Ford Motor Company September 1, 1993 and Oct 4-6, 1993

Background

On September 1, 1993 I visited the North American Design (NAD) office to participate in discussions with working level people in car development, body engineering, Alpha (an advanced technology group), and a group called Math Model Integration (MMI). These were informal discussions among a group charged with rethinking the company's body design and engineering process. The meeting took place in an atmosphere of open communication about an area of ongoing work; no formal policies of the company were decided and most views expressed were those of the individuals present.

On October 4-5, I visited the Product and Manufacturing Systems (P&MS) Group (part of Car Product Development) and particularly visited the CAD/CAM Department.[1] This group is responsible for developing and supporting the main in-house software used for body design and engineering, called PDGS®[2] (Product Design Graphics System) as well as major product data management systems. Both in-house users and suppliers are supported. On October 5 the annual PDGS Users' Conference was held. Speakers included all the senior managers of P&MS, who outlined the company's five year strategy in CAD/CAM as well as how it would affect suppliers. An important feature of the conference was the presence of four approved workstation vendors (Hewlett-Packard, Digital Equipment, Sun, and IBM) all of whom demonstrated PDGS in a UNIX®[3] environment. On October 6 I visited the Chassis Engineering Department and the Powertrain Systems Department.

History of CAD/CAM at Ford

Ford was one of the pioneers in automotive CAD/CAM. An early paper [Ref 1] defined the concept of "CAD/CAM-The-Master" and showed how analytical surface patches based on Prof. Steven Coons' mathematics could be used to create surface models of entire automobiles. [Ref 2] As few as 24 properly defined patches produced a credible car model. (See Figure 1.)

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[1] These department names reflect Ford's organization in the fall of 1993 and do not reflect any changes made after the April, 1994 reorganization announcement.

[2] PDGS is a registered trademark of Ford Motor Company.

[3] UNIX is a registered trademark in the United States and other countries licensed exclusively through Xopen Co Ltd.

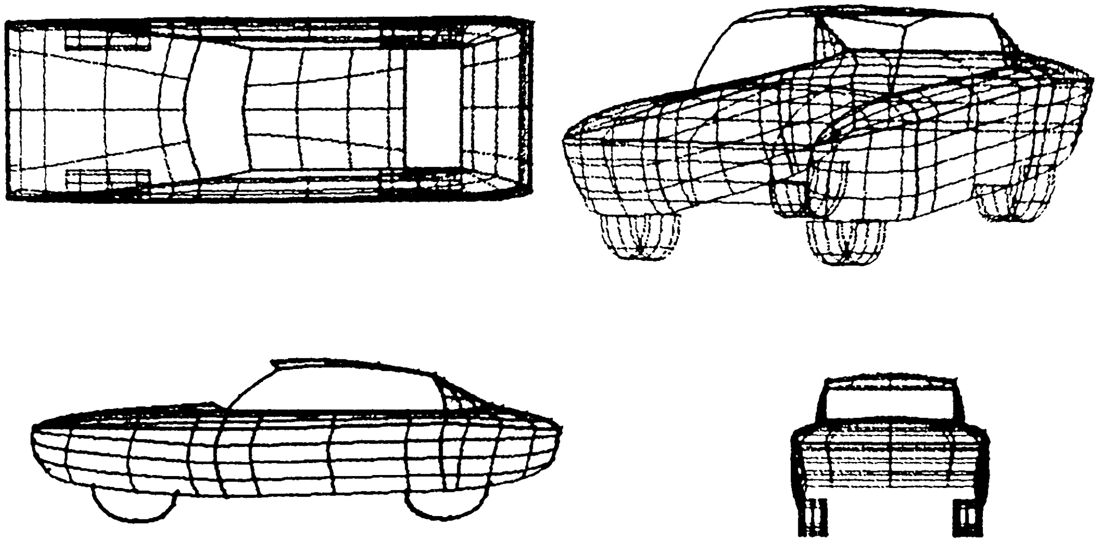
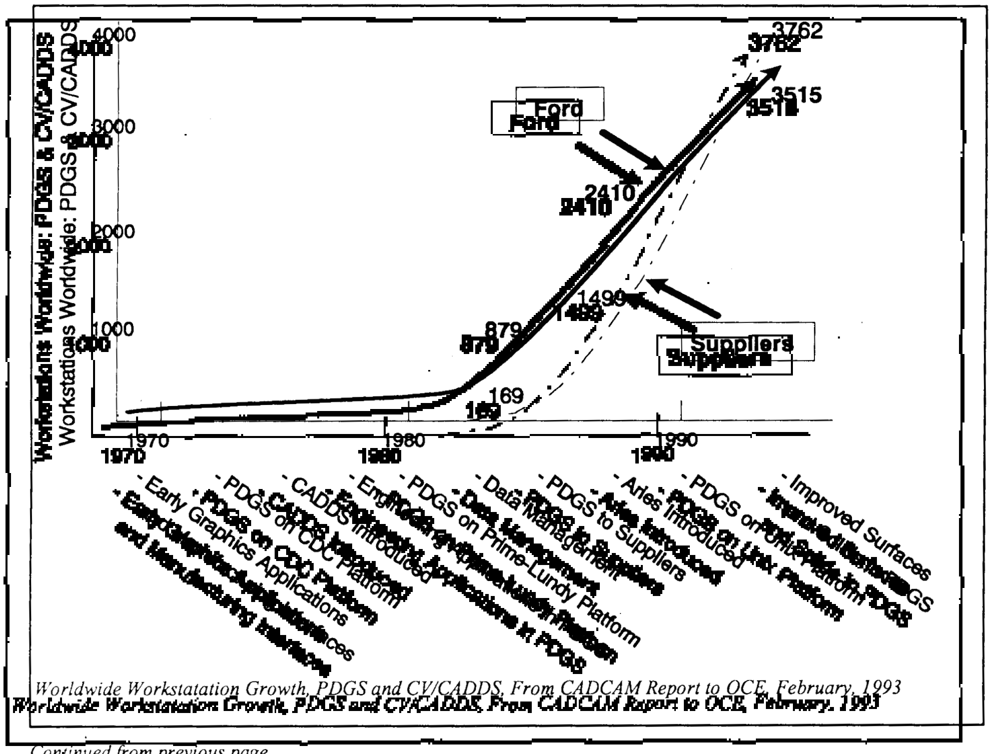


Figure 1. Example Early CAD Model of a Car. (from Ref 1)

Figure 2 sketches the main events in Ford's CAD/CAM development, including charting the number of user terminals or workstations over time.



Worldwide Workstatation Growth, PDGS and CV/CADDS, From CADCAM Report to OCE, February, 1993

Continued from previous page

Figure 2. Worldwide Workstation Growth, PDGS and CV/CADDS (from Ford CAD/CAM News, May, 1993.)

As this figure shows, large-scale development of CAD at Ford began in the early 1970s. Ford was an early user of ComputerVision software and Ford's influence on CV's product was large. In parallel, PDGS was developed. It ran on small process control computers rather than what we think of today as graphics terminals because it had a sufficiently sophisticated operating system to allow very large programs to run in a tiny memory (64Kb). This computer could generate graphics fast enough to permit them to be rotated in real time, an essential element of user interface in an era of wireframe models. In the early 1980s the platform consisted of a Prime Computer digital modeler plus an analog display driver made by Lundy (the "Prime-Lundy" system) which for many years produced faster graphics and rotations than any purely digital implementation.

Also in the early 1980s Ford began developing the "Data Collector," a centralized database manager that permits data sharing, holds information about product structure, and permits users to locate all product-related data such as CAD geometry. The idea is to keep the design tools separate from the data. The CAD vendors tend to join these, partly for reasons of competitive advantage, but the result is incompatible tools. Ford's objective is to make data the central defining element, and to require that all tools made or bought by Ford be able to communicate in a standard data format. Up to now this has not been fully achieved, and several approaches to it are being pursued.

As in most car companies, Ford's body design and engineering departments developed their own CAD separately from the mechanical departments (powertrain and chassis). Body design and engineering need free-form wireframe or surface models with some 3D representation capability as well as a great deal of specialized design and analysis capability that is unlikely to be available commercially. These capabilities include manipulation and modification of 3D surfaces, analysis of stamping, and crash simulation. Most car companies developed these capabilities themselves early in the CAD era. By contrast, mechanical component designers did not recognize the usefulness of 3D representations until much later. Instead, mechanical design was done mostly with 2D drafting software, whose output was conventional drawings. Even today as 3D begins to penetrate mechanical design, much of the output is still drawings, largely because most of the people in the process chain are used to using drawings to do their part of the work, such as fixture design.

The result at Ford (as at most car companies) was the emergence of at least two "CAD cultures," one centered on body design and the other centered on mechanical design, each with their own programming or support staff and preferred software vendors and partners. According to one manager, there are even important cultural and software differences between body styling and body engineering. Body engineering especially put a great deal of effort into developing its own CAD software, and today PDGS is often called one of the best body engineering packages in use anywhere ("developed by body engineers to do what they need done," said an observer at another company). PDGS data are used by assembly tooling designers and a large number of suppliers. Many suppliers have PDGS and can submit designs to Ford directly.

By contrast, the mechanical departments invested little in their own software and today use PDGS plus a collection of commercial software, primarily ARIES for 3D solid concept design and engineering, and ComputerVision CADDS for detail design, drafting, and drawing release. However, as discussed below, the Powertrain Department has close ties with ARIES, and many special capabilities have been and are being developed well beyond what is commercially available. Figure 3 is a sketch of the main CAD systems in use at Ford plus the main data paths between them.

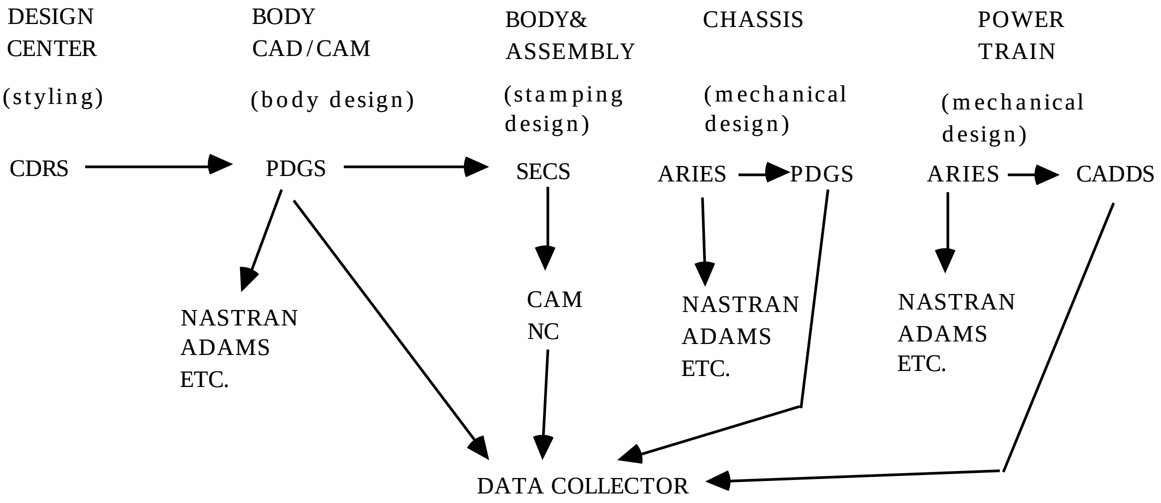


Figure 3. Sketch of Relationships Between Major Design and Engineering Centers at Ford and Their Respective CAD Systems (as of October 1993). CDRS is the Car Design Rendering System from Evans and Sutherland, and SECS is the stamping engineering computer system. NASTRAN is a commercial finite element stress analysis package, while ADAMS is a commercial kinematics and dynamics simulation package.

A competitive assessment conducted in the spring of 1993 concluded that Ford ranked just behind Toyota in overall CAD/CAM effectiveness, due to "Toyota's effectiveness in achieving enterprise integration by limiting strategic CAD/CAM use to a single system."[4] Among the steps taken or being planned to improve integration are

- adoption of UNIX as the basis for further PDGS development so that systems will be more open

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[4] Ford PDGS users' Newsletter CAD/CAM News, May 1993, pages 1-2.

- conversion of PDGS to the ACIS geometric modeler (a product of Spatial Technologies) which will permit direct exchange of models with ARIES, which is also based on ACIS

- development of STEP representations for mechanical part models (in the spring of 1994 a part model was made in ARIES, converted to a STEP model, transmitted by satellite to a supplier, and manufactured by numerical control)

Competitive analyses are done regularly, and one was just completed that compared Ford's approach with Boeing's CATIA system. Toyota approached Ford in the spring of 1993 with a wide-ranging proposal to sell its proprietary design software called CAELUM to Ford. While CAELUM was judged to have some advantages in certain areas, Ford apparently felt that its closed architecture was an overriding disadvantage. Ford has also looked closely at ProEngineer but at the time of my visit had not adopted it except in a few areas.

In my opinion, Ford will retain a variety of CAD systems for the foreseeable future.

World Class Timing

Ford has been working to improve its product development processes for many years. In the early 1980s it adopted a form of cross-functional teams for the Taurus development but did not incorporate the method as standard operating procedure. Later car programs were not as fast as management wanted, so in 1992 the World Class Timing program was initiated. The goal was to reduce development time from the current average of over 54 months to a more competitive 37 months. Table 1 gives the main milestones for WCT. See [Ref 4] for more details on WCT. Note that prior to Program Implementation there is a period of planning that includes selection or advanced development of a powertrain. No car company can consistently develop new engines and transmissions in the same time frame as new bodies, chassies, and interiors.

Powertrain declared (PT) (60 months before Job #1	Powertrains identified or new designs started
Program definition (PD) (43 months before Job #1)	Program strategic intent, market strategy, technology alternatives, sourcing, model range. Engineering funds approved
Program implementation (PI) (37 months before Job #1)	Approval to start, architecture, hardpoints, key structural sections approved for theme development. Wall of invention here. Long lead funding approved. "Workhorse" prototypes
Theme decision (TD) (33 months before Job #1)	Approval of single interior/exterior theme

Theme confirmation (TC) 31 months before Job #1)	100% feasibility of interior and exterior. Early sourcing complete
Program confirmation (PC) 24 months before Job #1)	Board of directors approves final commitments by suppliers and operating divisions. Final funds approved. Structural prototypes
Prototype readiness (PR) 21 months before Job #1)	Structural prototype and CAE done. Content of confirmation prototype frozen. Design at Job #1 level. Prog mgr's approval of Job #1 design, manufacturing processes, and purchasing plans. Confirmation prototype done at 9 months before Job #1.
Signoff (SO) 7 months before Job #1	Prog mgr certification that design and mfr capability meet customer requirements
Launch readiness (LR) (3 months before Job #1)	Prog mgr approval of integrated launch
Job #1 (J1)	Integrated launch completed. Mass production starts
Program status (PS) 6 months after Job #1)	Comparison of goals and actuals in terms of customer reactions. Lessons learned documented

Table 1. The World Class Timing Guidelines, adopted 1992. The activities can be grouped into four phases: Planning (PT and PD), Design (PI, TD, TC, and PC), Development (PR, SO, and LR), and Production. In this table, "integrated launch" means that the new vehicle is gradually installed in an operating factory without stopping production of the existing vehicle. In practice this can be quite difficult, especially if new tooling is needed. Recent launches have begun 7 months before Job #1, even in cases where the design of the new vehicle was constrained in order to use most of the old tooling.

The WCT process is too new to have been used yet for a complete car development cycle. Implementing it requires, as discussed below, formation of new work organizations and development of new computer tools.

Visit to Corporate Design, September 1, 1993

This visit comprised a brief demonstration of the new international design facility and a day discussing design process improvement with a working level team.

The international design facility, described in the Sunday New York Times for August 29, 1993, [Ref 3] consists of an Ethernet satellite linkup of computers and design studios in the US, Europe, and Japan. Designs can be made using CDRS in one location, sent to another location (say the UK) while they are modified using two -way conversation and a paintbox program, and finally sent to a third location (say Turin) for analyses and carving of a clay model. The long term intention is to use tools like this and others to permit designers and engineers in many areas of car development to interact, comment on the design, avoid costly errors, and cut car development time from 36 months to as little as 24. Clearly, establishing this capability was important in providing a foundation for the April, 1994 reorganization that is intended to unify most of design and engineering in one location.

I saw a demonstration of this software suite on September 1, 1993. In this demo, the full 3D CDRS model was not actually modified in real time over the satellite. Instead, a paintbox program called Art Cam was used to make comments or changes, including color changes, to a scanned photo of a car or clay model. This tool is one of a "technology suite" that can be used in an integrated way to do concept and preliminary design studies. Figure 4 sketches the tools in this suite and how they relate to each other.

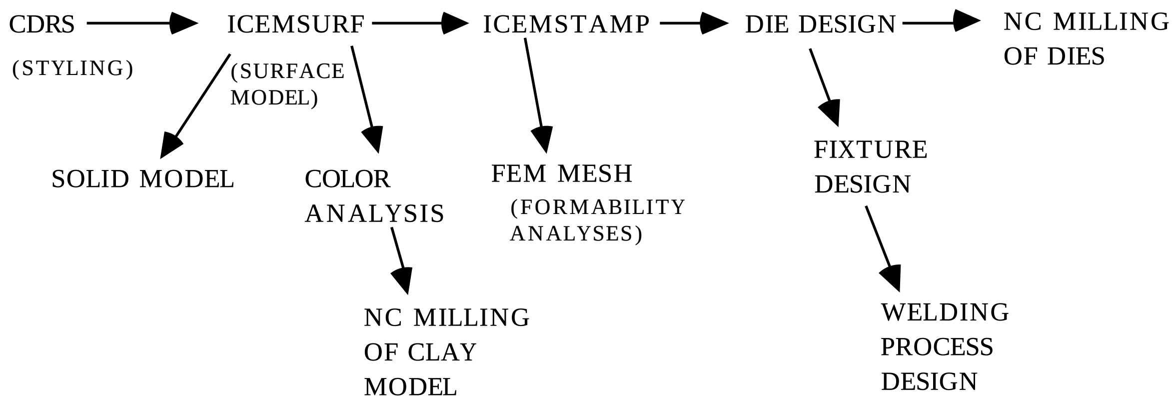

Figure 4. Sketch of the Technology Suite Available for Worldwide Design Studies. ICEMSURF and ICEMSTAMP are European design packages developed Volkswagen.

According to my guide, this software is as good as PDGS and is in use on current car design programs. (But on a later visit to the PDGS group I heard nothing about the Technology Suite and can only conclude either that both are in use or that there has been no decision on which to use in the future. I suspect that the Technology Suite takes advantage of newer technology and software capability in some areas of early car design but is not fully equipped to do all the things that PDGS and SECS can do jointly.)

Discussion with Working Level Group

This group is made up of representatives from several organizations involved in body styling, design, engineering, and CAD tool development. Many had not met each other before joining the group. It is intended to forge relationships between the various groups at the working level, to identify design process improvements, and to understand each others' work. An interesting part of the discussion comprised a detailed comparison of the outgoing but still used process called "Clay the Master" with the incoming but not fully implemented "WCT" based on "CAD-CAM the Master." Another interesting discussion topic was how "walls" arise in the path of a design process and how they can be overcome.

The diagram shown for the Clay-the-Master process was a flowchart indicating departmental responsibilities and handoff dates for information transfer. It appears in sketch form in Figure 5.

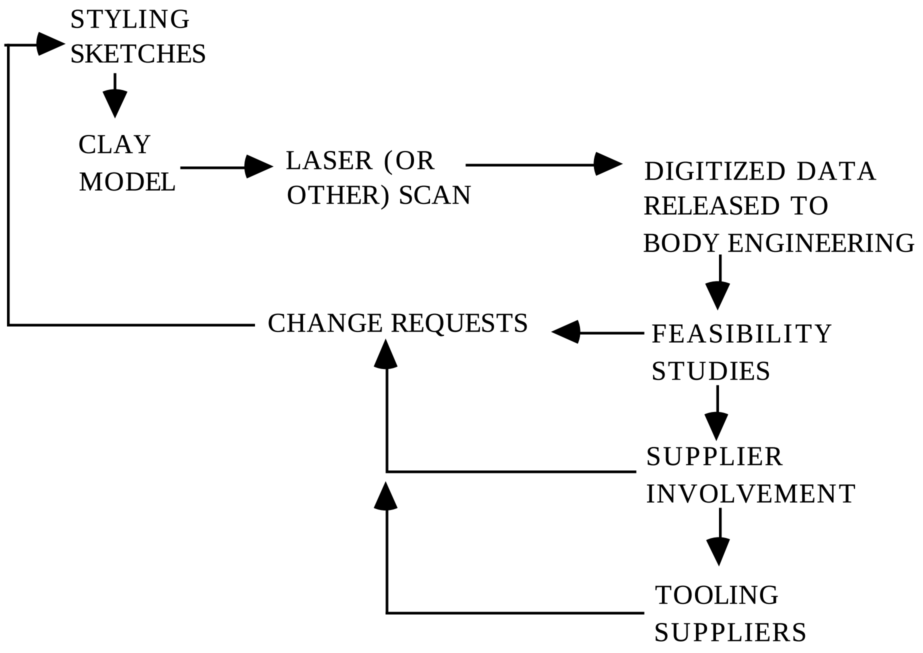

Figure 5. The Body Engineering Process Under "Clay-the-Master." This process iterates a lot because there are explicit "walls" between the steps and no one can see ahead to determine what is coming. Each handoff raises the cost estimates, alters the dataset, compromises the original goals, takes time, adds errors, and so on.

To a surprising degree, this process is still practiced. In fact, as the visit to P&MS the next month showed, new versions of PDGS have enhanced Ford's ability to adjust a math model to fit scan data taken from clay models. This indicates that clay will continue to play a strong role in the Ford design process, and that hand-made modifications to clay will have to be accommodated by the CAD tools. ("No one will buy off a computer model," said my guide to the Technology Suite.)[5]

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[5] Both Toyota and Nissan claim to have a version of CAD the Master, Toyota since the mid 1980s and Nissan since the early 1990s. NC-carved clays serve as display and buyoff models but the CAD data are the master from which body engineering is done. My visit report on Toyota describes their CAD-driven styling and body engineering process.

The language and the symbols used to describe Clay the Master were those of bureaucracy, with organization charts, formal information hand-offs, and responsibility boundaries. By contrast, the language and symbols used to describe the evolving process, loosely called CAD-CAM the Master and including Math Model Integration, reminded me of a computer program flow chart, complete with decision blocks and information flows both forward and backward. (This chart is loosely sketched without most of the details in Figure 6.) It carefully documents the analyses done at each stage, where the supporting information comes from, and where it goes. Typical information includes accurate locations for the A and B pillars (A is where the windshield glass meets the car, while B is at the back of the driver's door). This information is used in crash test simulations.

Other information supports design of soft tools (test stamping dies that are made of soft steel rather than tool steel to speed up making them). Still other information supports design of the assembly system, including welding feasibility, fixture planning, and determination of master control points to preserve tolerances. Additionally, costs are estimated for all the important body parts. This chart is aligned to the WCT decision points and is designed to ensure that body engineering provides information when the decisions need it. No organization boundaries appear on this chart, just tasks, approximate dates, and information flow paths.

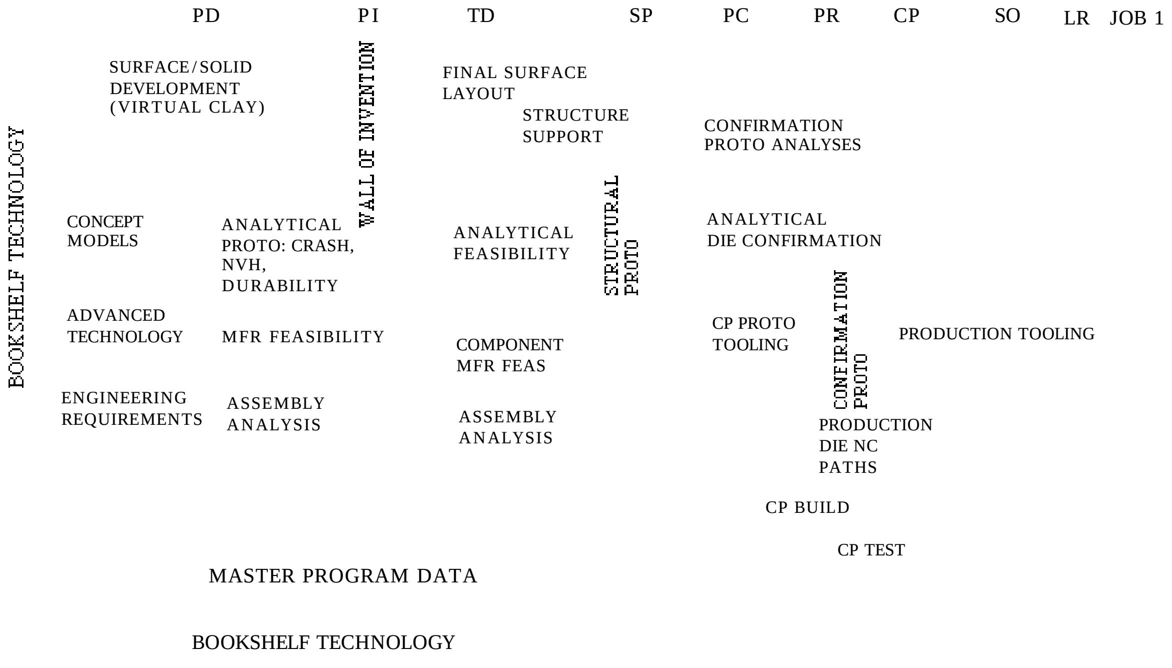

Figure 6. Sketch of "CAD-CAM the Master" Body Engineering Plan. "Bookshelf Technology" includes any parts, processes, or engineering tools available. NVH is noise, vibration, and harshness. This sketch of the plan omits the information flow paths, which generally flow up and down during

each major phase, and left and right between phases, implying look-ahead involvement of people later in the process in the earlier stages. As noted, this process is still under detailed development and has not been tested end-to-end in a car development program.

The process is evolving from the model in Figure 5 to that in Figure 6. The working level people noted the following facts of life in this process:

- Design is difficult, and many decisions are made only after the conflicting needs of many parties are discussed. For example, the body design is described at one stage by 66 master cross section wireframe models, which are modified many times to meet the needs of different aspects of design. Similarly, the original surface model does not have any subdivisions into individual panels. These cutlines must be determined. Important issues of appearance, tolerances, and stamping feasibility are involved. At many stages in the design the model is incomplete, and analyses must be made with the data available. The "styling surfaces" are used to launch tooling designs, well before the "tooling surfaces" are available.

- In the early stages of design, no histories are kept, and design changes are made freely with no formal approval process. A lot of problems are identified and ironed out in ad-hoc meetings.

- Many analyses are required early on for which there are few supporting tools. Engineers work from experience, judgment, and simple analyses.

- As the process wends its way toward the end, it becomes more formal, with more scheduled meetings. Approximate data turn into approved released wireframes. Formal design histories begin to be recorded. A formal engineering change approval process is initiated. When problems are found in the confirmation prototype, formal design change procedures are invoked, especially if they affect the visible surfaces that were "approved" some time before. So there is still unwanted iteration late in the process.

- In spite of the information-flow emphasis shown in Figure 6, the process is still schedule-driven in fact. Major events in the schedule are the various kinds of prototypes. These have been designed to test particular aspects of the design, such as fitup of sheet metal parts, action of the suspension and drivetrain systems, and crashworthiness.[6]

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[6] The problem of integrating prototypes into the design process appears to be a generic one affecting most industries where analysis cannot completely predict how a design will behave. Similar examples can be found in analog and radio frequency electronic circuit design. Prototypes can be looked at as controlled experiments with a specific list of hypotheses to be tested and a program for testing them. Too often, however, the protos are built to the schedule and some of their value is lost.

- This is still a person-driven process, and it takes the right kind of people to make it work. Looking ahead to anticipate problems, and planning fallbacks if they arise, requires a history-oriented culture that stores up knowledge and applies it when needed. In my opinion, Japanese car companies do better than most US firms at preserving corporate knowledge.

- The willingness to change requires change to be perceived as improvement rather than an admission of errors. Thus involving downstream people early and asking them to sign off on incomplete designs exposes them to later difficulties if they ask for changes. Development of the necessary organizational and personal trust required to run the new process is a challenge that management has recognized.

Product and Manufacturing Systems (P&MS)

I visited the managers in this group who are responsible for CAD/CAM development and CAD/CAM support and attended the 1993 PDGS Users' Conference where these managers gave talks about the future of PDGS. One of them was a CAD pioneer who has watched PDGS grow to be the main CAD system for body engineering at Ford. It was originally developed by experienced designers who gave it the capabilities it needed. More recently development has passed to programmers. Still, Ford's programmers are more aware of designers' needs than programmers at outside CAD companies.[7]

The P&MS department is continually asked to compare PDGS to emerging tools like SDRC and ProEngineer. The current view is that these tools are still unable to handle many practical problems that arise in organizations with hundreds of designers. The main issues are data access, data integrity, and configuration control. Engineers spend an inordinate amount of time looking for the information they need to begin a task or confirming that they have all the data. In the past such data would have been found in someone's drawer or bookshelf. It may take an expert a month to assemble the data needed to run a competent crash analysis. The goal is to reduce this to one day by improving computerized product data.[8]

Parametrics and associativity are also emerging issues. Parametrics are dimensions or other quantities that a CAD system can link directly to

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[7] About 40% of the employees in this department actually work for Ford. The rest are outside contractors. Some of the contractors who leave the department are hired elsewhere inside Ford and become PDGS users.

[8] Boeing recognized this problem and provided CATIA with a data finder that could locate and assemble on the screen all the parts of the plane that were within a specified distance of a given point in aircraft coordinates. This permits the designer to see if there will be assembly errors, something that previously was possible only after building the plane.

geometry. Structures of related parameters can be built up, such as "Keep radius R1 equal to half of radius R2." Associativity carries these parameters from the original solid or surface models in which they are defined down to drawings that are derived from the models. If someone changes the R2, then not only will R1 change but Presto! the drawings will change too. But perhaps these drawings have already been released to the shop; and perhaps the person changing R2 did not know that R1 was connected to it. So some configuration control is needed, along with rules saying who can change models and when.

But more is involved than just rules, because parametrics and associativity raise entirely new questions about how design ought to be organized and how data ought to flow. As noted above, Ford's body engineers are still in the process of thinking through their processes (as of late 1993) and have not decided yet what the best information flows are. P&MS management have strived to provide a stable CAD environment with only a few systems to contend with. Users are too fearless of opening the shop to lots of modern looking tools.

Management also wants the needs of the design process to drive the capabilities of the tools and the longer term CAD strategy. For this reason, their approach to CAD development is to unify access to data by the various tools, to improve existing tools, and to add new capabilities, but not to use CAD to impose a work flow on the overall design process. (See the next section for an outline of near term CAD development plans.) The individual work groups' processes are still in flux, as the above discussion of my September 1 visit shows, and it may be that no overall work flow can emerge from process analyses that are carried out by the individual departments.

Comparing Ford's and Toyota's body styling and engineering, it appears that Toyota speeds up the design process by overlapping tasks, starting a follow-on task before its predecessor is finished. Ford apparently does this as well, since body engineers get nightly updates of styling information and can (really must) begin die design before styling is finished. At Toyota, a system similar to CDRS permits stylists to obtain photo-realistic renderings of car designs, but a computer operator puts the design into the software using the stylist's sketches. At Ford, stylists run CDRS themselves. On the other hand, stylists do not make clay models; that is done by clay specialists who have many tricks that CAD has a hard time capturing. So clay is directly in the design data path.

Also, Toyota has linked styling data directly to body engineering and die feasibility analyses. Ford has yet to make this link as direct as Toyota's , and its stamping feasibility software is not as user-friendly as it should be, so it is not used often enough. Still, only 5% of panels have stamping problems, and (according to an expert at GM) these areas are pretty easy to identify in advance even if fixing the problems is not always easy. On the other hand, crash simulations are very accurate at Ford and are widely used.

Beyond the above developments and trends, it was said during this visit that new kinds of data relationships are needed to improve the design process. Designers need to know how things are related so that they can anticipate what analyses will be needed. For example, suppose a component is heat-sensitive; will it be located near hot items? How is the designer to find out? Perhaps preliminary analyses must be done using an old part because the new one has not been designed yet. One needs a prototype bill of materials and a separate final bill of materials. Existing data management systems are not able to provide such services, in part because not enough of the necessary attributes have been identified.

PDGS Strategy

At the user group meeting, Bert Moberg, CAD-CAM Development Manager, sketched the objectives for future PDGS capabilities that are to be achieved over the next four years:

1. Geometric modeling - solid models will be added; enhanced ability to make comparisons will be added, such as between CAD surfaces and clay scan data, or between an old design and a new one; the GEOFIT program will be given enhanced ability to carry manufacturing information like tolerances, references to tooling holes, and coordination of such features with mating parts in other datafiles. User-defined features will be supported in 1995. A sketcher with constraint management is also planned.

2. Surface development - NURBS will be implemented, color surface shading will be added, and better methods for modifying and evaluating surfaces will be added.

3. Machining and mechanical design - 5 axis milling will be supported, as will an enhanced interface to the ADAMS kinematic and dynamic modeling program. Design templates will be created by senior designers for use by less experienced ones. These templates will contain the major elements of assemblies such as suspensions.

4. Electrical Design - access will be provided to an electrical design library; interfaces will be written to circuit simulation packages like SPICE and SABER; data on wiring technologies will be provided, as will methods for optimizing the location of splices and cost modeling of wire harnesses

5. Product data management will support secure, rapid, worldwide access to product information.

6. Advanced projects are under way to shorten the time to do important CAE studies like crash and air flow.

The major themes behind this strategy are to bring engineering closer to the beginning of the design process, provide tools that are easier to use and that make a better connection to the underlying engineering or product data, provide enhanced tools for creating and evaluating surfaces, and enhance the performance of the PDGS organization, including faster software development and better help for users.

Chassis Engineering Department

Chassis design is different from body styling and engineering in many important ways. Body engineering is primarily surface modeling, while chassis design is 2.5 D or 3D modeling. Fit and finish dominate exterior styling while severe dynamic loads, crash absorption, and fatigue dominate chassis design. (In unibody cars, most of the crash load is taken by the body, but in larger cars like the Explorer or pickup trucks, the body and frame are separate and the frame takes the crash load.) Styling usually defines an exterior shape while chassis design, such as steering, engine supports, or frame, must fit within the confines set by styling. Thus chassis designers are continually working to fit their components within defined spaces, analyzing them for strength or durability, rearranging the components, or asking for more space.[9]

A major problem in chassis design is that tiny details can make the difference between a design that lasts the required 100,000 miles and one that does not. Often such details cannot be captured in a CAD model or in fact will be different in important ways on the final part than they are in either prototype parts or computer models. In the early stages of design, only rough space constraints are known, so conclusive stress and fatigue analyses cannot be carried out anyway. Thus there is at present no way to avoid building and testing physical prototypes. In addition, construction and execution of a competent computer stress or fatigue model still takes longer than making and testing a physical prototype. The overall result is that chassis design does not finish until late in the car design process, and important problems are not found early enough.

A saving feature is that chassis components are usually quite similar from car to car, so the design process can be standardized to some extent. An effort of this type is under way. It will create the structure of a design, such as the basic kinematic relationships between suspension elements, linked by a

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[9] Space requests are not easily obtained. Chassis designers generally find themselves pushed out from the car's inside by forces that begin in marketing and extend through the power train. Styling fences chassis in from the outside. Marketing and styling usually win in these situations.

set of parameters. The designer can put in different parameter values and come up with a trial design rapidly. Chassis elements often function in only a kinematic way, so making them fit in the defined space is the main problem the designer solves.

But other elements of the suspension are not primarily kinematic. These include springs, bushings, and tires, whose compliance contributes fundamental features to the behavior of the overall suspension. Analytical capability here is weak, and research is currently being funded to improve the situation. Some of this is aimed simply at characterizing the nonlinear behavior of tires, but the longer range vision is to be able to characterize handling and ride quality.

The Chassis Engineering Department uses CAD extensively but still relies on wireframe models. Too little experience has been acquired with solid modeling, so the potential for these models is still not known. Stress and dynamic analyses are obvious targets, but others, such as design for assembly (see below) have not been identified or else no tools for attacking them are available.

Beyond seeking improvements in basic design capabilities, the department is carrying out analyses of the main information flows to find the critical paths, with the aim of bringing opportunities for analyses further forward in the process. In addition, a design history book is being compiled and made available to the engineers so that past problems will not be repeated. A systematic procedure for making the required calculations is also being written down. At present this is a pilot project addressed to one part.

A final area where the chassis department wants to improve design is in the area of assembly. Most of a chassis is assembled manually. The major issues are weight, access for fitting the parts in, and access for the tools, such as those that align body and chassis or that tighten fasteners. Conventional Design for Assembly does not deal with these issues.

Powertrain Systems

Powertrain Systems supports the design and analysis activities of engineers who design engines and transmissions. An important effort of this group is called the Analytical Powertrain (APT). Its aim is to create an integrated process for analyzing and designing engines and transmissions. The underlying data appear to be primarily geometric, with associated analyses. Approaches being utilized include feature-based design (FBD) and parametric design (PD). The attributes and advantages of these two approaches are being studied to determine the best way to apply them. The underlying methods themselves are still evolving, and the efforts of the APT will help define what capabilities FBD and PD should support. "It is an opportunity to find a relationship between shape and numbers." The full potential for FBD and PD should include standardizing design procedures, linking geometry seamlessly to engineering analyses, making dimensions and tolerances more rational, creating design libraries, and in some sense giving structure to the process of creating and dimensioning geometry.

The engineers directing this project have created a model of their process that covers all of the concept design, preliminary analyses, and detailed design. It does not yet extend to process design, assembly planning, or factory floor layout. The format of this model follows that shown in Figure 6 except that it is stratified horizontally in more detail to separately delineate the activities involved in CAD, CAM, and CAE. The items on the "bookshelf" have also been defined in more detail, and include specific examples of analyses, data, design histories, and other information that is intended to be available. But before this vision can be fully implemented, several issues related to the underlying design tools must be resolved, related to the interplay of data, features, and parameters.

One of the basic issues involved is how to use features and parameters together to define a somewhat standard geometry, say an engine, and still be able to modify it significantly without having to build a completely new model. A basic engine design will be used for 25 years but significant modifications will be made every 5 years. The required changes will include adding or deleting features, or significantly changing a feature in ways that cannot be captured parametrically (circle to rectangle, for example).

Another issue concerns how to blend parameterizable features like fuel intake ports with non-parameterizable surfaces like fuel intake manifolds. Small shape details drastically affect the fuel flow, so it would be useful to synthesize the shapes from engineering models of flow rather than create a shape and analyze the resulting flow.

A third issue concerns creation and management of "features for their users." It is estimated that a single part may involve definition of as many as 1500 features if one includes all those that are present for manufacturing purposes but are machined or cut off later, plus those that are used for fixturing, plus the corresponding features on the fixtures themselves, plus features on packaging that fits snugly around the parts, etc. A large fraction (easily more than half) are likely to be used by suppliers (of castings, fixtures, dies, packaging) rather than by Ford itself.

A final issue related to parametric design is the observation that designers are primarily visual, but parametric design appeals to analytical needs and analytical thinking. Engineers are trained in analytical approaches but too often the actual design is done by designers[10] who do not have an engineering education. It is necessary to find a way to involve engineers more directly in the design process. The main way the APT is attempting this is via the construction of analytical design tools linked to solid models.

One project under way involves construction of macros in the ARIES CAD system.[11] These macros are capable of generating the base geometry of a competent design based on past experience. A complete engine block with cylinder walls and cooling passages is an example. The designer can get started quickly with such a macro. An engineer who is not an ARIES expert can do meaningful work. In addition, the structure of the underlying parameter logic will prevent serious errors. The resulting geometry is directly in ARIES, and associated CAE models can quickly perform analyses such as vibration and stress. Creation of meshes is still a bottleneck, however.

Another objective is to eliminate much of the effort currently required to recreate datasets for the different analyses. An element in the approach is to use STEP to create standard data formats. Some successful experiments have already been carried out using STEP. However, ARIES is not good enough for drafting tasks, such as creating the notations for dimensions and tolerances or for generating drawings, so at present ComputerVision's CADDS is used. A data converter from ARIES to CADDS is in place, but a reverse converter is not. This complicates the process of revising the models and performing CAE on the revisions if problems are found during or after drafting.

A number of design modules are being developed. Some of these involve use of the knowledge capture product ICAD. A program to create crankshafts and evaluate their manufacturing feasibility is one example. Another is a hose-routing program. It permits the designer to specify endpoints, keepout regions, minimum bend radii, and even "must pass through" regions.

A final example tool comprises a noise generation model of the engine, transmission, front frame, and firewall. The model is a hybrid of analysis and empirical data. The noise generated by the mechanical parts of the powertrain and its mounts is modeled analytically, including the effects of fuel ignition, while the noise transmission of the firewall is modeled empirically from laboratory tests. The entire model runs on a Macintosh and

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[10] In the US car industry, a "designer" is what in other industries would be called a "draftsman." Such a person makes detail drawings and is usually responsible for dimensions and tolerances.

[11] ARIES is a strategic partner of Ford and devotes considerable effort to supporting Ford's needs in advanced design tools. ARIES was recently purchased by McNeil-Schwendler Corporation (MSC), significantly enhancing ARIES' capabilities in CAE.

the resulting noise plays on the computer's speaker. The user can operate the model by varying the engine RPM as well as the cylinder firing order. Different firing orders make significant differences in the noise transmitted to the passenger compartment.

This model nicely illustrates an issue that is often contentious in cross-functional design. There are noise generators and there are noise transmitters. Here the generators "belong" to the powertrain department while the transmitters "belong" to the body engineering department. If the noise is too high, who is to revise their design? This model may help determine where effective modifications will most easily be found. However, a cost model will also be needed to help determine which of the identified changes is the best one to make.

Summary

Ford is an organization with a mix of in-house and purchased CAD tools. It is also in the midst of a massive reorganization. A great deal of important design activity passes across organizational boundaries, so the flows of design information are being redefined as this report is written. But even within organizations the design process is under revision. In addition, the capabilities of both in-house and commercial CAD are being improved, both to sharpen local design or analysis capabilities as well as to support more sophisticated information flows.

These events have several consequences: Ways must be found to easily improve CAD as hardware and software capabilities grow. Closed systems must become open, and in-house systems must be linked with commercial tools. Design managers are realizing that more sophisticated methods will require engineers, rather than designers, to do an increasing amount of the actual design. CAD must support the needs of these engineers and help manage the information flows that will result from new organizations and process improvement studies. The CAD developers will have to move fast when the new structures to emerge.

The individual centers of functional expertise, such as styling, body engineering, chassis, and powertrain, retain the expertise and much of the responsibility for design process and design tool improvement. They each develop the tools they need plus ways of interchanging data between those tools. This has the advantage of enabling the engineers to function productively. Among the functional organizations, powertrain's probing questions about the relationships between parametrics and features and its use of knowledge representation software are particularly interesting. The P&MS group also is tackling significant problems as it evolves toward an all-electronic worldwide styling and design system.

As an organization, Ford appears to recognize the importance of computers to the overall success of the design process, and also realizes that CAD must support rather than create this process. Its approach, as of this writing, is based on multiple CAD-CAM-CAE systems rather than one system such as Chrysler has adopted.

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