' concept has evolved to this new approach which incorporates technological advances in product engineering.

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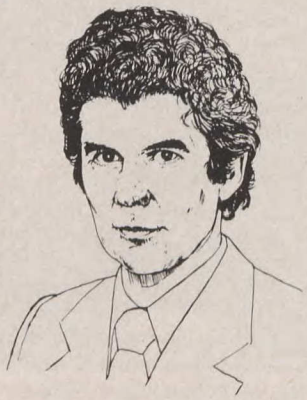
2. B Allum, J Paterson, B Shastry, Computer system accelerates design of printed circuit boards, Telesis, Vol 4 No 5, April 1976, pp 144-150.

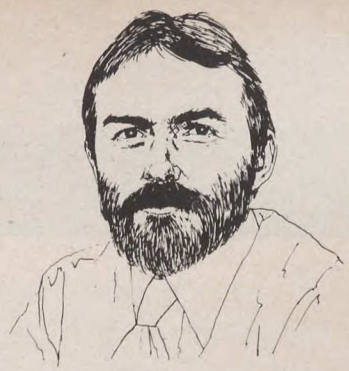
Following graduation from Ottawa Technical High School in 1957 **Ken Blais** began his apprenticeship with Ontario Hydro. He joined Bell-Northern Research in 1963 to perform drafting services in transmission and aerospace development. In 1967 Ken became manager of transmission drafting services.

He played a major role in introducing printed circuit design digitizing and photoplotting facilities into the engineering design services department during 1970-1975, prior to the introduction of fully computerized circuit pack generation systems such as Copes. In January 1978, Ken was appointed manager of engineering design services.

His major interests include human/industrial relations, management teamwork, and motivational theories in production environment. Ken enjoys outdoor activities such as fishing and hunting.



Bill Clipsham is a graduate of the University of Saskatchewan, receiving a BA in mathematics and physics in 1961 and a MA in physics in 1963. Prior to joining Bell-Northern Research in 1967, he was with Northern Telecom in Montreal. Until 1974, he worked in the computer centre, first as a systems programmer then in a variety of managerial positions. Throughout this period, he was heavily involved with computer communications development. From 1974 to 1977 he worked on the design and development of the Datapac network. He is presently manager of planning for computer aided design.



David Pearson graduated from Imperial College, London University, England, and went on to do research into the mathematics of thunderstorm creation and behaviour. In 1969, he moved to International Computers Limited in Kidsgrove, Staffordshire, and after a short period doing work on the digital simulation of operating systems, he joined the 2900-series architecture group, with particular responsibility for software engineering. In 1971, he became manager of software engineering at ICL, and his group went on to develop and support a computer aided design and evaluation system for mainframe software development. In 1973, he moved to the marketing organization of ICL for twelve months and was project manager for the introduction of 2960 systems to British universities. He then returned to product development and after a short period working on the design of a high-throughput operating system for the 2960, he resumed his position as manager of software engineering.

In November 1977, he joined BNR and took over responsibility for development of Copes and the integrated software engineering system. Since that time he has become manager of advanced development systems and directs the majority of tools development within BNR.

Une réalisation exemplaire de gestion et de contrôle automatique d'entrepôt pharmaceutique

par Jean-Pierre BOURBON (*)

Près de Stein, en Suisse, se trouve l'un des entrepôts automatiques les plus modernes du monde. Construit selon les spécifications de CIBA-GEIGY, le géant suisse de la chimie, cet entrepôt fait partie d'un complexe de 30 millions de francs suisses. Il est opérationnel depuis le début de l'année. Avant d'en arriver là, 40 hommes-mois ont été consacrés à son étude et à son développement, pendant que la programmation et l'organisation opérationnelle prenaient encore 100 hommes-mois et impliquaient l'écritude de 300 programmes ainsi que 100 fonctions et sous-programmes.

Le système met en œuvre un réseau informatique hiérarchisé à quatre niveaux, l'un à Bâle où sont fabriqués les produits actifs, les trois autres à Stein où ces derniers sont stockés, mis sous leur forme finale, expédiés en gros ou bien distribués.

Avantages retirés de la gestion et du contrôle automatiques de l'entrepôt : l'accès plus rapides aux stocks, l'impossibilité d'oublier des palettes et, fait étonnant, une utilisation à 99 % de l'espace de stockage disponible.

Dans un entrepôt classique, des produits spécifiques sont assignés à des zones spécifiques. Ainsi, tandis que la zone de rayonnage pour un produit peut être pleine à 90 %, le produit d'à côté peut n'occuper que 20 % de son espace réservé. Les entrepôts classiques utilisent aussi des chariots élévateurs à fourche qui exigent un certain espace pour manœuvrer. Par conséquent, dès que le taux d'occupation dépasse 70 %, les allées deviennent encombrées et l'efficacité dans l'utilisation de l'espace tombe.

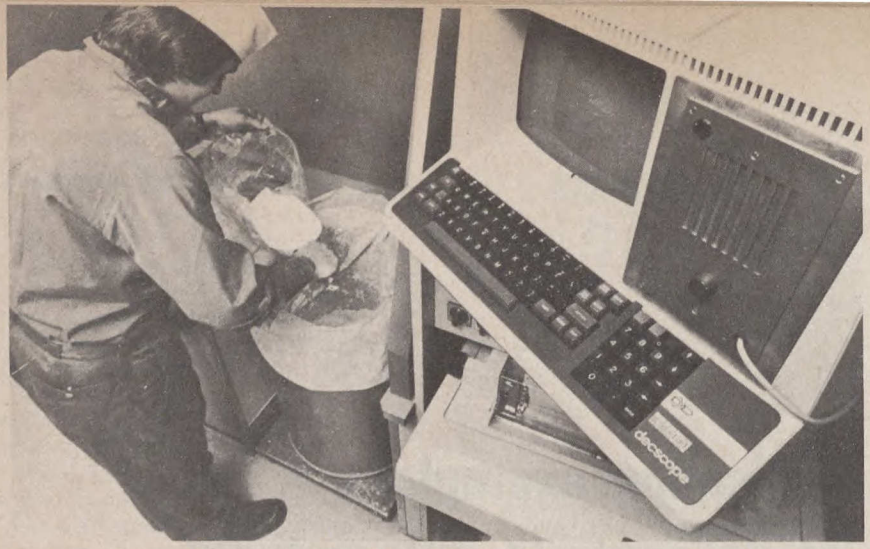
En transférant la tâche d'emmagasinage à des convoyeurs et à des grues automatiques et en laissant un DECdatasystem-550 de Digital Equipment choisir l'espace disponible de façon aléatoire, CIBA-GEIGY s'est donnée le moyen de stocker davantage de marchandises dans un espace donné. En même temps, le DDS-550 garde un état précis et constamment mis à jour du stock dans les deux sections de l'entrepôt, dont l'une traite des palettes standard, l'autre des petites planches en contreplaqué.

32000 LOTS PHARMACEUTIQUES

Le complexe CIBA-GEIGY de Stein, qui emploie 1200 personnes, à d'autres missions en dehors de l'entreposage. Il est spécialement responsable de la fabrication des produits pharmaceutiques sous la forme où ils seront finalement administrés aux patients : tablettes, capsules, ampoules ou suppositoires par exemple.

La gestion et le contrôle automatiques d'entrepôt a permis à CIBA-GEIGY d'utiliser 99 % de l'espace de stockage disponible.

(*) ***Digital Equipment.***



Le pesage des produits est également contrôlé par ordinateur. Chaque poste de pesage est connecté par un terminal de visualisation VT 50 et une imprimante d'étiquette LA 35 à un ordinateur PDP-11/34 de Digital Equipment.

Les produits actifs sont fabriqués à Bâle, située à 35 km, et sont livrés et stockés à Stein jusqu'à la fabrication finale et à l'emballage. Ainsi, la distribution à partir de l'entrepôt de Stein peut s'effectuer à trois niveaux : soit les produits actifs sont fabriqués en vrac à Bâle et distribués par Stein ; soit les médicaments dans leur forme finale sont expédiés en gros aux sociétés affiliées ; soit encore, les médicaments dans leur forme finale sont complètement emballés et distribués localement.

Cette tache est encore compliquée par le fait que les produits à Stein peuvent avoir l'une des quatre classifications suivantes : en «quarantaine», c'est-à-dire non encore analysés ; bloqués, signifiant que le lot ne satisfait pas aux normes de CIBA-GEIGY ; d'usage limité, c'est-à-dire restreint à certains pays à cause des accords de licence ; complétement libres, enfin, ne supportant alors aucune restriction. Chaque fois qu'une commande client doit être satisfaite, chacune de ces situations doit être prise en considération.

Avec ces contraintes, on comprend le besoin d'information. On peut manipuler manuellement jusqu'à 6000 ou 8000 palettes de produits non règlementés comme, par exemple, des écrous et des boulons, mais à Stein, il existe 32000 lots différents, avec une série de considérations à prendre en compte pour chacun d'eux.

UN RESEAU HIERARCHISE

Le système de gestion et de contrôle d'entrepôt comporte un réseau informatique hiérarchisé à quatre niveaux, un niveau au siège de Bâle, les trois autres à Stein.

l'IBM/370-168 de quatre mégaoctets basé à Bâle est responsable de la gestion globale des stocks. Il traite les commandes venant des clients, le planning de la production, l'émission de commandes de produits auxiliaires, l'émission d'ordres de production pour les produits actifs et avise Stein de l'arrivée des commandes avec leur numéro d'ordre.

Au second niveau, à Stein, il y a deux DECdatasystems 550. L'un est actif, l'autre est en réserve, ce qui permet d'utiliser ce dernier pendant la journée pour le développement de programmes, l'analyse des données et l'impression des documents de travail. La nuit, les deux machines fonctionnent en parallèle parce qu'il n'y a pas d'opérateur de service. Ainsi, si l'une des machines tombe en panne, l'autre conservera toutes les informations nécessaires. La mission du système DDS-550 est le suivi effectif des stocks. Le système sait où sont stockés chaque produit et, en fonction des différentes restrictions, décide dans 85 % des cas quel lot doit être pris pour satisfaire un ordre de fabrication ou une commande client.

Pour les 15 % restant, les affectations sont faites manuellement à l'aide d'un des 19 terminaux de visualisation VT 50. La décision est prise par l'opérateur qui tient compte de multiples exigences : ne pas partager un emballage stérile entre différentes commandes ou arriver impérativement à un chiffre rond par exemple.

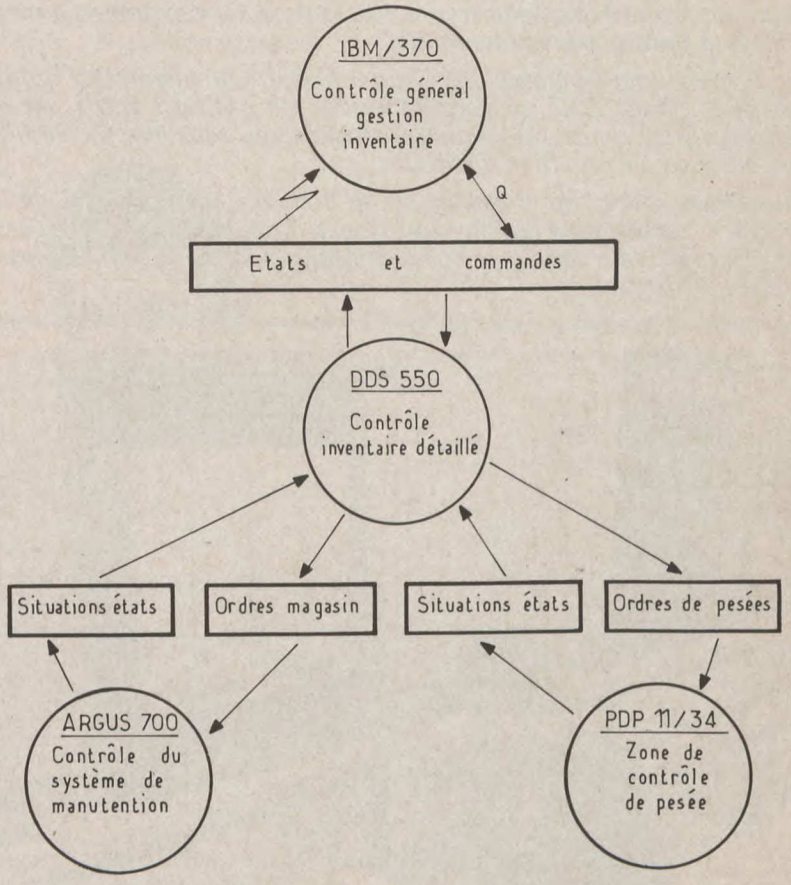


Fig. 1. — Schéma synoptique du système d'indexation.

Le DECdatasystem-550 transmet alors les instructions à un système Argus 700E de Ferranti qui contrôle les convoyeurs et les grues pour le stockage en hauteur dans les deux sections automatisées de l'entrepôt. La section 1 manipule les produits stockés sur palettes standard (80 x 120 cm) dans 24.000 emplacements. La section 2 stocke les produits sur des planches en contreplaqué de 40 x 60 cm rangées dans 13.000 emplacements. Ce système, mis au point par CIBA-GEIGY, permet de manipuler de petits lots plus efficacement. L'Argus ayant reçu l'ordre de prendre une certaine palette ou de la retourner à l'entrepôt, rend compte au DECdatasystem, une fois la tâche accomplie.

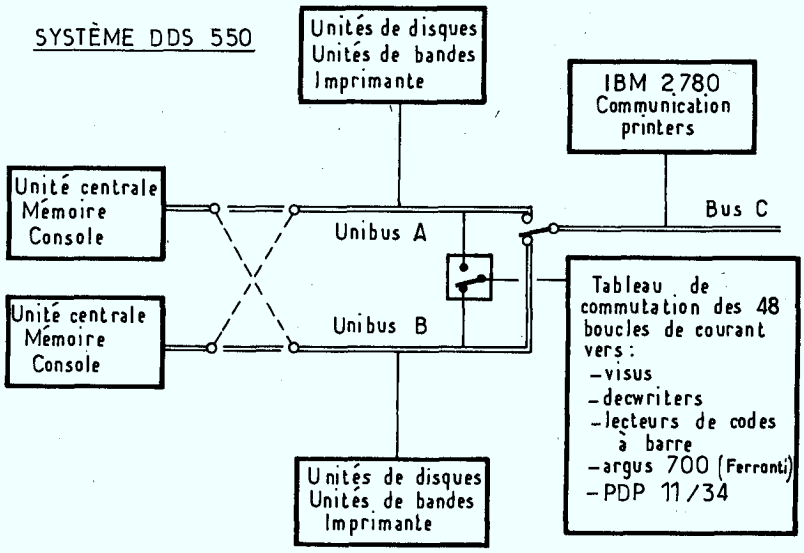
Le quatrième et dernier niveau comporte des microprocesseurs Intel 8080 installés dans les grues. Ils reçoivent un code d'emplacement de l'Argus et pilotent les grues. Ce pilotage comprend l'accélération, la décélération et le freignage, ainsi que la montée vers le niveau indiqué et la descente à partir de ce niveau. Les Intel 8080 sont également utilisés pour activer les lecteurs de code à bâtonnets dans la section des produits disposés sur les planches en contreplaqué. Lorsque la planche en contreplaqué passe au-dessus d'un faisceau lumineux, la lumière réfléchie par l'étiquette portant un code à bâtonnets fixée sur la face inférieure est analysée par le microprocesseur. Cette information, en même temps que les détails de ce que la planche contient, est passée directement au DDS-550, permettant à celui-ci de garder une trace jusqu'à ce que la planche soit finalement vidée et affectée à un nouveau lot.

PESAGE : UN CONTROLE DE PROCESSUS

Afin de garantir le maximum de précision dans la production des produits pharmaceutiques sous leur forme finale, CIBA-GEIGY a profité de la construction du nouvel entrepôt de Stein pour centraliser et informatiser le processus de pesage à la sortie. Le pesage des composants qui forment le mélange a lieu dans 9 postes. Chaque poste est connecté par l'intermédiaire d'un terminal de visualisation VT 50 et d'une imprimante d'étiquettes LA 35 à un ordinateur PDP-11/34 de Digital Equipement. Dans les postes, il y a trois classes de balance allant des milligrammes aux kilos.

L'opérateur prend un certain lot de produits dans le poste et, à l'aide du terminal, indique au PDP-11/34 de quel produit il s'agit. Le 11/34 passe cette information au DDS-550 qui, en retour, lui donne la quantité à peser de ce produit spécifique pour une commande particulière. Cette information est affichée sur l'écran de visualisation. Après le pesage, le PDP-11/34 lit la balance pour s'assurer que l'opérateur a bien pesé. Si tout est correct, il imprime une étiquette sur l'imprimante LA 35. L'opérateur attache cette étiquette au lot avant de procéder au pesage de la commande suivante. Pour chaque quantité pesée, le PDP-11/34 transmet l'information au DDS-550.

Le PDP-11/34 dispose de 80 K mots de mémoire, contrôle 22 balances, 9 terminaux de visualisation VT 50, 9 imprimantes LA 35, une console de dialogue DECwriter LA 36 et une unité de disques souples qui stockent les programmes.



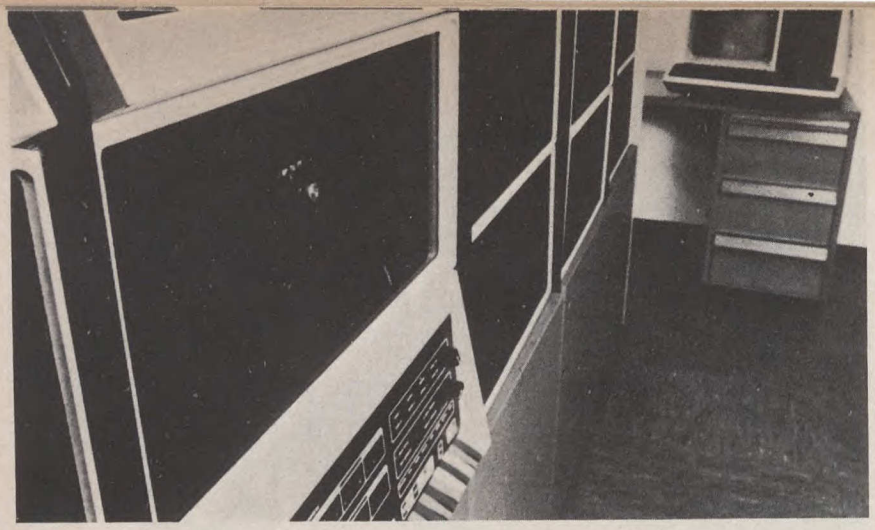
UNE HIERARCHIE LOGIQUE

Ce mélange d'exigences a donc logiquement conduit au concept hiérarchique pour le système. Pour plusieurs raisons, il était nécessaire de séparer les fonctions de pur contrôle de processus des fonctions commerciales. Cependant, les fonctions de contrôle de processus exigent une communication en temps réel avec le système commercial. Or le système universel multi-utilisateur IBM/370 à Bâle ne pouvait satisfaire ces exigences à un coût raisonnable. C'est pourquoi a été développé un système commercial complémentaire sur le site de Stein.

Deux aspects importants dans la conception du système de Stein étaient la disponibilité du Système et la sauvegarde des données en cas de panne. Pour CIBA-GEIGY, le temps de panne ne devait pas dépasser deux heures, et il fallait par ailleurs s'assurer la possibilité de restitution automatique des données après une panne.

Ces exigences ont donc conduit à la décision d'installer deux DECdatasystem-550 avec diverses possibilités d'interconnexion. La configuration du système comprend deux processeurs PDP-11/45 avec 256 K octets de mémoire centrale chacun, deux consoles de dialogue LA 36, deux imprimantes par ligne LP 11, deux contrôleurs de bande magnétique TU 16 avec deux dérouleurs de bande de 1600 bpi chacun, deux unités de disque de 88 mégaoctets chacune et deux contrôleurs de disque à tête fixe avec deux unités de disque de 1 mégaoctet chacun.

La moitié des périphériques sont connectés à l'UNIBUS du premier processeur PDP-11/45 ; l'autre moitié est connectée à l'UNIBUS du second processeur. Une extension de bus commune supportant cinq autres imprimantes par ligne et une interface de communication IBM 2780 peut être connectée soit au premier bus, soit au second par un commutateur UNIBUS. D'autres facilités de commutation comprennent un ensemble d'échangeurs de bus permettant aux unités centrales avec leur mémoire et leur console d'être commutées entre le premier et le second bus. En plus, 48 lignes à boucle de courant peuvent être commutées entre le premier et le



Deux DEC datasystem-550 sélectionnent de façon aléatoire la surface de stockage disponible et gardent un état du stock avec remise à jour constante.

second bus, soit par commutation matérielle, soit par des commandes d'opérateur «invalidation/validation». Les lignes à boucle de courant sont utilisées pour les 19 terminaux de visualisation, les 13 imprimantes DECwriter, les 5 lecteurs de code à bâtonnets et pour la connexion des sous-systèmes Argus 700 et PDP-11/34.

Grâce aux facilités de commutation, les deux DDS-550 ont permis de réduire le temps d'indisponibilité du système à environ 10 ou 15 minutes. Cependant la procédure de reconstitution exige environ une heure et demie. Elle commence avec les fichiers sauvegardés le matin et utilise la bande d'enregistrement qui contient toutes les transactions sur les fichiers jusqu'à l'arrivée de la panne.

ECHANGE DE DONNEES

Une communication bidirectionnelle entre Stein et Bâle est établie tous les jours, l'IBM 370 fournissant au DDS-550 les informations sur les ordres d'expédition, les ordres de livraison à la zone de production, les ordres d'achat et de réapprovisionnement et les livraisons attendues des autres usines ou des autres fabricants. En retour, le DDS-550 rend compte à l'IBM 370, de tous les mouvements de produits afin de mettre à jour le niveau des stocks. Actuellement, cet échange s'effectue par bandes magnétiques mais, bientôt, il se fera par ligne téléphonique louée avec l'émulateur 2780 fonctionnant sous le système d'exploitation RSTS/E version C de Digital Equipment.

L'application est construite autour de RSTS et de BASIC PLUS. Le logiciel d'application est une réalisation maison et CIBA-GEICY a conçu son propre système de base de données. Connaissant la structure qu'elle désirait, la société à estimé qu'elle pouvait économiser bien des accès disque si elle utilisait ses propres pointeurs pour accéder à une banque de données générales.

Toute l'acquisition de données s'effectue sous forme de dialogue et non en mode page. Le fonctionnement en ligne a lieu entre 7 heures et 16 heures 30. Avant 7 heures, il y a une période de mise en route et d'impression de documents de travail. Après 16 heures 30, les données sont sélectionnées pour transmission à Bâle. Enfin, de 18 heures à minuit environ, les machines sont occupées au traitement par lots.

Malgré ses nombreuses tâches, la disponibilité du système a été régulièrement supérieure à 98 %. **«Nous avons eu très peu d'ennui avec l'ensemble du matériel, y compris avec les dispositifs de commutation»**, déclarent les responsables du projet de CIBA-GEIGY. **«Nous avons été également satisfaits du logiciel qui nous a permis de faire notre programmation avec des langages de haut niveau»**. Plusieurs autres possibilités, examinées au stade de l'étude, auraient nécessité la programmation en assembleur, ce qui aurait entraîné beaucoup plus de travail. Récemment, une mémoire-cache a été ajoutée aux processeurs 11/45, ce qui a eu pour effet d'accélérer considérablement l'exploitation.

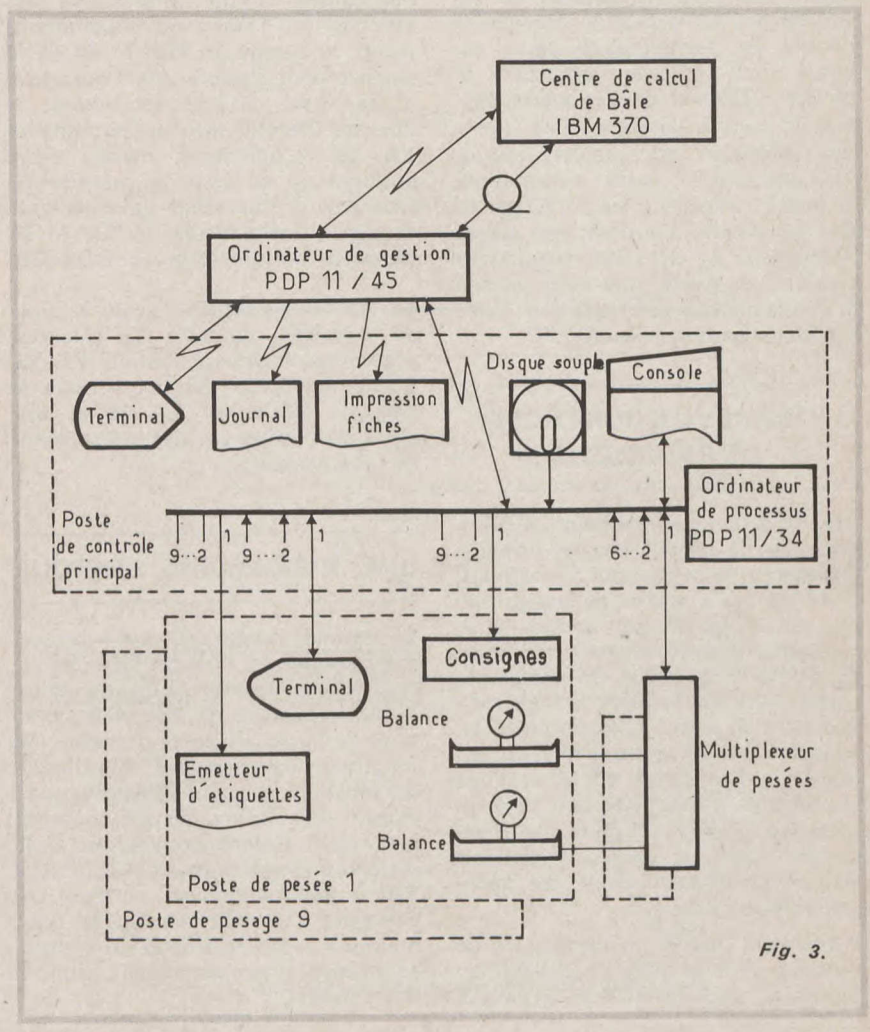


Fig. 3.

La robotique: la technique de l'avenir

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La construction d'automates existe depuis l'Antiquité. On peut voir au Musée du Louvre une figurine égyptienne à bras articulé représentant un boulanger pétrissant sa pâte. Quant à Vaucanson, il mérite sa renommée pour les remarquables automates qu'il construisit au XVIIIe siècle.

Mais ces mécanismes ont pour ambition d'imiter les mouvements de la vie; ce sont des objets de curiosité ou d'agrément sans utilité économique, sans aucune finalité de production.

C'est en 1960 qu'apparaissent aux Etats-Unis les premiers robots industriels. Ces nouvelles machines n'ont pas la prétention d'imiter les mouvements de l'homme, mais plus simplement de résoudre un certain nombre de problèmes d'automatisation en vue d'un travail de manipulation. L'apparence parfois anthropomorphique de ces machines ne découle alors que de certaines solutions choisies.

En vue d'un travail de manipulation, les robots industriels sont des machines automatiques capables d'emmagasiner «un cycle de mouvements quelconque dans l'espace», puis de le restituer de façon plus ou moins répétitive, lors de la phase d'exécution.

Les premiers robots industriels ont été développés par la société américaine Unimation, pionnière en ce domaine.

Depuis cette époque, l'électronique et la micro-informatique ont étonnamment progressé et la notion de «robot industriel» s'est élargie et enrichie. Ce faisant, le terme lui-même est devenu flou, les commerçants n'aidant pas toujours à dissiper les ambiguïtés de terminologie.

Les bras de chargement sont parfois abusivement inclus dans la catégorie des robots, en raison d'une certaine parenté des techniques utilisées, notamment la commande numérique. Ils ne font pas partie des robots d'un point de vue technique, car ils ne permettent pas des mouvements quelconques.

Les télémanipulateurs comportent toujours un homme dans la «boucle de commande»; ce ne sont donc pas des machines automatiques.

Parmi les robots industriels, il faut distinguer entre manipulateurs programmables et robots proprement dits, qui correspondent à deux stades d'évolution.

Le manipulateur programmable, à ne pas confondre avec le gouverneur programmable ou l'automate programmable, exécute les ordres enregistrés correspondant aux positions successives qu'on lui a fait prendre, lors d'une phase d'apprentissage. Répétant indéfiniment les mêmes gestes sans aucune «intelligence» lors de l'exécution, le manipulateur programmable ne peut donc avoir que des fonctions très répétitives, ce qui justifie son appellation.

Le robot proprement dit peut être défini comme un automate doté de **capteurs,** véritables organes sensitifs artificiels qui, en lui permettant d'appréhender son environnement, rend possible son adaptation aux variations de ce milieu. A la différence du manipulateur programmable, le robot ne répète plus indéfiniment le même geste, il crée des variations autour de ce geste: n'étant plus «aveugle», il est capable d'optimiser son action.

Aujourd'hui, tous les pays industrialisés s'intéressent activement aux développements des robots. En France, dans le but de promouvoir une industrie de la robotique, des chercheurs, des industriels et des utilisateurs se sont rassemblés au sein de l'A.F.R.I. (Association Française de Robotique Industrielle). Cette association comprend une quarantaine de membres, et notamment la Régie Renault, qui apparaît comme le chef de file avec des réalisations très remarquées.

Après avoir utilisé dans ses usines les premiers robots disponibles sur le marché, la Régie a fourni un effort très important pour élaborer les siens propres.

	Machines spéciales	Robots industriels	
Automatiques	Bras de chargement	Manipulateurs programmables (faculté de saisie de l'environnement très limitée)	Robots (Importante faculté de saisie de l'environnement par capteurs)
	< 6 degrés de liberté	⩾ 6 degrés de liberté	
Non automatiques	Télémanipulateurs		

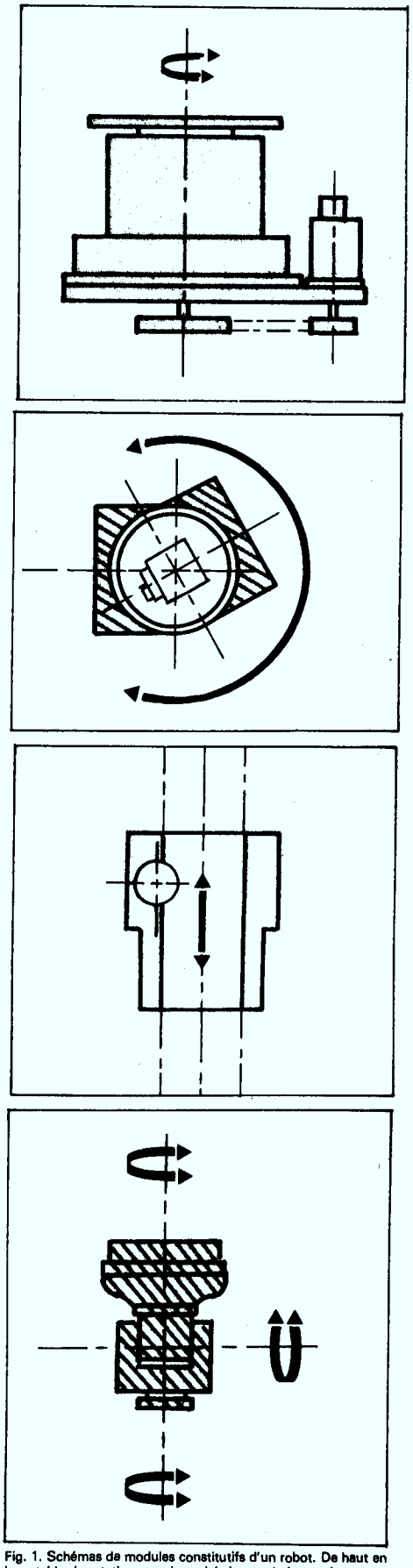


Fig. 1. Schémas de modules constitutifs d'un robot. De haut en bas: table de rotation, coude, unité de translation, poignet.

C'est à partir de juin 1974 que les recherches dans ce domaine ont été entreprises par la Direction Déléguée aux Automatismes (D.D.A.), avec le concours de la S.O.F.E.R.M.O. (filiale de la Régie), pour les études mécaniques.

La gamme de produits comprend actuellement:

— des robots adaptés à la soudure de caisses de véhicules;

— des robots de peinture capables de peindre aussi les intérieurs de carrosserie;

— des robots de manutention destinés à des tâches très diverses.

Les premiers de ces robots ont été testés depuis plus de deux ans en production et ils sont une trentaine à être implantés, ou en cours d'implantation, à l'usine de Flins et à l'usine de Billancourt.

Il s'agit de manipulateurs programmables; les recherches continuent et débouchent en laboratoire à la D.D.A. sur de véritables robots.

Cet effort de création est prolongé par la Société ACMA-CRIBIER, filiale de Renault qui, fabriquant ces robots, cherche à les commercialiser à l'extérieur de la Régie et à prendre une part notable du marché, en France et dans les grands pays industriels.

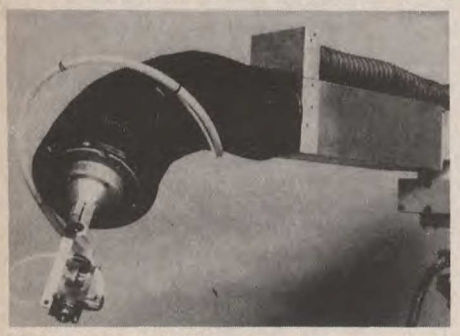


Fig. 2. La trompe dite d'éléphant: quatre vérins actionnent les câbles qui l'animent.

La conception des robots Renault

Un robot, ou un manipulateur programmable, est à la base une machine universelle de manipulation. Bien que jamais totalement atteinte dans la pratique, cette universalité est importante dans le concept «robot». De plus, elle conduit à des machines standard, dont les intérêts sont multiples:

— grande souplesse d'emploi, qui permet des changements dans la fabrication consécutifs aux modifications du produit ou à l'expérience acquise en production;

— rapidité de mise en place d'un moyen de production aux performances bien connues, sans risques nouveaux;

— banalisation de moyens de production et possibilité de moduler en plus et en moins l'investissement, pour suivre l'évolution de la demande réelle;

— diminution des investissements.

Les coûts de fabrication bénéficient de l'effet de série.

Pour présenter ces machines, on peut distinguer les éléments suivants:

— l'architecture mécanique et la structure modulaire;

— la motorisation et la transmission;

— le système de commande.

Ces éléments sont communs aux manipulateurs et aux robots; pour leur présentation, on ne distinguera donc pas ces deux machines. Rappelons simplement que le robot proprement dit possède, en plus du manipulateur:

— des capteurs lui permettant de saisir son environnement;

— des organes supplémentaires de traitement des informations fournies par les capteurs.

L'architecture mécanique

Le positionnement d'un corps nécessite 6 coordonnées, par exemple: 3 pour repérer un de ses points et 3 autres pour repérer son orientation autour de ce point. Pour être capable de positionner de façon quelconque un objet, un robot doit donc pouvoir fixer ces 6 coordonnées, ce qui implique qu'il ait au moins 6 «degrés de liberté», c'est-à-dire 6 possibilités de mouvements indépendantes les unes des autres. Un nombre inférieur conduit à une machine qui n'est plus universelle. Par contre, si le robot en a davantage, sa capacité à situer un objet augmente, puisqu'il peut donner une position de plusieurs façons différentes.

Bien qu'un axe supplémentaire soit coûteux à réaliser, la souplesse qui en résulte est très intéressante, voire indispensable, lorsque le robot est gêné dans ses mouvements par des obstacles qui lui interdisent certaines attitudes; c'est le cas d'un robot devant pénétrer à l'intérieur d'un véhicule, où la caisse limite bien les évolutions. Il a donc été créé des robots à 7 degrés de liberté, en particulier pour peindre l'intérieur des véhicules.

Par ailleurs, un robot travaillera d'autant plus vite et avec plus de précision qu'il est plus petit. Aussi, afin de limiter les porte-à-faux et la taille des éléments en mouvement, il peut être intéressant d'ajouter un axe supplémentaire dissocié du robot lui-même, et dont le rôle est de déplacer la pièce à travailler.

Lorsque le robot est implanté sur une chaîne comportant un transfert de pièces en continu, si l'on sait le synchroniser en toutes circonstances avec le mouvement de la chaîne, on peut considérer l'avance de cette chaîne comme un véritable axe supplémentaire du robot, et d'utiliser comme tel. On augmente ainsi substantiellement ses possibilités géométriques, sans réduire ses performances dynamiques ni nécessiter davantage de mécanique. De ce fait, c'est une combinaison d'emploi très favorable pour un robot industriel.

La structure modulaire

Contrairement à une idée anthropomorphique, il n'y a pas de forme idéale pour un robot.

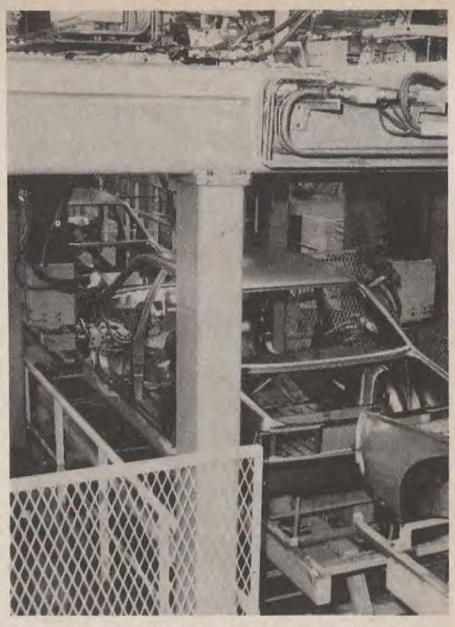


Fig. 3. Soudure par points des Renault 18 à l'usine de Flins.

A l'utilisation, chaque structure a ses avantages et ses inconvénients. Aussi doit-elle être choisie en regard de l'application.

De ce fait, il n'est pas souhaitable de standardiser un seul type de robot, puisqu'il ne pourra pas résoudre élégamment tous les problèmes posés. Cela est contraire à l'intérêt de machines standard universelles. Cette incompatibilité est résolue par une standardisation des éléments ou modules constitutifs du robot. Une homothétie appliquée à ces modules permet des variations de tailles et de capacités. Différentes morphologies peuvent alors être obtenues de façon standard, par l'assemblage de modules de base communs à toute une famille de robots.

Il existe une douzaine de modules différents. Ce sont essentiellement:

— **les tables de rotation** (rotation perpendiculaire aux faces d'appui);

— **les coudes** (rotation parallèle aux faces d'appui);

— **les unités de translation** de faible et grande course;

— **les poignets** (ou têtes 3 axes), comportant trois axes concourants, qui forment entre eux un trièdre déformable. Cet ensemble possède 3 degrés de liberté et est utilisé pour orienter l'objet manipulé par le robot;

— **la trompe,** structure polyarticulée, avec un rayon de courbure variable, mais régulier. Ses deux degrés de liberté et son faible diamètre lui permettent d'atteindre des cavités peu accessibles pour un poignet de robot. Elle est par contre limitée en capacité de charge et, de ce fait, utilisée principalement sur les robots destinés à la peinture.

Ces modules ont permis de réaliser les robots «type 80» et les robots de peinture. D'autres configurations restent possibles.

Les robots «type 80»

Trois structures:

— **le robot vertical.** Il se compose d'une table de rotation tournant autour d'un axe vertical, d'un bras et d'un avant-bras qui se déplacent dans un plan vertical; l'ensemble est articulé par deux coudes d'axes horizontaux. L'extrémité de l'avant-bras porte un module poignet;

— **le robot horizontal.** Il comprend une unité de translation portée par une table de rotation et sur laquelle se déplace, dans un plan horizontal, un bras et un avant-bras articulés l'un à l'autre par un coude d'axe vertical. L'extrémité de l'avant-bras supporte un poignet;

— **le robot portique.** Il est constitué d'un cadre ou portique, sur lequel se déplacent deux chariots à axes croisés. Ils supportent une unité de translation verticale, munie à son extrémité d'un module poignet.

Les robots de peinture

Deux structures:

— **le robot «7 axes».** Une table de rotation supporte trois bras, articulés par des coudes. Les deux premiers ont un axe horizontal et le dernier un axe perpendiculaire à l'axe du second coude. L'extrémité de ces bras se termine par une trompe, qui porte elle-même un module de rotation;

— **le robot «6 axes»,** simplification de la structure précédente, obtenue en supprimant un axe, généralement le dernier coude.

Des modules autonomes

Un robot se compose d'un certain nombre de modules autonomes comportant chacun:

— des fonctions de guidage;

— une chaîne cinématique avec un moteur;

— des capteurs de position;

— des faces d'accouplement qui permettent la liaison avec les autres modules.

Parce qu'il est déplacé par le module situé en amont, pour lequel il apparaît comme une charge, et pour des raisons d'encombrement évidentes, le module doit être aussi léger et compact que possible.

C'est l'une des raisons du choix d'une solution hydraulique pour la motorisation des axes. En effet, pour les puissances mises en jeu (4 kW environ pour le type 80), un moteur hydraulique a un rapport (puissance/masse) très supérieur et un encombrement nettement inférieur à celui des moteurs électriques.

Mais ce n'est pas là le seul avantage de la solution hydraulique: les considérations suivantes sont également importantes.

La motorisation et la transmission

Pour le travail de soudure, il est évident que l'efficacité d'un robot est d'autant plus grande qu'il soude plus de points à chaque cycle. Or, le temps pour réaliser un point dans une séquence de soudure se décompose en deux temps élémentaires: la durée technologique du soudage et le temps de déplacement de la pince entre deux points successifs.

Dans ces déplacements, souvent courts — de l'ordre de 45 mm — le mouvement réel à l'extrémité d'une pince est fonction de la loi de commande, mais aussi des modes vibratoires propres du robot, qui vont se superposer au mouvement commandé. En conséquence, la précision maximale possible est limitée en absolu par l'amplitude de ces vibrations.

De plus, pour une précision utile donnée, le positionnement est d'autant plus rapide que la raideur du système est plus grande, c'est-à-dire que la fréquence propre du système est plus élevée.

Les servo-moteurs hydrauliques répondent à ces impératifs. Leurs qualités dynamiques sont dues essentiellement aux raisons suivantes:

— utilisation de hautes pressions, de l'ordre de 110 bars;

— masse de la partie mobile faible, vis-à-vis de celle du système entraîné;

— faible compressibilité des huiles.

La solution hydraulique présente d'autres avantages, comme la possibilité d'utiliser des accumulateurs hyddrauliques, excellents moyens de stockage d'énergie. Le groupe hydraulique peut être dimensionné pour la puissance moyenne de l'installation.

Bien sûr, cette solution a aussi des inconvénients, notamment les risques de fuites, les risques d'obturation et surtout l'usure des composants, ce qui oblige à un filtrage très poussé des huiles.

Enfin, les composants, dans cette technologie, sont actuellement relativement chers.

Les servo-moteurs employés sur les robots de soudure ont, selon les axes, une cylindrée de 3 à 40 cm^3 par tour. Le modèle le plus fréquent est de 10 cm^3.

L'organe de commande est une servovalve (Moog), qui est à la fois l'amplificateur de puissance et l'interface entre l'électricité et l'hydraulique. En première approximation, cet organe délivre un débit d'huile proportionnel au courant de commande.

Les moteurs actuellement utilisés sont des moteurs à pistons axiaux de cylindrée fixe (Donzelli - Moog). Un nouveau moteur particulièrement bien adapté au problème des robots a été défini et mis au point par le Groupe d'Etudes Hydrauliques de la D.R.D.A. Ces moteurs ont des vitesses de rotation variables, entre plus et moins 2500 tr/mn. Comme les vitesses de déplacement des modules de rotation sont notablement plus faibles, un réducteur est intercalé dans la chaîne cinématique.

Ce réducteur, outre un très faible encombrement, doit avoir une grande raideur, une faible inertie d'entrée, une absence de jeu et être réversible.

Pour les modules de rotation (tables et coudes), le réducteur retenu est un «Harmonic Drive». Malheureusement, il est exceptionnellement peu raide et présente une très forte inertie d'entrée. C'est lui qui, actuellement, limite le plus les performances des modules sur lesquels il est utilisé. Des études réalisées à la D.D.A. et à la S.O.F.E.R.M.O. ont abouti à un réducteur original qui, tout en ayant les qualités de «l'Harmonic Drive», ne présente pas ses défauts. Ce réducteur fait l'objet d'un brevet déposé par la Régie.

Les unités de translation font appel à des réductions classiques obtenues par trains d'engrenages.

Le poignet est un module assez particulier, puisqu'il permet trois degrés de liberté, mais sa chaîne cinématique, quoique complexe, est assez classique.

Il faut remarquer l'interdépendance entre les trois mouvements, qui fait qu'un moteur ne commande pas un seul axe. Ainsi, la première rotation a une influence sur les deux rotations suivantes.

Cette disposition est très gênante avec un système de commande classique; en effet, puisqu'il n'existe pas de relation directe entre un moteur et un axe, en mode manuel, l'opérateur ne peut pas commander directement un axe seul. Par contre, un système de type commande numérique calcule, pour chaque ordre de l'opérateur, l'ensemble des commandes sur les trois moteurs, et il en résulte le mouvement simple demandé, par compensation automatique des interférences de mouvements.

C'est un exemple des possibilités qu'offre la commande numérique de machine en matière de cinématique.

(A suivre)

Transport et distribution d'énergie électrique

Organisé par l'Association INTER-EQUIPELEC avec le concours de l'Union internationale des producteurs et distributeurs d'énergie électrique-UNIPEDE, un colloque international «Transport-distribution d'énergie électrique» se tiendra à Paris, du 10 au 13 décembre 1979, dans le cadre d'ELEC 79, Exposition internationale de l'équipement électrique (Paris - Parc des Expositions - Porte de Versailles – 10-15 décembre 1979).

Les communications présentées seront consacrées aux sujets suivants:

- *electrification des réseaux HT et THT;*
- *conception et réalisation des postes ouverts HT et THT;*
- *les postes blindés HT et THT;*
- *le SF6 en moyenne tension;*
- *les réseaux urbains moyenne tension basse tension;*

Renseignements: Association inter-équipelec, 13, rue Hamelin, F-75783 Paris Cedex 16, Tél. (1) 505 14-27

Research and design with computer graphics

Smaller companies without computer graphics capability need not be at a disadvantage. Services are available at cost at the non-profit Ontario Research Foundation.

HIGH PRODUCTIVITY, cost-effectiveness and more stringent customer requirements are making heavy demands on engineers. Conventional engineering methods of design, prototype construction and testing in today's environment have already cost many organizations their competitive edge in the marketplace. However, new techniques are now being implemented to profitably meet the market challenge.

The Ontario Research Foundation in Mississauga recognized the importance of adapting computer graphics to the needs of Canadian industry. With the use of mini-computers, computer bureaux and their supportive peripherals they are able to solve more efficiently many "dynamic problems" in their Engineering Dynamics Analysis Section. They are presently using computer graphics in two main areas:

- Experimental dynamic analysis of structures and machinery
- Analytical finite element analysis techniques for both static and dynamic analysis.

Dynamic analysis

Modern technology in electronic instrumentation, computer hardware and sophisticated software have made possible the evolution of modal analysis. This method of problem-solving incorporates computer graphics as the preferred method of displaying the vibratory characteristics of a structure. This enables the engineer to assess their effects in the performance of such a structure. All structures, such as vehicles, buildings and machines can vibrate. Measurement of these vibration phenomena determines the structure's dynamic characteristics. The use of modal analysis methods is instrumental in pinpointing problem areas.

Approximately 60 percent of the testing assignments performed by the Dynamics Analysis Group at Ontario Research involve the use of animated mode shape displays on a computer graphics terminal. Without integrating the graphic display with the dynamic analysis capability of the mini-computer system, many assignments would become expensive and time-consuming to the individual client. All the dynamic characteristics of a structure are not fully understood until they are observed on a prototype model. Modal analysis techniques make it possible to visualize how the structure moves. This is accomplished by a technique of animating in slow and exaggerated motions the relative deflections of all points measured on a structure.

The systems equipment includes a Tektronix R-4012 rack-mounted computer display terminal and 4631 hard copy unit operating in conjunction with a DEC PDP 11/34 mini-computer. A Zonic Technical Labs data management and Fast Fourier Transform processor is used for data acquisition.

The animated mode shape technique has been used, for example, in identifying the vibratory response of the cab of a large road grader subjected to physical excitation. The response of the machine can be identified in terms of the individual modal contributions. The first step in the vibration analysis is to describe the geometry of the structure to the computer program in terms of a series of physical locations. In this case, 40 points were assigned to the grader, allotting a greater proportion of points to the cab, the area of major interest. The input data is then fed into the modal analysis program in the mini-computer. Using a large variety of commands, the system runs at a transmission speed of 9600 baud, or 960 characters per second.

The grader is subjected to forced excitation and the resulting vibration signals are recorded and processed. Figure 1 shows a graphic representation of the vibrations on the road grader. Using computer terminal graphics, the engineer is able to compare the analytical data with the experimental. Thus, the analytical parameters can be manipulated to obtain the optimum mathematical model of the structure. Once the dynamic characteristics are adequately defined in this manner, design changes can be made on the analytical model and their effects observed by use of graphics display. The flexibility and speed of graphic display methods allows the engineer to provide rapid and cost-effective solutions to problems. Ontario Research has found that the scope of application for display techniques is limited only by the user's imagination.

The greater the opportunities for data feedback and display between the

Through non-profit contract research, Ontario Research Foundation provides a multi-disciplinary resource for industry, consultants and governments. It sold a broad range of industrial technologies to 1600 industrial clients last year. Areas of major emphasis include energy, environment, materials, products and processes, and resources.

Engineering research and design is one of many technical or laboratory capabilities that Ontario Research provides at cost to small and medium-sized companies that are not large enough to have their own in-house resources, and to larger organizations as a specialized supplement to their own in-house technical staff.

graphic terminal and its operator, the greater is its versatility as a testing or design tool. The Tektronix R-4012 display terminal, which has a flicker-free screen display producing a fast pictorial graphic and alphanumeric presentation, is ideal for this purpose. Using this terminal in conjunction with the mini-computer, the user is able to orient the modal display into any desired size or viewing position. This can be seen in Figure 2, where various views of the road grader are shown on the hard copy taken from the image on the terminal screen.

It can be seen that the display terminal is a vital tool in such analyses. Vibration amplitudes during testing may be far too small to be seen by the human eye. By processing them in the mini-computer programs, these deformations can be exaggerated so that they are clearly visible on the terminal screen. Structural deformations can be displayed in different orientations to show combinations of bending and torsion.

The mini-computer-based dynamic analysis system is designed for both laboratory and field testing. Each piece of equipment has a custom-designed "Impact Case" for protection during transit. The equipment has travelled successfully for assignments in the Northwest Territories, aboard ship in Lake Erie and to many local sites. Portability of this system obviously enhances its usefulness.

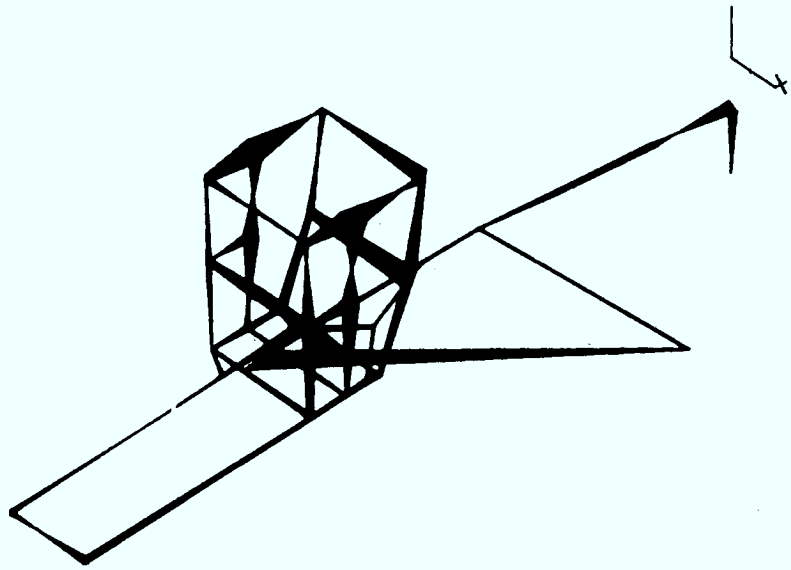


Figure 1. Graphic representation of vibrations on road grader.

Finite element analysis

This particular technique gives the engineer the ability to evaluate proposed designs using a computer model. As part of the finite element procedure, the geometrical accuracy of the computer model can be verified with the use of interactive graphic display.

Applications of finite element analysis include static, dynamic, thermal and plastic analyses. The Engineering Department's Computer-aided Design and Analysis Section at Ontario Research is presently using these techniques. The equipment in use for finite element analysis is a Tektronix 4010-I computer display terminal and a 4631 hard copy unit operating on a time-share basis through several bureaux. By using a 'hard wired modem' the system communicates input and output data by telephone line. This is accomplished at a transmission rate of 1200 baud, or 120 characters per second.

The 4010-I terminal promotes easy data input and easy-to-interpret output data. The screen presents high-resolution graphs, charts and plots without the delay necessary for printouts or hand plotting. Through the computer programs, the images may be displayed as full diagrams or as sections. Single components can be enlarged and presented on the screen to focus attention to specific areas. Windowing, as this process is known, is used in areas where particular detail is important, for example, where there are high strain gradients.

In both dynamic and finite element analyses, Ontario Research uses the Tektronix 4631 hard copy unit. This transportable unit provides immediate, clean, dry copies at the touch of a single button. The copy size, which is 8½ by 11 inches, is very convenient for insertion into reports.

Recent worldwide developments and innovation in digital technology have allowed exploitation of existing mathematical theory, such as modal and finite element analyses, thus allowing problems to be solved in a more sophisticated and yet practical manner. Development of these techniques in Canada, especially in the field of dynamic analysis, continues to be undertaken at Ontario Research. This allows them to make more effective use of their engineers and programmers. They have found that graphic systems are not only beneficial to them but also allow them to serve Canadian industry more efficiently. More and more users around the world are relying on high quality computer graphics to get the job done. ■

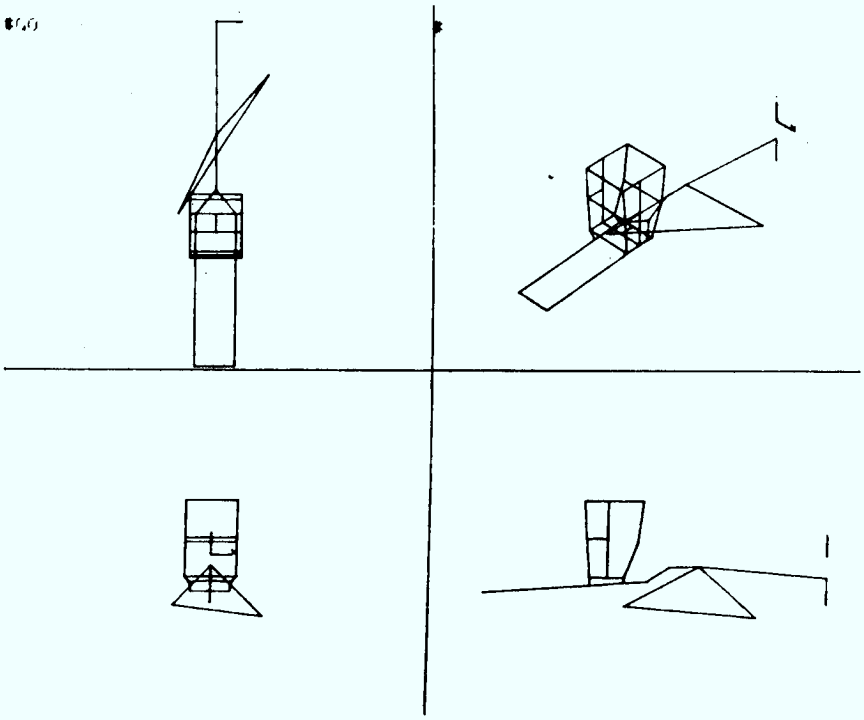


Figure 2. Various views of road grader taken from image on terminal.

A partial view of the design office at Canadair. At left foreground, an engineer uses a remote computer terminal.

Computer helps Canadair design the 'Challenger'

A more efficient aircraft design and a significant shortening of the design and development cycle is made possible by extensive use of computer power.

CANADA'S CURRENT SUCCESSFUL entry into the executive jet transport market—the Canadair Challenger—has received wide attention as an innovative aircraft design. Over 100 production units of the executive configuration have been ordered, with first delivery scheduled for late 1979.

One of the reasons for this acceptance is the imaginative design concept of the Challenger wing, which has been a significant factor in enabling the aircraft to meet performance criteria for a long-range business jet.

The aerodynamic performance of the aircraft is largely the result of an advanced transonic airfoil, designed to delay the onset of the drag rise that normally occurs at high Mach numbers, thereby achieving fuel-efficient high cruise speeds. The airfoil has a further advantage in that sections are generally of a greater thickness-to-chord ratio than conventional airfoil sections with similar performance. This results in a lighter wing structure capable of carrying more fuel for the same wing area and, therefore, in a greater maximum range.

During the past two years, aerodynamic analysis and performance studies of the Challenger have been sup-

2D METHODS

- SINGLE LIFTING AIRFOIL
  TRANSONIC VISCOUS FLOW
- MULTIPLE LIFTING AIRFOILS
  POTENTIAL FLOW
  SUBSONIC FLOW
  VISCOUS FLOW

3D METHODS

- THIN LIFTING SURFACES
  SUBSONIC INVISCID FLOW
- COMPLETE AIRPLANE
  SUBSONIC INVISCID FLOW
- AXI-SYMMETRIC BODIES
  TRANSONIC INVISCID FLOW
- TRANSONIC WING
  INVISCID FLOW

Figure 1. Computer methods in use for solving aerodynamic problems.

ported by a major wind tunnel testing program, occupying about two thousand hours of tunnel testing, using three Challenger models and six different wing designs, to define and refine the high-speed and low-speed configurations.

Tests have been performed to establish wing profile and planform, nacelle position, flap configuration and control surface characteristics.

The initial test flight of the first aircraft took place on November 8, 1978 and, after a series of 25 further test flights at Montreal, the aircraft was flown to the Canadair test facility in the Mojave desert on December 22, 1978 for the aircraft flight certification program.

Aerodynamic analysis

At Canadair, extensive use has been made of the computer for solving complex aerodynamic problems in the areas of analysis and design, to establish aerodynamic loads and for flight simulation. Figure 1 shows the type of aerodynamic computer methods currently in use at the Montreal aircraft builder's engineering department.

Two-dimensional methods are used for the design and analysis of single transonic airfoil sections (Figure 2) and of multiple airfoil sections as in the case of a high-lift configuration with a slotted flap (Figure 3).

Three-dimensional methods include first a computer program to determine the pressure distribution on thin lifting surfaces (wings) in subsonic inviscid flow. Another, more complex method, a so-called "panel method", is used to determine the flow around the entire aircraft configuration. With this method, the detailed pressure distribution on each major component of the aircraft can be calculated, including the effects of mutual flow interference of these components. Since this method simulates the flow around the aircraft in detail, it can be used similarly to a wind tunnel to study the aerodynamic characteristics of many wing-fuselage-nacelle configurations, before selecting one closest to the optimum design for testing.

Figure 4 shows the surface panel representation of the Challenger aircraft used in this method. Figure 5 shows an example of the output obtained with this method, i.e., the chordwise pressure distribution at wing station 0.567 semi-span for various flap deflections.

However, this "panel method" is limited to flight speeds up to Mach 0.7 where the flow around the wing is subsonic. At higher flight speeds, the local flow becomes supersonic and shock waves are formed on the solid surfaces. For the latter case a transonic method must be used, say Canadair engineers,

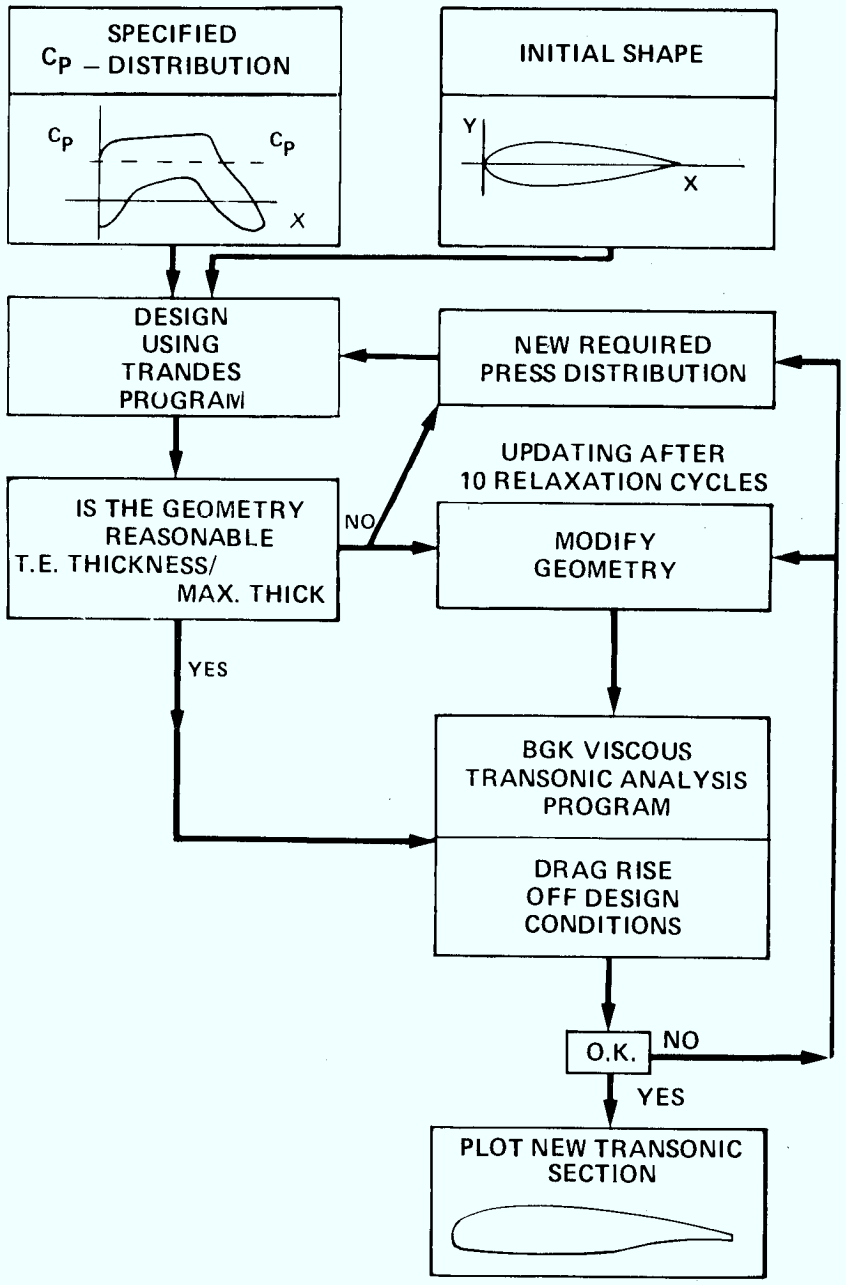


Figure 2. Transonic airfoil section design.

such as the axi-symmetric bodies or the transonic wing method.

"These methods are based on the exact equation that describes transonic potential flow, whose solution became possible only in the last decade with the availability of advanced computers," said Fotis Mavriplis, Eng., Senior Staff Specialist at Canadair, responsible for aerodynamic development aspects of the Challenger aircraft, including the wing design.

The above methods are applied to an IBM 370/158 computer except for the transonic wing method, which is in the process of being transferred to the IBM 370/158. Mr. Mavriplis is enthusiastic about the benefits of the shortened design and test phases attained through use of computerized analysis and design.

"The computer saves a considerable amount of time and money on wind tunnel testing and configuration development" he notes.

"With the techniques we used, we were able to considerably reduce the time and cost of developing the aircraft configuration. With the aid of computer methods we were able to study many aerodynamic configurations before selecting the final basic one for refinement by wind tunnel testing," said Mr. Mavriplis.

One of the computer programs used at Canadair is the IBM CSMP (Continuous System Modelling Program), which was designed by the IBM Canada Laboratory and is now being marketed worldwide. CSMP is a proprietary IBM modelling package using a high-level computer language. It is spe-

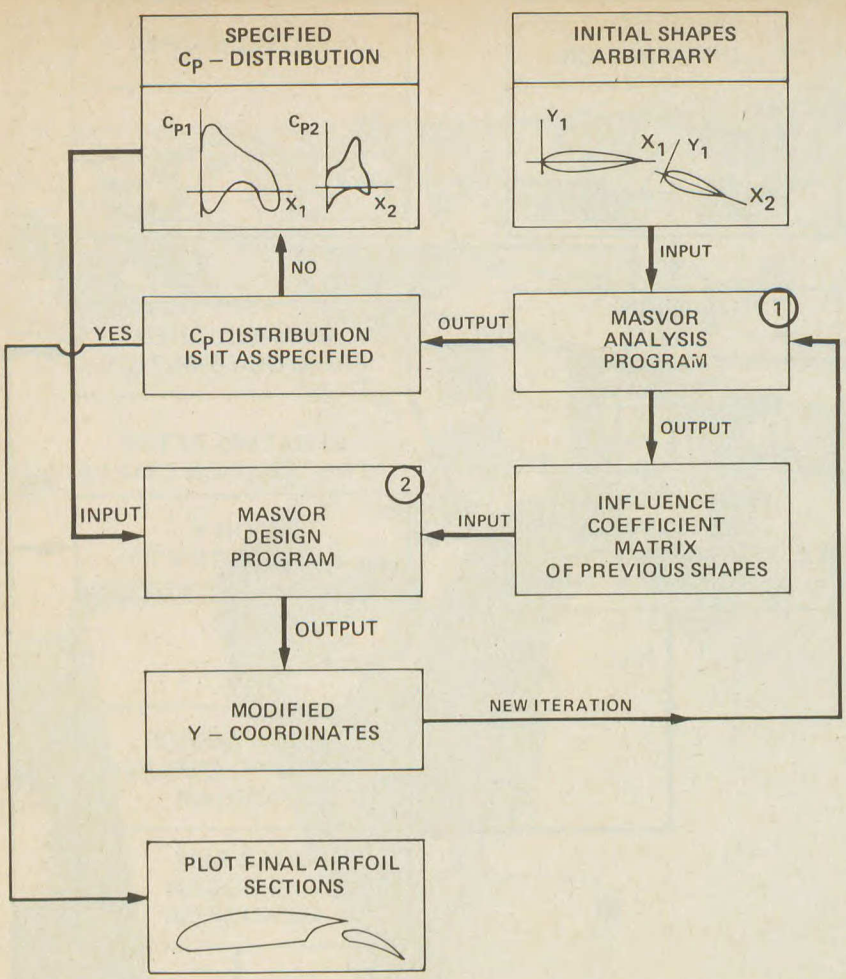


Figure 3. Computerized design of multi-element airfoil sections.

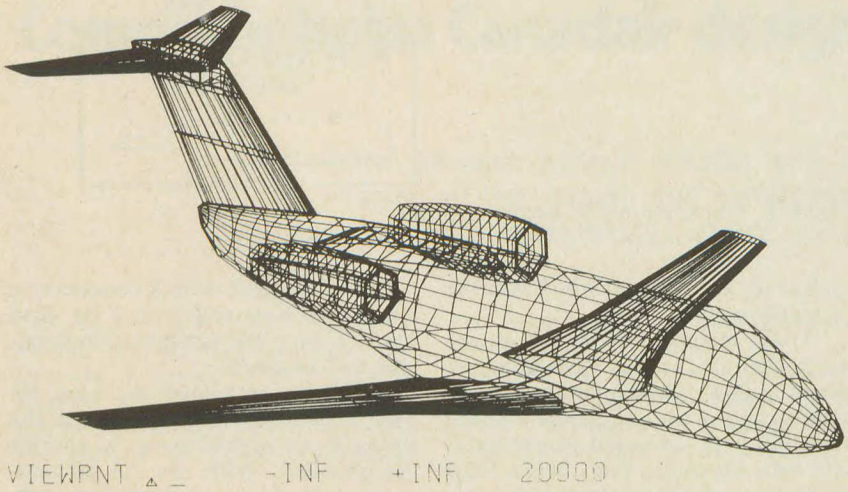


Figure 4. Surface panel representation of CL-600 Challenger.

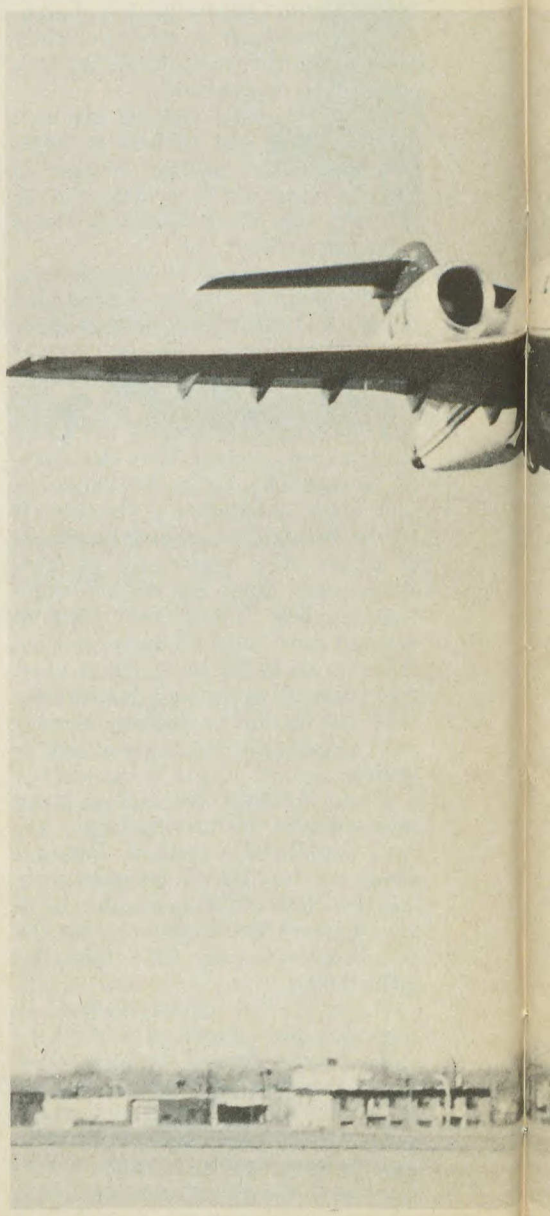
cifically designed for dynamic system simulation, and is used to simulate both static and dynamic flight conditions. It is also used to evaluate balanced and transient aircraft load distribution for various flight manoeuvres.

The structural design loads of the aircraft are determined in several stages by using a variety of computer programs, as shown in Figure 6. Wind tunnel test data and computations with the "panel method" are used for determining the aerodynamic load distributions. Wind tunnel data are also used as input to the CSMP program to compute aerodynamic loads for balanced and transient manoeuvres. Distributed weight data are used as input to another program to compute inertial loads. These are then combined with incremental loads due to aeroelastic effects, which are computed with the NASTRAN program, in order to determine the structural design loads in terms of shear, bending moment and torsion.

The performance requirement placed on the Challenger and the proposed first delivery date for late 1979 pointed to the need for an extremely short design and development cycle. The project was given the go-ahead in November 1976 and, just over two years later, the first aircraft was flown. Typically, the aircraft industry takes at least four to five years to complete this cycle and Canadair engineers credit computerized design with having been a major factor in its reduction.

Other applications

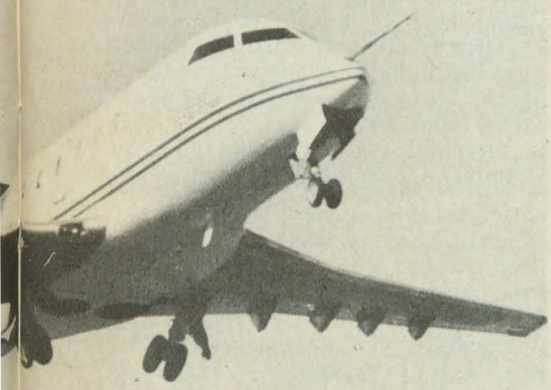
The design capabilities of the IBM 370/158 are available interactively or



for batch operations. In the interactive mode, a designer enters data at a CRT terminal and actually performs the modelling operation at the terminal, varying data and observing changes in characteristics on the display screen. While designers use this interactive capability for specific tasks, most design activity is handled in the batch mode.

Reg Perkins, Director, Systems and Computer Services at Canadair, emphasizes the importance of computerized design to the company's engineering team.

"The team has been able to shorten the design cycle by a significant period, mostly as a result of using the computerized modelling capability available on our large computer systems. As we begin production of the Challenger, we will be using our numerical control program to perform the intricate precision milling, cutting and drilling needed to produce the various aircraft component surfaces."



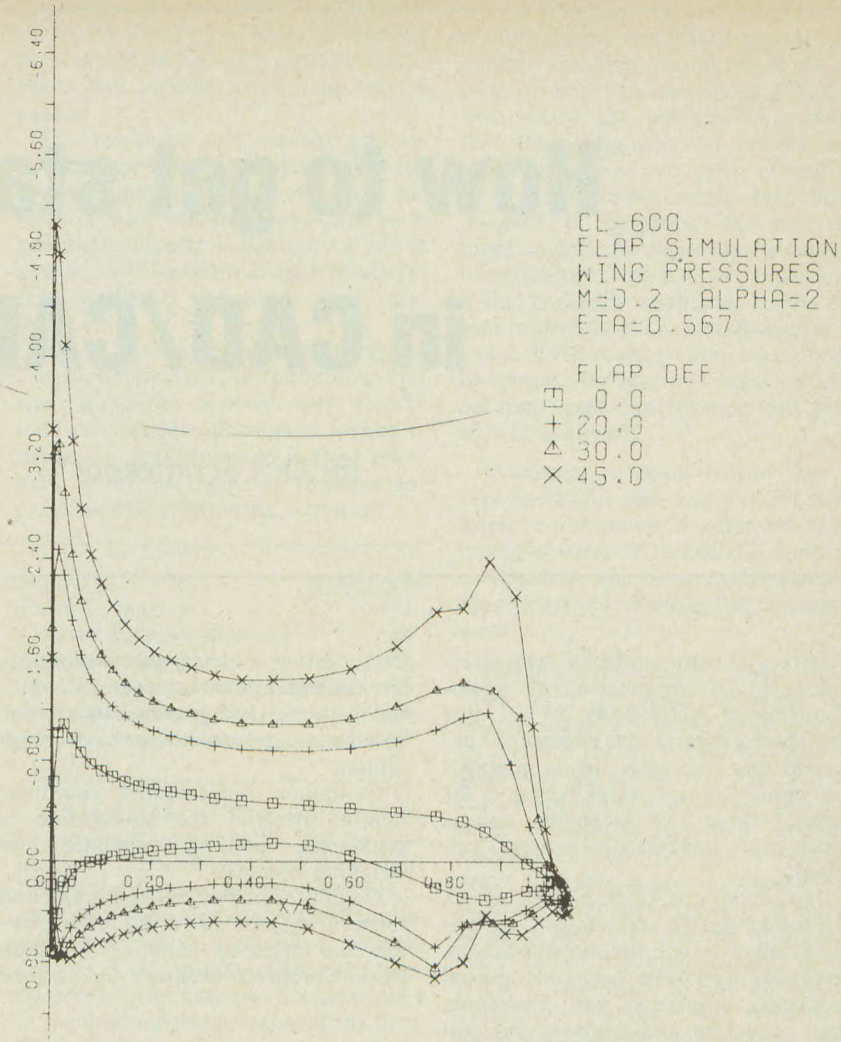


Figure 5. Chordwise wing pressure distributions for various flap deflections.

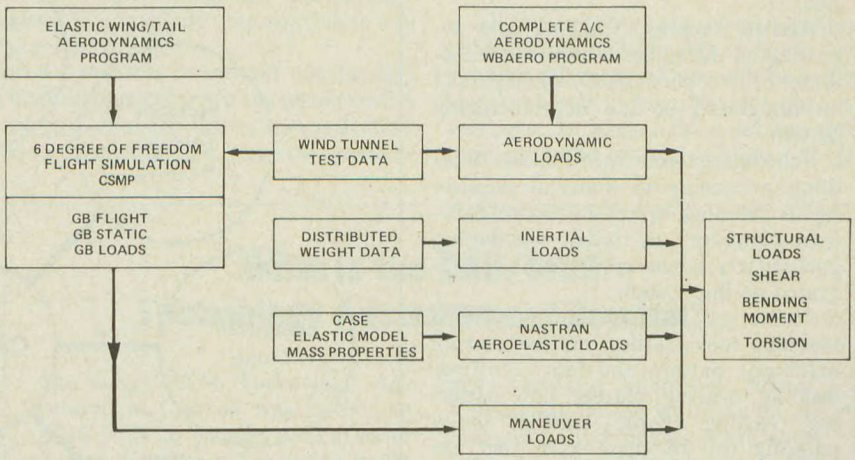
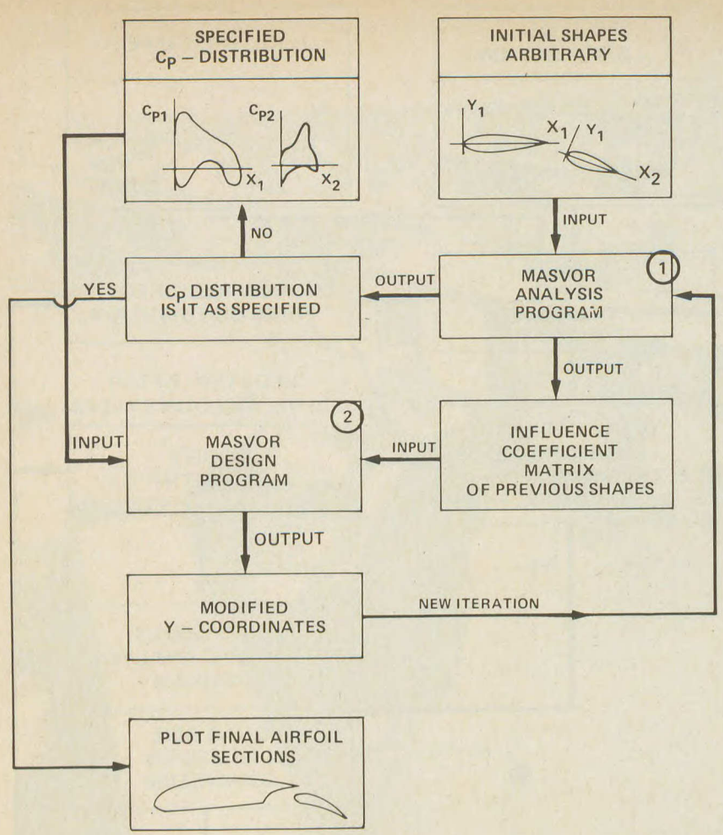


Figure 6. CL-600 design load methods.

Digital simulation plays an important role in the final stages of testing and analyzing flight dynamics. Control modification analysis, handling qualities, analysis of potential problems prior to flight testing and resolution of operational flight test anomalies are all subjects for computer analysis.

Using the computer to perform a variety of complex and otherwise time-consuming design and analysis functions has resulted in significant benefits to Canadair and the Challenger design team. It has also resulted in a more efficient aircraft design and in a considerably reduced design and development cycle for the company's new executive jet. ■

Reprinted from Design Engineering, February 1979



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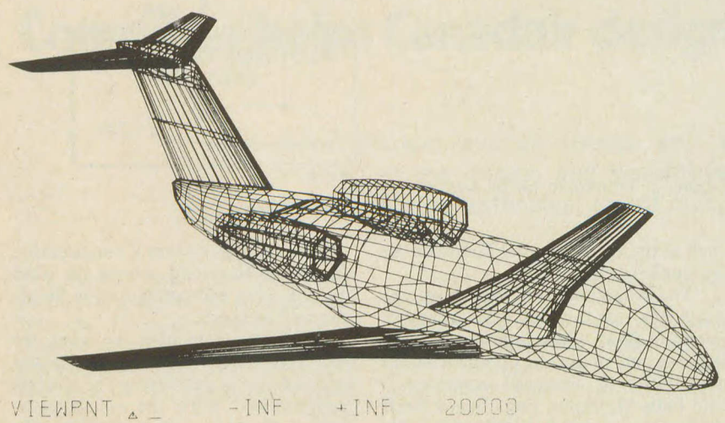

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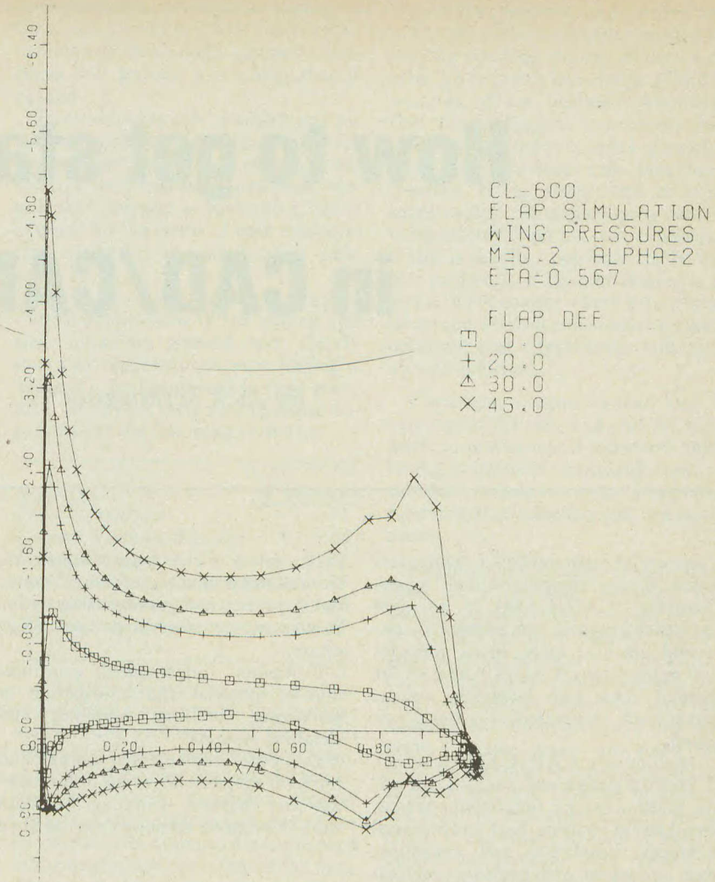

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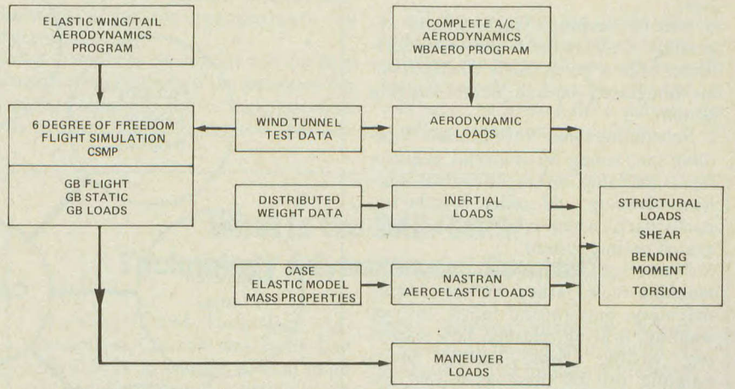

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How to get started in CAD/CAM

*By Jack Scrimgeour**

Contrary to common belief, computer-aided design/computer-aided manufacturing (CAD/CAM) is not just computer graphics and numerical control of machine tools. In its concepts and applications, CAD/CAM goes far beyond these two elements, and is much more integrated or systems oriented.

In summary, CAD/CAM includes:

□ Product design and analysis, including graphic design, functional analysis, stress strain analysis, heat and material balances, simulation and modelling, data reduction and analysis and cost estimating of the proposed product or system to determine fitness of purpose, and economically optimized production;

□ Record keeping, tracking and reporting on the status of individual customer orders, particularly when part of an integrated on-line manufacturing system;

□ Scheduling and information handling pertaining to material requirements planning, inventory control facilities planning and order scheduling, particularly when related to an integrated on-line system.

□ Numerical and computer control of machine tools, lathes, milling, boring machines, pattern and fabric cutting, welding, brazing, plating, flow soldering, casting, flame cutting, spray painting (all of these exist and are under further development).

□ Integrated materials handling using computer operated conveyors, robotic units, etc.

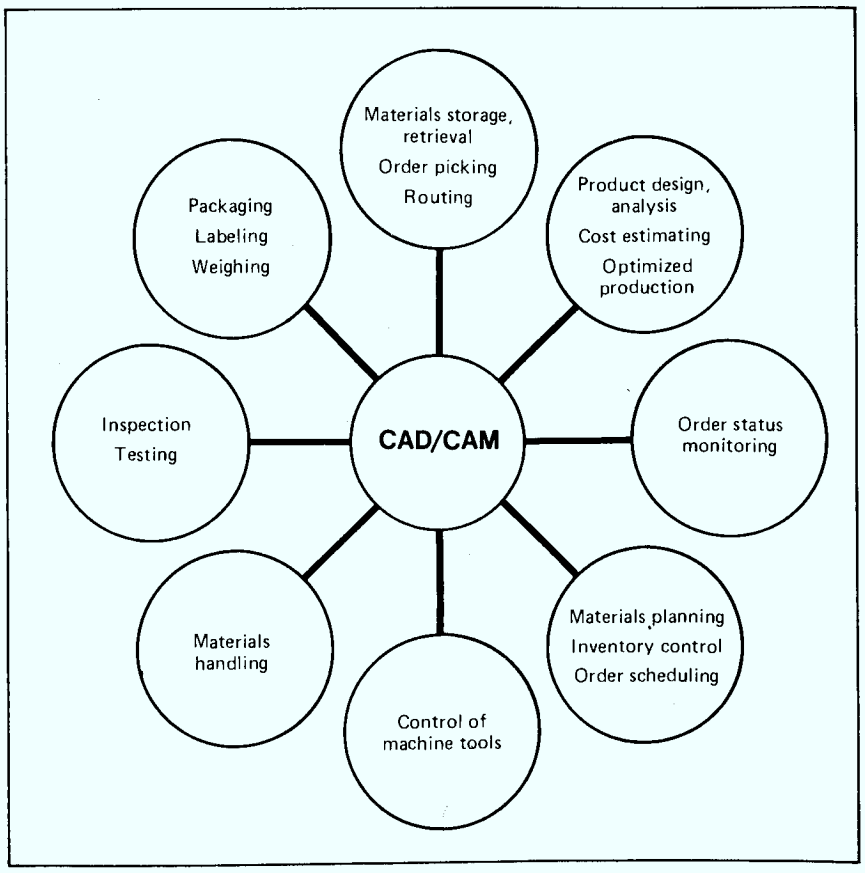
□ Automated inspection of machined parts, testing of electronic components, circuits and products, automated material inspection and grading using sensor based computer systems, pattern recognition.

□ Computer implemented coordination of material and information in packaging, bottling, labelling and weighing systems.

□ Computer implemented storage and retrieval systems involving order picking and material handling for both work in progress inventory and finished goods inventory. Automatic label reading, routing of packages, parcels, baggage in shipping, sorting and distribution centres.

CAD/CAM technology will yield its greatest economic and productivity gains when all or most of the above application areas are married or joined together to form an integrated system. Hence, there is a strong development trend in this direction.

In considering CAD/CAM, the first question is, does it fit into my situation



**Jack Scrimgeour is a consultant in the Technology Branch, Department of Industry, Trade and Commerce, and a member of the CAD/CAM Technology Advancement Council.*

and, if so, can I afford it?

A good way to start getting the answer is to be sure somebody in the organization has the responsibility. Somebody should become informed and be thinking about what the impact will be within the organization.

This may involve an individual or a small group receiving or assuming responsibility; reading some of the many papers available on CAD/CAM systems and technology; attending CAD/CAM conferences; joining one or more appropriate technical societies; identifying some specific CAD/CAM opportunities in the firm, determining the cost, savings and economic justification. In short, one should reduce as much as possible the technological distance between the decision makers in the organization and the sources of technological information.

In Canada, company projects have been observed within the past year for (a) adopting microprocessor technology within the companies' products, (b) computer aided design and (c) computer aided manufacturing. Project costs in each case are of the order of a million dollars. That doesn't mean all projects need be so large for all firms, but multiply even a smaller figure by the thousands of firms in Canada who must each make their own adaptations to these technologies, and the total bill is staggering.

One way therefore to keep the total cost under control, and to be able to afford it, is to avoid re-inventing the wheel. This means we should strive to only do privately within each user company that part of each project that must be done privately for reasons of genuine uniqueness or genuine confidentiality. Duplication can be avoided and the costs reduced if other portions are done by consultants, suppliers, systems houses, development centres and OEMs with costs spread over groups of similar users.

"Group Technology" has a special meaning in CAD/CAM related to parts similarity, but maybe we need a form of "group technology" to identify and recognize projects with similar elements. Much of this can and will happen naturally. Also the directory of companies supplying CAD/CAM systems and services available from the Department of Industry, Trade and Commerce, and the index of OEM suppliers in Canada appearing in Computer Data Magazine, Aug. 78, are useful references in this regard. Furthermore the Canadian Institute of Metalworking at McMaster University recently commenced a survey of NC users in Canada that may reveal opportunities for mutual improvement by group action.

With respect to actual systems implementation, there is a common misconception that since the computer is the main element in CAD/CAM applications and technology, computer suppliers will provide everything that is needed.

Good software aids, manuals and encouragement may be available, but for special applications, and especially for systems with real-time input and output, the computer is basically a "do it yourself kit" in terms of both total system hardware and application software.

A 1972 survey of process computer control applications in the mining and steel industries showed very clearly that user organizations were finding it necessary, and preferred in their planning, to rely on their own in-house capability for the following activities:

Activity	*% In-house*
Process Analysis	*81*
Control Systems Analysis	*66*
Programming	*61*
Hardware System coordination	*46*
Software maintenance	*85*
Hardware maintenance	*57*

CAD/CAM systems will tend to evolve along similar paths, first because many of the problems and their solutions are unique to the individual plant, at least in their first analysis and implementation, and secondly because CAD/CAM systems, like real time process control systems, are embedded in the production operation of the firm. Their performance becomes so critical to the success or failure of the firm that responsibility for their design and operation cannot be farmed out or delegated to an outside organization to any great extent.

A computer consultant can be very helpful, particularly if the people on the project team are new or inexperienced. It can be expensive, however, particularly if the project is structured in such a way that the consultant is paid for a lengthy learning period while he obtains an in depth knowledge of the intricacies of the business—knowledge that the company's own people have already acquired over years of employment and experience in the department involved. If the project can be structured so that the consultant is contributing mainly from his past experience, if this is readily applicable to the current project, or if his contribution is for a part of the project where his costs can be spread over several similar projects, optimum cost effectiveness will probably be achieved.

Computer systems houses can be very useful for this, and also for hardware co-ordination if extensive interfacing is involved, especially from the computer to non-computer equipment, for example production and test equipment.

Application packages, usually developed by a computer supplier, consultant, systems house or other user can be useful if the particular package is a good fit to the application. Otherwise it can be like trying to wear someone elses shoes. Computer runnning time and memory can be excessive if the program contains many unwanted features, or if extensive conversion of data formats, etc., are required in order to use it in the new environment. In any event, it is unusual to find an existing application package that doesn't require considerable modification, even though software packages, like someone else's husband or wife, may look good from a distance.

All this says that the sooner you can establish a knowledgeable in-house capability, the better off you will be in the long run; even if it is two persons, or only one, or even half a person, depending on the company's size. □

What Is the CAD/CAM Technology Advancement Council?

The CAD/CAM Technology Advancement Council was formed in April 1978 to provide a focal point for encouraging and assisting in the application of CAD/CAM technology in Canada. It consists of nine members from industry, four from academic institutions and four from government. The Council's objectives include identification of general areas where Canadian industry can successfully utilize CAD/CAM, providing a centralized source of information, promoting liaison between interested parties, maintaining liaison with foreign organizations and making representations to the Government. The council disseminates information on CAD/CAM technology through professional journals and business publications and through cosponsorship of conferences and seminars. The Council can be contacted through J. Scrimgeour, Technology Branch, Department of Industry, Trade and Commerce, 235 Sparks St., Ottawa K1A 0H5, 593-7861.□

Advanced computer technology for better productivity:

Distributed control systems: part of the solution or part of the problem?

by J. F. Sutherland

Some problems inherent in distributed process control systems which the designer must anticipate and solve, are considered in this paper. Basic system architecture will determine whether a distributed control system is a more efficient process controller or a communications system nightmare. To show a successful approach to distributed control, a line of general-purpose microcomputer modules is described. These modules have been successfully integrated into a wide variety of industrial process control systems.

DISTRIBUTED control—integration of the process controller into the design of controlled process—is as old as the machines which started the Industrial Revolution. The development of the steam engine flyball governor by Watt in the late 1700s was crucial to the mechanical design of the engine. The reliability of the operation was improved and each engine became an independent system. In the mid 1800s, automatic devices were invented to monitor the water level in a boiler and sound an alarm if the level was too low or too high.

Coordination of many controllers into a single system was impossible until ways could be found to communicate supervisory information from a master controller to each subcontroller. With the introduction of pneumatic and electronic controllers, it became possible to interconnect individual controllers directly and obtain better control of the process.

Early process control computers were able to perform complex calculations for an entire process without requiring external communication between controllers. However, process variables, sensors, operator control stations, final control elements and the computer had to be interconnected with vast amounts of expensive cabling.

Inexpensive large-scale integrated circuits now available offer the systems designer an opportunity to return to traditional methods of distributed process control, but with far greater control accuracy and intelligence than was formerly possible. If distributed systems are to be successful in industrial control, it will be due mainly to the system designer's awareness of potential problems which must be solved. It took a hundred years for earlier engineers to solve the problems of system coordination, because they needed resources not yet invented. We are fortunate in having the resources needed for solving the problems imposed by the integration of many small subsystem controllers into a completed coordinated system. However, since no two system designers, given the same resources, will arrive at exactly the same conclusions, some of the approaches to final system architecture suggested by this paper may be new and unfamiliar.

The discussion of distributed control system problems is followed by a description of a set of microcomputer-based control modules designed with the intent of solving some of those problems and circumventing pitfalls. Finally, some typical distributed control systems using those modules are discussed to demonstrate the success of this design philosophy.

Problems of Communication

The simple presence of a microprocessing element in a subsystem does not automatically solve the communication problem for the system architect. The microprocessor can do only one job at a time. While it is moving data back and forth between the Universal Asynchronous Receiver Transmitter (UART) and working memory, it cannot control the process. Since the control capability of the microprocessor is of primary importance, any reduction in that capability must be minimized. Therefore, the data-moving job should be done by a dedicated processor, rather than by the process controller in its spare time. The volume of communicated data generally increases as experience with the system is gained and more control innovations are tried. Otherwise, why provide the flexibility of programmed controller functions? Also, if the system designer depends on a subsystem controller to handle communications, he may be tempted to leave out the message protocol refinements which provide for error detection and message security. Microprocessor time available may be insufficient for exhaustive encoding, decoding, byte counts, checksums, source codes and parity.

Similarly, a microprocessor which is controlling the process should not be interrupted by a high level processor with a request for data unless it is certain

that its control functions can safely be suspended for a short time. There is always some danger that an erroneous external event may cause the controller to "hang up" and lose control of the process.

Direct memory access controllers provide a way for the communications controller to update the common data registers of the RAM of the process control microcomputer without interference. However, some serious problems can be caused by simply using DMA to update or recall RAM data in the conventional manner.

The most obvious system problem occurs if the communications controller fails to complete a memory access and the process control microprocessor is indefinitely denied access to the RAM. In cases where memory-mapped I/O modules are used to interface the process, the entire process controller would be stalled and the process would not be controlled. It must be recognized that loss of control can result from a single failure of a supervisory level communications controller. Even though the problem could be solved by incorporating an access timer in the DMA controller, it would still be possible for a defective 3-state data line driver on the communications controller to corrupt the memory data transactions to and from the process control microcomputer.

A second problem which could result from the use of a single DMA to update and recall RAM data becomes apparent when the memory bus time budget is analyzed. With only one memory bus for working data memory, program instructions from PROM memory, I/O controllers, data entry interface modules, and communications controllers, the process control microprocessor will suffer a reduction in throughput due to the DMA activity initiated by the communications controller.

Normally, a communications controller which depends on DMA does not contain sufficient internal data buffering to store an entire message data block until it has been verified to be error-free. Therefore, portions of the received message must be transferred to active memory locations in RAM, but held inaccessible to the process control microprocessor until verification can be completed. This assures that erroneous data is not handed over to the process control microprocessor, but it may cause the communications controller to monopolize the memory bus and adversely affect the responsiveness of the process controller.

An inadequately isolated communication medium will expose the internal system buses to the electrical noise influences of the external world. It is important that a means be provided for noise isolation to keep destructive noise transients from destroying the system hardware.

In addition, communications protocol must not require handshaking on the part of the process controller, if graceful system degradation is a prime requirement. The communications subsystem will usually complicate the job of system checkout or maintenance if it is not properly integrated into the process control system.

Problems of Reliability

Most industrial applications of distributed controllers demand extremely high reliability, largely because of good past experience with simple relay logic systems, solid state analog and digital systems and, more recently, computer-based monitoring and controlling systems. The new, large microprocessor-based systems are more complex than their predecessors. That increased complexity is not all bad, since it provides new features and usually permits better system operation. However, a system made up of uncoordinated control functions or of centralized and shared process controllers usually had fewer components to fail. A failure analysis of a distributed system is important, because it points out those series elements which are essential to maintaining control over the process. Almost every LSI device used in distributed systems contributes significantly to the system failure rate, and the cascading of several hundred individually very reliable LSI devices can result in an unacceptable system failure rate.

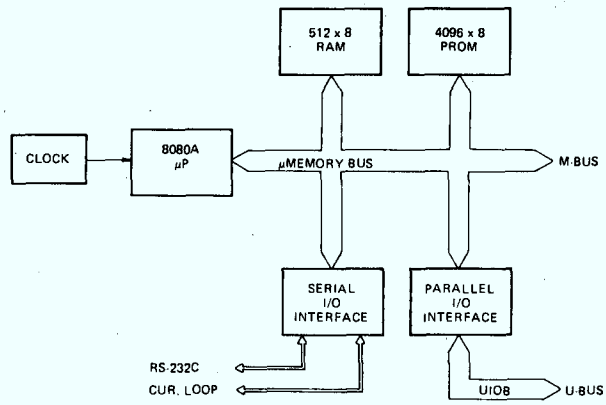


Fig. 1 — QMC functional block diagram.

If the distributed system is able to embody redundancy of the critical and complex portions of the control function, the total failure rate will be very much smaller. For example, if a function with 10 000 hours MTBF is made totally redundant, the resulting MTBF would be 100 million hours. The financial return of such a reliable control system must be weighed against the increased initial equipment cost and also against the increased maintenance cost, because even though the control system does not fail as often as the nonredundant system, the number of component failures will be twice as great.

Problems of System Maintenance

Personnel charged with maintaining a large distributed control system may not always have prior experience in the variety of circuit technology employed in ways not obvious to the user. When all control action is contained in systems composed of from three to 500 or more PC boards, the boundaries between software, hardware, instrumentation, control engineering and communications become very blurred.

When the system is specially distributed, the job of getting a failed system back on line may become

much more difficult than the change-out of PC boards in the control room until the system works. The instrument technician trained in maintenance of analog and digital parts of the system must be equipped with enough special test equipment to help in diagnosing hardware failures and pinpointing the problem quickly. It is particularly important that diagnostic tools in the firmware be usable by maintenance personnel without the aid of a process engineer.

Problems of Hostile Environment

Of all the design challenges faced by architects of distributed systems, probably the most frustrating are those resulting from the integration of control equipment with the process being controlled. Slabs and bars of hot steel are not very tolerant of any obstruction, even when that obstruction is a control cabinet or some cables. Remotely-mounted data monitors cannot be located in air-conditioned rooms, so circuits may be vulnerable to poor power supply regulation, temperature extremes, humidity, gaseous and airborne pollutants, along with physical abuse.

Before the designer decides to locate a "smart remote station" in a hostile environment, he must count the cost and justify his decision. The result of such a study may show that the extra expense of providing expendable electronics can be justified by improved performance or product, although treatment of computers in the same category as fuses and lamps would, until now, have been unthinkable. Because the computing element is now less expensive than interconnecting cables and supporting cabinets, it may now be considered as "throwaway" equipment in some severely corrosive environments.

Consideration must be given, however, to the effect on system reliability. If standby or redundant equipment is used, it will be subjected to the same hostile environment as the working system and might not be available for use when it is needed.

Problems of Long Design-Life Responsibility

Traditionally, process controllers in industrial plants have been expected to work forever or, at least, be capable of being maintained forever. Relays, pneumatic instruments, vacuum tube systems, magnetic amplifiers and simple discrete semi-conductors have generally been maintainable. The introduction of LSI devices, with all the hoopla surrounding it, brings also a feeling that the security blanket is not only a different color and weight, but is also difficult to hold on to.

Many of today's applications using the power and flexibility of the microprocessor are buried in a consumer product, sold, and forgotten. A new and "improved" LSI device appears on the market and the cycle is repeated.

The problems associated with the use of LSI devices in an industrial control system are beyond solution if the IC manufacturer objects to assuring a supply of parts for 10, 20 or 40 years. The IC process may not be repeatable 40 years from now and, if it is, the cost will probably be exhorbitant. Today's control

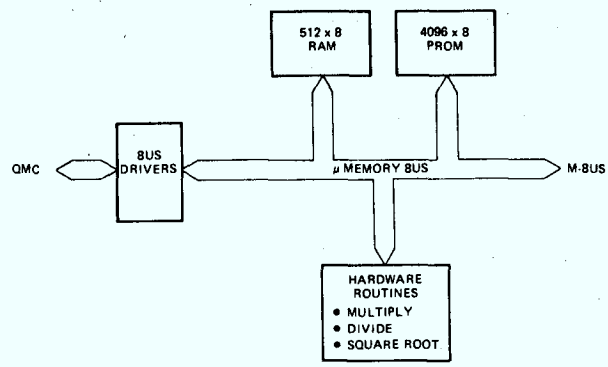


Fig. 2 — QME functional block diagram.

engineers have enough problems without worrying about a future generation's problems of maintenance. However, the time frame of concern for design life of today's distributed systems will probably exceed the IC manufacturer's product design life, which is usually ten years or less. Some components, such as germanium diodes and transistors, RTL and DTL logic family parts are now becoming orphans in the industry, because IC manufacturers see no financial return on their process investment. The concern with LSIs lies in the future time period of 10 to 20 years from now.

The problem of maintaining a 10 or 20 year design life can be made easier if a conservative standard IC family is adopted in the design of each module. During the early stages of parts procurement, it also helps if the LSI devices are not solesource or custom-designed parts. In the final stages of parts procurement, however, the differences between procuring once-catalog LSIs and a custom LSI will be minimal, because they will each be impossible to obtain off the shelf.

If the future needs for a particular LSI device are predictable, a die inventory could be bought and stored in dry nitrogen at considerably less cost than restarting an obsolete IC process line or storing completely packaged and tested spare LSI modules.

One alternative is to plan for the replacement of obsolete parts with new designs as they become available. It is at that point that the functional partitions designed into the process controller become very important. If a new module is to replace a module no longer maintainable, the interface signals must be simply defined without ambiguities. The signal interfaces rigorously defined by industry standards such as IEEE 583 and IEEE 488 can make the redesign effort much more productive and faultfree.

Q-Line Modules Designed for Distributed Control

New microprocessor-based control system modules called Q-LINE have been developed by Westinghouse for use in distributed control systems applied to a broad range of process control applications. Most of the basic modules are general-purpose modules, so that a few types can be combined to satisfy most system requirements. Only a few are designed for specific applications.

Initially, the Q-LINE consists of a microcomputer card (see Fig. 1) which controls data transactions on

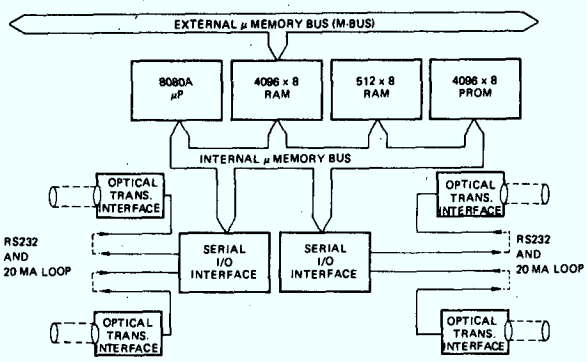


Fig. 3 — QMD functional block diagram.

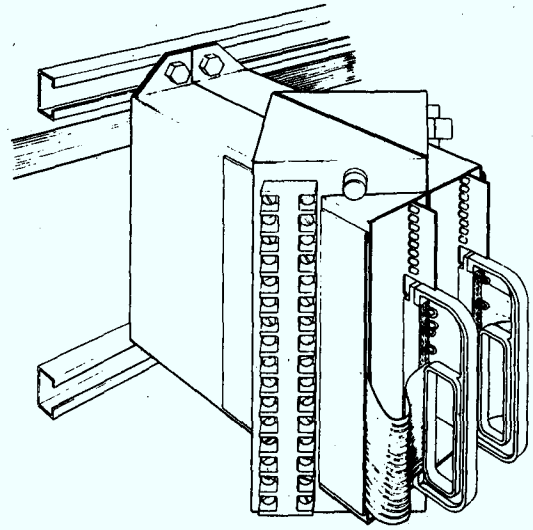


Fig. 4 — Integrated I/O termination module.

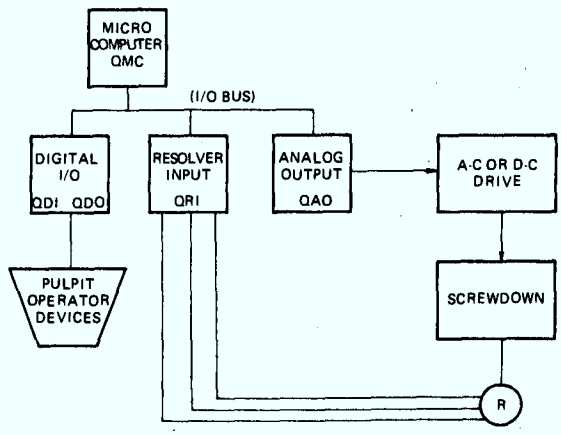


Fig. 5 — Microprocessor based position regulator.

either of two 8-bit data buses. Each bus has been optimized for a particular use.

The U-bus conveys process I/O data by means of I/O point cards which provide isolation, signal conditioning and memory-mapped I/O data buffering. Data transferred over the U-bus is coupled through CMOS 3-state drivers and receivers. Length of the U-bus is limited to 15 m. The low power consumption and high noise rejection of the CMOS logic used permits Q-LINE systems to operate satisfactorily in hostile environments.

The M-bus (see Fig. 2) is a high speed memory expansion bus which permits the construction of large-scale arrays of microcomputers. Two-ported, shared RAM modules, data link controllers, bipolar PROM memory expansion and arithmetic processing units can be added easily. Low-power Schotky 3-state drivers and receivers on the M-bus modules provide fast data transactions, assuring that the 8080 microprocessor on the microcomputer module will not be required to wait more than 500 nanoseconds per byte transferred. The M-bus, like the U-bus is an internal bus, and its length limitation of 8 meters permits routing of cables between panels within a single cabinet lineup.

An isolated serial data port is provided by the microcomputer module to communicate with local keyboard/printer devices. Since the baud rate is programmable and either a 20 ma current loop or an RS-232C interface may be used, a great variety of maintenance and diagnostic instruments can be connected through this port. The preferred serial ports, however, are located on data link controller cards (see Fig. 3), which use a microprocessor or other added hardware to handle protocol and message checking. Correctly received messages are placed by the on-board microprocessor into a shared memory, also located on the data link controller. Contention for shared memory between the microcomputer module and the microprocessor on the data link controller is handled on a first come, first served basis.

Local communications between microcomputer modules are handled by shared memory modules which bridge the gap between two M-bus arrays. The shared memory module is designed so that a fault on a system connected to one port cannot be propagated through the module to disturb data transactions on the other port or its associated M-bus. This feature of memory isolation benefits software designers just as isolating amplifiers help preserve system integrity for hardware designers.

If more than two microcomputer modules need to share data, it is possible to add still another microcomputer module dedicated to the distribution of data between the source and the destination modules in a single cabinet or lineup. Because it is dedicated to data transfer, it can move that data at a rate of 60 000 words (16 bits per word) per second. The internal bus controller is also capable of detecting the failure of any microcomputer module in the array. Similarly, if desired, the internal bus controller may be backed up by a second bus system with an extra set of shared memory modules. As many as sixteen shared memory modules may be connected to a single microcomputer module to generate the equivalent of a 32K byte RAM with 16 individual data ports.

All of the Q-LINE modules are equipped with on-card power supply auctioneers which provide for automatic switching to a backup bus should the primary power supply fail. A single-voltage power bus is distributed throughout the system for simple maintenance procedures, avoiding the sequencing problems usually associated with multiple-voltage power distribution systems.

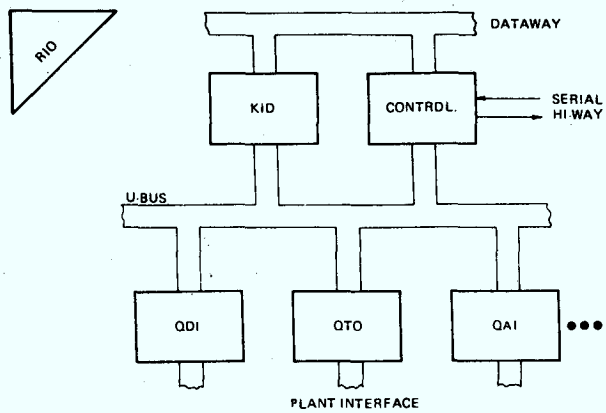


Fig. 6 — RIO remote.

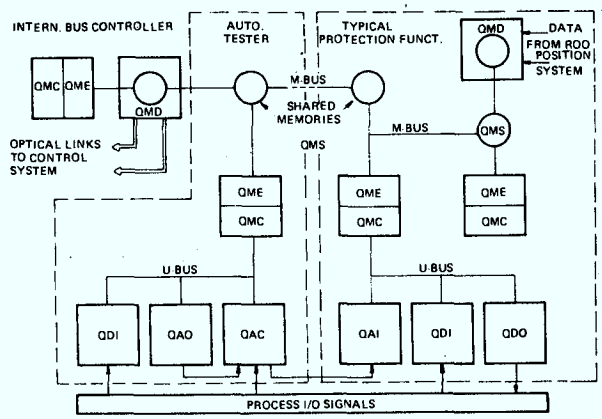


Fig. 7 — Nuclear protection system (partial)—block diagram.

The typical process I/O signals (analog input, analog output, digital input and digital output) are interfaced by I/O point cards on the U-bus. Process signal conditioning circuitry on each point card is electrically isolated from the U-bus for common-mode voltage rejection. Further, the cards are designed to withstand the ANSI C37.90A-1974 surge withstand test. Front edge connectors are used to connect process wiring using either direct, prefabricated cables or screw terminal blocks located adjacent to the point cards.

An integrated I/O termination module (see Fig. 4) or "wrapper" provides in a single unit the necessary customer connections, along with physical protection for two I/O point cards. Therefore, if both front and rear access is permitted, 32 I/O point cards may be distributed throughout the customer termination area of a single-bay cabinet 220 cm, high. If very many M-bus expansion cards are needed, they, along with the microcomputer module, are located in a separate 12-module crate, which also fits into the single-bay cabinet.

Q-LINE I/O point cards may also be used in a remote I/O data collection system. In applications of this type, the cards are located in a CAMAC-compliant remote crate and interfaced through an adapter module which converts all U-bus signals to CAMAC dataway signals.

Examples of Q-Line Applications

Fig. 5 shows Q-LINE modules used in the design of a position regulator system for steel mills. The system will accept a position setpoint provided manually by the operator or automatically by a coordinating minicomputer. Position feedback is provided by a special-purpose U-bus point card which contains all of the electronics needed to convert shaft position accurately to 1/1000 of one revolution over a 64-revolution span.

In Fig. 6, standard Q-LINE I/O point cards are used to build a remote station on a CAMAC serial highway. The remote stations are interconnected by a coaxial cable which transmits data at the rate of 5 megabits per second. Up to 63 remote stations may be controlled by a single master controller. In some applications, these remote I/O systems have resulted in significant cost savings by reducing cable requirements.

Fig. 7 shows how a cluster of microcomputer subsystems is constructed to perform complex calculations in a nuclear reactor protection system. An internal bus controller distributes data between source and destination shared memory modules. Since the calculations must be completed very quickly, the arithmetic processing unit on the memory expander module provides a set of fast, off-line arithmetic functions in hardware. Communications between quadredundant channels is provided by optical data link controllers operating at a rate of 19.2 kilobits per second.

Conclusions

Clearly, the trend toward distributed controls will continue only if the problems of communication, reliability, maintenance, hostile environment and long design life can be solved satisfactorily. Designers of new systems must recognize these potential problems and accommodate or eliminate them, so that the resulting products and systems perform as well in the plant as they did on the drawing board. Otherwise, none of the subtle justification for distributed control will be realized by the process engineers and the operators, and they will return to more traditional control philosophy.

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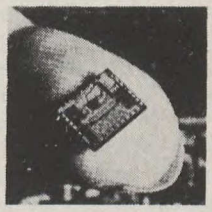
Les répercussions de la technologie du microprocesseur et de l'ordinateur sur l'industrie manufacturière



Le microprocesseur est le plus récent phénomène d'une série continue de réalisations qui se sont succédées à un rythme surprenant au cours des 30 dernières années dans l'industrie de l'électronique et de l'informatique.

par N. J. Scrimgeour
Conseiller, Direction de la technologie, ministère de l'industrie et du Commerce, Ottawa.

Sans perdre de vue le microprocesseur proprement dit, la communication d'aujourd'hui porte sur une catégorie importante d'applications qui devraient avoir des répercussions considérables sur l'industrie manufacturière — j'ai nommé l'application de la technologie du microprocesseur et de l'ordinateur dans la conception informatisée et la fabrication informatisée. Ces deux secteurs sont souvent identifiés par le sigle CAD/CAM, ou «Computer Aided Design» et «Computer Aided Manufacturing». D'autres parlent de «révolution microélectronique» ou de «la troisième vague de la révolution industrielle». Mais, quelle que soit la désignation, cela revient au même pour l'industrie manufacturière, car les répercussions de cette idée de la technologie seront considérables.

Qu'est-ce que CAD/CAM?

En dernière analyse, il faut considérer CAD/CAM en tant qu'un **système intégré de conception et de fabrication.** C'est d'ailleurs sous cet aspect qu'il sera de plus en plus envisagé. En effet, ce sont ceux qui le considéreront et l'appliqueront dans ce sens qui réaliseront les plus grands gains économiques et de productivité.

À l'heure actuelle, CAD/CAM est consititué d'éléments épars. Même si l'on reconnaît la réalité de ces aspects au point de vue système, CAD/CAM peut signifier des choses bien différentes selon les utilisateurs, par suite des intérêts et responsabilités individuelles, ainsi que selon la façon dont chacun a été mis en contact avec CAD/CAM.

Une façon de considérer CAD/CAM consiste à identifier les activités et les applications à l'intérieur du cycle de conception et fabrication qui, dans ce contexte, constituent la plus grande partie de l'activité totale que l'on peut traiter de manière informatique. Comme l'indique le tableau 1, ce sont essentiellement :

- La conception informatisée
- Le traitement des commandes des clients
- Le contrôle de la production, des matériaux et des stocks
- La commande numérique des machines-outils et autre équipement de production
- La manutention automatisée des matériaux (robots)
- L'inspection et les essais automatisés
- L'emballage automatisé
- L'entreposage automatisé

Une autre façon d'envisager CAD/CAM consiste à identifier les technologies nécessaires à sa mise en place, à savoir :

- Les graphiques par ordinateur
- L'électronique
- La mécanique
- La simulation et les modèles
- Les calculs techniques
- L'optimisation
- L'analyse numérique
- La conception des bases des données
- La conception de l'interface
- Les systèmes répartis
- Les langages de programmation
- Les protocoles de communication
- L'ergoingénierie
- La transmission des données
- L'ordonnancement des productions
- Le contrôle des matériaux et de l'inventaire
- Les robots

- La technologie des machines-outils
- La commande numérique
- Les capteurs et les instruments
- Le contrôle par rétroaction
- La reconnaissance des modèles
- Les effets socio-économiques

S'intéresser à la mise en place d'un système CAD/CAM, c'est s'intéresser dans une certaine mesure à la plupart sinon à la totalité des sujets ou technologies ci-dessus.

LES PROGRÈS DE LA TECHNOLOGIE INFORMATIQUE

Étant donné que l'ordinateur est manifestement l'élément commun et le coeur de pratiquement tous les systèmes CAD/CAM, il est bon de passer rapidement en revue les progrès technologiques accomplis par l'industrie de l'informatique qui auront permis d'en arriver à de tels systèmes. Il faut cependant établir clairement dès le début que, dans les systèmes CAD/CAM, on emploie principalement **l'ordinateur comme machine de base.** Une bonne partie de la technologie utilisée dans les applications CAD/CAM, et qui doit faire l'objet de mises au point ultérieures, est de nature informatique, mécanique et manufacturière. Ce sont les utilisateurs «maison» qui doivent effectuer une bonne partie de ces mises au point. Par conséquent, ce serait une erreur que de considérer CAD/CAM comme un produit mis au point et fourni uniquement ou principalement par l'industrie de l'électronique.

Le premier ordinateur est arrivé au Canada par bateau en 1952 de chez Ferranti, Manchester (Angleterre), pour aller s'installer à l'Université de Toronto, où il fut connu sous le nom de l'**ordinateur Ferut.** Son temps d'addition à point fixe était de 1,2 ms et son temps de multiplication, 2,2 ms. Les divisions se faisaient grâce à un sous-programme réciproque de 95 ms. La mémoire fonctionnelle se trouvait sur l'écran de tubes à rayons cathodiques appelés tubes Williams, d'après le professeur F. C. Williams, leur inventeur, et il fallait la rafraîchir périodiquement parce qu'elle se détériorait et perdait même les informations malgré le recyclage automatique des modèles de bits. A notre connaissance, le premier ordinateur utilisé dans l'industrie manufacturière canadienne fut installé par Orenda Engines Limited en 1956, bientôt suivi par d'autres ordinateurs conçus pour établir des conceptions industrielles plus générales non reliées à la défense nationale.

Le modèle d'ordinateur Ferranti installé à l'Université de Toronto était de grandes dimensions, car ses divers éléments remplissaient toute une salle et il coûtait cher.

Or, un microprocesseur est extrêmement petit. Les pastilles de microprocesseur coûtent environ $10. Pour être juste, un microprocesseur n'est pas un ordinateur complet, mais c'est essentiellement l'unité arithmétique, étant donné qu'il n'y a pas de mémoire, de source d'alimentation de courant ni de périphériques d'entrée/sortie. Ce microprocesseur particulier, qui est le COSMAC 1802 RCA utilisé dans CMOS, contient 16 registres de 16 bits, mais il fonctionne en mode d'octet c'est-à-dire de 8 bits, étant donné que les opérations n'utilisent que la moitié supérieure ou inférieure de chaque adresse de registre ou de mémoire. L'exécution de la plupart des instructions, comme l'arithmétique à point fixe, exige 16 périodes d'horloge. Si l'on utilise une horloge de 2 mégaherz, cela veut dire 8 microsecondes par instruction, ce qui, si l'on ne tient pas compte des différences de dimension des mots, est environ 250 fois plus rapide que le premier ordinateur utilisé au Canada.

Comment ce changement a-t-il pu se faire et quelles sont ses implications?

Le nombre d'éléments par circuit (portes/pastilles) a doublé chaque année depuis 1959, ce qui a donné une augmentation de 1024 éléments par circuit tous les 10 ans[1]. De pair avec l'emploi de la gravure par faisceau électronique ainsi que d'autres techniques du genre, cette tendance à la miniaturisation devrait continuer jusqu'à ce que l'on atteigne d'autres limites physiques, comme la résistance à la rupture diélectrique du silicone, la capacité d'extraction de chaleur et le pourcentage de la surface des pastilles que l'on peut utiliser pour les circuits[2].

Au niveau de l'utilisateur, il est difficile de relever les améliorations des rapports prix/rendement des ordinateurs, tout autant que les coûts de calcul, étant donné la grande diversité des types de problèmes et des architectes d'ordinateur dont disposent les utilisateurs, mais on peut dire que chaque année l'amélioration a été d'environ **32% pour le coût de la mémoire, 23% pour la logique et 11% pour les communications.** Les améliorations du coût de calcul de 10 sur 1, ou plus, tous les dix ans, signifient qu'un calcul qui coûtait $1000 dans les premiers jours de l'informatique ne coûtait plus que $10 en 1972. Selon ce raisonnement, le

Système de gestion d'usine Honeywell, basé sur ordinateur et microprocesseur.

même calcul ne coûtera plus que $1 en 1982 et 10 cents en 1992. On estime que les dépenses effectuées par l'industrie manufacturière américaine uniquement pour l'équipement de graphiques informatisés, de logiciel et de services informatiques augmenteront au rythme de 22% par an, passant de $251 millions en 1977 à $316 millions en 1978 et $1,5 milliard en 1986. Cependant, des symptômes très clairs indiquent que l'on atteindra une «limite de programmation» dans bien des nouvelles applications possibles de l'ordinateur, ce qui fait que des applications comme celles dans les communications et le traitement des mots, où l'utilisateur ne voit pas le microprocesseur (par opposition aux applications où l'utilisateur établit lui-même des programmes) bénéficient des taux de croissance les plus élevés au point de vue nombre d'applications et chiffres d'affaires.

La gamme des applications possibles est aussi vaste que le savoir humain et personne ne peut arrêter ou même retarder les changements qui ont lieu, même si on le voulait. CAD/CAM représente l'un de ces domaines d'applications, et il revêt une importance particulière à cause de ses répercussions sur les industries manufacturières.

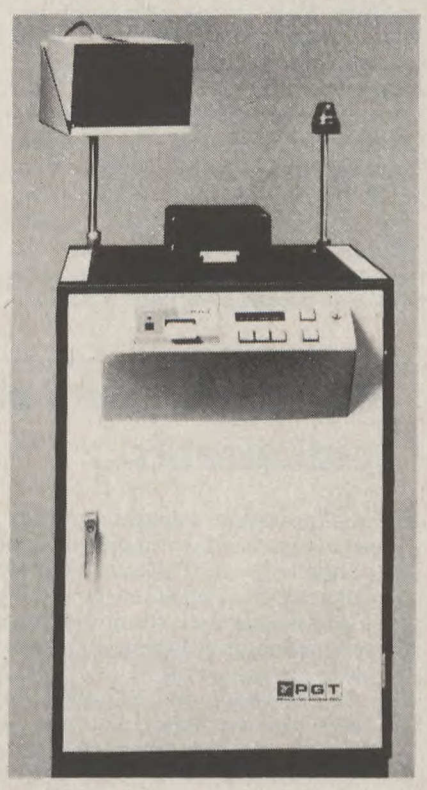
LE CANADA A-T-IL BESOIN DE CAD/CAM?

C'est là une question valable et importante. La réponse à long terme réside dans la structure de l'économie, non seulement telle qu'elle existe de nos jours mais telle qu'elle existera à un moment donné de l'avenir. On peut identifier quatre secteurs économiques de base, accompagnés de leurs perspectives à long terme, à savoir:

1. Des ressources non renouvelables — qui, un jour, seront épuisées.
2. Des ressources renouvelables — qui atteignent leurs limites naturelles et dont le rendement devient constant.
3. L'industrie manufacturière secondaire — qui présente des possibilités de croissance future à long terme.
4. Le secteur des services — limité par un rapport maximal naturel égal à la somme de 1 + 2 + 3.

La main-d'oeuvre du Canada s'est accrue de façon linéaire d'environ 7 millions en 1964 à 11 millions en 1978, soit une augmentation de 285,000 nouveaux emplois nécessaires par an, autrement dit plus de 1,000 nouveaux emplois par jour ouvrable[5].

L'importance du secteur manufacturier comme source principale de création d'emplois est donc manifeste.



En haut: analyseur de matériaux PGT-810 avec microprocesseur.
Bas: enregistreuse à dictée-transcription avec contrôle par microprocesseur.

Le rapport du Conseil des sciences porte une attention particulière à la nouvelle vague de changements qui s'effectuent dans les méthodes de production industrielle par suite des progrès de la technologie de la micro-électronique et des microprocesseurs. Ces nouveaux produits électroniques sont non seulement la cause de changements radicaux dans l'industrie et l'électronique, mais ont également des répercussions importantes sur d'autres formes de production industrielle.

Quelle est donc la force d'entraînement qui pousse les changements technologiques? Si nous identifions clairement les facteurs impliqués, nous nous trouverons dans une meilleure position pour accélérer ou retarder ces changements selon nos désirs et nos objectifs. La figure 1 n'est donc pas un dessin artistique d'un simple phénomène, mais elle illustre le résultat final d'un processus complexe qu'il vaut la peine d'examiner d'un peu plus près.

Dans une société libre et concurrentielle, la force de motivation la plus forte d'un changement industriel est la conscience d'une justification économique. En ce qui concerne la technologie CAD/CAM, cela signifie la conscience, par le personnel technique et de gestion, de ce que peuvent faire ces systèmes, ainsi que la conscience des bénéfices économiques que l'entreprise ou un organisme particulier retirerait de leur application. Les décisions des gestionnaires sur l'investissement nécessaire pour implanter des nouveaux systèmes et des nouveaux équipements, ainsi que l'allocation des ressources internes, des équipes de projet, ainsi de suite, sont habituellement basées sur des rapports et des propositions préparés et présentés par le personnel technique. **Ainsi, le changement technologique d'une industrie dépend de la façon dont elle a pris conscience de la justification économique, de l'initiative et des ressources d'information des gestionnaire techniques et de direction de l'entreprise ou de l'organisme.**

Reconnaissant que l'information et cette prise de conscience sont des ingrédients importants du processus, et que c'est dans les premiers stades de formation que l'on peut le mieux influencer l'introduction d'une nouvelle technologie, les forces du marché

pourront ensuite être totalement adéquates, le ministère de l'Industrie et du Commerce a établi en 1978 un Conseil pour le progrès technologique de CAD/CAM. Ce Conseil est fortement axé sur l'industrie.

De temps en temps, le Conseil diffusera des renseignements de nature générale sur CAD/CAM.

Les principaux véhicules utilisés pour diffuser cette information seront normalement des revues techniques établies plutôt que des campagnes de publicité postale. Des conférences et des séminaires commandités seront également utilisés.

Quelle sera l'évolution des systèmes CAD/CAM?

Ceci est également un question importante. On trouvera au tableau 1 les principaux secteurs d'application des systèmes CAD/CAM et au tableau 2 les technologies inhérentes à ces applications. Même si la liste des technologies semble longue au premier abord, c'est certainement une liste incomplète. En fait, une bonne partie des activités de R & D qui ont lieu à l'heure actuelle n'offrent guère d'intérêt, au moins en ce qui a trait à des applications industrielles possibles de ces systèmes.

Si vous vous imaginez en train de vous promener dans un grand atelier ou une grande usine avec un microprocesseur dans votre main, et si vous vous rendez compte de la complexité de l'équipement en place et des opérations exécutées, vous vous rendez immédiatement compte qu'il y a encore beaucoup de chemin à parcourir avant de pouvoir adapter le microprocesseur à ce système manufacturier.

Étant donné que le travail est surtout orienté vers les systèmes, les ingénieurs en électronique et en informatique doivent en apprendre davantage sur le génie mécanique et le génie manufacturier. **Il ne suffit pas de programmer que l'opération de production 12 se déclenche lorsque le quatrième bit est réglé à la position haute.** Il faut également savoir comment se déroule cette opération de production, ce qu'il manque à l'heure actuelle lorsque l'ordinateur entre en jeu, comment l'opération peut faire défaut, comment on peut éviter des défaillances, et comment on peut tout remettre en route lorsqu'il y a panne. Inversement, les ingénieurs en mécanique doivent en savoir davantage sur les ordinateurs et l'électronique. De nos jours, **une machine-outil n'est pas une simple pièce d'équipement mécanique commandée par un conducteur.** C'est un équipement électronique programmé. De plus, dans bien des cas, il est rare qu'elle fonctionne de manière autonome, c'est plutôt une unité d'opération qui fait partie d'un tout, autrement dit un système de production hautement automatisé et intégré.

Le microprocesseur jouera un rôle clé dans cet environnement. Pour être souples d'emploi et pratiques, ces systèmes doivent évoluer d'une façon hiérarchique. Cela implique l'utilisation d'un microprocesseur ou d'un petit ordinateur à l'intérieur ou immédiatement connexe à chaque pièce d'équipement de production, qu'il s'agisse d'une machine-outil pour découper le métal ou d'un appareil qui soude, brase, plaque, moule, peint, manutentionne, inspecte et même assemble les pièces. Si l'on place un microprocesseur en tant qu'unité de contrôle, avec une interface de communications dans chaque pièce de l'équipement, on obtient un système dit à intelligence répartie. On peut placer des programmes contrôlant des opérations détaillées ponctuelles dans chaque pièce d'un équipement local, ou en aval de celles-ci de façon à ce qu'ils soient déclenchés, selon le besoin, à partir d'un ordinateur central. Dans un tel système réparti, **le fonctionnement de la machine-outil peut être maintenu sous contrôle local en cas de panne du système,** ou ce qu'il y a encore de plus important, si l'on n'a pas encore réalisé l'implantation de tout le système. En outre, chaque fabricant et fournisseur d'une pièce d'équipement peut incorporer le microprocesseur dans son produit. En fait, c'est ce qu'il désire, parce que cela lui donne une plus grande maîtrise de l'action et protège en même temps la position de son produit traditionnel et de ses capacités inhérentes sur le marché. En fin de compte, cela déplace une bonne partie de

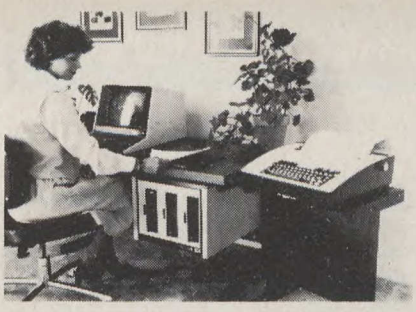
De beaux jours pour les ordinateurs...

L'industrie canadienne des ordinateurs et traitement communication et informatique progresse plus rapidement que la plupart des indicateurs économiques. En 1970, les Canadiens ont dépensé $1.2 milliard pour répondre à leurs besoins en services d'ordinateurs et communication. Cinq ans plus tard, ce montant avait plus que doublé (2.2) avec $2.7 milliards, alors que, pendant cette même période, le Produit National Brut du Canada n'avait augmenté que de 1.93 fois. Le rythme de croissance entre 1975 et 1980 devrait être identique à celui de la période 1970-75. On devrait atteindre $5.6 milliards en 1980 et $9.5 milliards en 1985.

L'industrie de service des ordinateurs a enregistré un revenu de $1 362 millions, en 1977, soit plus du double qu'en 1973 ($651 millions). En 1977, plus de 590 entreprises au Canada assuraient la fourniture, l'entretien, la vente de pièces et accessoires, la formation technique dans le domaine des ordinateurs. Les revenus d'exploitation, en 1977, atteignirent $416 millions et on les estime à $500 millions en 1978.

D'après le dernier recensement effectué par la Société canadienne de traitement de l'information, il y aurait au Canada quelque 8 251 grands ordinateurs (au 1er mai 1978). On appelle "grands", les ordinateurs qui se louent $1 000 ou plus par mois. Donc, entre 1974 et 1978, le nombre des installations importantes a plus que doublé, passant de 3 897 à 8 251. IBM domine encore le marché mais sa part dans le secteur grosses installations a décliné de 39.1% du total, en 1974, à 22.3% en 1978. Digital Equipment arrive maintenant au second rang, son pourcentage du marché passant de 10.2% en 1974 à 17.7% en 1978.

On ne possède pas de statistiques précises sur les "petits" ordinateurs (ceux qui se louent moins de $1 000 par mois) mais il est certain que les très petits ordinateurs dominent largement le marché en ce qui concerne le nombre d'installations. Il y en avait 8500 en 1976 et Canadian Datasystems prévoit qu'ils seront 36 000, en 1985.



l'effort de mise au point vers le fournisseur plutôt que vers l'usager.

Un certain nombre d'installations industrielles ou de systèmes de démonstration s'orientent vers cette direction et cela vaut la peine d'en mentionner quelques-uns. Cela implique dans chaque cas une série de machines-outils à commande numérique, ou d'autres procédés de protection programmée, alliés à un système programmé de manutention des matériaux, habituellement sous la forme de **robots industriels,** ou de robots industriels fonctionnant avec des convoyeurs, tout cela pour former une cellule de fabrication, ou un système de fabrication très souple.

On peut s'attendre que les robots industriels jouent un rôle important dans de tels systèmes, parce que ce sont des équipements de manutention de matériaux programmables, d'une grande souplesse d'emploi, et qui s'interfacent facilement d'une façon hiérarchique à un ordinateur de commande plus central qui contrôle un sous-système de fabrication.

Exemples de systèmes:

— Le système de fabrication de l'Université de Stuttgart.
— Le système de fabrication de l'Université de Berlin.
— Une ligne de montage pilote automatisée pour la fabrication de petits moteurs, conçue par le Centre R & D de Westinghouse dans le cadre d'une étude de la Fondation nationale des sciences, avec l'aide du SRI international, du laboratoire Charles Stark Draper et du MIT.
— Un système utilisé avec un robot à six bras de Cincinnati Milacron pour fabriquer des pièces compliquées d'un moteur diésel à l'Université de Trondheim en Norvège.
— Un système impliquant une commande numérique directe de quatre machines-outils, un robot et un dispositif de stockage à l'école secondaire technique norvégienne pour la recherche industrielle et technique (NTH-SINTEF) en Norvège.
— La réorientation du programme de la Méthodologie de la fabrication non-humaine (Projet MUM) au Japon, visant à mettre au point une cellule de travail, d'ici 1984, qui fabriquera, usinera, montera et vérifiera les pièces, plutôt que de constituer une usine entièrement automatisée comme prévu antérieurement.
— Un système fourni par Standard — Modern Tool Ltd. à Toronto, avec des robots Unimate et des unités de contrôle programmables Allan-Bradley pour une série d'opérations de la fabrication de rouleaux de fusion des machines à photocopier Xerox.

Les grandes entreprises, et spécialement les constructeurs d'automobiles, seront les premières à mettre au point et à utiliser les systèmes CAD/CAM, car ce sont elles qui sont le plus stimulées au point de vue économique et elles ont les compétences techniques nécessaires pour faire oeuvre de pionnier dans le développement des «maillons manquants» nécessaires à l'intégration des systèmes.

Les entreprises moyennes suivront, surtout si l'on entreprend des «projets collectifs» pour répartir les frais de solution de problèmes communs.

Dans certains cas, **les petites compagnies peuvent déjà utiliser des systèmes CAD ou CAM,** si l'importance de leur production est suffisante. Dans certains cas, on peut également utiliser CAD ou CAM sous contrat de fournisseurs externes, dès qu'ils deviennent disponibles dans l'infrastructure industrielle. Cela est d'ailleurs déjà le cas dans l'industrie électronique pour la conception et le dessin des planches de circuits imprimés pour l'insertion automatisée des composantes des circuits imprimés, ainsi que dans l'industrie de la coupe du métal où les machines-outils sont contrôlées de façon numérique par des bandes elles-mêmes préparées par les ordinateurs d'un fournisseur d'informatique indépendant spécialisé. Cependant, même s'il y a beaucoup d'exceptions à la règle, à cause de leur taille, de leur fragmentation et de la diversité de leur économie, les petites compagnies doivent en général attendre que la nouvelle technologie soit incorporée à l'équipement de production standard, tout à fait au bas de la courbe taille/coût. Ce n'est que lorsqu'un produit de haute technologie devient «courant» qu'une petite entreprise peut en général se permettre de l'utiliser.

A Maintenance Overview of CAM Technology

A special problem posed by CAM is the speed at which it has evolved. This problem grows critical with respect to maintenance. Here's a summary of what is being done in this area at Caterpillar — and what remains to be done to develop a truly effective maintenance capability

RICHARD W. BLANDOW
Superintendent, Electronic Repair
Caterpillar Tractor Co.

THE ROLE OF MAINTENANCE is changing. Management, education, and personnel must be developed to meet the challenges of the 80's. Maintenance philosophies must change. The maintenance organization must be self-sufficient, and it must interact with manufacturing in order to be successful. Just as we now ask production people to understand our technology and our growing pains, we must make an effort to familiarize ourselves with the production process. PM (preventive maintenance), machine-down reporting, floor level repair, service centers and PC board repair facilities must be organized in-house. In-house capabilities are especially necessary in a three-shift operation.

Organization. If PM is to be successful, it must be organized around production schedules. Air filters must be changed to prevent excessive heat buildup within cabinets. Spindle drives and axis drive calibrations should be checked to insure correct feeds and speeds. Machine-down reporting is an option which can provide — manually or automatically — complete details on machine status and history.

Information of this type can provide vital statistics to both production and maintenance supervision. It also can provide time-saving historical information to the repair technician. Production schedules demand that inventories of spare parts be kept on hand. Today's computer technology can be especially beneficial to service departments by recording repair status and inventory status.

Spare Parts. Along with education and test equipment, a supply of spare parts must be available. The rapid advance of the mini- and microcomputer technologies has provided a wide variety of applications for electronics. The expense involved in having spare parts available is substantial, and the cost is amplified with the number of different types of machines. The trend by suppliers seems to be toward a "family of products." This simply means that the same electronic circuit boards would be used in all products, but configured differently. We need this badly, but at the present time each model or generation is different and requires a different set of spares. Spares are also required to support "module swapping," which still remains the number one means for fast repair.

Swapping allows the technician an opportunity to get the production machine back into service rapidly. However, this approach may also cause problems of the following types:

1. Many of the boards swapped out may still be good
2. Bad pin connections may "go away" when the module is swapped, leaving a good board
3. Problems of an intermittent nature may not show up when a module is tested by a repair facility
4. It is difficult, if not impossible, to maintain the "like-new" integrity of a large supply of PC boards.

Accordingly, spare parts are a must in order to alleviate the problem of long delays in getting new modules or in getting modules repaired.

Obsolescence. It is our experience that module availability is also affected by obsolescence of PC boards and the components used on the boards. Obsolescence in this case means that the supplier does not have the modules in stock and special building is required. We have also found that along with a supply of spare parts, we must have an in-house repair facility. In Caterpillar's East Peoria plant, Electronic Repair (ER) has a complete staff of electricians who specialize in the repair of electronic components on three shifts. The word "component" covers a broad range and generally means anything electronic. PC boards, power supplies, counters, timers, gages, and other modules are only a few of the items repaired.

Programmable controllers, computers and computer peripherals are also repaired by this group. A supply of replacement parts such as transistors, IC's (integrated circuits), capacitors, and resistors are stocked in an attempt to repair components as quickly as possible. Benches with power supplies, oscilloscopes, signal generators, digital multimeter and desoldering equipment are provided for repairmen.

Computer systems are now being developed to maintain a rapidly growing inventory of parts. A library of parts manuals, data books which explain component operation, and cross reference charts are necessary to repair the multitude of PC boards. A service center to aid in maintaining the more

popular programmable controllers and peripherals is available. Similarly, computer systems are available to provide means of testing other computers and computer peripherals. Automatic test equipment (ATE) is available to aid in the repair of the more complex PC boards. Staff engineers work closely with ER electricians to pinpoint problem machines in the factory and to resolve repetitive problems. The staff engineers are also available to develop new test routines and diagnostic programs.

Fading Electricians. Maintenance is changing because the technology is changing — and as a result the traditional electrician is rapidly fading from the industrial scene. Unfortunately, educational programs are trailing the real-world applications. Proliferation — a problem in the past — is accelerating with the advance in technology. The solution to this problem is standardization. The alternative is specialization, which ultimately means more people. Software and firmware, an outgrowth of computer technology, are additional maintenance responsibilities. Special and one-of-a-kind machines require special attention. New and additional tools are required to repair machines. Parts supplies must be increased to service the variety of machines. Diagnostic development and use must be encouraged with the maintenance man in mind. We cannot impede progress, but we do need some control. Plant engineering management must be aware of the facts and get involved.

Management at Caterpillar is aware of the facts. New educational programs are being organized to include mini- and microcomputer technologies. New craftsman and operator training seminars are in progress. A specialized staff of electrical and electronic engineers is available for manufacturing support. Spare parts are available and an in-house repair facility has been organized. We are doing our part, but we do have several short and long term needs:

► STANDARD DOCUMENTATION. This is crucial. Standard roadmapping of electronic schematics is required. Components and signal names should be clearly marked on schematics. Standard logic symbology is needed to complement advances in semiconductor chip technology. It is recommended that manufacturers make use of published JIC, EIA and other published standards.

► MANUAL PREPARATION. Machine manuals must be prepared with maintenance personnel in mind. Block diagrams and descriptions are a necessity. Circuits and information flow must be described in detail. Sample signals should be shown along with a discussion. We find that all too often the manuals are vague or written for factory servicemen.

► DETAILED PARTS LISTS. Advances in chip technology and single source components create a demand for detailed parts lists. A cross reference of components should be included when applicable. Truth tables and/or descriptions of special components are necessary. Parts interchangeability is needed to reduce parts inventories.

► SOFTWARE MANUALS. Complete software manuals are needed. Explanations of operating systems and executives are needed. Operating procedures for maintenance diagnostics must be simplified. Examples of operator input and results are helpful.

► INTERFACE STANDARDIZATION. More standardization of control interfaces is required. This will allow use of available terminal readers, printers and intraprocessor communications options. Advances in CAD/CAM can be applied to in-house equipment. Requirements for specialized I/O programming and monitoring equipment should be phased out. All too often, special cables, connectors or PC boards are required in order to use peripheral equipment.

► POWER REQUIREMENTS. New controllers must consume less power. New heat dissipation techniques must be developed to eliminate air conditioning, fans and filters.

► MACHINE DOWN REPORTING. Automatic machine-down reporting capability would be beneficial. Monitoring for speeds, feeds, feed hold, cycle start, and the like is needed to determine machine utilization. ■

— Adapted from "Maintenance Overview of Cam Technology — Today and Tomorrow" by Richard W. Blaudow, Caterpillar Tractor Company. MS78-966.

Computers: A $20 Billion Base by 1983

COMPUTERS HAVE THE POTENTIAL to make the greatest impact on manufacturing since mass production techniques were introduced, says Charles R. Williams, a vice president of Sperry Univac and head of that company's commercial computer marketing activities in the United States.

Manufacturing, Williams notes, is the largest single market for computers in the United States with an installed base valued at about $13 billion compared to $50 billion for all market segments.

Williams claims that the manufacturing market for computers is expected to reach an installed base valued at $20 billion by 1983.

"This growth will provide a new systems market potential of $7 billion and a total potential including replacement systems of approximately $12 million," he adds.

"We see a revolution taking place in computer usage in manufacturing dictated by inflationary pressures on labor costs and interest rates and the need to increase productivity to stay competitive in world markets. Because of this situation," says Williams, "we expect our sales to manufacturing companies to exceed 35% of our total sales by 1982.

"Five years ago," Williams points out, "Sperry Univac made a commitment to dedicate a significant part of the company's resources to providing systems especially tailored to the manufacturing market. To date we have invested approximately $20 million on the Univac Industrial System (UNIS), a special production planning and control software system.

"Moreover, we have invested another $25 million to establish and maintain a dedicated manufacturing marketing organization, staffed with industry specialists, throughout the United States."

Williams notes that this organization consists of branch offices in key industrial centers devoted exclusively to the manufacturing industry. ■

CAD/CAM merges mechanical engineering with computer technology

Significant improvements in quality, production and schedule performance are achievable through the efficient application of CAD/CAM technology

by Jack Scrimgeour and John Nassr

Profitability and productivity are the ultimate consideration for economic survival in the world's marketplaces. The producer of goods must constantly ask himself how he can design and produce a better product.

Design and manufacturing engineers are realizing that significant improvements in quality, production and schedule performance are achievable through the efficient application of CAD/CAM (computer-aided design and computer-aided manufacturing) technology. Management and technical personnel are faced more with the question of "How do we apply it?" rather than "Should we apply it?"

Application of CAD/CAM technology is expected to have a widespread and significant impact on manufacturing industries throughout the world's major industrial sections. Because of this, there is an increasing sense of urgency in Canada to get involved in order to improve our competitiveness in the marketplace.

Advances in computer technology

Because the computer is the heart of virtually all CAD/CAM systems, it is worthwhile to briefly examine the technological advances that have made such systems possible. However, it should be clearly established that in CAD/CAM systems the computer is basically an available tool. Much of the technology used in CAD/CAM applications, and which must be further developed, is of a systems, mechanical and manufacturing engineering nature. A great deal of this technology needs to be and is being developed "in-house" by the user. It would be a mistake to consider "CAD/CAM" as a product developed and supplied solely, or even primarily, by the electronics industry.

Basically it is the continued improvement in the performance/cost ratio of available computers that makes applications like CAD/CAM possible. This in turn is possible primarily because of the continued miniaturization of logic and memory devices, embodied today in the term "micro-electronics", and typified by the ubiquitous and pervasive microprocessor.

At the user level improvements in the price/performance ratio of computers, or the cost/calculation, are difficult to track over the variety of problem types and computer architectures available to the user, but have kept improving every year by a factor of about 32% for memory costs, 23% for logic and 11% for communications.

Improvements of 10 to 1 (or more) every ten years mean that a calculation costing $1000 in the early days of computing would cost only $10 in 1972. On this basis the same calculation will cost only $1 in 1982 and 10 cents in 1992. Economic changes such as this keep opening up new applications as long as the organization and development of applications know-how and the "people cost" of programming can keep up. For example, the expenditure by U.S. manufacturing industries on computer graphics equipment, software and services is projected by a leading market research firm to grow at a 22% annual rate, increasing from $251 million in 1977 to $316 million in 1978 and $1.5 billion in 1986.

Yearly improvements in cost and performance of computers, coupled with an expanding awareness of their capability, have made possible a continual supply of new application areas. Figure 1 illustrates this constantly-expanding base and scope.

CAD/CAM awareness

Recognizing that awareness of technological change and economic justification of new production technologies are key factors in the industrial process, the Department of Industry Trade and Commerce established in 1978 a CAD/CAM Technology Advancement Council. This is an industry/academic/government body with membership primarily from industry and objectives focused primarily towards users in industry.

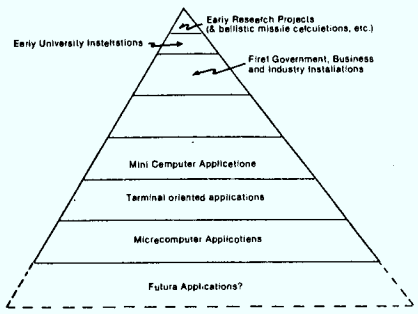


Figure 1: The expanding base of computer applications.

Mr Scrimgeour is a Consultant with the federal Department of Industry, Trade & Commerce's Technology Branch. Mr. Nassr is President, Canadian Advanced Production Consultants Ltd., Montreal. Both are members of the CAD/CAM Technology Advancement Council. This paper was presented to the Second Annual Conference of the Canadian Society for Mechanical Engineering, May 31-June 1 in Sherbrooke, Quebec.

TABLE 1

Summary of CAD/CAM application areas

Computer Aided Design
Product design and analysis including graphic design, functional analysis, stress strain analysis, heat and material balances, simulation and modelling, data reduction and analysis and cost estimating of the proposed product or system to determine fitness of purpose and economically optimized production.

Customer Order Handling
Record keeping, tracking and reporting on the status of individual customer orders, particularly when part of an integrated on-line system.

Production, Material & Inventory Control
Scheduling and information handling pertaining to material requirements planning, inventory control, facilities planning and order scheduling, particularly when related to an intergrated on-line system.

Automated Production
Numerical and computer control of machine tools, lathes, milling, boring machines, pattern and fabric cutting, welding, brazing, plating, flow soldering, casting, flame cuttting, spray painting (all of these exist and are under further development).

Automated Material Handling
Integrated materials handling using computer operated conveyors, robotic units, etc.

Automated Testing
Automated inspection of machined parts, testing of electronic components, circuits and products, automated material inspection and grading using sensor based computer systems, pattern recognition.

Automated Packaging
Computer implemented coordination of material and information in packaging, bottling, labelling and weighing systems.

Automated Warehousing
Computer implemented order picking and material handling for both work in progress inventory and finished goods inventory. Automatic label reading, routing of packages, parcels, baggage in shipping, sorting and distribution centers.

Notes:
CAD/CAM technology will yield its greatest economic and productivity gains when all or most of the above application areas are married or joined together to form an integrated system. Hence there is a strong development trend in this direction.

The council will from time to time disseminate CAD/CAM information of a general nature. This will include papers on CAD/CAM usage in Canada and other countries, including case histories of specific applications, listings of supplier capabilities in Canada and current information on worldwide CAD/CAM activities.

The main channels for making this information available will normally be through established journals and trade publications rather than by direct mailing, and through co-sponsorship of conferences and seminars.

Two publications on CAD/CAM, prepared prior to the council's formation are already available at no charge from Publication Distrubution, Department of Industry, Trade and Commerce, Ottawa K1A 0H5. The first, entitled "CAD/CAM and Canada" is a reprint of articles on CAD/CAM applications in Canada. The second, "Computer Aided Design and Manufacturing in Canada" is a directory of Canadian firms and organizations supplying CAD/CAM applications, with emphasis on economic justification. This publication will continue to appear as appropriate material becomes available, primarily in journals and eventually also in collected reprint form. Contributions from authors for this series are welcome.

Journals currently participating in the CAD/CAM series of papers are: *Canadian Machinery and Metalworking, Canadian Data Systems, Canadian Controls + Instruments, Materials Management and Distribution, Design Engineering,* and *Engineering Digest*. The review of such publications and involvement in professional society activities will help keep management, engineering and manufacturing personnel aware of the significant aspects of CAD/CAM technologies.

Small companies, however, find it difficult to foresee or forecast the extent of CAD/CAM applications in related industries, or more significantly, the degree to which such applications may be efficiently utilized in their own operations. Many of these cannot be expected to be aware of the industry trends as a whole or to recognize the impact of breakthroughs achieved in the suppliers' technology. Hence, a dramatic "CAD/CAM revolution" could be taking place even though many potential users are unaware of it.

Only those very close to leading edge installations may be in a good position to anticipate and predict the trend. One should take note, therefore, of the statement by the president of General Motors, E.M. Estes: "I think it is fairly safe to say that within 10 years computers will control about 90% of all the new machines in G.M.'s manufacturing and assembly plants.[3] One of the subtleties associated with such a pervasive technology, with such diversity of applications, and with contributing developments taking place and in motion in so many separate places, is that it is easy to think that not much is happening, when in fact a tidal wave of change is approaching. The "fully automatic factory" may be only a concept or may only be realized in a few special cases. However, on a narrower front the marriage of computer-operated production equipment with computer programmed industrial robots, manufacturing cells or "flexible manufacturing systems" could become a widespread reality in the very near future.[4,5]

Factories of the future

For years engineers have been using computers in product design functions. Many are familiar with the applications and benefits derived from use of the computer in areas listed in Table 1, but few use or have had much exposure to graphic systems. Simply stated, graphics

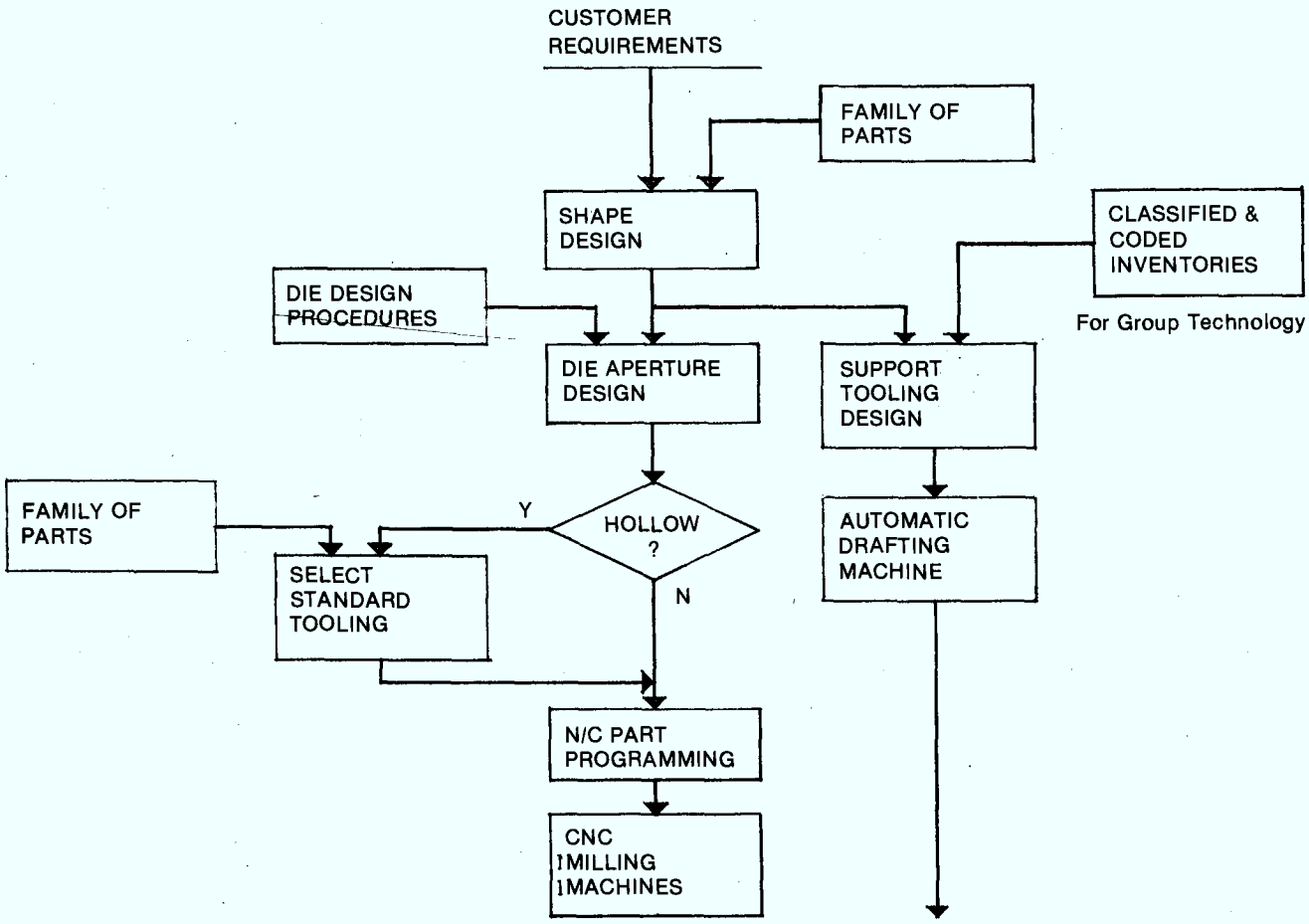


Figure 2: CAD/CAM in extrusion die production.

involves the establishment of lines, circles, curves, etc., selection of design element and dimensioning standards by means of an interactive computer system. The resulting pictures can be stored, hard copied, recalled for change or reviewed by anyone having access to the system.

Such graphic packages are available in mini and maxi versions and cater to a wide range of design complexities. They can be interfaced to function with many other systems related to other activities in the organization such as machined parts programming and the direct operation of N/C machines to fabricate the parts.

Such a capability is not hypothetical; in fact, we have many examples in Canada where some significant thrusts have been made in this direction. One such system, in operation for about two years, involves the design and programming for manufacture of EDM electrodes used for cutting die apertures for aluminum extrusion production. This represents a merger of both design and manufacturing functions and is made possible by the use of computers. Figure 2 outlines the essential elements of the system. It is more fully described in Reference 6.

The introduction of such a system for other or more complex applications may appear to be an awesome task both technically and financially. Because of this, most companies aware of CAD/CAM technology should approach the application from both the CAD and CAM directions. By establishing an integrated plan with common operational time-phased objectives, companies can introduce CAD/CAM technology without the trauma so often associated with the introduction of a new technology.

Nowhere has this been more visible than in the installation of numerical control equipment. Less than 10 years ago, there were two N/C camps in Canada—those for and those against. Today it's hard to find a discouraging word. Because the present number of installations represents only a small fraction of the potential, first-time users can be expected to enter the "for" camp in ever-increasing rates. The success of their installations will depend heavily on the equipment specified and the ease with which organizational and functional changes and additions can be implemented.

In the centre of the implementation activities required for successful N/C operations is the mechanical engineer. His initial task is usually machine/control specifications and selection. For an N/C machine with a CNC control the engineer must consider a wide variety of system options with which he may be unfamiliar.

Selection will be based upon such major factors as the type of parts to be machined, batch sizes, complexity, programming requirements and techniques and interface functions involved.

Handled with care, production status from the first installation of an N/C machine can be achieved quickly, smoothly and profitably. The engineer soon finds that he is evaluating, specifying and justifying (with much less trouble) the second machine, as well as in-house versus time-shared computer-aided programming systems, terminals and a host of other improvements which may be purchased and/or developed in-house. In a multi-machine environment he soon realizes that the industrial robot with microprocessor control could be in-

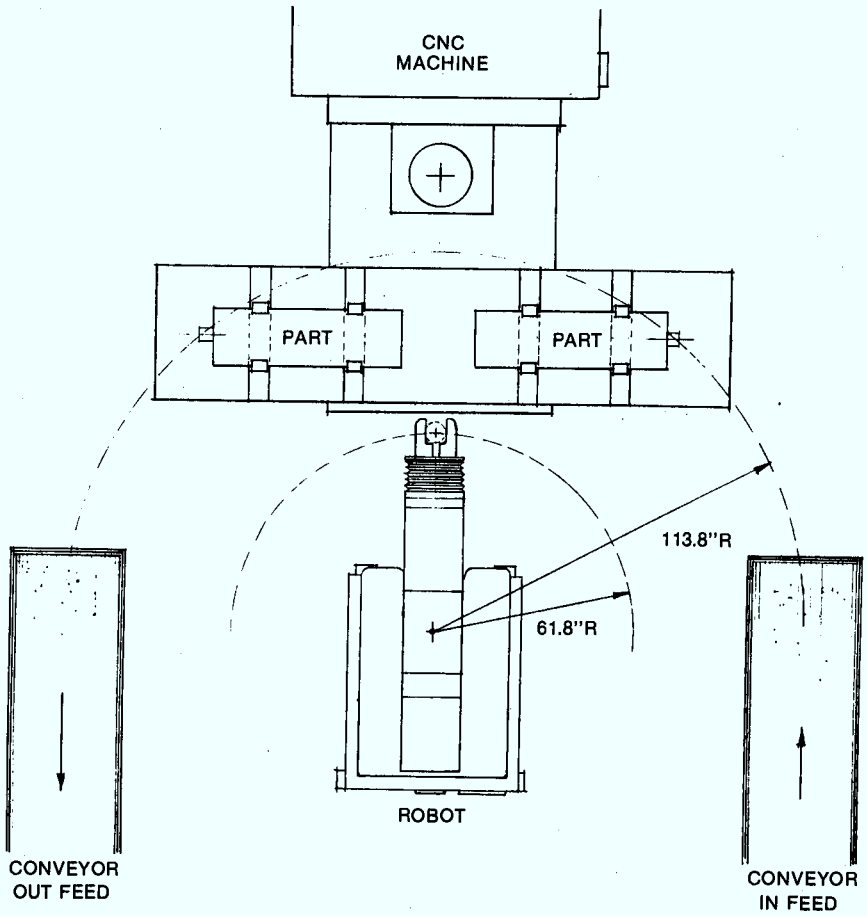


Figure 3

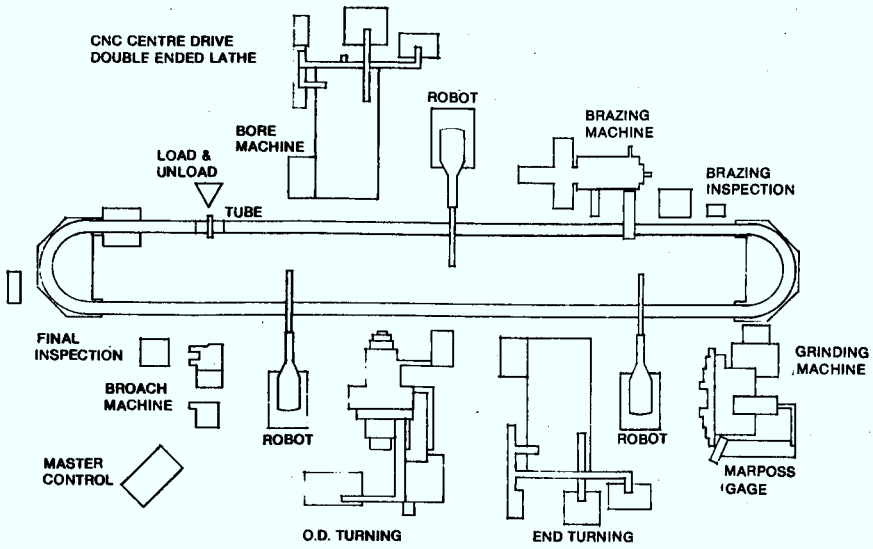


Figure 4

tegrated with the N/C equipment and programmed to handle parts or functions which may be hazardous or monotonous. Perhaps an automatic parts handling or raw material handling system is called for.

Traditional insitutions such as the Canadian railways already have such systems and some have been operating for several years.[7] Figure 3 illustrates one such system. Further expansion might be the inclusion of an automatic inspection station or other equipment where a higher level of integration of hardware and computer control or software is needed. Figure 4 illustrates one such Canadian designed and manufactured system.[8] This has been in operation (in the U.S.) for about two years. This integrated computer-aided manufacturing cell was designed against specific requirements to manufacture fuser rolls for the photocopier industry. Within the mechanical limits of the machines, different parts could be produced by changing the control software. Hence, the concept of a flexible manufacturing system is illustrated. In the development of such a cell, the engineer found it necessary to work with software development specialists within his own organization as well as outside consulting specialists to effect such a high level of integration.[9]

Having reaped the rewards of this manufacturing cell, management asks the engineer (or vice-versa) to begin to plan for additional cells which will ultimately be tied together by other material handling systems. During operation of the cell or group of cells, updated status is continually fed back to a computer base of information to allow real time analysis and optimization of functions to occur.

Such integrated computer-aided manufacturing (ICAM) operations will include all "aspects of control, machinery and manpower economics, raw material procurement and stocking, materials handling, parts fabrications and product assembly, finished product inventorying and shipping, and all the other auxiliary functions which would be merged into an integrated system".[10]

The diagrams shown represent real operating CAM systems and CAD/CAM systems involving Canadian manufacturing enterprise with Canadian engineering, system programming and manufacturing expertise. They represent only a small percentage of the potential applications that could be in use in Canadian industry today.

CAD/CAM is expected to have a widespread impact on the Canadian manufacturing industry spread across many sectors as follows.[11] These

estimates have been arrived at by considering jointly the economic contribution of each sector to the total GNP, and the probable impact of CAD/CAM technology on that sector.

		% of total impact
Manufacturing Industries		49.1
Transportation Equipment	8.3	
Metal fabricating industries	7.6	
Electrical products industries	4.6	
Food and beverage industries	5.2	
Primary metals industries	4.8	
Paper and allied industries	3.0	
Printing, publishing & allied industries	2.7	
Leather, textile, knitting, clothing	3.7	
Other manufacturing industries	9.9	
Construction Industry		8.4
Transportation		11.0
Wholesale Trade		10.9
Retail Trade		5.5
Public Administration and Defence		6.0
All other, not specifically identified above		9.1
Total		**100%**

It will be noted that the above figures give estimates for the relative impact of CAD/CAM technology on major sectors of the economy, but do not estimate the magnitude of the impact in absolute terms. This is much more difficult to estimate. It has been the subject of a major study in the U.S.[12] and has been the subject of much discussion and debate in other countries, most notably the U.K.[13–18] One writer, highly familiar with the U.K. evaluations, sees the Canadian manufacturing industry as being particularly vulnerable to the negative effects of the micro-electronics revolution unless strong and immediate measures are taken to adopt this technology.[19]

A senior computer industry executive in the U.S. cites the computer as a vital factor in productivity improvement and estimates that over the last decade computer usage has provided at least 15% of the 2% annual growth in productivity in the U.S.A. He further estimates that this can be improved even further due to new computer price/performance ratios being achieved and that an incremental percentage point improvement in productivity achieved in this way could sufficiently accelerate economic growth in the U.S. to drive unemployment down to 3.4% by 1990.[20]

The Canadian engineer who is currently involved in such activities will likely live to see even further integration of both hardware and software technology to help make possible the productivity gains needed to keep the Canadian manufacturing industry competitive.

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Help needed for Canada's secondary manufacturing industry

New technologies are available to improve output in many different production situations. Among these is the development of robot recognition systems

by D.R. Strong

Canada's secondary manufacturing industry needs help. The same goods that we produce in medium volume are produced more efficiently in high volume by larger first-world countries or by labour-intensive operations in non-industrialized countries. It is becoming increasingly difficult to compete.

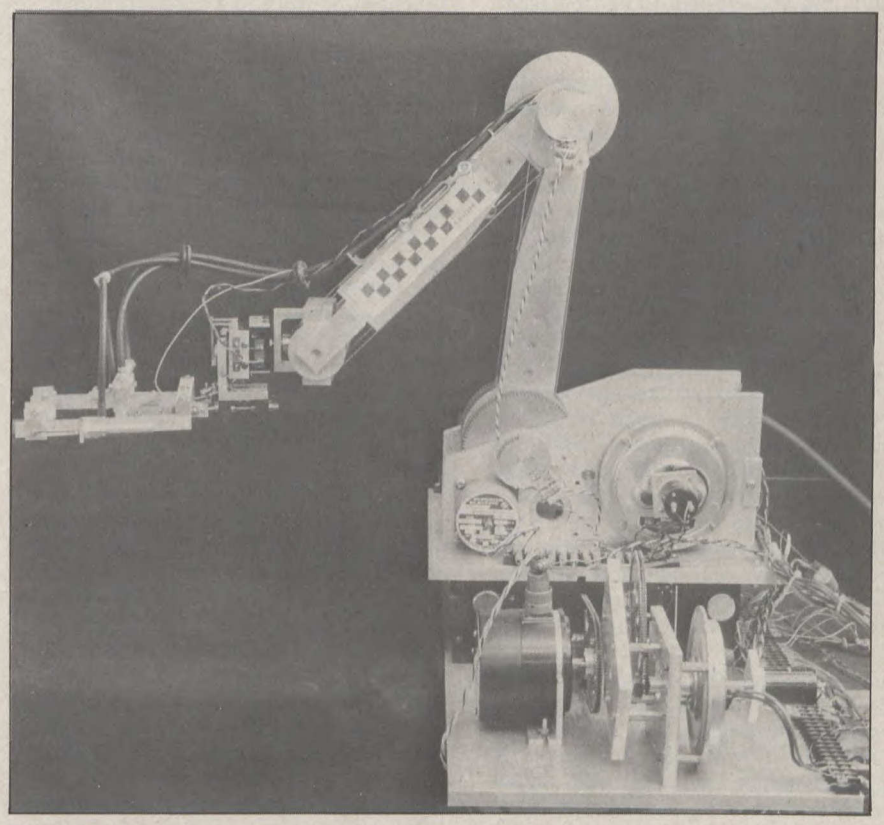
New technologies are now available to improve output in many different production situations. For Canadian manufacturers, one of the most significant of these is a technology specifically designed to improve productivity in medium- and mixed-volume manufacturing operations. The cornerstone of this technology is the new third-generation microcomputer, available since mid-1978, which replaces the much larger and more expensive standard minicomputer. The new microcomputer provides powerful machine intelligence, and combined with the latest techniques in electro-mechanics, electro-optics, hydraulics and new materials, machines and processes are being created which will change our entire approach to manufacturing.

Almost every first-world country is now involved in significant programs to develop machine intelligence that will improve manufacturing productivity. Because Canada's manufacturing volume is small and we have few free trade alignments, we must work with great urgency to develop the newest medium-volume manufacturing technologies, and then help manufacturers make the best possible use of these developments. This area of technology, flexible automated manufacturing (FAM), is associated with other names and processes such as computer-assisted manufacturing (CAM), deskilling, versatile plastics, robotics, programmable machines controllers, power tools, NC mills and latches, and modular systems and machines. These all refer to technologies which are making medium volume manufacturing more cost effective.

Some process assistants, like power tools, have been used successfully for many years. Others, like computer-assisted manufacturing and robotics, are much more recent in development and use.

Robotics and FAM

The aim of flexible automated manufacturing is to use machine and other technologies so that medium-volume



The Robot Arm/Vision System (ARVIS) is capable of performing pick-and-place activities and recognition functions.

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production can approach the cost-effectiveness of high volume production. Costs could be reduced by increasing the output per man hour, reducing required production skill levels, performing operations which can not now be performed in medium volumes, remove or reduce the effect of hazardous environments, and improve product consistency to reduce the quantity of rejects.

Presently the most important area of flexible automated manufacturing is robotics, because robots perform jobs never before performed by machines. The general aim of the robot arm is to do what the human does in about the same way that the human does it. A minimum industrial robot is an automatically controlled arm which has a grappling mechanism or hand. A more versatile and useful model would have some sensing capability such as touch, compliance or vision.

With the availability of such machine intelligence, automation is no longer associated with single function machines which require high-volume manufacturing to be cost-effective. These new intelligent automated machines are characterized by their flexibility and are truly multi-function units. Not only can they perform a variety of production operations, but they can economically produce at medium volume. Their flexibility also allows them to be "plugged-in" to many manufacturing operations which are now labour-intensive.

As with many new technologies, the implications of the developing robotics technology are far reaching and not yet fully understood. At present the majority of robots are placed in the auto industry, performing such tasks as painting, welding and materials handling. No touch or vision capabilities are required and human are relieved from working in unpleasant and hazardous environments. Studies of the 6000 operational robots in industrial use reveal a pattern of positive acceptance and increased efficiency. A recent West Germany report estimated that two to three percent of the industrial work places could be suitably filled by the present robots. Of even more significance, the same report suggests that with the availability of sensing robots—robots which see and feel or recognize—up to 30% of all work places in industry could be taken over by robots.

Despite massive support of foreign electronics industries by their governments ($500 million/year in the U.S., $300 million/year in Japan, $150 million/year in Germany, $126 million in 1978-79 in U.K.) no country is yet marketing an industrial robot system which has sensory capabilities. To date, energies have been put into developing motion control, accuracy and set-up programs. Having accomplished this, technical development is now centered on developing machines which see, feel or recognize. It is known that recognition systems are being developed in the U.S.A. by Stanford Research Institute, the Illinois Institute of Technology and General Motors and in Japan by, among others, Mitsubishi, Hitasi, Kawasaki and Toyko Institute for Technology. What is not widely known, is that Canada too is developing a robot recognition system. It is the Robot Arm/Vision System (ARVIS) by Leigh Instruments (Fig 1 and 2).

The present breadboard model, developed with the assistance of a National Research Council IRAP grant, is capable of performing pick-and-place activities and recognition functions. It has force sensors, compliance and a vision system.

The production model of the Arm Vision System will be capable of performing a variety of assembly operations in a manufacturing environment. It will be an electromechanical system with vision, force and position sensors. Design features will include ease of set-up, reliability and versatility of job applications. The robot ARVIS will typically perform batch-type manufacturing functions or work in a production line.

Benchmark operation sequence

The following test describes a typical manufacturing operation sequence that demonstrates the effectiveness of the automated system. The sequence involves the pressing of a metal cylinder into a prepunched square metal plate.

Manual sequence operation. In the manual operation, the operator places the cylinder onto the bottom plate of a press and places the square metal piece on top of it. He then operates the press, which presses the square piece down over the cylinder. The pieces are joined with a friction fit. The operator then removes the assembly and places it in a pile.

Automated sequence operation. In the machine operation, the cylinders are put into a rotary vibrating table which moves the pieces to an output point. The square metal pieces are placed in a stack. A tunnel jig to receive the cylinders is fixed to the table of the press and a stack of cookie trays is placed beside the press. The sequences begins as the hand-arm picks up the cylinder from the vibrator table output and places it into the jig. A square plate is taken from the stack and is held under a camera where its orientation and position are determined. It is then positioned on top of the cylinder. The arm moves away from the press, which closes, joining the metal pieces together. As the press opens, the arm picks up the assembly, turns it upright, so that the square piece is on the bottom, then places it on the cookie tray. It performs this operation repeatedly, each time placing the finished piece in an organized fashion on the cookie tray. When the cookie tray is filled, the arm picks up an empty cookie tray from the stack, places it over the filler tray and continues the operation.

The arm replaces the operator in the assembly operation and organizes the assembled pieces in a way that allows them to be easily handled automatically in a later operation. It is evident that the assembly job could be automatic using standard automation techniques, but if volume is too small to justify the automation, then the Robot ARVIS with its ease of set-up could be a cost-effective solution. Because machine vision can be used, it is possible to present parts from a very poorly organized area and place them in the production operation with reasonable accuracy.

It should also be noted that this operation is presently being done by hand. It is a tedious, boring operation that does not require human intelligence or dexterity and is the type of job that very few people would miss.

Production model

A production system capable of performing such robotic operations will comprise a machine vision subsystem, a hand/arm subsystem and a microcomputer. In so far as it is possible to anticipate the demands on these subsystems, the following descriptions are suggested:

The hand/arm subsystem will allow six axes of freedom capable of moving the end effecter in the X, Y, & Z dimensions and the roll, pitch and yaw orientations. By placing a compliance system between the wrist and the end effecter, the end effecter can align itself to jig points or end stops. Current state of the art and market information indicate that such a system will move at a rate of about 1 m/second, carry up to 2 Kg and stop with an accuracy of about 1 mm. Versatility will be increased by interchangeable end effecters of various job-related designs. The end effecters will move within a volume approximately 0.5m in width, 0.5m in height and 1m in length.

The vision system sees an object as a two dimensional image typically dark on a light background. The system receives information through an imaging system, either solid state or vidicon-type video camera. The signal is preprocessed in

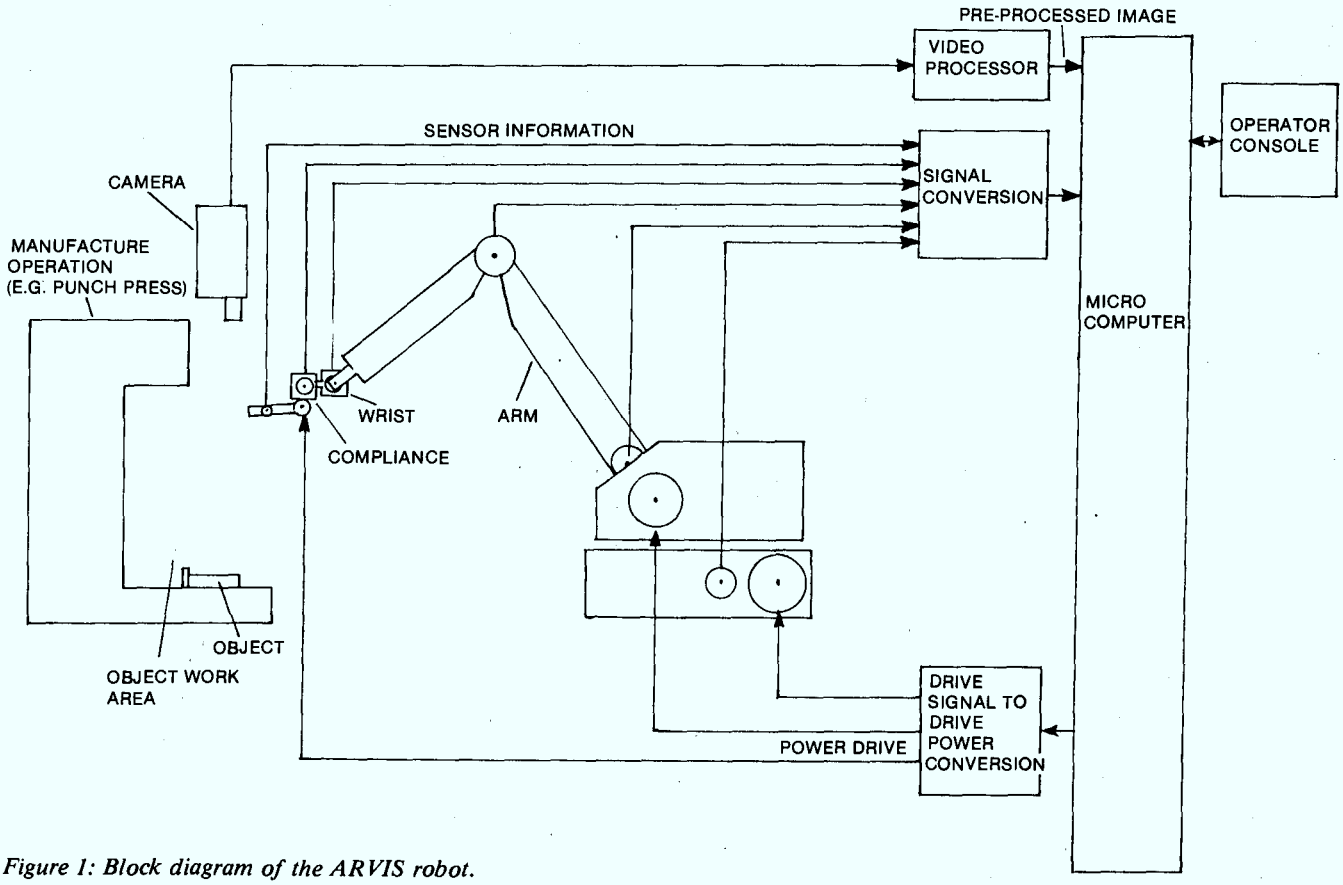

Figure 1: Block diagram of the ARVIS robot.

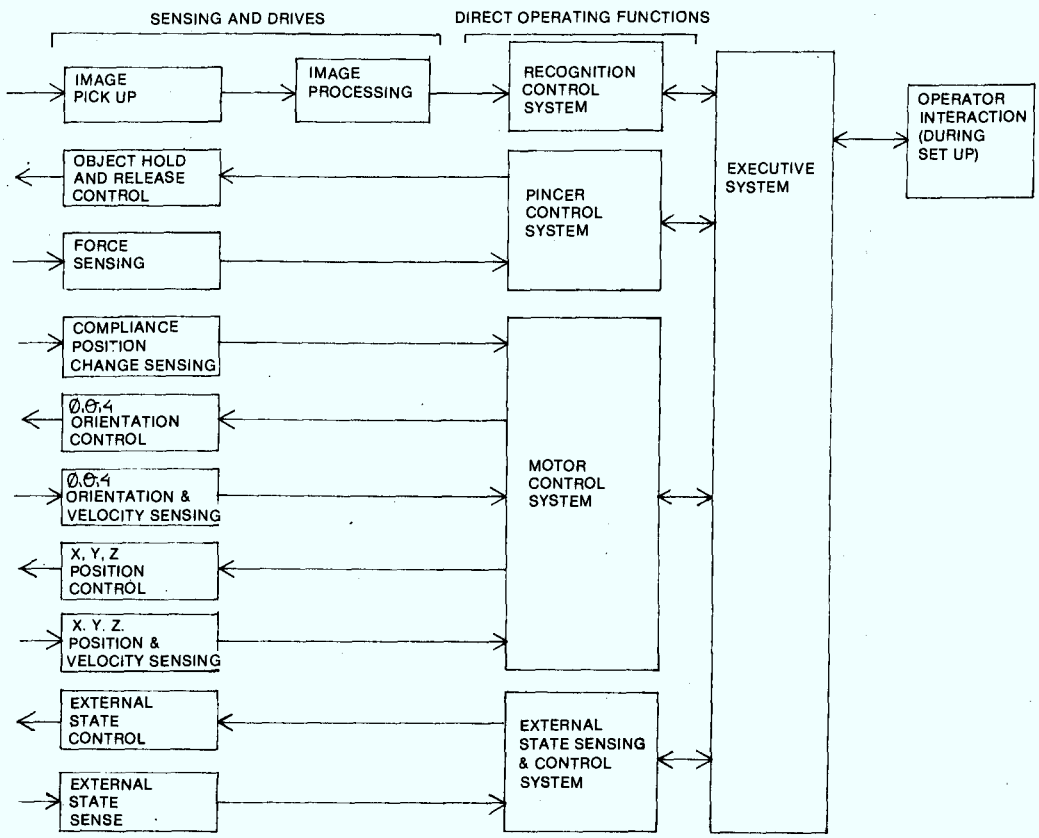

Figure 2: Robot ARVIS functional block diagram.

real time in electronic hardware and sent to microcomputer. A production model would recognize a single object, similar objects in a stack or similar objects randomly overlapped. A cursory market survey suggests that the system would have to recognize a wide variety of objects within an accuracy of ±1mm and orientation to within ±2°.

The micro computer system performs four main operating functions: pattern recognition, pincer control, motion control and external state control. These operating funcitons are coordinated and controlled by the executive control function. The operating functions continuously monitor and control their related sensors and drive functions. The executive control, using stored operating sequence information and information from the operating functions, controls the system during the run time. During set-up and while in the learning mode it assists the operator in establishing new sequences.

Ease of set-up will have to be a prime design concern to ensure that the full potential of the prodution system is exploited. Ideally, a semi-skilled operator would guide the machine (in learn mode) through a sequence, and the movements would be recorded. The system would then faithfully repeat the sequence. In general, to be competitive, the system must function effectively in an industrial environment and be maintainable by regular plant staff. It must be conveniently mobile so that it can be moved from operation to operation within the plant.

Typical uses

The Leigh ARVIS will be suitable for jobs related to lifting an object from a stack, a moving belt or a semi-orderly array, and placing the object into a manufacturing operation such as a press, a punch, or a gluing machine. The system will also stack objects, arrange or align them, and will guide them through a cutting or stitching operation. Both rigid and semi-flexible materials can be handled. Metal, plastic, leather, canvas and thick film are all within its handling capability. Objects such as shoe parts and speaker components are typical examples.

FAM in Canada

Developing a robot of this type in Canada will have particular significance. Our Canadian manufacturers need robot systems intelligent and flexible enough to perform a wide variety of tasks so that a single robot system can be put into various medium volume assembly lines and perform a different task in each situation.

The Arm/Vision System is being developed specifically to meet the needs of medium- and mixed-volume producers. This type of machine will launch Canada into the field of flexible automated manufacturing and provide such benefits as increased productivity, increased efficiency and lively market possibilities for the system. FAM offers another very special business opportunity—that of reducing our need for centralized manufacturing.

As flexible automation progresses, certain products will be almost as inexpensive to produce in medium volume as in high volume. The concept of one or two large, high-volume plants distributing nationally and internationally will give way to many, medium-volume plants producing for local markets. The potential business prospects for licensing and franching will be very interesting indeed.

Canada stands to benefit from an early entry into the flexible Automated Manufacturing Technology in four ways:

- Assistance to medium-volume manufacturers, supplying Canadian markets and competing with high volume and labour intensive imports. These firms will see the most dramatic benefits from flexible automation techniques. FAM can make their production more efficient, reversing the failure or low profit pattern of such companies and helping maintain jobs and money in Canada.
- Assistance to medium volume manufacturers supplying world markets with medium and high technology products. A significant effort in automating this sector will keep Canada competitive with first-world producers. For her economic size, Canada could carve out a very significant slice of this market if automation is introduced with an integrated and strategically planned policies.
- New product areas will be created from the system technology. The robots, computers, systems, hardware, software and consultant services are only a few of the new products and business areas that will be generated as automation progresses. Careful development of our marketing policies should ensure that we maintain a competitive edge for Canadian users while at the same time making good products available to foreign buyers.
- New distribution patterns and business possibilities will arise as medium volume production approaches the economies of high production. Licensing and franchising are two lucrative marketing formulas foreseen as the economies of FAM develop. Manufacturers will have the option to decentralize their manufacturing functions while centralizing their design, advertising and management functions. Such a structure would lend itself to exporting technology while retaining management control in Canada.

It is essential that Canada establish a position in the field of sensory robot technology so that the benefits of the technology will be available in Canada rather than remaining with our foreign competitors. With flexible automated manufacturing applied strategically and with the sophistication it demands, more and more products will become cost-effective in medium volume. The pressure from high-volume and labour-intensive imports will decrease. Canadian manufacturers will more confidently address the challenge of manufacturing today's products and the products of the future.

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Manufacturing engineering teaching and research at McMaster University: a decade of development

The Metalworking Research and Design Group and the Canadian Institute of Metalworking are two facets of an extensive manufacturing engineering focus at McMaster

by Dr. J. Tlusty

At McMaster University the importance of advanced manufacturing engineering has been recognized since 1970 when a strong team in the Mechanical Engineering Department developed post-graduate courses and research in various areas of production engineering.

About two dozen individuals formed the original Metalworking Research Group—one materials science professor, four mechanical engineering professors, five post doctoral research associates and about twelve M.Eng. and Ph.D. students. The Group obtained a substantial development grant from the National Research Council to execute a research program concentrating on metal forming, metal cutting and machine tools, and within a period of three years established well-equipped laboratories with up-to-date machines and instrumentation.

At about the same time the Department of Industry, Trade and Commerce helped fund the establishment at McMaster of the Canadian Institute of Metalworking, primarily as a facility for the development of numerical control in machining. The Institute's activities consist of NC maching development projects for industry and the training of industrial groups to recognize first the need and then the planning of NC, along with instruction in the programming and maintenance of equipment. In addition, the Institute has undertaken various projects for increased productivity in the manufacturing industries.

Since then establishment activities have further developed, both in the Metalworking Research Group—concentrating on teaching and research—and in the Canadian Institute of Metalworking—concentrating on development and applications. Not only have M.Eng. and Ph.D. theses been produced on a variety of special topics in the general field of manufacturing, but extensive activities have been carried out in contractural industrial research. To date a total of 135 MWRG Research Reports have been written, most of them describing various industrial research projects.

A decade of research

Three original members of the Group—Dr. J.L. Duncan, Dr. J.D. Embury and Dr. R. Sowerby—are still engaged in metal forming research. Their work deals with the experimental and mathematical modelling of metal forming processes; both the process variables and material variables are coupled in an attempt to assess the useful limits of formability of materials and the corresponding forming loads and deformation modes.

Dr. M.C. deMalherbe, also a founding member of the Group, was most active in supervision of graduate students on a wide range of topics related to production engineering. He has since left to become Dean of Engineering at Carleton where he is busily engaged in developing research projects in the area of powder metallurgy.

Dr. I. Yellowley spent a very fruitful period with the MWRG and devoted his time to computer-aided plant layout, cost estimating, process planning and scheduling. While he now continues his industrial engineering activities in a large company in Hamilton, he remains in close contact with the MWRG.

Dr. H. ElMaraghy, who joined the manufacturing group in 1978, is carrying out research in the area of computer-aided manufacturing and integrated CAD/CAM systems. Her current research activities include the use of computer graphics in numerical control part programming, plant layout, geometric modelling and automated drafting.

Dr. J. Tlusty has been active in studies of tool wear, machinability of materials, chatter in machining and structural dynamics, and numerical and adaptive control. When he found a common interest with colleagues active in computer-aided design, the group was renamed the Metalworking Research and Design Group (MWRDG). Dr. M.A. Dokainish, J.N. Siddall and R.W. Newcombe joined to practice a combination of CAD/CAM. The group's interest has extended into robotics, automation of assemblies and inspection, and this has resulted in the group being joined by four electrical engineering professors with specialization in digital controls: Drs. C. Campbell, C.

Dr. Tlusty is a Professor in the Department of Mechanical Engineering at McMaster University, Hamilton.

Carter, R. Kitai and N. Sinha. The group intends to exercise the use of microprocessors in the control of machine tools, robots and inspection devices.

Thus, at the end of the first decade, the research activities in manufacturing at McMaster are not only on-going but are continuing to expand in scope. Basic courses are taught in manufacturing engineering and industrial engineering and advanced courses in metal cutting, machine tools, metal forming, computer-aided manufacturing in mechanical engineering. An additional step has been the introduction of a program leading to a Bachelor's degree in manufacturing engineering. This program, which starts in the fall of 1979, is based on the courses mentioned above as well as on newly developed courses in design for manufacturing, individual projects in manufacturing and manufacturing laboratories.

Under the guidance of C.E. Crozier, the Canadian Institutue of Metalworking has steadily increased its volume of activities and has been very successful, both in its impact on industry and in its ability to generate income. In addition, the interaction between the faculty teaching and research and CIM is constantly increasing.

The McMaster groups have also received international recognition. Two of the professors are members of the prestigious International Institution for Production Engineering Research (CIRP). The annual North American Metalworking Research Conference (in its seventh year) started at McMaster. One member of the team has been awarded the 1979 Society of Manufacturing Engineers Gold Metal.

Research projects

Research activities at McMaster are diverse.

Metrology of NC machine tools, especially large ones, has been systematically developed. A system of basic measurements which makes extensive use of laser interferometry was derived to relate errors in straightness, positioning, pitch, yaw and roll of individual coordinate motions to the workpiece accuracy in the whole working zone, including thermal effects. This work is at the forefront of activities concentrating on accuracy of machining, together with the work of the Lawrence Livermore Laboratory and of the National Bureau of Standards. Companies using this technology include Canadair, G.E. Scarborough, Dominion Engineering, Stelco, and Westinghouse T&G (Figure 1).

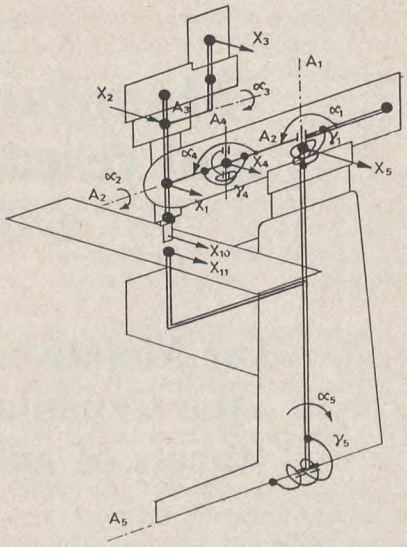


Figure 2: A model of a milling machine abstracted from dynamic tests for the purpose of computation of design changes.

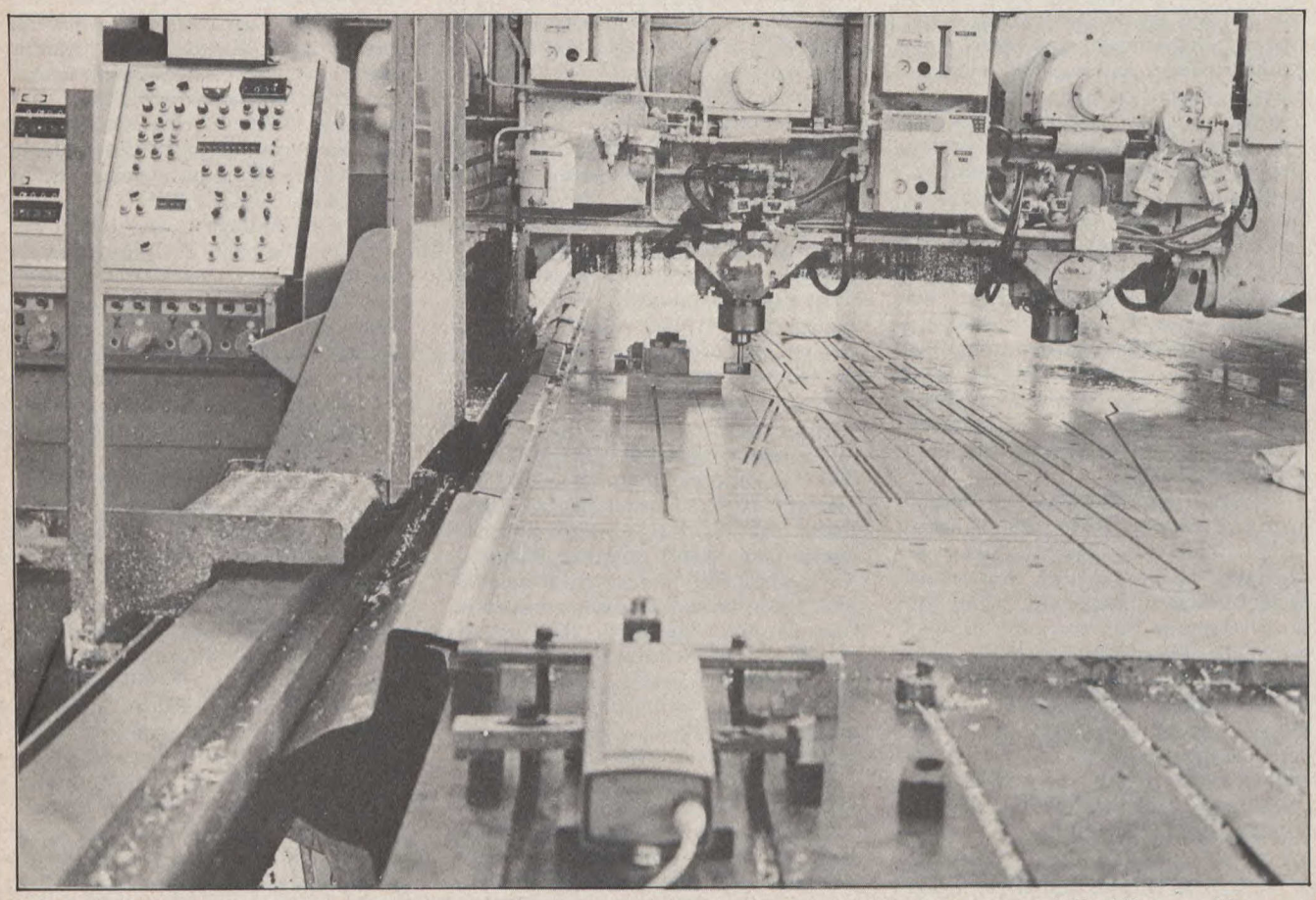


Figure 1: Laser (in the front) interferometer used in the analysis of accuracy of a five axis gantry type NC milling machine.

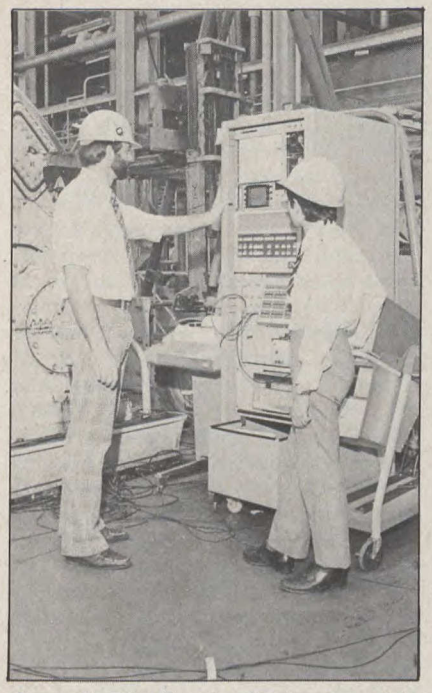


Figure 3: The Fourier Analyzer used in dynamic measurements of a turboelectric generator.

Chatter in machining, structural dynamics. This work concentrates on improvement of experimental methods using the minicomputer-based Fourier Analyzer and on using the experimental data for the identification of a computational lumped mass model for optimizing structural design changes. This is applied primarily to machine tool structures (Figure 2), but also to other machines (Figure 3). In addition, research of the dynamic cutting force coefficient is being carried out for determining the effects of cutting conditions on chatter.

Tool chipping and breakage. Experimental and computational analysis is carried out of chip formation and corresponding loads on the tool both in continous and interruped cutting. Mechanical and thermal stresses are included. This research should lead to improvements in selection of tool grades, cutting conditions and geometry of the cutting edge. Special emphasis is given to stress distribution at the exit of the tool from the cut (Figure 4).

Numerical control and adaptive control. A home-made retrofit of a milling machine for NC was a useful exercise for students as was the development of corresponding software for CNC and adaptive control where the strategy is to control the cutting force in die sinking by champing feed rate. Research concentrated on the fast entry of the cutter into a wall or a corner.

Sheet metal formability studies. Experimental and theoretical investigation tried to assess the useful limits of formability (i.e. prior to wrinkling, necking or tearing) of sheet materials under a variety of stretch forming and deep drawing deformation models (Figure 5).

Bauschinger effect in plate fabrication processes. MWRDG is developing mathematical models of the Bauschinger effect in fabrication processes which are subject to strain reversals (e.g. certain pipe-making operations). The approach has been to employ a combination of continuum and microscopic models to describe the Bauschinger phenomenon and to correlate the models with observ-

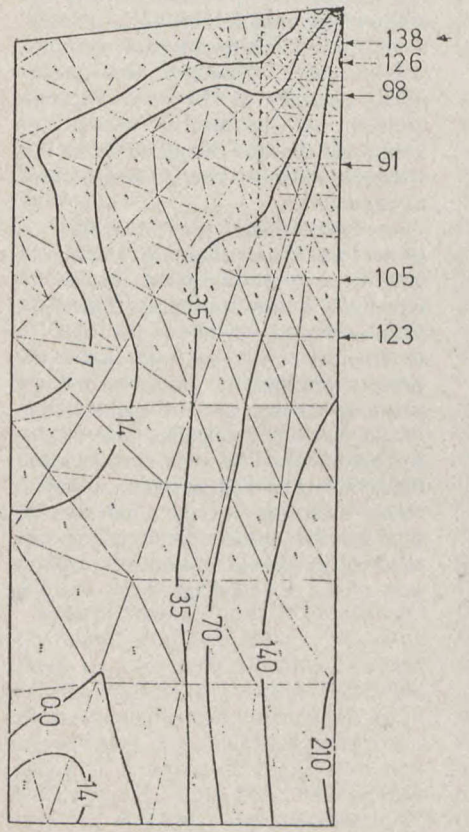


Figure 4a: Stresses in the tool. Normal stresses show a tensile maximum at a distance from the edge which can lead to breakage.

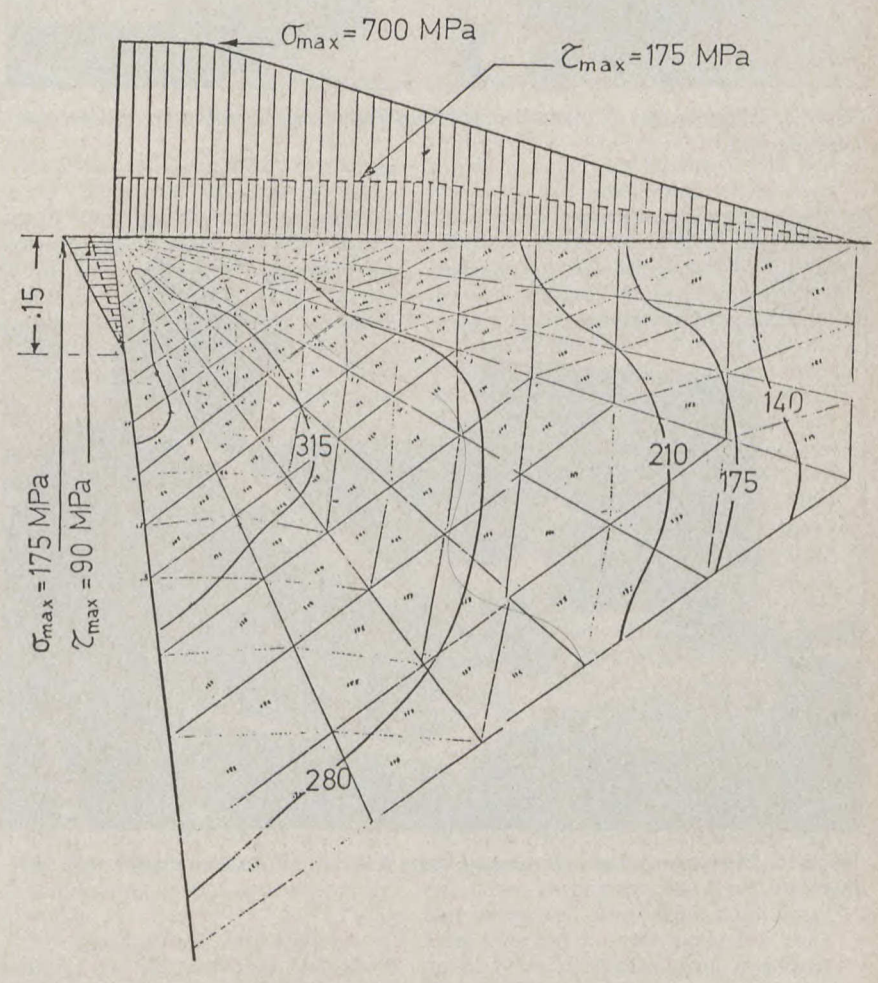


Figure 4b: Stresses in the tool. Shear stresses are maximum 315 at the cutting edge leading to chipping.

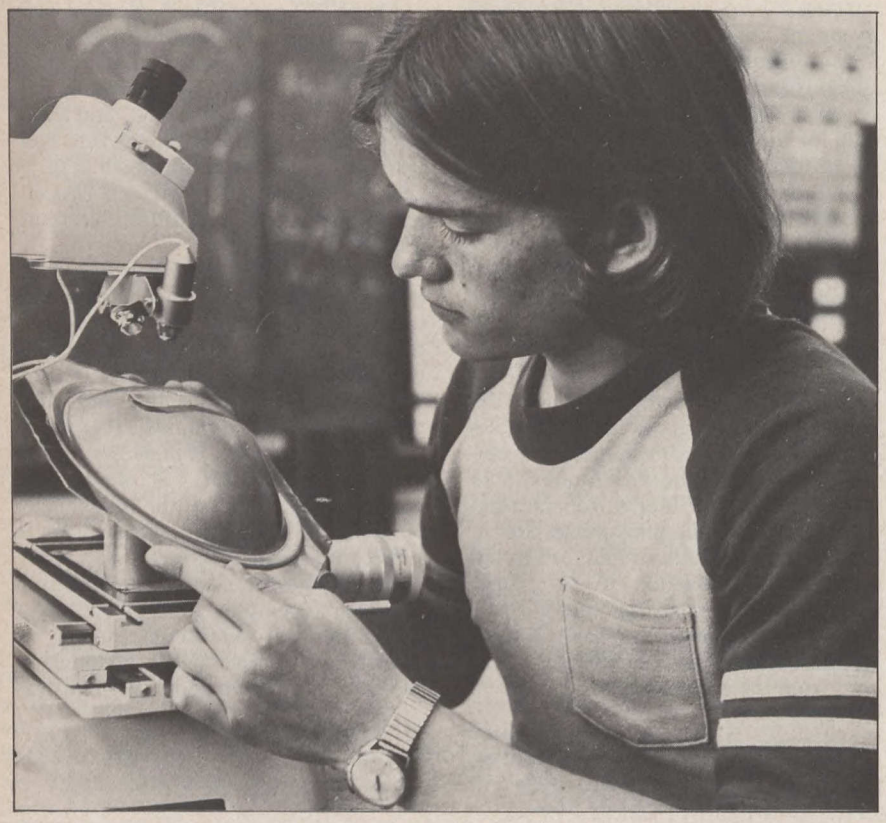


Figure 5: Measurement of fracture strains and gross strain distribution in deformed diaphragms.

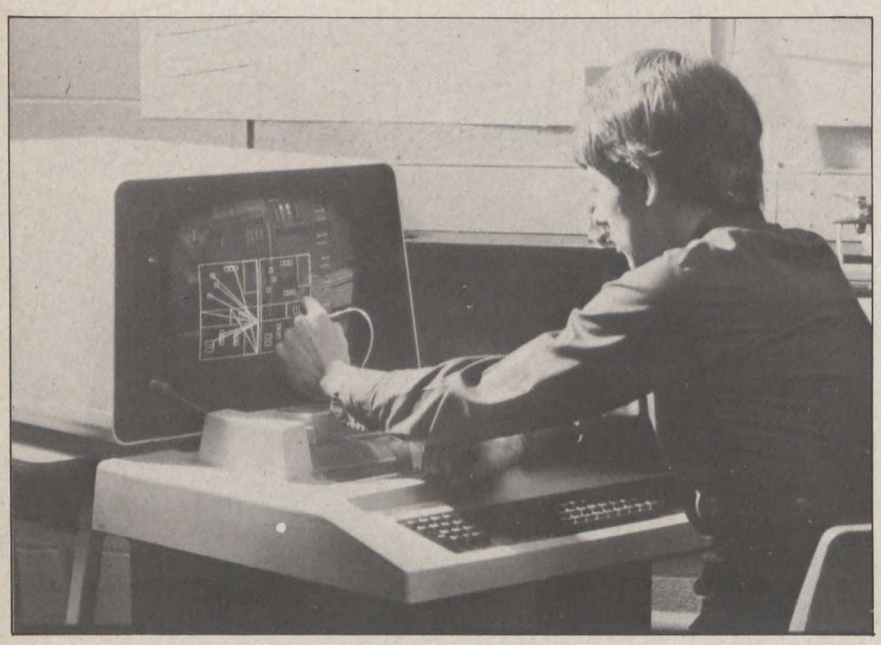


Figure 6: Development of plant layout using a computer graphic display and light pen.

ed forward and reverse flow behaviour on a variety of spheroidized, dual phase and HSLA steels. The material response under reverse loading is then incorporated into analytical models of the fabrication process.

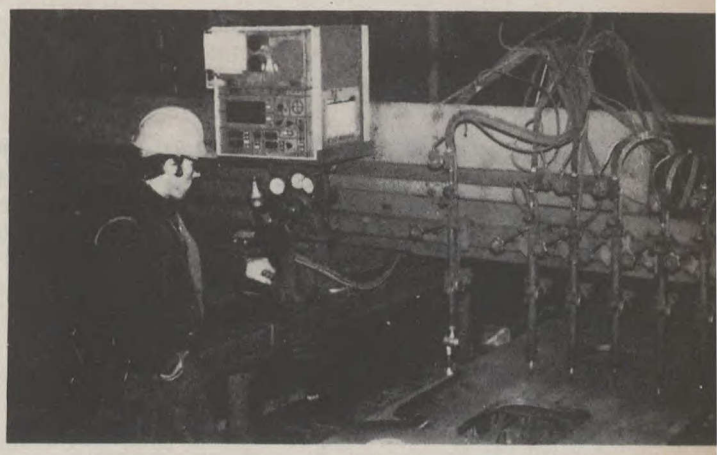
Modelling of deformation processes—general. A variety of projects have been studied from both an experimental and theoretical viewpoint. These investigations include the warm and cold heading of fasteners; deformation characteristics of roll bonded materials; fracture characteristics of alumnium alloys, spheroidized, dual phase and HSLA steels; incremental (rotary) forging operations; bulk deformation processes e.g. upsetting, drawing and extrusion; thermoforming of superplastic sheet and the forging and coining of superplastic alloys; and texture development in sheet metals.

Computer-aided NC part programming. A system capable of verifying and editing NC tapes for milling operations has been developed. It uses a PDP 11/34 minicomputer and a refreshed graphic CRT. The system enables the NC part programmer to either create an NC program or read in an existing tape. The system simulates the cutting operation and displays the tool motion and the shape of the part as cutting progresses. It allows verification of both tool motion sequence, geometry and dimensional accuracy of the part. Through dimensional geometric modelling, techniques are now being added to the system to enlarge its scope and increase its capabilities.

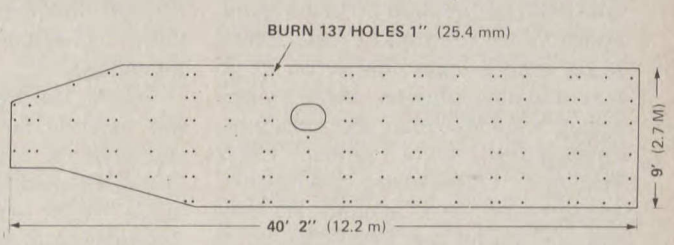
Computer-aided plant layout. A project which uses computer graphics to develop and modify plant layouts interactively is now in progress (Figure 6). It is designed to allow the user to develop the best layout according to the process product or group technology planning concepts and will enable him to locate machines, calculate and display production flow between machines and departments as well as obtain a dimensional hard copy of the final plan. A package for automated sketching and drafting developed in-house is used as part of the new package.

NC Flame Cutting Slashes Costs

Costs for fabricating large boxes, which required producing over 2700 holes in 1" steel plate, were cut two thirds by eliminating drilling and reaming



FLAME CUTTING MACHINE with NC unit has cut cost of fabricating three scrap charging boxes by two thirds.



SIDE PLATE, made from 1" thick steel, requires 137 bolt holes. Two of these plates are needed for each box.

THE MOST SPECTACULAR of many improvements generated by NC flame cutting at National Steel Car, Ltd., Hamilton, Ontario, Canada, involved burning, rather than drilling, over 2700 holes, $^{15}/_{16}$ and 1" (23.8 and 25.4 mm) in diameter, through 1" thick steel plate.

These holes were required in scrap charging boxes periodically fabricated by the railroad car builder for a neighboring steel mill. Inside dimensions of the 3000 ft^3 (84 m^3) capacity boxes are about 40 ft (12.2 m) long x 9 ft (2.7 m) wide x 9 ft high. They consist of a 1" thick carbon steel shell completely lined with 1" thick abrasion resistant steel. The wear plates were bolted to the shell for easy replacement.

Previous Processing. Producing the 453 bolt holes in the shell and the same number in the wear plates for each box by flame cutting with the optical tracing method was impractical. This was because the necessary accuracy could not be maintained, and the cut surfaces were too rough. As a result, the manufacturing sequence was time consuming and costly.

After flame cutting the shell end, side, and bottom plates, the parts were moved to the machine shop. A two-man crew located, center punched, and drilled the holes, using a radial drilling machine. When the shell was assembled, flame cut lining plates were clamped in position. An operator, using a hand torch, burned holes in the wear plates, with the shell serving as a template. The wear plates were then disassembled and moved to the machine shop, where the rough holes were reamed and countersunk to receive the flat head assembly bolts.

Present Method. When National Steel Car purchased two Burny NC units made by Cleveland Machine Controls for retrofitting to existing flame and plasma cutting machines, they soon learned that they could cut more accurately. Tolerances of $\pm^1/_{16}$" (1.6 mm) were easy, and small cuts could be held to $\pm^1/_{32}$" (0.8 mm). Also, the electronic controls produced smoother cuts, often comparable to machining. Because of these improvements, it was decided to burn the bolt holes in both shell and wear plates for the next order of three scrap boxes.

Punched tapes required to operate the NC units were checked for accuracy by operating the machine with the cutting oxygen turned off. By measuring the flame marks on the plate surfaces, the dimensions were proven quickly without cutting. With the tapes and control unit, each part was cut to shape using a single torch. Then without moving the shaped part, up to six holes at a time were burned with multiple torches.

Advantages Obtained. Overall savings were dramatic. Flame cutting of the numerous holes with one operator eliminated the two-man drilling operation, as well as the time wasted moving the shell plates to and from the machine shop. The wear plates only required countersinking, and the time spent aligning, clamping, hand burning the rough holes, and reaming was eliminated.

Accurate dimensions of the shapes and holes assured good alignment, thus minimizing assembly and welding costs. All three scrap boxes were completed in less time than ever before, and the total fabricating costs were reduced by two thirds.

Other Applications. Although not as dramatic, the NC units have improved the quality and reduced costs on numerous other operations. In most of these applications, the close tolerances maintained generally reduce fit-up problems and welding time. The precise cutting of small holes helped lower the cost of fabricating flat car centersills by almost half. Since the operations are simplified, people with limited previous burning experience can learn to operate the equipment in a few days.

Because there are no templates that must be aligned with the plates, time is saved on every setup. Making punched tapes for complex shapes and high volume parts is faster than preparing templates. Also, tapes are not always needed. About 50% of National Steel Car's requirements are for circles, rings, and rectangles produced directly from instructions dialed into the control by the operator. Instructions to cut more complex shapes, usually in small volume, can also be entered into the electronic memory from a written program, using switches on the front panel of the NC units.

National Steel Car feels that their two NC units paid for themselves in less than a year. In fact, they are so profitable, flexible, and trouble-free that an original plan to buy completely new NC flame cutting machines will probably be shelved. The capital saved could more than pay for new Burny NC units on the other six flame cutting machines already in their shop. ■

The Who and What of NC/CAM

There is a veritable alphabet soup of acronyms and buzz words surrounding numerical control and computers. Many belong to hardware and processes but some, however, belong to organizations and programs. Here is a look at what they are and where they are going.

By KEN GETTELMAN, Editor

Detroit had very little to cheer about in that depression-riddled year of 1932. Hard times were the reality with numerical control and computers more than 20 years away. Automobile demand was falling faster than a roller coaster on its initial downhill plunge. Many nameplates were destined for museums. Among those were Franklin, Cord, Auburn, Duesenberg, Whippett, Huppmobile, and Oakland. All were famous during the 1920's. Soon to disappear were such names as LaSalle, Packard, Hudson, Studebaker, Nash, and DeSoto, which survived the 1930's in style but could not thrive after the 1940's.

SME and CASA

The leading engineering societies at the time would not admit people to membership unless they held formal engineering degrees. Then, as today, many of those responsible for supervising tooling and production engineering functions could not boast a full degree status. In an effort to provide some sense of professional status and security, a handful of automobile industry tooling people assembled and formed the American Society of Tool Engineers (ASTE). The local Detroit chapter of ASTE soon had many offspring in the great manufacturing centers of the industrial midwest. Chapter 2 was organized in Racine, Wisconsin. Chapter 3 sprang up in Cleveland, 4 in Milwaukee, and 5 in Chicago. Today, there are well over 200 chapters in the United States and another 20 scattered around the world.

In the early 1950's the ASTE became the American Society of Tool and Manufacturing Engineers, and about ten years ago it simply became the SME or Society of Manufacturing Engineers. Its total membership is approximately 45,000 and it is a professional society. Membership is held by individuals.

Today, the interest of manufacturing extends far beyond the single discipline of tooling and SME has special-interest groups organized to serve such activites as finishing, assembly, and computers. The latter is served by CASA (Computer and Automated Systems Association), which falls under the SME aegis. CASA has a few of its own local chapters. The group sponsors the annual CAD/CAM (computer-aided design/computer-aided manufacturing) conference, which brings experts together to deliver papers on any functional use of the computer in the overall manufacturing environment. This could include anything from designing a product to controlling raw materials or finished goods in a warehouse with the aid of a computer. The vast majority of CASA's emphasis is on the practical applications of a computer in the manufacturing environment. CASA is headquartered at SME, One SME Drive, Dearborn, Michigan 48128.

The first public awareness of numerical control occurred in 1954. Eight years later, a few of the pioneers organized to create the Numerical Control Society. It has approximately 3300 members and has seen many changes in its brief 16-year history. It, too, is a professional society with individuals holding membership. Its national headquarters is now located at 1800 Pickwick Avenue, Glenview, Illinois 60025.

For NC Society members, the big change has been the explosive growth of the programmed and automated control concept itself. In 1962, numerical control was largely confined to machine tools. At the first technical meetings, there used to be serious discussions about whether absolute or incremental programming was the most practical. There were also spirited discussions about tape formats and other basic fundamentals that related strictly to the controlled machine tool.

The ink on the one-inch, eight-channel perforated-tape standard had hardly become dry when NC users were suddenly becoming aware of the computer sneaking onto the production floor to do jobs other than NC workpiece programming. Nor were controls confined to directing machine tools. The programmable controller with marked similarities to numerical control and with some vast differences (mainly the inability to position a cutting tool to a randomly selected location on a workpiece) was further confusing the issue.

CAD/CAM

What had once been a beautifully isolated discipline of programming a cutter through a workpiece now became a portion of the larger concept of computer-aided manufacturing (CAM). The logical association of CAM was computer-aided design (CAD). It didn't take long for CAD and CAM to become the acronym CAD/CAM. Any astute NC machine tool user is quite aware that the computing capability he utilizes has an implication that extends far beyond the metal cutting operation.

The whole question of whether or not the term NC is now indicative of the members' interest is something that the NC Society has had to weigh for some time. There is a strong core of direct NC machine tool interest among the membership, and for that reason the name has been retained even though everything from computer graphics to computer structural analysis are items that may appear on the agenda at any given NC Society meeting. The problem has been resolved with the restructuring of the NC Society into three divisions: numerical control, computer-aided design and computer-aided

manufacturing with chapters being formed for each of the interest areas.

APT and CAM-I

The first users of NC machine tools were the aerospace companies. They were doing more than drilling simple hole patterns. It was their four- and five-axis sculpturing that led to NC in the first place. Once the physical control concept became a reality, the problem immediately became the development of workpiece programs for the controls to use in directing machine tools to sculpture aerospace components. Computer capability was the only answer. There was always sufficient computer hardware, although it carried a heafty price tag in the 1950's. Software was another matter. Computer accounting programs left something to be desired in the development of NC workpiece programs.

In the mid-1950's the Aerospace Industries Association (AIA) banded together and developed the APT (automatic programming of tools) processor language. They realized that after much effort and lavish expenditures of man-hours they had indeed developed a working NC processor language. But they also realized that it was far from perfect, and it could be seen by those involved with APT that development, refinement and improvement would be an indefinite, ongoing process.

The AIA did the logical thing and, in 1961, turned the ongoing APT development over to a contractor with sufficient resources to carry out its further development and capability. That organization was the Illinois Institute of Technology Research Institute (IITRI) and APT remained in the hands of IITRI for over ten years. In that intervening decade it became quite apparent to everyone that, while APT was an excellent NC processor, a lot of computer software would be needed for manufacturing functions other than machine tool programs. However, no one contractor could be expected to do the entire job.

So the nucleus of APT supporters set up a new organization called CAM-I (Computer-Aided Manufacturing-International). One of its projects is the maintenance and further development of the APT processor language for the control of NC machine tools. But today, CAM-I goes far beyond the single NC function. It has some two dozen different projects under contract. All of them relate in some way to the use of the computer in the design or manufacture of products ranging from bolts to aerospace.

Some of the current projects include Computer-Aided Process Planning (CAPP), Geometric Modeling, Job Shop Control, an Advance NC Processor that goes beyond the capabilities of APT, and a Sculptured Surfaces System.

The functioning of CAM-I can better be understood by knowing the structure of its organization. CAM-I is, in its own words, a not-for-profit research and development corporation dedicated to the advancement of the application of computer technology to manufacturing functions. Currently, there are more than 100 industrial and educational members worldwide. Most of the very large aerospace, automobile, construction equipment, and machine tool builders in the United States hold membership. CAM-I is an international organization with members in both Europe and Asia. Each member pays a $5,000 annual membership fee. Membership is held by corporations—not individuals. In this respect, CAM-I differs quite markedly from professional societies such as SME and the NC Society, where individuals hold membership.

For their membership fee, a corporation has the right to participate in the deliberation and voting of what projects will be undertaken and in determining the overall direction that will be taken by CAM-I. If a specific project is undertaken, CAM-I will seek sponsors to provide leadership and direction for that particular project. For this privilege, the sponsoring members pay an additional fee.

The actual development work of the projects is done by contractors who provide their talents in return for a fee payment. Once a project, or a phase of a project, is completed and approved, it goes into the public domain and is available to anyone who is willing to pay a nominal fee for the documentation. For example, the latest approved version of the APT NC processor, known as APT IV, is now available for $475. This release is a complete processor for generating cutter location data from APT language input. The cutter location data serves as the input to a postprocessor for commanding numerically controlled machine tools. The release is organized into a load module to initialize the system, a translator, an execution complex which calls from the subroutine library, and a CL (cutter location) editor. The release has print and macro capabilities and some bounded surface capability. Specifically, it contains: parametric surfaces (a FORTRAN-oriented language for the cutting of analytical surfaces), sculptured surfaces, system macros, linearization, and cycle.

The entire documentation package for APT IV consists of: the APT encyclopedia, APT dictionary, three volumes of the computer system manual, deficiency corrections report, and a nine-track magnetic tape. The printed material consists of 2250 pages.

CAM-I has a catalog of its current offerings, which include manufacturing computer programs and printed material. CAM-I is located at 611 Ryan Plaza Drive, Suite 1107, Arlington, Texas 76011.

CIRP

Another organization with a very active interest in the use of the computer as a manufacturing resource is CIRP. Its full name is College International pour l'Etude Scientifique des Techniques de Mecanique. In the United States it is known as the International Institution for Production Engineering Research. CIRP is not an organization for the average manufacturing manager. It is a very prestigious organization with membership by invitation only. No one nation may have more than 15 members. The United States currently has 11 members. Dr. M. Eugene Merchant, Director of Research Planning for Cincinnati Milacron recently served as president of CIRP.

All of the current members have made names for themselves through notable original research or development activities backed by significant presentations of technical papers, books, or other publication activities. Most have doctorate degrees. CIRP is an advanced think tank in every sense of the word. Its proceedings do not make for light reading, but within those proceedings is the frontier of

manufacturing technology development. It is an excellent window to the future of manufacturing technology. Its annual meetings are held each fall in various countries throughout the world. The last meeting hosted by the United States was at the University of Michigan in 1967.

In addition to the private organizations and societies with an active interest in some or all phases of CAD/CAM, there are several specific government programs underway leading toward better development and implementation of the concepts.

ICAM

Perhaps the best known is ICAM or Integrated Computer-Aided Manufacturing. It is a United States Air Force program administered by the Air Force Materials Laboratory at Wright-Patterson Air Force Base, Dayton, Ohio 45433. It has an incredible $100 million funding through 1983. Some of the work will be done by the AFML itself, but most will be accomplished by various organizations working under contract. ICAM is a long-range project and it will probably be at least three years before the first phases of the program begin to bear fruit.

The main area of concentration is the development of systems and software to fully utilize the computer as a manufacturing tool. The objectives are the reduction of manufacturing costs and the utilization of the best manufacturing technology in the production of aircraft and other material for the United States Air Force. Mr. Dennis Wisnosky of the Air Force Materials Laboratory is in charge of the program. His telephone number is 513-255-2676.

MTTF

Another program that has just been funded by the Air Force is the Machine Tool Task Force (MTTF). It is managed by the Manufacturing Technology Division of the Materials Laboratory at Wright-Patterson Air Force Base. But the actual organization and work of the task force will be coordinated by the Lawrence Livermore Laboratory (LLL), a U.S. Department of Energy facility at Livermore, California.

The task force has 100 members and they come from machine tool builders and users, research laboratories, and government agencies, as well as from engineering centers in West Germany, Belgium, England, and Canada.

The task force will identify machine tool technology advancements and areas of research and development that can significantly improve manufacturing. They will also study the improved application of computers to control machine tools and to manage machining operations. The findings of the task force will be presented at a conference to be held in Chicago in 1980 and in publications available at that time. The head of the task force is George P. Sutton, Precision Engineering Program, Lawrence Livermore Laboratory, L-471, Livermore, California 94550. The telephone number is 415-422-7600.

CASDAC

The United States Navy has its own program underway to utilize the computer as a powerful aid in both the design and manufacturing of ships. It is called CASDAC and stands for Computer-Aided Shipbuilding Design and Construction. The computer has already brought about many changes in the shipyards. The extensive lofting that used to be required for hull structure members is now obsolete. It has been replaced with computer processing and the generation of programs to control NC benders and flame cutters to cut, bend, and fabricate those hull elements without the need of the space and time consuming lofting function. The CASDAC program is also a combination of the Navy's own staff work and contract project efforts. The coordinator of the program for the Navy is Mrs. Raye J. Parrott, Department of the Navy, Naval Ship Engineering Center, Code 6150B, NC2, Room 5W15, Washington, D.C. 20362. The telephone number is 202-692-0335.

MANTECH

The United States Army does not have an all-encompassing program but has a number of projects underway which come under the heading of MANTECH (Manufacturing Technology). One of the projects that has been completed and which took a good look at the computer and numerical control was the Numerical Control Language Evaluation Study.

The study clearly showed that the degree of skill and expertise required for NC programming is not related to the machine tool, control system, or particular NC processor language. The primary determining factor is the geometry of the workpiece to be machined. The Numerical Control Language Evaluation Study was funded by the Army through the Numerical Control Society. The principal contractor was Advanced Computer Systems of Dayton, Ohio. The results of that project are now available from the Numerical Control Society, 1800 Pickwick Avenue, Glenview, Illinois 60025. The cost is $60.

Although all of the Army Arsenals and Development Commands are represented in the MANTECH effort, it is coordinated by the U.S. Army Communications Research and Development Command, Attn: DRDCO-AM, Fort Monmouth, New Jersey 07703. Mr. Dave Ruppe is in charge and his telephone number is 201-544-4778.

IPAD

The National Aeronautic and Space Administration (NASA) has its IPAD program. IPAD stands for Integrated Planning for Aerospace Design. No one can argue with the brilliant success of the United States space program. The IPAD program is designed to facilitate the planning and design of the space program components with the aid of a computer to reduce the cost and time burdens associated with the space effort. As with the other military and agency programs, IPAD is a combination of in-house and contract efforts. The NASA program is focused at the Langly Research Center, Hampton, Virginia 23665. Mr. George C. Salley, Center Code LARC/246 can be contacted about IPAD. His telephone number is 804-827-2426.

DIPEC

The Defense Industrial Plant Equipment Center at Memphis, Tennessee 38114 is charged with maintaining an equipment supply that could be brought immediately into

use in the event of a national emergency. The problem is a rapidly changing manufacturing technology. Tools and equipment that were the latest state of the art just a few years ago have been supplanted by a rapidly changing technology. As a result, DIPEC holds a number of meetings and seminars to inform service personnel of the latest developments and what equipment DIPEC plans to hold in its inventory. Heading up the DIPEC activity is Mr. Garland Smith; his telephone number is 901-744-5228.

MTAG

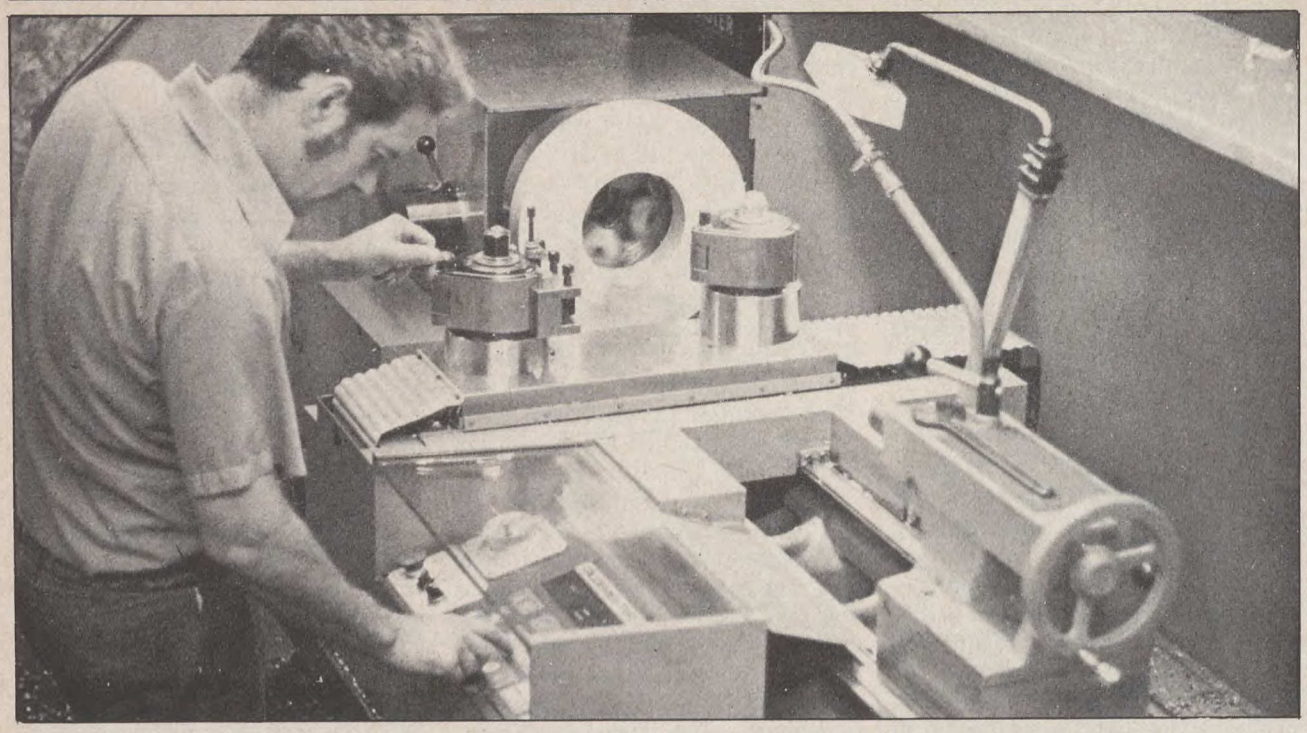
The Department of Defense (DOD) is quite aware that the various services have many manufacturing technology projects planned or underway. In an effort to prevent duplication, overlapping, and waste, MTAG (Manufacturing Technology Advisory Group) was formed. It is comprised of representatives from all of the services who are involved in some kind of manufacturing technology effort. The function of MTAG is to exchange the results of programs and plans for new programs so that the services do not duplicate each other's efforts. MTAG has a number of specific committees, including CAD/CAM. Not only are all of the services and NASA represented on the CAD/CAM committee, but it also includes representatives from various technical societies and trade organizations. They include the Society of Manufacturing Engineers, American Defense Preparedness Association, the Forging Industries Association, the National Bureau of Standards, and the Numerical Control Society. The chairman of the CAD/CAM committee of DOD's MTAG is Dennis Wisnosky.

It may be wondered why the DOD and such organizations as CAM-I have very similar programs underway. The answer is rooted in defense policy. CAM-I and most societies, while primarily domestic, have some overseas members who are not involved in a United States security arrangement. The Defense Department programs have military security overtones. In spite of this fact, there is a certain amount of cross-fertilization flowing among the various programs. The same individual experts may surface in more than one capacity or they may be found serving on more than one liason committee.

But one fact remains perfectly clear: Every important industrialized nation in the world except the United States has an organized program, national in scope, of some kind to develop their manufacturing technology. Most of it centers around the use of the computer to bring quantum leaps to manufacturing efficiency. Almost invariably the programs bring together the best efforts of government, the academic community, and the private manufacturing sector.

All of these programs have as their objective the improvement of manufacturing technology as a national goal. In the United States, the only such national effort is still limited to the concept of military defense. Thus, for better or for worse, the DOD has now become the wellspring from which the really long-range and expensive manufacturing technology programs will be financed. **MMS**

Reprinted from Modern Machine Shop, September 1979



CNC for job shop on the go

THE REPUTATION of Barrie Welding and Machining (1974) Ltd., Barrie, Ont., is that it can "make anything" and "fix anything". The owners tend to boast about that, and with some justification, it seems, because that's what you hear from some of the firm's customers too.

It was precisely with that reputation in mind that the company late last year acquired an advanced machine tool—a computer controlled Gildemeister NEF 480. In fact, it was the first of these machines sold in Canada.

Says Jim Sheardown, one of the four partners that own Barrie Welding: "We had to refuse quite a few jobs because we couldn't competitively do larger jobs with quantities of 10, 20, 30 off."

Not being a production shop—runs of 50 are about tops—Barrie Welding hadn't seen much advantage in numerical control, with its apparent emphasis on volume production. That reputation is perhaps not quite deserved, but all the same, it wasn't until two of the partners saw the machine at the 1976 Chicago International Machine Tool Show that they got interested.

The lathe, in fact, was conceived and designed just for the types of jobs a company like Barrie Welding gets into. The company produces small volumes of parts—up to a few dozen—for, typically, machinery and equipment builders, while on the other hand it is a custom builder of industrial machinery itself, making its own parts a few at a time.

Barrie Welding and Machine was acquired by the four partners five years ago. Initially, it started out as a repair shop but, says Sheardown, as the number of customers grew, and they demanded more services, "we grew along with them."

That meant gradual entry into custom manufacturing, whereby the company could draw on the partners' experience in both machine shop work and welding. It has got to the point, in fact, that manufacturing outstrips repair activity.

Although the company does a lot of work for local industry, parts are also shipped to other parts of the province, and some even as far as Alberta and British Columbia.

But, the company has stuck with low-volume custom work, which is one of the limitations on the type of jobs it will accept.

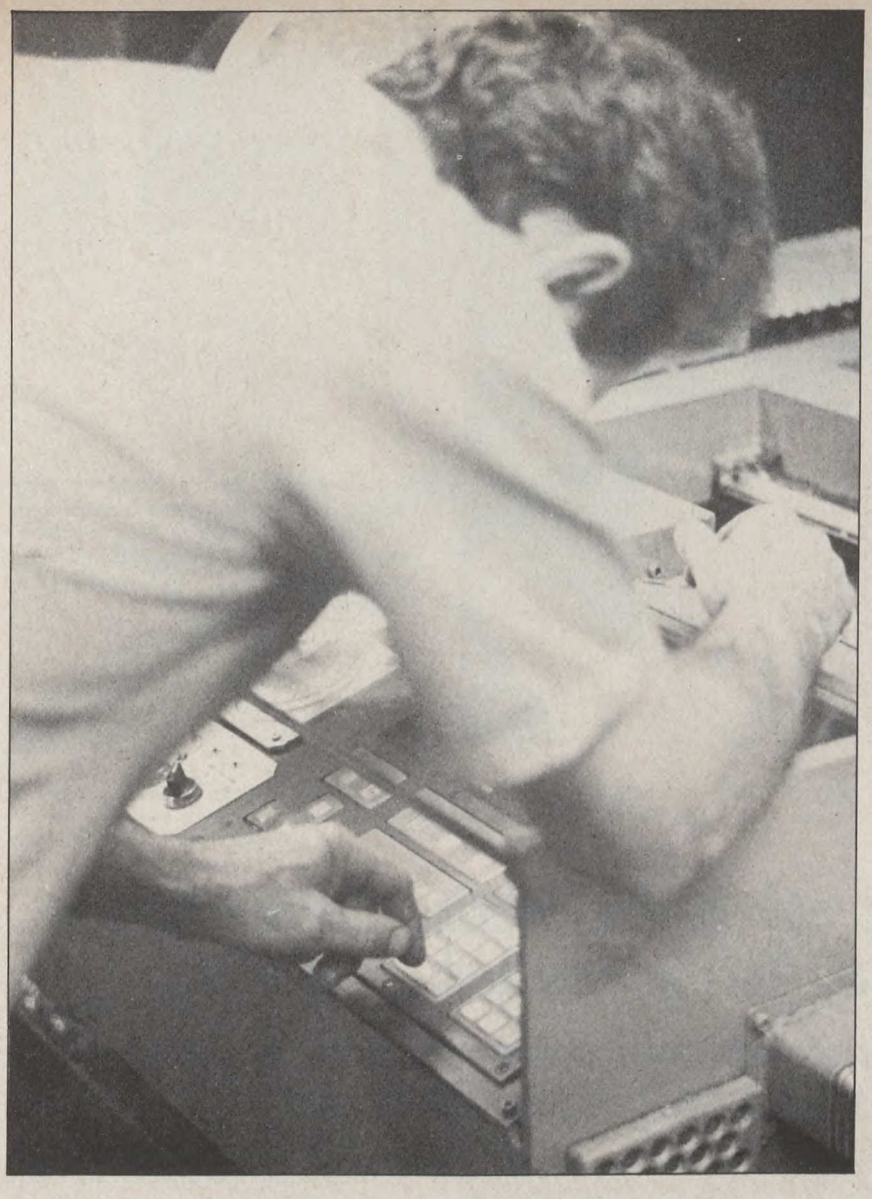
The other limitation is size—simply a function of the type of machinery in the shop: lathes ranging in size from 8 in. to 48 in. with a maximum length between centres of 12 ft.; three horizontal boring mills, a 3-in., a 4-in., and a 5-in. (just being installed); a grinder capable of taking 50 in. corner to corner, a 3x3 planer, three vertical boring mills, 36 in. and 60 in.; and last but not least the computerized lathe. An N/C mill is the next major piece of equipment on Barrie Welding's future acquisition list.

Barrie Welding now has 65 people working in the 36,000 sq. ft. plant.

"Most of the men are very versatile compared to a lot of shops because they are working on a wide range of jobs using a variety of machines," says Sheardown.

The new lathe is a relative newcomer to North America. The machine was shown for the first time in Canada at the Production Show in Toronto last May by the distributor, B. Elliott (Canada) Ltd., Toronto.

"What attracted us was the fact that it was the type of machine on



Opposite page—*Designed for command input that "supports the operator," Gildemeister NEF universal lathe features control console mounted on machine, which is used for all programming.*

Left—*Machine operator Howard Finelay, of Barrie Welding and Machine (1974) Ltd., Barrie, Ont., uses control console to set up job. Machine is said to be ideal for low-volume production—company's specialty.*

which you don't have to do a lot of programming to run your parts," Sheardown says. "You don't need to use tape, so you've got a simpler program, and lower costs initially, and still get reasonable production, especially on short runs. That's what we looked for."

The NEF actually is one of the first tapeless-control, or manual-input, CNC machines on the market, using canned cycles incorporated in its computer memory for some of the more complicated routines such as tapers or circular interpolation and screw-cutting. The control console is mounted on the machine and programming is done on this console.

The lathe has a swing diameter above the bed of 480 mm, facing traverse of 290 mm, and turning length of 1000/2000 mm. The Fanuc Mate-L control can store 250 blocks of programming in its internal memory.

At Barrie Welding, two machinists have been trained to operate the machine after having learned the basics of NC at a seminar at the Canadian Institute of Metalworking at McMaster University, Hamilton, Ont. To be sure, for the first six months nobody worried much about getting production out of the machine, although, says Sheardown, they got some work done on it almost immediately.

"The programming was usually taking a lot longer than it should have," Sheardown says. "Certain parts still take a lot longer than they would if you had everything down pat. But it didn't take nearly as long to get into production as it might have for some other machinery. Some parts we tried to run were not terribly efficient, and other parts worked out super.

Howard Finelay, one of the two operators, agrees. "It is a little bit like driving a car," he says. "You can learn it in two weeks, but it takes a long time before you are any good at it. But once you get on to it, it is easy."

"Learning is still an ongoing process, though. Being a jobbing shop, you are always programming new parts," Sheardown says.

Even more than six months, he considers, hasn't been enough to get to know the machine fully, and they are making new discoveries about its versatility regularly. For some jobs, it has paid off already. For instance, the company was required to make a series of mating sets of rolls for a wire-making machine, with complex geometry and close tolerances. The job was difficult to program, but would have been infinitely more difficult by manual machining methods.

Eventually, though, the company expects to profit from its new lathe's potential for improved productivity.

"If you use that machine efficiently, you should be able to get more production using the skilled men you have," says Sheardown, acknowledging that skilled manpower is one of the most serious problems faced by the company.

Shortly, the company will acquire a reader for the machine so that programs, once developed, can be stored and re-used without re-programming the machine tool itself. This saves some time, and eliminates the possibility of human error and the consequent loss of more time. This accessory will be extremely useful to fill repeat orders of which Barrie Welding now gets quite a few. □

A pattern piece is discussed by Tony Levine, (left) manager and outside contact man for Computer Marking Services and Michael Toll, operations manager, The Camsco 5000's Versated plotter is in the foreground.

Computer Grading and Marker Making Service Bureau Established at Ontario Research Foundation

. . . new service brings electronic system within the means of the most modest size garment manufacturer

SMALL TO MEDIUM SIZE apparel manufacturers can now cut themselves a slice of the productivity pie formerly enjoyed by only the half-dozen largest Canadian garment makers able to afford an in-house, computerized pattern grading and marker making facility.

In response to long expressed concern about the productivity and competitive position of the Canadian apparel industry, the Textiles and Clothing Technology Centre at Ontario Research Foundation has established a computer grading and marker making service bureau at its Sheridan Park headquarters. Computer Marking Services is organized around a new, $450,000 Camsco Markamatic 5000 and operates on a fee basis. The new service brings the speed and accuracy of electronic pattern grading and marker making within the means of even the most modest size garment house.

Garde Rule Tables and style specifications are keyed into the computer memory and programs are run by Ms. Natalina Chow.

Not only will the service put Canadian manufacturers on a more profitable footing, it will help them counter the import threat by making them more competitive with companies in the Far East and Europe.

Computer Marking Services became fully operational this month.

A Long Time Coming. It was a long time coming. In 1972, a task force sponsored by the federal Ministry of Trade and Commerce recommended that a productivity and development center for the clothing industry be established and that it "provide services in areas of activity where equipment costs and demand make it uneconomic for individual firms to acquire the equipment, e.g. computerized pattern grading".

A client's master sample pattern is traced with the digitizer by Ms. Maggie McPherson. The digitizer converts the shape and all reference points and directions into computer language.

In 1973, the Apparel Manufacturers Association of Ontario, urged the initiation of a commercial pattern grading and marker making facility. The 1975 Sector Analysis of the Textile and Apparel Industries conducted by the government of Ontario also supported the concept.

Three years later, the Honourable Jack Horner heard much the same story from yet another task force formed to study the problems of the clothing industry.

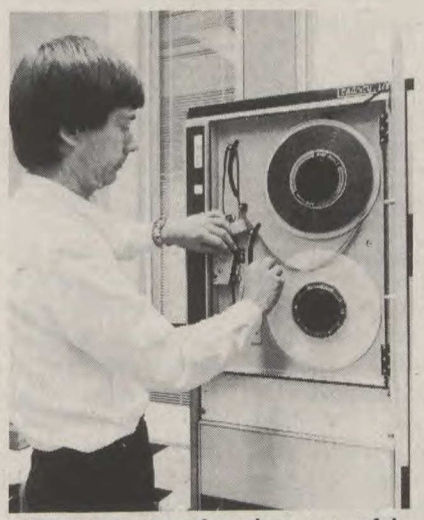
What was surprising about the various reports and recommendations was not so much that they advocated wider adoption of computer technology but that they all zeroed in on the pattern grading and marker making function as the principle bottle neck between approval of the sample pattern and the cutting of the piece goods.

The problem was not confined to Canada, except that foreign manufacturers were quicker to move into computerized pattern grading and marker making as a means of eliminating it. Often, the foreign garment makers received government assistance in order to protect an important source of exports.

Better Fabric Utilization. The chief advantage of a computerized system is significant improvements in fabric utilization, claims Dr. Mike Williams, director of the Textiles and Clothing Technology Centre.

Another main benefit is fast turnaround times. At present, turnaround at Computer Marking Services is 48-hours, but Dr. Williams predicts a 24-hour service when a second shift is added in the near future.

In addition, Computer Marking Services will help reduce pressure in meeting seasonal demand, increase the ability of a firm to respond to mid-season style changes while the new trend is still hot, reduce raw material costs for patterns and markers, trim storage costs for patterns and markers since all pertinent information is stored on memory discs at ORF, shave insurance premiums because patterns and markers are safely stored on magnetic tape in a vault, preserve confidentiality through coded storage, and save on paperwork.



Coded patterns and markers are safely stored on magnetic tape such as this one being threaded by Michael Toll, operations manager of Computer Marking Services.

The net result will be a much better bottom line performance.

CMS will pick up and deliver as well as assist any company employing the service in training its staff in the use of the new technology. In addition, CMS technicians will counsel company personnel in communicating with the computer system.

The new service will not replace a shop's present pattern grader/marker maker, stresses Dr. Williams, nor will it necessarily be cheaper. Rather, the system will liberate some highly paid, highly skilled people to concentrate on tasks which could add to the productivity and profitability of a company such as the development of new lines or designs where their expertise is irreplaceable.

Since time, money and space are the fundamental assets of any business as well as the constraints on its margin of profit, any savings in one or more key areas has a positive effect all down the line, especially the one at the bottom of its P & L statement.

The patterns and markers generated by the Camsco Markamatic 5000 system are accurate and faithful to the original. Any special techniques a company uses in developing its patterns or the manner in which they are graded is preserved since the company supplies all the basic information which is fed into the computer.

Manufacturers with qualms about design security can rest easy. The Ontario Research Foundation has been privy to industrial secrets for fifty years and considers confidentiality as one of the ironclad rules throughout its entire operation. The fast turnaround possible with the computer is itself a plus security factor. The less time it takes to shepherd a new design through the pattern grading and marker making stages, the less chance there is for leaks. To further assist in preserving security, all patterns, markers and companies are coded.

Working conventionally, the task of grading a pattern into the required size range once the master pattern sample has been designed is a long job with the degree of accuracy depending on the pattern grader's skill. There never seems to be enough time and the job is subject to unceasing pressure.

In contrast, at Computer Marking Services, a client's Grade Rule Tables and style specifications are first keyed into the computer memory.

Next the client's master sample pattern showing all the notch marks, dart points and drill holes along with a grain line to indicate its eventual positioning on the fabric, is placed on a large grid and traced with the digitizer.

If the fabric has a repeat pattern, plaid or border print, a vertical stripe indicating the repeat will also appear on the sample.

Computer Language. The digitizer converts the shape and all reference points and directions into computer language. The operator then keys in the desired size range and the graded patterns appear in a nested arrangement on the graphics display screen. Accuracy is to 1/64th of an inch.

At this point, any errors are corrected. A master plot is printed on the plotter and returned to the client for verification and approval.

As currently practiced, the next step would be to generate a marker by laying out all the graded patterns full-size on a huge sheet representing the fabric length and width. By juggling them about the marker maker derives the best use of the fabric. The process involves endless trips up and down a sheet so big it is difficult to grasp at a glance.

At Computer Marking Services, the job is compressed into minutes. The marker maker sits at a graphics console and selects the styles and sizes to be marked along with the width and length of the finished marker from specifications furnished by the client. The graded patterns are disdisplayed in miniature across the top of the screen with the marker as a rectangle of the same scale near the bottom.

The graded pieces are transferred to the marker with an electronic stylus. The technician aims for the most economic arrangement possible and can move pieces up, down, right, left or tilt,

An electronic stylus is used to transfer graded pattern pieces to the marker by Michael Toll, operations manager of Computer Marking Services. The computer warns of overlaps or other errors and provides a running tally of the fabric.

rotate and flip them as needed in the search for greatest efficiency. During this operation, the computer warns of overlaps or other errors and provides a running tally of the fabric utilization being achieved.

It is just this precise control which produces the impressive increases in fabric utilization.

Once the computer indicates that optimum efficiency has been reached, the marker is stored in the memory disc and the plotter is engaged to print out the completed version in 1/5th scale for customer checking and verifications.

Printed Fuel Size. Upon verification, the marker is printed full size. Computer Marking Services can provide markers of virtually any length, and in widths of 45, 50, 59½, 65 and 108 inches, or even 143 inches for specialized industries. Styles and sizes can also be mixed on the same marker panel.

CMS is staffed with garment, not computer, people. Tony Levine, the manager and outside contact man, has more than 20 years in the business. Michael Toll, operations manager, has a background of pattern grading and marker making which covers a wide spectrum of the apparel business, Aquascutum, Highland Queen and more than two years with Levi Strauss and Co.

In assembling the team, Ontario Research felt that the main emphasis should be on recruiting top notch apparel people who could be trained in the operation of the computer. This assumption has proved correct and the group is considered to be of the highest standard.

Computer Marking Services is prepared to undertake a sample project on a "no charge" basis in order to demonstrate the efficacy of the system. Once a client is satisfied with the grading and marking the system provides, there are two options to consider. The first is a "Cost Justification Evaluation Survey" conducted by Ontario Research consultants at standard rates which compares the cost of the client's present method with the cost of using CMS.

The second choice is to begin using CMS for selected styles while continuing to use the in-house organization and increasing the number referred to the bureau until an optimum split is achieved.

Thus far, the only snags encountered with the system have been due to incomplete information from manufacturers, either due to reservations about design security or lack of knowledge about the specific information needed. However, these problems will disappear as manufacturers become familiar with the operation of the system.

As for the future, Computer Marking Services considers pattern grading and marker making as the tip of the system's capabilities. It plans to explore the possibility of direct computer design of patterns and the actual engineering of patterns, both of which could result in further time savings and greater efficiencies in apparel manufacturing.

MERCHANDISING TEST

Bertrand Frank Associates, Inc., Management Consultants to the apparel industry, in response to the success among their clients of their manufacturers' "Merchandising Awareness Self-Survey" now is making this comprehensive self-test available to the industry without charge. The Self-Survey covers the spectrum of merchandising functions in detail. It emphasizes areas such as Customer Service, Finished Goods and Fabric Inventory Management and Merchandising Planning, but comprises much more.

It is available free as a trade service. Write to: Public Relations Department, Bertrand Frank Associates, Inc., 475 Fifth Avenue, New York, New York 10017.

Five-axis NC machine cuts floor-to-floor time by 60%

Impeller machining proves CAD/CAM in production

With reference to CAD/CAM it can be said that manipulation of stored data to functionally integrate the activities of Design and of Manufacturing is successful if it provides increased productivity and reduced costs. The authors have selected the production of high performance centrifugal impellers as an example of CAD/CAM—an example which meets the foregoing criteria. Impellers are the highest cost parts in the PTG family of engines produced by Pratt & Whitney Aircraft of Canada Ltd.

Our first introduction of CAD/CAM was in 1967 when we reduced the floor to floor machine standard for the PT6 Impellers from 90 hrs. to 34, by replacing with flank milling, the then established point generating method for milling multi-axis blade cavities. This arose from our basic idea of sweeping the blade flanks with a milling cutter in continuous flank contact throughout the blade configuration. The design development required in conjunction with the development of the machines and tooling, involved complex mathematical analysis. The successful results achieved laid the base for all future advanced impeller designs. We have shipped 15,000 engines to date in the PT6 Turbo-Prop family of engines, incorporating the smaller 9 in. size impeller.

The cost impact arising from these earlier efforts was considerable and is based upon our 1979 engine forecast, the comparison being between our in-house costs with flank milling against our best vendor prices; it shows a saving of 41% on our smaller 9 in. impellers for turboprop engines, and of 33% on the larger impellers for jet engines.

We make the bulk of our impellers on 13 four-axis flank milling tracer machines, which we developed especially for machining impellers with the Hayes Co. of England in 1963 to 1965. We have also installed a five-axis numerically-controlled machining center recently to productionize new impeller designs at the early design stage.

Regarding our jet engines, the JT15D family uses a larger 14 in. dia. impeller, of which the latest designs to obtain higher performance have posed problems at the machining development stage. It is the development work on this size which is described.

Computer aided design (CAD) has played a key role in defining all of the complex geometry required for the flank milled design. Data are stored in a computer data base from which we can readily generate the tool paths and the tapes in the case of the N.C. machine.

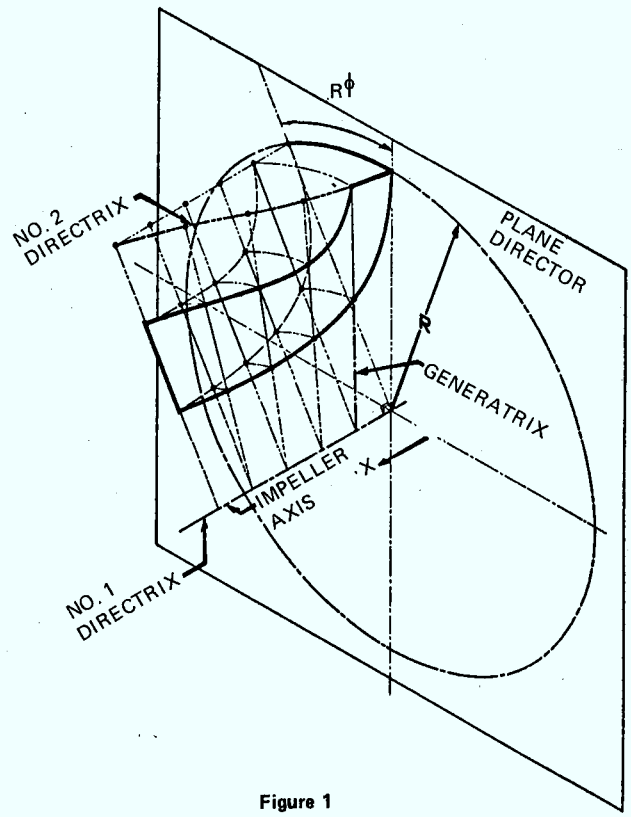


Figure 1

On this illustration of impeller blade definition, the curve shape is defined by Rϕ versus X

Up to the late fifties, impellers were defined in a very simple manner. A curve was drawn on a circular cylinder with a radius equal to the impeller trailing edge radius. The curve most commonly used was an ellipse, a circular arc or a parabola. Generating lines were radial and assumed to intersect the defined curve. The impeller hub and tip surfaces of revolution were then derived. The intersection of these surfaces with the generating lines defined the limits of the blade camber surface. Blade thickness was then applied to the camber surface. Generally a tapered thickness was selected and was applied equally to either side of the camber surface. A conventional airfoil shape was applied to the leading edge. Figure 1 graphically illustrates the method of blade definition. The curve shape is defined by Rø versus X.

The basic restriction of this method is that the aerodynamic loading is a function of the curve selected and the cross-sectional flow area distribution defined by the hub and tip contours. This severely limited the scheduling of the aerodynamic loading and flow diffusion. The radial blade elements however, simplified the stress calculations.

To manufacture a blade such as that mentioned above could only be accomplished by point generation. Because the generating lines are radial, a tapered tool centre line would be near radial. To try to produce this impeller by flank milling would require a long tool to avoid chuck

L. Brown, Chief, Process Development & Manufacturing Methods
J. C. Plucinsky, Chief, General Aerodynamics Pratt & Whitney Aircraft of Canada Ltd.

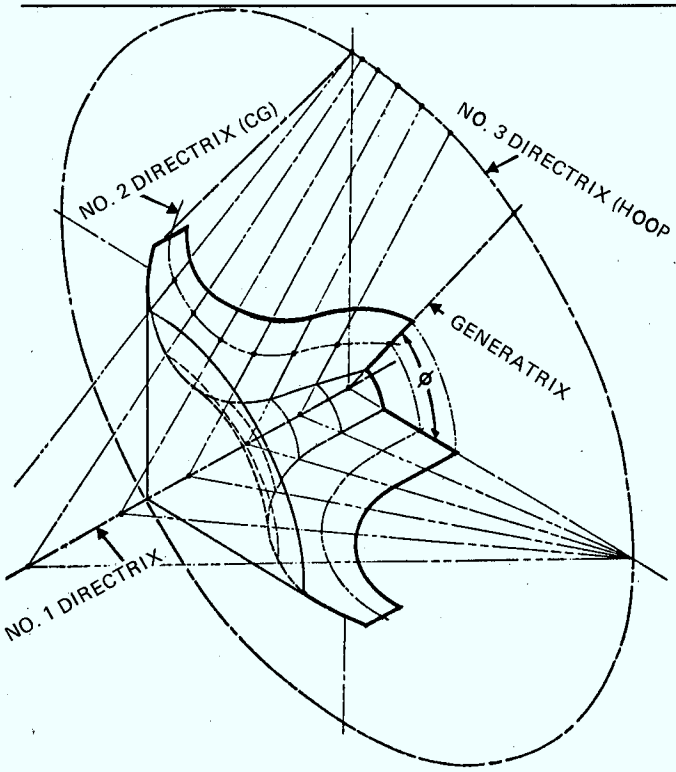


Figure 2

Illustrating an array of generating lines which emanate from a hoop (no. 3 directrix)

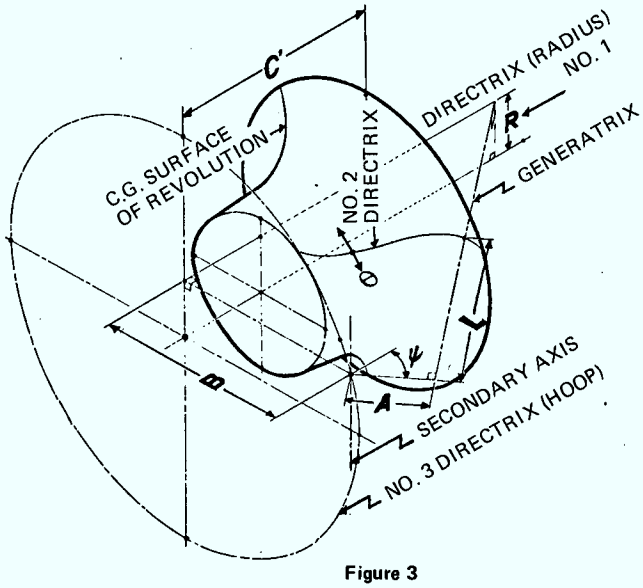


Figure 3

The final definition of the generating system. The hoop or pivot point is defined by an offset dimension 'B' and an axial position 'C' with the impeller

interference with the blade in the radial portion of the impeller.

To circumvent this problem of tool length it was desirable to pivot the tool about a point such that its centre line was near normal to the hub surface of revolution. Fig. 2 illustrates an array of generating lines which emanate from a hoop (No. 3 directrix). Each generating line passes through the hoop, through a line in space (No. 2 directrix) and through the impeller axis (No. 1 directrix). The line in space can assume any desired shape defined by R and ø versus X. Again the hub and tip surfaces of revolution defined the boundaries of the blade. The thickness distribution was then defined, as before, along a generating line.

This mode of blade definition provides freedom for scheduling aerodynamic loading and flow diffusion independently. The blades can also be swept at the trailing edge for optimum aerodynamic performance. When the tool was applied to the resultant surface its centre line closely followed the array of generating lines. Consequently, tool overhang can be minimized.

A trace of the blade in a radial section normal to the impeller axis, however, resulted in a curved section. This produced an additional stress due to a bending moment. In order to minimize and or distribute these stresses the blade was allowed to lean. This was accomplished by permitting the generating line to miss the impeller axis by a variable offset R (No. 1 directrix) with respect to X.

To generalize the definition of the generating lines, a variable offset A from the hoop was introduced. The need for this will become clearer later on.

Figure 3 illustrates the final definition of the generating system. The hoop or pivot point was defined by an offset dimension "B" and an axial position "C" with respect to the impeller. The generating line angle was denoted by and the position of the line in space (No. 2 directrix) was defined by "L". "O" indicates the angular location of the line in space with respect to a meridional datum plane. Therefore for every position on the line in space we can define 5 independent coordinates O, Ψ, A, L &R. Initially to simplify matters was considered to be the independent variable. In this manner a family of generating lines can be used to define a blade camber surface. The hub and tip contours and thickness were defined as described earlier.

The camber surface curve fitting was accomplished by deriving the geometric relationship between adjacent lines in space. Consider any two lines such as shown on Fig. 5. These generating lines have a unique relationship between each other which can be defined by the minimum distance between the lines (RGR) and the angular relationship between the lines (YG). The position and vector of RGR were expressed by HGR and TG measured with respect to the hoop and a meridional plane respectively. The blade surface can then be expressed by line segments normal to the reference generating line passing through the adjacent line (denoted by line ab). The values of HGR TG and VAR

(where $VAR = \frac{RGR}{\tan y G}$)

are computed for all generating lines and curve fitted with respect to position along the No. 2 directrix. In this manner the blade camber surface was completely defined. This approach to a surface definition lends itself well to applying a tool.

The tool was applied to the surface in a manner similar to that used for two dimensional shapes except that spheres were applied to two points on the surface. The fillet radius and tip contour intersections with the generating line were used as the match points. Two spheres

with radii equal to the tool radius plus ½ the blade thickness was applied to the camber surface and the positions of their centers were determined. A line joining these centers then established the tool center line. Some additional complexity was encountered with a tapered tool but this was easily overcome with an iterative computing technique. This tool matching process was repeated for each generating line. The tool center line was defined in the same system as that used for defining the generating lines.

Application of the Hayes machine

The Hayes machine is illustrated on Fig. 6. The workpiece is positioned on the carriage by dimensions "C" and "B" with respect to the pivot axis. A double acting cam, controlling motions "O" and "L", is located above the impeller. The tool and cam follower are aligned and are offset by a fixed value of "A". A second cam "H" is shown diagrammatically on the perimeter of the carriage. It controls the tool offset RD. The Hayes machine is equipped with only 4 degrees of freedom. Ψ is the independent variable and "O" (rotation about the impeller axis), "L" (tool immersion) and "H" (tool offset with respect to the axis) are the dependent variables.

Initially when defining an impeller all generating lines were assumed to pass through the hoop and consequently the "AG" (G denotes generating line) dimension was constant and equal to zero. When the tapered tool was applied to the generating lines the matched tool center line missed the hoop by a value "AT" (T denotes tool). Consequently, a new variable, "AT" was introduced. A different family of tool center lines was derived for each side of the blade with a different "AT" function. The Hayes machine is limited to only 4 (four) degrees of freedom, namely, dimension "A" is a fixed offset. To utilize the Hayes machine it is necessary to redefine the family of generating lines such that, when the tool is matched, the "AT" value will remain constant. Because the suction and pressure sides of the blades must be treated separately two machine settings were required to achieve the best match.

The underlying principle of this method of impeller blade definition was that surfaces can be defined with straight lines. But in fact the surfaces machined cannot be represented by straight lines. Only the tool center line is straight. The actual machined surface is curved because the impeller blades are twisted especially in the inducer. Consequently, the cutting edge is wrapped around the tool. To derive the resultant machined blade, axial traces of the tool trajectory were derived for the suction and pressure surfaces. This then defines the final blade shape. These sections were scribed on mylar and represent the engineering master drawing (EMD).

Application to the OM-1 machine

The Sundstrand OM-1 Machine, shown diagrammatically on Fig. 4, has five degrees of freedom and is tape controlled. There are no geometric restrictions. In fact all the motions Ψ, O, L, H & A can now be treated as dependent variables of position along the line in space. This provides the additional freedom needed to produce the complex shapes of transonic inducers. In addition it provides the flexibility needed to lead the tool in or out of the work piece as well as provide some control in maintaining the tool center line near normal to its direction of motion. Tool feeds and speeds were also derived analytically to assist the process planner in developing optimum cutting conditions. Roughing and pre-finishing cuts were derived leaving a uniform stock for the finishing cut. Multiple cuts for very deep channels can also be derived.

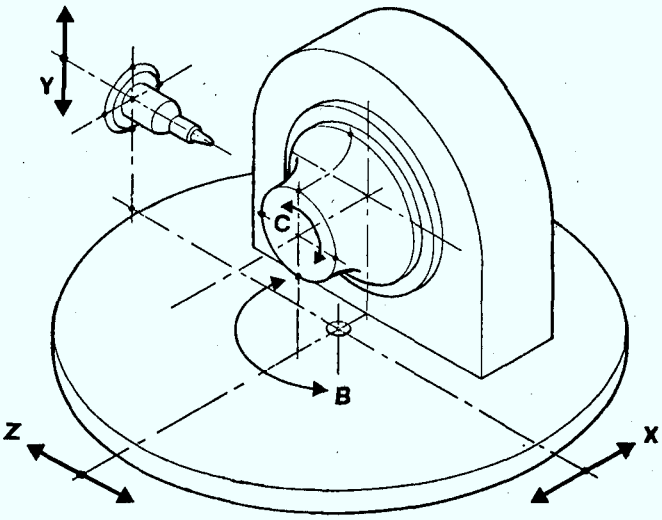


Figure 4

The OM-1 machine is five-axis and tape controlled. No geometric restrictions are involved, all motions can be treated as dependent variables of position along the line in space

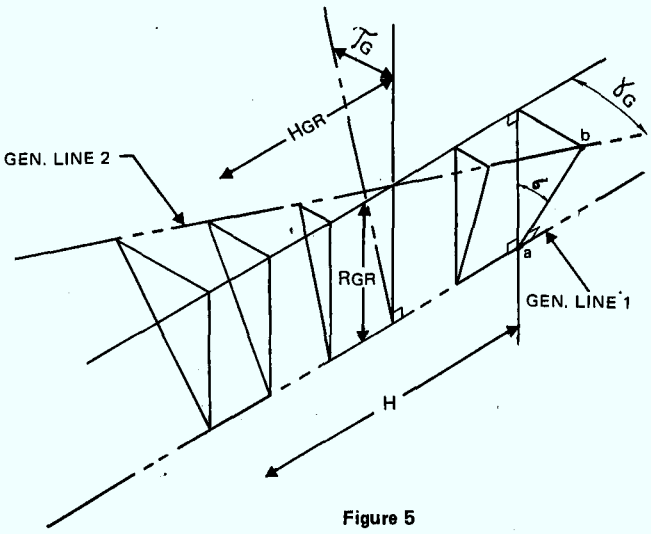


Figure 5

These generating lines have a unique relationship between adjacent lines in space

The Aerodynamics' department conceives the impeller design. They specify the flow center of gravity (C.G.) line which was assumed to be the No. 2 directrix needed to define the blade surface. They also specify the number of full and splitter blades, the hub and tip contours as well as the leading edge geometry and blade thickness distribution.

Manufacturing Process Development Dept. evaluates the machining difficulty and cost. At this stage the tool size and shape is established and the machine is selected.

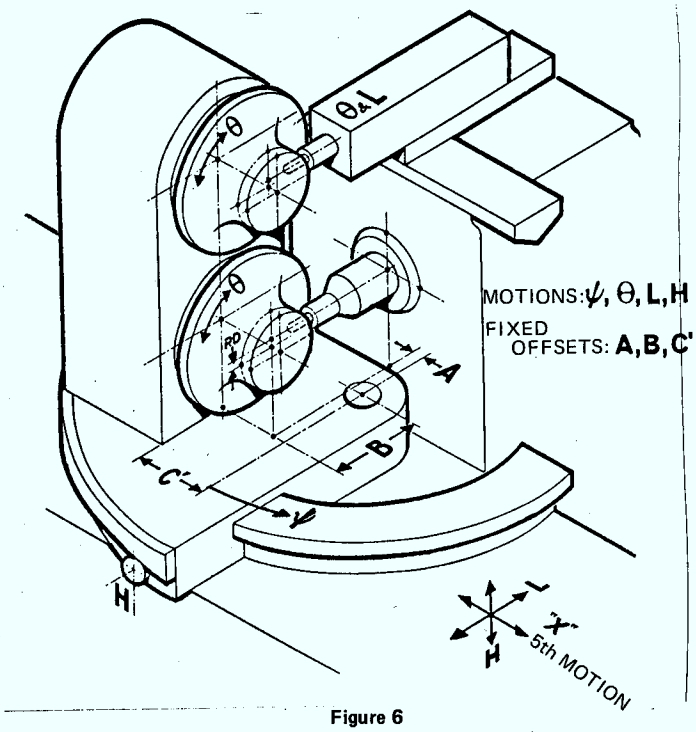


Figure 6

On the milling machines the work-piece is positioned on the carriage by dimensions 'C' and 'B' with respect to the pivot axis

The Stress Department evaluates the blade. Initially they assume that all generating lines pass through the hoop and the axis of the impeller. Stress Dept. then optimizes the offset from the impeller axis to reduce the bending moments and redistribute the stress. They also comment on the thickness distribution and the design in general. If unacceptable the design is recycled through the Aerodynamics Dept.

If the design is acceptable to Stress the blade leading edges are defined. Because of the vertical cam gradient limitation of the Hayes machine (CAM H) the leading edge definition is restricted. The OM-1 does not impose any such restriction. The Stress department then rechecks the leading edges because the blade has been twisted and leaned to derive the desired aerodynamic shape and blade angle distribution. The design is then recycled through Process Development Dept. because of the CAM restrictions of the Hayes machine. The gradient of the CAM controlled "H" motion can in fact be excessive and may restrict the leading edge definition. The Vibration department evaluates the blade and if found acceptable the part then enters the final definition stage.

The machine motions are derived for the suction and pressure sides of the blade. Roughing and finishing cuts, offsets and all other pertinent data are derived. NC tapes are produced to cut the cams for the Hayes machine. Tapes are generated for all the motions of the OM-1. The blade at this stage is fully defined.

The machining data are then used to define the EMD's, the airfoil data (AD) and the inspection gauging data. All of this information as well as the machine motion data are then stored in a permanent data file. The data transfer between departments is accomplished via computer data files.

The P&WC impeller design system is fully automated. The impeller is designed to suit the machine. The design includes a compromised solution mutually agreed to by the aerodynamics, stress and manufacturing departments. More importantly the compromise is arrived at during the design stage when the required changes are least expensive. Also the component cost and complexity are known before being fully committed to production.

Manufacturing development aspects

The impeller for the advanced JT15D-4 jet engine has a radically different blade design, in particular the length of the aerofoil leading edge, the gaps between blades and the degree of curvature. These all posed manufacturing problems.

Going back to the −4 impeller, it is machined on the Hayes 4-axis tracing mills. On these machines the operator must stop the machine to load and unload on the completion of each set of cuts, in total 13 times for each impeller. At the beginning of each new series of cuts the machine requires some resetting. This increases lead times. Continuing with the −4, the roughed impeller receives after 8 operations on the Hayes machines. This is followed by 4 finishing operations on the blades and 2 finishing operations on the hub profile and wedges to produce a finished result.

As a production method this was developed under CAD/CAM as originally stated. Changes to the blade form required iteration with the computer base data to produce the required cam designs for tracing. The cams in turn are produced on N.C. machines.

In all of the Hayes tool paths on blade cutting the tool must return by the same tool path in order to maintain part integrity. This adds time.

Let us now return to the "Q" advance design impeller and review the development of a production method using a 5-axis machining center. It is less demanding on the operator because there are no set ups other than loading a tape. Once the part is loaded it is machined through to the end of the operation.

We required a target time for the "Q" impeller based upon the Hayes method as a basis of comparison. Based upon the extensive Hayes experience on the −4 impeller and considering the increase in the number of blades from 32 to 36, the increase in the aerofoil length and the increase in the number of cuts to compensate for the longer leading edge, we derived a target machining standard of 99 hrs. The titanium forging is profiled, prior to the Omnimil operation.

After considerable development tryout, it was found possible to finish the full section side of the blade in three cuts. In three more cuts the suction splitter (smaller blade) was finished. The early research cutting, with changes in the solid carbide cutting tools, indicated a better deflection control of the blade if we finished this suction side first. Under certain conditions, where the cutter penetration path changed rapidly, we were troubled with variances in the degree of cutter deflection.

It became necessary to control closely the manufacture and maintenance of the cutters. It must be born in mind that, with the increase in both the number and the depth of blades, our tools now were 10 ball-end diameters long and 8° included angle. We are considering procure-

ment of a numerically-controlled cutter grinder to obtain maximum control of the accuracy of these solid carbide cutters.

As a comment at this point, the success of our efforts to date is largely a measure of our ability to manipulate the complex tool path geometry from the computer data base thus giving us complete flexibility to research the best metal removal rates compatible with high product integrity. This is largely what CAD/CAM is all about.

The pressure side of the full blade is finished in one flank-milled cut, as is the pressure side of the splitter. A few more cuts to remove the wedges and the blade cavities are completed. With the Hayes method the wedge shapes and the hub profile have to be finished on a different machine. Here on the Omnimil all has been accomplished in one operation on the multi-axis N.C. machine.

Machining performance comparison

A significant gain in productivity from 99 hrs. to 39 hrs. using the N.C. machine was achieved. We were able, by virtue of the 5th axis capability, to reduce the 5 cuts roughing to 3 cuts. However, additional cutting research is required before we can close the book on this impeller.

A brief comparison of the tooling requirements shows the two special cams required when using the Hayes machines. Five of each would be required for the −4 impeller. With the NC Omnimil only one cutter was required—and a tape and a manuscript.

With reference to setting times, on the Omnimil we load and unload once per impeller, and on the Hayes machines 14 times. This figure illustrates:

a. an improved handling time on the Omnimil,
b. additional durable tooling costs on the Hayes machine.

Looking at the machine standard hours, the total of 48 on the right is for the −4 impeller and the 39.3 hrs. on the left is for the more complex "Q" impeller. As we have already indicated, the equivalent comparison in terms of machining standards would be 39.3 hrs for the Omnimil versus 99 hrs. for the Hayes machine when machining the "Q" impeller. The "Q" impeller will become the production impeller for our JT15D-5 jet engine.

All results indicate improved productivity and lower costs. We can handle more complex parts with better technology. We get more economy with reduced lead times. And additionally, it is important that the productionized method be established at the experimental stage.

Some closing remarks about CAD/CAM would be appropriate. We have, in essence, a complete CAD/CAM cycle for machining impeller blades. We need only define the cutting tool, the viable feeds and speeds and some miscellaneous functions; the rest is generated from stored computer data.

This paper has outlined the design interaction process with the basic aerodynamic definition and culminating with the final machined product. This paper illustrated the degree of integration of the activities of design and manufacturing as applied to the development of high performance centrifugal impellers for gas turbine engines. This design system has succeeded in reducing cost and increasing productivity of a very complex component. □

The time may soon arrive to put a robot in *your* shop

By Jake Koekebakker, Associate Editor

Industrial robot salesmen have pursued potential customers for nearly 15 years with nothing less than missionary zeal. Robots, so they proclaimed, were the ideal answer to the problems of a manufacturing industry beset by rising labor costs, challenges by environmental and occupational health and safety authorities, and pressures for improved productivity.

Even though a modest but steadily growing number of robot applications appeared to substantiate this claim (there were some unmitigated disasters too, to be sure), the robot market boom, which the robot makers in their enthusiasm fully expected, failed to materialize. Industry, it seems, just wasn't buying the concept.

Until recently. For the omens appear to signal a turn of the tide. Nobody seems as yet quite certain of the reasons for or the extent of the marked upswing in robot sales that has been observed, but that it is there, of that there is no longer any doubt. The robot's time may have finally come.

Omen: On October 10, 1979, Unimation Inc., Danbury, Conn., until now the largest of the robot manufacturers and one of the first in the field, announced a record order for 100 Unimate robots by Chrysler Corp. It was, said Unimation, the largest sale of robots in U.S. automotive history.

Although in its announcement Unimation didn't specify the dollar value, it was believed to be of the order of $6 million.

At about the same time, Cincinnati Milacron Inc., a much more recent entrant in the robot field, but coming up fast, announced an even larger, $8-million order for its T³ "Tomorrow Tool" industrial robot by Volvo Car Corp. of Sweden.

Between them, the two deals alone almost beat total automotive industry robot sales predicted for 1979 only eight months earlier by Frost & Sullivan Inc., New York-based international market research organization. Its figure was $15 million.

Omen: The same Frost & Sullivan market study projected total industrial robot sales for 1979 at close to $80 million. Even if it *didn't* underestimate sales in other industry sectors as it almost certainly did in the automotive field, the probable outcome would still be pretty respectable for an industry that did, according to F&S, no more than $26 million of robot business in 1977.

And looking further ahead, F&S may be seeing pies in the sky, but by 1985, it says, robot makers should be booking $438 million. Solid growth, Frost & Sullivan researchers call it. The robot industry, used to years of scraping by, wouldn't argue with that.

Omen: Not just one, but at least two prestigious market research organizations felt confident enough about what's happening to stick their neck out. A market study by International Resource Development Inc., Norwalk, Conn., makes far more conservative predictions than F&S, but they, too, would indicate an end to the slow and painful growth of the robot market throughout the late Sixties and early Seventies. In 1979, IRD says, robot sales should total $40 million, doubling to $82 million by 1984 and again nearly doubling to $140 million by 1989 (these, like Frost & Sullivan's, are 1979 current dollars).

Omen: In the summer of 1979, the Society of Manufacturing Engineers (if any organization in North America has been a hotbed of robot buffs, it has to be SME) published a list of robot manufacturers containing 27 names. Only five months later, five new names showed up at the ROBOTS IV Conference and Exhibition in Detroit. They may have been missed before; if so, they sure weren't hiding their light any longer. They were selling robots. No telling who else might be getting in at any time from here on.

One of the reasons why industry now seems more willing to open its doors to robots than before may be that robots have become better—much better. That fact could be slowly sinking in and superseding a lingering bad taste left by the earliest

About this article

CM&M associate editor Jake Koekebakker first became interested in industrial robots when doing the research for an article on materials handling. Quick realization that robot technology encompasses much more than only handling, and could, in fact, be one of the most important production tools of the future, prompted Koekebakker to start a permanent file on the subject. Last summer, he attended a three-day seminar on "Robots in Manufacturing," organized by the Society of Manufacturing Engineers and led by William R. Tanner, one of America's leading authorities on robotics. CM&M's associate editor came away with an SME "Certificate of Completion" and much new learning to add to previously gained insights. This feature is the result. Says Koekebakker: "Once you get as deeply involved in a subject as I did in robots, it becomes difficult to know what sources to credit with respect to what you write. I can only say that none of it is of my own invention. It certainly would not have been possible writing this article without the input from Tanner, SME, and Ken Adams of A. F. Mundy Associates, as well as many others I talked to. As for any shortcomings, they are mine."

robot generations, which, most industry observers agree, just didn't work all that well.

In addition, technological capabilities are now available that were still unheard of 10 years ago—particularly in control technology and programmability. Robot makers have discovered electronic logic and computer-type software. They have given some robots unprecedented adaptability to a wide variety of increasingly complex tasks.

Another reason for the increasing popularity of robots is that while labor and other production costs have continued to soar, robot manufacturers have, by and large, held the line on prices.

Whatever the reasons, the 1980s may well be the Age of the Robot. More and more plant managers will almost certainly have to be seriously considering robots as a means of improving productivity. And in doing so, they may find themselves largely on their own. For, even though robots are already being used in numerous applications, each individual situation is, in some respects, unique. Being a relatively new technology, robotics can as yet claim little in-depth experience. What there is of it is often jealously guarded by those that have it in the belief it gives them a competitive edge. They don't want to share that with anybody else.

It's not unlikely, therefore, that in robotics applications the wheel is being reinvented many times over.

The other thing the potential or neophyte robot user has to contend with is a briskly competitive atmosphere in the robot industry itself. Fact is, few robots can do all things, and even less do all things equally as well. Robot salesmen, in their understandable fervour, have been known to conveniently ignore this occasionally (it's nothing new—it happens in any line of business). There are definitely optimum choices to be made in a field that may now include over 30 makes of machines. Many of these are aimed at specific types of jobs. It pays to know which is which.

The word is, beware, learn all you can, and keep your feet on the ground. Which is what this Survey is all about.

It is based on the premise that many plant managers today no longer need to be convinced of the weird and wonderful miracles robots can perform for them. What they need to know is: Can I solve *my* problem by means of a robot and, if so, which one?

This survey is intended to help you find some of the initial answers and identify some possible solutions.

Let's assume you have a specific problem. For example, you want to load a part into a machine tool and, following the machining cycle, take it out again. Whatever the reason, you want to automate that operation.

You have heard robots can do that sort of thing. Yes, but almost every machine loading and unloading operation is different from any other. In fact, for every machine loading and unloading operation robots *can* do, there probably is one they can *not* do.

So, before getting completely stuck on the idea of getting a robot for the job, ask yourself: Are there any other ways to automate it? Keep your options open, and start from square one.

Square one is studying the job. What is it *really* that goes on there? How is it done? Why is it done that way? Could it be done any other way? And where are the potential glitches? Don't just find out what the likely problems are; analyze all that could *possibly* go wrong.

You've got to know that job better than the operator himself. The more you study it the better. Sit in a corner and watch for a shift or two, if you can get away with it without driving the operator crazy.

At this point look for all the reasons why you should *not* get a robot.

Here's one of the most common reasons why you shouldn't. Your operator, like thousands, nay, hundreds of thousands like him, has got a tote box of parts on one side, and he starts the cycle by picking one part out of the box, and . . . hold it! He did what? Pick one out of a box-full of parts?

A robot can't do that—at least none you can buy today. Robots have no way of telling where the next part is unless it is in the exact same spot as the previous one, or another, precisely predefined spot. Nor can they pick up parts unless these are in exactly the same orientation. You don't want the robot to put the part into the machine backwards, do you? The robot wouldn't know where to reach or how to orientate its gripper, unless you want to install a lot of fancy electro-optical gear, and even if you could afford that, the results would be dubious with today's off-the-shelf technology. They are working on it, but as off today it's not on.

The only way to get around the problem is to present the parts in an orderly way—say, neatly stacked in rows on a pallet (not even all robots can be programmed to handle that). But how are you going to accomplish it, looking back up the line? It could be a real headache. Experience in the field, in fact, indicates that 50% of all the cases where it was thought a robot could be applied turn out to be unworkable due to lack of parts orientation.

All this goes to show that robots are no simple answer. And it demon-

What's a robot?

It has sometimes been hard to tell what is a robot and what is not. The last word on the subject, hopefully, comes from the Robot Institute of America. An RIA committee consisting of users, manufacturers and researchers put the matter to a vote. The winning definition: A PROGRAMMABLE, MULTI-FUNCTION MANIPULATOR DESIGNED TO MOVE MATERIAL, PARTS, TOOLS OR SPECIALIZED DEVICES THROUGH VARIABLE PROGRAMMED MOTIONS FOR THE PERFORMANCE OF A VARIETY OF TASKS. So that's what it is.

The robot market into the '80s

$ thousands

	1977	1979	1981	1983	1985
Electrical Machinery	3,406	15,840	41,108	58,400	163,812
Automotive	1,924	14,880	21,156	32,120	53,874
Fabricated Metals	11,622	16,480	26,144	56,648	67,014
Electronics	78	1,600	11,696	12,264	70,080
Heavy Machinery	5,512	12,240	18,576	23,944	12,702
Others	3,458	18,960	53,320	108,624	70,518
Total	26,000	80,000	17,200	292,000	438,000

Source: Frost & Sullivan Inc., New York

The more you are in charge of your own engineering, the better

Parts must be presented to a robot in an orderly way. Here, ASEA robot picks workpieces of indexing table for deburring operation

strates something else, and that is that you've got to think systems. Robots never work in isolation. What you are looking for is a system component, and it's got to be compatible with the rest of the shooting match.

OK, suppose you've figured all the angles, racked your brain, cursed the boss (and, heaven forbid, your wife), and there's nothing for it, a robot seems to be the answer. Now what do you do?

For one thing, get rid of the idea of getting "a robot." You can get 40 robots, maybe more, all of them different. Some, in fact, so different you wonder why they still call them robots.

What you have to do is to start two more or less concurrent processes. One is to study robots, and the other to engineer your application. The former you can start doing by referring to the list of robots in this Survey, and the latter by reading this:

If you are not sure you can handle your own engineering, by all means get outside help, preferably from a qualified consultant (robot systems consultants are still a rare breed, but there are some). But *don't* leave it to a robot manufacturer. By all means, treat the manufacturer's salesman with respect, and listen to what he has to say, for he knows his robot, but listen with critical reservation. For, after all, he's there to sell robots—his. The more you are in charge of your own engineering, the better. Nobody knows your plant and the job in question as well as you do—if you've done the homework you should have done anyway.

Don't forget, there may be other robot users that could give you valuable tips. Ask the manufacturer's rep about them. He *may* tell you. If not, wonder why not.

What happens next is that you start to match your engineering requirements against a matrix of comparative robot specifications, such as the one presented in this Survey. It will give you an idea of what's available that is compatible with your needs and with your financial resources.

Any generalized description of the major functional parameters of industrial robots tends, as with any equipment, to be limiting when applied to the individual machine. Various robot makers have their own preferred ways of describing their products. The following should only be seen as an attempt to provide the potential user with a set of descriptive terms on the basis of which a comparative evaluation can be made over the broadest possible range of capabilities. It is, in other words, a means for making the initial assessment of what's in the ballpark and what's not.

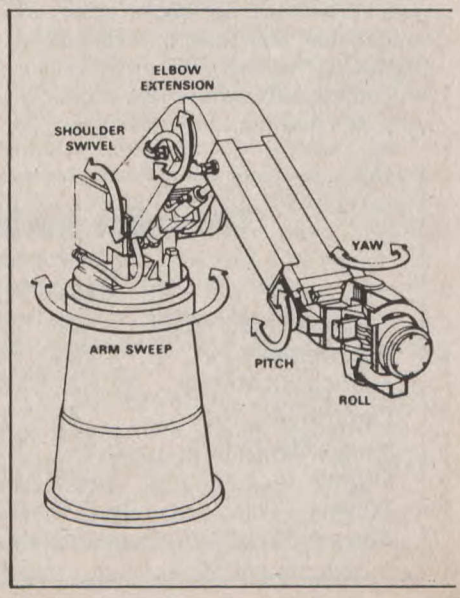
Axes of motion—To a great extent, the robot's axes of motion, or degrees of freedom, determine the complexity of the aggregate movements it is capable of. The term, in essence, expresses the number of moving joints.

Arm movement—This defines the robot's "reach", or "work envelope". The work envelope usually has one of three shapes, cylindrical, spherical and spheroidal, depending on the basic configuration of the arm and on the major axes of motion. For practical purposes, the description of the work envelope can be simplified by citing only its three major parameters: Degrees of rotation about the centre axis (*horizontal* arm sweep); *vertical* motion at both minimum and maximum arm extension; and *radial* arm extension, measured from the centre axis. It is a simplification, but it gives a rough idea.

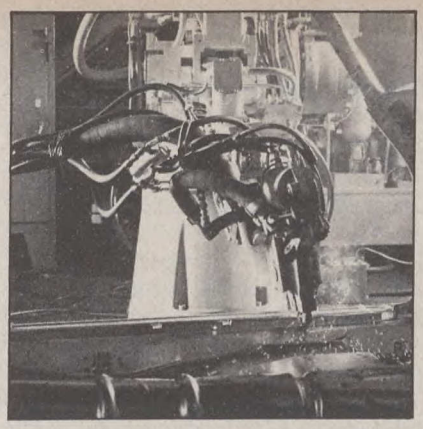
Wrist movement—Although wrist movement can make a minor contribution to the shape and size of the work envelope, its main significance is the ability to orientate the gripper or any other end-of-arm tooling. *Pitch* refers to wrist movement in the vertical plane; *yaw* represents movement in the horizontal plane (swing); and the ability to rotate is denoted by *roll*.

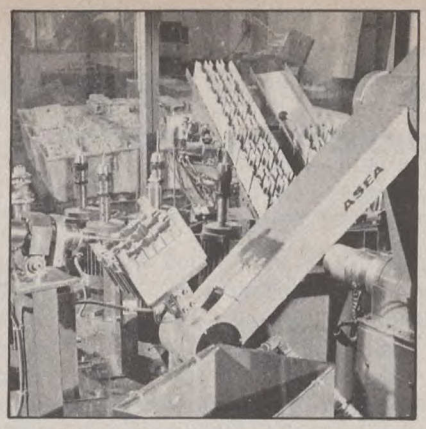
End of arm speed—You can get more arguments about a robot's end of arm speed than you can shake a stick at. It varies depending on the axes about which the arm is moving, its position in the work envelope, and the load being carried, to name a few factors. Keeping that in mind, a reasonable, though somewhat simplistic, question to ask still is: How fast can the gripper get from an arbitrary point A to an arbitrary point B in the envelope, empty, and how fast can it move back from B to A fully loaded? The best answer you can expect is a ball-park figure, unless you are willing to accept your answer in the form

Axes of motion represent complexity of aggregate movements of which robot is capable. Both models shown here have six axes of motion



The tool may be brought to the work, as a Cincinnati Milacron robot spot welding autobodies is doing (left), or the work may be brought to the tool, as demonstrated by ASEA robot drilling and deburring contactor housings

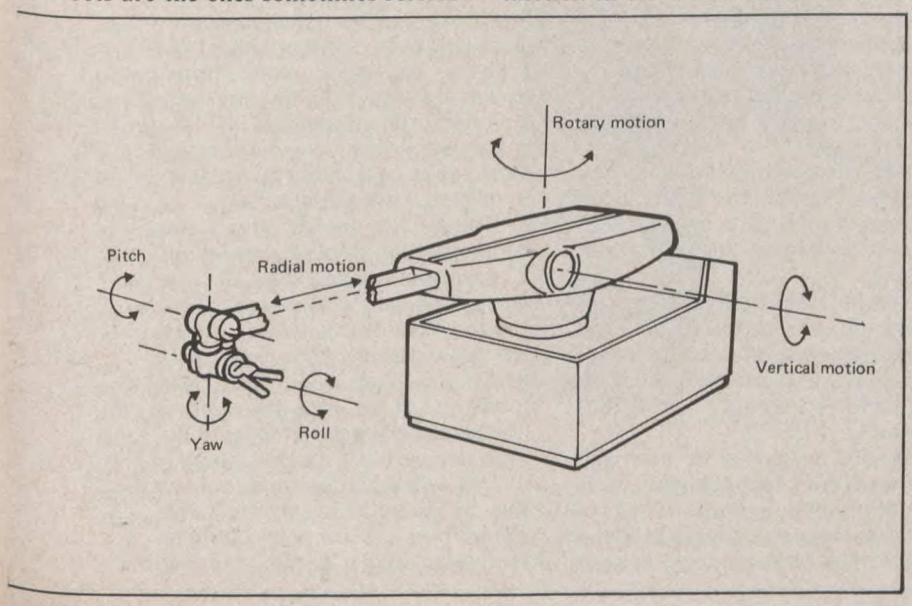




of a differential equation, or something like that.

Weight carrying capacity—You can get almost as many arguments about weight carrying capacity as about end-of-arm speed, primarily because the two are so closely related. You are still in torque/inertia/momentum/acceleration territory here. Still, it is relevant to ask: What is the weight the robot can practically move from A to B? It is defined as the maximum load that can be carried, at low speed (this is given as a percentage of the maximum speed), and as the load that can be carried at normal operating speed. Again, the answer is a ball park figure, and you can take it with a grain of salt. (Some robot makers circumvent the issue by stating the robot's static load capacity, but what good is that? You want to get the stuff moved!)

Control—Some people like to talk about low-, medium-, and high-technology robots. The inferiority/superiority inference it carries, well, it just is not fair, and what does it tell you anyway? Much more revealing—and technically precise—is to classify robots according to the type of control employed. *Non-servo* robots are the ones sometimes referred to as "end-point" or "limited-sequence" machines. They move between end-points on each axis only (although some intermediate stops can in some cases be provided). They provide relatively high speed; a high degree of repeatability, to within 0.25 mm; and are low in cost, simple to operate, program and maintain, and highly reliable. But they are limited in programming versatility and positioning capability. *Servo-controlled* robots, typically, provide the capability to execute smooth motions with controlled speeds and sometimes even control of acceleration and deceleration, resulting in controlled movement of heavy loads. You can't just throw a 1,000-lb. load through space without servo control. They can be programmed to any position on each axis anywhere in the envelope; more than one program can be stored. End of arm positioning accuracy is of the order of 1.5 mm. (0.050 in.). These machines are more complex, and therefore involve more sophisticated maintenance, are less reliable, and more expensive. An important distinction in servo-controlled robots is between *point-to-point* and *continuous-path* machines. Point-to-point robots are programmed for each end of arm position, without regard for how they get from one point to the next. They are represented primarily by the largest, heaviest-load-capacity machines. In continuous-path machines, on the other hand, the paths that the end of the arm takes through space are defined by the program. Continuous-path robots are smaller and lighter than point-to-point robots, have higher end of arm speeds, and load capacities are generally less than 10 kg. They are used mainly for applications such as spraying paint, arc welding, and grinding and polishing. Some machines, incidentally, act as if they are in the continuous-path category, but really are point-to-point devices; it's just that they provide the capability for defining one heck of a lot of points; each point, nevertheless, must be programmed in.



Memory—The robot memory is part of the controller. It stores the commands that have been programmed in and, through the controller, tells the robot what to do and when. Since the type of memory determines how commands are stored, it gives an indication of the sophistication of the program it is possible to executive, and the degree of flexibility in programming that is possible. *Mechanical step sequencers* include devices such as rotating drums. Other memory devices are pneumatic systems such as *air logic* controllers, electrical memories such as *patch boards* and diode matrix boards and step switches and, finally, electronic memories, which include *magnetic tape* cassettes, floppy *discs*, and *microprocessor*-type devices (ROM, RAM, PROM). It should be pointed out that a combination of memory devices is often employed, such as

Don't simply try and emulate a human operator by a robot

tape cassettes in conjunction with a microprocessor-type memory.

Programming method—There are three basic approaches to telling a robot what you want it to do: Off-line—by presetting the cams on a rotating stepping drum, for instance, or connecting up air logic tubing (for non servo robots, programming also includes the setting of limit switches is on each axis). This type of programming is usually referred to as *manual*, and is associated with mechanical, pneumatic and electrical memories. As soon as you get into electronic memories, with the potential for more complex programs, you would be all day if you are lucky, or all week if you are not, just wiring up your robot. Instead, what you do is either push buttons, or, and this is almost literally true, you take your robot by the hand and show it what to do. The push-button approach, referred to as *lead-through*, consists of manoeuvring the robot arm from one desired position to the next by means of the control console; all you have to do is push the "record" button at each point, and, once the program is complete, the robot will repeat this sequence from point to point, *ad infinitum*. If you are not so much interested in the exact positions through which the robot arm will sweep, but more in the actual trajectory, you could still program it simply by defining a lot of points. A lot easier would be, though, to use *walk-through* programming; you physically guide the robot arm (or a special teaching arm) through the desired motions, and the robot will repeat *exactly* what you taught it, including any goofs.

Memory capacity—There are several ways memory capacity can be expressed. Simplest is to indicate the number of steps or distinct motions and functions the robot can perform in a single program.

Positioning accuracy—How closely can you program a robot hand to go where you want it to go? Or to put it in another way, how closely should you position a part for the hand to be able to pick it up? Unless equipped with a special sensing device, a robot cannot see what it is doing, so this is an important quantity.

Repeatability—Once you have got a robot hand to go where you want it to go the first time, repeatability will determine how close to that same spot it will return—again and again, and again.

Power—What makes the robot move? It is not a moot question. For one thing, the working environment has a lot to do with the choice of power system. Many of the same criteria apply here as with other types of industrial machinery.

Cooling—Some robots need cooling. The main thing is to make sure you know which type of cooling, and you better talk to your plant engineer, too.

Maximum ambient operating temperature—They say robots can stand the heat of any shop and keep going when a man would long since have dropped in his tracks. Well, there *are* limits. To be sure, end-of-arm tooling may take a lot more before burning its fingers, than the arm and base, and the control console a lot less, particularly if it has a mess of computer logic inside. All of this has got to do also with how much cooling may be required.

End of arm tooling—This is what goes on the end of the arm to do the job. Mostly, it will be a gripper, often referred to as the hand. But it doesn't have to be a hand. Actually, you can put anything you like on the end of the arm. Besides grippers, vacuum

What's coming? Sensory feed-back, specialization,

William R. Tanner, president of Tanner Associates, Farmington, Mich., is recognized as one of the most knowledgeable authorities on robotics in the United States, and well known in the field throughout the world. His more than 10 years of direct experience with robots is backed by more than 20 years in product and manufacturing engineering in the automotive and aerospace industries. He was responsible for the conception, development and installation of the first multiple-robot transfer line production system for body spot welding at Ford Motor Co. He developed one of the first robot systems for exterior painting of automobile bodies, and numerous other tool handling, material handling, and assembly applications for industrial robots. He has served as a technical advisor to several major industrial robot manufacturers. Here's what he has to say about what's coming in the Eighties:

□ "The major thrust is in development of sensory feed-back capability. It gives the robot the capability to see or feel or otherwise sense a load, and to react to what its sensor is telling it.

"Sensor development in itself is pretty well state of the art. You can interface a solid-state camera with a microprocessor for less than $3,000.

"On the other hand, robot manufacturers are working on new control schemes that will allow on-line input data to modify a program that has been stored even while it is running.

"What's lacking is the marriage of these two technologies. It is easy to hook up sensors to microprocessors to digest and produce usable data, but how do you plug it into a robot if the robot is talking one language and the microprocessor is talking another? That's the problem. You can't go someplace and buy a standard interface package. The robot manufacturer would have to tell the interface manufacturer all about his language and how his logic operates. Most robot companies don't want to tell you a thing about that.

□ "One of the trends that I see coming is that robots will be less of a general-purpose kind of machine. They will become more specialized, like the painting robots. We see it already with systems in which the basic robot has been modified, or at least the control has been modified, to facilitate doing a certain class of applications.

"You will see more and more of this as manufacturers and users realize that it is not particularly effective to buy a general-purpose

pads are the most common off-the-shelf tooling, but put on anything you desire (if you want to pay for custom design)—put on a foot if you like, and you can make it kick the garbage can.

Interfacing—Except in a few applications, most robots need to communicate and interract with the outside world. This can take the form of simply on/off signals by means of electrical, or pneumatic, contacts, or consist of more complex electronic signals. *Inputs* are the number of lines over which the robot will accept signals from the outside world, and *outputs* are the lines over which it will send signals to external equipment.

It would be easy if you could just sit down and say, I need so and so much work envelope and such and such a control scheme, and then just select the set of numbers that most closely fit the picture. But, remember, you are dealing with a system. There are a lot of other factors that have to be taken into account.

Here are some considerations that may help doing that:

□ There is a rule of thumb in the industry that says that if you can replace two men with a robot, you can probably afford to look at a medium-priced, servo-controlled robot; if you can replace one man, you are probably looking at a non-servo or bang-bang machine; if it is only half a man (half his time, that is) you may have a problem justifying any robot.

□ Don't simply try and emulate a human operator by a robot. On the one hand, there are things a man can do that a robot can't do—many things, come to think of it. But on the other hand, some robots can do tricks no union would stand for, like working all day long without getting tired hanging upside down from the rafters (in some plants they mount them on an overhead crane). It's great for saving floor space. Nor does a robot really care whether it is taking the work to the tool or the tool to the work; there are places where they have a robot manipulate heavy, bulky workpieces around a pedestal-mounted welder, i.e., no part fixturing, and getting it in and out of the fixture all day long.

□ Again, try and think of all the screw-ups you can, and imagine the dire consequences as picturesquely as possible. Such as when a robot puts transmission casings on overhead conveyor hooks, and the hook isn't there when it should be (or it may be swinging). What does the robot do? Ouch! And there is more, much more.

□ How do you index parts for pick-up when they've got to be in the right spot within, say, 50 thou?

□ Robots are reputed to be capable of 98% uptime. But they can, and do, break down for the other 2%. And if those 2% come in one or two chunks, it could be a sort of major catastrophe. It might not kill you, but it could cost you a bundle. So, what do you figure in the way of back-up? Can you put a man back into the operation? Yes, *can* you? Suppose you did hang your robot from the ceiling to save floor space. Can the man still squeeze in there? And so forth.

Moral: Take these things into account in your trial layout.

□ If you can, buy a little extra. Moving a 50-lb load? Figure on 60 lb, or 75 (don't forget end-of-arm tooling—it can weigh too). You don't want to overspecify more than you have to, but what's the price of peace of mind? And after all, you might want to change your mind after you've ordered the machine, or somebody else might do it for you.

□ Try and think of all these things *before* you get anywhere near deciding which robot you are going to install.

□ Try and think like a robot—no kidding.

There are a lot of other considerations to keep in mind but they are no different from those related to installing any piece of machinery. Such as: reckon with utility requirements; figure out safety-related consequences of the installation (barriers around work envelope, safety interlocks, etc.); and how will the rest of

and software

machine and apply it to a specialized task.

"I don't know how long it is going to take before some enterprising company will come up with a better robot for press loading. It is a big class of potential robot applications that is not particularly well-satisfied by what is on the market today except for very small parts. For large parts, current robots are either to slow or too inaccurate to do an effective job of loading and unloading presses. What is needed here is something that is fast and accurate.

"Another area where I see the trend towards more specialized robots is in assembly. I see the assembly robot as having off-line programming capability, sensory feed-back capability, fairly good manipulative power, and fairly easy change-over.

□ "The trend in the last six or seven years has been to hold the line on prices. I don't necessarily see any large price increases coming down the road in the near future—primarily because the volume is finally starting to go up.

William R. Tanner

□ "I see more people getting into the robot business. I know there are more people looking at it, and they are taking a fairly intelligent approach. Many of them are looking at certain segments of the robot market.

□ "Control capabilities keep going up. The price of electronics keeps coming down. You can buy a lot more computational power and control capability now than five years ago. That trend is going to continue to a certain extent, although I think it is rapidly reaching the point where software development is becoming a major expense to the manufacturers. The trend is towards more software and less hardware. A major advantage to this is that your control system is not going to be obsolete in a couple of years. You can upgrade the same machine with the latest software, and keep it operating."

The main criterion: What does a robot mean to the bottom line?

the plant lay-out be affected. And so forth, and so forth.

One vital item worth worrying over from day one is end-of-arm tooling. It could be a bit of a problem. If you have a simple transfer operation, you can in most cases get off-the-shelf tooling from the manufacturer—in fact, some of them have quite an assortment. But the number of operations where standard tooling does not fit in is far from negligible.

If the manufacturer doesn't offer custom tooling—and many do—you can always go to a tooling shop. Or you can make your own. People have been known to make perfectly acceptable end-of-arm tooling out of a few pieces of dirty old scrap iron. In some cases all you need is a bracket to, say, mount a welding gun. It isn't necessarily complicated, but it *can* be. You better be prepared to experiment, starting early.

Another consideration that merits premeditation is maintenance. Chances are, your maintenance people's idea of a robot is strictly Star Wars style.

Remember the way it was with NC? Well, a lot of maintenance crews did get used to that. All it took was some extra, specialized knowledge.

Robots may be odd beasts, but underneath the cover plates there is really nothing much that would phase an averagely competent plant mechanic or electrician. Certainly on the mechanical side, robots are straightforward and easy to fix.

Of course, you can plan to rely on the manufacturer for maintenance. But robots have a way of quitting mid-morning on Monday or any other time as inconvenient as possible. Don't count on getting a company maintenance man flown down less than 24 hours later. By then, it doesn't make much difference anymore whether he fixes the thing in five minutes, which has been known to occur, or three hours, or six, or twelve. It's all equally embarrassing.

Generally, it's much better to plan having the manufacturer train your own people. Most of them will, if they know what's good for them.

Several skills may be involved—separately or in combination. Number one, probably, is the electrician; some basic training in solid-state electronics would be helpful but not necessary. Your pipefitter may have to look after the hydraulics if your robot has any, which is likely, but there is nothing magic about robot hydraulics. Just a lot of it, in some. And, finally, the plant mechanic may

Why robots are a better deal today

Ken Adams, of A. F. Mundy Associates (Canada) Ltd., Rexdale, Ont., is known as one of the most knowledgeable robot experts in Canada. He has been in the field for the past 10 years, specializing in production systems, particularly those involving machine tools of every description. In fact, there are very few machine tools with which he hasn't had hands-on experience, and, he claims, very few major shops in Canada he hasn't been into. He was responsible for the installation of one of the first sophisticated robot system installations in Canada, at International Harvester, the first to combine a depalletizing, feeding and loading and unloading operation, using three robots. Having lived through a decade of robot evolution, Adams explains why he thinks robots today are a better deal than they have ever been:

" . . . One of the biggest problems originally was the cost of the machine versus cost of labor. I think that if you were to go back today to applications that you looked at six or seven years ago and at the time weren't able to justify, half of those same applications would not only now be solved better from a technology standpoint, but they could now be justified easily. The price of robots hasn't changed that drastically. It has perhaps gone up by 20% as all manufactured goods in that category have. Volumes have gone up, so the manufacturers have been able to build more machine at less cost than they could have originally.

"But, more importantly, the cost of labor has gone up so drastically that the robot now is economically more viable. Added to that of course, there is the question of occupational health and safety.

"Reliability probably still is the one of the greatest concerns most potential users have. Initially, robots were used in a cut and try situation. The manufacturer had a general idea of what his machine would do, and the end user had a general concept of what *he* wanted the machine to do. Where the two were compatible, you had a very successful application. Where the two were not compatible, for one reason or another, you had problems. Now, when you look at the technological development that has occurred in the last 15 years, on the mechanical side as well as in electronics and control systems, and when you couple progress in these areas to the progress that has been made in systems engineering, to the experience that has been gained in choosing the correct applications and the correct kinds of tooling, you will find the overall reliability of the robot is probably much better than the reliability of the average NC machine tool. I don't think there is too much question about that.

"The other thing that's happened to improve this overall reliability is that manufacturers have realized, from looking at the experience of the machine tool industry, that in order to improve the reliability, they had to train their customers in preventative maintenance. They also had to discipline themselves in the maintenance area to make sure that they had available the necessary parts and the necessary service people to keep the product running.

The other discipline manufacturers have imposed on themselves is to say no, and turn down an application that it is not feasible and viable. Certainly the older companies are doing this now. The younger companies may not to as great an extent, but even they are now getting enough sales engineering expertise, not to get

have to stand by. No telling what he might have to get into, but those fellows are used to that.

The point is, when you are doing the preliminary evaluation, take into account what maintenance skills you would need and, regardless of who does the maintenance, the location of the manufacturer's service depot(s). A rule of thumb used in the industry, incidentally, is that for every 10 to 12 robots you need one maintenance man per shift.

While you are doing all this planning, you may ask yourself from time to time: Is it all worth it? That's a good question. The fact is, one of the major reasons why the robot industry hasn't up till now seen as much growth as it expected is that all too often ROIs (return on investment) proved to be inadequate.

It is being said that one of the main justifications for robots is their ability to relieve the human worker of undesirable jobs. In practice, that just doesn't turn out to be the key factor—not in North America, anyway. While there are some robot installations that were put there specifically to meet occupational health and safety regulations, most robots are bought for the hard-nosed reason of reducing production costs or improving productivity. The main criterion, in other words, is: What does the robot mean to the bottom line?

There are several ways of measuring this, of course, and they are no different from those followed in assessing any capital equipment. You'll probably want to go with a straight ROI calculation, or look at pay-back time.

There are, of course, some "non-economic" justifications too, although you can hang a dollar sign on almost anything you want to. They should enter the picture. Health and safety certainly is one of them. And the fact that the robot doesn't get tired—therefore: more consistent productivity; but also note the potential for better quality, and reduction of scrap and rework. And there will be less worry about absenteeism, goofing off and messing up.

One robot bonus some people are still fond of mentioning is its flexibility, namely that it could be moved somewhere else when the job it is bought to do expires for some reason or other. That *may* be true for *some* robots, for *some* tasks. In practice, it rarely turns out that way. Industry experts say very few users have ever moved their robots. They usually stay put, wherever they were placed originally, doing what they were bought to do there.

Who knows? Not that many robots have been anywhere all that long—long enough, in any case, to outlast their original job, and who is to say that day may not come? But in terms of the more or less immediate requirements, reckoning with the average pay-back times, which are no less than seven years, it's a tenuous argument at best. Don't use it.

The objective of this article is to assist the potential robot user in doing some of the preliminary planning. Hopefully, what it will lead to is the possibility to identify two or three serious candidates. That will only be the beginning of the real nuts and bolts evaluation, talking brass tacks with the manufacturers.

One hazard in compiling a listing such as the one that follows is missing someone. From the outset, the objective was to include *all* North American sources of industrial robots and all of the products they offer. In all, CM&M contacted 32 manufacturers.

The companies whose names are on the list are, as far as could be ascertained, suppliers of one or more types of industrial robots. Unfortunately, some failed to respond to our requests for information, and their product(s) could not be included. That doesn't mean they might not be worth a try if you are looking for a robot. Perhaps you'll have better luck than we did.

In the case of each manufacturer, an attempt was made to list each available model separately. Only where too much overlap in the specifications for very similar models occurred were they combined. And it goes without saying that in some cases optional configurations are available which space did not permit being listed.

The data in the following pages are based on information provided by the manufacturers in the form of answers to a questionnaire. Bear in mind that in some cases the answers are, of necessity, interpretations and/or approximations. We verified each answer as well as we could, and we believe they will provide the user with a reasonable basis for comparison. But the final proof of the pudding is the manufacturer's own spec sheets.

Ken Adams

caught in taking on applications that they can't handle.

"On the other hand, there are enough customers now with robot experience that if a potential user has questions, he can go to people that have been using robots now for five or six years—in some cases nine or ten years, and get some reasonably honest answers as to the kinds of problems that they experienced when they installed their machines."

Pick and place

Several among the manufacturers of mechanical transfer devices objected that their products are not really robots. Given the definition of a robot as a *programmable* device, which pick-and-place machines are not, this objection is justified. But in some cases, this may be all you need. The manufacturers of mechanical transfer devices, therefore, are listed separately, although their products are not included in the Survey listings.

References

The Industrial Robot Market; *Frost & Sullivan market study; 1979; 250 pages; Frost & Sullivan Inc., New York.*

Industrial Robots in the 1980s; *International Resource Development report; 1979; 208 pages; International Resource Development Inc., Norwalk, Conn.*

Industrial Robots; *Volume I; William R. Tanner, Editor; 1979; Society of Manufacturing Engineers, Dearborn, Mich.*

SPECIFICATIONS / Source / Model	ASEA IRb-6	ASEA IRb-60	Auto-Place 10	Auto-Place 50	Binks MK II-90
Axes of motion	3, 5 or 6	3, 5 or 6	6	6	6
Movement					
arm—horizontal (degrees of arc)	340	330	200 (360)	200 (360)	85
vertical (min. mm, max. mm)	520-1510	170-1900	0-508	0-127	2057
radial (mm)	950	2000	940 (1093)	940 (1093)	914
wrist—pitch (degrees of arc)	180	195	(270)	(270)	190
yaw (degrees of arc)		300	(270)	(270)	190
roll (degrees of arc)	360	360	270	270	190
End of arm speed					
average max. unloaded (m/s)			2.5	1.5	1.7
normal operating, loaded (m/s)			1.2	.74	var.
Weight carrying capacity					
max. at low speed (kg @ %)	10 @ 60	100 @ 60	4.5 @ 25	14 @ 25	27.2 @ 50
at operating speed (kg)	6	60	1	4	13.6
Control					
non-servo			✓	✓	
servo—point to point	✓	✓			
continuous path	✓	✓			✓
Memory					
mechanical step sequencer					
air logic			✓	✓	
patch board (electrical)					
magnetic tape/disc					
microprocessor	✓	✓		✓	✓
other (specify)					
Programming method					
manual			✓	✓	
lead-through	✓	✓			
walk-through					✓
Memory capacity (no. of steps)	250-15,000	250-15,000	24 (100+)	24 (100+)	2x300 sec.
Positioning accuracy (± mm)	0.1	0.2	1.3	1.3	4
Repeatability (± mm)	0.05	0.1	0.6	0.6	4
Power—hydraulic					
pneumatic			✓	✓	✓
electric	✓	✓			
Cooling—air					✓
water					✓
none	✓	✓	✓	✓	
Max. ambient operating temperature (°C)	50	50	50	50	45
End of arm tooling					
off the shelf—gripper	✓	✓	✓	✓	
vacuum pad			✓	✓	
other (specify)			Magnets	Magnetic	
custom design	✓	✓	✓	✓	✓
Interfacing					
Inputs (number)	16+	16+	Any number	Any number	16
Outputs (number)	14+	14+	Any number	Any number	16
Potential application(s)	1 3 10 17* 20	1 3 10 17* 20	2 7 8 9 11 14 15 17 18*	2 4 7 9 11 12 14 15 17 18*	Paint spraying
Number installed—U.S.	not spec'd	not spec'd	300	400+	7
Canada	not spec'd	not spec'd	6		
Overseas	not spec'd	not spec'd	70	10	40+
Price of basic unit F.O.B. manufacturer (U.S.$)	60,000	90,000	70,000	12,000	75,000
Name of Canadian representative	ASEA Ltd	A. F. Mundy Associates Canada Ltd.	A. F. Mundy Associates Canada Ltd.	Binks Mfg. Co. of Canada Ltd.	
Location(s) of service depot					
parts	White Plains, NY. Montreal Toronto	White Plains, NY. Montreal Toronto	Troy, Mich. Rexdale Ont.	Troy, Mich. Rexdale, Ont.	Franklin Park, Ill.
service	same	same	same	same	same

***1—arc welding 2—assembly 3—deburring 4—die casting 5—drilling 6—flame cutting 7—forging 8—foundry 9—gauging 10—grinding 11—heat treating 12—injection moulding 13—investment casting 14—machine loading & unloading 15—metal stamping 16—palletizing 17—parts handling 18—press feeding 19—routing 20—spot welding 21—spray painting 22—tracking.**

SPECIFICATIONS / Source / Model	Cincinnati Milacron T³	Cincinnati Milacron HT³	DeVilbiss TR-3000	General Numeric Fanuc 1	Industrial Automates 9500
Axes of motion	6	6	6	5	
Movement					
arm—horizontal (degrees of arc)	240	240	135	210	90 (120)
vertical (min. mm, max. mm)	0-3960	0-3960	2044	500	178
radial (mm)	2465	2615	2185	800	609
wrist—pitch (degrees of arc)	180	180	176		180
yaw (degrees of arc)	180	180	176		180
roll (degrees of arc)	240	240	210	90/80	180
End of arm speed					
average max. unloaded (m/s)	1.3	0.9	1.7	1	0.76
normal operating, loaded (m/s)	1.3	0.9	var.	1	0.76
Weight carrying capacity					
max. at low speed (kg @ %)	45	100		20	4.5
at operating speed (kg)	45	100	4.53	20	4.5
Control					
non-servo					✓
servo—point to point				✓	
continuous path	✓	✓	✓		
Memory					
mechanical step sequencer					
air logic					
patch board (electrical)					
magnetic tape/disc				✓	
microprocessor	✓	✓	✓	✓	✓
other (specify)					
Programming method					
manual				✓	
lead-through	✓	✓			✓
walk-through			✓		
Memory capacity (no. of steps)	700+	700+	2 hr.	80	1000
Positioning accuracy (± mm)	1.3	<1.3	0.35	1	0.3
Repeatability (± mm)	1.3 (0.6)	1.3	2	1	0.3
Power—hydraulic	✓	✓	✓		
pneumatic					
electric				✓	✓
Cooling—air			✓		
water	✓	✓	✓		
none				✓	✓
Max. ambient operating temperature (°C)	50	5-50	35	45	not spec'd
End of arm tooling					
off the shelf—gripper	✓	✓		✓	✓
vacuum pad				✓	✓
other (specify)			spray gun	✓	magnetic
custom design	✓	✓		✓	✓
Interfacing					
Inputs (number)	8+	8+	13+ TTY	8	16
Outputs (number)	8+	8+	5+ TTY	14	16
Potential application(s)	5 9 16 19 20 22*	16 17 20 22*	Spray painting	not spec'd	12 14 17*
Number installed—U.S.			100	2	15
Canada	>200	>200	11		1
Overseas			900	30	5
Price of basic unit F.O.B. manufacturer (U.S.$)	63,000	68,000	68,000	30,000	11,845
Name of Canadian representative	Cincinnati Milacron Cda. Ltd.	Cincinnati Milacron Cda. Ltd.	DeVilbiss (Cda.) Ltd.	Hall Smith Co. Ltd.	
Location(s) of service depot					
parts	Cincinnati Montreal Toronto Windsor	Cincinnati Montreal Toronto Windsor	Toledo, Ohio Barrie, Ont.	Elk Grove, Ill. Burlington, Ont.	West Allis, Wisc.
service	same	same	same	same	same

***1–arc welding 2–assembly 3–deburring 4–die casting 5–drilling 6–flame cutting 7–forging 8–foundry 9–gauging 10–grinding 11–heat treating 12–injection moulding 13–investment casting 14–machine loading & unloading 15–metal stamping 16–palletizing 17–parts handling 18–press feeding 19–routing 20–spot welding 21–spray painting 22–tracking.**

SPECIFICATIONS / Source / Model	Manca (modular)	Modular Machine Mobot	Nordson	Prab 4200/5800	Prab Versatran E
Axes of motion	1-7	1-7	6	3-5	3-7
Movement					
arm—horizontal (degrees of arc)	100-360	360	116	270	240
vertical (min. mm, max. mm)	10-1,250	761	2788	826	761
radial (mm)	1,250	20,000	1000	1473	761 (1068)
wrist—pitch (degrees of arc)	to 360	360	240	90	220
yaw (degrees of arc)	to 360	360	240	90	220
roll (degrees of arc)		360	240	180	359
End of arm speed					
average max. unloaded (m/s)	1.1	0.5	2.5	1.27	1.27
normal operating, loaded (m/s)	to 1	0.3	var.	1.27	1.27
Weight carrying capacity					
max. at low speed (kg @ %)	to 1,700	200 @ 10	25 @ 30	56.7	56.7
at operating speed (kg)	to 1,700	200	15	45.4	45.4
Control					
non-servo	✓	✓		✓	
servo—point to point		✓			✓
continuous path		✓	✓		✓
Memory					
mechanical step sequencer	✓	✓		✓	
air logic					
patch board (electrical)	✓				(✓)
magnetic tape/disc		✓			
microprocessor		✓	✓		✓
other (specify)	prgr. cntr.			prgr. contr.	
Programming method					
manual	✓	✓		✓	✓
lead-through		✓		✓	✓
walk-through			✓		
Memory capacity (no. of steps)	optional	unlimited	30 min.	24-100	4000
Positioning accuracy (± mm)	0.1	1	2	0.20	0.76
Repeatability (± mm)	to 0.01	1	2	0.05	0.51
Power—hydraulic	✓	✓	✓	✓	✓
pneumatic	✓	✓			
electric	✓	✓			
Cooling—air				✓	✓
water	✓		✓	✓	✓
none		✓			
Max. ambient operating temperature (°C)	not spec'd	65	43	50	50
End of arm tooling					
off the shelf—gripper	✓	✓		✓	✓
vacuum pad	✓	✓		✓	✓
other (specify)	magnetic				
custom design	✓	✓	spray gun	✓	✓
Interfacing					
Inputs (number)	optional	unlimited	8	8	50
Outputs (number)	optional	unlimited	16	8	50
Potential application(s)	14 17 18*	part handling	finishing	4 5 7 8 11 12 14 15 17 18*	All ex'pt spray paint
Number installed—U.S.		50+	10	not spec'd	not spec'd
Canada			2	not spec'd	not spec'd
Overseas	>300		25	not spec'd	not spec'd
Price of basic unit F.O.B. manufacturer (U.S.$)	not spec'd	15,000	85,000	20,000-35,000	35,000-55,000
Name of Canadian representative			Nordson Cda. Ltd.	Can-Eng Mfg. Co.	Can-Eng Mfg. Co.
Location(s) of service depot					
parts	Rockleigh N.J.	San Diego	Amherst, Oh. Scarborough, Ont.	Kalamazoo, Mich.	Kalamazoo, Mich.
service	Rockleigh NJ Menomonee Falls, Wisc.	San Diego	same	same	same

***1–arc welding 2–assembly 3–deburring 4–die casting 5–drilling 6–flame cutting 7–forging 8–foundry 9–gauging 10–grinding 11–heat treating 12–injection moulding 13–investment casting 14–machine loading & unloading 15–metal stamping 16–palletizing 17–parts handling 18–press feeding 19–routing 20–spot welding 21–spray painting 22–tracking.**

SPECIFICATIONS / Source / Model	Prab Versatran F	Reis 1215	Rimrock 195	Seiko 100	Seiko 200
Axes of motion	3-7	5(6)	5	4	3
Movement					
arm—horizontal (degrees of arc)	300	270	190	—	90 (120)
vertical (min. mm, max. mm)	to 1520	1200	—	50	20
radial (mm)	to 1520	1500	2032	200	—
wrist—pitch (degrees of arc)	270	360	—	—	—
yaw (degrees of arc)	180	±180	—	—	—
roll (degrees of arc)	300	360	90	90-180°	—
End of arm speed					
average max. unloaded (m/s)	1.27	1.2	1.016	0.2	0.5
normal operating, loaded (m/s)	1.27	1.2	~1.016	0.2	0.5
Weight carrying capacity					
max. at low speed (kg @ %)	to 906	25	27.21 @ 57	1.5	0.3
at operating speed (kg)	to 680	5-25	27.21	1.5	0.15
Control					
non-servo			✓	✓	✓
servo—point to point	✓	✓			
continuous path	✓				
Memory					
mechanical step sequencer				✓	✓
air logic				✓	✓
patch board (electrical)	(✓)			✓	✓
magnetic tape/disc					
microprocessor	✓	✓		✓	
other (specify)			prgr. contr.	prgr. contr.	prgr. contr.
Programming method					
manual	✓		✓	✓	✓
lead-through	✓	✓			—
walk-through		✓	✓		—
Memory capacity (no. of steps)	4000	682+	23	256	256
Positioning accuracy (± mm)	1.3	0.6	0.25	0.01	0.01
Repeatability (± mm)	1.3	0.6	0.25	0.01	0.01
Power—hydraulic	✓		✓		✓
pneumatic		✓		✓	✓
electric		✓	✓	✓	
Cooling—air	✓				
water	✓				
none		✓	✓	✓	✓
Max. ambient operating temperature (°C)	50	50	80	60	60
End of arm tooling					
off the shelf—gripper	✓	✓	✓	✓	✓
vacuum pad	✓			✓	✓
other (specify)					
custom design	✓		✓	✓	✓
Interfacing					
Inputs (number)	50	8	6	4+	4+
Outputs (number)	50	8	2	4+	4+
Potential application(s)	All ex'pt spray paint.	not spec'd	Die casting	Press Feeder	not spec'd
Number installed—U.S.	not spec'd	—	—	not spec'd	not spec'd
Canada	not spec'd	—	—	not spec'd	not spec'd
Overseas	not spec'd	20	—	not spec'd	not spec'd
Price of basic unit F.O.B. manufacturer (U.S.$)	55,000-110,000	55,000	20,000-60,000	4,000	6,000
Name of Canadian representative	Can-Eng. Mfg. Co.	—	Vacumet Ltd.	Hall Smith Co. Ltd.	Hall Smith Co. Ltd.
Location(s) of service depot					
parts	Kalamazoo MI	Elgin IL	Columbus, Ohio	Torrance, CA	Torrance CA Burlington, Ont.
service	same	same	same	same	same

***1—arc welding 2—assembly 3—deburring 4—die casting 5—drilling 6—flame cutting 7—forging 8—foundry 9—gauging 10—grinding 11—heat treating 12—injection moulding 13—investment casting 14—machine loading & unloading 15—metal stamping 16—palletizing 17—parts handling 18—press feeding 19—routing 20—spot welding 21—spray painting 22—tracking.**

Source / SPECIFICATIONS / Model	Seiko 400	Seiko 700	Sterling-Detroit ROBOTARM	Thermwood E	Unimation 1000
Axes of motion	4	5	3		3 to 5
Movement					
arm—horizontal (degrees of arc)	—	90 or 120	90°	135	208
vertical (min. mm, max. mm)	100	40	203.2	2134 mm	900-1900
radial (mm)	400 (700)	300	—	762, 2108	1060
wrist—pitch (degrees of arc)	—		optional	180	90-180
yaw (degrees of arc)	—		optional	180	90-180
roll (degrees of arc)	(180)	90/180	120°	270	
End of arm speed					
average max. unloaded (m/s)	0.57	0.6	0.61	1.02	1
normal operating, loaded (m/s)	0.57	0.6	0.61	1.02	var.
Weight carrying capacity					
max. at low speed (kg @ %)	4	1	272	Not spec'd	22.9
at operating speed (kg)	4	0.5	272	8.2	12
Control					
non-servo	✓	✓	✓		
servo—point to point				✓	✓
continuous path				✓	✓
Memory					
mechanical step sequencer	✓	✓			
air logic	✓	✓			
patch board (electrical)	✓	✓			
magnetic tape/disc				(✓)	
microprocessor				✓	
other (specify)	prgr. contr.	prgr. contr.	prgr. contr.		CMOS
Programming method					
manual	✓	✓	✓		
lead-through				✓	✓
walk-through				✓	
Memory capacity (no. of steps)	256	256	1000	3000/5 min	up to 256
Positioning accuracy (± mm)	0.025	0.025	0.1	3.2	1
Repeatability (± mm)	0.025	0.025	0.1	3.2	1.3
Power—hydraulic			✓		✓
pneumatic	✓	✓		✓	✓ (wrist)
electric	✓	✓		✓	
Cooling—air				✓	✓
water					
none	✓	✓	✓		
Max. ambient operating temperature (°C)	60	60	Any	50	50
End of arm tooling					
off the shelf—gripper	✓	✓	✓		✓
vacuum pad	✓	✓	✓		✓
other (specify)					
custom design	✓	✓	✓	✓	✓
Interfacing					
Inputs (number)	4+	4+	16	8	6
Outputs (number)	4+	4+	16	8	6
Potential application(s)	Assembly	not spec'd	4 7 12*	17 21*	7 12 14 17 18*
Number installed—U.S.	not spec'd		500	—	not spec'd
Canada	not spec'd	1500	50	—	not spec'd
Overseas	not spec'd		15	—	not spec'd
Price of basic unit F.O.B. manufacturer (U.S.$)	7,500	8,000	25,000	45,000	23,950-24,950
Name of Canadian representative	Hall Smith Co. Ltd.	Hall Smith Co. Ltd.	J. S. Bulmer	—	CAE Morse Ltd.
Location(s) of service depot					
parts	Torrance CA Burlington, Ont.	Torrance CA Burlington, Ont.	Detroit, MI	Dale IN	Danbury, Ct. Farmington Hills, Mississauga,
service	same	same	same	same	same

***1–arc welding 2–assembly 3–deburring 4–die casting 5–drilling 6–flame cutting 7–forging 8–foundry 9–gauging 10–grinding 11–heat treating 12–injection moulding 13–investment casting 14–machine loading & unloading 15–metal stamping 16–palletizing 17–parts handling 18–press feeding 19–routing 20–spot welding 21–spray painting 22–tracking.**

SPECIFICATIONS / Source / Model	Unimation 2000/2100	Unimation 4000	Unimation Puma 250	Unimation Puma 500/600	Unimation Arc Welding
Axes of motion	3 to 6	3 to 6	3 to 6	5	5
Movement					
arm—horizontal (degrees of arc)	208 max	200	330 waist	320	90
vertical (min. mm, max. mm)	1890/2480	1672-2830	not spec'd	not spec'd	1000
radial (mm)	1041/1365	1321	not spec'd	not spec'd	not appl.
wrist—pitch (degrees of arc)	211	226	240	200	50
yaw (degrees of arc)	200	320	630	300	180
roll (degrees of arc)	360	370	630	270	165
End of arm speed					
average max. unloaded (m/s)	1	1	1.5	0.3	0.01
normal operating, loaded (m/s)	var.	not spec'd	not spec'd	not spec'd	0.01
Weight carrying capacity					
max. at low speed (kg @ %)	136	205	not spec'd	2.27	5 at 100
at operating speed (kg)	12-50	90	3.5	not spec'd	5 at 100
Control					
non-servo					
servo—point to point	✓	✓	✓	✓	
continuous path	✓	✓	✓	✓	
Memory					
mechanical step sequencer					
air logic					
patch board (electrical)					
magnetic tape/disc					
microprocessor			✓	✓	
other (specify)	Plated wire	Plated wire			semi-cond
Programming method					
manual					
lead-through	✓	✓	✓	✓	✓
walk-through					
Memory capacity (no. of steps)	2048	up to 2048		not spec'd	not spec'd
Positioning accuracy (± mm)	1	not spec'd	not spec'd		1
Repeatability (± mm)	1.27	2.03	.05	.1	1
Power—hydraulic	✓	✓			
pneumatic					
electric				✓	✓
Cooling—air	✓	✓			✓
water					
none					
Max. ambient operating temperature (°C)	50	50	45	45	50
End of arm tooling					
off the shelf—gripper	✓	✓	✓	✓	
vacuum pad	✓	✓			
other (specify)					torch holder
custom design	✓	✓	✓	✓	
Interfacing					
Inputs (number)	9	9	8	8	1
Outputs (number)	9	9	8	8	4
Potential application(s)	1 4 6 7 8 11 12 13 14 16 17 18 19 20	1 4 6 7 8 11 12 13 14 16 17 18 19 20*	2 14 17*	1 2 14 17 20*	Arc welding
Number installed—U.S.	not spec'd	not spec'd	not spec'd	not spec'd	not spec'd
Canada	not spec'd	not spec'd	not spec'd	not spec'd	not spec'd
Overseas	not spec'd	not spec'd	not spec'd	not spec'd	not spec'd
Price of basic unit F.O.B. manufacturer (U.S.$)	33,000-56,000	48,000-70,000	35,000	35,000	35,000
Name of Canadian representative	CAE Morse Ltd.	CAE Morse Ltd.		none	
Location(s) of service depot					
parts	Danbury, Farmington Hills, Mississauga,	Danbury, Farmington Hills, Mississauga,	Danbury, Conn. Farmington Hills, Mich.	Danbury, Conn. Farmington Hills, Mich.	Danbury, Conn. Detroit, Mi.
service	same	same	same	same	same

***1–arc welding 2–assembly 3–deburring 4–die casting 5–drilling 6–flame cutting 7–forging 8–foundry 9–gauging 10–grinding 11–heat treating 12–injection moulding 13–investment casting 14–machine loading & unloading 15–metal stamping 16–palletizing 17–parts handling 18–press feeding 19–routing 20–spot welding 21–spray painting 22–tracking.**

Robot suppliers

ASEA Inc.,
Four New King Street, White Plains, N.Y. 10604 (914) 428-6000.

ASEA Ltd.
10300 Henri-Bourassa Blvd. W., Saint Laurent, Que., Box 700, Post. Sta. Cartierville, Montreal, Que. H4K 2J8 (514) 332-5350

AutoPlace, Inc.,
1401 East 14 Mile Road, Troy, MI 48084 (313) 585-5972; Cdn. rep.: **A. F. Mundy Associates Canada Ltd.,** 66 Racine Rd., Rexdale, Ont. M9W 2Z7 (416) 745-6976

Binks Manufacturing Co.,
9201 West Belmont Ave., Franklin Park, IL 60131; (312) 671-3000.

Binks Manufacturing Co. of Canada Ltd.
17 Vansco Rd., Toronto, Ont. M8Z 5J5, (416) 252-5181

Cincinnati Milacron Inc.
Industrial Robot Division, 4701 Marburg Ave., Cincinnati OH 45209; (513) 841-8386.

Cincinnati-Milacron, Canada Ltd.
122 N Queen St., Toronto, Ont. M8Z 2E4; (416) 233-3216

The DeVilbiss Co.
300 Phillips Ave., Toledo, OH 43692; (419) 470-2169.

DeVilbiss (Canada) Ltd.
P.O. Box 3000, Barrie, Ont. L4M 4V6 (705) 728-5501

General Numeric Corp.
390 Kent Ave., Elk Grove, IL 60007; (312) 640-1595; Cdn. rep: **Hall Smith Co. Ltd.,** 3505 Mainway, Burlington, Ont. L7M 1A9; (416) 335-6008.

Industrial Automates, Inc.
6123 W. Mitchell St., West Allis, WI 53214 (414) 327-5656.

Manca, Inc.
Leitz Building, Rockleigh, NJ 07647 (201) 767-7227.

Modular Machine Co.
2785 Kurtz St., San Diego, CA 92110 (714) 224-3494.

Nordson Corp.
555 Jackson St., Amherst, OH 44001 (216) 988-9411.

Nordson Canada Ltd.
849 Progress Ave., Scarborough, Ont. (416) 438-6730

Prab Conveyors, Inc.
5944 E. Kilgore Rd., Kalamazoo, MI 49003 (616) 349-8761; Cdn rep: **Can-Eng Manufacturing Co.,** 6800 Montrose Rd., Niagara Falls, Ont. L2E 6V5 (416) 356-1327.

Production Automation Corp.
12956 Farmington Rd., Livonia, MI 48150 (313) 261-0890.

Reis Machines,
1450 Davis Rd., Elgin, IL 60120 (312) 741-9500

The Rimrock Corp.
1700 Rimrock Rd., P.O. Box 19127, Columbus, OH 43219 (614) 471-5926.

Seiko Instruments, Inc.
2990 West Lomita Blvd., Torrance, CA 90505 (213) 530-3400; Cdn rep: **Hall Smith Co. Ltd.,** 3505 Mainway, Burlington, Ont. L7M 1A9 (416) 335-6008.

Sterling-Detroit Co.
261 E. Goldengate, Detroit, MI 48203 (313) 366-3500; Cdn rep: **J. S. Bulmer,** 725 Fernhill Blvd., Oshawa, Ont. (416) 576-0612

Thermwood Co.
P.O. Box 436, Dale, IN 47523, (812) 937-4476

Unimation, Inc.
Shelter Rock Lane, Danbury, CT 06810 (203) 744-1800; Cdn rep; **CAE-Morse Ltd.,** 4500 Dixie Rd., Mississauga, Ont. L4W 1Z6 (416) 625-5161.

Mechanical Transfer Devices

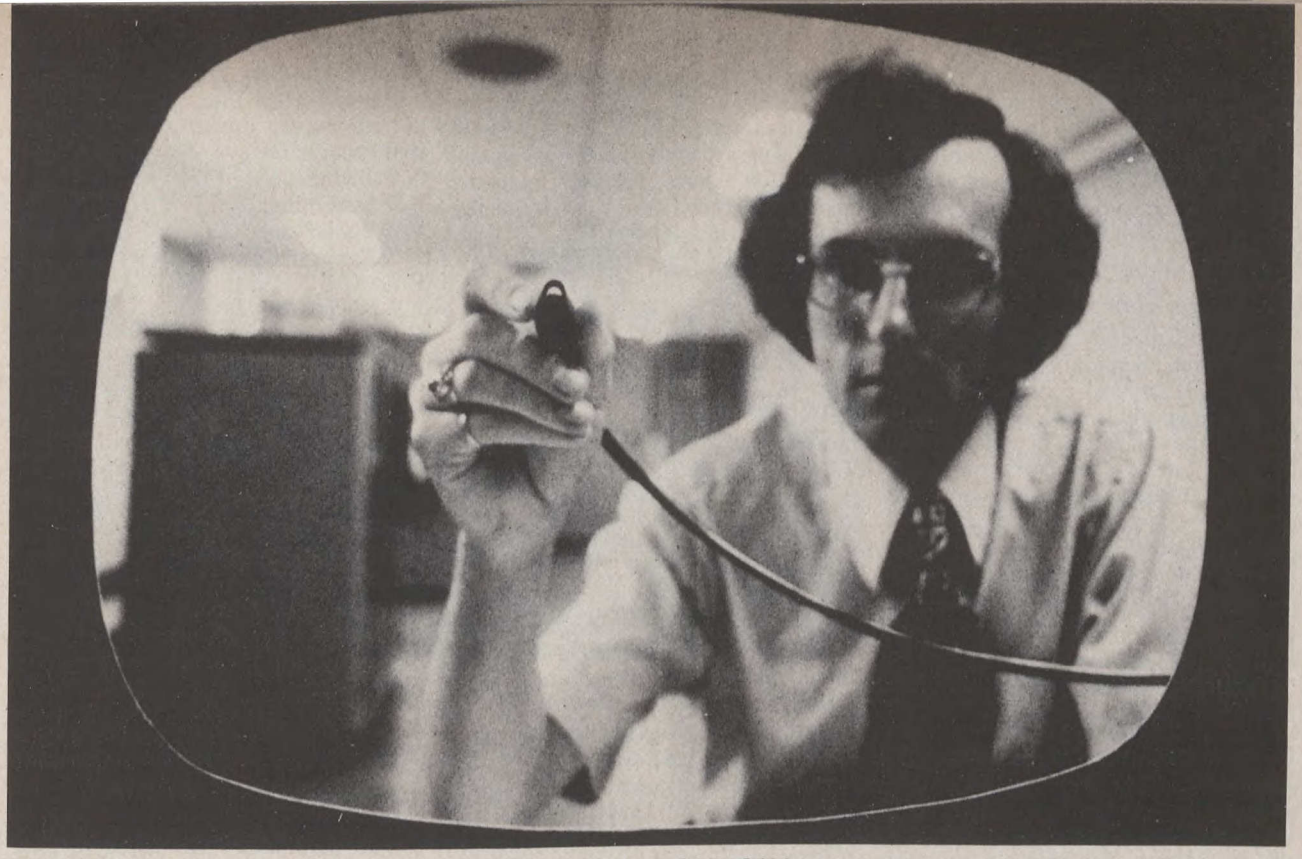
Automation Devices, Inc.
Automation Park, P.O. Box AD, Fairview, PA 16415; (814) 474-5561

Livernois Automation Co.
25200 Trowbridge, Dearborn, MI 48124 (313) 278-0200

Pickomatic System, Inc.
37950 Commerce St., Sterling Heights, MI 48077 (313) 939-9320

R & I Manufacturing Co. Inc.
91 Prospect St., Thomaston, CT 06787 (203) 283-0127.

The Van Epps Design & Development Co. Inc.
4760 Van Epps Rd., Cleveland, OH 44131 (216) 661-1337.



A CRT's-eye view of a designer at work, light pen in hand. CAD/CAM system is now in use at Domglas, Hamilton.

CAD/CAM in the glass industry

How one Canadian company examined the potential, selected a system and successfully implemented a change to CAD/CAM in its quest for efficiency.

THE INTRODUCTION OF computer-aided design (CAD) into the glass industry has been a slow, painful process. Glass companies have for a number of years been aware in a general sense that computers could help them design better containers and produce better mold equipment. Mold equipment production has been automated to a certain extent for many years by the use of numerical control (NC) equipment for the production of neck rings and, latterly, mold cavities.

One of the basic reasons why the industry has not yet introduced CAD on a large scale stems from a lack of understanding of the cost-benefit relationships which will result from the introduction of such a technical tool. Another problem area was the widespread belief that the accurate calculation of off-round volumes could not be accomplished except by the use of expensive, sophisticated 3-dimensional techniques.

A Domglas survey of the marketplace circa 1975 produced a number of very limited time sharing glass-oriented programs, mainly aimed at verifying volume calculations of round containers. One relatively primitive glass-oriented CAD system was also found but tests indicated that the accuracy of off-round volumes calculated was not acceptable.

Upon completion of the survey all the programs on offer were judged to be totally inadequate. A new and completely different approach to the problem was required. A study of the objectives to be achieved by automating the aforementioned functions was necessary.

Defining the objectives

The most obvious objective was to improve the productivity of those individuals involved in the design/engineering/drafting function. Secondary objectives included increasing the accuracy of all design/engineering calculations, introduction of new and more sophisticated engineering analysis and, finally, shortening the line of communications between the engineering staff and the NC programmers.

A rather important objective was to have the equipment dedicated to the above mentioned tasks only. Time sharing—and especially remote time sharing—was to be avoided. To achieve the objectives several parameters had to be met. These included:

- Automation of the drafting function.
- Ability to calculate volume and proportion all types of containers.
- Automation of the mold equipment engineering function.
- Production of high quality drawings on automated equipment.
- Automation of container strength analysis function.
- Direct NC tape preparation or even DNC.
- Model the container forming process to eliminate the need for unit sampling.

Adapted from a paper by Hans J. Kleiner, Manager, Mold Design & Manufacture, Domglas Inc., Hamilton, Ontario.

The design/drafting function had been automated in other industries, notably the aerospace industry, for some time. The advent of the minicomputer had enabled this field to expand and to achieve a price level within the reach of even small to medium sized companies.

Selecting a system

A set of general specifications was written and negotiations were conducted with several companies in the computer graphics field. These led to the eventual selection of Information Displays Inc. of New York to be the supplier. Collaboration between IDI and Domglas resulted in a detailed set of specifications being drawn up and the development of the computer-aided design system presently in use at the Domglas Mold Design & Manufacture facility. Two years of effort were involved in bringing the project to its operational state.

The name of the game today is "return on investment" (ROI). It is not justifiable to spend between $100,000 and $500,000 on a CAD system and end up automating only one part of the design function. To achieve a sufficient ROI, the total container/mold equipment design function must be automated. A further extension into computer-aided manufacturing (CAM) from CAD, while increasing the cost and the risk, can greatly increase the ROI.

It is not the intention of this article to delve deeply into the economics of CAD/CAM or to derive any working formulae. This has been done many times. Three formulae will be presented which will serve to allow a quick calculation of the economics of CAD. The glass industry situation with regard to these formulae will also be examined.

There are a number of attributes which have been stated for CAD which represent both tangible and intangible value. Let's deal first with the determination of the tangible values. The most important of these is the breakeven productivity ratio, PR, defined as

$$PR = \frac{RM + RC}{RM} \quad (1)$$

where

RM = wage rate for the man

RC = the usage rate for the CRT console with both of the above being defined as dollars per hour.

If the productivity ratio of the man at the CRT console is greater than the breakeven productivity ratio then the application is economically viable. The productivity ratio of the man at the CRT console can be determined by using

$$PRS = \frac{\text{Conventional Time—Off System Time}}{\text{On System Time}}$$

$$= \frac{H1 - H2}{H3} \quad (2)$$

It is important to realize that any application can be classified into components.

For example, suppose T_1 represents the total cost to accomplish a particular application using current methods. Suppose further that T_1 is partitioned into costs as follows:

A_1 = Planning & Schedule
B_1 = Set Up
C_1 = Data Preparation
D_1 = Computing
E_1 = Analysis & Evaluation
F_1 = Documentation & Administration
G_1 = Correlated factors unaffected by the introduction of CAD.

In this case, A_1 through F_1 represent the component tasks whose costs will be affected (increased or decreased) by the introduction of CAD. After the introduction of CAD, T_2 will be composed of the same components, A_2 through F_2. In a specific situation, these components will be chosen to fit the application.

An analysis of manual design times must be carried out and values for off system and on system times must be estimated. In most cases, values of PR will exceed 3.00 by a large margin.

The glass industry can group its types of jobs fairly simply and as a result can establish a table as follows:

Type	Container Design and Drawing Times (Hrs)	Mold Equipment Design and Drawing Times (Hrs)			
		ISBB	IS62 P&B	H-28	MPLC
Plain Round	x	x	x	x	x
Decorated Round	x	x	x	x	x
Plain Non-Round	x	x	x	–	x
Decorated Non-Round	x	x	x	–	x

Once this table has been obtained, average values of H_1, H_2 and H_3 can be determined by use of an appropriate weighting scheme of

A % Plain Round
B % Decorated Round
C % Plain Non-Round
D % Decorated Non-Round
E % ISBB
F % IS62 P & B
G % H-28
G_1% MPLC

where A through G_i reflect the individual company's workload. The average saving per job can then be determined from

$$DELTA\ T = F(RM, RC)$$

$$= K + RM(H_1 - H_2) - RM \times H_3 - RC \times H_3 \quad (3)$$

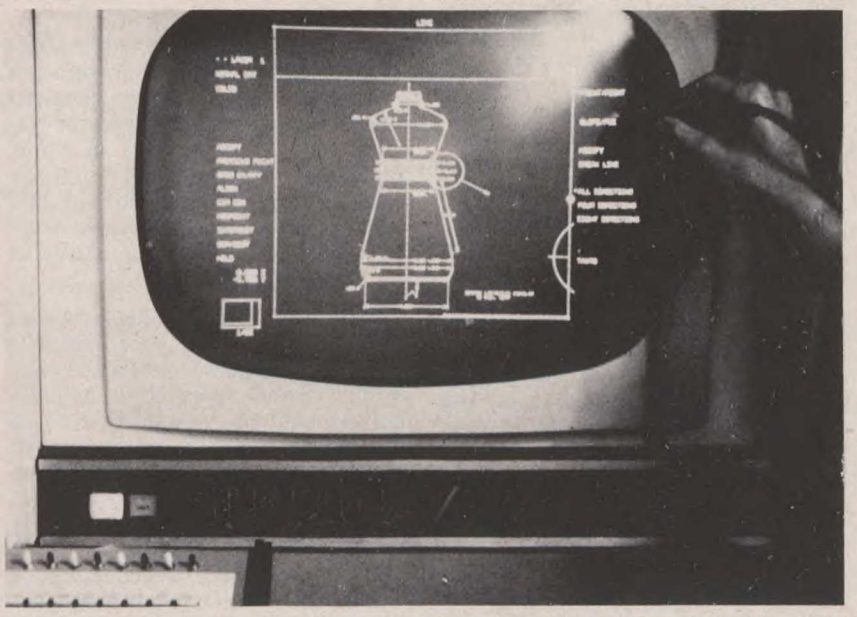
where

DELTA T = The change in time required to do a job due to the introduction of CAD.

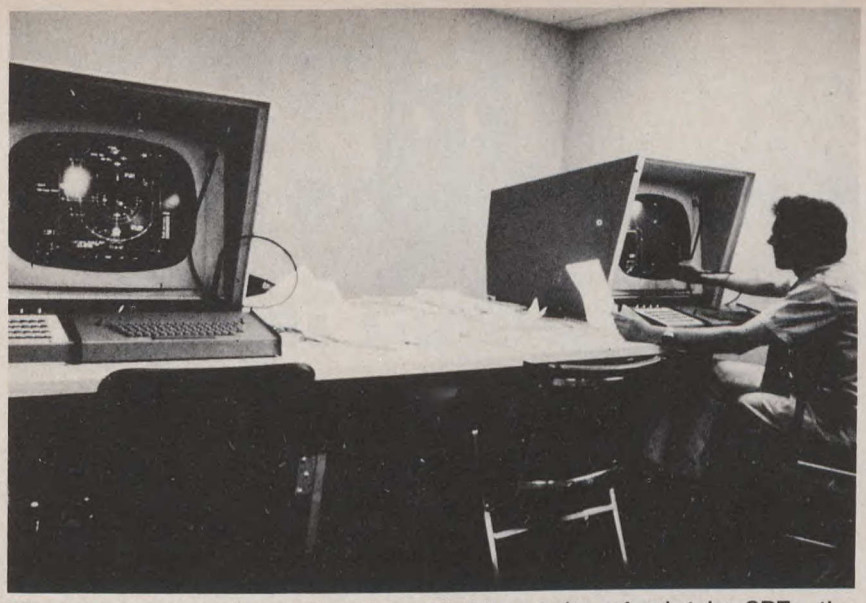
K = The cumulative cost effects (gains and/or losses) resulting from the use of CAD but not directly a function of the graphic system or of the graphic console user.

The parameter "K" could include such effects as:

(i) reduction in the multiplicity of standards presently employed in mold equipment design.
(ii) stricter adherence to standards.
(iii) reduction in lead time required.
(iv) reduced dependence upon hard-to-train, high salary designers due to reduced training required and easier comprehension on the part of new designers.
(v) material or weight reduction in product.
(vi) different technician and administrative support.
(vii) reduced number of evaluation cy-



A design in progress. The designer works on the face of the CRT with a light pen just as he would on a piece of paper with a pencil.



The computer graphics workstations. Visible are the refresh tube CRTs, the light pens, the function keyboards and the alphanumeric keyboards.

cles due to increased engineering calculation accuracy.

These may be considered the intangible values associated with introduction of CAD.

H_1 = the hours the potential graphics user would employ in the conventional task whose cost was earlier defined as T_1.

H_2 = the hours (expected to be less than H_1) that the user would expend after the introduction of CAD, but not in the use of the graphics console.

H_3 = the hours that the CAD user spends at the console.

How the CAD system functions

The CAD system can be divided into three parts, the hardware, the drafting software or programs, and the specially developed software for container design and analysis and mold engineering. The system at Domglas is totally housed in one room of the Mold Design & Engineering Building and represents an investment of approximately $1¼ million. Obviously, the company requires a return on investment for an expenditure of this magnitude. This is achieved in several ways:

(1) a productivity increase for designers when operating the system.

(2) 100% accuracy in volume calculation and mathematical formulation of container geometry.

(3) better service for customers.

The designer works on the face of the CRT with a light pen just as he would on a piece of paper with a pencil. However, he is now 100% accurate. Minimal special training is required and the best way to learn is just to play with the system in order to understand what each function does. The operator has available some 30 major drawing functions on a special keyboard. Each of these has between five and 15 subfunctions which appear along the sides of the CRT outside of the actual drawing area and are activated by the light pen. Further information may be entered through a keyboard similar to a standard typewriter keyboard. These three "input" devices allow the designer to specify exactly the size and location of lines, arcs, fillets, text, etc. that are required to define a design and produce a drawing. Finished drawings are stored in a temporary mass storage memory capable of holding upwards of 3,000 drawings. Permanent storage is via magnetic tape. Once a design has been completed, a permanent ink hard copy drawing is made on one of the system flat-bed plotters.

The computer itself works with a mathematical representation of what the designer is drawing on the CRT. This mathematical representation is used to accomplish the required analysis and engineering and the final results are converted into instructions for the mechanical movement of the plotter arm to produce a hard copy.

The question of where one gains the knowledge necessary to evaluate the CAD hardware and software is often posed. The answer is really very simple. A number of universities offer courses on CAD ranging from basic introductory courses to courses on managing CAD. These last anywhere from two days to two weeks and are well worth the time and money.

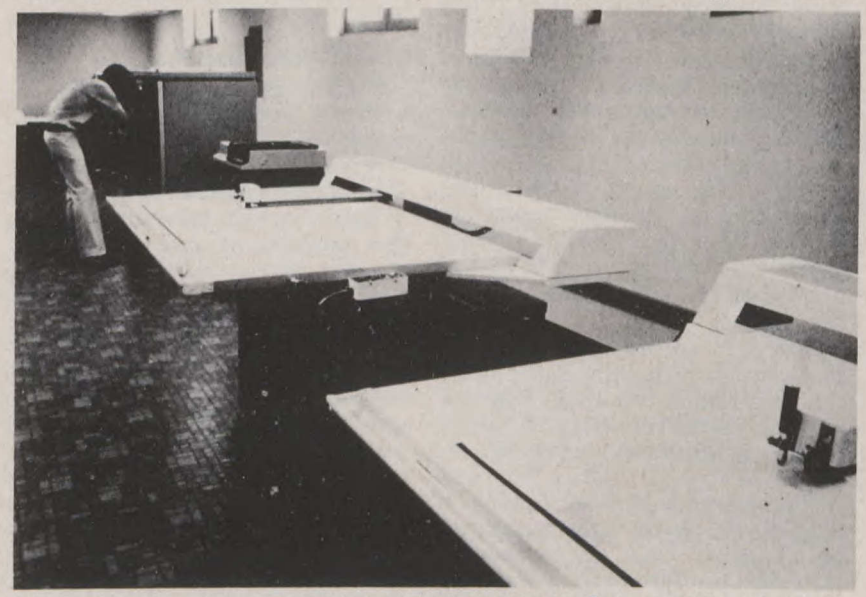
The Domglas CAD system

Reference was earlier made to the fact that the total design/drafting function must be automated. A number of commercial CAD systems are available. All have basic drafting software with the only variances occurring in the degree of sophistication. The requirement that the hardware be dedicated to this task (and hence "in-house") limits systems to those operating minicomputers as CPUs. (This restriction applies only to the glass industry where the size of staff used for container design and mold engineering is relatively small).

Most of the hardware specifications of these systems are very similar. The individual component manufacturers may vary but capabilities do not vary to a large degree. The vendors who integrate the system and provide the software vary a great deal in both price and capability.

The one piece of hardware that does vary in capability is the designer's console CRT. Two basic types are available, refresh and storage tube CRTs.

It is not intended in this article to review individual pieces of hardware, but the designer's CRT type will affect



The final output of the system comes from plotters. Once a design has been completed, a permanent ink hard copy drawing is made.

both training and mode of operation and hence is of extreme importance. In our evaluation the refresh tube was found to be very much superior for the design of containers and mold equipment. The reasons are as follows:

(1) the refresh tube is dynamic while the storage tube is static or, at best, of limited dynamic capacity. The ability selectively to erase, rotate, move, copy, edit text, etc. makes conceptual design work—and especially mold equipment design work—much easier.

(2) working on the face of the CRT was judged to be more natural (like a pencil and a piece of paper) and easier for the design personnel to learn.

Information Displays Inc. was the only system supplier that offered a refresh tube CRT/minicomputer turnkey CAD system. That advantage, plus a more sophisticated drawing geometry package, won IDI the contract.

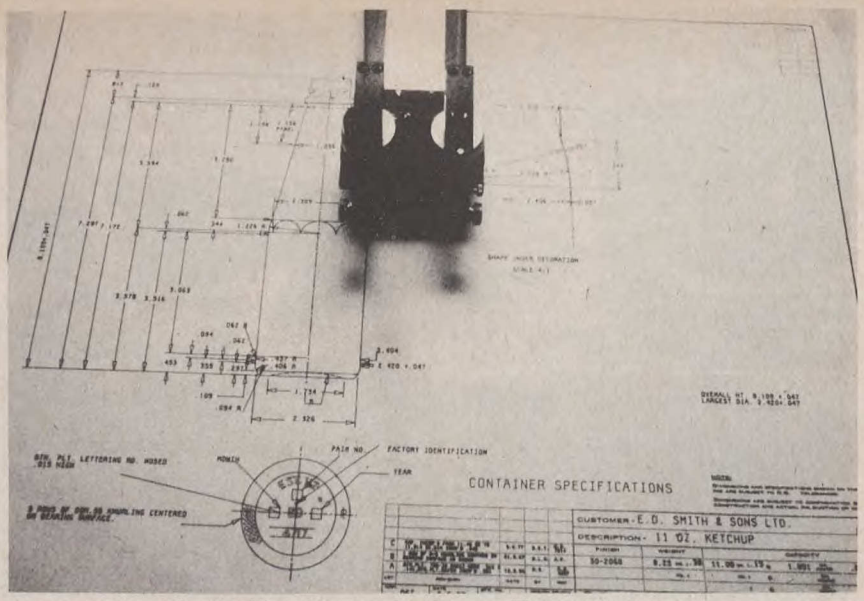
Domglas at this point, with input from IDI, wrote detailed specifications for three pieces of application geometry required to turn a drafting CAD system into a container/mold equipment design and drafting system. The specifications were used by IDI to produce the required software. These three application programs were:

(1) Volume Analysis. A modified version of Durands Rule is the basis of the volume software. The information required by the system consists of suitably labelled front and side views and cross sections. For rounds, the front and side views are the same and only one is required, along with a single cross section. For off-rounds, both front and side views are needed, along with known cross sections positioned at the correct relative levels. The operator can interrogate the system as to the cross section shape interpolated by the system between known sections. If it is not satisfactory, the cross section may be modified and now used as a given cross section. Accuracy of the volume calculation software has been 100% for round containers and 99.9% for off-round containers.

The discrepancy in off-round containers may not lie with the computer software but rather with the physical limitations of model and mold makers in blending between varying cross sections.

(2) Design Proportioning. A subroutine of the volume program, design proportioning is used in two ways. These are to bring conceptual design to correct volume and to design families of containers.

This software is quite flexible in terms of the options that the designer has available. Only textual instructions need be added to the information used for volume analysis. These instructions include required volume,



An example of the final hard copy of a design. These ink drawings can be used to yield excellent quality reproductions.

features required to be held or changed to discrete sizes (if desired), and relative rates of change (if desired).

(3) Family of Parts. The design of mold equipment may be the single most critical factor about CAD in terms of meeting ROI requirements. This is where the majority of the savings will occur. The object should be for the system to design all equipment that has known variables. All mold equipment has variable sizes that are based on the container, or blank, to be made and are thus "known variables".

The designer should have only to provide these sizes to the computer and have the computer produce the resultant mold equipment designs. The volume programs outlined earlier will also contribute to faster, more accurate blank/plunger designs.

This has been accomplished on the operational system.

Operational experience

The Domglas CAD system was delivered in January 1977 and became operational in May 1977.

A three week training period was initiated for each operator. The first week is spent learning the system and its operation with an experienced operator. The second and third weeks see close, but decreasing, supervision of production work.

Individuals who show a normal degree of flexibility in their everyday work have no problem adapting to this new tool. However, some designers without a sufficient geometrical background have not been able to adjust and could not master the use of CAD.

The projected increase in productivity has been somewhat slower in materializing than originally anticipated but has now reached the desired level.

The number of consoles will vary for each application, but experience has shown that this consideration can be a potential bottleneck, depending upon the degree of opposition to the implementation of a shift system in the design office. The response at Domglas has been to introduce a mini-shift system that utilizes the equipment between 7:00 am and 6:00 pm for production and to schedule experimental work outside of these hours. An alternative solution, if funds are available, is to have sufficient consoles to accomplish the workload on a one-shift basis.

Conclusions on CAD/CAM

Sophisticated CAD has been introduced into the glass industry. Domglas is believed to have the most advanced turnkey installation in that industry. The firm has progressed a considerable distance towards the goal of the generalized CAD/CAM concept outlined earlier in this article. Domglas is actively working on all the necessary hardware and software to make the concept a reality. The glass industry would then have a fully integrated operational CAD/CAM system.

One note of warning though to potential CAD/CAM users. For all the benefits that this tool can bring to any industry, the introduction of CAD or CAM or CAD/CAM will not be easy. This tool has drawbacks which must be overcome. These include:

- Expense.
- Reliability of both hardware and software.
- Lack of easy adaptability.
- Vendor problems.
- Management problems.

CAD is beneficial for Domglas and for many other companies. To overcome the above problems and make CAD beneficial, the user's staff must be dedicated, enthusiastic and flexible.

Reprinted from Design Engineering, February 1980

Lack of skills and insight What could keep CAM down

By J. E. Crozier*

The shortage of skilled machinists and mechanical engineers as well as management ignorance could deny computer-aided manufacturing to Canadian shops, study says

THE MAJOR CONSTRAINTS to the increased utilization in Canada of computer-aided manufacturing (CAM) systems in the future will be the lack of technically qualified personnel and, secondly, the lack of management understanding.

This is a conclusion of a study conducted by the Canadian Institute of Metalworking on the utilization of CAM in Canadian industry. This conclusion differs notably from that in a similar study in the United States, where the lack of investment capital was cited as the number-one problem, followed by the difficulty of connecting hardware and software modules into more complete systems.

The CIM study is based on the results of a survey of 258 industrial companies and the answers of 105 of them to a detailed questionnaire. The study examines the strengths and weaknesses in staffing and economics as well as the present and future technological direction as perceived by the respondents.

Geographically, the centres for CAM growth in Canada have been the area that encompasses a 100-mile radius from Hamilton, Ont., and the greater Montreal area. In the last few years significant expansion has occurred in Vancouver, Winnipeg and Edmonton as well. The survey was conducted in these areas.

Numerically controlled machine tools are an essential component of CAM, but there are others, including the programming system hardware, the machine tool language processor and post processors, software for engineering computations, engineering design and drafting, production and part scheduling, and the integration of the hardware and software into a complete system.

Thirty-four of the respondents had a minimum of five NC machines, and project a significant expansion within five years. The majority of these companies will double the present number of NC machines and switch from manual programming to in-house minicomputer programming. Several of these companies are contemplating the progression to interactive graphics for design, drafting, and NC programming. Most of these users consider the computer an essential or important tool in the control of their manufacturing or design operation.

How do the respondent companies view the future for CAM?

The prediction is that NC machine tool installations will approximately double in five years, from the current 600 to 1200, according to the survey. Asked to relate their expectations in various technology areas related to CAM relative to their present position, the majority replied that production and parts scheduling from a computer data base will represent a major impact on their company in five years time. Engineering computation, automated design drafting and NC machines also were rated as high-growth areas.

The main difficulty, the respondents agree, is skills. All companies surveyed rated skilled machinists as the most difficult to hire. The large companies are also finding manufacturing engineers difficult to hire—more difficult than NC operators and programmers. These latter two categories are rated second and third for small and medium-sized industries.

When asked "What would be the best way for your company to increase the number of skilled workers," the majority of companies stressed government assistance and urged more emphasis on on-the-job training programs. The idea of industry taking care of training without government assistance received less than 5% support from those surveyed.

Seminars and work shops external to the company are not as popular as in the United States. Industry favoured in-house training programs by a wide margin.

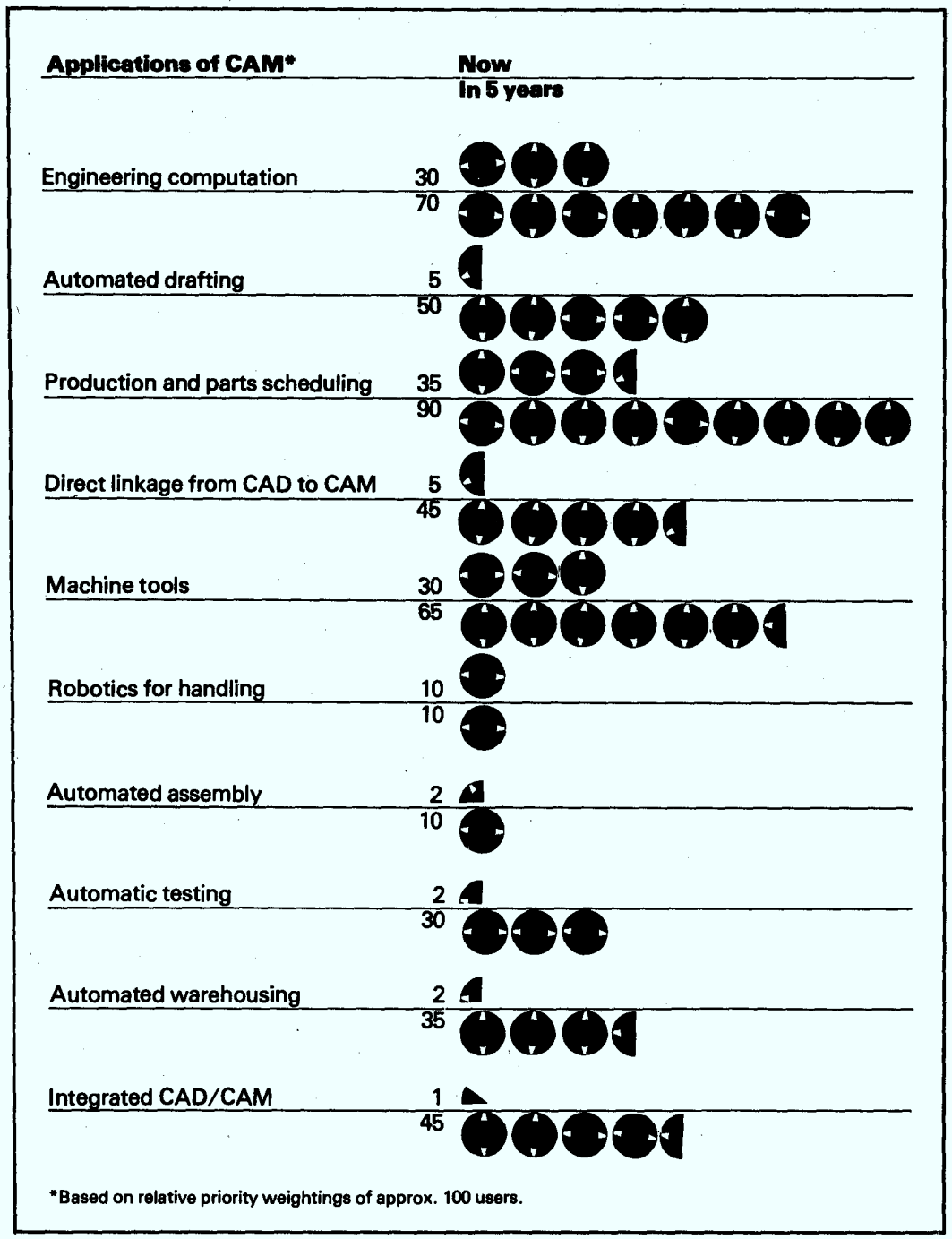
It appears from the survey that the skill level problem relates directly to another problem—tape revision.

The concensus of opinion is that tape revisions are not entirely based on the complexity of the part geometry or related to computer processing problems. At least 30% of the users surveyed indicate machineability problems as being the number-one complaint, followed by process planning mistakes and tooling problems. Other uses indicate that scheduling, optimization and design changes also resulted in tape changes.

Manufacturing engineers can solve the machineability and tooling problems with the support from a skilled machinist. The present trend, however, has been to utilize the NC programmer and a semi-skilled NC operator. Unfortunately, this trend will continue unless a major change in the education process takes place in industry and at educational institutions, with government support.

One individual associated with a large NC user stated in an interview that "industry should be supported and encouraged to take on apprentices at an earlier age before the attraction of highly paid production jobs is available to them." Universi-

*J. E. Crozier is manager of the Canadian Institute of Metalworking.



Production and parts scheduling from computer data base are rated high in most plants for next five years, but integrated CAD/CAM has long way to go, says user survey

ties, on the other hand, should look at the requirements in industry and offer manufacturing engineering programs that will interest the bright students.

Here are some other conclusions from the study:

Those surveyed see their own competition as quite progressive, actively upgrading to higher technology. For example, the medium-sized companies (100-500 employees) stated that 75% of their competitors were using NC machine tools and that 35% had purchased an in-house computer.

Initial start-up time is a major disappointment for NC users. Approximately 45% of those surveyed were either disappointed or very disappointed with the start-up time for equipment that incorporates some computer control.

With respect to overall reliability, user satisfaction rated extremely high; 75% said the equipment produced what they expected and a further 15% better than expected. Return on investment received a similar rating.

Mechanical reliability rated higher than electronic reliability; 25% of those surveyed were unhappy with the performance of electronic systems.

How do metalworking managers see the importance of the use of computers in the control of manufacturing and design?

About 50% consider computers essential to remaining competitive. Another 55% consider them merely important to remain competitive. Five percent said they feel computers will have "some" impact and only about 1% reckon they would have little or no impact at all.

Further analysis of the survey data is currently being undertaken at the Canadian Institute of Metalworking, and it is hoped that a detailed report will be available later this year. □

Reprinted from Canadian Machinery & Metalworking, March 1980

CAD/CAM—BRIDGING THE GAP FROM DESIGN TO PRODUCTION

An engineer can use a computer to design a component, analyze its stresses, and check its mechanical action. Production people can use the same computer to transform the design into hardware through NC machining or other automated processes. Now the two technologies—CAD and CAM—are merging, allowing a single individual to conceive of an object and then set in motion the computer-controlled processes that will produce it.

JOHN K. KROUSE
Staff Editor

TODAY a design engineer can define a part shape, analyze stresses and deflections, check its mechanical action, and automatically produce engineering drawings—all from the same graphics terminal of a computer-aided design (CAD) system. Furthermore, production people can draw upon the geometric description provided by CAD as a starting point to create NC tapes, determine process plans, instruct robots, and manage plant operations with computer-aided manufacturing (CAM).

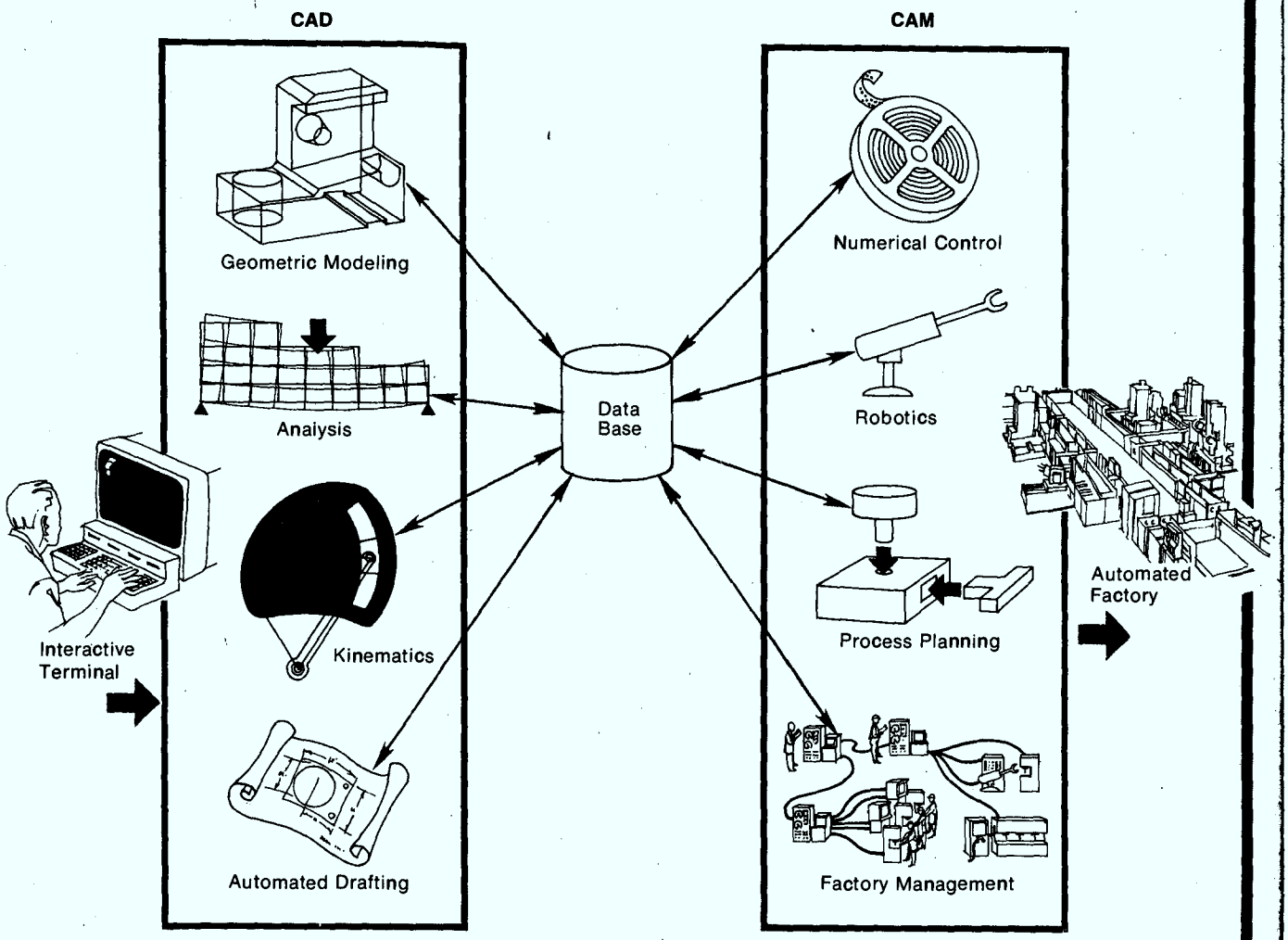
These two technologies are now being combined into unified CAD/CAM systems, where a design is developed and the manufacturing process controlled from start to finish with a single system. Such capabilities are presently available on the most sophisticated CAD/CAM systems in a few large manufacturing operations. But more and more plants are gaining this capability. And experts predict that unified systems will lead to what forward-looking managers have long envisioned: the automated factory.

This evolution of CAD/CAM technology will result ultimately in the integration of many diverse technical areas that have developed separately for the past thirty years. Initially, CAD systems primarily were automated drafting stations in which computer-controlled plotters produced engineering drawings. The systems were later linked to graphic display terminals where a geometric model describing the part shape could be created, and the resulting data base in the computer was used to produce drawings. Graphic terminals allowed the user to communicate with the computer in pictures instead of raw columns of numbers, and thus allowed access to the computer by users untrained in programming. Now, advanced systems based on interactive graphic terminals have analytical capabilities which permit the part to be evaluated with techniques such as the finite-element method. And kinematic programs allow the motion of mechanisms to be studied.

Concurrently with the development of CAD technology, CAM advancements were also being made, mostly in numerical control. Until recently, experienced programmers were required to produce and verify NC instructions. But now, instructions can be produced automatically for complex shapes, and tool paths can be verified quickly with computer simulation. In addition, these systems may also have limited process planning features for determining a sequence of fabrication steps and factory management capabilities for directing the flow of work and materials through the factory. The newest feature of CAM is robotics, a field in which automated manipulator arms handle tools and workpieces.

A major milestone was the combination of the CAD features—geometric modeling, drafting, finite-element analysis, and kinematics—into

INTEGRATED COMPUTER-AIDED ENGINEERING (CAE) SYSTEM



Putting the Pieces Together

In an idealized CAD/CAM system, the user interacts with the computer via a graphics terminal, designing and manufacturing a part from start to finish with information for each activity stored in the computer data base. With CAD features, the user may construct a geometric model, analyze the structure, perform kinematic studies, and produce engineering drawings.

With the CAM portion of the system, the user creates NC instructions for machine tools, produces process plans for fabricating the complete assembly, programs robots to handle tools and workpieces, and coordinates plant operation with a factory management system. Many present systems have all the CAD functions interfaced, and a few even have limited NC capabilities. But the other CAM functions are still in the early stages of development and usually are performed apart from the CAD system.

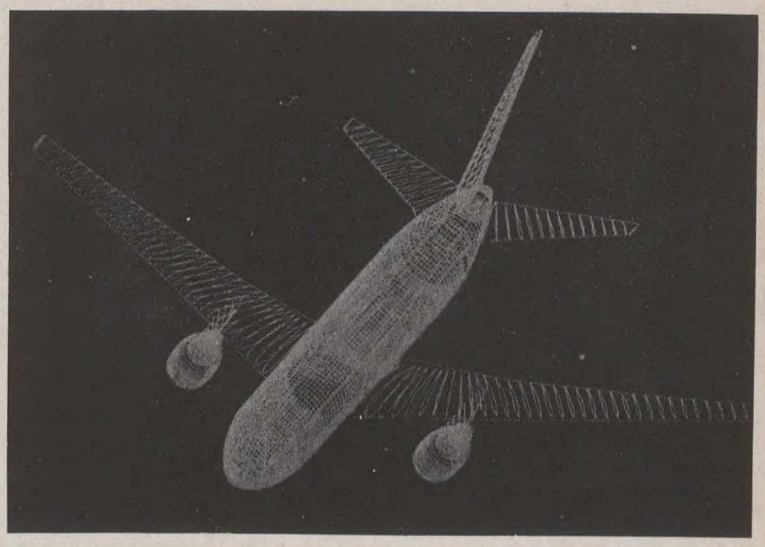
Efforts by IPAD, ICAM, and CAM-I to advance and integrate CAD/CAM technologies are aimed at creating what many observers are calling CAE—an acronym for Computer-Aided Engineering or the broader area of Computer-Aided Enterprise. This level of sophistication would lead ultimately to the automated factory.

a unified system with the CAM capability of automatic NC tape preparation. This advancement finally bridged the gap between the two technologies and made it possible for an engineer to go from an initial concept to the finished part with one system.

Not only have CAD/CAM capabilities increased dramatically over the years, but the cost of these systems has decreased—allowing what was exotic and prohibitively expensive a few years ago to become commonplace. Only ten years ago, a computer and the required graphics equipment for a CAD/CAM system cost several million dollars and could be afforded only by a few automotive and aerospace giants. Now, equivalent systems cost a few hundred thousand dollars and are within the budget of most substantial manufacturers. The combination of economic and technical development has led to the gradual permeation of CAD/CAM into general industry. Major users of the most sophisticated systems are still large aerospace and automotive companies. But a growing number of other manufacturers are starting to use computer

Aircraft Leads the Way

CAD/CAM probably receives its widest use in the aircraft industry. One of the leaders of CAD/CAM applications is Boeing Co., which is developing an integrated CAD/CAM system for the 757, 767, and 777 family of aircraft. Plans are to consolidate computer services so that all engineers—regardless of location or discipline—will have access through interactive-graphic terminals to the same huge data base, which will grow to include the geometry for thousands of aircraft components as well as data for structural analysis. When design and analysis are completed, the data will be used either to produce NC machining commands or detailed drawings and instructions for manual machining.



Geometric model of Boeing 767 was produced by interactive graphics from a computer-lofting system. The resulting data base is used for producing engineering drawings, layouts, clearance studies, and automated assembly.

systems to design and fabricate products ranging from fasteners and beverage bottles to tin cans and electric motors.

Many experts see CAD/CAM as the key antidote for sagging U.S. manufacturing productivity and predict the widespread use of CAD/CAM systems throughout general industry in the near future. However, these experts also point out that CAD/CAM is still in its infancy and must be greatly refined before its full potential is realized. This refinement is basically viewed as twofold. First, the sophistication of individual CAM functions must be developed to come up to par with present CAD technology. And secondly, individual CAD/CAM functions—which have essentially developed separately—must be combined into truly integrated systems that will be faster and more powerful than present systems where functions are merely interfaced.

Cooperative efforts to achieve this level of refinement are underway on several fronts. Individual areas of CAM technology are being developed by the Computer Aided Manufacturing International Inc. (CAM-I) organization. And individual CAD/CAM functions are being linked together, with framework programs being developed jointly by the U.S. Air Force Integrated Computer Aided Manufacturing (ICAM) project and the NASA Integrated Program for Aerospace Vehicle Design (IPAD) program. In addition, data communication between individual CAD/CAM systems is being standardized with the Initial Graphics Exchange Specification (IGES).

Because CAD/CAM technology is changing so rapidly, it appears very confusing to many people—even to experts intimately involved with its development. There are some who regard CAD as being only automated drafting and CAM as being merely NC tape preparation. At the opposite extreme are those who include all engineering tasks performed with a computer as CAD/CAM. In reality, CAD/CAM systems are comprised of definite functional areas of design and manufacturing, from geometric modeling of components to management of the entire factory.

CAD Functions

Experts say that CAD functions may be grouped in four major categories: geometric modeling, engineering analysis, kinematics, and automated drafting.

Geometric Modeling: The designer describes the shape of a structure with a geometric model constructed graphically on a CRT screen of the CAD system. The computer then converts this pictorial representation into a mathematical model stored in the computer data base for later use. The model may be used for other CAD functions, or it may be recalled and refined by the engineer at any point in the design process.

Geometric modeling is considered by many experts to be the most important feature of a CAD system because so many other design functions in the system depend heavily on the model. The geometric model may be used, for example, to

create a finite-element model of the structure for stress analysis. Or the model may serve as an input for automated drafting to produce engineering drawings. And if CAD and CAM systems are interfaced, the geometric model can be used to create NC tapes for fabricating the part.

Most modeling is done with wire frames that represent the part shape with interconnected line elements. Depending on the capabilities of the system, the model may be a 2D type representing a flat part, a 2½D model representing a part of constant section (having no side-wall details), or a full 3D model.

Three-dimensional wire-frame models often do not adequately represent the solid nature of an object and sometimes require further definition. An advanced geometric modeling technique that overcomes this problem is 3D solid modeling, which forms models with building blocks of elementary solid shapes called primitives. One of the most advanced of these 3D solid modeling systems is the SynthaVision program—a software package marketed by Mathematical Applications Group Inc. Other 3D solid modeling programs being developed around the world include PADL, developed at the University of Rochester under a National Science Foundation grant; COMPAC, developed at the Technical University of Berlin; PROREN, from the Ruhr University Brochum in Germany; and ROMULUS, from Cambridge University in the United Kingdom.

Because the geometric model is used ultimately as a basis for machining a part, CAD geometric modeling is tied closely to the NC technology of CAM. A pioneer in the move to tie these technologies together is the CAM-I organization, which is studying SynthaVision, PADL, and the other 3D solid modeling schemes to establish a common link between these models and NC systems. CAM-I also has been the driving force in the development of a system to create NC tapes for sculptured surfaces, complex contours that cannot be described with the usual lines and curves of conventional modeling systems. Structures with such contours include a wide range of parts from turbine blades and automobile bodies to pop bottles and camera cases.

Developments in 3D solid modeling and sculptured surfaces processing are two of the most significant advancements in geometric modeling. These technologies continue to be refined and linked with comparable NC capabilities, and experts predict that integrated systems ultimately will be developed to model and machine any general shape.

Analysis: After the geometric model is created, some CAD systems allow the user to move directly to analysis. With simple keyboard commands, the user may have the computer calculate, for example, weight, volume, surface area, moment of inertia, or center of gravity of a part. But the most powerful method of analyzing a structure on a computer is probably the finite-element method. In this technique, the structure is broken down into a network of simple elements that the computer uses to determine stresses, deflections, and other structural characteristics. Such analysis requires tremendous computational power on large mainframe computers, and manual construction of the elements is a tedious, time-consuming task. Therefore, implementation of the finite-element method without a CAD system is difficult.

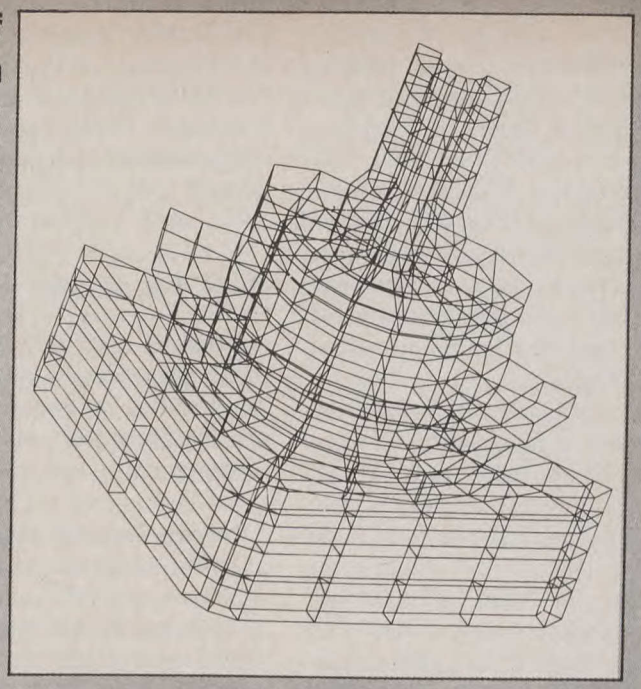
In integrated CAD systems, the user can call up the geometric model of the part and may use automatic node-generation and element-generation capabilities in the system to create finite-element models. Once a part is modeled, the user may specify the load parameters and perform an analysis by such programs as NASTRAN, STRUDL, ANSYS, or SAP. With graphics post-processing, the computer then may condense the huge amounts of output from the analysis data and present it in graphic form for quick evaluation. Output data, for example, may be displayed showing a deflected shape superimposed over the original model, with deflections exaggerated for evaluation. Or a color-coded model may show areas of high stress. Deflection mode shapes may even be animated to show deflection during operation.

If the finite-element analysis shows too much deflection or stress or other unwanted characteristics, the geometric model may be modified and the finite-element model changed and re-analyzed. Thus, the designer can see how the structure will behave before it is actually built, and he can modify it without building costly physical models and prototypes.

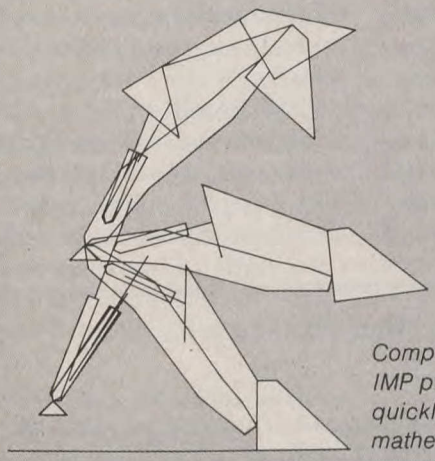
Perhaps the most revolutionary aspect of CAD analysis concerns the combination of analytical and experimental data to create a total system model. In such a system, characteristics of elastic components such as shock absorbers and isolation mounts are determined by testing, while rigid structures are analyzed with finite-element techniques. The data are combined to create a system model, which can then be exercised with data representing loads. In an automotive application, for example, input data may simulate wheel unbalance, braking, turning, or tire impact with a curb or chuckhole. The computer program

Roots of Computer-Aided Design

Interactive graphics capabilities—the heart of today's CAD systems—developed in the early 1960s in the aerospace industry with extraordinary amounts of government funding. These early systems were originally driven by large mainframe computers. But developments such as timesharing and minicomputers permitted compact, less-expensive systems to move to private industry, evolving into the CAD systems of today. Interactive graphics permitted man to communicate easily with the computer in pictures instead of columns of raw numbers and eliminated the need for the user to have experience in programming and computer operation. The earliest areas to utilize this breakthrough were kinematics and finite-element stress analysis—now two of the most mature CAD technologies.



Finite-element analysis is aided greatly by computer graphics. Models of structural components, such as this created with the UNISTRUC system from Control Data Corp., are represented by a network of line elements that the computer converts to a mathematical description for subsequent analysis.



Complex mechanisms such as this front-end loader, simulated by the IMP program at Structural Dynamics Research Corp., can be designed quickly without traditional pin-and-cardboard models or lengthy mathematical equations.

responds by predicting the response of the total vehicle to these conditions. The method has also been used to improve the structural integrity of trucks, buses, crawler tractors, and washing machines.

Kinematics: Many CAD systems have kinematic features for plotting or animating the motion of simple, hinged parts such as doors or cranks. Such analysis can ensure that moving compounds do not impact other parts of the structure. Specialized programs have also been developed for designing and analyzing more complex mechanisms such as four-bar linkages. The mathematics describing these mechanisms is so complex that designers traditionally have resorted to pin-and-cardboard models or cumbersome graphical techniques to develop practical mechanisms. Much of this tedium, cost, and complexity is now being stripped away by computer kinematics. The design of an automobile hood linkage, for example, requires only a few minutes of interaction with a computer, whereas hundreds of man-hours can be required for manual design of the same part. In most cases, the computer allows so many design trials that the final choice approaches an optimum.

Hundreds of mechanism-design programs have been developed in universities to solve very specialized problems, but only a handful have been refined sufficiently to be commercially practical. Among these are ADAMS and DRAM, developed by Milton Chace of the University of Michigan; IMP, developed by John Uicker of the University of Wisconsin; KINSYN, developed by Roger Kaufman of George Washington University; and LINCAGES, developed by Arthur Erdman of the University of Minnesota.

These programs are offered to the user in several ways. In some cases, the programs may be run on a time-sharing network. However, frequent users often find it economical to purchase the programs outright for use on in-house computer systems. Also, early versions of some programs are in the public domain and may be purchased for a small documentation charge of a few hundred dollars. However, these early versions lack the refinement and support of up-to-date programs provided by the software vendors.

With ADAMS, DRAM, and IMP, the user inputs language statements, and the computer then provides output data such as link positions, forces, velocities, and accelerations. KIN-

SYN and LINCAGES programs, however, develop mechanisms based on required motion paths. The LINCAGES program requires some use of a keyboard, but KINSYN is totally graphical. The user simply draws motion requirements on an electronic tablet, and the computer immediately provides the design information on a display screen.

The capability of a computer to develop a mechanism design has wide implications in CAD technology. According to experts, future engineers will also have programs and computers available to completely synthesize a complex mechanical system based solely on its intended function. In other words, the user will describe the requirements for a product, and the computer will provide a design to meet that set of specifications. Some experts predict that, by the year 2000, design will be done in a cockpit-type module in which both design synthesis and analysis will be carried out even for such complex mechanical systems as automobiles.

Drafting: With automated drafting, detailed engineering drawings may be produced automatically from a data base. In addition, most drafting systems have automatic scaling and dimensioning features.

A typical CAD system with automated drafting can generate up to six views on a screen. Any design change made on one view is automatically added to the others.

Detailed drawings can be made by drawing from a "menu" with drawing functions such as size and location of lines, arcs, text, cross-hatching, and dimensions.

CAD systems can be five times faster than manual drafting. And for design changes, CAD systems can be as much as 25 times faster. In the future, this CAD productivity is expected to be even greater with faster plotting techniques and with more terminals being operated simultaneously by a central computer.

CAM Functions

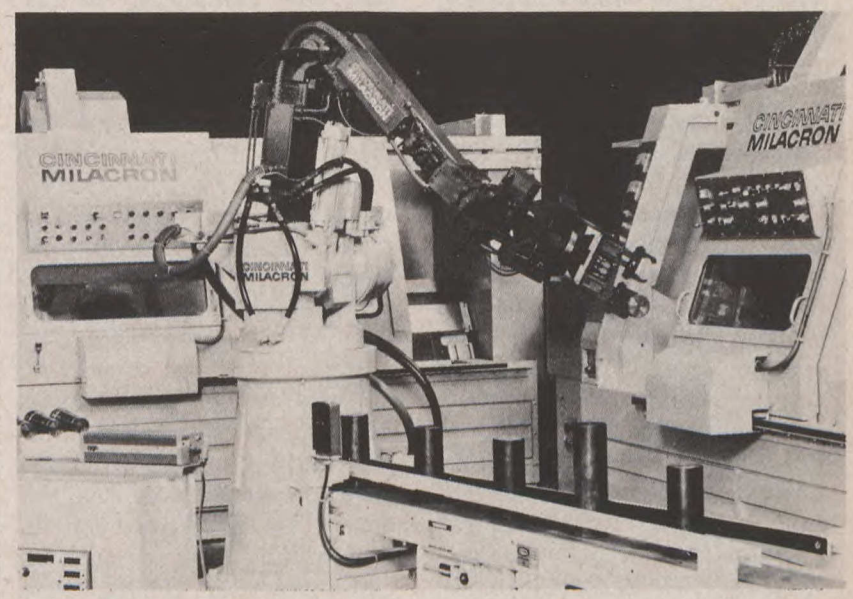
Present activity in CAM technology centers around four main areas: numerical control, process planning, robotics, and factory management.

Numerical Control: Probably the most mature of CAM technologies, NC refers to the technique of controlling a machine tool with prerecorded, coded information to fabricate a part. NC instructions are written in control languages such as the Automatically Programmed Tool (APT) and stored on punched paper tapes or magnetic tapes for controlling the machine tool. More advanced systems may use Computer Numerical Control (CNC), where the machine is hardwired to a minicomputer which stores the NC instructions. And the most sophisticated systems use a Direct Numerical Control (DNC) scheme which links several minicomputers to a central mainframe computer. Some DNC systems have eliminated the intervening minicomputer and have a direct interface between the central computer and machine tool.

Traditionally, NC instructions are written from engineering drawings by programmers. The program then must be tested on the machine and re-

Toward the Automated Factory

Experts predict that by the end of this century we will see the automated factory: the ultimate goal of CAM development. Present ICAM and CAM-I plans are to have robots and NC machine tools divided into units called group-technology work cells, combining two or more manufacturing processes to fabricate a family of similar parts. A materials-handling system could connect the cells to create higher-order manufacturing centers which, in turn, could be further interconnected to create an automated factory.



Cincinnati Milacron T³ industrial robot tends two NC turning machines much the same as a human technician. In this work cell, the robot delivers randomly sized parts to the appropriate machine, removes finished parts, inspects them at a laser gaging station, and then stacks them.

fined several times before the part is machined properly. These iterations can account for as much as 30% of the tool operating time and significantly increase the cost of machining a part.

Advancements in computer technology now make creation and verification of NC instructions much more efficient. By checking the tooling program with computer simulation, for example, less machine-tool time is spent verifying the cutting paths. Perhaps more important, the computer itself can now generate an NC program directly from a geometric description of the part. However, these automatic capabilities are restricted to flat parts, highly symmetric geometries, and other specialized shapes. Lockheed-California's CADAM system, marketed by IBM, and McDonnell Douglas's CADD system are examples of such systems.

CAM-I is at the forefront in developing capabilities to program general 3D shapes. Developments such as the Sculptured Surfaces Processor and the Advanced NC Processor bring the technology close to an integrated, generalized system—which many experts claim is not far in the future. According to one CAM-I spokesman: "The problems are immense but not unsolvable. It is a matter of solving an enormous jigsaw puzzle, cleverly arranging and applying existing technology."

Process Planning: Whereas NC is concerned with controlling the operation of an individual machine, process planning considers the detailed sequence of production steps from start to finish. Essentially, the process plan describes the state of the workpiece at each workstation. Process planning has been a part of manufacturing operations for some time, but only recently has the computer been brought to bear on this activity.

An important element in process planning systems is a concept called group technology, which organizes similar parts into families to allow standardized fabrication steps. Most of the current process planning systems use a retrieval technique based on part families and existing data bases for standard tooling and fabrication processes. The CAM-I Automated Process Planning (CAPP) system was one of the first of these systems, and a commercial system called MIPLAN is also available.

Such retrieval systems, however, are far from the generative process planning systems many experts envision for the future. Currently under development by CAM-I, the generative process planning system would produce process plans directly from the geometric model data base with almost no human assistance. In such a system, the process planner would review the input from design engineering via computer communication and then enter this input into the CAM system, which would generate complete plans automatically.

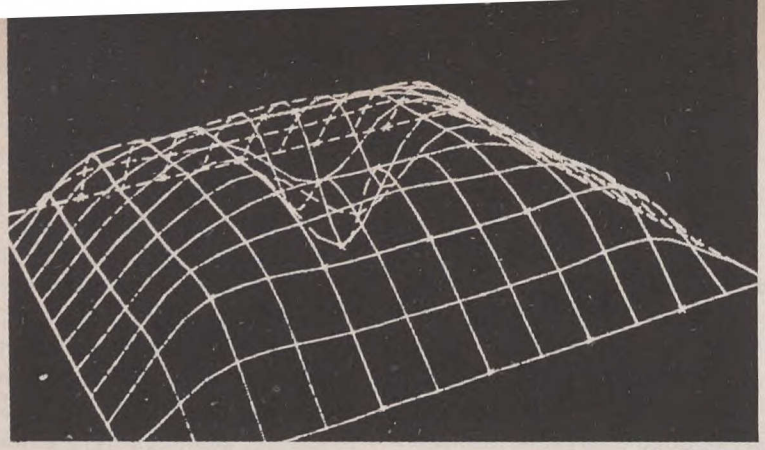
Robotics: Automated manipulator arms—or robots—are used to perform a variety of material-handling functions in CAM systems. Robots may select and position tools and workpieces for NC machine tools. Or they may use their hands—called end effectors—to grasp and operate tools such as drills and welders.

Most robots presently are programmed with a so-called teach mode in which a person physically leads the robot through the required steps of an operation. But manual teaching is time-consuming and error-prone. And changes in the program usually require the entire sequence of tasks to be retaught.

To overcome these problems, present efforts in robotics are aimed at developing robot programming languages with which an operator develops robot instructions through a computer. These languages extend the robot capabilities beyond those of the traditional teach mode. The Stanford Research Institute Robot Programming Language (RPL), for example, includes capabilities for interpreting video signals for visual recognition of parts. And Draper Industrial Assembly Language (DIAL), developed at Charles Stark Draper Laboratory, uses electronic force-feedback that duplicates human sense of touch in assembling components. One of the most advanced languages currently under development is the IBM Automated Parts Assembly System (AUTOPASS), which will attempt to eliminate the need for a robot to have de tailed instructions. In this scheme, the robot program would automatically determine grip points and motion paths from the geometric data base.

Robot capabilities are also being developed as part of the U.S. Air Force Integrated Computer-Aided Manufacturing (ICAM) project, where the goal is to organize every step of manufacturing around computer automation. As part of this program, a robot is being used to make sheet-metal parts for the F-16 aircraft. Here, the robot selects bits from a tool rack, drills a set of holes to 0.005-in. tolerance, and machines the perimeter of any of 250 types of parts. Production rates with this system are reportedly four times greater than those of conventional manual fabrication.

Factory Management: This portion of CAM ties together the other areas to coordinate operations of an entire factory. Factory management systems may rely heavily on group

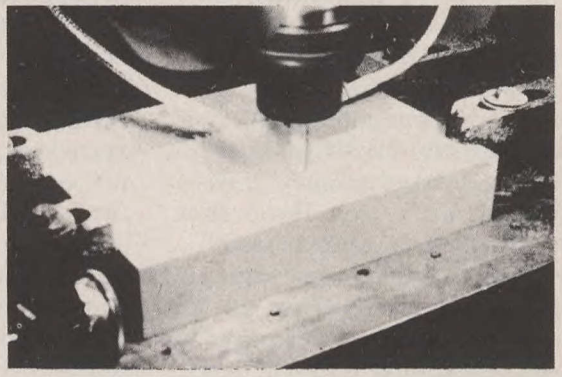


Complex surfaces are represented by a network of interconnected patches in the CAM-I Sculptured Surfaces Processor. After the surface is modeled, the processor output may be used to create NC instructions to fabricate a contoured part.

From Shape to Tape at the Keyboard

The writing of numerical-control instructions formerly was a time-consuming art requiring experienced programmers. But now, some CAD/CAM systems automatically create NC tapes directly from a geometric model. And the program can be verified at the terminal with computer simulation.

Present systems are limited to certain part geometries, however, and must be greatly refined before NC instructions can be produced automatically for more general geometries. A big step in this direction is the development of the CAM-I Sculptured Surfaces Processor, which models and develops machining instructions for complex contoured shapes.



technology, with families of similar parts fabricated in individual manufacturing cells. Computers also perform various manufacturing management tasks such as inventory control and scheduling in systems that have come to be known as material requirements planning (MRP) systems.

Experts predict that individual manufacturing cells eventually will be linked together and controlled by a unified computer system, paving the way for overall automation of a factory. Any such CAM system is envisioned as being hierarchical in nature, with middle-level computers controlling the operation and work-scheduling of one or more cells, and the overall system being controlled by a central computer. Forecasts of the future of production technology by the University of Michigan and by the International Institute for Production Engineering Research both indicate that factories totally automated by computer will be a reality before the end of this century.

Cooperative Efforts

Integration of the many aspects of CAD/CAM technology is too complex to be tackled solely by one company, or even a single industry. But the potential benefits of these systems are too great to afford to wait for full integration to occur unaided. Therefore, governments, private industry, and universities around the world are cooperating in an effort to advance and integrate CAD/CAM technology.

CAM-I: Computer-Aided Manufacturing International Inc. was formed in 1972 to advance CAM technology. Over a hundred industrial companies, educational institutions, and government agencies in North America, Europe, and Japan pooled resources to form this nonprofit organization. Basically, it provides a convenient conduit for transferring information between companies using computers in design, analysis, and manufacturing. Acting as a unified group, the members advance applied computer technology more effectively than if acting separately.

CAM-I representatives develop and execute long-range technical planning for the application of computers to design and manufacturing operations. CAM-I develops concepts and reduces these concepts to functional specifications, system specifications, and prototype software to demonstrate and justify industrial application.

IPAD: The Integrated Program for Aerospace-Vehicle Design is a NASA-sponsored project underway since 1976 aimed at developing a software program for integrating existing CAD functions and for de-

veloping efficient ways to handle the huge amounts of data involved in such systems. Although functions such as geometric modeling and finite-element analysis are already interfaced in existing systems, one IPAD spokesman characterizes them as "quick and dirty fixes rather than truly integrated systems." Essentially, IPAD will provide a basic software framework in which all the separate functions of CAD will operate in an integrated manner.

The goal of IPAD is to increase productivity in the aerospace industry, but the program also is expected to benefit other activities such as shipbuilding and automotive design.

The system is being developed by the Boeing Co. under contract to NASA, and a preliminary design has been completed. A detailed design is presently being developed, with software scheduled for release in 1981, after which users are slated to accept responsibility for maintaining the system.

ICAM: Integrated Computer Aided Manufacturing is a U.S Air Force program attempting to develop one master program that will coordinate all the sophisticated design and manufacturing techniques now employed piecemeal by industry. In cooperation with IPAD, the ICAM program will attempt to integrate such diverse engineering functions as design, analysis, fabrication, materials handling, and inspection. Plans are to have both the IPAD and ICAM programs available to both design and manufacturing and to have a common language used for geometric descriptions.

The ICAM program is divided into 10 tasks or "thrust areas" to integrate all computers in a metal-working factory. Goals include development of hardware and software demonstration manufacturing cells in selected aerospace plants. These would produce sheet metal parts, believed to be the most difficult to fabricate automatically. The cells would make use of robots. A major ICAM goal is the complete robotized and computerized sheet metal fabrication center, which is scheduled for production in 1985.

IGES: A spin-off of the IPAD and ICAM programs is the Initial Graphics Exchange Specification (IGES), which will attempt to standardize the communication of geometric data between computer systems. Presently, most CAD systems, having been developed in-house or by turn-key vendors, use a different format to organize and transmit geometric data. Thus, communication between different CAD systems is characterized by one expert as a "Tower of Babel."

IGES will serve as an interim specification until the American National Standards Institute develops its own specification—a process that is expected to take three to four years. This interim specification has just recently been issued and is based on the standardized form of communication used at Boeing Co. MD

For More Information

General information about CAD/CAM concepts and the efforts to develop totally integrated systems may be obtained from government groups and service organizations by circling the following numbers on the Reader Service Card:

800 IPAD Project Office
NASA Langley Research Center
Hampton, Va. 23665

801 ICAM Program Office
Air Force Materials Laboratory
Wright-Patterson Air Force Base, Ohio 45433

802 Computer Aided Manufacturing International Inc.
611 Ryan Plaza Drive
Arlington, Tex. 76011

803 Structural Dynamics Research Corp.
2000 Eastman Drive
Milford, Ohio 45150

Specific information on individual CAD/CAM systems may be obtained from computer system producers, equipment manufacturers, and software vendors by circling the following numbers on the Reader Service Card:

804 Applicon Inc.
154 Middlesex Turnpike
Burlington, Mass. 01803

805 Auto-trol Technology Corp.
12500 North Washington St.
Denver, Colo. 80233

806 Calma Corp.
527 Lakeside Dr.
Sunnyvale, Calif. 94086

807 Control Data Corp.
Box 0
Minneapolis, Minn. 55440

808 Computervision Corp.
201 Burlington Rd.
Bedford, Mass. 01730

809 Digital Equipment Corp.
200 Forest St.
Marlboro, Mass. 01752

810 Gerber Systems Technology Inc.
40 Gerber Rd.
South Windsor, Conn. 06074

811 Hewlett-Packard Co.
Computer Systems Group
11000 Wolfe Rd.
Cupertino, Calif. 95014

812 International Business Machines Corp.
Data Processing Div.
1133 W. Chester Ave.
White Plains, N.Y. 10604

813 Lockheed-California Co.
CADAM Program Office
Burbank, Calif. 91520

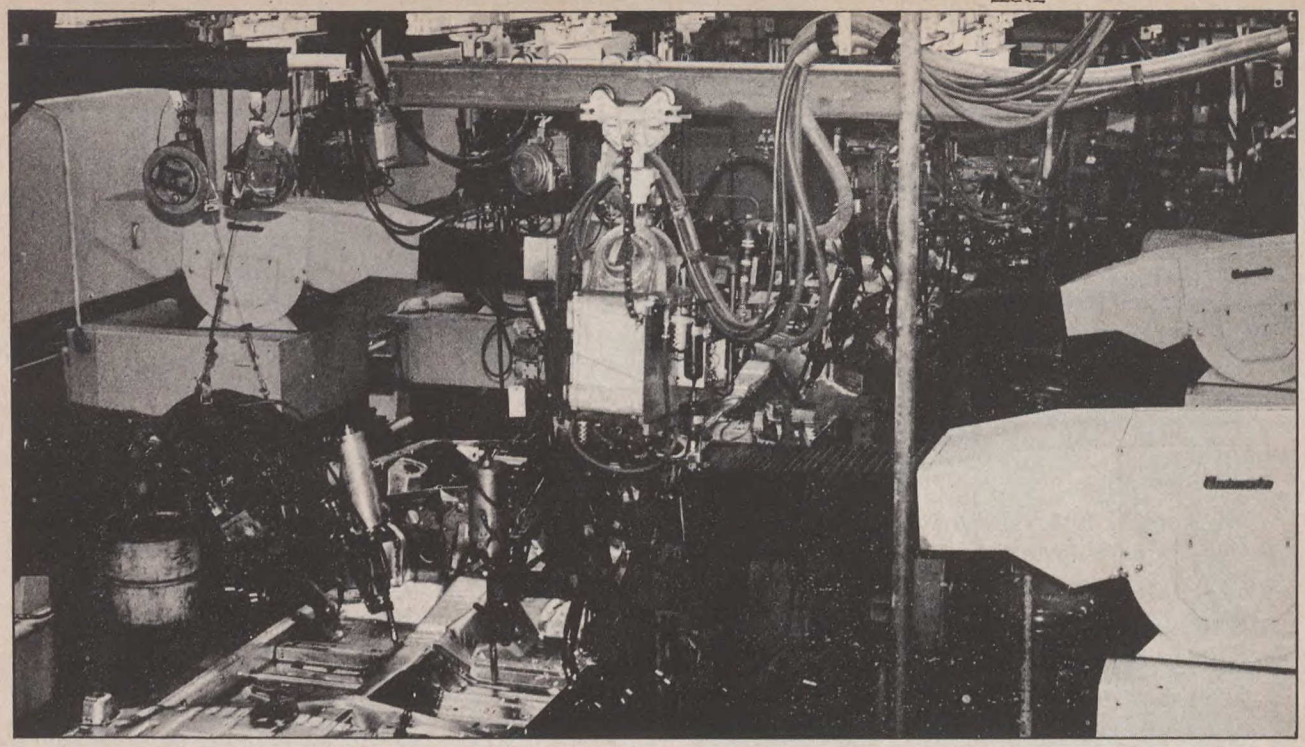
814 McDonnell Douglas Automation Co.
Box 516
St. Louis, Mo. 63166

815 National Computer Systems Inc.
4401 W. 76th St.
Minneapolis, Minn. 55435

816 Perkin-Elmer
2 Crescent Place
Oceanport, N.J. 07757

817 Prime Computer Inc.
40 Walnut St.
Wellesley Hills, Mass. 02181

818 Tektronix Inc.
Information Display Div.
Box 500
Beaverton, Oreg. 97077



Auto plants pick robots for some of toughest jobs

By Jake Koekebakker

Robots have started to appear on Canadian auto assembly lines for a number of as yet untried applications, upholding the automotive industry's tradition of pioneering.

The automotive industry has always played a pioneering role in the application of industrial robots. These mechanical handling devices have, indeed, become a fairly familiar sight at many auto plants throughout the United States, where they are an integral part of the production system.

Canadian auto plants, although the introduction of robots there is more recent, are upholding the pioneering tradition. Several robots are performing tasks there that had not been done previously anywhere else.

To be sure, the robot population in the Canadian plants is as yet small. The largest single "family" is at the St. Thomas, Ont., auto assembly plant of the Ford Motor Co. of Canada Ltd., where they now have 13. General Motors of Canada Ltd. has two robots at its truck assembly plant in Oshawa, Ont., and two others at its metalcasting plant in St. Catharines, Ont., while American Motors (Canada) Ltd. has one at its Bramalea, Ont., plant*. Chrysler Canada Ltd. is the only company that has, so far, no robots on the line.

Ford's is a classical assembly-line welding application.

Prior to tooling up for production of 1978 Fairmont and Zephyr bodies in 1977, a decision was made to incorporate 13 robots in body-metal assembly—five Unimates 4000s for welding of front-end structures, six 4000s for underbody assembly, and two Unimate 2000s for pretacking roof rails to body sides. Four additional Unimate 2000s were added at a later date for welding of door and window flanges.

Robots are particularly suited for these operations, explains plant operations manager Denton Grenke.

"The robots were put in locations, where they do repetitive tasks on every car and where it was possible to use automatic transfer to place the product into position for the welding operation."

"They are handling welding jobs in which access would be awkward for a human operator. They are the kind you have to reach for. On the other hand it would be overcomplicated and uneconomical to try and pick up those welds by means of hard automation."

One of the best examples of the robots' ability to reach around corners is evident on the line pretacking roof rails to body sides. The two robots, one for the left side and the other for the right, have to go through considerable movement to reposition the weld gun for each weld.

Grenke says a human operator, using the same welding equipment, could probably make a better weld, but expresses doubt a man could keep going at the same rate for a full shift in these more physically demanding jobs.

*CM&M was not able, at this time, to obtain details about the AMC installation due to a plant shutdown.

(Opposite page) Six Unimate 4000 robots weld auto underbodies on Ford assembly line at St. Thomas, Ont. averaging 25 welds/minute

In each of these applications, the robots place an average of about 25 welds per unit. With an average line speed of 62 units per hour, that works out to about 25 welds per minute, which, says Grenke, is considered about ideal.

Since the line speed varies, some adjustments have occasionally to be made. The robots' programmability makes this relatively easy. On the front-end line, for instance, which comprises an automated weld press followed by a seven-station weld line, at least three different programmed routines are available for the five robots. In each program an attempt is made to optimize the robots' operational cycle for a particular line speed by varying the number of welds made, their sequence, and clamping routines.

A similar approach is used on the underbody line, which consists of a four-stage automated press and a three-station weld line with six robots. In both of these applications, all the equipment, including the transfer line, presses, and robots, is controlled by programmable controllers.

On an assembly line equipment reliability is vital. The robots at the St. Thomas plant, however, have given no cause for complaint. In fact, Grenke estimated up-time at close to 98%, which is what is claimed for these machines by the manufacturer, Unimation Inc.

"We have more problems with the rest of the gear than with the robots," he says. "We have more problems with positioning, and with the welding guns."

Grenke credits this remarkable performance to exhaustive preparation and training plant staff prior to installation.

"The biggest thing, we found, was the training of the skilled tradesmen to maintain them," he says. "That probably was the key to the program.

"The big thing with robots, we learned, is that unless you do a proper PM (preventive maintenance) schedule, you lose accuracy. We placed more emphasis on PM, I think, than on anything else."

Accuracy is particularly critical on the body construction line, where the robots are welding door and window flanges—right on the edge of the exposed metal. The welds are placed within ¼ to ⅜ in. from the ½-in. flange requiring 0.100 to 0.120 thou accuracy. It was, incidentally, a job given to robots at the initiative of the St. Thomas plant in spite of the warning of robot experts in Detroit that it wouldn't work, because the body structures on the transfer line were thought to shake too much. It turned out the system worked well in spite of this, provided, says Grenke, the robots are given sufficient attention by the maintenance staff.

"You've got to care for the robot the way you would care for a person," Grenke asserts. "It needs that kind of attention."

Two Nordson robots installed on an experimental basis at GM's truck assembly plant in Oshawa, Ont. last November to paint pick-up truck boxes proved their worth very quickly. The two apply the first colour coating. Already, at the urgings of the production staff, a decision has been made to install two additional robots sometime next year for the second colour coating.

The original installation owed its experimental status to the fact that the robots were called upon to perform two functions not previously tried in the North American auto plants. First, while robots are stationary, they paint items on a moving line, at a rate of 45 an hour. Secondly, the system is capable of changing the spray colour automatically as required.

"So far, the robots have been very successful," says Tass Eilert, assistant superintendent of plant engineering at the GM truck plant.

The way the operation is set up, the two robots, which have been named Lavern and Shirley by the operating staff, are staggered, one on each side of the moving conveyor line. As the boxes enter the spray booth and move into position alongside the first robot, located to the left of the line, the first spray cycle is started, covering the left outside and right inside of each box, as well as parts of inside and outside front and back and bottom. When the first cycle has been completed, in approximately 1.2 minutes, the box has meanwhile moved into position alongside the second robot, on the right hand side, which coats the right outside and left inside, and completes the remainder of the job.

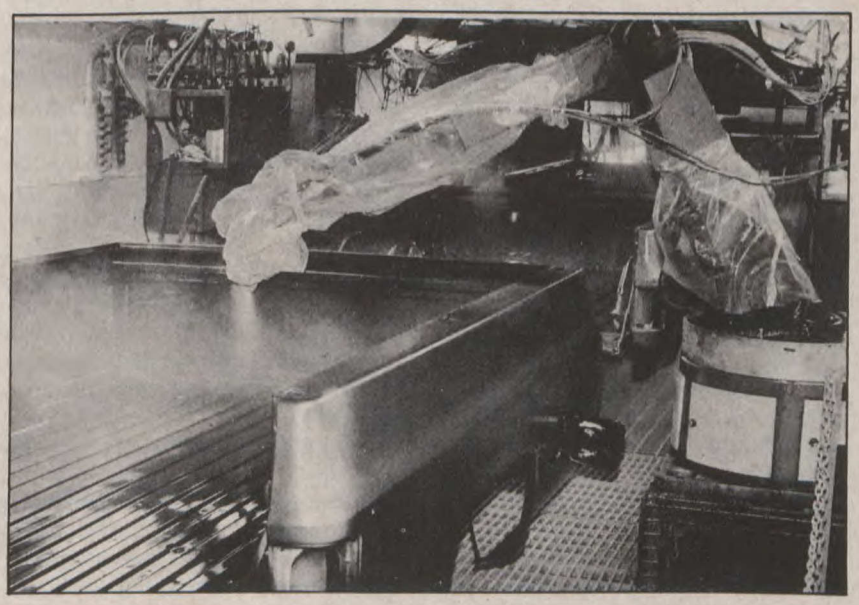
"It is an awkward type of operation," says Eilert, explaining the necessity of reaching across, and into, the box to achieve the correct spray gun distance to the interior surface.

To accommodate different box styles, four robot programs are available in the robot memory (the system can actually handle as many as six programs).

The appropriate program is selected by an operator just before each box enters this spray booth. The operator also keys in one of 26 available paint colours to the programmable controller, which controls the automatic paint dispensing system.

What is unusual about the system is that the robot program is tied to

Truck box is painted by Norton robot at GM truck assembly plant in Oshawa, Ont., applying first colour coat



line speed. Line stops are a fairly frequent occurrence. As the line slows down and comes to a stop, the robots compensate for the initial deceleration and then stop spraying, holding their position. They continue the spraying cycle as the line starts up again, compensating for the acceleration until full line speed has been attained.

"It was one of the features we asked for when we installed the system," says Eilert. "We wanted the robots to pick up where they left off if the line stopped in the middle of a program cycle period." Likewise, the system can operate at a range of line speeds, although in practice this speed is rarely varied.

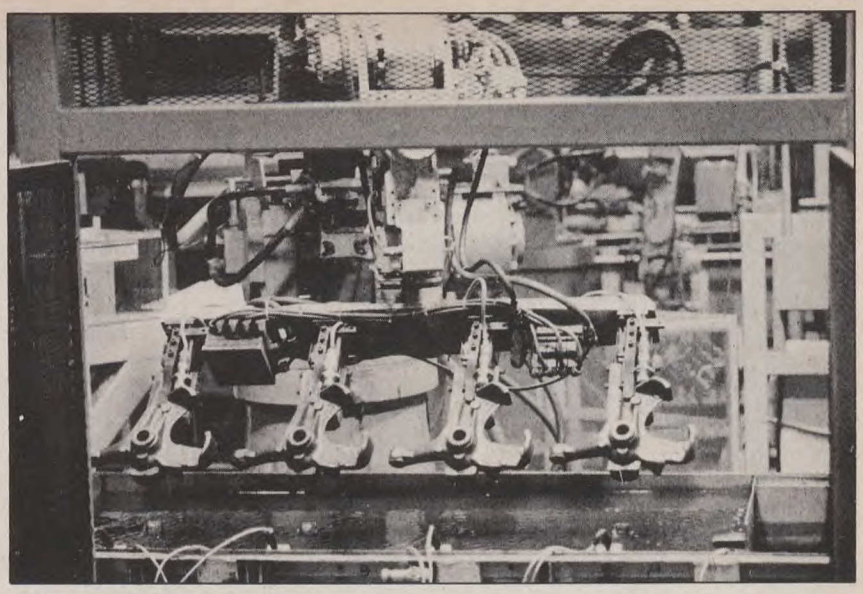
The main reason robots where selected for this particular application was the difficulty of this type of operation. It involves large surfaces to be coated, with considerable, and unavoidable, bounceback of paints, creating an unfavourable working environment within the spray booth. As well, in order to achieve the specified gun-to-surface distance the operator has to lean out over the side of the box—at 45 times an hour a considerable physical exertion—with the added hazard of damaging the exterior of the box (a second colour coat is still being applied manually this way; it is this operation which is now also slated for conversion to robots sometime next year).

Like all painting robots, Lavern and Shirley are programmed by the walk-through method in which an operator guides a specially designed robot training arm through the entire spraying cycle. According to Eilert, this has been the most difficult aspect of the robot system.

"We found that extensive training of the operator is needed before he can program a robot," Eilert says, explaining that the guiding of a robot only requires a psychological adjustment of the operator.

"They have to train themselves to guide the arm as if it were only a spray gun and they were painting a job as the gun normally would.

An inevitable by-product of introducing of a robot into a plant is the creation of new in-house domain of expertise, involving both plant engineering and trades. You can not hire these specialists, either permanently or temporarily, at least not yet since there are only few of them. Nor can you just send a few guys to school in the expectation that they will return as fully qualified robot experts. The real learning only starts with the arrival of the robot itself.



*Steering knuckles are being positioned for ultrasonic test **(above)** at GM metalcasting plant, St. Catharines, Ont. by Cincinnati-Milacron T³ heavy-duty robot. Castings are transferred from loading rails shown at top left **(opposite page)** to test station.*

Nowhere was this more apparent than in GM's metalcasting plant, where two Cincinnati Milacron T³ robots arrived last October. Says Richard Baumann, an electrical engineer on the plant engineering staff charged with the robots' care: "You take the course down at Cincinnati, and you are lucky if you get four of five hours of hands-on experience, but when you do play with it, there are no constraints.

"Now you come onto the shop floor with innumerable constraints you have to work around, and this is when you start finding out what a robot can do and cannot do, and what you have to do to program it.

"I think from the time the machine came on the floor to the time we felt we knew what we were doing with it was a week and a half."

The decision to employ a robot was prompted by a change in the casting process for production of steering knuckles for cars and light trucks, which necessitated retooling two automatic ultrasonic test stations. The changes centred on replacement of two transfer devices that have been handling the castings, but could not be adapted to the new system. Plant engineering concluded robots could do the job as well as hard automation, and would be less vulnerable to obsolescence.

But the application was, as far as is known, the first of its kind.

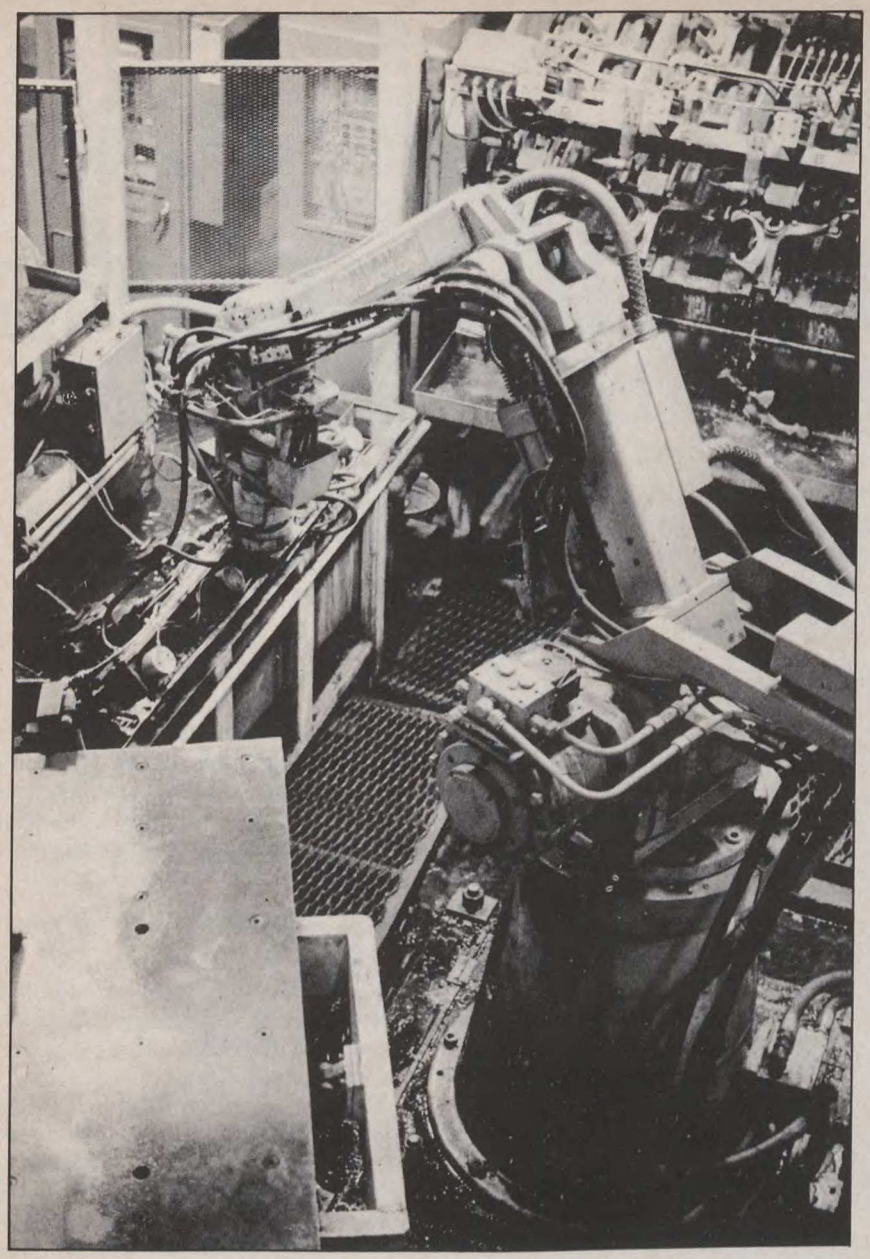
"From what we have learned from talking to other users, very few robots are actually picking parts up and placing them precisely in a fixture, then removing them from that fixture again, and disposing of them into another fixture. It is a tougher application than most because you have to hit the position very closely."

Testing the integrity of steering knuckles is a critical aspect of the Motor Vehicle Safety Standard. Each single part has to be certified as having at least 85% to 90% nodularization. Ultrasonics provide a sensitive quantitive measurement of nodularization, and is employed in a testing system that automatically signals the parts' acceptability on a go/no-go basis.

This requires a handling system capable not only of presenting the part to the test jig, but also automatically separating out the rejects, and only forwarding parts that passed the test.

The major requirements of such a system are that, 1) it makes no mistakes, 2) it has accurate positioning capability, and 3) it is fast.

The first requirement did not present any significant difficulties. A robot system such as the T³ can accommodate several fail-safe levels, due to its programmability, which allows checks to be built into the operating cycle to ensure that when the grippers finally release the part, it is a good one without exception.



As for accuracy and speed, that was something else again.

There are two independent test lines, officially designated as the "East" and "West" system—one for car steering knuckles, weighing 17 lb each, and the other for truck steering knuckles weighing 23 lb each. Each line has its own robot (known to plant personnel as Mork and Mindy)—the first heavy-duty versions of the Cincinnati Milacron T3.

The operating cycle, in which the robot arm moves from a set of loading rails to the test fixture, on to a scrap disposal bin, to a punch, and back to the loading station, takes about 30 seconds.

To attain that rate, the end of arm speed reaches 50 in./s during swings—with a load at times in excess of 100 lb, including the weight of end-of-arm tooling. The acceleration, as it is described by Dave Braithwaite, senior electrical engineer in charge of the robot program, is "awesome"—enough to flex an 8-in. concrete floor underneath supported by 16-in. steel beams. "You can feel it through your boots," Braithwaite claims.

"I think the thing that came closest to catching us napping was fixturing," he said. "It is not like fixturing a transfer machine.

"A transfer machine isn't accelerating at the rates the robots are, but this is how we get the production out of the system. We have the capability of getting very high velocities and accelerations, and we need them."

The inertia of the parts, however, places extreme demands on the grippers and modifications had to be made on the original design to give a better hold. Braithwaite admits that if the implications of acceleration had been fully appreciated, the grippers would have been designed differently to start with.

"I think that tool design, to be effective, has got to be involved in the process design. I think in the next one we will have a lot more of that sort of involvement from the beginning of the tool design process."

Another example he cites is the design of the fixtures in the testing equipment.

"The tooling we received had the kind of lead-in into the nest that you would have with a human operator. With robots we find that you should use a longer lead-in on a wider angle because the robot cannot go there and sort of waggle it around to hit the slot. It just has to position it and let it go. It has to fall in.

"So, the tool designer has to have a very good appreciation of how the robot is going to work, and he has to adapt to it."

Nobody, however, has to adapt to the degree the programmer does. Says Baumann, who did most of the programming: "I can think like a robot now, but I couldn't a year ago." As an example Baumann points out that the Cincinnati system moves on all axes simultaneously, and in point-to-point programming it solves the geometry of the optimum path itself. This path, Baumann notes, is not necessarily anticipated by a novice programmer.

"This is something you find empirically, that you can make certain types of moves at maximum velocity, and other types of moves you have to tone down. This is just a pure and simple learning experience. That is all it is. It is something that I cannot convey to someone with words on paper."

Apart from an intermittent, though persistent, malfunction of Mindy, which was finally traced down to a damaged cable, the robot systems have performed satisfactorily, and the engineering staff is gradually turning over more control to operating and maintenance personnel.

"We have got a system out there now that very rarely fails due to the fact that we don't have a casting in the right orientation or can't get it into the fixture.

"For the last six months we have learned what we had to do." □

PRODUCTION IN MOLDING

Say "goodbye" to the guesswork

General Electric's plan to use computers at the grass-roots level to optimize mold design and mold filling and cooling promises a multimillion dollar payoff by the mid-1980s. Spin-off applications from the CAD/CAM system could further magnify the benefits.

"If we can develop this program and simplify the mechanics of using it to the point where it can be used easily by the average mold designer or manufacturing engineer, the savings to General Electric would amount to millions of dollars annually."

That assessment by one of the program managers underscores the size of the stakes that induced the company to make a major dollar commitment to the project. Now in its fourth year of development by the Automation Technology Branch under the direction of Robert J. Douglas at GE's Corporate Research and Development operations in Schenectady, the program combines computer-aided design and manufacturing (CAD/CAM), computer modelling and interactive graphics.

Its purpose is to increase productivity in injection molding by designing and optimizing molds and molding conditions at a computer terminal instead of by traditional cut-and-try methods in the plant. With an estimated 1000 presses in service, injection molding has become a major manufacturing process at GE, and one well-worth optimizing.

General Electric is giving high priority to increasing productivity in its manufacturing processes, including injection molding. It is convinced that the best way to accomplish that goal is not through the traditional, incremental improvements from hardware refinements, but through process optimization using computer analysis and simulation.

In the 10-yr span between 1970 and 1980, the number of computer-aided design work stations in the company has increased to several hundred from literally zero. These have been used primarily for product design; now the interest is moving to tool design also.

When fully developed in the mid-1980s, the system will "lace together," via a series of interrelated computer programs working from a common data base, the sequence of currently separate steps needed to create an efficient mold and optimum molding cycle.

Once the numerical definition of the desired part geometry is entered into the computer's data file, the program will enable designers and manufacturing engineers to design and optimize virtually every aspect of an injection molding process.

Initially the program is focusing on advanced technics to predict the flow behavior of the melt through the runners and into the mold and to design the mold cooling system for minimum cycle time. Eventually, depending on further assessment of the software development costs, GE will extend the use of the part description in the data base to creating numerical control programs to machine the cavity and then inspect the molded parts.

The ability to move from the numerical definition of the part to an NC programs to cut the mold already has been demonstrated experimentally on a PP housing. The lead-time saving is estimated at 35%.

Major elements of the system

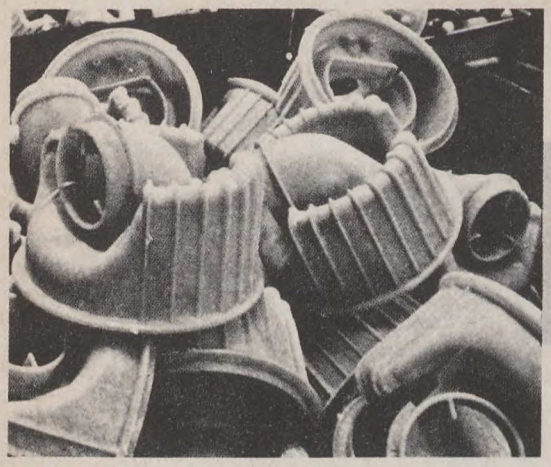
Though some of the subprograms in the total CAD/CAM system are still in the development stage, its potential scope borders on the spectacular:

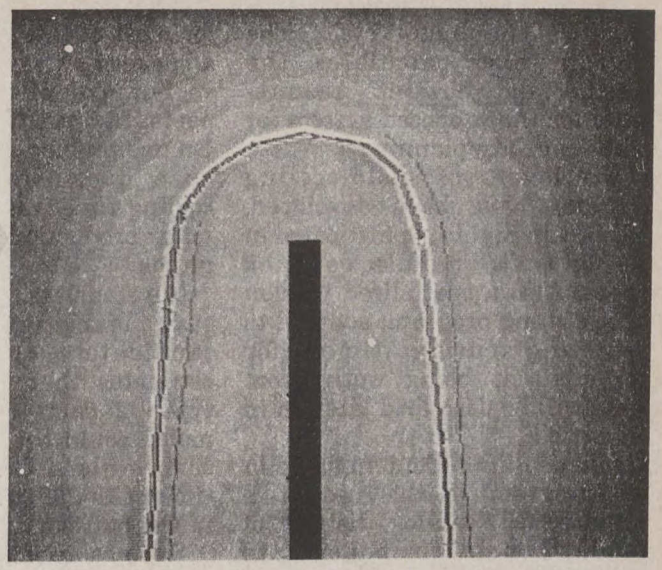
Runner design and mold filling. These two separate, but interrelated analytical programs will give designers and process engineers a powerful tool for designing and optimizing the molds and molding process. The runner program, which will be particularly valuable for multiple-cavity molds, will assist in configuring and balancing the runner system and in sizing the gates. Its output is input data for the mold-filling program to predict melt-front propogation, mold filling time and clamping pressures. It also will provide the basis for predicting how the mold will fill, if thinner walls can be used, and whether the part will have excessive stress.

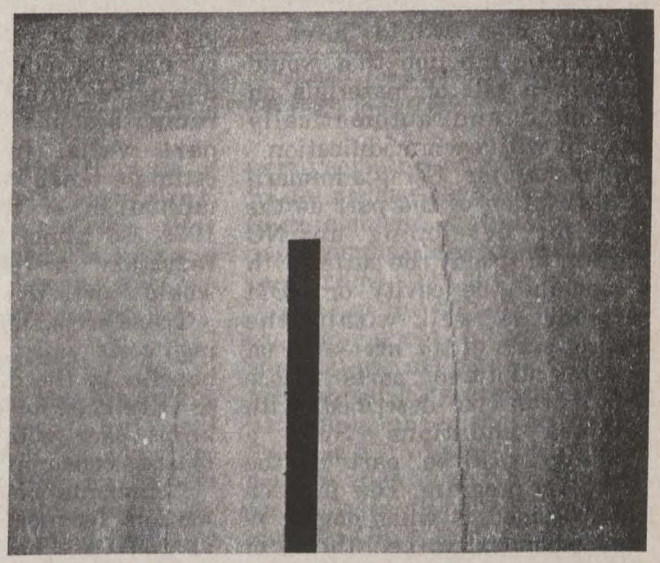
Mold cooling. The mold-cooling analysis, which is to receive the output from the mold-filling program, will enable the mold designer to try out, on the computer, his proposed layout and geometry of the cooling lines.

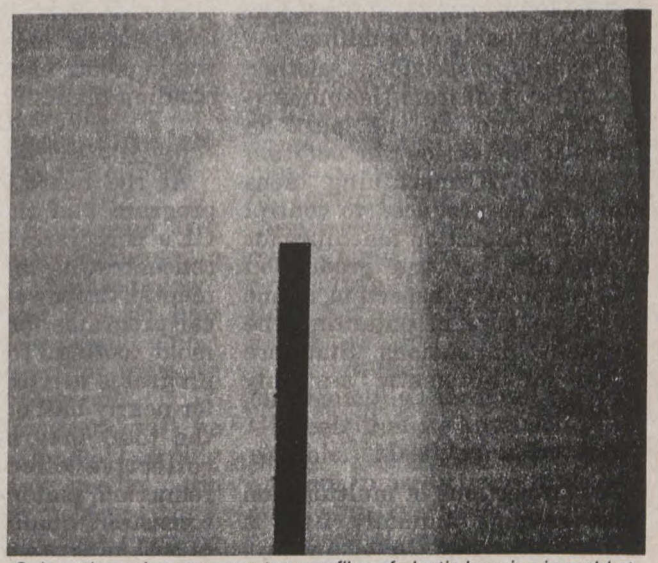
The program forecasts part-

CRT 'pictures' predict temperature profiles to aid in cooling design





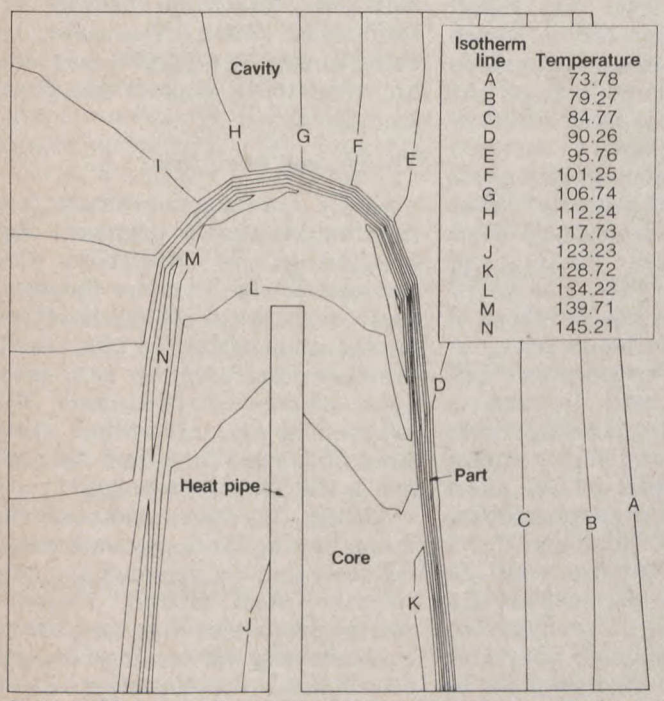




Results with dishwasher drain

	Previous experience	Analytical prediction
Mold open	5 sec	5 sec
Inject	8 sec	6 sec
Cooling	42 sec	21 sec
Total	55 sec	32 sec

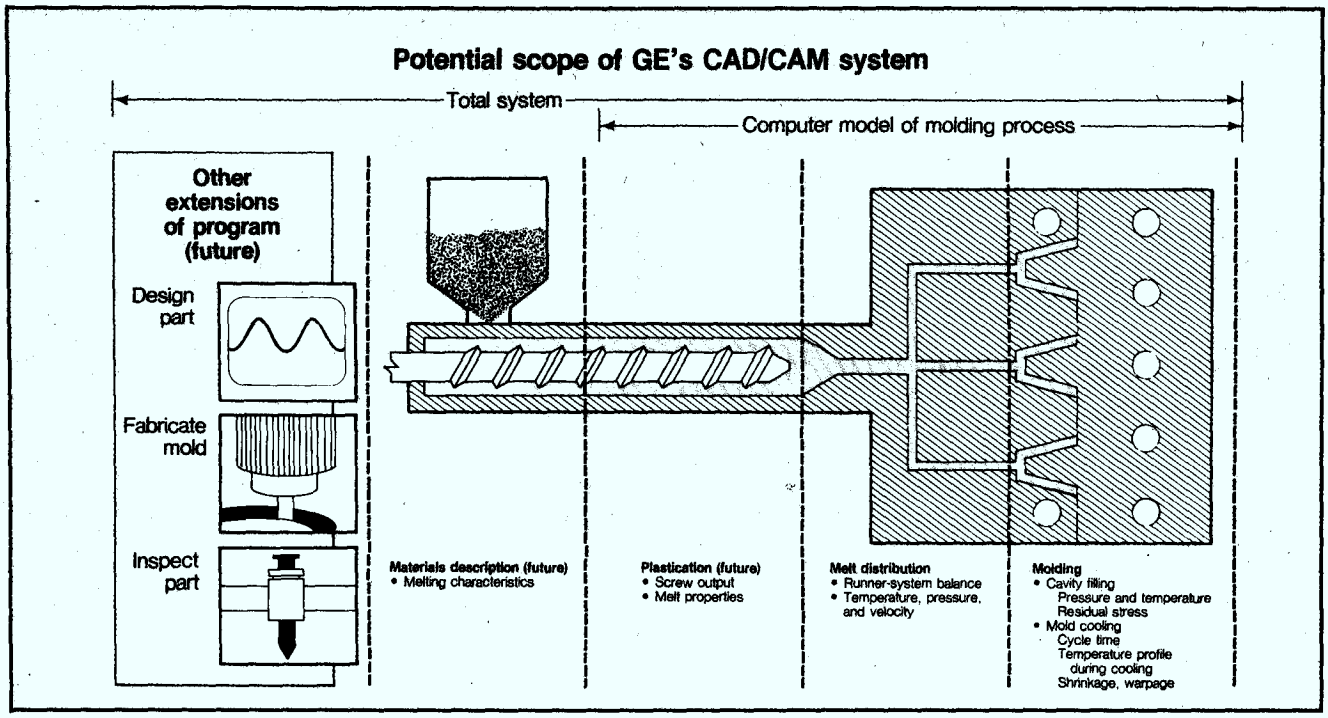
***Actual tests: 33 ± 2 sec (40% savings)**



Isotherm line	Temperature
A	73.78
B	79.27
C	84.77
D	90.26
E	95.76
F	101.25
G	106.74
H	112.24
I	117.73
J	123.23
K	128.72
L	134.22
M	139.71
N	145.21

Isothermal lines on outline drawing give same temperature data from finite element analysis as color pictures at right. Less exotic, this approach also is less costly.

Color values show temperature profiles of plastic housing in mold at 6-sec intervals. Heat transfer is predicted by computer analysis for cooling-line layout with added heat pipe (dark bar). Each color represents a specific temperature.



Cooling arrangement optimized by finite element program cut 40% from molding cycle for plastic component. The analysis showed value of adding a heat pipe. Schematic shows potential scope of GE's computer-based program to model entire molding process.

in real time, with the computer quickly recalculating each modification, until he obtains the best possible cooling layout for his particular mold and cavity geometry. Based on comparisons between the predicted and actual cooling times for specific parts, GE feels that the predictions should be accurate within 10%.

The 1-D program, which resembles previously state-of-the-art cooling-time analyses, makes certain simplifying assumptions about part geometry and temperature. One of the chief accuracy features of the finite-element heat transfer analysis is that it does not assume a constant part-surface temperature, but actually calculates the temperatures and cooling rates at selected intervals on the surface.

This enables the designer to anticipate and correct problems that cannot be deduced from the "1-D" program. For example, it identifies hot spots in specific areas of the part so that the designer can modify the cooling-system arrangement to prevent the part from being ejected too hot from the mold. The ability to predict and correct temperature differences between various areas has direct quality implications: eliminating the temperature differential reduce the chances of warpage and the amount of stress in the molded part. These extra capabilities, however, do not come cheaply; finite element analysis requires more computer power.

Mold filling program

The mold filling program is the second of the two analytical programs on which GE corporate R&D is concentrating. Its purpose is to aid in mold design by predicting how the melt will flow and fill the cavity.

It will answer such questions as: Will the mold fill properly? What clamping force is needed? How much viscous shear heating will occur? Is the gate geometry suitable? What is the likelihood of residual stress in the part?

The mold-filling program will also enable the part designer to experiment with thinning down the part walls and forecast how various thicknesses would affect the melt flow, injection pressure and stress level in the part.

The mold-fill program will be linked directly to the mold-cooling program because it predicts the temperature of the melt and, thus, the amount of heat that must be removed during the cooling cycle. The mold-fill analysis will require simplifying assumptions about part geometry, for the immediate future at least, because the use of finite element analysis to predict more complex flow paths is beyond the current state of the art.

Some of the ongoing analytical work on mold filling is being conducted at the School of Mechanical Engineering at Cornell Univ. under the direction of Prof. K.K. Wang. The work is being funded by an NSF grant and an industrial consortium that includes GE.

Thermoset cure time

GE is not focusing totally on thermoplastics; a program for predicting the cure time for thermosets also is under development. As with the cooling-analysis for thermoplastics, the purpose of the thermoset program is to save cycle time, in this case by predicting the minimum cure time. Expected cure time savings are in the 20 to 30% range.

Though there are other methods for predicting thermoset cure time, GE feels that its approach is more reliable. Most current systems attempt to predict cure time based on chemistry (molecular change) or thermal measurement (heat evolved as a percent of theoretical amount from the reaction).

Rigidity is a key criterion for

surface temperatures and the cycle time for a proposed cooling arrangement as well as the theoretical minimum cycle. The program also calculates the pressure and flow-rate requirements for the proposed system for chiller-capacity planning.

Two levels of mold-cooling programs have been developed, one of them highly sophisticated in its power to handle complex shapes. Also a specialized version of the cooling program, adapted to predicting curing times for thermosets is being worked on. These will be described later on in this article.

Mold detailing. Contemplated in this program is the use of a computerized catalog listing of standard mold components to assist in detailing the mold. The program also would have a bookkeeping function that would maintain a bill of materials on each mold and automatically update it with each modification.

NC machining. Using a numerical description of the part as the basis for developing an NC program to specify the cutter path to machine the cavity or EDM electrode is well within the existing state of the art—at least for nonsculptured parts whose surface can be described with standard equations. Such a capability will be part of the CAD/CAM program. The question to be decided is what degree of shape complexity (i.e., three- or five axis milling) the program should be capable of handling.

Automatic inspection. Another potential spinoff from the numerical definition of the part is automatic inspection. In addition to tapes for NC machining, tapes could also be produced to control automatic inspection machines for QC checking of the production part. Automatic inspection is one way to be sure of obtaining the consistent dimensions that are critical for automatic assembly operations.

Projected benefits

GE's projections of multimillion dollar savings annually from a fully-implemented CAD/CAM program, while obviously speculative, are definitely not blue-sky.

"There's no question that, given the power of the computer, we could make some improvement in cycle time and mold performance for most of the parts GE makes," a spokesman says.

"For complex, hard-to-mold parts, the justification is obvious. On one problem part that we used as a demonstration case, the cooling time was cut by 40%. But many production parts aren't such plums.

Nevertheless, after eliminating such marginal or unsuitable candidates, the R&D group estimates that over 50% of the types of parts that GE typically molds could benefit in cycle-time savings alone. Cooling-time reductions of 15-25% for these parts "are in the ball park," they assert.

Savings in material costs also can be expected in a substantial percentage of parts by using the runner and mold-fill programs to downsize unnecessarily large runner systems and to thin down part walls. Industry sources estimate that GE molded 120 million lb of thermoplastics in 1979, so almost any systematic reduction in resin consumption would represent a major saving.

Those projections are for operating costs only. There will be benefits to the capital budget too as GE's need for molding capacity keeps pace with the growth in plastics consumption.

Comments Bob Douglas, Automation Technology Branch manager, "If we had this CAD/CAM program in place now, the savings from shorter molding cycles alone would create extra capacity in our molding plants."

Mold filling and mold cooling

At the heart of the CAD/CAM program and the area on which GE's corporate R & D has been concentrating most of its developmental firepower are the analytical programs for mold filling and mold cooling. Together these two programs are expected to account for nearly half of the savings from the total program through their collective effect on cycle-time reduction, material economies and consistent quality. Pilot versions of both programs are scheduled for release in a user-oriented form to selected plants in the near future. They are part of a cluster of four related programs which, when completed, will constitute a computer model capable of simulating the entire injection molding process from plastication to the cooling portion of the molding cycle (see drawing, p75).

Mold cooling

Of the filling and cooling programs, the cooling analysis is more highly developed. Actually there are two cooling programs: a so-called "1-D" program, and one based on finite element analysis. Both do essentially the same thing, but the finite-element approach is intended for more complex parts. The finite-element technique mathematically divides a part into a grid of any desired size. It provides a much more precise analysis of the effects of some physical or mechanical phenomenon (heat exhange, temperature distribution, and cooling rates) on complex parts than can be obtained from averaging-type analyses.

The cooling programs enable the mold designer to develop the most production-efficient mold by evaluating, at a computer terminal, the heat-transfer efficiency of various possible arrangements of the cooling lines. Using the graphic-input features of the terminal, the designer will describe the cooling-system characteristics—e.g., type of coolant, number of circuits, size and spacing of the cooling lines and their distance from the mold surface, number of bends, presence of bubblers and baffles, etc.

The computer will integrate this information with data describing the heat load—type of plastic, shot size, melt temperature, type of mold metal and other relevant thermal factors—and calculate the rate of heat removal at various pressures and coolant flow rates.

The computer also will calculate the cooling time corresponding to each layout and compare it to the theoretical cooling time for the injected shot. If the predicted and theoretical cooling times are too far apart, the designer can modify the cooling system layout, by resizing or adding lines or heat pipes, for example, to improve the cycle efficiency.

The designer can work out his problem on the computer terminal

deciding how soon a thermoset part can be removed from the mold. Its analysis therefore is designed to predict the increase in modulus of the material as a function of time, mold temperature, exothermic heat, heat-transfer characteristics and related factors in the process.

After the decision is made at what stiffness level the part may safely be ejected from the mold, the process engineer can then tailor the molding cycle to provide only the cure time needed to produce the requisite degree of stiffness. Another capability of this program will be its ability to reduce the chances of warpage in variable-thickness parts by helping the designer plan the proper location of heaters in the mold.

'Productionizing' for plant use

A major objective of the R&D effort is to make the molding CAD/CAM system as simple as possible to use. The intent is to enable the average manufacturing engineer or designer in any GE plant to use the computer to solve his problem without having any of the specialized scientific background or programming skills required by the present "developmental" version. Terminals eventually will be installed in the principal GE plants that do injection molding.

"Our basic premise is that the simpler and more convenient the program is to use, the more useful it will be, and the more GE will benefit," says Robert J. Douglas, manager of automation technology at the corporate research center. Douglas' group is doing the analytical work in the CAD/CAM program and is collaborating with other groups in the Center in developing the software for a field-practical version of the system.

"When the pilot system is released to selected plants next year, we want it to be no more complicated to use than reading a menu or shopping list. Though some of the technology is very sophisticated, we will make the program relatively easy to use."

Two routes are being followed to reduce the skill level needed to use the CAD/CAM program: interactive programming and graphic input/output displays.

Interactive programming

In interactive programming, sometimes called "menu programming", the computer actively assists the user in organizing the information it needs to proceed with the calculation.

After the user, via the terminal keyboard, identifies the specific program he wants, the computer asks a series of questions, one by one, that call for the data relating to the problem to be solved, for example, part description, type of plastic, melt temperature, number of cavities, etc. When the program is fully integrated, some of this information already will be in the computer's data files.

Depending on the kind of terminal used, the computer's questions may be either typed on paper or displayed on a cathode ray tube (CRT). In either case, interactive, user-computer programming eliminates the need to know a special programming language in order to supply the data to the computer and helps an inexperienced user organize the information needed to run the program.

Graphic terminals

Computer graphics is the other route being taken to simplify and streamline user communications with the computer.

"We are giving a lot of attention to developing easier and faster ways for the terminal user to understand the data that the computer develops," Douglas says. "It's much easier to understand the results of an analysis when they're presented in the form of drawings or curves instead of as lists of numerical data. Graphics can be a major help in visualizing what will happen if a particular process variable or design decision is changed."

A number of different approaches to both data input and program output are being explored. For the mold filling and mold cooling programs, the possibilities for output display range in sophistication from simple two-axis graphs and outline "drawings" to multi-

colored three-dimensional cross-sections shown from various perspectives. Because of the programming costs for elaborate color graphics are so high, GE is evaluating the cost-effectiveness of various types of information-display techniques that might be used in the "productionized" version of the CAD/CAM program.

As a minimum, the production version most likely will have the capability to show on the CRT a schematic of the heat-exchange system in the mold, and graphs depicting the temperature-pressure-heat transfer relationships for the proposed layout.

Beyond that, GE has developed the capability for presenting the results of the finite-element heat-transfer analysis at several levels of graphic sophistication. The simpler presentation would be a schematic drawing of the part in the mold, with isotherm lines representing the temperature distribution through the part and the mold. A more elegant, and costly, approach which has been used experimentally, is to show the cross-section of the part and mold in shades of color corresponding to the calculated temperatures (see photos, p73).

Though a number of decisions about the scope and details of the CAD/CAM system still must be made, General Electric plans to have at least two parts of the system in operation next year, namely, the mold-filling and mold-cooling programs.

Prototype versions of those subprograms already are being evaluated at product molding plants to guide in developing the final user versions and establishing cost-benefit relationships.

The R&D molding-productivity programs in Schenectady, which represent no small commitment even for a company of GE's size, already have demonstrated the power of computer simulation to deliver shorter molding cycles, more consistent quality and better material utilization. The programs, if they live up to their promise, also will make GE a formidable competitor in the 80s.

Bernie Miller

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JOHN K. KROUSE
Staff Editor

GEOMETRIC MODELS FOR CAD/CAM

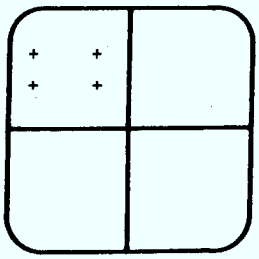
Stick-figure pictures of geometric models on CRTs may appear simple. But they represent huge amounts of size and shape data in computer memory. And geometric models are the starting point for virtually every function in computer-aided design and manufacturing.

THE MOST important feature of CAD/CAM is the geometric model—the representation of part size and shape in computer memory. Experts consider the model critical because so many other design and manufacturing functions use its geometric data as a starting point. For example, the geometric model may be used to create a finite-element model of the structure for stress analysis. Or the model may serve as an input for automated drafting to produce engineering drawings. And when CAD and CAM are interfaced,

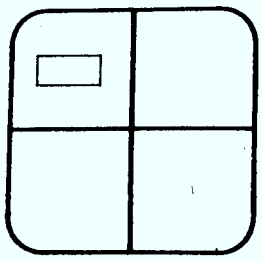
Building a Wire Frame

Most geometric models are constructed with wire frames—the simplest approach to modeling and an adequate method for most engineering applications. In this sequence of pictures, a wire-frame model is created on the terminal display of a typical CAD system. Of course, step-by-step procedures for creating models differ from this generalized representation according to system capabilities and the individual technique of the user.

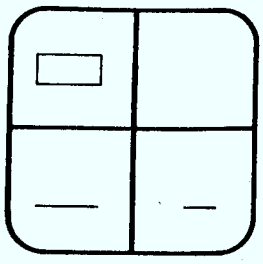
Most turnkey systems use a split-screen approach, as shown here, in which multiple views are displayed and manipulated simultaneously. And some systems use a single so-called trimetric model view with working planes specified for each operation. However, these are merely different ways of pictorially displaying the actual 3D geometric model contained in the computer data base.



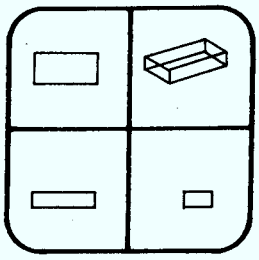
(1) *Screen is split into sections for top, front, side, and isometric views. Four points are specified on the top view representing vertices of that face.*



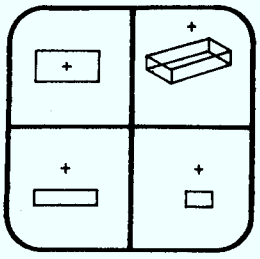
(2) *User commands the system to connect points with straight-line elements outlining the top face of the part.*



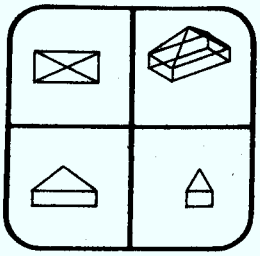
(3) *User commands the system to project the image into the other three views.*



(4) *Face is projected into the second dimension, producing a rectangular block.*



(5) *A point is specified above the block.*



(6) *User commands the system to connect the point to the top corners of the block, creating a pyramid. Model is complete.*

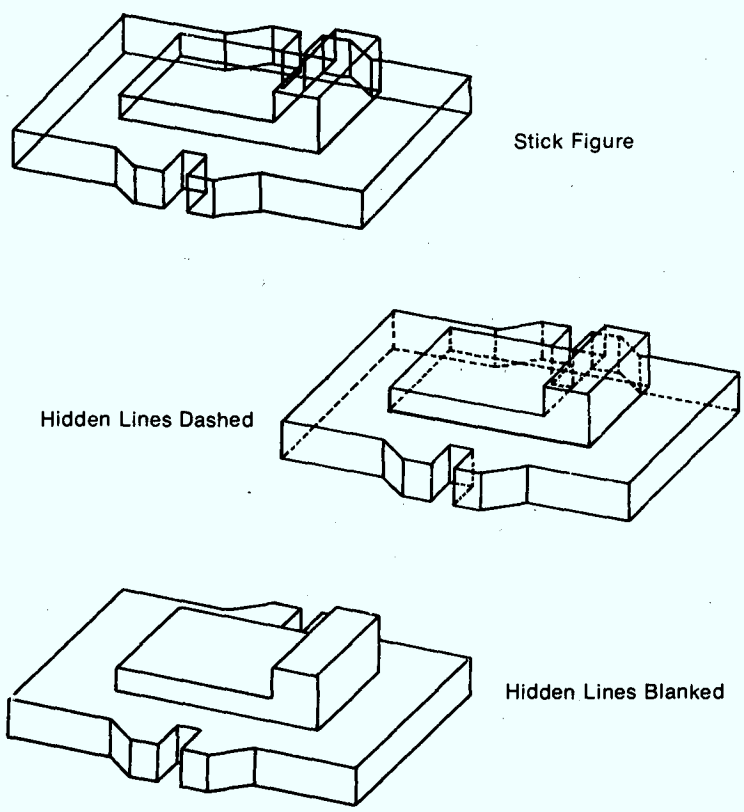
the geometric model can be used to create NC tapes for making parts on automated machine tools or to produce process plans outlining the sequence of steps required to fabricate structures.

Users typically create geometric models through pictures drawn on interactive-graphics CRT terminals. In this way, no knowledge of computers or computer programming is required. Geometric models may conceivably be created without the use of graphics systems. However, the ease and speed with which systems allow users to enter and extract data from computers have made CRT geometric pictures virtually synonymous with the geometric models they represent.

Depending on the capabilities of the CAD system and user requirements, the geometric model may be a 2D type representing a flat part, a 2½D model representing a part of constant section with no side-wall details, or a full 3D model. Although 2D and 2½D models are adequate for a limited variety of part types, most present geometric modeling research aims at developing 3D models to represent generalized part shapes.

Most modeling today is done with "wire frames" representing part shapes with interconnected line elements. Also called edge-vertex or stick-figure models, wire frames are generally the simplest models to create. Consequently, stick-figure models expend relatively little computer time and memory. And they provide precise information about the location of surface discontinuities on the part. However, wire frames contain no information about surfaces themselves nor differentiate between the inside and outside of objects. Thus, wire frames can be ambiguous in representing complex physical structures and often leave much interpretation to users.

Many ambiguities of wire-frame models are overcome with surface models—the next highest level of sophistication in geometric modeling. Surface models define outside part geometries precisely and help produce NC machining instructions where definition of struc-

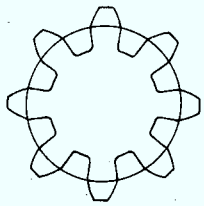


From Stick Figures to Solids

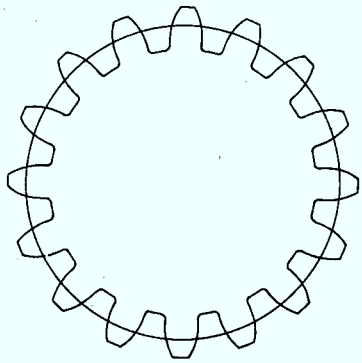
Complex networks of visible lines often make geometric models confusing to interpret. Some CAD systems can make the solid geometry of the structure more apparent by dashing or deleting hidden lines. Some systems require that users perform this task manually. But more advanced systems incorporate automatic hidden-line removal. A Computervision system, for example, automatically establishes surfaces between line elements, and a simple keyboard command either dashes or removes lines that would be hidden from view. This automatic feature currently is restricted to flat planes, but hidden-line removal in more complex surfaces such as cylinders is under development.

Modeling with Numbers

Not all geometric modeling requires manipulation of points and lines on a CRT screen. Systems such as Computervision's Parametric Element Processor automatically generate a geometric model from a few key parameters supplied by the user. The system uses these supplied values to scale and modify a base design stored in computer memory. The system can design gears, transformers, aircraft panels, exhaust pipes, fasteners, and other parts where the geometry depends on a consistent set of parameters.



Select No. of Teeth	8
Select Diametral Pitch	3.5
Select Pressure Angle	20



Select No. of Teeth	16
Select Diametral Pitch	3.5
Select Pressure Angle	20

ture boundaries is critical. However, surface models represent only an envelope of part geometry, even though features such as automatic hidden-line removal easily make the model appear to be solid.

The inability to represent the solid nature of parts leads to difficulties in calculating parameters such as weight, volume, and moments of inertia. And user interpretation often is required, for example, to determine if the model represents a totally solid object or a thin-walled structure made of sheet metal.

The highest level of sophistication in geometric modeling is 3D solid modeling—an approach using combinations of elementary cubes, spheres, and other so-called solid primitives to create complex models. Although solid models may appear to be similar to wire-frame or surface models with hidden lines removed, solid models allow the solid nature of an object to be represented in the computer, facilitating computation of parameters such as weights and moments. And cross-sections can be cut through the model to expose internal details with minimal user interaction. Solid modeling represents the cutting-edge of modeling technology, but is considered a prototype technique still under development. These systems presently are very expensive, relatively slow, and require extensive user expertise and computer time. However, most turnkey-CAD-system vendors are developing more practical, easy-to-use solid modeling features expected to be available in the mid-1980s.

Wire Frames

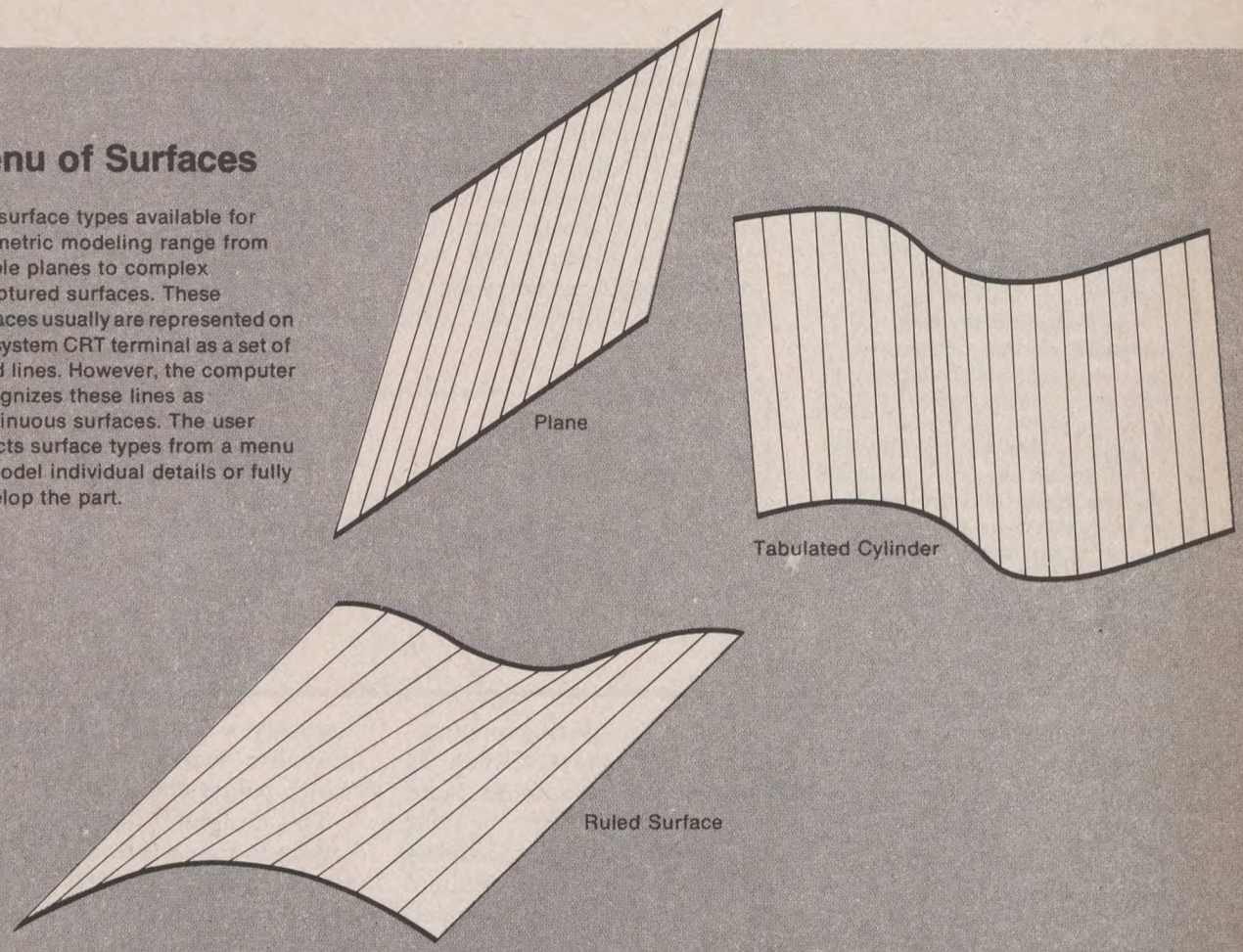
Wire frame models are created by specifying points and lines in space. To create the model, the interactive terminal screen usually is divided into sections showing various views of the model. Or some systems use only a single view with a movable working plane on which points and lines lie.

The designer uses the CRT screen in much the same manner as a drawing board to create top, bottom, side, isometric, and other views of the model. However, unlike mechanical drafting systems, CAD systems provide many automatic features to speed design. Essentially, the designer need not manually draw each line in a wire-frame model. Rather, the CAD system constructs the lines based on user-specified points and commands chosen from an instruction menu.

Most lines comprising wire-frame models are straight. To generate a line, the user may designate two end points and give the computer a LINE command. Or a line may be automatically produced parallel or perpendicular to another line or tangent to a curve. Some CAD systems produce straight-line elements with up to 40 such techniques.

Menu of Surfaces

The surface types available for geometric modeling range from simple planes to complex sculptured surfaces. These surfaces usually are represented on the system CRT terminal as a set of ruled lines. However, the computer recognizes these lines as continuous surfaces. The user selects surface types from a menu to model individual details or fully envelop the part.



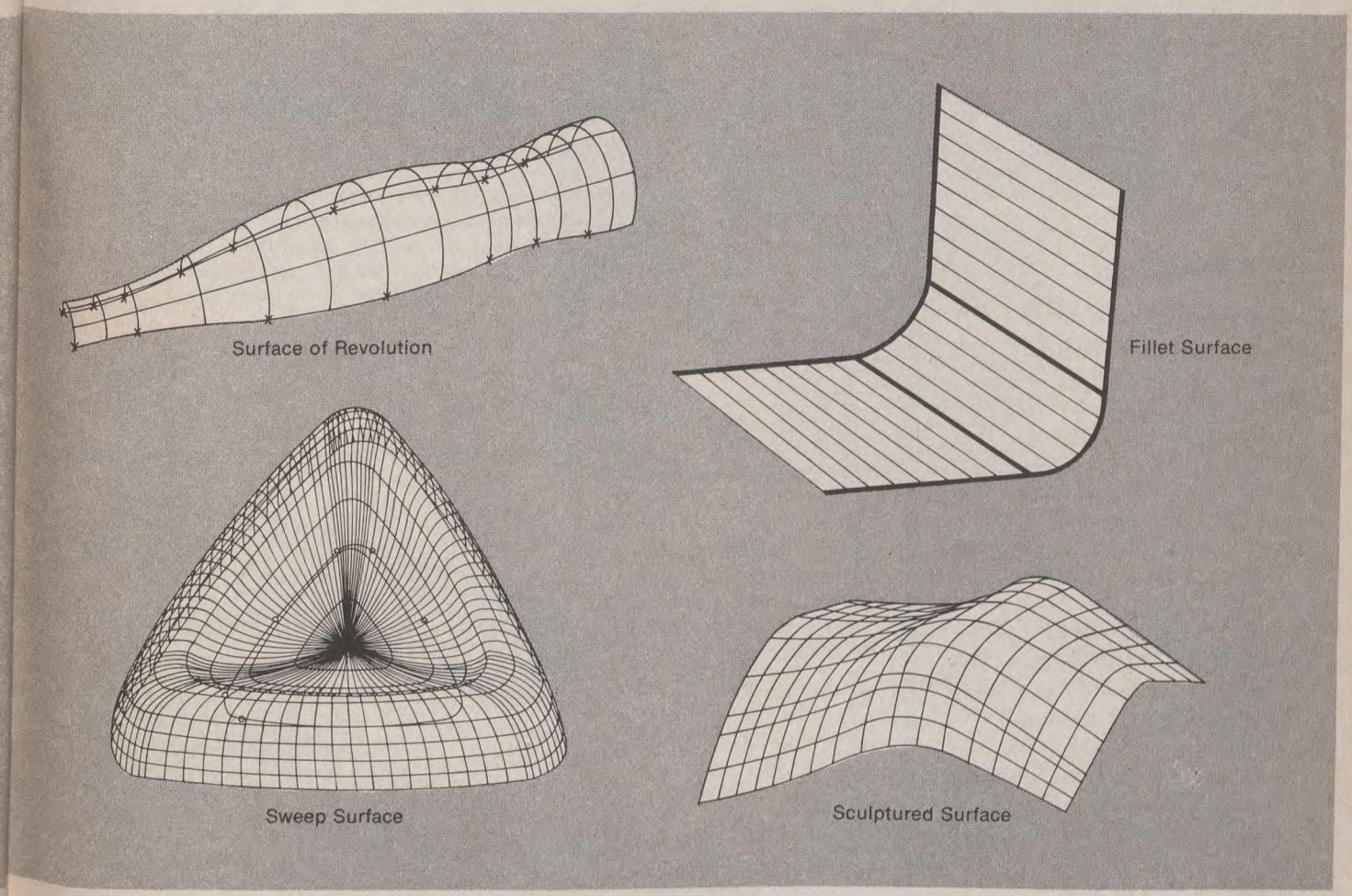
Similar automatic features can also produce curved lines. Circles may be produced by specifying a center point and a radius, three points on the circumference, or tangent points on two or three other curves. And conics (complex curves such as ellipses, hyperbolas, and parabolas) may be produced by specifying appropriate points. Most CAD systems can also generate splines—smooth, continuous curves fit through a series of arbitrary points specified by the user.

Many other CAD features provide additional user modeling aids. For example, points and lines created in one view may be automatically projected into other views. And once specific details have been modeled, the system can duplicate them repeatedly at specified locations on the model. In some systems, individual lines can be deleted from the model at any time. Moreover, in working with complex models, users can temporarily erase selected lines from the screen without deleting them from the model to view more clearly the area under construction. Erased lines can be recalled to the screen at any time. Likewise, certain model areas may be enlarged and later reduced. After completing a model, users may blank out or dash hidden lines to give the view a solid appearance.

Surface Descriptions

Surface models are created by connecting various types of surface elements to user-specified lines. The entire model may be comprised of different types of interconnected surfaces. However, surface-modeling an entire structure may provide more detail than necessary for many applications, so some models combine surfaces for detailed faces and with wire frames representing the rest of the part.

CAD systems provide extensive surface menus from which to model. Typical surface menus include planes, tabulated cylin-



ders, ruled surfaces, and surfaces of revolution, along with sweep, fillet, and sculptured surfaces.

The plane, of course, is the most basic surface type. The system merely creates a flat plane between two user-specified straight lines. A tabulated cylinder is the projection of a free-form curve into the third dimension. Basically, this is a curved plane between two arbitrary parallel curves.

A ruled surface is produced between two different edge curves. The effect is a surface generated by moving a straight line through space with the end-points resting on the edge curves.

A surface of revolution is created by revolving an arbitrary curve in a circle about an axis. This capability is especially useful in modeling turned parts and parts with axial symmetry. The sweep surface is an extension of the surface of revolution. Sweep surfaces, however, sweep an arbitrary curve through another arbitrary curve instead of a circle.

The fillet surface is a cylindrical surface connecting two other surfaces in a smooth transition. This is a tedious, subjective operation that has been done manually in industry for years. But CAD systems quickly solve the problem of blending surfaces with the precise mathematical continuity required by aerospace, automotive, and other high-technology industries.

Sculptured surfaces represent the most general surface representation and are also called curve-mesh surfaces, free-form surfaces, B-surfaces, and cubic-patch surfaces. A sculptured surface is a differential surface created from two families of curves. These two families are not restricted to being orthogonal, nor are the curve types fixed. In fact, curves in each family need not be parallel. The two curve families intersect one another in criss-cross fashion, creating a network of interconnected patches.

Sculptured surfaces are complex contours that cannot be described with the usual lines and curves of conventional modeling. Typical structures containing such contours range from helicopter blades and automobile bodies to camera cases and glass bottles.

Solid Modeling

Solid models are formed by adding and subtracting solid primitives—basic geometric shapes such as spheres, circular and elliptical cylinders and cones, ellipsoids, rectangular parallelepipeds, wedges, and toruses. This approach is based on the assumption that most complex objects can be subdivided into these simple geometric figures. In addition to combining primitives, some solid modeling systems can also produce sweep solids by projecting two-dimensional areas into the third dimension. This allows complex structures to be more easily modeled and also speeds modeling simple part-shape.

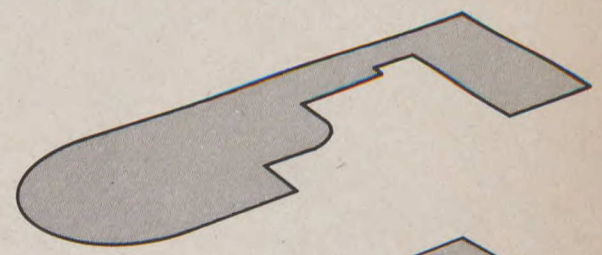
One of the most advanced 3D solid modeling systems is the highly refined SYNTHAVISION program containing over 12 primitives. The program costs $150,000 and must operate on large in-house computer systems. Thus, program use has so far been largely restricted to large corporations such as GE and Boeing that have purchased SYNTHAVISION more for evaluation than practical use. However, the program probably will soon be available less expensively on time-sharing networks.

Less-expensve solid modeling programs still considered prototypes are also available from universities and research institutions. However, these pro-

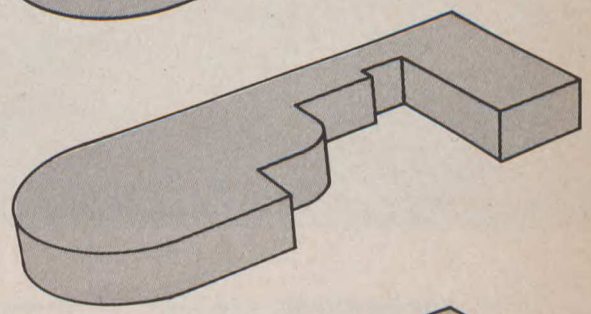
Geometric Models from Building Blocks

Surface descriptions of complex solids represented by conventional wire-frame models often are too ambiguous to be interpreted by computers without manual intervention. This problem is being overcome with a 3D solid building-block approach used by programs such as SYNTHAVISION from Mathematical Applications Group Inc. In this technique, geometric models are constructed on the CRT by adding or subtracting cones, cubes, spheres, and other elemental shapes referred to as primitives.

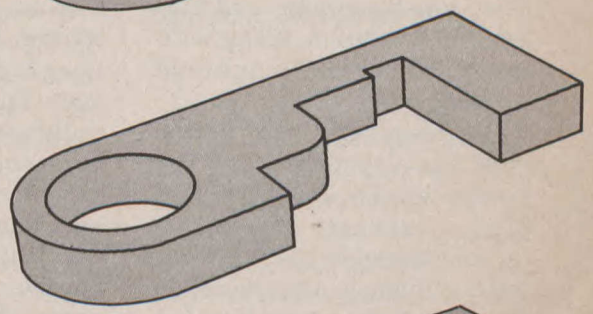
The ROMULUS geometric modeling program from Shape Data Ltd. uses combinations of solid-primitive modeling and sweep operations in which two-dimensional lamina areas are swept through the third dimension to produce complex geometric solids. In the sequence of displays here, this concept was used to model a sample part for a recent CAM-I study undertaken to evaluate various modeling schemes.



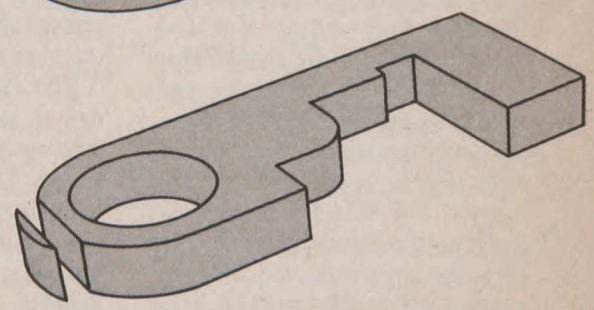
(1) A two-dimensional lamina is created with straight-line elements and arcs to represent the basic outline of the part base.



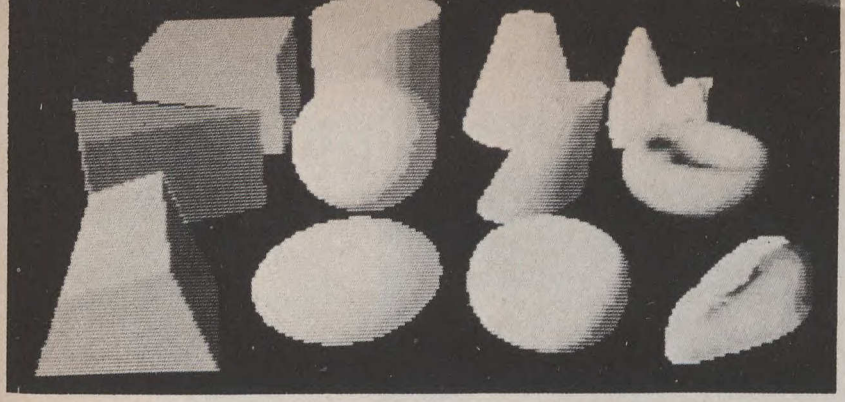
(2) A solid object is created by applying the linear sweep operator on the lamina.



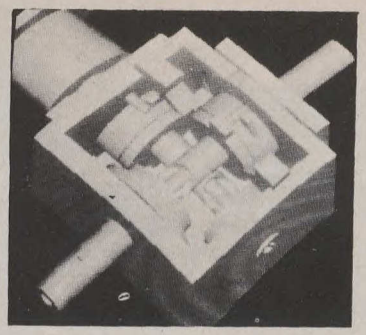
(3) A hole is created in the block by subtracting an infinitely long cylinder from the block.

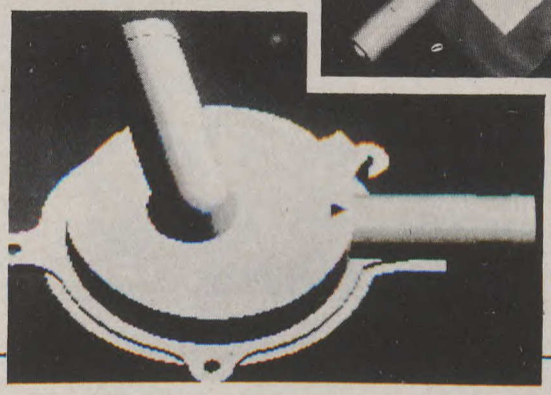


(4) A section operator is used to chop off the end of the block, creating two models. The smaller one is discarded.

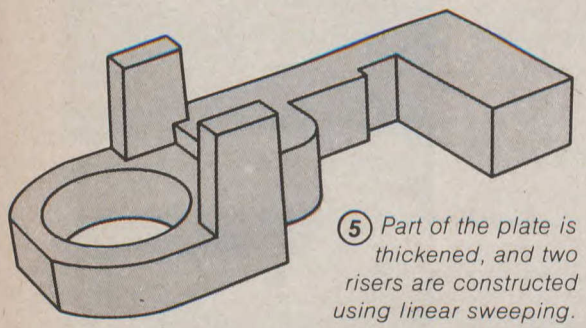


Menu of SYNTHAVISION primitives includes most primitives needed to create elaborate 3D models. With keyboard commands, the user selects the primitive size, orients it on the screen, and adds or subtracts the primitive from the model. The cylindrical primitive, for example, can be subtracted from the model to create a round hole.

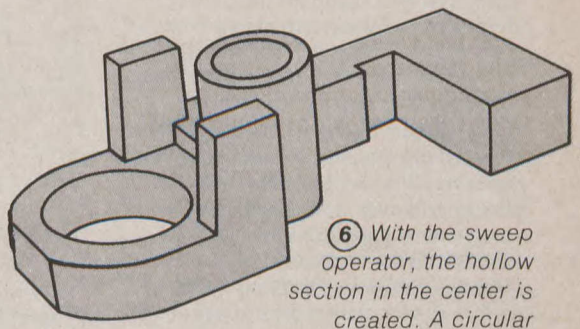




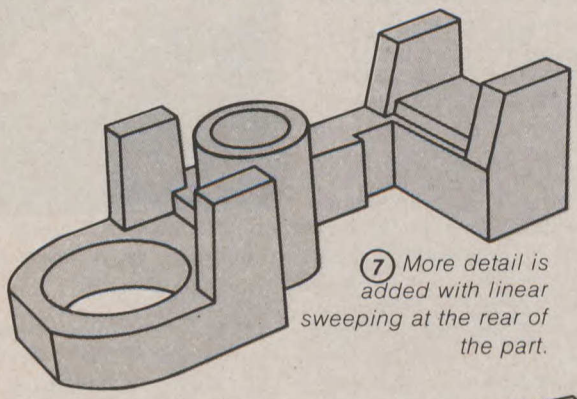
General Electric Co. uses solid primitives to model products ranging from a relatively simple dishwasher pump housing (left) to a complex hand-station mount for a military ordnance item (above).



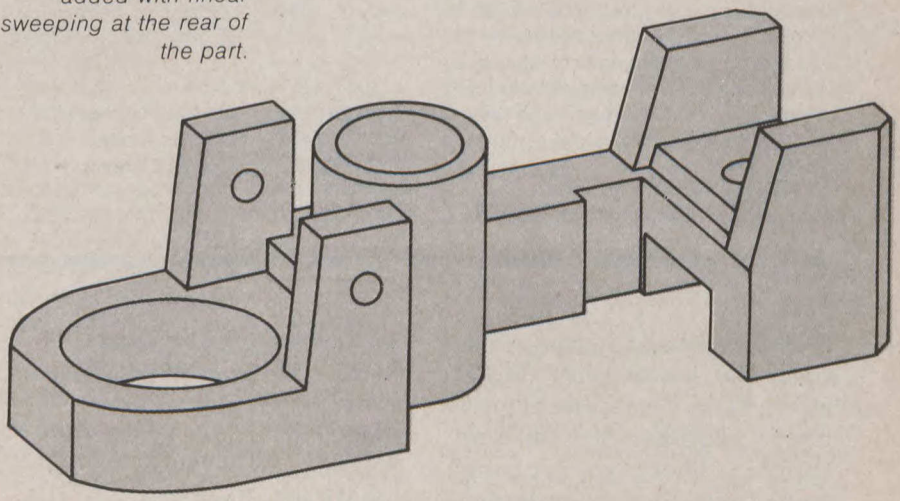
(5) Part of the plate is thickened, and two risers are constructed using linear sweeping.



(6) With the sweep operator, the hollow section in the center is created. A circular cross-section is swept up, creating the cylinder in the middle.



(7) More detail is added with linear sweeping at the rear of the part.



(8) Smaller holes are added by sectioning with an infinitely long cylinder, and the geometric model is complete.

Many Ways To Model

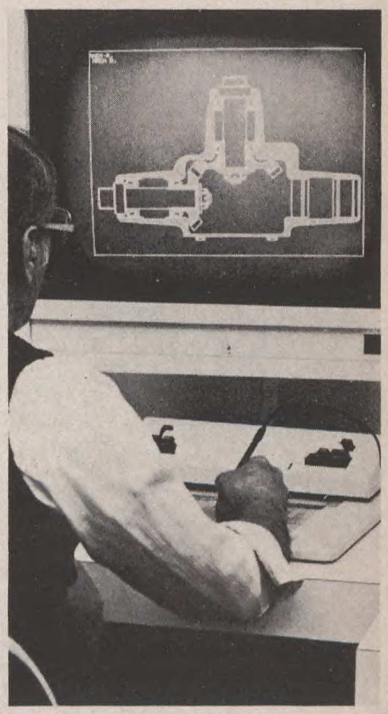
The basic concepts of creating a geometric model are essentially the same, regardless of the particular CAD system used. However, CAD systems use a variety of input, display, and data-handling techniques. So specific steps for creating geometric models may differ between systems.

The most obvious system differences involve methods of interacting with the computer. Virtually all systems enter commands and data through a typewriter-like keyboard. However, there are many ways to manipulate points and lines and select specific menu commands. Many systems use an electronic stylus and digitizing tablet. Others use light pens touched to the CRT or incorporate touch-sensitive screens activated by contact from a finger or pencil. Some systems use mechanical cursors or joystick arrangements connected to the terminal. Advanced systems using direct voice commands and eye position for data input are presently being developed at universities and research laboratories.

Less obvious is the type of display terminal used in a system. Some systems use relatively inexpensive raster tubes to produce rapidly changing but jagged lines. More expensive storage tubes have better line quality, but the entire display must be retraced to delete lines or change views. The most elaborate systems use refresh terminals with excellent line quality and the ability to change the display rapidly.

Probably the least obvious difference between systems concerns the type of computer used because the terminal is often remote. Some stand-alone systems may have a dedicated minicomputer connected to several terminals, while other systems are connected directly to a large main-frame computer. Some systems use both a minicomputer and mainframe to perform various computations and data-handling tasks.

McDonnell Douglas Automation Co. CADD system uses a combination of light pen, typewriter keyboard, and a smaller menu keyboard to create a model. A minicomputer processes data for the display. The minicomputer is in turn connected to a large mainframe which performs complex calculations.



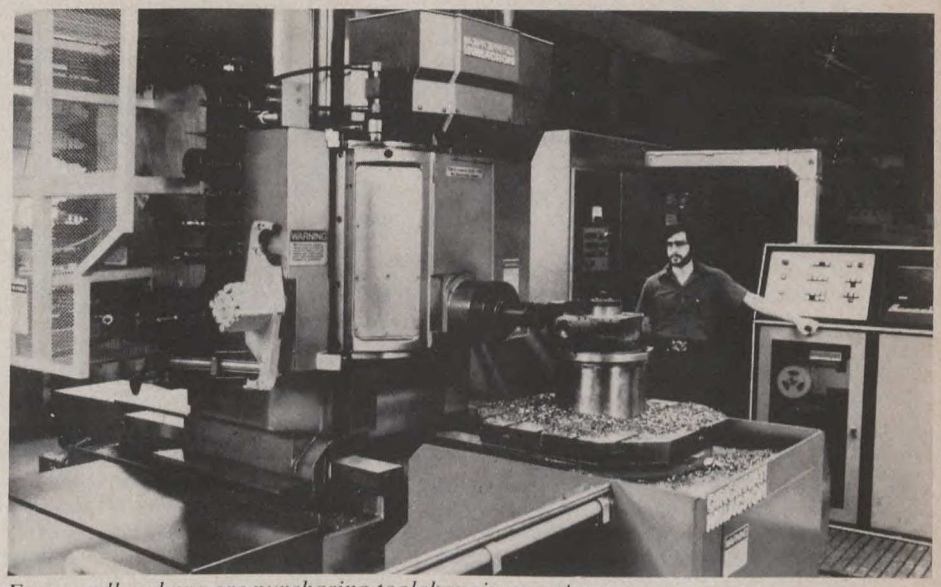
The Applicon IMAGE system uses an electronic tablet and stylus to manipulate points and lines and to select specific menu commands. This system uses two separate minicomputers for performing calculations and processing graphics data.

grams incorporate fewer primitives and less overall refinement than commercial programs and have less software support. There are probably more than 15 such programs being developed around the world including PADL, developed at the University of Rochester under a National Science Foundation Grant; COMPAC, developed at the Technical University of Berlin; PROREN, from the Ruhr University Brochum in Germany; and ROMULUS, from Shape Data Ltd. in the United Kingdom. MD

Machining Centers on the Move

In just over 20 years, machining centers have evolved from huge, expensive machines to compact models that even job shops can afford. They represent a matured product, but their evolution continues

GARY S. VASILASH
Associate Editor



Even smaller shops are purchasing toolchanging machines. One result of their demand is increased reliability.

IN TERMS OF CONVENTIONAL MACHINES, it's fair to say that the machining center is the new kid on the block. According to Lee Musser of Cross & Trecker Corp., the horizontal machining center was introduced by Kearney & Trecker in 1958. The vice president-marketing and corporate development of Cross & Trecker notes, "Early machining centers had few options or capabilities, but with their capabilities of changing tools automatically, they were still much more productive than manually operated machine tools." There have been many changes in the past two decades, from the days of machines with manual toolchangers. "It's a matured product now," says Jerry Suhling, manager of horizontal boring machines and machining centers, Giddings & Lewis Machine Tool Co.

Maturation means that there are machining centers with automatic toolchangers in vertical and horizontal configurations in sizes to handle small cubes to massive, complex workpieces. The number of tools ranges widely: Burgmaster Div., Houdaille Industries Inc., will be introducing a machine at IMTS-80 that has eight fixed tools. From 40 to 60 tools are commonly found on a given center, and that's often exceeded.

In addition to the variety in size, there's a marked trend in the use of machining centers in larger sytems. But the area where there has been the biggest growth and sophistication is, without question, that of controls.

Although machining centers are at a stage of high technological development, one point must be noted. According to Roy D. Hern, Jr., product manager-machining centers, Cincinnati Milacron, "Today, the manual toolchanger market is about 5 to 7% of the total machining center market." Manual toolchangers are fading out, but they're available and in use.

Vertical or Horizontal

That's a question that prospective users must answer before purchasing decisions can be made. The early machining centers were primarily verticals. Now there are approximately the same number of each being sold. John Hendrick, senior vice president, M.M.T.S., Inc., a subsidiary of Mitsui & Co. (U.S.A.) Inc., observes that, "Everybody tends to start out with a vertical machine. But the second is often a horizontal."

Just why is a matter of speculation. One possibility is the fact that many journeymen are trained on Bridgeport-type machines, so they are familiar and comfortable with the vertical configuration.

Roy Hern of Cincinnati Milacron raises two other points: "Traditionally, first-time buyers of machining centers buy a vertical machine for two reasons. First, a vertical machine is normally less expensive. Second, the vertical machine is typically a more flexible piece of equipment." Cost and flexibility are prime considerations for the job shops, which are getting into machining centers in a big way. Hern points out, "With a vertical machine, you have a large table for plate, and you can put an indexer on it for small cubes."

Large captive shops, which have a handle on the type of production requirements they'll be having, tend to go to the horizontal machines. One fairly new development in this area is the traveling column design. Instead of utilizing a pallet-changing mechanism that moves the workpiece to the spindle, the column goes to the work. The machines using a traveling column normally have dual tables, so the machine acts like a miniature production line, with workpieces being changed on the idle table.

Bud Bloom, national sales manager, Kanematsu-Gosho (USA) Inc., says, "There's a trend toward using machining centers in transfer lines since the lines are being built with the capability of switching over from one part design to another." He adds that, "The moving column maintains parallelism between the machining center and the transfer line, so it fits right in." He feels that manufacturers of horizontal machines that have a moving table system rather than a moving column will switch over to the latter in the future.

While a number of machines have been introduced to handle 20 to 24" (508 to 610-mm) cubes, Thomas Shifo notes that the number of heavier duty machines is on the rise. The general sales manager of White-Sundstrand Machine Tool Co. says that one reason for this is: "Machining centers are being applied today to higher production situations. Since the machines only

have one spindle and must compete with alternate processing methods employing several spindles, recent machining center designs have emphasized heavier milling, faster toolchanging, and faster axis motions."

DeVlieg Machine Tool Co. specializes in the medium to heavy duty fields, and according to Bob Miller, its vice president of sales, DeVlieg will be introducing a new machine at IMTS-80 that's designed to machine heavy workpieces with high accuracy.

"There's a definite need for high accuracy in the manufacture of larger components," Miller says. "Not only is this accuracy needed in the mechanism you're making the part for, it's needed for reducing manufacturing costs — those for fitting, scraping, and assembly — as well as for facilitating inspection procedures."

Management Control

Jerry Suhling of Giddings & Lewis describes another reason why management is turning toward machining centers for the more massive workpieces:

"The parts normally run on our machines are fairly large, expensive and complex, and have a long leadtime," Suhling says. "By running these parts on a machining center, you can control the cycle time and decrease the leadtime." Explaining, he goes on, "Since you are making the part on one machine — or at least doing some 90% of the machining on it, since some ancillary operations can be more economically performed on other machines — you reduce the time needed because you don't have the material handling from one machine to another, nor queuing time at the machines, and so on."

Suhling says that this means management control of the machining process, which he feels is a primary reason why more companies are turning to machining centers. He also points out that good, repeatable accuracy is attained, then notes another plus that results from predictable machining cycles: "Inventory can be decreased because you know precisely what you need."

Evolution of Controls

But whether you're talking to builders of horizontal or vertical machines, big or small, all agree that the real action is the area of controls. As Lee Musser of Cross & Trecker points out, "Early NC systems made machining centers possible." He adds, "First-generation NC used vacuum tubes, so the control was both huge and expensive." Size and comparative costs have both been reduced, while capability has been increased substantially.

The progression was to solid-state controls in the early '60s, and integrated circuits in the late '60s. CNC controls ushered in the '70s; minicomputers and microprocessors are now the going concern. And the '80s will be the decade of bubble memory.

The most obvious change brought about by control developments is that many builders are moving away from the stand-alone CNC control in a separate cabinet to a single-unit design. As a spokesman from Monarch Sidney aptly puts it, "In effect, by putting the control and machine together, you get rid of the 'refrigerator' on the side of the machine."

One advantage of the built-in control is the reduction in required floor space. Not only is floor space saved since the separate control cabinet is eliminated, but machine placement is facilitated by a pendant-mounted control. The pendant can be swung around for right or left-hand positioning. As a result, two machines can be placed side by side with their pendant controls positioned so that one operator can manage both machines from a single station.

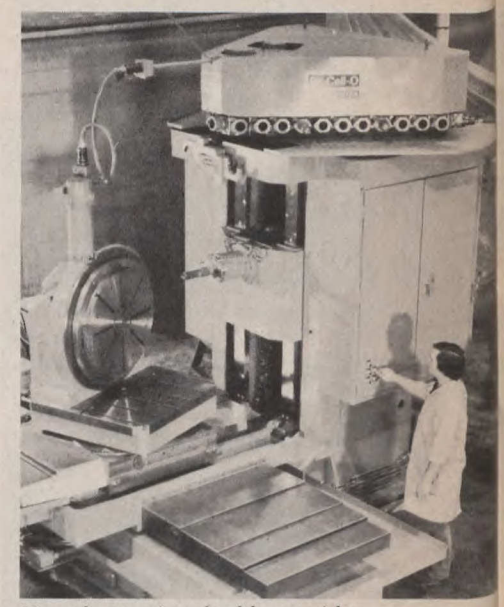
Although advances in microprocessor technology have naturally ended up in machining center controls, there is an added impetus for the machine builders. Roy Hern of Cincinnati Milacron says, "One of the things that job shop demand has created is high reliability machines since job shops often rely on the vendor for machine maintenance." (It should be noted that this high reliability is found in machines with both built-in and stand-alone controls.)

One reliability-related benefit that built-in controls provide is described by a Burgmaster Div., Houdaille Industries Inc., spokesman in this manner: "A builder checks the machine and control on the shop floor prior to shipping. If the control is built-in when it arrives at the customer's plant, there's no remarriage of the machine and control, which could result in a crossed wire or other defect."

User-oriented Diagnostics

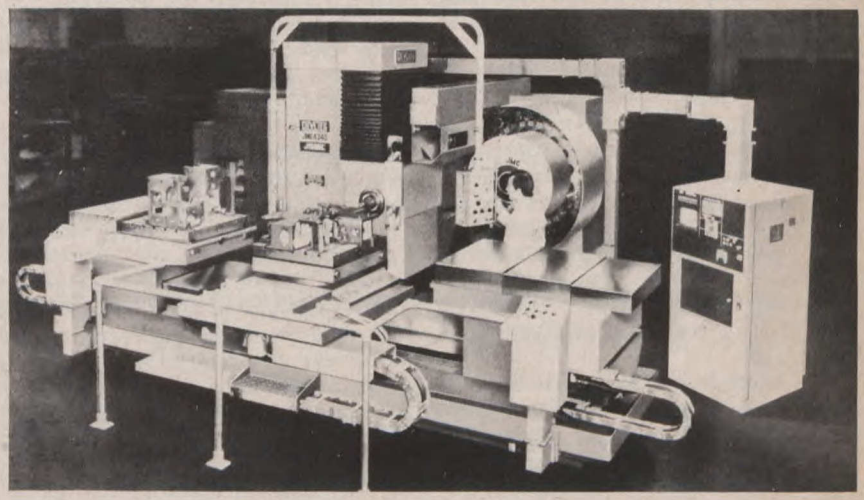
A very distinct trend in controls of either configuration is improved user-oriented diagnostics. That is, messages are being displayed and/or printed out in English. Dave Lundeen, vice president and general manager at Monarch Cortland, says, "The English-language display immediately gives the user much more information than he's used to — and he doesn't have to glean it from a service manual."

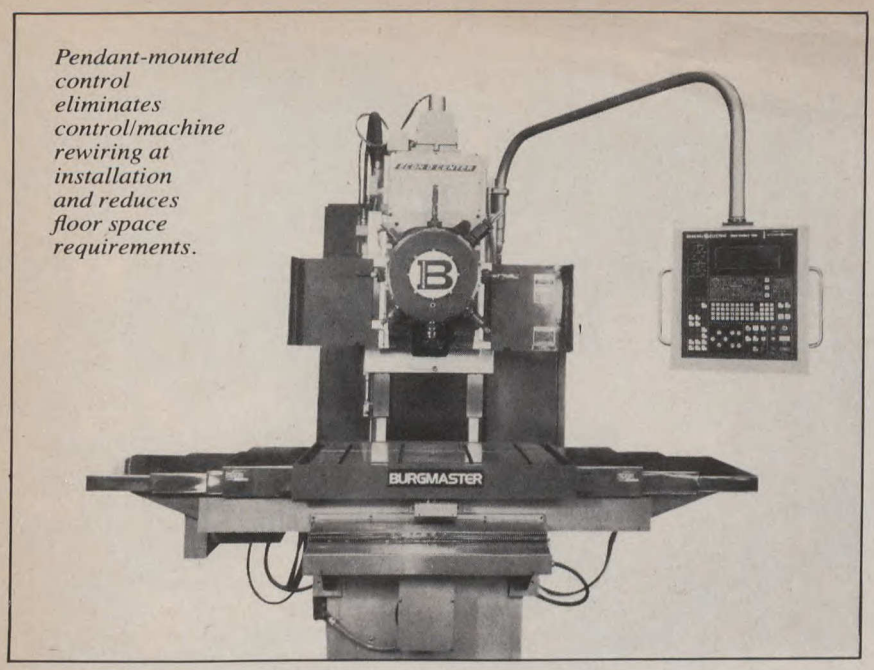
Not only do the diagnostics check the mechanical portion of the machine, but the electrical as well. Some companies utilize resident diagnostics (e.g., all Cincinnati Milacron diagnostics are resident) while others are hooked up to



Use of an optional table provides a fifth axis on this machine.

Although this is a heavy duty machine, it is highly accurate — linear positioning accuracy in the X and Y axes are ±0.0003" in 40" of travel.





Pendant-mounted control eliminates control/machine rewiring at installation and reduces floor space requirements.

a central computer. (According to Lee Musser, almost all of the machining centers shipped domestically by Kearney & Trecker have tie-ins by regular telephone lines to a computer center in Milwaukee; European installations are connected via the phone system to a diagnostic center in Stuttgart.)

The importance of diagnostics to the user cannot be overstated, particularly when the user is a job shop. What the diagnostic system does is isolate the problem(s). As Roy Hern of Cincinnati Milacron points out, "Once the problem has been isolated, the fix is readily apparent and can often be handled by the shop repairman." He goes on, "If a limit switch has failed, for example, the repairman can often get a new one and make the replacement." Having to locate the problem manually could be extremely difficult, perhaps impossible.

Higher Accuracies

However, hand-in-hand with the improved diagnostics go better machining accuracies. Jerry Suhling of Giddings & Lewis says, "Five to 10 years ago, people didn't think we'd be able to get the kind of accuracies we're now getting with machining centers. Machining centers have matured to the point where their accuracy and repeatability approach those of a precision jig borer." The manager of horizontal boring machines and machining centers adds, "They're every bit as good as a horizontal boring machine."

Machine accuracies are being improved by computer-aided design and by new machine materials (e.g., nonmetal wayliner materials with improved slip-stick characteristics). And Charles Hooper, manager of sales engineering, Pratt & Whitney Machine Tool Div., Colt Industries, notes that control developments enhance such machine developments. "There's much more accuracy with CNC today than there has been before — such as the ability of the control to compensate for ballscrew inaccuracies with software," Hooper says.

As mentioned, bubble memory is now making its appearance on the scene. White-Sundstrand builds the Micro-SWINC™ LM/MM; General Numeric has its GN8M machining center control; and a FANUC 6M CNC control with bubble memory is used in a new Okuma-Howa vertical-spindle machining center that will be introduced at IMTS-80.

Magnetic bubble memory provides a number of advantages. Storage is electronic, so disc handling, wear and damage are eliminated. Bubble memory has a small size, occupying approximately 5% of the volume required by a floppy-disc reader. These and other advantages clearly indicate that bubble memory will soon become *de rigueur* in modern controls.

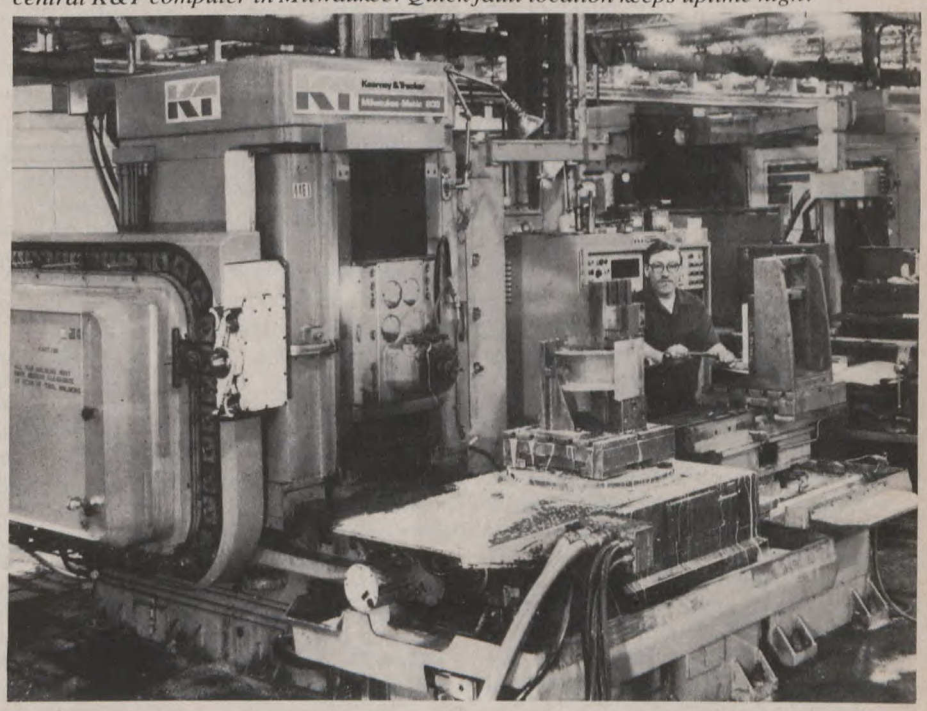
Inspection Probes

Another relatively new development for machining centers is an inspection probe, which was introduced by Kearney & Trecker at IMTS '78. One type of probe is currently being employed in White-Sundstrand Omnimils. The probe is an extremely sensitive stylus that is loaded into the spindle, where an electrical interface is set up.

According to Thomas Shifo, general sales manager of White-Sundstrand, "The probe has a number of applications. It can be used to qualify fixtures. It can calibrate the accuracy of the machine. The probe can be used for inspecting parts. And another application is checking core shifting, so real-time adjustment can be made." With regard to inspection, in one application some 25 hours of bench inspection were replaced by 12 minutes of probe inspection on an Omnimil.

Automatic toolchanging capability, improved controls, and other features make today's machining centers highly

Diagnostics for this machine are hooked up via telephone lines to a central K&T computer in Milwaukee. Quick fault location keeps uptime high.



productive — and profitable. One of the primary reasons that so many job shops are buying the machines is that once one of their competitors acquires one, they must do the same in order to stay in the same league.

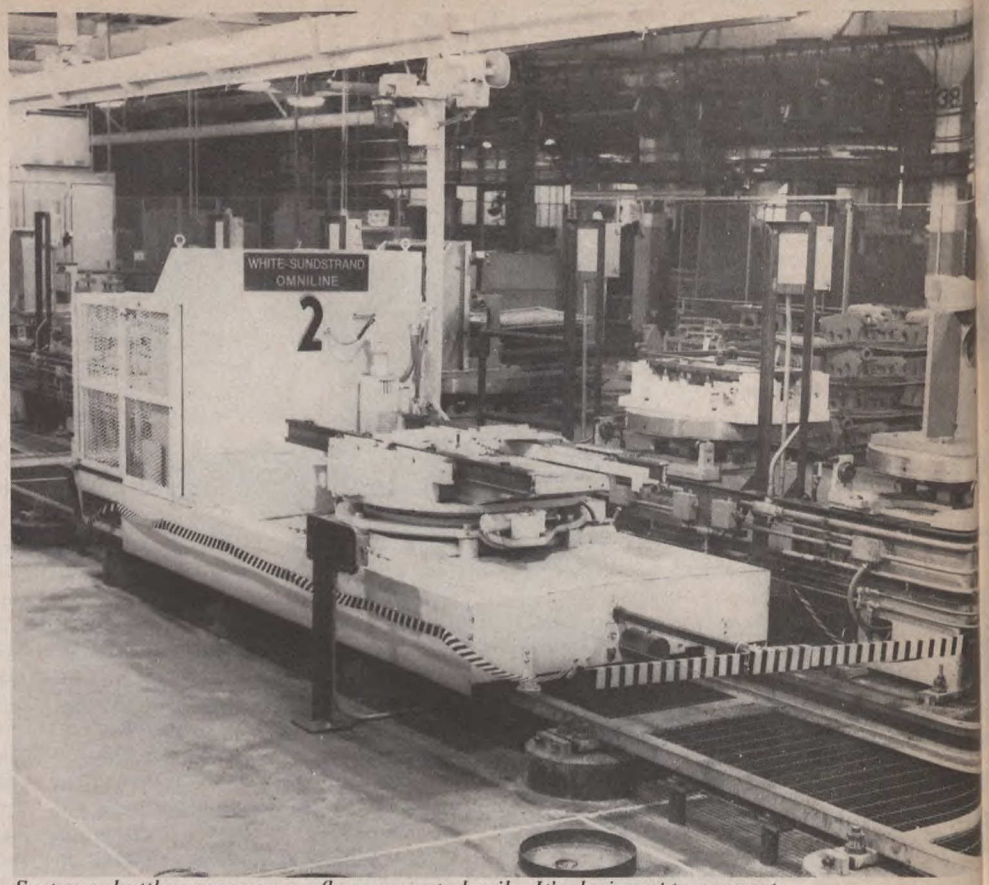
Naturally, machining center builders are looking for ways to still increase the productivity. One approach taken by Kearney & Trecker (and others) is called the "unmanned machining center." According to Lee Musser of Cross & Trecker, "The unmanned machining center provides the same capabilities of a machine with an operator, but you just don't need the operator."

Explaining the unmanned machining center concept, Musser says that it is surrounded by pallets. The control is capable of storing 15 to 20 or more part programs. During the second and third shifts — when the unmanned machining center is most typically used since that's when labor costs are highest — the pallets move around the machining center and up to the spindle.

"The unmanned machining center looks for the proper program for the part," Musser says, then notes, "You can put in many different parts and run all night."

During the day, loading and unloading, maintenance, inspection, and toolchanging are performed.

Not only are savings realized due to reduced labor costs, but — as Musser points out — "Many utilities are giving time-of-day rates." Which means that power is cheaper at non-peak periods. "A machining center uses quite a bit of energy, so it makes sense to run at night and take advantage of the lower rates," he adds.



Systems shuttle car moves on floor-mounted rails. It's designed to connect machining centers with other machine tools for automatic batch processing.

Flexible Manufacturing

While machining centers are primarily used as discrete machines in a plant, Bob Ellig, sales manager, Workcenter Operations, Ex-Cell-O Corp., says, "In the past year or two, interest has increased in flexible manufacturing systems." He notes that this interest has been piqued because "Systems provide almost the same advantage that transfer lines have over conventional machines: they limit handling by the operator." They also have an advantage over transfer lines in that flexible machining systems can be more readily rearranged to handle new requirements.

Flexible machining systems are typically made up of machining centers working in concert with other types of machines, all under the control of a central computer. The workpieces are on pallets which move throughout the system, transferred by dragchains located beneath the floor or by some other mechanism. While transfer machines are designed for high volumes, flexible machining systems are primarily designed to handle the low to medium range.

Business is good for the builders of machining centers. This is a result of strength in the aerospace, energy-related, tool and die, farm machinery, industrial truck, machine tool, and other industries. All queried had backlogs; some expect shifting of markets in the future, but no real downturn.

Many companies are expanding their manufacturing facilities for machining centers. For example, Monarch Cortland, according to Dave Lundeen, its vice president and general manager, is increasing its vertical toolchanger production capability 50% this summer. Kearney & Trecker recently added 86,500 ft^2 (8045 m^2) to its machining facilities and is now building 73,500 ft^2 (6836 m^2) more.

The Imports

However, in one sense, business is *too* good as far as some domestic machining center builders are concerned. Machines are being imported at an alarming rate. Although imports are coming from various European countries, Japanese machines are singled out as having most impact on the American market.

M.M.T.S., Inc., is the exclusive U.S. distributor of Okuma, OKK, and Mitsui-Seiki machining centers, which are all made in Japan. John Hendrick, senior vice president of M.M.T.S., responds to the question of why a U.S. buyer would purchase a Japanese-built machine by saying, "It's as good or better than an American-made machine, and then there's price and delivery — primarily delivery. The buyer doesn't have to wait a year or two to get a Japanese machine."

Bud Bloom of Kanematsu-Gosho (USA) Inc. handles Mitsubishi, Okuma-Howa, and Hamai machines. When asked the same question, he has basically the same response as Hendrick: quality is equal or better, the price is competitive (not much lower, as it once was), and deliveries are quick.

"We have machines on order all the time," Bloom says. "Right now, we have over 200 NC machines on order. Our worst delivery situation is 11 months. Our best is immediate, from stock." When questioned, Bloom had a vertical machining center available in stock for delivery.

The U.S. machining center builders are working on meeting their orders and they have backlogs. They can't provide the same deliveries as the Japanese. So while Japanese machines have a healthy share of the market now, they will undoubtedly have it in the future. ■

CAD/CAM activities at NRC

by K.A. Steele

A very significant aspect of the work in the laboratories of the National Research Council is the research in direct support of industrial innovation. Some of this work relates directly to Computer-Aided Design and Computer-Aided Manufacturing. CAD and CAM includes all activities which are assisted by a computer in the process of design and manufacturing. These terms are applied to discrete parts manufacturing rather than to continuous process industries such as oil refineries or pulp and paper mills. The work at NRC is solely technical or engineering oriented and does not involve production planning, materials and inventory control, and financial administration.

WITH possibly one exception, there is no specific program of CAM/CAD within the NRC laboratories. There are a number of projects, primarily in the Engineering Divisions, which involve computer-assisted design and manufacturing. A great number of them are carried out within the Computer Technology Program with the primary concern to develop and promote industrial opportunities through the transfer of new computer technology to industry.

The one exception is the Manufacturing Technology Center of the Division of Mechanical Engineering. This group has acquired a number of NC machines so as to demonstrate to representatives from industry the techniques possible with such machines. Preparation of the control information for these machines is done either manually or with the assistance of computer programs.

This group is also involved in research in electron beam welding and ECM and in demonstrating the capabilities of these techniques. Using a computer in NC applications demonstrates the time savings obtained and minimizing errors in all but the simplest applications.

THREE MAIN AREAS

There are three principal areas of activity within the laboratories of NRC which involves in CAD/CAM technology:

1 - Modeling and simulation to aid engineering design.
2 - The Teleoperator project (remote manipulator arm).
3 - Numerical control machines in various shops.

Modeling and Simulation. The Analysis Laboratory and the Control Systems and Human Engineering sections of the Division of Mechanical Engineering have developed modeling and simulation techniques for a variety of industrial applications.

When designing a new device of a system it is of considerable benefit to apply simulation techniques for the study of models of the real entity to a system. Simulation has been used by these groups for some years in close cooperation with industrial firms. A significant aspect of this work is the use of hybrid computer technology to implement a number of models. This combines the advantages of digital (precision and non-linearity) and analog (dynamic and multiprocessing speed) techniques in one processing system to yield real time results of tests with various parameter values.

Another feature is the use of special interactive display systems functioning with the computer model. Such displays allow non-specialists in computer technology to run the computer simulation and gain a feel from the model as though it were the real system. Using interactive techniques originates from the realization that optimizing a process or improving a machine design requires sound engineering practise, experience, observation, and intuition. The assistance provided to companies has resulted in a growing commitment from many of them to use simulation techniques in the solution of their design problems.

Recent plans indicate that the simulation activities will be continued. There are presently contracts with consulting engineering firms to study the feasibility of a commercial hybrid computer facility for engineering design. Should a facility become a reality, then greater emphasis in the work at NRC would be placed on exploring improvements to the methods and possibilities for computer modeling, and on extending the studies to new areas in engineering design.

The Teleoperator Project. This project represents a step in the field of robotics yet it is very much related to CAD. It involves the construction of a robot equivalent to a human arm for use by NASA as equipment for the Space Shuttle Orbiters. Under agreement between NASA and NRC, the remote manipulator arm was designed and constructed by a team of Canadian contractors with assistance from the Department of Communications and the laboratories of NRC.

Spar Aerospace managed a team of subcontractors comprising its Technology Division, CAE Electronics Ltd., and Dilworth, Secord, Meagher and Associates Limited.

Overall direction and management of this program was undertaken by a project office established by the National Aeronatuical Establishment of NRC. Contribu-

tions were also made by the personnel of three other divisions of NRC.

The first concerns work in the field of computer graphics which was employed for simulations of the arm motion to gain and understanding of the operational problems involved with the functioning of the arm. Developments by the Computer Graphics group in the Division of Electrical Engineering demonstrated improved methods of display, and in particular improved techniques for the removal of hidden lines in scenes depicting the dynamic use of the arm. Secondly, the hybrid computer modeling facility of the Analysis Laboratory provided the means for modeling the remote manipulator system for the purpose of determining optimum end effector trajectories, investigating alternate arm control alogarithms, and to study the sensitivity of the arm performance as a function of various design parameters.

The third area of research was that of computer control or assisted control of devices such as the manipulator arm. A scientist at the National Aeronautical Establishment of NRC developed a video photogrammetry system for three-dimensional motion control. His system is based on the moment description of the two-dimensional distribution of a two-state variable. A moment sampling processor derives, in synchronism with the video camera scan, the area and first moments of the video signal within each of four computer controlled window apertures. The data from the sampling processor is processed in a minicomputer to determine the centroids for four targets on a rigid body.

From this information the frame-by-frame solution of the position and orientation of the body with respect to the camera is computed. Development of this type of system was desirable to overcome limitations in positional information available to the operator of the manipulator arm because of the limited angles of direct view and the limited resolutions of the closed circuit television camera.

NC CONTROL OF MACHINE TOOLS

Numerical control is frequently the first step taken in utilizing CAM/CAD techniques. The application of NC machines does not necessarily imply the use of computers, but in virtually all cases it means digital information input to a machine controller which interprets the information to control machine motions and other functions.

These motions may be much more complex than can be effected by manual means. For example, manual control of motion in more than one axis simultaneously is not feasible. Numerical control allows a greater number of operations to be performed with fewer steps and on a smaller number of different machines. To a manufacturer, this means better utilization of personnel and machine with less errors.

Most of all NC technology being used in the laboratories of NRC is not for research in NC or for the purpose of demonstration. It is used in divisional shops in support of other research and development work. The requirements of accuracy and repeatability plus complexity of part design, have made the use of NC equipment very attractive. The alternative has frequently been expensive, manual-intensive manufacture or alterations of design in non-optimum ways to allow easier manufacture by conventional methods. A description of several examples of the use of NC technology by the Laboratories follows.

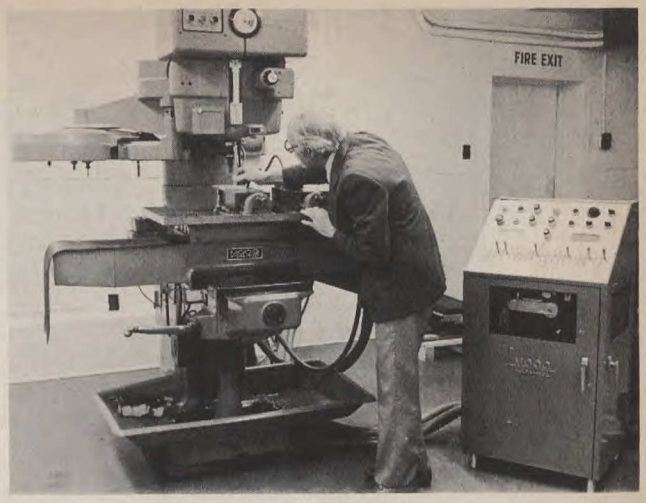


Fig. 1 - The Vancouver Laboratory conducts regular seminars on NC machining to familiarize western companies with NC machining technology and computer programming.

NC APPLICATIONS AT NRC

The National Aeronautical Establishment has for some years provided wind tunnel facilities for use by NAE engineers and also for use by industry as a national facility. In support of this activity they also operate shops for producing models such as air foil sections for test purposes.

One of the more significant pieces of equipment used is a milling machine equipped with a controller with parabolic interpolation. Normally such controllers allow point-to-point control or linear and circular interpolation. In this case it is convenient for machining air foils to have parabolic interpolation. It simplifies the procedures used to prepare the control information to the desired tolerance. These procedures involve the use of computer programs written specifically for these tasks and run on the computer of the central computing facility for NRC (a time sharing service on an IBM 3032 machine).

The use of NC machines and computer assistance in the preparation of the control information at NAE is an example application in which this technology is essential. It would be impractical technically and economically to attempt to make the model air foils by conventional methods. It is mainly because of this that the aircraft industry are the leading users and developers of NC technology since its inception about 20 years ago, and more recently also in the broader field of CAM/CAD.

The Marine Dynamics and Ship Laboratory of the Division of Mechanical Engineering operates a number of facilities to aid in the design of ships. One complex of

numerical controlled machinery is designed for the special purpose of cutting large wooden hull models which can be 6 m in length. The cutting is performed by passing the hull block back and forth on a platform beneath a frame which contains the cutting head. Cutting is done in planes parallel to the waterline. Model design information is normally provided from drawings by ship architects and extensive use of computers is made for digitizing, curve fitting, 'fairing changes', and preparing the control information for the model cutting machine.

A new facility which should be functioning soon will provide for NC milling of model ship's propellors which has been done until now by time consuming and difficult conventional means. The computer programs supporting this work have been produced especially for these tasks by the laboratory scientists and are run on computers within the Ship Laboratory.

THE WESTERN (VANCOUVER) LAB

While the shop for making model hulls and propellors is oriented to support a design process, some of the techniques may in time be used for manufacture. Many small boat hulls are now made of plastic reinforced with glass fibres and the molds used in the lay-up are made using a 'plug' which is similar to the wooden hull models just described. There is interest on the West Coast to have a facility for making plugs which could be used in the manufacture of fishing boats as large as 20m in length. The NRC facility has been used to make a plug for a recreational sailboat hull and thus demonstrated that the methods are valid.

The Western Laboratory (Vancouver) of the Division of Mechanical Engineering operates numerically controlled equipment to assist engineering firms and small machine shops in Western Canada with the introduction of numerically controlled machines. This facility undertakes the following functions: to develop N/C tooling and techniques to produce close tolerance parts for laboratory use; to make information on NC available to industry; to conduct seminars on various aspects of numerical control including metal cutting techniques and programming to produce control information; to demonstrate machine tool programming and the machining of samples for individual firms.

This is a similar undertaking to that of the Manufacturing Technology Center in Ottawa, but with an orientation to respond to the perceived needs of Western Canadian industry.

It is interesting that the Western Laboratory has identified in its work a field of interest nearly identical to that arising from work in the Model Shop of the Division of Electrical Engineering. At the West coast this need is identified as a "low-cost NC part programming system using graphics to clarify the language syntax of computer-assist systems". The Electrical Engineering Model Shop acquired an NC milling machine with a CNC (Computer Numerical Control) controller several years ago and began using it with control programs written at the controller console and later used computer assistance by means of an APT processor in the NRC time sharing system.

The essentially manual method of preparing control data by using the machine controller (as a text input device and editor) is relatively convenient for simple problems although it is not a reasonable method when the machine with controller is busy cutting metal. The relatively high cost of preparing control data using APT on a time sharing service makes it also unsatisfactory. In addition, there appears to be a common fault among the larger NC programming languages of which APT is typical in that much of the processing done is not required by modern microprocessor driven machine controllers. The result is that some calculations are done twice: once by the APT system and then again by the controller processor. This situation led to investigation of alternative methods of providing assistance to the machine programmer.

A number of small commercial systems for providing computer assistance are available such as ENCODE, PROMPT, APTTYPER, and others, but all appear unnatural and unnecessarily awkward to communicate with because they use text input and for the most part text output. A much more natural way to communicate the geometrical information for the control requirements to the computer is by employing interactive graphic methods. Some commercial systems using these methods are now available but all are very expensive and provide all or most of the capabilities of the modern versions of full APT processors.

This is not considered essential for a majority of jobs done by small machine shops where 2½D capability is generally quite satisfactory and 3D to 5D problems are seldom encountered. The Computer Graphics Section of Electrical Engineering is currently actively encouraging the development of a microprocessor based NC part programming system with emphasis placed on the use of interactive computer graphics techniques for communicating information to the computer. This would not be an APT-like processor nor would it be a system which adheres to any of the APT conventions.

Other applications of NC technology include circuit layout, mask preparation, and hole drilling for manufacture of printed circuit boards. This is done in both the Physics and Electrical Engineering divisions primarily in support of internal projects. Computer assistance is used in preparing the control data for drilling sequences and in some cases is used also to reduce much of the repetitive operations in making the line artwork of the printed circuit mask.

Studies are also taking place of the use of finite element analysis methods in the solution of structural design problems and damage tolerance analysis by the Structures Laboratory of the NAE. This work includes assessment of commercially available computer programs.

Computer assistance has become very widely accepted in the work taking place in NRC laboratories. In those applications which aid the design process or the manufacturing process it can be observed that there is a very wide diversity in the software (computer programs) used. Most have been prepared in-house by NRC staff for the particular solution of specific problems. Extensive use of CAD or CAM program packages has not yet begun to take place. This is probably a reflection of the fact that problems of design or manufacture are not amenable to general purpose programmed solutions. Even in the case of numerical control where the APT programming language and its successors occupy a prominent position in terms of

usage by industry, much of the software used at NRC has been prepared in-house. The large general purpose programming systems appear to offer many features but often the feature desired is not among them or is not well done or convenient to use.

Interest in general purpose CAD systems is, however, present at NRC. A recent survey among NRC staff of potential interest in CAD techniques resulted in over thirty responses although only three or four could be considered to be involved currently in CAM/CAD problems. There is a growing realization within the laboratories that methods employing computers which were too expensive to consider a few years ago should now be reassessed as costs of computer hardware, particularly of microprocessor based systems, continue to decline in relation to other costs. The computer can be a very cost-effective assistant.

The need for increased laboratory research and development in the CAM/CAD area is rapidly taking on greater significance in view of Canada's deteriorating position as a competitive industrial nation. The general objective of developing computer techniques as an aid to industrial productivity particularly in the manufacturing sector is an accepted priority within the Computer Technology Program. Toward this end, plans are underway to formulate a program in automated manufacturing and industrial robotics. Many of the necessary basic skills and expertise (Remot Manipulator System of the Teleoperator Project, complex systems simulation, control systems development, image processing and computer graphics, machine vision, process scheduling and production planning, instrumentation and sensor development, digital signal processing, microprocessor technology, etc.) already exist either within or outside the Computer Technology Program.

What is needed is the recipe under which these inter-disciplinary activities can be integrated effectively and focussed towards this common goal. Several market application studies by outside consultants are presently being negotiated to help identify the particular Canadian industrial needs and opportunities in robotics technology for automated manufacturing. These studies will contribute to the formulation and implementation of a coordinated R & D program in industrial robotics in collaboration with Canadian industry and universities with the overall aim of developing an industrial manufacturing capability in robotics so that future Canadian manufacturing needs can be met with Canadian resources.

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