

CHRYLSER

Visited August 25, 1993 - Host Dr. Gustav J. Olling

Chrysler is the third largest car maker in the US, seventh in the world. Its 1993 sales amounted to \$43 billion. It currently has about 128000 employees and sold over 2.5 million vehicles in 1993. Of the Big 3 it is the least vertically integrated, outsourcing 35% of design, 90% of stamping dies, 100% of assembly tooling (robots, fixtures, etc.) and 70% of its vehicle components. As discussed below, this degree of outsourcing is a strong incentive to unify CAD between Chrysler and its suppliers of both tooling and parts.

Chrysler has perhaps been the most daring of the Big 3 in revamping both its design organization and its CAD infrastructure. These events occurred approximately at the same time in 1989 as part of a major effort to generate new products. Figure 1 is a schematic of the platformteam concept. Each team consists of about 750 people drawn from the functional areas listed at the left. The team takes over design after a period of concept design in which the market and product requirements are established. Originally only the LH team was established. The PL (Neon) team was started next. By now all the teams shown are operational.

See Figure 1: Platform Team Concept

When it was first formed, the LH platform team needed CAD support that was ready to go and would adequately if not excellently cover the entire spectrum from concept design to manufacturing. After considerable searching, Chrysler chose CATIA. The company has since developed an array of add-on design and data management tools to augment CATIA and has also developed independent styling software whose data output feeds into CATIA directly. Stereolithography has also been brought into the design process and is institutionally integrated through add-on facilities in CATIA. Each of these topics is dealt with in detail below.

CAD/CAM Infrastructure

Both Boeing and Chrysler have adopted the French CAD system called CATIA. This system was originally developed by Dassault Aircraft and later transferred to a separate company called Dassault Systemes. CATIA has become widely used in the US aircraft industry due to Boeing and is also widely used in the European auto industry. Chrysler's story is particularly interesting because it is a company-wide decision, whereas at Boeing it applies only to the 777. Chrysler arrived at its decision after a careful study and a series of pilot demonstrations. Several key aspects of the decision were

- Chrysler had extremely limited resources in the late 1980s and needed new car designs fast. The platform team concept was introduced at that time with the requirement that four new cars, one new 3.5 liter engine, and a new 4 speed electronic automatic transmission be developed in 39 months using 750 people and \$1.6 billion. Only with an integrated CAD/CAM system could the computing needs of these programs be supported. Once all the design, engineering, manufacturing, and management people were co-located on one team, it made no sense to provide each discipline with its own computer system, as had been done in the past.

- Chrysler's strategy was that end-to-end CAD integration was much more important than world-class excellence in individual computational steps of the process, as long as an upgrade path could be identified. This decision is similar to Japanese priorities but is unlike US methods, in which excellence in the elements seems to be sought first, after which integration is attempted. But integration at the system level is an entirely new learning process. It is during such a process that companies often take their first wide ranging view of the design process as a whole. A lot of problems are usually uncovered when integration is attempted, ranging from overlapped and underlapped scopes for each step, to simple mismatches in assumptions about data structures. Such discoveries often require that the carefully constructed "world-class" steps be redesigned and reprogrammed.

- Estimates by Chrysler of its parts and design tasks indicated that 70% of the parts could be designed using 2D drafting, 20% required 2.5D and 3D prismatic wire frame, surface, or solid modeling, and 10% required 3D sculptured surface capability in the CAD system. However, a large part of the capital investment in equipment and tooling in factories is devoted to making those sculptured surfaces, indicating that designing them correctly and quickly is extremely important. More importantly, given the importance of integration, the whole spectrum of automotive parts from 2D to 3D sculptured surfaces should be handled consistently, preferably by one software system. Chrysler's late 1980s survey of CAD vendors revealed that about 40 systems existed that could do 2D and 2.5D but only 4 could do those plus 3D prismatic and sculptured surfaces. Of those 4, only one appeared to have the required resources to have an assured future. That one was CATIA. An important ingredient in its future was its partnership with IBM which supplied marketing, access to both mainframes and workstations, and the promise of both workstation and mainframe operability for future versions of CATIA.

- While CATIA did not have world-class capabilities at every step in 1989, it was moving to an open architecture. It also was judged superior at that time in its ability to deal with multiple parts, a factor that was basic to Boeing's decision as well. Chrysler identified a firm in the UK called DECS that had used CATIA for car design and had proved that the extra routines needed could indeed be written efficiently and integrated smoothly. This firm also showed how to select CATIA users successfully, an important issue since one criticism of CATIA is that it is hard to use.

- Chrysler also focused efforts on blending CATIA into the business and transactional activities of design. For example, there is now a menu command called "transfer" which automatically sends a datafile to a supplier. A similar set of easy-to-use commands prepares and sends solid model files to Chrysler's central stereolithography facility. These are little things but they do what users need, a key to gaining their acceptance.

- More importantly, Chrysler realized the importance of data management to rapid design, and implemented the CATIA product data management system to ensure that information gets to the people who need it, and so that information can be found easily. It also is developing its own product data management system to integrate the entire design process.

- Just as important, Chrysler has encouraged its suppliers to adopt CATIA as well, a path that is made easier by the existence of a workstation version. Many suppliers now have workstations that are linked by high speed networks directly to Chrysler. The incidence of errors caused by IGES data translations has dropped significantly. While data translators continue to be used, the company's strategy is phase them out.¹

CATIA was piloted at the Jeep and Truck Engineering center, formerly American Motors' design center, in 1988. The engineers themselves decided CATIA was superior to the existing Chrysler CAD system. In January 1989 the LH team adopted it. Other platform teams followed suit as they were formed in 1990 and 1991. The basic infrastructure was laid during this time, consisting of the main body engineering and packaging capabilities. A large training effort was required. Most of the users were on the mainframe (almost 2000) while a recent surge has brought up several hundred workstation users. These are distributed over four main sites and linked by T3 lines. Over 90 vendors and 50 additional Chrysler design and manufacturing sites are linked by dialups.

Among the general software modules being used are drafting, 3D design, surfaces, and solids. Within computer-aided engineering (CAE), modules in use include piping and tubing, schematics, kinematics, finite element analysis, DADS (a kinematics and dynamics tool), and VSA (a tolerance analysis package). In computer-aided manufacturing (CAM), modules include NC milling, robotic simulation, and Valisys (used in conjunction with coordinate measuring machines (CMMs)). Since 1989 the emphasis has evolved from providing individual design tools to linking users into work groups by giving them access to a common database and data management tools. A new emphasis on advanced design aids was launched in 1993. An example, assembly tooling, is discussed below.

¹This contrasts with the strategy of the German car industry (plus Volvo) which has published a national standard for data exchange using a reduced version of IGES. Every CAD vendor wishing to sell to the German car industry or its suppliers had to show by the end of 1992 that it was compliant with this standard.

Ron Bienkowski, the Executive Engineer in charge of the Technical Computer Center (actually more involved with providing software than hardware), divides the evolution of CATIA capability into four phased activities (See Figure 2)

See Figure 2: Evolution of "Product Development Machine"

- Building the Infrastructure with "individual tools" - training individuals in each of the platform teams, bringing design suppliers on-line, linking design of sheet metal parts to die manufacturing, and more recently performing more tooling design for both bodies and power train in CATIA.
- Exploiting the Capability with "power tools" - training users in advanced capabilities including analysis tools, solid modeling, and "digital mockup" (similar to Boeing's digital preassembly); more recent activities include studying and re-engineering the design processes in powertrain and packaging, to be followed up by new design macros integrated with CATIA. (Packaging means allocating 3D space in a variety of situations, such as placing people inside the car's interior and placing equipment under the hood.)
- Digital Model Management with "work group tools" - developing electronic release of designs, integrating design data with the CATIA Data Management system (CDM) and Chrysler's own product data model (PDM), linking design with a bill of materials during concept design, and later starting to manage assemblies.
- Product and Process Information Management with "product development intelligent models" - this is future work involving draw die simulation, generative process planning for machining stamping dies, rapid model creation using parametrics (a feature that should be available with CATIA version 4), more intensive use of interference checking and kinematics, and more use of solids in engine and transmission design.

An important contribution to Chrysler's rapid evolution into CATIA was provided by a UK consulting firm called DECS. This firm showed Chrysler that it was feasible to design cars using CATIA. Its personnel provide many of the specialized macros that the designers use in specific car design problems. DECS has special skills in body styling macros, providing intuitive ways to edit the body exterior. DECS also appears able to conceive of design from a more systematic point of view than is typical in the car industry. It understands the key interfaces and tolerances and advises on how to assign elements of a design to different design groups in order to preserve the system-character of the design. One example is a macro that joins a number of body module elements in order to check total stackup of dimensions. This replaces a method that utilized wood mockups.

DECS also contributed several intuitive modules that make styling easier, including using "procupines" to help visualize surface curvature. This technique is similar to one used in the past in the university research community for visualizing a number of parameters related to surface normals.

Now that the base has been laid, Chrysler has documented several advantages. Design is faster, and errors caused by data conversions are disappearing. Physical prototypes are no longer needed to check that parts fit. Engineering analyses can be substituted for rough calculations because the data are there and access to analysis software is easier. Vendors get accurate data so there are fewer errors and disputes. More engineering analysis is being done, reducing the number of physical prototypes. Some significant weight reductions have been achieved. It was estimated that the potential exists for reducing design cycle time 30% just from use of an integrated CAD/CAM/data management system.

Chrysler's diagram of how all of this plays together is shown in Figure 3.

See Figure 3: Engineering and Scientific Computing. Note that in spite of the intention to eliminate translations between CAD systems within Chrysler's operations, the need for translations outside of the company is still acknowledged. Given the amount of outsourcing that Chrysler carries out, it is likely that translations will be required in the future.

Specific Applications

1. Assembly Tooling Design (Host Al Knasinski)

This is an example of direct use of design data by manufacturing engineers. In the body shop, several sheet metal stampings must be held in fixtures while a robot or other welding apparatus welds them together. The design problem is to create the fixtures, design a workcell, select the robot(s), choose the weld guns, and determine the welding sequence, from which the robot program can be created. The weld guns are usually catalog items, which speeds up design, and both the robots and the fixtures are purchased from vendors. These vendors have direct access to the database that includes body part and tooling designs. The work I was shown is new and was used on the Neon. The LH did not have access to this kind of tool, and several problems were noted that this program is intended to correct.

At the time of my visit, tooling design could not presently use fully surfaced body part designs, since they contain too much data. Tooling design requires that several part models be on the computer screen at once, increasing the computing load. So a macro was written to strip away most of the surfaces, presenting a "clean part" comprising a wireframe with selected regions

surfaced.² These regions are those where some tolerance-critical information is needed, perhaps a place where the assembly fixture will grip the part or where a CMM will take a quality reading during manufacturing. Vendors will use these locations in fixture design and welding programming. Each such patch has five points located on it with numerical location data behind them, permitting location and surface orientation to be determined:

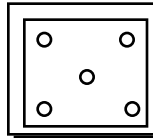


Figure 4. Example Surface Patch with CMM Points Marked.

Once the clean data model of the part is made, all other information is added as overlay files that show up in different colors depending on whose data they are. The original product data are in violet while all the fixtures and the datum reference marks are in green. In a departure from past practice, the tooling designers not only design the fixtures but also assign weld spot locations based on criteria supplied by the structural analysts, which are later checked by the analysts. (In the past, the structures group specified the spots, and interferences with tooling clamps had to be corrected later.) Each spot has a unique serial number drawn from a standardized numbering system. Attached data associated with the spot include the part names, the material type, and several welding parameters such as weld gun squeeze force and electric current.

Tooling clamp designs are taken from a catalog provided by the clamp vendor. Another catalog contains weld guns. Three standard types are now available: pinch, scissors, and C-shape, along with sizes, squeeze forces, electric current capacities, catalog number, etc. The designer can automatically search this file for candidate guns but must make the selection manually. A picture of the gun appears on the screen and the designer can maneuver it on the image of the part and fixture to see if it can access the welds. Automatic alignment of surface normal and weld approach angle helps this process. However, no algorithms are used to find the gun that will do the most weld spots in a series without requiring a new gun, nor is an algorithm available for helping to assign weld spots to robots or workstations in order to help balance the workload among several robots.

Indeed, the approach used by these designers is similar to the philosophy heard at Lockheed: if you give the designer a vivid enough display, he/she will

²At Boeing, such stripping is apparently not necessary. Boeing has so much mainframe power available that many fully surfaced parts can be positioned and rotated on the screen at once for the purpose of "digital preassembly." In fact, Boeing has added so much code to basic CATIA (by one estimate spending \$1 billion since 1986 to essentially quadruple the size of the original code) that Boeing effectively has a version of CATIA unlike anyone else's. (Source: David FitzPatrick phone conversation, March, 1994, plus comments heard at the 1994 CATIA users' conference at Chrysler, March, 1994.)

know what to do. In fairness to the Chrysler engineers, this tooling design system represents the first time any such capability has existed there, so the main achievements have been in standardizing the approach, creating the catalogs, attaching numerical data to weld spots, and rationalizing the design activities among tooling, structures, welding, and the vendors. Algorithms can come later.

Once the weld gun has been chosen for a particular set of welds, a robot is selected and the simulation package RobCad is used to see if the required cycle time can be met and all the welds can be reached. A rotating table workcell design was adopted for most of the tooling for this particular car:

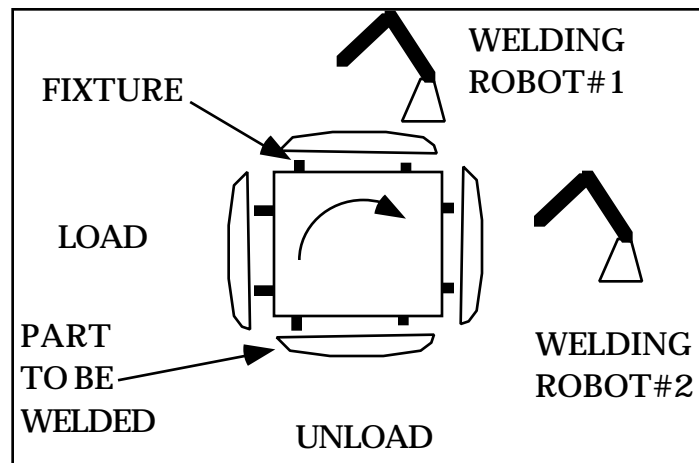


Figure 5. Sketch of 4-sided Welding Station for Car Parts Designed Using CATIA Plus Drawing and Library Functions Created by Chrysler

Chrysler has had to improve the dynamics and calibration accuracy of RobCad's models of robots. With that completed, they report that a robot programmed off-line as described here can be set up and be working on the factory floor in 3.5 hours compared to 15 hours before.

2. Interior and Exterior Styling (Hosts Mike Holmes and Jack Thompson)

As far back as 1971 Chrysler had some kind of CAD for body styling and engineering. However, until the late 1980s clay models were the main way of developing styling alternatives and presenting them to management. Typically this process took a long time, especially when management liked one portion of one model and another portion of another model.

Several years ago Chrysler funded Evans and Sutherland to create a surface design, editing, and rendering system. The result is CDRS (Computer Design Rendering System). It permits a stylist to create an exterior model of a car quickly and edit it easily. Surface smoothness, slope, and second derivative can be maintained across boundaries between individual parts. The result can be shaded realistically and, like the Toyota system, one can shine lines of light on the model and see intuitively if the surfaces have the desired smoothness and

character. A single display image can be generated from model data in about 30 seconds. A typical car model occupies about 28 Mb of memory.

The models can be shown to management as well as to manufacturing for their comments. Pieces of existing designs can be joined to make new designs. Some preliminary engineering tests, such as formability in stamping and crash resistance, can also be checked using these models. Aerodynamics can be partially checked but the results are incomplete because the underbody is not included in the simulations. Data can be exchanged into and out of CATIA.

As of the time of my visit, it was not clear if management and styling really were comfortable approving a design based only on a computer display. It is customary in most car companies that use computer styling to make a clay model from the CAD data using a CNC milling machine and then trim the clay by hand. If the design is approved as is then there is no problem, but if manual changes are made to the clay then the problem is to get those changes back into the CAD model. At the moment the US car firms use some kind of digitizing to capture the clay plus a numerical algorithm to fit a mathematical model to the data. Fully satisfactory and accurate digitizing systems are still being sought.

As part of the process of moving to a complete CAD master for both styling approval and body engineering, Chrysler undertook an experiment early in 1993. A hood was designed in CATIA and a clay model was cut from the data for styling's approval. Body engineering took over after approval (no digitizing of changes was needed) and designed stamping dies. Analyses of formability were made. Die addenda were added using mathematical formulas. (Addenda are parts of the die needed to clamp the metal during stamping. The metal in these areas is sheared off later.) NC cutter paths were taken directly from the final model and dies were cut from near net shape castings using a very fine cut pick (space between successive cuts along the surface) to hold the final shape to the numerical data. Finally, 108 hours after styling approved the shape, the part was stamped. Naturally, this test was a kind of race and the part was relatively shallow and thus easy to stamp, but the time is vastly shorter than the typical 30 weeks. The test indicates how quickly such processes could be accomplished in daily design practice.

3. Product Data Management (host Walt Weglarz)

A Chrysler engineer told me "CAD is data management." This is interesting because one would normally say CAD is design or something similar. If one is designing something simple with only a few parts, or if one is the only designer, then CAD seems to be design. But when one is designing something with 10000 parts and there are 500 designers, 100 suppliers, and 100 tooling vendors, then CAD revolves around data management.

In 1989 as CATIA was being introduced, Chrysler had the chance to completely redo its product data management system. At that time there were no standards for data, no design libraries, no standard naming conventions, etc.

Designing a data model to support design brings one face to face with the question of what designers do and what data they need. Chrysler has spent three years studying its design processes and stripping away many non-value-adding steps to reduce the process to its efficient core.

The final data system is called the Product Data Base (PDB) and includes an Electronic Bill of Materials (EBOM) and the CATIA Data Manager (CDM) for keeping track of geometric models. The PDB was still under development at the time of my visit, and it was not completely integrated with CDM. However, the outlines of the final integration were clear.

PDB is an interesting example of in-house software development. A review of commercial product data management systems indicated that they could deal only with a simplified situation in which only one product was being developed at a time and that product had a stable parts list of its own. The commercial software assumed that many identical products would be made. In such a situation, one can even assign a "part number" to the final assembly. In a sense, these systems were production data managers rather than design data managers. In the car industry, design is a fluid situation in which each car is a mix of new and previous parts, and manufacturing consists of joining many parts based on the customer's order, so that no delivered car can have a "part number."

The system Chrysler developed contains CDM, a bill of materials that breaks every assembly into subassemblies and components, and a part applicability system that shows which parts can be used in which car models. During design, any part can be in one of three conditions: being designed (belongs to engineering), being shown to other departments for comment, or released (including released to suppliers). Wide viewing and limited change capability are permitted. A design management system will be introduced soon, permitting design steps to be assigned to engineers along with requirements such as cost, weight, and schedule. Each night the status of the design can be accumulated, including projected total vehicle weight and cost. Manufacturing, purchasing, finance, and management can all see what is happening. So this system supports the platform team concept directly. In the past, neither current weight nor current cost estimates were available, causing nasty surprises.

Introducing such a system causes some cultural changes. Wide visibility has advantages and disadvantages. One soon finds a number of incompatibilities between the way different departments operate. People are reluctant to let go of their data. Contract designers want to keep their design methods to themselves since that knowledge determines their value in the contract labor market. The visibility and reliability of paper are hard to abandon.

But the advantages are much larger. For example, Walt estimates that procurement and inventory control will be able to eliminate 30000 to 40000 paper requisitions per year. Another area where efficiency can be enhanced is "space claim." Space is a scarce commodity in vehicle design. For example, space under the hood is being compressed by aerodynamic hood designs. Space claim would

be a way of forcing designers to claim space for their part or assembly and then deal directly with each other via the database to find out how to make everything fit.

In the future, there will be opportunities for standardizing design activities, capturing designers' knowledge, and recommending design procedures in routine cases. A lot remains to be done in assembly modeling, which presently consists only of the family tree lists of parts in each subassembly. As in most companies, designers tend to focus on the individual part they are designing. The CAD vendors' focus on geometry as the only data worth managing encourages this. Significantly, geometry is a piece of the PDB.

4. Stereolithography (hosts Lavern Schmidt and Tom Sorovetz)

Stereolithography (SL) has been in use at Chrysler since 1990. Now there is an ongoing service bureau connected electronically to the rest of the company. A CATIA macro automatically converts a part solid model into the required .STL data format and sends it over the network to the bureau, which delivers the part usually in a few days depending on its backlog. As many as 160 parts per month were made in 1992. Savings over conventional die or mold making for prototype parts range from \$10000 to \$40000, not counting the value of the time saved.

Applications go beyond display parts to include mold masters and actual test parts. Examples include an intake manifold, a shift fork for a manual transmission (moves the idle gears that cause speed changes), and a complete working prototype hand-held diagnostic I/O device for use by dealer service personnel. Prototype molds include high temperature rubber cast over the SL master and molds made by spraying zinc nitride onto a plastic master mold. The latter was used to mold 100 test parts for the I/O device. Other molds have moving parts that operate on slides machined separately and added to the mold.

At the moment their SLA machines are capable of yielding less than 0.010" tolerances in the Z direction, slightly better in X and Y. These are typical mold tolerances, I was told. (Separately I have been told that half an order of magnitude smaller is more typical of die and mold tolerances. In the year since this visit, I have learned that better materials are becoming available that support tolerances at the level of 0.003".) Tolerances are hard to hold in this method for a variety of reasons. For one, the material tends to both shrink and age, especially if there are thin walls. When high accuracy is required, a different resin is used.

In addition to making SL parts from CAD data, Chrysler wants to make them from digitized data taken from actual parts. Such digitizing must meet specifications similar to that desired for scanning clay car models.

Summary Comments

Chrysler's relatively small size makes certain things harder and other things easier than for its US competitors. It has less financial resources and must

compete using far fewer people. Efficient use of data and rapid, accurate exchange of data with suppliers are essential for its survival. The sense that survival is the issue, plus a lack of large past investments in now-obsolete hardware and software, have made it easier for Chrysler to focus on its new design methods and CAD environment. Finally, the people I met were in high spirits and strongly committed to their work and their company's future.



PLATFORM TEAM CONCEPT

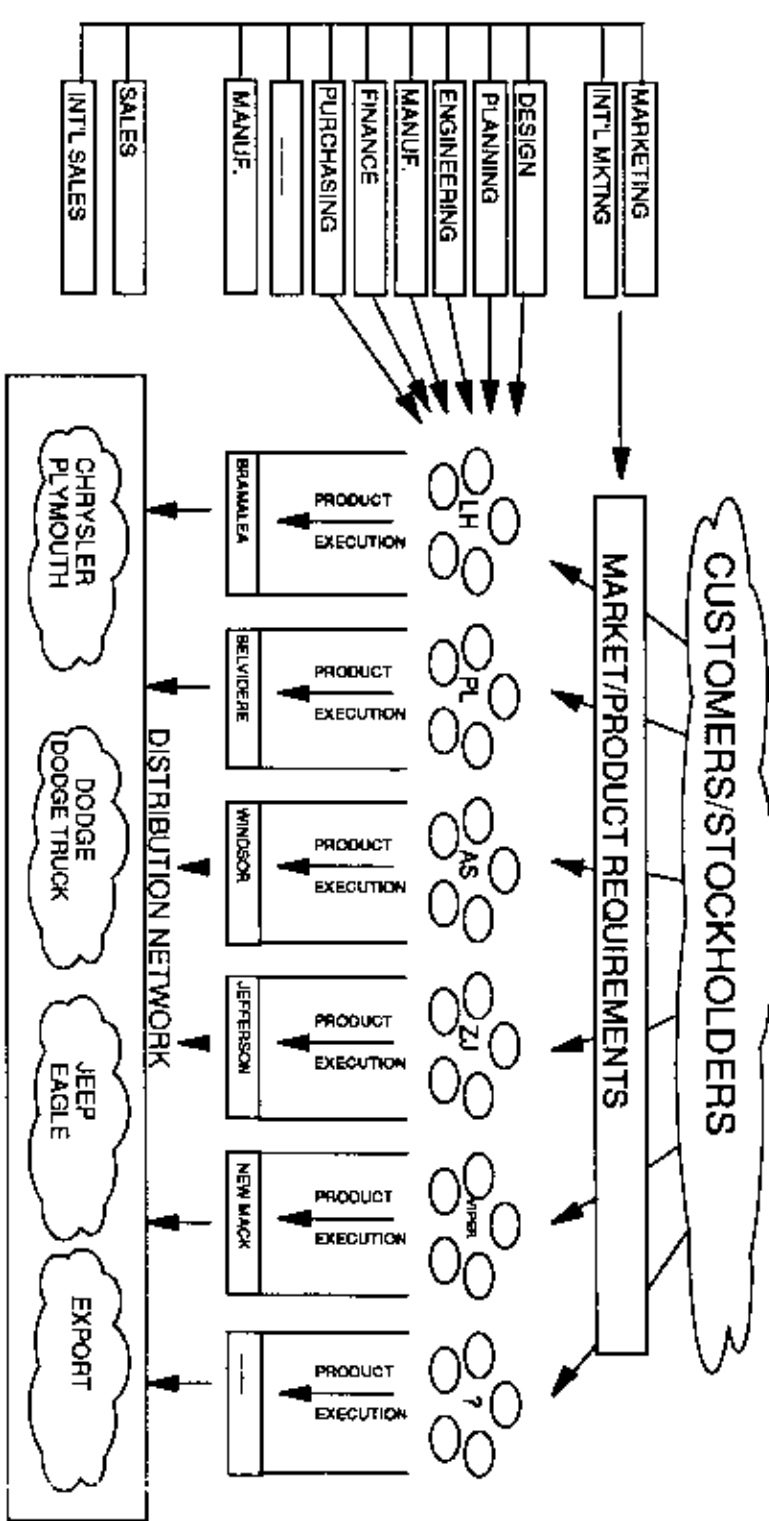


Figure 1

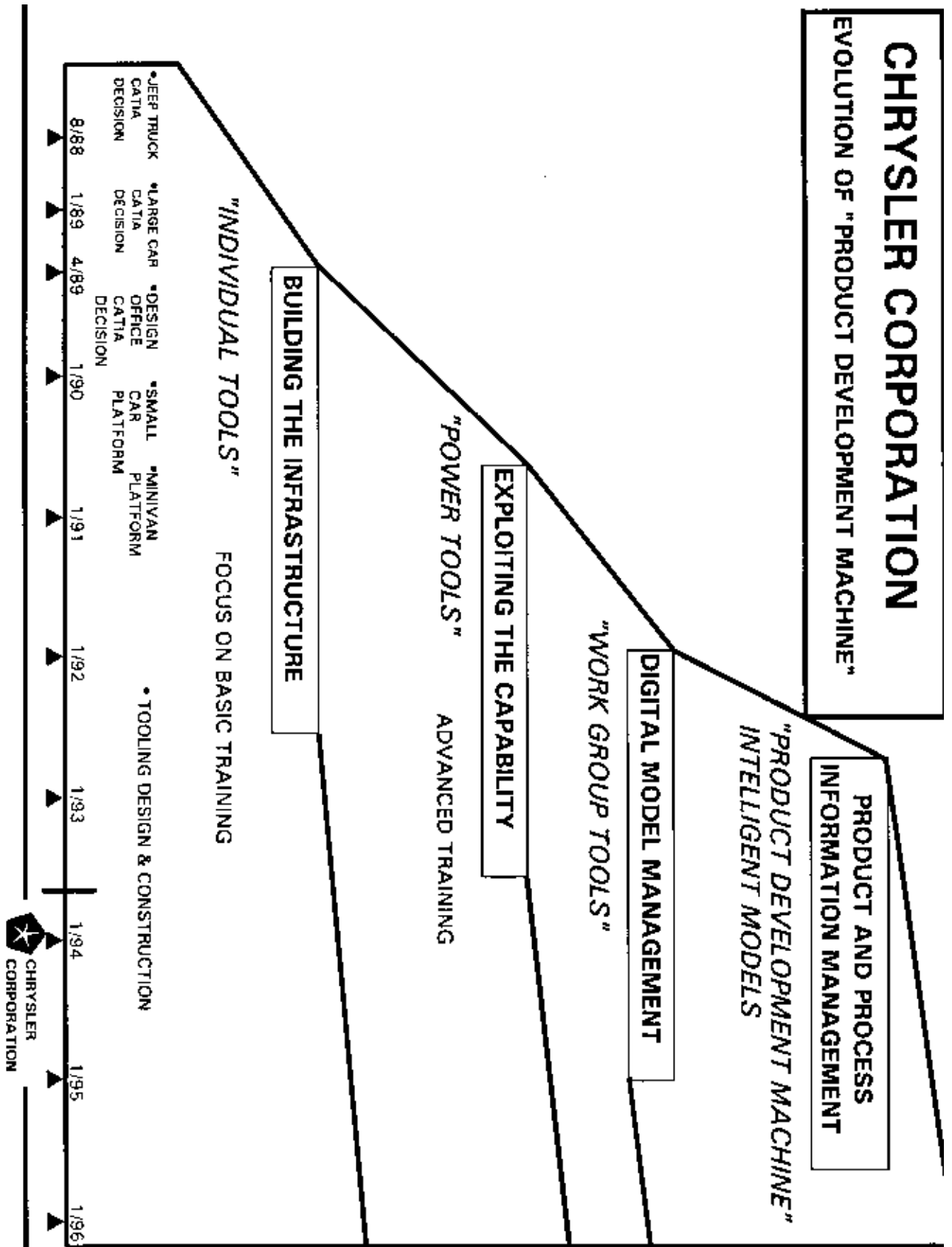
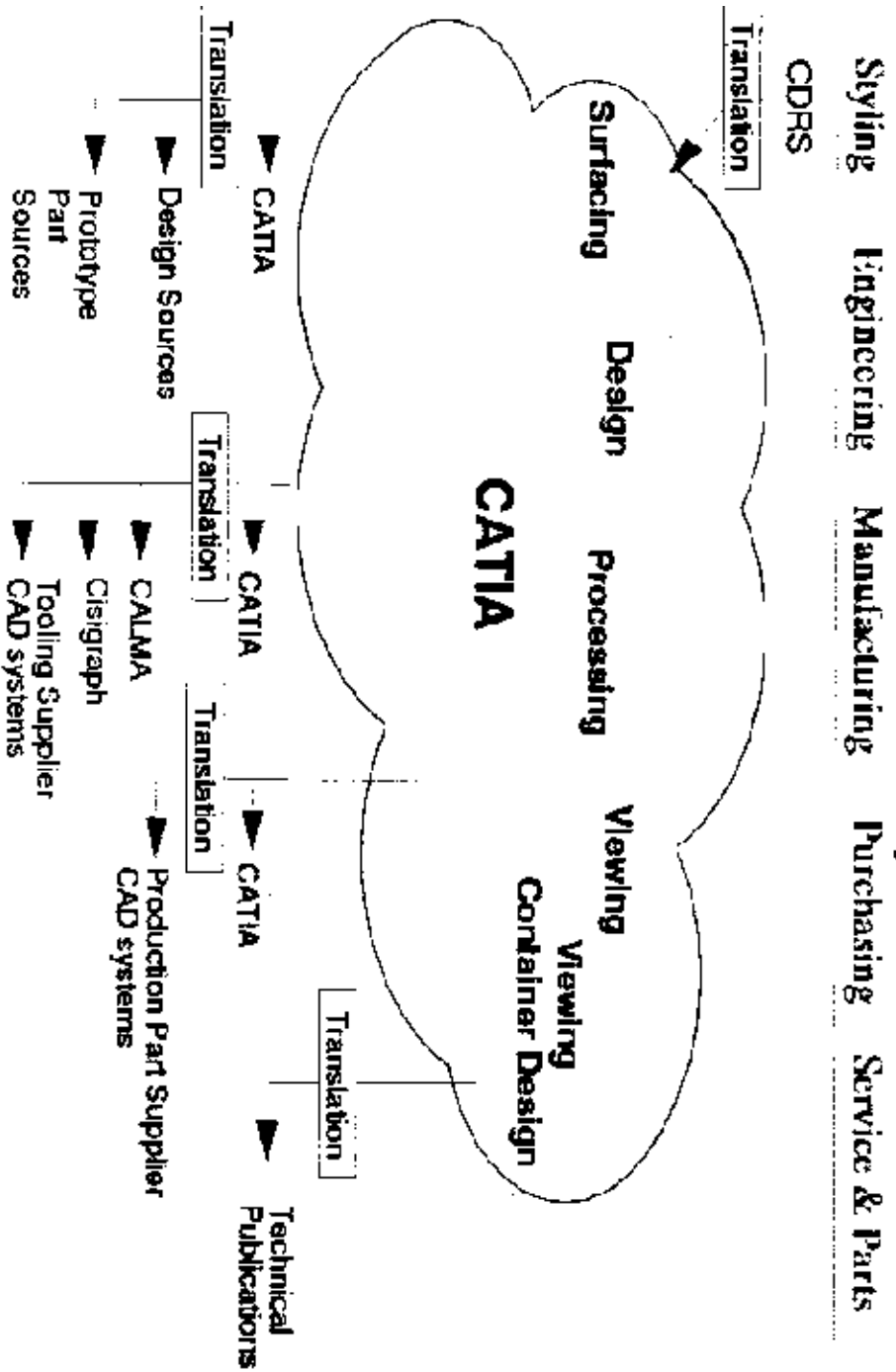


Figure 2

Engineering & Scientific Computing

CATIA is the CORE system



June 2, 1999

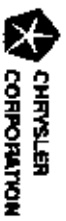


Figure 3: