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THE DESIGNER OF THE 90'S: A LIVE DEMONSTRATION

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A LOOK BACK

Whenever we attempt to look forward to anticipate changes that need to be made, we must first look back to see where we have been, for our experience, our history, and our culture should, and does, affect our vision of the future. Certainly, this principle applies in the area of aerospace design, and it is with this principle in mind that we take a few brief moments to look backward to see what we have learned that can be applied to the future.

When Orville Wright climbed into the seat of his power driven, heavier than air machine on that fateful day in December of 1903 at Kitty Hawk, North Carolina, he represented the ultimate in intimate involvement in the design process. The Wrights conceived the design; they worked out the details of the design; they analyzed the design both structurally and aerodynamically; they determined how the design could be built; they tested the design; and they ultimately flew the design. They knew all there was to know about that machine.

With that beginning, the era of flight began, and yet the knowledge required to fly had only been scratched. In a larger sense, that flight began an era of aerodynamic reason and understanding that probably reached its zenith in the late 40's and early 50's. There was so much to be learned that no one person could learn it all. Theoretical understanding was progressing at such a rapid pace that the average engineer had to begin specializing in particular disciplines so that he could remain cognizant in at least some part of the industry. As a result, aerospace engineering organizations were developed that recognized that need, and the aerospace specialist was born. This was both required and right.

The 1950's brought with it a new innovation that made even more sophisticated analyses possible. The advent of the computer opened up opportunities to analyze configurations and structures previously thought impractical. With it, the need for a new, more highly specialized engineer was created: the Engineer/Programmer. The tool became a technology in itself, and the Engineer/Programmer developed large, complicated analysis systems capable of analyzing structures of almost any complexity, limited only by "cpu power." These systems developed by the Engineer/Programmer in themselves bred another specialist, the applications user, who made it his full-time job to understand and execute these mammoth systems. This, too, was required and right.

HERE WE ARE

The 1960's and 1970's continued this trend of increased specialization as computer power and affordability dramatically increased so that today we are an aerospace engineering society that for the most part is made up of individuals who are experts in localized disciplines. What we lack are significant numbers of design engineers who can embody all the disciplines into a single design. As a matter of fact, the highly sophisticated computer solution techniques are rapidly making the young engineer ignorant of very worthwhile "back-of-the-envelope" solutions. Furthermore, engineers in general are becoming insecure of all but the most sophisticated solutions.

The ramifications of such a situation are significant. First of all, the numbers of functional specialists are staggering: conceptual designers, detail designers, stress analysts, fatigue analysts, aeroelasticians, dynamicists, mass properties engineers, materials and property experts, vibroacousticians, aerodynamicists, propulsion analysts, reliability experts, maintainability experts, producibility engineers, static tést engineers, dynamic test engineers, flight test engineers, ad infinitum. That in itself is not necessarily bad, but in the design process as it is practiced in most aerospace companies today, the designer upon completion of his concept will shuffle out the design to all the different disciplines for them to weave their magic. What comes back to him is a series of usually late, conflicting requirements that puts the designer into the mode of iterating the requirements between the different disciplines to come out with a design that meets everyone's requirements. Unfortunately the requirements of some functional disciplines are not included since members of those teams are in such short supply they cannot cover all the bases. When everything is working perfectly, however, the system is tedious; time consumption is odious; and the design is hardly integrated. Furthermore, the design may be unproducible.

A LOOK AHEAD

Somehow, a less costly and higher quality design must be produced that encompasses all aspects of design including producibility. Producibility is singled out here because historically design engineering has emphasized configuring and sizing the aircraft so that it can meet its defined mission. How it will be built is someone else's problem. We see this as a serious flaw in the system. In addition, the other "ilities", ie., reliability and maintainability, must have their proper places in the initial phases of the design. And finally, the iteration time with all the different disciplines must be drastically reduced.

We have decided in the Military Aircraft Division of LTV Aircraft Products Group that to solve this problem, we must return more responsibility to the designer. That is, we want the designer to have the ability and the responsibility to design in the different disciplines himself without having to depend on analysts to do it for him. We want the analysts to act as specialists who work in the role of facilitator, consultant, and final analysis and checkoff.

In short, the designer will become the integration specialist with enough knowledge to at least preliminarily include all the design considerations in the design. In large measure, the only limitations to his ability to finally design in the different disciplines might be final definition of loads as defined by the customer. On the other hand, he will not be expected to perform major analyses such as finite elements, for example

Finally, we expect significant cost reductions using this approach, and we must provide a mechanism by which we can ensure that the improvements are reflected in the bids to the customer. Otherwise, we will use the additional time to further "fine tune" our design. Therefore, we must provide estimating tools that automatically include the productivity improvements that are provided.

THE DILEMMA

Certainly, we have defined a concept that sounds good, but how do we make it happen? The designer, as he reads this, probably feels like the poor guy in Figure 1. We are telling him he has the responsibility to be cognizant of all elements of design engineering and to personally include those elements in the design. He knows though, as we do, that no one engineer is likely to possess all this knowledge, and yet we believe that centralizing the design of a part in the hands of a single designer is the only way to get a truly integrated design and a resulting cost reduction.

"YOU MUST BE KIDDING!"

Figure 1

THE SOLUTION

The expert knowledge provided to him by individuals in the past must now be provided to him automatedly at his design work station as tools that he can use when he needs them. These tools must be computerized and must be provided in terminology that he can understand. Specifically, they must not be provided to him using terminology that the specialist uses but instead must be provided to him using terminology that he uses. The tools must be easy and convenient to use, and they must be integrated with his own design tools.

The expert system programming languages available now on the market provide us the opportunity to accomplish these goals. At LTV we are using these languages to capture the knowledge of our experts and, in turn, to provide that knowledge in an easy to understand way to our designers. In this way, we are capturing the thought processes of our experts and are coupling those thought processes with appropriate analysis tools so that the designer always has immediate access to the expert. Furthermore, our Engineering memory will never be lost as we shall always be updating these expert systems as design techniques change. This, by the way, becomes one of the main responsibilities of the specialist in this new design environment.

Realizing that multiple expert systems will be required for the designer to have access for all the different disciplines, we want to share data between those systems. This drives us, of course, to integrated data bases, and the development of those data bases becomes an integral part of the overall system. Furthermore, the different expert systems will be providing conflicting data requirements to the designer, thereby necessitating the need for an expert manager who will help him negotiate the conflicts. This is shown schematically in Figure 2 and represents probably our biggest challenge.

Finally, these tools must be brought to the designer in an easy-to-access manner that will encourage him to use them. In our way of thinking, this means that the same graphics terminal must be capable of delivering both the design tools and the design graphics. In addition, the terminal should be capable of accessing multiple computers simultaneously since the tools might be resident on a different machine than the design graphics machine.

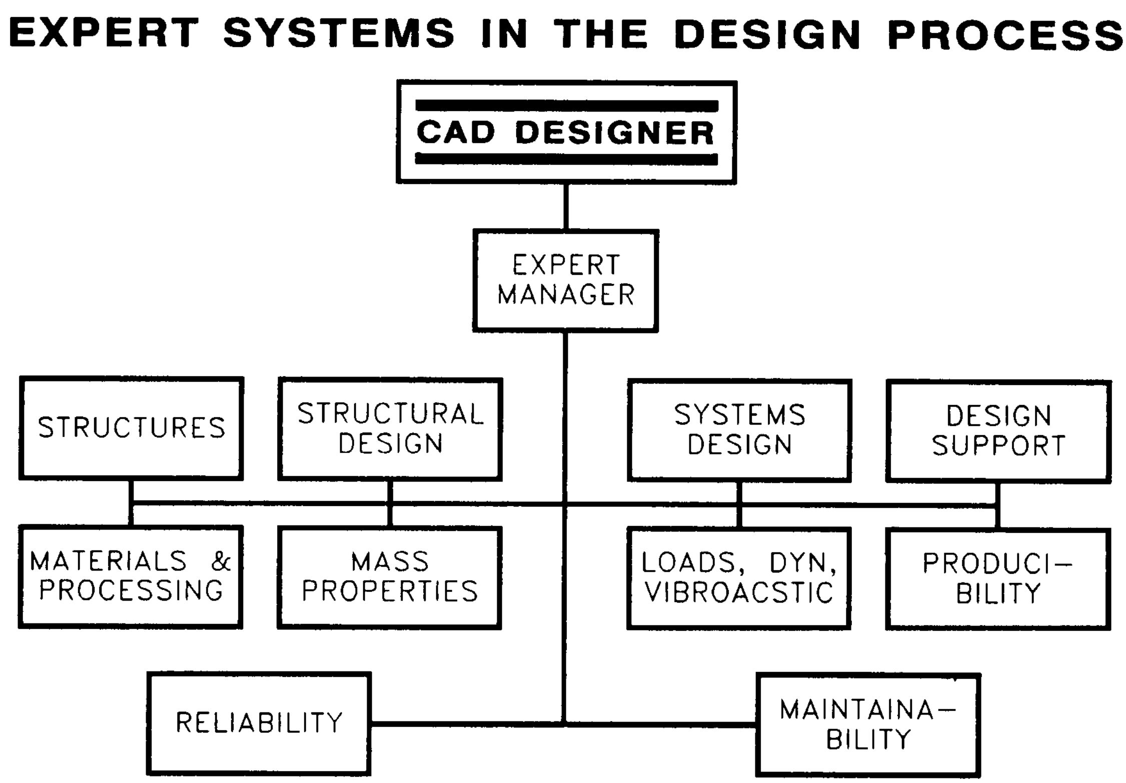
EXPERT SYSTEMS IN THE DESIGN PROCESS
CAD DESIGNER
EXPERT MANAGER
STRUCTURES
STRUCTURAL DESIGN
SYSTEMS DESIGN
DESIGN SUPPORT
MATERIALS & PROCESSING
MASS PROPERTIES
LOADS, DYN, VIBROACSTIC
PRODUCI- BILITY
RELIABILITY
MAINTAINA- BILITY

Figure 2

THE CULTURE

It should be apparent by now that we are not talking about automating the way we currently design our product. Instead, we are talking about changing the design process, putting more responsibility in the hands of a single designer. We are talking about culture changes. These kinds of changes are sometimes painful and sometimes involve turf battles. The team effort, where everyone is working together, must be emphasized. Willingness to change must be encouraged at every level. The analyst must be willing to accept that his role will be more one of providing the tools to the designer. Design teams must be co-located where communication is a standard and not an exception. Ultimately, this realization must be carried beyond the portals of Engineering to include manufacturing and quality technologies so that some day we'll be able to almost close that circle as it is shown in Figure 3.

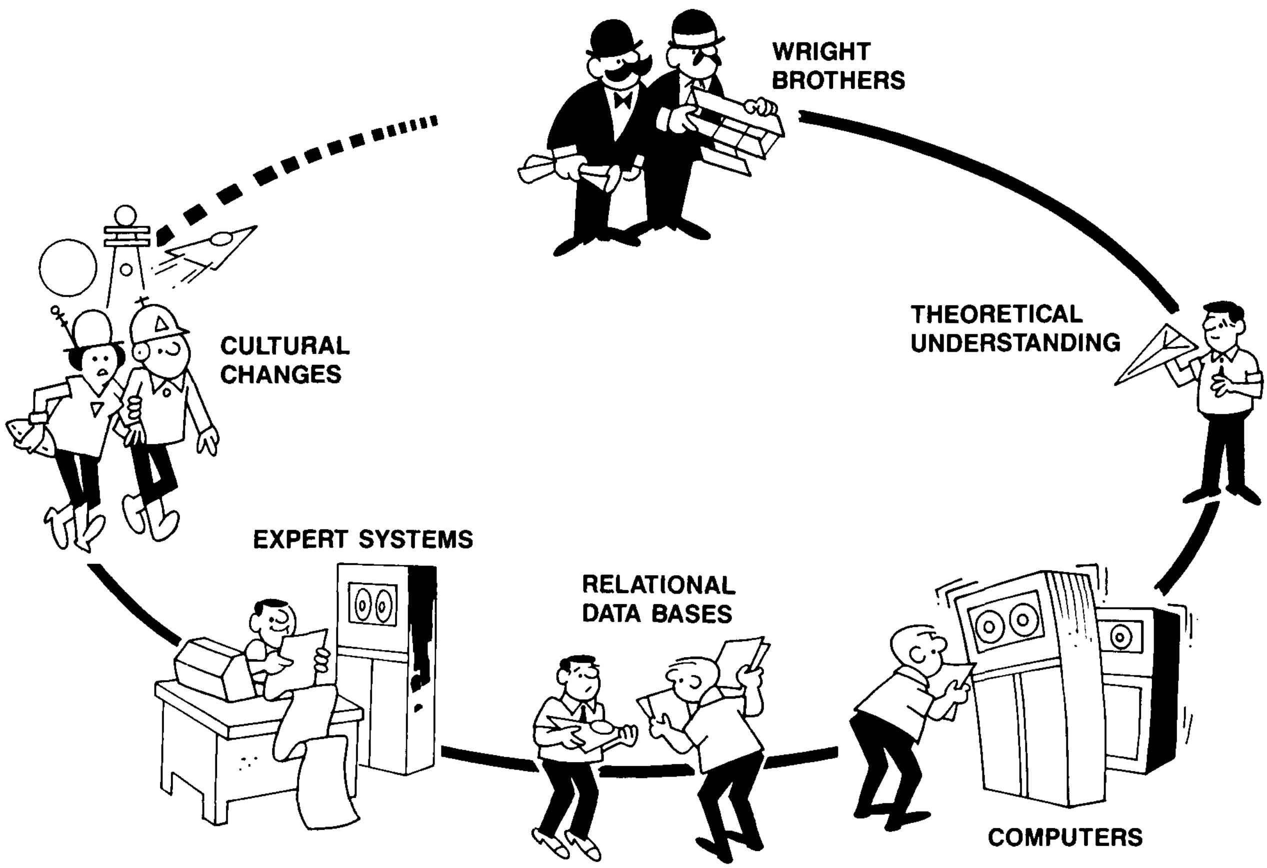

Figure 3

THE LTV AIRCRAFT PRODUCTS GROUP EXPERIENCE

The remainder of this paper details our experiences in developing the tools to meet the goals previously described. We started from scratch with a new organization, Computer Integrated Engineering (CIE), in April of 1986, and we obviously have a long way to go. We believe, however, we have glimpsed the future, and this paper is our first attempt to share that with the rest of the industry.

The Medium

The design tools that we are currently constructing are targeted to be utilized by the designer concurrently with the design graphics environment. As a result, we had to find a way to deliver tools to assist the design process at the design graphics workstation. One assumption we made is that Engineering will continue for the next several years to use IBM mainframe based design graphics packages until graphics workstations themselves become powerful enough and software mature enough to perform design graphics tasks locally in a cost effective manner. This seems reasonable since most major aerospace companies currently use IBM mainframe based design graphics packages for production work. CADAM, marketed by CADAM Incorporated, and NCAD/NCAL, which is a proprietary product of the Northrop Corporation, are the design graphics software packages currently in production usage by LTV APG Engineering for 2-D drafting and 3-D respectively.

The first approach we investigated as a solution to the problem of simultaneously delivering CIE tools and design graphics was that of utilizing the IBM 5080 equivalent graphics terminal which is the normal device used to display the design graphics. We hoped that this terminal could concurrently display the CIE tools with the design graphics. Although a simultaneous 3270 text window is supported on the IBM 5080 in addition to the high performance graphics capability utilized by the design graphics, access to the graphics capability of the 5080 device is restricted to a single software package at a time. Virtually all our tools require graphics display capability. The final conclusion was that the IBM 5080 equivalent terminal itself could be used only if the design graphics package was exited, the CIE tool was executed to completion, and the design graphics package was re-entered. This was deemed as an unacceptable limit on the interactivity between the design graphics and the CIE tools.

Another approach we considered was the provision of each designer with an independent graphics terminal for execution of CIE tools. This would provide the designer with two independent graphics display screens and two separate keyboards for entry into each system. This approach was deemed highly undesirable due to the loss of integration between the design graphics and the tools. Providing separate screens and keyboards not only consumes extra physical space, but is much more difficult for the designer to operate than a single screen and keyboard functioning in an integrated environment.

A third approach investigated was utilization of an engineering workstation that could emulate an IBM 5080 graphics terminal in software. This approach has the added advantage that workstations have powerful windowing tools that allow for the development of systems with extremely responsive user interfaces. There are several such products currently on the market; however, they all have the common problem that software emulation of an IBM 5080 is a compute intensive task which typically cannot be performed even half as fast as a hardware implementation without an unreasonably high investment in the workstation platform. Since our goal is to increase the productivity of the designer, provision of a slower design graphics terminal is hardly progress.

A unique product was found that combines a hardware implementation of an IBM 5080 equivalent graphics terminal and a workstation. At the time we originally discovered it, this product, called a CommSet 1080, was still under development as a joint effort by Spectragraphics Corporation and Digital Equipment Corporation (DEC). We obtained an evaluation machine and tested it with great success. This product consists of a standard DEC Color VAXstation 2000 and a standard Spectragraphics 1080GX. DEC VAX computers are already in use in many places within LTV. The VAXstation 2000 has the capability to run, within the constraints of VT220 or Tektronix 4014 terminal emulation, any software developed for any VAX computer within LTV without modification. The other half of the CommSet 1080 product is the Spectragraphics 1080GX. This device was already in use in several locations within LTV as an IBM 5080-002A equivalent terminal. The CommSet 1080 provides the user with a complete engineering workstation which can simultaneously display and use information from several different sources. One window on the workstation can be a design graphics terminal session utilizing the IBM 5080 equivalent capability implemented in hardware by Spectragraphics. Provision of a workstation for the designer allows the majority of the CIE tools to run locally on the workstation, providing excellent response time to the designer. The CPU power of each workstation is roughly equivalent to that of a DEC VAX 11/780. Since the workstation is directly connected to the network, it can easily exchange information with or provide terminal sessions to host VAX systems or IBM mainframes. We demonstrated the feasibility of this approach utilizing the vendor evaluation equipment to implement a preliminary sizing application developed for Structural Design. The windowing capability of the workstation has allowed the designer exactly the desired capability to simultaneously display and manipulate information from the design as well as from CIE tools that can be run locally on the workstation. The CommSet 1080 makes it possible to provide a full performance IBM 5080 equivalent graphics terminal in a workstation windowing environment.

We have concluded, therefore, that the requirements we had for delivering the tools to the designer can be met. Currently, the CommSet 1080 meets those requirements, and we are sure that more vendors will be entering this market. In the environment we have defined, simultaneous accessibility to multiple software applications on multiple hardware platforms is an absolute must, and the technology is now available to support that need.

The Tools

Having defined a philosophy and identified a medium to implement that philosophy, all that remains is to present those tools we are currently developing for the designer. The intent of all these tools is to give the designer the capability to perform more of the design himself and to design in from the beginning reliability, maintainability, and producibility considerations.

The principle tool used by the designer in the development of "drawings" is software designed to provide him with the capability to draw. Hence, the theory of design is left to the designer's experience and intuition. Even though some graphics software offers application and analysis programs to assist the designer with his tasks, these programs are usually benign in that they offer virtually no instruction or reasoning as to their use or application.

The tools being developed are designed to assist the designer in making the correct decision for a given set of circumstances. A very large portion of the time used to develop a piece of software is devoted to being certain the user interface is understandable by the user. In most of our cases, when an analysis or application is accessed by the designer, the logic for its use is part of the program. All software applying the "expert system" technology provides, as an integral part of the code, the set of rules required to obtain that particular solution. In addition, the source of all rules, be they logical or heuristic, are provided as a matter of course. Tools currently under development are summarized as follows.

PRELIMINARY SIZING: This series of programs offers preliminary sizing based on Tension-field and Shear resistant analysis of beams with flat shear webs, lug stress analysis, and joint loads analysis. Even though the term preliminary is used to describe the analysis, the methodology is as valid as the loads that are being supplied. The program emulates the way in which the analysis procedure is applied within LTV, but for the most part is an exact parity of procedures described in numerous sources. However, instead of providing the designer with raw code, the program is prefaced with a description of the code, a definition by question and answer sessions to assure understanding, and an exclamation of the output.

MATERIALS DATA BASE: Physical and mechanical data are assembled as common reference for any program that might require materials type information. Our materials data base has been limited to those materials most commonly used by our organization. Those include aluminums: 2xxx series, 5xxx series for cryogenics, 6xxx series for welding, and several 7xxx series for structural applications; titaniums, Ti6-4 and Ti10-2-3; steels to include stainless, high nickel, and inconel; composites to include fiberglass, kevlar, graphite, bismaldeide, and polyimide. Mechanical data for composites such as areal weight, resin content, density, and fiber volumes are readily available to the user be they a person doing a query or a program seeking specific information. Similar types of data are stored for metals such that rapid accurate access is possible. Other attributes of the data include the applicable material and/or process specifications cross-referenced to LTV specifications, the Military specifications, and the vendor specifications. The intent of this software is to supply needed data to the users in a very timely manner, but just as important is the need to provide the same information to all users; i.e., standardization.

STANDARDS PARTS DATA BASE: Similar to the MATERIALS DATA BASE, the principle intent is assurance that the part being referenced by the designer is a part that is a standard (whenever possible) for our company. Our data base thus far is limited to fasteners, simple fittings, and simple brackets. The key to the base is establishing the calls that will make the part unique. For instance, querying a base for all fasteners that have hex heads would produce several hundred types (which is in most cases unacceptable to the user); on the other hand, if the query said "give me a list of all fasteners that have HEX heads, have SHEAR strengths greater than 6000 lbs, but less than 7000 lbs, must be workable in a 900 deg. F environment", then the list would be greatly reduced, and a selection could be easily made that would still be from a list of standard parts. Using standard parts obviously reduces both design and manufacturing activity costs.

RELIABILITY EXPERT SYSTEM: An expert system using the backward chaining approach is used to select fasteners to be used for metal to metal, metal to composite, or composite to composite mechanically fastened joints.

Fasteners as related to structural reliability, account for about 60% of the aircraft structural maintenance items. The software uses a commercially available expert system shell, a relational data base, and an internally developed knowledge base (about 250 rules), the latter being unique to LTV. This system when applied will eliminate most of the problems associated with improper selection of fasteners. Some of the criteria used for selecting fasteners include: type of joint-single or double shear; fastener configuration-single or multi row; application-safety of flight, primary or secondary structure; location on vehicle-internal, in ducts, on the surface, fuel cells; type of installation-wet or dry, blind or open.; acoustic environment and others as would apply to the successful selection of fasteners. The expert system allows us to provide to the designer the knowledge base of our company and the industry at a point in the design process when it is most needed. By using this type of system, we are able to retain the knowledge that much more experienced personnel have observed. As these more experienced personnel retire or are promoted into managerial positions, their knowledge is retained.

MAINTAINABILITY EXPERT SYSTEM: Unlike the RELIABILITY function, MAINTAINABILITY is primarily interested in the time required to remove, repair, and replace a particular item. Their function depends almost entirely on the final configuration of the vehicle and, as a result, their ability to assess the maintenance factors only occurs near the end of the design phase. However, many examples, specifications, and requirements exist in journals, design handbooks, and technical orders. The challenge for the maintainability engineer is to move that information to the designer at a stage when the design can effectively be changed and in a form that is useful to the designer. This expert system through a series of calls and a combination of question and answer sessions allows the designer, using the Hypertext technique, to "leaf" through large volumes of information and find the bit of information that is specifically applicable to his component.

COST AND PRODUCIBILITY EXPERT SYSTEM: With cost a very prime consideration in any design, this module, CAPES, is one of the more important tools available to the designer. The concept employed is to provide the designer with the capability of choosing the least expensive method of manufacturing a particular part; i.e., should the part be a forging, bar, extrusion, plate, or composite. Each selection is dependent on the available manufacturing equipment, the availability of material, type of material, and if the part is a standard. This software is customized for LTV and must be constantly upgraded to reflect new manufacturing techniques and processes. Our ultimate goal in developing this particular application is to elevate manufacturing design considerations to the same level as configuration design considerations.

ACOUSTICS EXPERT SYSTEM: Acoustic design analysis is a difficult technology that historically is best performed by an expert in the field. The acoustics expert system attempts to capture the knowledge that has been stored by the expert and present that knowledge in an easy-to-understand manner to the designer. In this system, basic structural elements such as stiffened beams (metal or non-metal) or sandwich panels subjected to noise emitted from turbofan, turbojet (w or w/o afterburner), wakes/cavities, or unducted fans can be analyzed to determine the effects of acoustics or to size the structure to withstand the environment. The program provides the designer or project manager guidance as to the severity of the acoustic environment and helps in the design of a particular part if the software indicates a potential problem.

SCHEDULING SYSTEM: Numerous scheduling systems, more commonly called PROJECT/PROGRAM MANAGEMENT SYSTEMS, are available on the market. We are acquiring and modifying one of these systems to meet our specific requirements. Primarily, we are changing the input/output screens to use our "words" or "meanings". These systems are designed to provide real-time scheduling as opposed to hand-developed manually supported schedules that usually are only valid the minute they are prepared. To effectively provide information necessary to assess the progress of a project, information to the drawing level coupled to any organization that supplies data must be available. For the lead designer or lead supervisor to effectively manage, he must have intermediate check points within the drawing schedule that allow him to determine progress. More importantly, PROJECT MANAGEMENT SYSTEMS provide the designer, the lead person, the supervisor, project or program manager the capability of doing "what if" studies in real-time, thereby allowing the person to manage (as opposed to reacting). Similarly, the designers (or the person who is doing the task) must have and understand the activities they are tasked to do and when they are tasked to do them, and what happens when they do not. Even though this software will more than pay for itself, just satisfying a need within the design community, it can be and will be a lot more than that. Along with the Drawing Tracking System described below, it will unite Engineering and Manufacturing into a more cohesive unit, giving Manufacturing insight into what Engineering is doing and Engineering insight into how its decisions affect Manufacturing. To compete in today's marketplace, integration of <u>all</u> technologies is mandatory, and integrated scheduling is a big part of that.

DRAWING TRACKING SYSTEM: With any project that requires even a few drawings, specifications, or procedures, the requirement to maintain configuration control of the product, to know where and when the data is being used, and to provide visibility to the users of "things to come" is of the utmost importance to the effectiveness of the project and the company. Our drawing tracking system is being devised to provide control at the earliest possible time of the activity. Specifically, when the designer determines from his schedule that a drawing of the part should begin, he provides the parameters that make the drawing unique (e.g., the part is a forging to be machined that is the cap of a spar which is the front spar of the vertical tail which is part of the aircraft). The same scheme used for the Work Breakdown Structure for the vehicle will be used to collect charges necessary to prepare the drawing and all supporting data necessary to build the part. All phases of the DRAWING TRACKING SYSTEM are electronic in nature such that designation, sign-off, release, traceability, accessibility, availability, and maintainability of individual deliverable items are simple and effective.

ENGINEERING EXPERT: Integration of these tools presently remains at the discretion of the designer. As we continue to develop design tools, the need for an ENGINEERING EXPERT will become more important. In those cases where the functional requirements conflict, the designer must be provided assistance in making decisions. As previously stated, this represents probably our biggest challenge, but it is a challenge that must be addressed.

THE CONCLUSION

The United States Aerospace industry is on the verge of a new plateau, and that plateau can be summarized in one word, INTEGRATION: integration of manufacturing and engineering, integration of data bases, integration of scheduling, and, we believe, integration of all design functions within a single discipline. We believe that to compete in an international market, this will be essential. We have attempted in this paper to express our logic for that conclusion, and we at LTV are working diligently to employ that belief in our design process. We hope that the paper has been helpful in stimulating your own thinking, and we welcome any comments that you might have on this subject.