GM network station—A low cost graphics system for body tooling

by THOMAS J. RENO
General Motors Corporation
Warren, Michigan

INTRODUCTION

Over the years, General Motors has been actively involved in both the development and use of Computer Aided Design/Computer Aided Manufacturing systems to aid in the design, engineering and manufacturing of automobiles. The use of CAD/CAM technology permeates most of our operations, but nowhere is it as important and pervasive as in the body tooling process. The demands for safety, environmental protection and energy conservation have required a responsiveness that only CAD/CAM systems could provide. No longer can we afford the long lead times of 3+ years previously required to go from design concept to steel. Today we must respond quickly and effectively to an ever changing car market—and CAD/CAM is helping us to do so by dramatically shortening the body tooling cycle.

The impact of CAD/CAM on our body tooling process has been demonstrated many times, but never more convincingly than in the years following the 1974 oil embargo. This new technology enabled us to produce the 1976 subcompact Chevette in only two years in response to a then rapid shift of public sentiment to small cars.

CAD/CAM contributed heavily to the design and tooling of our 1977 full size cars. In fact, Mr. Howard Kehrl, GM Executive Vice-President, stated in a Business Week article that only through use of this technology were we able to produce our 1977 'B' and 'C' models at all, after a nine month initial delay and a major shift in specifications halfway through the program. Computer graphics was also used to evaluate the structural characteristics of proposed designs and to eliminate much of the trial-and-error process previously involved in making design changes.

CAD/CAM has truly come of age and is now an integral part of our business. It is difficult to imagine how we could design and build a car without it. But CAD/CAM did not just happen in General Motors. Its acceptance today is the culmination of a long process begun in the late 1950's when the possibilities of the newly emerging technologies of Numerical Control and visual man-computer interaction were first recognized.

SYSTEMS ORIGINS

The GM Research Laboratories pioneered man-computer communication through their DAC (Design Augmented by Computer) project. At the same time, GM Manufacturing Development was developing N/C technology for sculptured body tooling. Significant resources of both people and money were devoted to these projects and to related developments in the areas of mathematics and computer science until usable prototype systems were available. These prototype systems included sophisticated new mathematics capable of representing the types of curves and sculptured surfaces found on automobiles; data bases and data structures capable of storing these mathematical models; regional milling capabilities for both ball cutters and end-mill cutters; and user interfaces which permitted the easy addition of other new applications such as structural analysis, vision studies, etc.

In 1967, Manufacturing Development was assigned the responsibility of transforming these prototype systems into usable production tools. The result was two complementary systems, CADANCE (Computer Aided Design and Numerical Control Effort) and INCA (Integrated Numerical Control Approach), which together provided an effective CAD/CAM base for design, engineering and tooling. Additional application and system development was undertaken by Fisher Body and Design Staff to finally bring all of the development efforts into full production use. The systems in use today at GM are the result of all these combined efforts.

COMPUTER AIDED DESIGN BACKGROUND

The CAD systems in General Motors were all developed as outgrowths of the original DAC system and used computer graphics and time sharing as the base upon which they were built. Today approximately 75 graphic consoles served by two large computer installations at the GM Technical Center are employed by our divisions and staffs to do body
design and engineering work. The CAD systems all employ refresh graphic display devices and accept virtually all of their input via light pen selection from the face of the screen. Similarly, all of the output is transmitted to the user via displays on the screen. This combination of time-sharing, graphic input and graphic output provides an unbeatable combination for problem solving. Mistakes are detected instantly and the problem can be re-run at once. Long delays waiting in input and output queues are totally eliminated. The lead time savings achieved using this technology are truly impressive. Very often 6-8 weeks are eliminated from a conventional 12 week job.

COMPUTER AIDED MANUFACTURING BACKGROUND

The CAM systems developed for body tooling exploited the technology of Numerical Control and used the computer facilities available at the time. This was, as mentioned earlier, in the late 1950’s and 1960’s. At that time, batch mode computer runs using card input and obtaining printed output was the standard bill of fare. Some minor improvements such as Remote Job Entry (RJE) facilities and Time Sharing Option (TSO) were added to the batch systems, but the basic philosophy of our CAM programs remained unchanged. There was no way to avoid the long waits in input queues and output queues, the randomness of courier deliveries, or the large stack of printed output which had to be examined for possible errors.

The CAM programs, such as INCA and APT, used by GM were developed to process the masses of numerical control data required for wood model and die construction. Human decisions were emulated within these programs wherever feasible or possible. Nevertheless, human intervention was required to analyze and evaluate intermediate results produced by these computerized processing aids. These results were in the form of computer listings and usually had to be converted to graphical form via sketches or drafting machine drawings. This process obviously was very time consuming.

For a number of years, this mode of operation was accepted, although the long time delays associated with each step were excessive. The technology of N/C, however, progressed and saved time and money in spite of long processing times. Indeed, instead of working to improve the process, we worked on improving the technology of N/C. Regional milling techniques and flow line cutting were honed to perfection. Sophisticated evaluation techniques and surface linking programs were developed and brought into production use. A data storage and retrieval program which virtually eliminated data cards was perfected and has been operational since the late 1960’s. CAM technology indeed grew to where today nearly all full size interior and exterior sheet metal wood models are cut using N/C.

REASONS FOR CHANGE

All the while, however, the operational procedures remained unchanged. The CAM systems became a victim of the computer technology upon which they were based. The batch mode operating systems did not allow any meaningful operational improvements to be made. It still took several weeks to produce a complete set of cutter tapes for a complex wood model. The CAD systems, on the other hand, had benefited from new advances in computer hardware and software and were achieving remarkable results in both processing capability and lead time reduction. The N/C lead times began to be the bottleneck and it soon became apparent that improvement in processing techniques was essential.

Based on the effectiveness that computer graphics had demonstrated in the area of Computer Aided Design, it was obvious that this technology could provide similar processing improvements to our Computer Aided Manufacturing systems. However, it was not obvious exactly how to proceed to implement a graphics CAM system in GM. Since we were attempting to modernize an existing operation—not start a new one—we had to take into account constraints the existing program imposed on us. These were geography, cost, and time.

GEOGRAPHICAL CONSTRAINTS

In GM, the vast majority of design activities occurs within the square mile area of the GM Technical Center. Tool manufacturing, however, encompasses a much larger area and even extends to West Germany where Adam Opel is an active participant in our CAM activities. Any modification of our CAM system for body tooling had to encompass all tool manufacturing. Computer graphics—even today—has difficulties economically locating consoles more than one mile from the computer. Consequently, any move of our CAM systems towards computer graphics had to be independent of the large Technical Center computers.

COST CONSIDERATIONS

As to cost, the batch N/C systems had been tuned over the years to the point where processing charges were quite minimal. Also, CAD via graphics had created an excellent data base from which our CAM activities could begin. This meant that very often the full power of the large Technical Center computers was not needed for our CAM work, and if we used them we would be incurring greater processing costs than necessary. This again indicated that a solution independent of the large Technical Center computers was required.

IMPLEMENTATION TIME CONSIDERATIONS

The repertoire of computer programs used in die model construction is very extensive. All of the programs are required in some degree to complete the job. Any modernization of our CAM system would have to take this into account and provide access to similar facilities. Since it would be impractical and very expensive to convert all ex-
isting programs to a graphical format, any new system would have to be compatible with the in-place system.

SYSTEM SPECIFICATION

With these considerations in mind, Manufacturing Development began exploring hardware/software combinations that would meet our objectives. We needed a system that was inexpensive, could operate independently of large computers, and yet could communicate freely with the existing in-place systems. In 1973, we began development of a Low Cost, Stand-Alone N/C Review System to bridge the gap between CAD and CAM. This system answered the questions of geography, cost and time and seemed to be a start towards getting the benefits of graphics into our body tooling manufacturing.

HARDWARE COMPONENTS

The system developed consisted of:

- Mini-computer with Disk Storage
- Interactive Graphic Terminal
- Medium Speed Dial Phone Line
- N/C Tape Punch

Its total purchase price is approximately $75,000, which equates to less than $10/hour for a one-shift operation. This is well below the cost of large central time-sharing computers and even less than batch system costs. The system is indeed a stand-alone system. It can be placed in any room of any plant and requires no special wiring, floors, or unusual cooling. Its dial-up phone line and N/C tape punch enable remote units to communicate with each other or with the central computers at the Technical Center. These features overcome the geographic and implementation time constraints imposed on our CAM system.

HISTORY AND INITIAL IMPACT

Initially, this system simply provided a graphic input and output facility for our existing batch mode CAM programs. Substantial lead time was gained by simply reviewing data and input commands graphically before submitting them, thereby detecting errors early in the game and correcting them before batch runs rather than after. Similarly, graphic review of the output was faster than laboriously scanning pages of printout or waiting for full size drawings to be made on already overloaded drafting machines.

The initial components of the system were few. There was a data base manager to store and retrieve information. Function buttons were available to change views, shift, scale, rotate data, etc.

In addition to these graphic data review features, other computational programs were available to:

- Create arcs, circles, straight lines
- Modify Data (delete, insert, move points)
- Transform Data (Rotate, Translate, etc.)
- Create Card Images for Job Submission to Large Computers
- Teleprocess
- Punch Mylar Tape

This simple review system allowed us to export Computer Aided Manufacturing technology to our plants and was a start towards bringing the benefits of computer graphics to the manufacturing floor.

A CHANGE IN DIRECTION

The use of this low-cost review system never became very pronounced, however, because even while doing our initial development work on the system we realized the potential we had at our fingertips. It became readily apparent that the mini-computer was never really being taxed. The users also posed the question, "Why, since I have all my data here, can't I generate my N/C tapes here?" This, then, marked the turning point of the project and brought about the renaming of the system to the 'Network Station.' This name symbolizes two things. First, the system is still part of our overall CAD/CAM program and depends on access to the central data bases via the telephone network. Second, once the data is received, the system operates as an independent station until the job is complete. The term 'Network Station' seems to fit nicely the function and use of the system.

DEVELOPMENT AND CURRENT CAPABILITIES

User divisions enthusiastically accepted this change of direction and even contributed manpower to assist in the software development. Eight departments representing five divisions and staffs have participated in the Network Station development. Some of the items added to the software repertoire to make possible a full stand-alone operation include:

- Additional Curve Generation Functions (Fillets, Sweeps, etc.)
- Curve Smoothing
- 3-D Meshing
- Surface Development
- Surface Linking and Trimming
- N/C Machining
- Interactive Cutter Location Verification and Modification

Through the use of this system, it is now possible to completely process our most difficult wood models without using any of our old batch CAM programs. This includes surface definition, cutter location, and N/C tape punching. Divisions with easy access to the Technical Center computers still find it more convenient to use the existing old CAD/CAM
interfaces, but they are all acquiring Network Stations for future use. Someday this new graphic CAM system may make our old batch systems completely obsolete.

NETWORK STATION DATA FLOW

The Network Station offers a range of CAM uses never before available in our body tooling process. The ability to teleprocess information, read in punched tapes, or create data directly on the system provides for a wide variety of different input sources. For example, inputs from all of these sources are a commonplace occurrence today.

- Teleprocessed Information from CAD Data Bases
- Digitized Information on Punched Tape
- 3-D Input from Hard Model Scanners
- Cutter Location Information on Punched Tape
- Experimental Drawings

These input sources cover all of the common ways in which data is now collected. Once entered into the system, the user can proceed to process the model. When finished, a number of choices are available for outputting results. These include:

- Punched Tape for Computer Controlled Mills
- Punched Tape for Drawing Machines
- Data for Teleprocessing
  - (a) To a Large Computer for Additional Processing
  - (b) To a Remote Site for Machining, Viewing, etc.
- Printed Process Sheets
- Printed Checking Information

NETWORK STATION ACCOMPLISHMENTS

As a testament to the productivity and flexibility of the Network Station, Fisher Body, Die Engineering Activity, now uses this system for virtually all of their CAM work related to body tooling. They have six systems which they now use to produce:

- All Wood Die Models (Inners & Outers)
- All Seat Bun Patterns
- All Bend and Sweep Gages
- Production Glass Block Tapes
- Die Profile Tapes

DIVISIONAL INSTALLATION

Fisher Body is by far the largest single user of our Network Station. They are not, however, the only user. Seven divisions and staffs have equipment either installed or on order. Several others are actively pursuing authorization for equipment. The tally as of now is 18 units installed, 3 awaiting delivery and 3 in the process of approval. The divisions also have tentative plans for 10-12 additional units in the next two years. These units are located as far away as West Germany, thus demonstrating the true stand-alone nature of the system.

GROWTH OF CAD/CAM CENTER

As you can see, the Network Station is rapidly becoming the dominate force in our N/C body tooling system. The growth of this system is well in tune with the expanded use of our Computer Aided Design programs and indeed complements and supplements our design and engineering systems. As the use of CAD grows, it too is spreading out geographically to our outlying divisions and plants. We are even now locating graphic design consoles in Lansing, Pontiac and Flint. The hardware used for both our CAD and CAM systems is interchangeable and thus permits multiple use of the same equipment.

MULTIPLE USES OF EQUIPMENT

For example, a typical remote installation consists of:

- Mini-computer and Peripherals
- Graphic Console
- Drafting Machine

When the mini-computer and the Graphic Console are connected, the result is a Network Station. The Design Console can be connected over high-speed telephone lines to the central CAD computers, thus allowing the mini-computer to be used for teleprocessing, other computing applications, or as an input source for the drafting machine.

The drafting machine, of course, can also operate independently of the mini-computer. This combination of hardware and software allows full use of all equipment, provides access to both CAD and CAM programs, and allows the user to operate either as part of the central design and engineering community or as a stand-alone station. Also, since no specialized hardware is used, it is easily maintained, can be inexpensively upgraded for more power, and a wide range of peripherals such as plotters, digitizers, etc., can be easily added.

ADAPTABILITY OF SOFTWARE

The intent of the Network Station has always been to get some computer power out to the plants where the work is actually done. Realizing that each plant operates somewhat differently, and knowing that one central development activity could never fill all of the needs of all the plants, we designed the Network Station system to be very easy to program. All application programs are written in Fortran. All input, output, and graphic commands are available to the programmer via simple subroutine calls. A simple programmer's manual is available which describes how to write Network Station programs. In addition to our own staff, we have trained twenty-two people representing six divisions
and staffs how to add applications to the system and they have all contributed to some degree. Our experience has been that a programmer knowledgeable in Fortran can be an accomplished Network Station programmer in a period of approximately four weeks.

POTENTIAL FOR COMPUTER AIDED MANUFACTURING

The impact of computer graphics on the GM body tooling cycle has been very substantial. But full lead time and dollar savings will not be achieved until the entire body tooling cycle from design concept to production die is affected. To date the major impact of this new technology has been in the area of product design. Our large graphics systems have been profitably used in body design and body engineering for several years. However, examination of the distribution of work in the body tooling cycle shows that 88 percent of all hours are expended in tool design and construction. Similarly, 70 weeks are consumed in this effort as opposed to only 17 weeks for panel design. Clearly, the greatest potential savings are in these areas, and we have scarcely begun to impact them.

THE BODY TOOLING SCENARIO

What is ultimately required is a general machining-manufacturing system for body tooling. This system would use high performance Numerical Control machines to do the milling and inspection of die models and dies. The processing, communications, and coordination would be done on small computers linked together by telephone lines. The system we envision would consist of at least three major parts.

The first would be Tool Design. Here the die models, dies and fixtures would be designed. The product design data would be used to determine how many and what kinds of dies are needed to produce a part and also the sequence in which the dies would be used. The amount of die tipping would be determined and the runoff conditions developed. Binders and die and checking fixtures would be designed. All the necessary drawings would be output.

The second part of the system would deal with the machining of the die models, dies, and related tools. The product design and tool design data would be used to generate N/C tapes to drive the mills. These tapes would contain all the machining information. They would be verified and used to machine wood die models, gages, and glass blocks. Tapes to cut metal would be produced either from the design data or by tracing the wood die models with computer controlled scanners. All tapes, process sheets, and listings that are necessary for setup and milling would be produced. If the use of computer controlled inspection machines becomes widespread, these tapes would also be generated.

The third part of the system would ensure proper utilization of equipment and metal in the stamping plants. Offal would be scrutinized to see if other parts could be produced from it. The press configurations and material handling equipment would be checked to see if they were available and not overloaded. Once this was assured, layout drawings would be generated and sent to the plants. In addition, material deviation studies would be done to ensure that no plant was using a higher grade metal to produce a part than other plants.

CONCLUSION

We are slowly working towards developing such a system, and the Network Station plays an important role in these future plans. We are already actively working with the divisions to develop programs in the areas of die processing, press planning, clay milling and 5-axis tool center computations. A prototype program for generating N/C inspection tapes is already available on the Network Station. Also, programs to minimize metal waste through optimum blank nesting are now under way. We are convinced that for N/C technology to succeed, it must become the "conventional process." The Network Station is helping this happen by placing the computer in the plant where the work is done and by removing the mystique from Computer Aided Manufacturing.

In summary, we have a tiger by the tail in our Network Station project. He has "devoured" every task given to him and still seems to have a voracious appetite. We are letting go of the tail a little at a time as we assign more and more of the new body tooling applications to him. We feel that it will take quite a while before either his appetite is satisfied, or we "run out of tail."