GENERAL MOTORS - VISIT DATE AUGUST 9, 1993 -

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General Motors is the world's largest automotive company. Some relevant statistics for automotive operations (excluding financial services, EDS, and GM Hughes Electronics) in 1993 and 92 are in Table 1.

	1993	1992
Total Employees	531,700	571,000
Total Salaried US Employees	71,400	79,600
Number of Vehicles Sold Worldwide	7,785,000	7,685,000
Average Hourly Labor Cost in US	$42.72	$42.21
Capital Expenditures	$5,146 million	$5,349 million

Table 1. Selected Data for General Motors Automotive Operations

Short History of Car Development Process Improvement at GM[1]

When GM acquired Electronic Data Systems (EDS) in 1984, a major objective was to use computers to capture and integrate the car development process. A program called C4 (for the combination of CAD, CAE, CAM, and CIM) was formed and given several floors of an office building in which to lay out its plans. One of its first steps was to create seven "lead groups" whose task was to map out the steps in design and manufacturing of each of the main technical areas of a car, such as engine, transmission, body, chassis, interior, and so on. The plan was to establish a baseline description of the existing process from which an improved process would be created. This improved process was intended to set the requirements for computerizing car design.

These groups used the Air Force modeling technique called IDEF to diagram the processes. IDEF is a hierarchical scheme that indicates each activity in a process as a box with two inputs (information and materials), one control or criteria input, and one or two outputs comprising information or criteria and materials. Each level of the hierarchy is limited to at most 5 process boxes. Each process box is typically expanded into one or more levels below. Typical IDEF models of real industrial processes usually have ten or more levels and hundreds of boxes with inputs and outputs running between adjacent levels and jumping across levels.

[1] Based partly on my own knowledge plus presentation by Ashok Aguiar on 8/9/93.

The results of the lead group activities fit this description. An entire floor of the office building was divided into rooms with cork board walls floor to ceiling. Each lead group had a room and literally covered the walls with IDEF models of the relevant processes. The C4 team soon realized that these diagrams were not very useful for describing the existing process, much less as the basis for creating a better one. My reading of one of these (for power trains) indicated that it did not describe the process in enough technical detail, but instead captured the names of activities like "design transmission" or "choose suppliers." Missing were the technical calculations, the tradeoffs, and a compilation of the necessary data for individual steps.

More important, the IDEF method was not able to convey the scope of the interactions between different designers or design activities clearly. The model was hierarchical but did not show the flow of information from task to detailed task in a way that could be seen vividly on the diagrams. In the end, it appears that the diagramming activity was dropped along with the ambition to put the entire design process on computers.[2]

Other C4 activities were more successful. A wide area network was installed permitting technical staff at 58 locations to communicate with each other and access databases. A program of "deproliferization" was undertaken to reduce the number of CAD systems from 26 to 2, the number of CAE systems from 110 to 44, and the number of computer hardware types from 16 to 5. A centralized Technical Data Management System was introduced.

The GM/EDS effort was successful in those areas that could be called computer-dominated, such as databases, networks, and deproliferizing. It was less successful in areas that are engineering-dominated. More recent efforts are being carried out by experienced engineers with software support. These appear to be more successful. The motivations are apparently

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[2]In the late 1980s the Advanced Engineering Staff launched a knowledge -based approach to putting design on the computer. The objective was to write down all the rules and calculations needed to design an item. Pilot programs were written, one for a connecting rod and one for a hood. Each of these required capturing over 1000 rules and calculations.
However, it appears that these early pilots were more of a jolt than a success. The realization that even a connecting rod required over 1000 rules offered a daunting prospect for capturing major portions of car design by this method. Secondly, a great deal of effort by programming experts is required to construct one of these models, and modification by users to capture improvements or exceptions is not practical at this time. So the result of the effort is a system that might have been right at one time, at least for a large fraction of intended uses, but it is not completely right and is not subject to easy change.

• to make the design process more "math-based" and less dependent on experience, unsupported guesses, and physical prototypes

• to capture knowledge that some perceive is drifting away in the heads of retirees or temporary employees

• to improve standardization of design approaches

• to provide a common database, improve communication, and generally speed up the design process

Individual design tools seem to emerge from two sources, the Tech Center R&D staff and the design and operating divisions. Each year the users make a wish-list that is prioritized by the C4 staff. The highest ranking ones are implemented.

Thus a certain division of labor has emerged, in which C4 has the lead in computing infrastructure while the users have at least begun to lead in defining applications developments. The remainder of this report discusses recent efforts in a number of these areas.

New Organization of Car Development and the Technical Center

In January, 1993 the North American Operations (NAO) Technical Center was created as part of a major reorganization of NAO. The new organization replaces the arrangement in place since 1984 which had decentralized car design and manufacturing into the domains of two large operating divisions, Chevrolet-Pontiac-Canada (CPC) and Buick-Oldsmobile-Cadillac (BOC). In previous corporate arrangements, the GM Technical Center was largely a research and development operation with staff or advisory duties in connection with development of new manufacturing capabilities. Car development took place primarily at the divisions. GM people are widely quoted as saying that the old organization fostered independence but this led to proliferation of parts, duplication of effort, loss of standardization of design, and yet cars that looked too much alike.

The company is now arranged in several more specialized divisions, and the GM Technical Center now is directly involved in the first two phases of design of vehicles and some of the accompanying manufacturing operations. These two phases take place at the new Vehicle Launch Center (VLC). Figure 1 sketches the new arrangement.

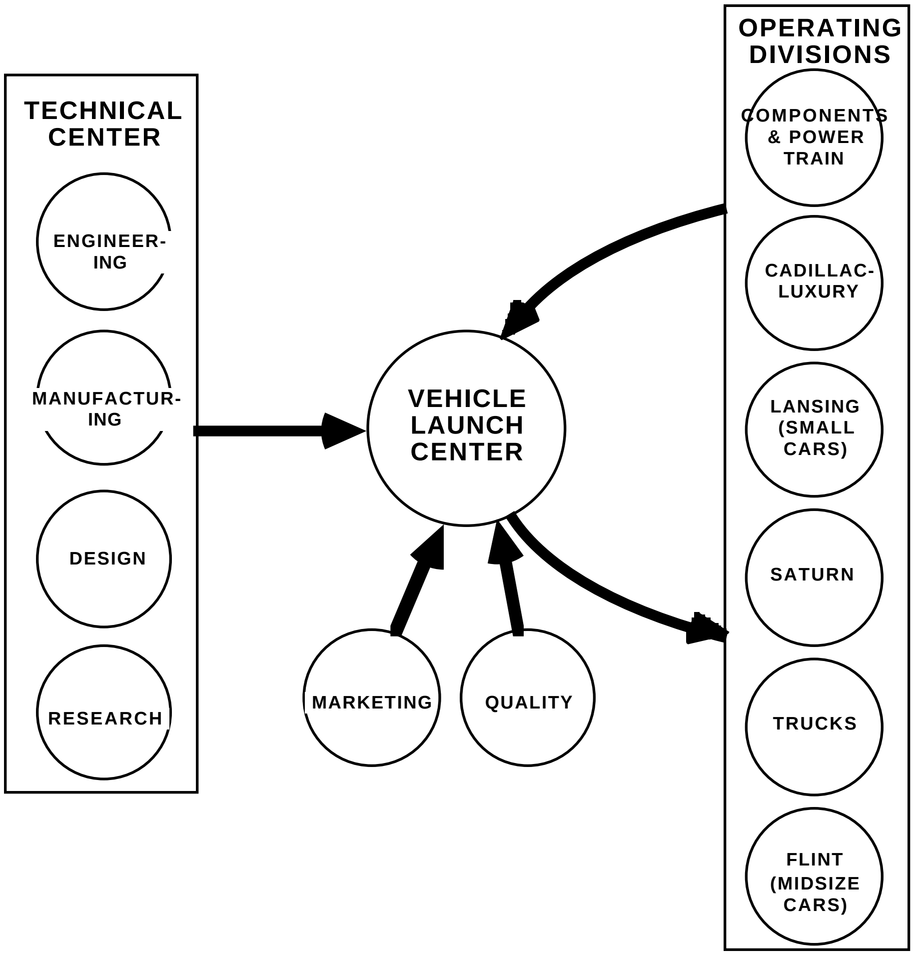

Figure 1. Relationship Between Technical Center, Vehicle Launch Center, and Operating Divisions. Car development program personnel spend their first year physically located at the VLC where they are joined by Technical Center personnel. Development personnel return to their divisions for the remaining years of the program. It is estimated that 1000 to 1500 people will work on any one program at one time or another, with the peak being around 1000.

The timeline for new car development is roughly as shown in Figure 2.

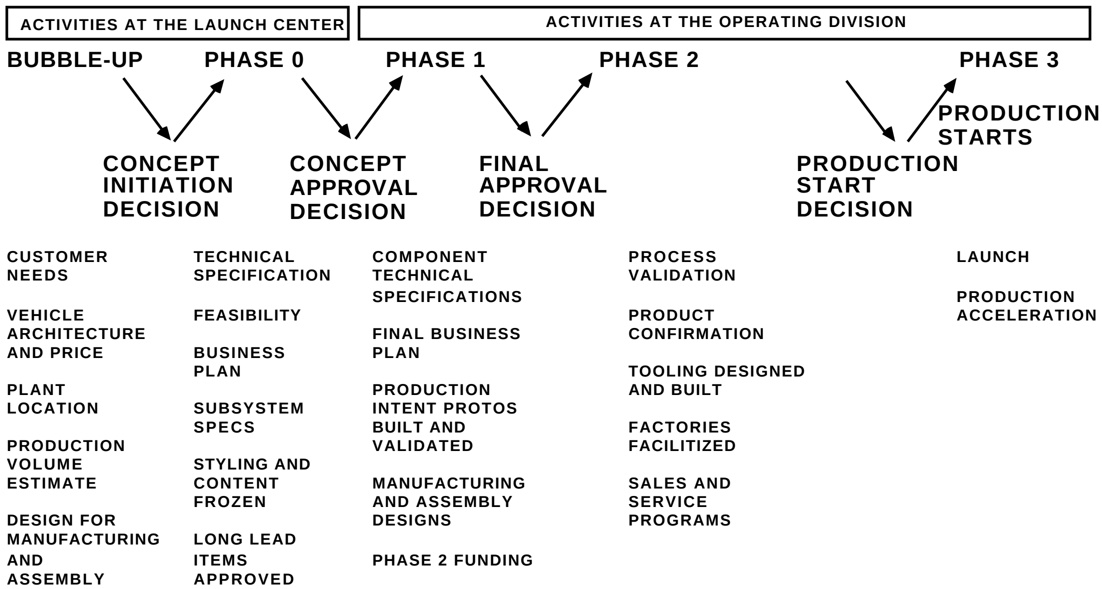

Figure 2. The "4 Phase Process" Showing Typical Activities in Each Phase. The left-right time arrangement is approximately in scale and the process steps comprising phases 0, 1, and 2 currently take about 4 years.[3]

During the time when activities occur at the Launch Center, engineers from the operating division work at the Center. People from the Technical Center, the Quality Center, and the Marketing Center take part in these phases. The goal is to force the definitive early phases to be more standardized in their approach, to put them near technical expertise, and to provide standard design tools and parts lists. Beyond the goal of standardizing the development processes of the different divisions, a longer term goal is to capture all the knowledge currently scattered throughout the company, make it available to the development programs, and provide a home for long term learning that can be passed from one program to the next. As Figure 1 suggests, the programs pass through the VLC but the expertise of the Technical Center remains to serve successive programs. GM hopes that Tech Center staff will see many development programs in quick succession, increasing their learning and expanding the corporate memory.[4]

Another goal is to create a more level workload for the engineers at the Tech Center by phasing different development programs, a practice called "cadence." Hopefully, load leveling will reduce the need for outside contract engineers and designers. Many at GM worry that contract engineers have too

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[3]Descriptions of the VLC and the 4 phase process appeared in Automotive News, December 13, 1993, pages 1, 16, 18, and 20, and in Ward's Auto World, March 1993, pages 75-78. Information was also taken from a GM Tech Center press release dated Feb. 26, 1993.

[4]Among the phrases one hears frequently from GM people is "corporate memory," and Toyota is widely praised for having this trait.

much valuable and specialized knowledge that can walk out the door unexpectedly. It will be interesting to see if this goal is achieved, because it appears that the real detailed engineering design will take place at the operating divisions during phases 1 and 2. Some of these divisions have what amount to permanent contracts with contract engineering houses that either provide engineers on site at GM or at their home offices.

As described below, this reorganization is being undertaken along with a renewed push to increase the mathematical and computer basis for car design and engineering. (The word for this is "math-based" design.) This effort, too, is a reversal of a past attitude that design and design tools are commodities that can be purchased. Some executives thought that either Toyota's or Boeing's CAD systems[5] could be purchased and placed directly in service. Toyota actually offered its systems twice in the past, once in the middle 80s and again in the last two years. On both occasions GM rejected the offers after determining that Toyota's approach was far more math-based than GM's and included a great deal of almost invisible but very deep technical memory without which the CAD system might well have been of limited use.

Only recently, then, has it been realized that, as a Nissan CAD planner said,[6] the design process is a carefully thought out system of technical and cultural factors that needs to be supported by a software system that is tailored to that process. As Table 1 shows, GM is reducing its salaried workforce, necessitating greater reliance on computer-based tools and making the need to capture knowledge critical.

The new organization is a compromise between the permanently centralized platform teams at Chrysler and the decentralized teams GM had since 1984. GM worries about a centralized engineering organization stifling creativity and flexibility, reasoning that the operating divisions are closer to the market, but also worries that the divisions are not close enough to deep functional expertise and reinvent things that are available elsewhere in the company. The reorganization is part of an effort to bring more discipline to car development that includes the activities described later in this report involving math-based design. It is also an acknowledgment that, as one person put it, "There is a tremendous amount of knowledge at GM but we don't apply it, and in some cases do not even know it exists."

Description of the Technical Center

[5] Boeing's system is actually at least 66% internally written code and less than 33% commercial code from CATIA, based on lines of code. Based on estimates heard at the 1994 CATIA Users' Conference held at Chrysler, April, 1994.

[6] See Whitney 1991.

The Technical Center contains four main divisions, much as it has in the past: the Design Center, the Engineering Center, the R&D Center, and the Manufacturing Center. Design handles what is usually called styling, which includes market research, exterior vehicle shape, interior design, colors, and fabrics. All car programs begin with styling. The Engineering Center has or will develop capabilities in areas where vehicle engineering, information, controls, and system integration are important. These include power train, chassis and vehicle dynamics, energy management, climate control, safety, and noise-vibration-harshness (NVH). The R&D Center will continue its programs of drawing in results of university and government research but has the added responsibility of developing an "R&D Portfolio" that is keyed to the needs of the operating divisions and serves the identified core competencies of the company. New capabilities and processes are the intended outputs. Finally, the Manufacturing Center is responsible for developing new manufacturing technologies and assisting the operating divisions in such areas as body engineering, design and production of stamping dies, production of prototype vehicles, industrial engineering and assembly plant processes, facilities engineering and plant operations, manufacturing information systems, paints and painting technologies, and benchmarking.

The decision regarding what expertise to keep in-house and what to farm out is basic to the structure of the Tech Center and the VLC. Gary Cowger, Executive in Charge of the Manufacturing Center at the time of my visit, explained the issue this way:[7] The goal is to build technical expertise in core areas and reduce effort in non-core areas. "Core", he says, is like "strategy" in the sense that people can disagree. Non-core, say batteries, is something about which there is no disagreement. He feels that manufacturing did not do a good job of explaining its contribution to "core" in the past. His organization now has line responsibility as a result of its connection to the VLC, rather than staff, or advisory, responsibility as in the past. Car programs will have to listen to what his people say, and his people will have to learn what their customers in the operating divisions need. "For the first time, one person has responsibility for control of manufacturing from the Tech Center to the plants."

Cowger sketched the degree of involvement of the different sectors of the Manufacturing Center in the different phases of car development as follows:

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[7]Informal talk to MIT Leaders for Manufacturing Program Research Committee, May 19, 1994.

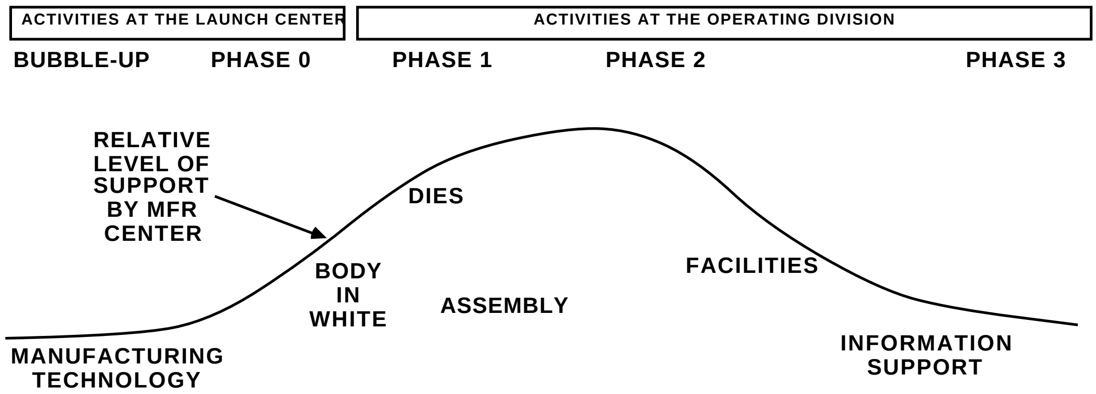

Figure 3. Types of Activities of the Manufacturing Center and When They Occur in the 4 Phase Process.

He also has a vision for how the design, development, and manufacturing processes can be systematized. This vision is similar to that described by Chrysler and consists of

• the bill of design, comprising the requirements for a new car design

• the bill of processes, a list of steps needed to design a car systematically plus a set of proven manufacturing technologies

• the bill of materials, the list of parts in a car

Of these, the last is in place, the middle one is in process of being established, and the first is yet to come but on its way.

CAD and Body Styling

GM has settled on two CAD systems, the Corporate Graphics System (CGS) for sheet metal design and Unigraphics (UG), a commercial package purchased from McDonnell Douglas, for mechanical design. CGS' capability in solids has been abandoned. However, UG has turned out to be less capable in solids than expected, so development continues. CGS, furthermore, is said to take 2 to 3 years to learn, and is not used by many of GM's suppliers. I did not get a clear impression of what GM plans to do about these conditions. The approaches of Ford and Chrysler are each different and more fully developed.

Car styling appears to be still done first in clay. Like Ford, GM is enhancing its ability to digitize the clay and create the "math model" from which further design proceeds. But it is anticipated that many designs will iterate between math and clay, and GM hopes to make the two-way process easy. There is, in other words, no strong push such as one sees at Chrysler, Nissan, or Toyota, to do initial styling on the computer directly or to use clay merely for display.

Brief Description of Stamping Die Design and Body Engineering

This description is intended to provide some background and vocabulary for the discussion below of recent GM die design tool development, but is not intended to be definitive.

The process of converting a clay or computer body outline into sheet metal comprises roughly the following steps:

1. Since the outline is a continuous surface, the first step is to divide the surface into separate panels, such as hood, fender, roof, door openings (called the "aperture"), rear fender quarter, etc. While some of these panels are obvious, such as the hood, others are not. The best example is the roof, where there are many ways of dividing it from the front windshield pillar (the A pillar), the rear window pillar (C pillar), the aperture, and the rear fender quarter. Important issues are mainly esthetic and concern where the joints are or how they are made. This process defines roughly 20 outer panels.

2. Beneath the outer panels are the inner panels. The inners are not stylish in any sense but must in fact be made more accurately than the outers. There are roughly three to four inners for each outer and they play the role of "bones" to the outers' role of "skin." The inners provide shape and dimensional accuracy for the outers, hence the accuracy requirement. Inners are responsible for structural strength, body rigidity, and crash resistance, so they are made of thicker material. Crash analyses mostly deal with inners.

3. Each panel, inner or outer, is made by stamping. Sheet metal is die cut into shapes called blanks and then given its 3D shape in powerful presses. The blanks are clamped around their peripheries by binder dies and then a convex shaped die presses the metal down into a concave receiving die. See Figure 4.

Typically this process requires 3 to 5 steps, each having its own binder and forming dies. A little arithmetic shows that as many as 20*4*5 = 400 die sets may be required to make all the panels for a car. Naturally this represents a huge design effort and a huge capital investment.

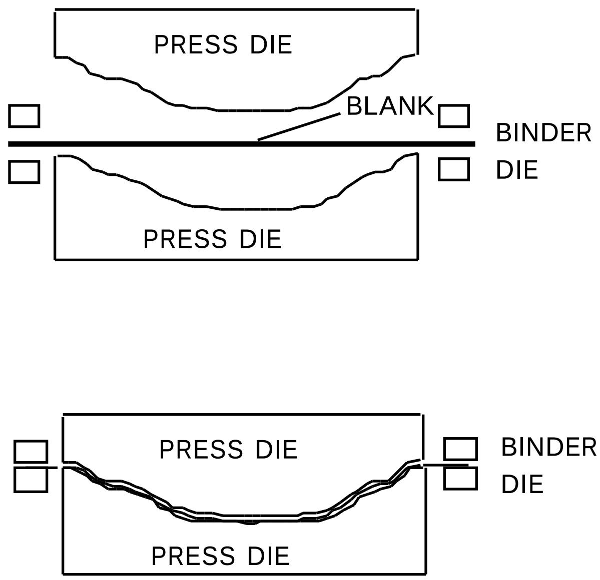

Figure 4. Die Stamping Process for Sheet Metal Car Parts. The blank is put in the die (above). The binder die closes first, then the press die. As the press die closes, it stretches the metal blank and pulls it part way out of the binder. The binder provides resistance to the force of stamping. The binder can be designed to apply different resistance at different places around its periphery, allowing more metal to be drawn into the die in places where the part is pressed more deeply.

4. Dies are designed in a series of steps. Expertise is required, especially to design the binders because they are intended to apply just the right amount of outward tugging as the metal is drawn into the die cavity. The shape of the press dies also requires skill to design since it is not the same as the shape of the desired finished part due to springback in the sheet metal. Problems can arise in die stamping because the metal is stretched too far, or too sharp a corner is called for, causing a rip or a wrinkle, or the overcrown is not correct and the parts spring back to the wrong shape.

5. When a die set is finished, it is tried out. The tryout period can last from a few days to months depending on the complexity of the part. This process is necessary in order to ensure that the part comes out the right shape as well as to prevent ripping and wrinkling. Tryout usually involves altering the die or the binder, adding or removing metal. Often "draw beads" will be added to the binder. These are ridges and matching grooves that hold the sheet metal more tightly than straight pinching with smooth surfaces can. A major problem for car makers is to document the changes made during tryout. Laser digitizing is being considered, much the same as it is done to capture clay models. However, the precision required to document small changes in die shapes may not yet be available by non-contact methods.

Each car company has expert designers as well as specific computer software engaged in this process. At least until recently, Toyota reputedly had the best software. Both Toyota and Honda are very systematic about keeping records of what shapes cause problems, saving time in the die design and production process.[8] This is an example of corporate memory. Clark and Fujimoto showed that constructing and trying out these 600 die sets is the longest single activity in car development, and car companies vary significantly in how long it takes them. Those with better in-house knowledge presumably do it faster. This point has not been researched definitively. However, as the visit report below shows, GM is not only working to improve its in-house die analysis and design capability but it is also improving its interfaces with outside die shops that are heavily involved in its process.

Visit to the Technical Center August 9, 1993

This visit included presentations by Tech Center R&D staff, C4 staff, and members of the Knowledge Center, a place where a number of new math-based systems are developed or taught to other GM employees.

1. Tech Center R&D Activities

Software for Die Design and Analysis

In the current design process, outside vendors play a role at various points in the process, requiring designs to be sent out in one incomplete state and received back, to be worked on further. In addition, it is often required to join portions of a panel designed in clay with other portions designed in CAD. A tool called SurfPlan has been developed to aid these various steps. It began as software to fit math surfaces through data digitized from clay models and has been extended to support other portions of the design process.

For example, early analyses of stamping feasibility are often done using an approximate binder because the actual binder is designed by an outside vendor. This permits analyses to begin sooner but requires that later the actual binder design be joined mathematically to the part shape design. SurfPlan supports both the simple binder for analysis and the process of joining the actual binder when it arrives. Overcrowning is also supported.

Filleting is supported as well. This is a mathematically difficult process because it requires a smooth concave shape to be joined to two arbitrary mathematical shapes representing intersecting surfaces. In the past, fillets were simply omitted from the CAD model and the dies received their fillets

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[8]Toyota also has die design analysis software that helps designers avoid panel shapes that are likely to cause long tryout times. See Toyota ONR visit reports from 1991.

when skilled machinists ground them in manually during tryout. This means that essential design steps were not documented and the knowledge was not recorded.

Every such piece of software has to be validated by designing test parts and comparing their shape to the desired one. SurfPlan is currently being used but as of my visit it was still being validated It is important to note the degree to which this software is a response to a somewhat awkward design process, with different steps being done by different companies at different locations.

Another program is the product of researchers at the R&D Center [Cavendish and Marin]. Called Innersurf, it is intended to help designers create the complex shapes of inner panels. As Figure 5 shows, these can be quite complex compared to the relatively smooth outer panels. The raised and depressed sections of the panels serve to strengthen them as well as to serve as mounting surfaces for attachments such as window regulators in doors or other panels that are welded to them. The designer is often given the locations for these attachments but no definite shapes for the corresponding surfaces. Not only must these surfaces be created but they must all be blended together consistently even though they lie in different planes.

Innersurf allows the designer can draw these shapes using CGS. Each shape is described by its outline and its location relative to a reference plane. After the outlines are located in space, the software will blend them together to form a complete multi-level surface. Formability analysis is done on the complete model by making a finite element mesh of each surface feature separately; these meshes are then unified and the analysis is done. This software is now part of CGS. Significantly, it took only 9 months to work out the basic math and the underlying logic of knitting surfaces together. However, it took another 4 years to bring the software to the point where it was bug-free, had a suitable user interface, and was fully consistent with CGS.

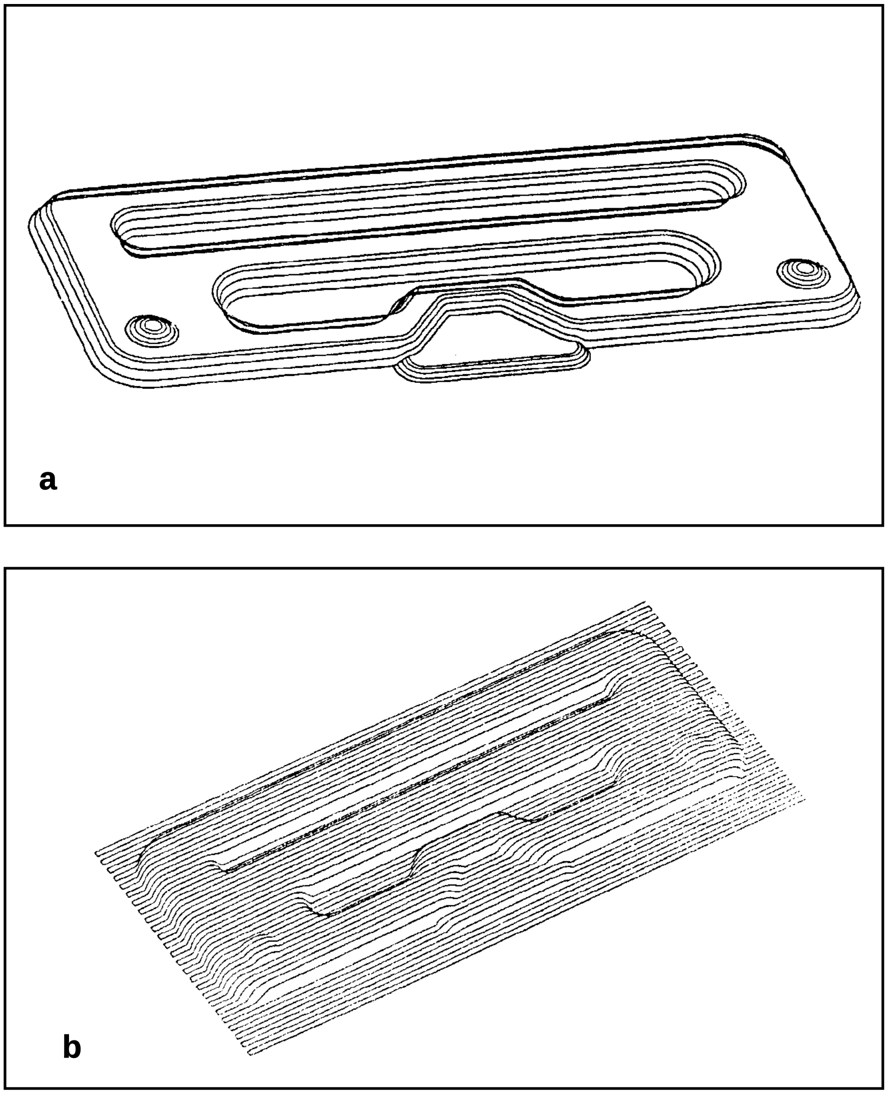

Figure 5. A Sample Sheet Metal Inner Panel Designed Using Innersurf. Above is the basic panel design shown with the features outlined in toolpaths keyed to the features. Below is a pattern of rectilinear NC toolpaths that will create the die surface. Source: [Cavendish and Marin].

2. C4 Staff Activities

C4 Strategy

Originally, as described above, the C4 vision was to develop a computerized car design process. Out of this effort came the 4 phase process but the integrated design system is no longer a specific objective. C4 concentrates on infrastructure although it apparently still is involved with increasing the detailed definition of the 4 phase process. The paper description now has about 160 defined steps but the goal is to expand it to as many as 5000, arranging them in a kind of flow chart with decision points and information on who does what, where the information comes from, and where it is to go.

This ambitious strategy is supported by a variety of infrastructure programs. The C4 INFRANET now links 58 locations with T1 lines, plus 50kb lines to other locations, allowing over 6000 users to communicate. At the same time, integration is hampered by the fact that few suppliers have CGS. As a result, communications outside GM still rely on paper heavily. Also, the emphasis has been almost exclusively on computerizing the product design process, so manufacturing is behind. This is reflected in the following statistics (as of August, 1993) for the number of computer consoles and their use:

NAME OF SYSTEM OR USE	**NUMBER OF CONSOLES**
CGS - BODY ENGINEERING	3400
UNIGRAPHICS - MECHANICAL SURFACES AND SOLIDS	1300
CADAM - 2D DRAFTING	1200
ENGINEERING ANALYSIS	600
ELECTRICAL DESIGN	500
TEST SYSTEMS	900
FACILITIES DESIGN	250

Table 2. Kinds and Quantities of Computer Consoles at GM. This table does not include Saturn, which is 100% on CATIA.

The group is also responsible for benchmarking GM's capabilities against other companies. The list of areas they track is interesting:

- computer-aided styling
- solid modeling
- feature-based design
- use of wireframe models
- assembly management, including electronic preassembly, tolerances, interferences, robot programming, configuration management
- virtual reality
- rule-based or parametric design

Also interesting is their conclusion that they feel their strongest competition in most of these areas is either Ford or some of the European companies. Not Japan.

The software technology portfolio consists of the following items:

New design and analysis methods:
- Surface modeling of inner panels
- Die casting models
- Machining models

Parametrics and Feature-based Design:
- Engine components
- Stamping dies
- Manufacturing processes

Rule-based Advisors ("for getting the right geometry"):
- Chassis
- HVAC
- Truck frames
- Welding tool design

Process Improvement Via Common Tools (i.e., integration of existing tools)
- Electrical system design
- Crashworthiness
- Fuel system design
- Power steering noise
- Publications (shop manuals, assembly process instructions)

Vehicle Systems Engineering

Two systems are intertwined in this effort, the car itself and the process by which it is designed. The inference is that the design process drives the definition of the tools needed to do the design. Major elements include capturing requirements from customers and turning them into detailed engineering specifications. This requires establishing corporate databases and analysis tools together. These databases include a corporate technical memory, described below, legal data about regulations, and marketing data.

A House of Quality requirements advisor has been written. It helps users flow requirements down to engineering specifications. Example data include performance and fuel economy information laid out against different market segments. A variety of empirical models relate these data, and some neural networks are in use. Used in one direction, the data might be used to help construct the torque-speed curve of a new engine. Used the other way, a market niche might be assessed for a proposed engine.

A Mechatronics design system has been in use for at least 7 years. It combines existing CAE software capable of describing mechanisms like hood opening and door slamming. It can predict door closing effort. Uses include relating HOQ information to engineering specs as well as helping to determine correct tolerances.

Body engineering is supported by a program that helps determine welding sequences, tolerances, fixturing points, and support of parts against their own flexibility.

Engineering integration includes under-hood thermal analysis and simplified stress and crash analyses.

Technical Memory

This interesting system is unlike any I have seen at any car company, though many Japanese firms have paper notebooks with this objective. (At least one Japanese company says that paper records are superior to computer records.) The GMTM system contains several elements:

Lessons learned
Guidelines
Standard Practices
DFM/DFA learning
"Yellow Pages" for documenting centers of excellence

Users can search for and retrieve information, put information in, and relate their needs to specific vehicle systems, such as body, chassis, power train, system integration, and manufacturing. (These correspond to the specialty areas of the Tech Center.) As of August 1993 the system contained about 100 megabytes of information in 2000 documents and was growing at the rate of 200 documents per month.

The system demonstrated was a prototype. Its contents were rather detailed, such as alternate types of body hardware. Effort is under way to expand the search and archiving strategy to include higher level topics such as thermal loads or assembly.

Business Systems

This project centers on product data management during design. It is called the Product Description System (PDS). It manages versions of designs and centralizes the process of releasing designs from engineering to manufacturing and helps keep track of drawings and part numbers. It also manages engineering work orders. An interesting byproduct is that the time to perform various engineering activities and design stages can now be measured. Finally, it can test model versions for consistency, ensuring for example that a car with air conditioning also has tinted glass. Prior to development of this system, each division of the company had its own release system.

3. Knowledge Center

The Knowledge Center has two functions, first to develop new software and, more importantly, to demonstrate it in use. The mission is to sell the math-based approach to the rest of the company. The Center holds regular classes on Design For Assembly and Just in Time manufacturing. To teach JIT there is a small mockup factory that "makes" simple structures out of LEGO blocks. Competitive vehicle teardown studies are done here also. In one such study it was found that a Japanese car had about 20% more parts than the corresponding GM car, but the Japanese car was easier to assemble. A large number of very small details were found responsible for this.

Some PC-based design aid software was on display as well. An interesting one provided support for managers running a team of engineers. The manager can view a task schedule and work progress reports and could assign work to individual engineers through the computer console. The overall task is modeled in IDEF showing the basic flow of information and sequence of tasks. Each engineer, by contrast has an IDEF model of the engineering work outlining the details of the task. Behind each box in the model is a set of folders containing background information, data, instructions on how to use analyses, materials data, previous designs, some object models to use with inherited attributes, and the Yellow Pages. In addition, there is a kind of spreadsheet for aiding the detail design process. It contains a drawing of the part being designed, a constraint propagator for linking the design to requirements, and a design critic that supported its critiques with reasons.

Another interesting system, also on a PC, will help a designer create a machining plan for a part, given a sketch rather than a complete model. It is intended to give a designer early feedback on manufacturing cost and feasibility. It contains a variety of design advisors in the area of DFM, process capability, workstation characteristics, and system integration, plus commercial DFA. In its present form the user must supply the information concerning the number of cuts, their required precision, and other judgmental information.

The Knowledge Center staff is confident that these tools can be brought to practical working versions and used in the company. They say, however, that their work is strongest in the technical engineering areas and weaker in task organization, such as who does what, with what, and for whom. This reflects the Japanese saying that, in addition to know-*how*, you need know-*who* and know-*why*.

Summary

On a time sequence basis, GM's reorganization is not the most recent but has been in place for too short a time for indications of its success to be evident in new cars. Only Chrysler has that much experience with radically rearranging its design processes. GM has by far the greatest concentration of capabilities and financial resources of the big three car makers. Its size and geographic dispersal make it difficult to manage, however, and too often its technical skills have not been applied at the working level. It should be noted that Boeing's radical makeover of its design methods and computing support was focused on a single product program rather than the whole company. It could be that GM will have to take a similar path in order to create a new methodology and computer tools that have credibility and enforceability across the company.

References

[Cavendish and Marin] Cavendish, James, and Marin, Samuel, "Feature-based Surface Design and Machining," IEEE Computer Graphics and Applications, Sept., 1992, pp. 61-68.