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Abstract: This paper presents a research aimed at identifying the contribution of computer-aided design to the concept of concurrent engineering. The paper reviews the available CAD software and major vendors. It also provides a few successful concurrent engineering projects. It also addresses the social and organizational dimensions of computer aided design. The final conclusion is that managers should plan ahead, consider organizational changes and know what to expect from CAD.

The Role Of Computer Aided Design In Concurrent Engineering, How To Implement And How To Manage

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CURRENT ISSUES IN MANUFACTURING MANAGEMENT

TERM PAPER

THE ROLE OF COMPUTER AIDED DESIGN IN CONCURRENT ENGINEERING, HOW TO IMPLEMENT AND HOW TO MANAGE

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ABSTRACT

This paper presents a research done aiming to identify the contribution of Computer-aided design to the concept of concurrent engineering. The paper reviews the available CAD software and major vendors. The paper also provides a few successful concurrent engineering projects. The final part of the paper is dedicated to the social and organizational dimensions of computer aided design. The final conclusion of this paper is that managers should plan ahead, consider organizational changes and know what to expect from CAD.

The major vendors referenced in this paper are SDRC and Algor. The recent projects in the aerospace industry are reviewed to observe the success criteria. It was observed that major CAD vendors are tending to develop systems that would create a concurrent engineering environment.

An annotated bibliography is provided so that the reader can further investigate the contribution of CAD systems to concurrent environments.

1. INTRODUCTION TO CONCURRENT ENGINEERING

Concurrent Engineering is now viewed by most corporations as a means to competitive, world-class manufacturing.[5] Broadly defined, concurrent engineering is the simultaneous design of products and their engineering, manufacturing, and marketing processes.

With a concurrent approach to engineering, teams attack all aspects of product development simultaneously in contrast to the traditional serial approach. Most changes come in the early stages when they are easily and inexpensively made. Fewer prototypes are needed, and the ones that are built often require only fine tuning. The end result: a product that takes less time to develop, has higher quality, and costs less since expensive changes and prototypes are virtually eliminated.[5]

In concurrent-engineering environment, designs are generated on a computer, where images are produced as they are conceived and drafting is mostly an auxiliary function. Drawings merely document designs like a final report, after designers create engineering databases on computers. Databases transfer electronically to the drafting and analysis departments for design verification, stereolithography shop for prototyping, spray-metal mold manufacturer for short-run tools, and tooling vendors for quotes and permanent-tool design.[4] Solid-modeling systems let designers see parts take shape on computer screens, much the same way machinists watch parts take form. At progressive companies, entire assemblies are designed with solid-modeling software.[20]

As claimed by many experts, concurrent engineering isn't just throwing a CAD/CAM system at a group of engineers and expecting them to run with it. According to the definition of CE in Computer Aided Engineering magazine, CE means management support, teamwork, consensus decisions, and agreement of what's the most logical solution.

The potential advantages of concurrent engineering have been recognized for decades. But earlier calls for it were thwarted by middle management fiefdoms and by the lack of computerized tools to spur cooperation between departments. Now that such tools are emerging, top management is cracking down and forcing design and manufacturing, in particular, to collaborate. More and more senior executives realize that U.S. industry's problem is not coming up with novel designs, it is getting products out the door.[1]

In all concurrent planning, effective collaboration among team members is the key to success, whether they are a group of physicians planning a medical procedure or a team of engineers designing a new VLSI chip.[32] Concurrent Engineering is a systematic approach to integrated product development that emphasizes response to customer expectations and embodies team values of cooperation, trust, and sharing.[33]

One of the breakthroughs accomplished thru concurrent engineering is being able to link design and manufacturing. The technologies allowing this link are CAD/CAM and PDM. PDM is abbreviated from Product Data Management. Most design and manufacturing organizations today have multitudes of workstations, PC's, and larger computers-all of different makes and models. Files containing geometric models, analysis results, NC tool paths, and process plans are scattered about, stored in a variety of formats.[3] Many experts believe the way to bring order to this almost chaotic situation is product data management. Such systems can provide the missing link between design and manufacturing, managing and controlling, the flow of information between these two vital entities.[20]

In the next sections several successful examples of concurrent engineering will be analyzed. The success factors and their relation to CAD/CAM integration will be observed. Later on a guideline will be developed to implement and manage CAD/CAM systems successfully in a concurrent engineering environment.

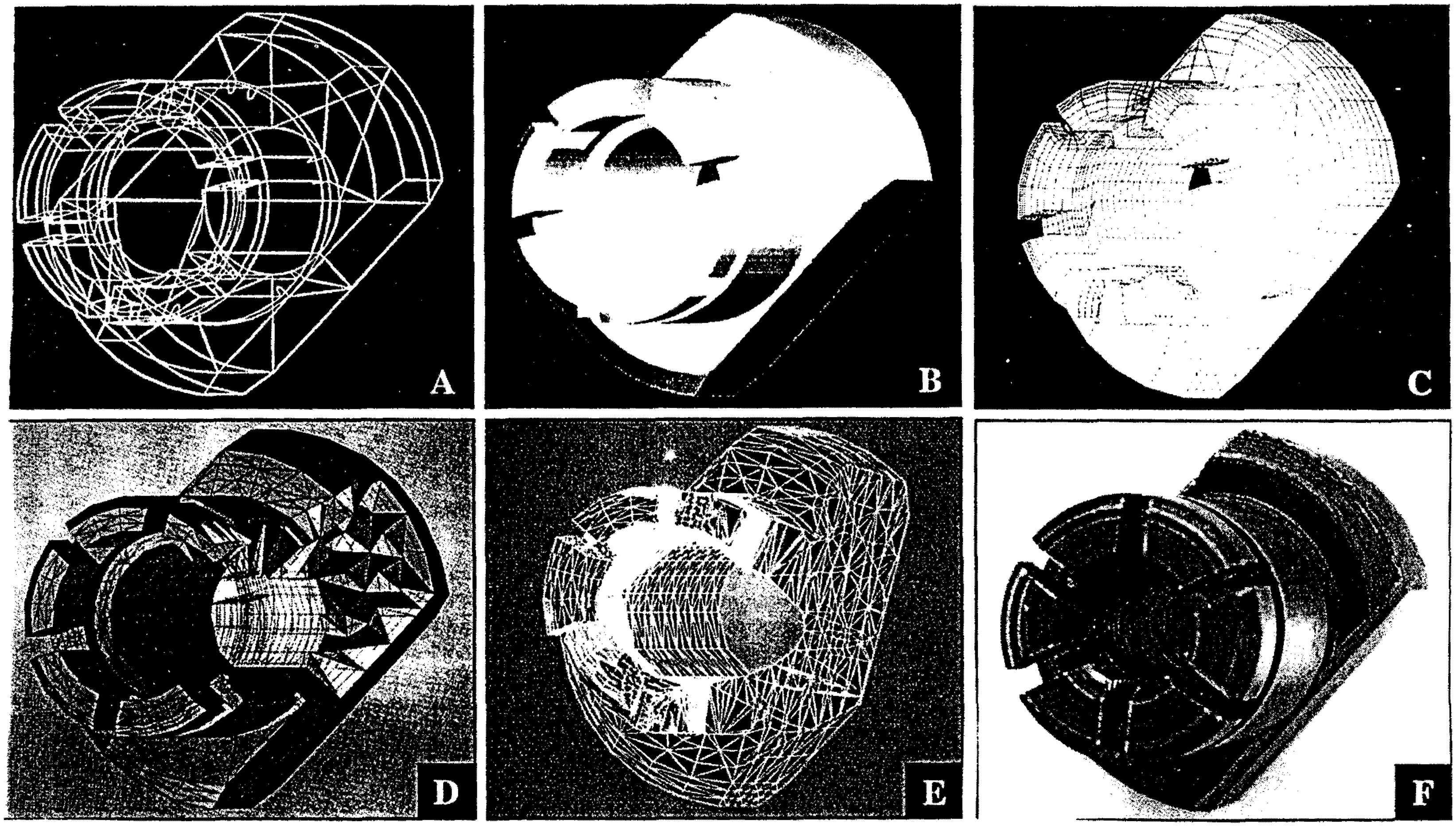

Figure 1 Solid Models Automatically from Wireframe CAD (By Algor) [17,18]

As reported in Machine Design [14], the general goal for most engineering companies is the same: bring better products to market in less time. Most firms are betting that concurrent engineering can help.

In this scheme, all departments in a company, such as design, marketing, production, and technical publications, work simultaneously on the project. While it sounds like the obvious way to operate, a concurrent process is possibly only when everyone has access to product data as it develops. That requires a network as well as up-to-date modeling software and a database for storing designs as objects rather than as a flat file of numbers. Nevertheless, the race is on. Software developers are fine tuning their modelers, making them easier to use, improving their features, and promoting a simultaneous-engineering environment.[14]

Solid models provide a big advantage when it come to fit checks assemblies. I-DEAS from SDRC allows putting an entire assembly together before ordering a single screw. These so-called soft prototypes are helping engineers trim the number of costly physical prototypes often down to one. The 3D modeler from Varimetrix features wireframes, surfaces and solids. After creating a design, such as a right-angle transmission, users can alter its history file and regenerate the design. Also, associative features allow updating a design and updating its toolpaths as well. A Gateway product will allow turning existing 2D drawings into solids.[22]

In addition to packing models with more data, concurrent engineering depends on software that is easier to use, requires little interaction for most functions, and which is nearly automatic with others. According to experts like Forrest Blair, president of Varimetrix, it is possible that software will make logical decisions for the user. That may require an expert to write his preferred-design rules into the software so that a less experienced user can work more efficiently.[14]

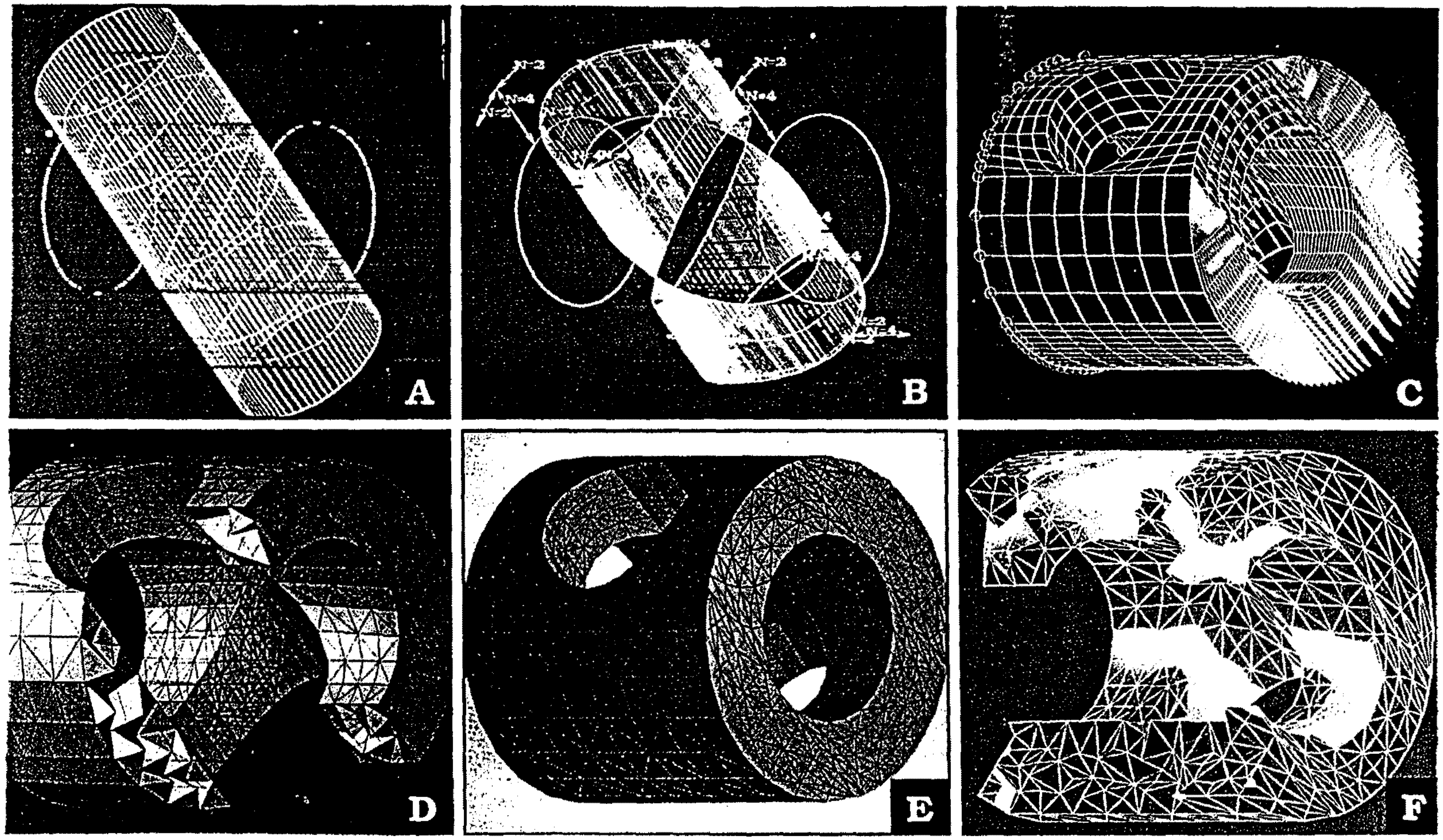

Figure 2 Fully-automatic solid mesh generator that works from a surface mesh (By Algor) [17,18]

Another possibility is that smart software may learn the preferences of the user. That demands better information management and artificial intelligence. These mentioned smart functions are showing up in the form of parametric design rules that allow changes to ripple through an organization regardless of where they originate. The first generation of parametric tools are available. Developers are also trying to extend the concept of the solid model to better handle aspects of concurrent engineering.[14] Industry is beginning to apply the term master-model to the notion of a model carrying intelligence. Product modeling is defined to be a way to describe a part as more than geometry. It involves design intent, such as surface finish, material, tolerances, and dimensions. According to many experts the master-model concept is driving the concurrent engineering. The master-model is defined to be packed with knowledge such as how the model was designed, how it will be used, and how it might perform.[14]

Smart or intelligent models such as those constructed with Pro/ENGINEER form Parametric Technology Corp. also carry design and manufacturing information. The PTC system allows for instance, sending notes from manufacturing engineers to upstream departments such as Tech Pubs so that they may furnish, say, repair guidelines in maintenance manuals. Aries Technology Inc. has developed its ConceptStation software to allow engineers to perform preliminary analysis early in the design process. The system is intended to reduce the number of iterations of a design, thereby reducing the length of the design cycle.[22]

Few parts are designed for use without interacting with other parts. Consequently, an association between the parts in an assembly means that making a change in one updates connecting items. Integraph's I/EMS solid modeller features such a capability. For example when electrical engineers design a lighter motor for a power tool, the existing housing model may be recreated with just a few button touches. Engineering is the creative art of managing change. CADDS 5.0 from Computervision accommodates the real world by allowing model changes either parametrically or with variational geometry. Parametric methods require that engineers describe in equations the relation between parts.[15]

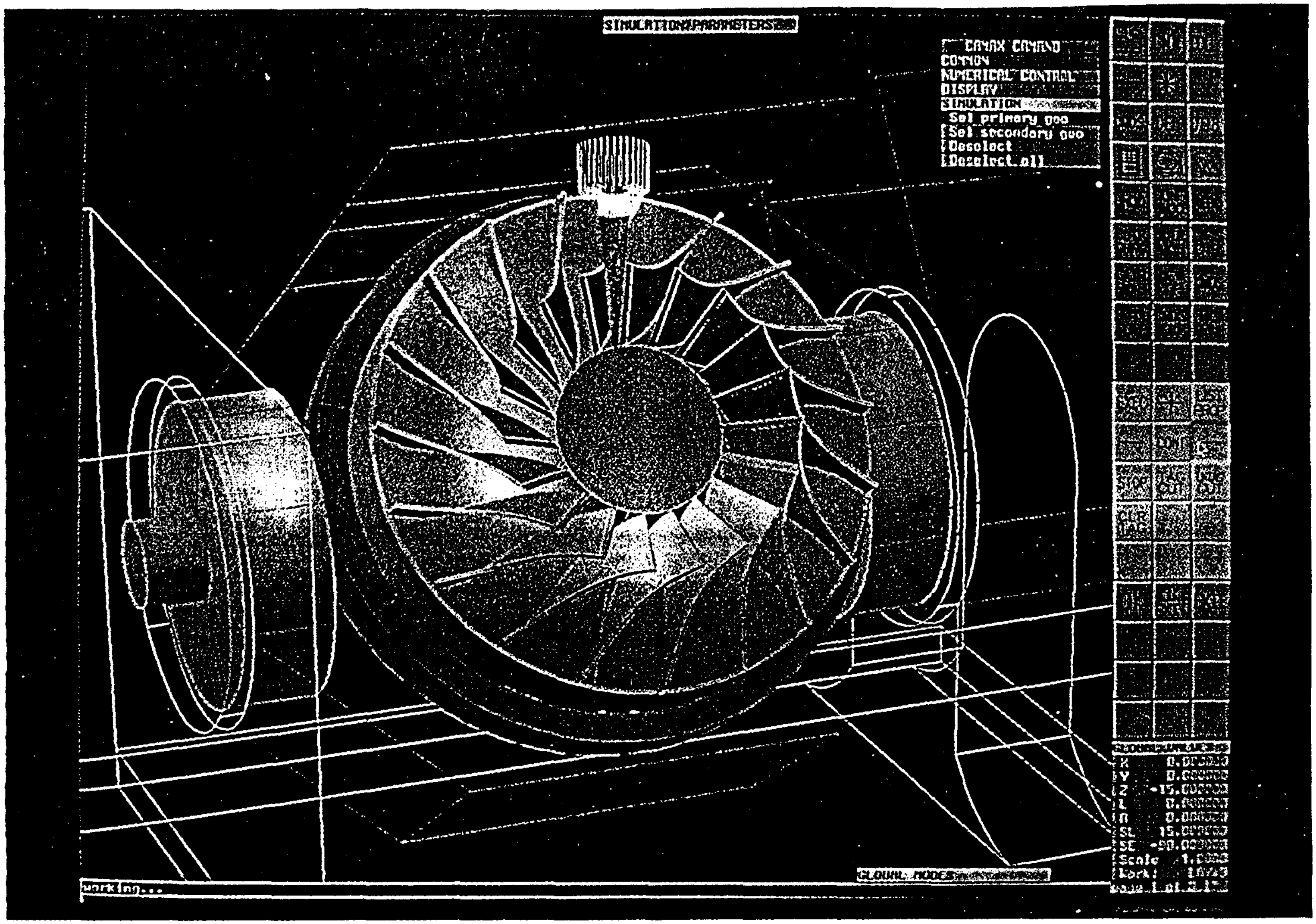

Figure 3 This turbine blade was designed, shaded, machined, and simulated with Camad software from Camax Systems [21]

2.2 Computer Aided Manufacturing

The growing list of features available in computer-aided manufacturing systems is placing more tools in the hands of manufacturing engineers. These tools are inspiring creative approaches to manufacturing problems. The Strata NC programming system from Spatial Technology Inc., represents tool paths and fixtures as solid models. Tool paths in Strata can be generated from scratch or from imported CAD geometries.[22]

Graphical CAM systems such as Camand from Camax Systems Inc. feature tool path verification capabilities that allow engineers to simulate a machining routine before creating an actual prototype. Parts with complexly curved surfaces generally require four- and five-axis machining capabilities. The ability to machine parts in more than three axes allows users to reduce the number of setups, improve accuracy, and decrease machine time.[23] Personal Machinist from Computervision operates as a stand-alone CAM system and can be integrated with the company's Personal Designer CAD software. The integrated version of Personal Machinist shares the same data base as Personal Designer, eliminating the need for data translation between CAD and CAM.[23]

According to manufacturing engineers, CAD has had a major impact on the increasing complexity of machined parts. Some companies are exploring the possibilities of using knowledge based systems to develop product definition data bases from CAM systems. These systems would do more than handle tool path geometry. They could be loaded with information about materials and tolerances. Often repeated routines such as pockets and slots could be stored, as could machining features such as fixtures and clamps.[23]

Automation can radically alter the manufacturing process and the roles of the people involved in it. Many companies as reported by Mechanical Engineering[22], are employing both software and engineers to cut time from design and manufacturing. In every instance the benefits derived from CAM are directly attributable to the people who implement the system and make it work.

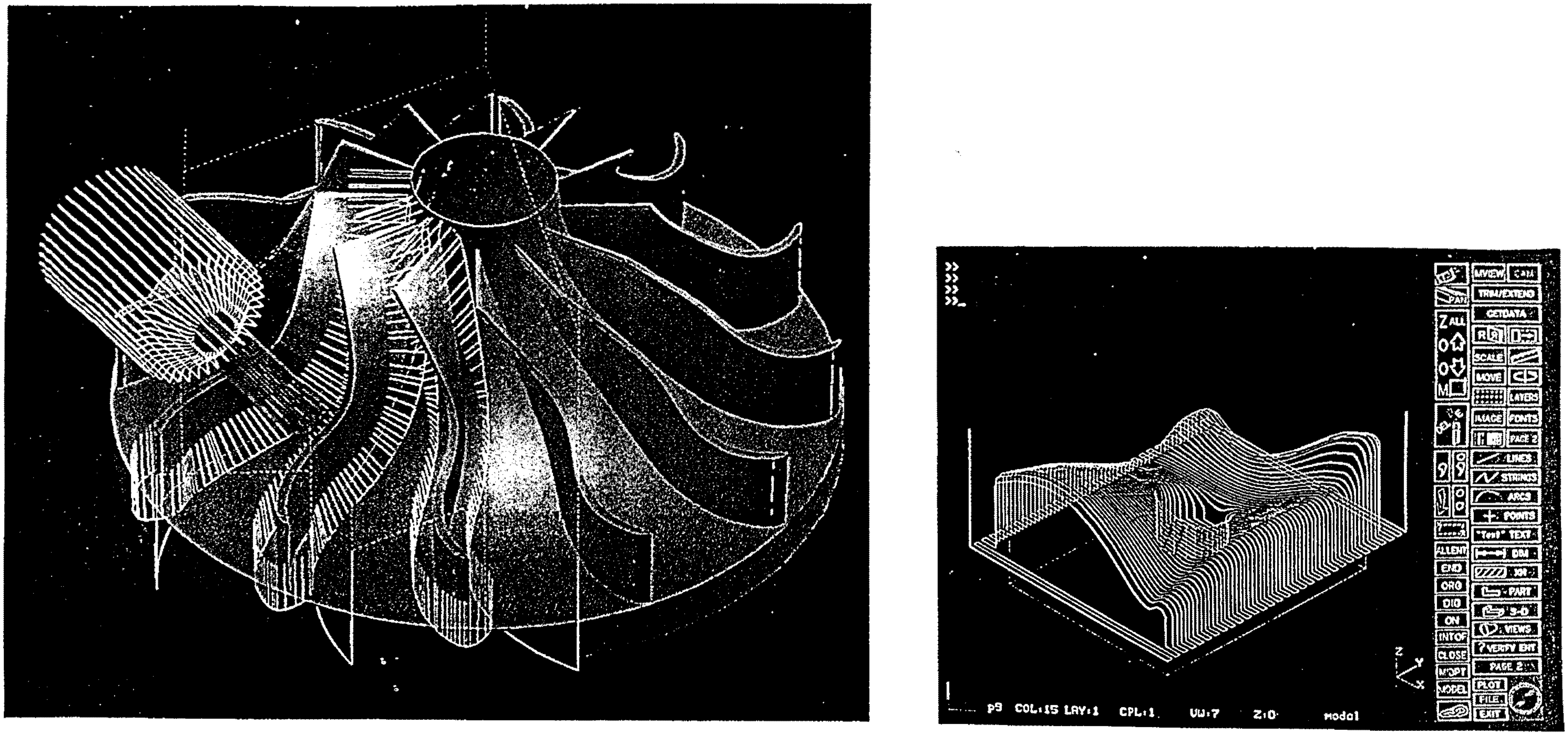

Figure 4 a. Parts with complexly curved surfaces can be easily modeled and machined (By Camad) [23]

b. personal Machininst from Computervision eliminates the need for interface btw CAD/CAM [23]

3. MAJOR CAD VENDORS AND SUCCESSFUL CONCURRENT PROJECTS

Parametric modeling software cannot by itself determine if a part will break or hold. Shape optimization software alone cannot vary the number of holes in a part. And FEA only systems cannot consider all factors needed to produce a part that can be easily manufactured. However a new breed of software has been developed specifically to handle such issues. The Eagle language from Algor contains three basic items: parametric geometry, information for FEA, and other factors such as cost and a wide variety of constraints. In essence, the Eagle package serves as a focal point for the concurrent engineering process.[18]

Other seamless interfaces to CAD packages let users perform stress, thermal and other analyses on CAD geometries. A complete CAE tool for implementing concurrent engineering in the AutoCAD environment is SDRC's Designer 1.0. It integrates various analyses while keeping the CAD look and feel.[14]

3.1 SDRC - Structural Dynamics Research Cooperation

As reported by many companies and magazines SDRC is defined to be the best CAD software producer. Their main product I-DEAS is accepted to be one of the wonders of the technology. They have been creating many other software that complement I-DEAS and provide additional capabilities. One of the areas where I-DEAS is utilized is the aerospace industry.

In aerospace industry, concurrent engineering is a proven methodology for improving product quality, reducing costs, and shortening time to market. properly applied, software systems can play a major role in making concurrent engineering work. From the early development of the Space Shuttle to the design of Space Station Freedom SDRC as it is reported in their journal called Dimensions, has been utilized.[6]

Grumman and SDRC : It takes an incredible amount of talent and cooperation to achieve a goal as lofty as that of creating and maintaining a permanently manned research facility in space. As reported in Dimensions[7], the use of I-DEAS is a central focus for many of the engineering groups at Grumman. The Grumman team produces I-DEAS solid models of each assembly stage of the space station. The models, which contain the geometry, mass properties, materials properties, and element configuration of the station, are distributed to the space station engineering community, allowing all engineering analyses to use the same program baseline data.[7]

Lockheed and SDRC : As reported in Dimensions[9], Lockheed Missiles and Space Company is using I-DEAS as a key component of an innovative new program to improve the development of satellites , and missiles. In today's highly competitive global aerospace industry, success depends on how quickly a company can get products to market, manage costs, and deliver extremely complex-yet highly reliable aerospace systems. To help meet those objectives Lockheed has launched a major initiative known as Computer Integrated Engineering and Manufacturing (CIEM). The program integrates the design, analysis, and manufacturing elements of mechanical product development in a concurrent engineering environment. The CIEM system integrates I-DEAS with specially developed tools such as an NC programming application and artificial intelligence-based automated process planning system to evaluate design producibility and automatically generate manufacturing work instructions. The visualization capabilities of I-DEAS let the engineering groups validate any problem.[9]

Aerojet and SDRC: Product development teams at Aerojet Electronic Systems are reported by Dimensions[10], to be using mechanical design automation tools within a concurrent engineering methodology to develop and produce an advanced sensor for the next generation of U.S. Air Force defense meteorological satellites. Aerojet is using I-DEAS software as the standard 3D modeling and drafting tool to dramatically improve the design performance and reduce cost and schedule.[10]

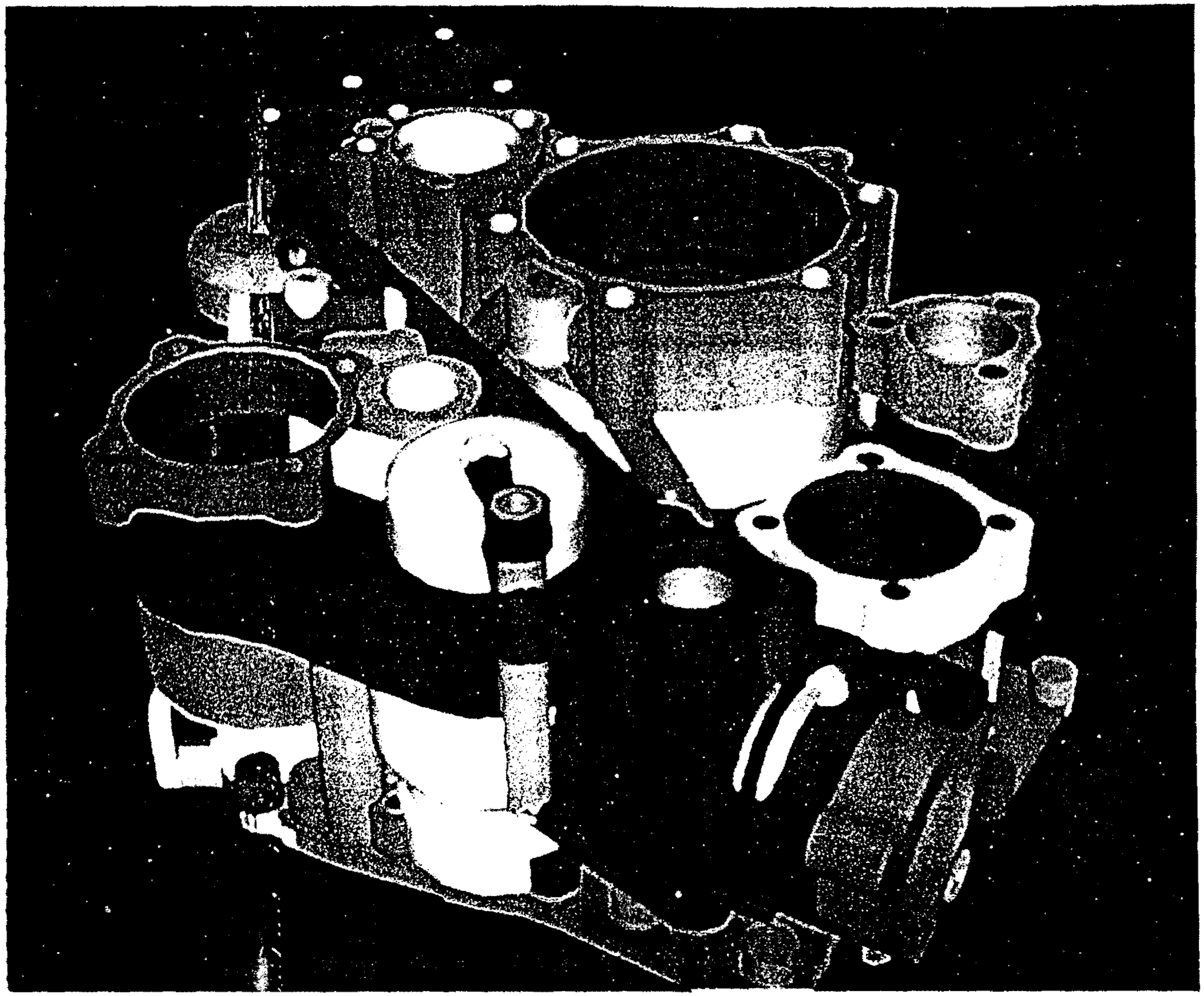

Figure 5. Lucas Engineers are using CAEDS to help shrink their product development process [11]

Lucas and SDRC: The Engine Systems of Lucas Aeropsace in Britain is using CAEDSS of SDRC to help support a concurrent engineering approach to the development of such products as aircraft engine fuel metering units. Since committing to CAEDS and their concurrent engineering strategy, Lucas has seen dramatic increases in engineering productivity. As reported by the Design Manager, the typical design process at Lucas has been streamlined. It now consists of the development of the solid model, analysis for tolerance stack-up prior to stress analysis, and incorporation of resulting modifications. At this point, stereolithography prototype modeling is used as a manufacturing aid, resulting in a significant reduction in time spent developing drawings or prototypes.[11]

3.2 ALGOR's EAGLE and Concurrent Engineering Modeling

The concept of the Concurrent Engineering Model, as defined by the Algor Engineers, focuses on the practical day to day issues an engineer faces. In addition it provides a path to generalize the experiences gained in a particular design situation for the benefit of future designs. Typical set of tools used for the Evaluation of a CEM and Concurrent Design Optimization is presented below.[17, pp 1]

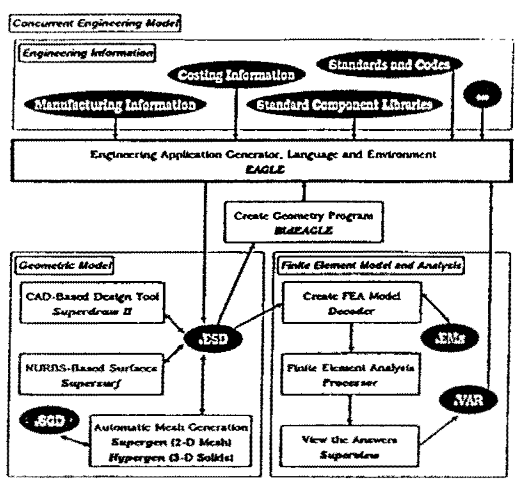

Figure 6. Concurrent Engineering Model

As described in Algor's published catalog [17], the basic technique of CEM is simple: Teach and Play. the user teach EAGLE what to do, either through programming or the application generator, and then play it repeatedly for what-if analyses. The CEM is reported to contain three basic items: 1) the parametric geometry, 2) the information for finite element analyses, 3) other factors such as cost relations and constraints from the design, manufacturing, transportation, and other departments.

EAGLE is recommended for a wide range of engineering situations, such as early conceptual design, managing family of parts, concurrent design optimization, graphical feedback for mathematical models and standard handbook calculations.[18]

A design optimization based on a CEM typically involves the following steps:

> <u>Determine the goal:</u> Typically the designer defines what the purpose of the design optimization is and how he/she will know that he/she achieved this goal.
>
> <u>Determine the modeling strategy:</u> Choice of software, Superdraw II, Beam Design Editor and Supersurf are the options
>
> <u>Perform one analysis the conventional way:</u> This will teach the system step by step what steps to perform for each what if analysis.
>
> <u>Running EAGLE</u>: Create the EAGLE program, Determine how to change design, Execute the EAGLE program, and Refine the EAGLE program

4. MANAGEMENT OF COMPUTER AIDED DESIGN PROCESS

As it can be seen in the previous sections, there is an information revolution underway in manufacturing companies today. Computer-aided design, engineering and drafting tools are being developed at an accelerating rate, and increasingly they are being linked to various types of computer-aided manufacturing equipment in such processes as fabrication, assembly, materials handling and testing.

Adler [29], lists the distinct benefits of CAD/CAM to be:

> "On the CAM side, manufacturing automation enhances accuracy, reliability, and efficiency, and ancillary tasks such as materials handling and tube cutting and deburring can be automated."[29]

> "On the CAD side, computerized databases facilitate the standardization of parts and thus help minimize the variety of fittings, thereby reducing design time and manufacturing complexity. Computer-aided engineering capabilities such as finite element analysis simplify sophisticated design analyses."[29]

In this section ways for successful implementation of CAD/CAM and management of change due to introduction of CAD/CAM will be discussed so that the above quoted benefits could be achieved.

Adler [24] describes the CAD/CAM integration as proceeding through a hierarchy of progressively broader and deeper integration:

> "1. downloading of data directly from the CAD data base to the manufacturing environment; 2. inclusion in the CAD data base of manufacturability design rules, criteria, and models so as to assure the reliability of the data that is downloaded; 3. inclusion in the CAD data base of automatic manufacturing

process planning, broadening the ability of designers to incorporate manufacturing concerns; 4. error recovery capabilities such that contingencies in manufacturing can be automatically identified, diagnosed, and rectified, or circumvented."

4.1 Effective Implementation of CAD/CAM

As Adler and Helleloid reports [24], the interest in CAD/CAM in many firms is driven by the need to reduce product development cycle time without adversely affecting product performance or cost.

Adler and Helleloid [24] conclude based on their research that traditional project management approaches must be adapted to support new levels of automation and new levels of learning. They also conclude that the existence of an interfunctional network of support would be more important to success than the presence of a single champion. Their final conclusion is that the focus on a culture of continual adaption implies that training should be directed at developing longer term learning capabilities, rather than being limited to immediate operational proficiency.

According to the field studies done by Robertson and Allen [25], managers ' views of CAD systems can be classified into three categories corresponding to the three types of capital:

Physical Capital; As observed [25], some managers saw CAD systems as physical capital, as electronic drafting boards. As reported [25], managers in this category did realize some productivity gains from the system. The engineers however were observed to express frustration that much more could be done with the system.

Human Capital; Managers in this category were observed [25], to believe that CAD systems allow the design engineer to understand the geometry and characteristics of the design more fully. This type of managers as reported [25], allowed their engineers the time necessary to complete a full three-dimensional CAD model.

Social Capital; This type of managers as reported by Robertson and Allen [25], took advantage of the ability of CAD systems to act as a common language between different specialties and used CAD design review rooms.

According to Adler [29], the payoff curve to CAD/CAM, like that of other technologies, has an S form, with most benefits appearing only after a certain threshold has been broken. The pathway to this breakpoint as suggested by many organizations is well known: "first simplify, then automate, finally integrate.

As reported by Badham [30], 21 out of 31 companies used savings in drawing labor as their cost justification basis for the purchase of CAD. And according to the same study the first three important motives for the introduction of CAD were observed to be cutback in the time required for a certain task, improvement of the basis for decision-making, and quality improvement. Same study shows examples of different firms having different product variations. These examples show that CAD/CAM systems are more likely to be utilized in firms where product variation is high.

4.2 CAD Organization Structure

According to Brooks and Wells [31], the new role activities of a CAD supervisory system are :

- developing the overall CAD strategy - strategic planning for training - periodic reporting - vendor update assessment - job allocation - monitoring CAD marketplace - user training - system monitoring - developing macros - investigating system problems - implementing systems update - providing user help - terminal allocation - developing standards and libraries - housekeeping

As Brooks and Wells [31], report a centralized CAD system forces the designer to work away from his first-line supervisor and within the potentially strong influence of the CAD manager and CAD support team, whereas an elite group of CAD operators may be created who are isolated from their manual colleagues; thus new artificial boundaries are formed that may constrain work allocation decisions. Same study [31], reports that organizations whose strategy is to reduce manual design to a minimum in the medium term endeavor to put all their new work on CAD. Some companies on the other hand select a single major project to be designed using CAD, as a pilot project.

Figures 7 and 8 [31], show generalized organizational structures in the drawing office that is found before and after CAD implementation. The only change is the sideways addition of the CAD manager and line support team. Figure 9 presents the new model developed by Brooks and Wells [31]. This model assumes that CAD is fully integrated into the design function, and is being used close to its full potential. In this new model design management is responsible to board level for providing a design resource to meet the needs of the company. Project managers are the ones responsible for the execution of specific projects. The lead designer is in a prime position to monitor the performance of the designers. The CAD manager is responsible to design management for the effective operation of the CAD system and for proposing strategies for its future development. System administrator is responsible for training and planning elements which were previously CAD manager's responsibilities.

This structure appears to remove all of the sources of conflict that have been identified in the relationship between traditional first line supervisors and the CAD manager/system administrator. At the same time this model provides many avenues for further development of the individual, either in the CAD management area or in more traditional design areas.[31]

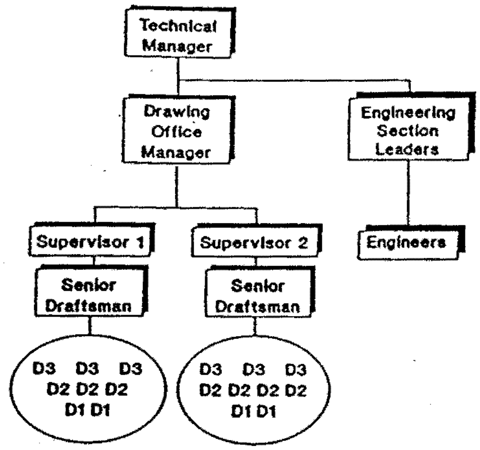

Figure 7. Pre-CAD Design Office (D1..3 are draftsmen) [31]

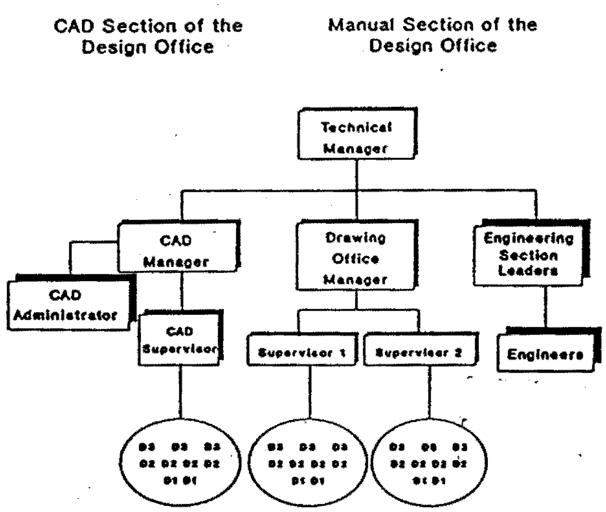

Figure 8. Post-CAD Design Office [31]

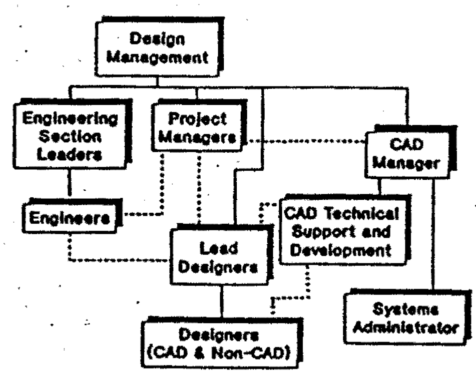

Figure 9. New Model

4.3 Barriers to Full Utilization of CAD

As reported by Liker et al. [26], the main reasons for underutilization of CAD is both technical and organizational lack of integration. The study by Liker et al. [26] provides a good overview of organizational fragmentation barriers to CAD promises and solutions.

CAD Promise	Organizational Fragmentation Barrier	Integration Solution
Automation of routine tasks	• Coordination needed to develop design standards and parametric design programs.	• Integrate across CAD users.
Complete 3-D picture	• Design engineers rarely use CAD.	• Better integrate jobs of design engineers and designers.
	• Designers threatened by engineers using 3-D.	• Better integrate jobs of design engineers and designers.
	• 3-D design often overkill for the design task.	• Integrate design task and CAD use.
Integrated CAD/CAM	• Brick wall between design and manufacturing.	• Integrate design and manufacturing.
	• Incompatability of CAD with vendors who NC machine parts.	• Integrate vendors into process.
	• CAD designers do not understand the requirements of CAM.	• Integrate CAD and CAM users.
Integrated CAD/CAE	• Analysts use stand-alone CAE tools but don't use CAD.	• Better integrate jobs of CAE specialists and designers.
	• Design engineers trust physical models over abstract analysis results.	• Better integrate design engineers and CAE specialists.
	• Automatic mesh generation programs are inadequate.	• Better integrate CAD and CAE technologically.
	• CAE departments are understaffed and too slow.	• Increase staff capable of using CAE, and integrate it into the design process.
Paperless design process	• Suppliers and customers rarely have compatible CAD systems.	• Integrate customers and suppliers.
	• Protocols such as IGES are not very good.	• Develop better technology for integration of disparate CAD systems.
	• CAD systems do not effectively support group work.	• Develop technology suited to groups at work.

Table 1. CAD Promises, Barriers, and Solutions [26]

5. CONCLUSIONS

The available software today let organizations pursue simultaneous or concurrent projects. As discussed throughout this paper CAD software that was developed and has been developed forces managers and engineers to work more concurrently and therefore dynamically. The fast rate of change of technology in this field also changes solid organization structures into more simple and flexible structures.

The contribution of CAD to the concept of concurrent engineering is obvious and significant as described in this paper. New CAD systems enable teams integrate whole design process easily and therefore shorten the product development process and decrease the time to market.

But there are few important items to be cautious about while implementing CAD. Throwing CAD into engineering department will not provide a concurrent environment. A strategic planning, and a full integration is a must. The following guide line is developed thru literature for managers thinking to utilized CAD or for managers having problems due to underutilization of CAD.

1. CAD systems when used as an aid to conversations, create a common language or set of references. While CAD systems may be directly responsible for some changes in the way engineering is done, many changes are only enabled by CAD systems. CAD systems should be evaluated for their ability to enable productive design changes, and not expected to automatically cause changes.