AUTOMATION OF THE AIRCRAFT DESIGN PROCESS

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Abstract

The increasing use of the computer to automate the aerospace product development and engineering process is examined with emphasis on structural analysis and design. Examples of systems of computer programs in aerospace and other industries are reviewed and related to the characteristics of aircraft design in its conceptual, preliminary, and detailed phases. Problems with current procedures are identified and potential improvements from optimum utilization of integrated disciplinary computer programs by a man/computer team are indicated. Although much progress has been made in the use of computers in design, current computer hardware and software technology can be exploited much more fully to create advanced aircraft designs better, faster, and cheaper than present procedures.

Introduction

Current requirements to produce technically superior aircraft at lower cost force the generation of optimized designs of greater technical depth in less time than in the past. Use of computers and computer programs to automate many engineering activities, including analysis and design, has grown to partially fill this need. Even more rapid future growth of automation is expected.[1-3] In this paper I will present a philosophical discussion of how far we have come in computerization of the design process and where we should be going and why. My commments are general and not detailed or exhaustive; they result from several years of observation and participation in the automation of analysis and design of aerospace vehicles, particularly for structures.

This paper starts with brief definitions of automation and design, followed by a description of the progress already made in computerization in the aerospace and other industries. Then the characteristics of the design process are reviewed and future opportunities for greater automation and their potential benefits are indicated, including changes in the design process, the design environment, and the designer. Finally, a few concluding remarks are presented.

The opinions presented in this paper are my own and do not necessarily reflect those of NASA. Because of my personal experience in structures, the discussion will be biased toward structural design, but the total aircraft design process will be considered.

Definition of Automated Design

The words "automated design" cause concern because in a literal sense they take all human sensitivity and control out of the process and turn it over to robots. Feeding an input to a design machine, pushing the button, and getting a finished data package out without human intervention is unacceptable. Ideas, insight, and innovation, that automations cannot provide, are required to generate a superior product. In this paper I am equating automated design to computer-aided design, and using these terms interchangeably, to describe the best combination of men and computers for designing a product. This definition should remove any fears that "automated design" means "designed by robots" because it implies that men are always in control.

The design process encompasses all activities required to generate the data needed to produce a product and therefore covers a wide scope of technical disciplines ranging, for example, from aerodynamics to noise to structures to manufacturing to economics. The computer is the digital computer hardware and software and all types of related devices or apparatus, including remote terminals and networks, that can be operated with or from it to aid the design process. The men form the design team that is essential to conceive, plan, conduct, and control the design activity. They are assisted by the computer which rapidly processes huge amounts of data needed by the men.

Computerization of Engineering

The increase in computerization of engineering is illustrated in Figure 1 by generalized views of the situation in about 1945, 1965, and 1985. In 1945, little use was made of computers, as we know them today; familiar tools of the past produced the aircraft and missiles of that era. By 1965, the digital computer was widely used in engineering analysis. However, the work was done in a batch mode with each individual engineer using a few programs to carry out his tasks. Each individual handled larger and more complex problems than before and a few large programs had appeared in some disciplines. More analyses were made during design and more design criteria and conditions were examined at greater depth.

By 1985, most engineers will be working with integrated systems of programs, with the computer and related devices providing all the tools he needs, almost completely replacing the familiar tools of the past. The capability illustrated is already in use by some engineers to make very sophisticated and comprehensive design analyses, using the tremendous data processing and calculating capability of the computer.

In the past, computerization of design was concerned primarily with calculations and numerous computer programs were written. Each of the principal U.S. aerospace companies or installations now has 400-1500 computer programs available for engineering use; a typical program contains about 1000 source statements with a range of 100 to more than 100,000. Today, many are being linked together within the computer so that they automatically interface or interact. The future will bring rapid increases in program integration. An integrated system connects program modules together, both within or across disciplines, for the greatest

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interaction and flexibility in program utilization and thus maximum useful automation.

In the fully computerized situation, the machine will do manipulation, storage, retrieval, cataloging, comparison, and other tasks that man has taught it, providing man with a vast array of engineering information for evaluation. Man will be the master and the computer will be the obedient slave, doing the dirty, dreary, routine tasks while man engages in creative, innovative, and judgmental activities. The ultimate development of an integrated system may achieve an intelligent dialog between the designer and the computer, man-machine partners that augment and complement one another in the design process.[4]

Another view of the growth of automation in vehicle design - past and future - is shown in Figure 2. It traces the automation of structural analysis from elements to complete vehicle capability, the emergence of automated structural design and its development to a mature technology, and the prospect of automated vehicle design growing rapidly from the embryonic systems now being used. In the last 20 years, structural analysis was revolutionized by computerization. From the vantage point of 1985, a similar revolution in vehicle design will be obvious.

The computer, of course, has many roles in product development besides design, Figure 3. Product development includes research, design, manufacturing, operations, maintenance, and sales. Many of these stages overlap and each involves computerization. Extensive computer-aided activities have developed in analysis, design, drafting, manufacturing, and management (see Ref. 5 for an example). These activities also overlap and do not exactly parallel the stages of product development, but each relates to design. In a larger view, future automated vehicle design will be part of an automated product development system. The design process and its automation must have compatible interfaces with the other stages of automated product development.

Progress Toward Automated Design

Progress toward automated design is illustrated in Figure 4, which lists a sampling of the code names and originators of programs in operation or under development in the U.S.A. The list is not exhaustive, simply representative.[6-14] Conceptual vehicle synthesis codes are widely used. They have a highly computerized, broad, multidisciplinary base and can rapidly analyze a proposed vehicle and synthesize an optimum configuration. Similar comprehensive systems have not been developed yet for the subsequent, more detailed, design phases of a complete vehicle. The other examples shown in Figure 4 are representative of progress in structural analysis and design. Some programs integrate loads and structures, including aeroelasticity considerations.

The structure of a vehicle contains many parts, pieces, and fasteners that must be examined in great detail for a variety of conditions. The airframe of a wide-body jet transport, for example, contains more than 1 million parts. The magnitude of the data that must be generated and evaluated has motivated structural analysts and designers of airplanes, missiles, space vehicles, ships, and buildings to become leading proponents of computer-aided design. Typically, they use finite-element structural models in their structural analysis and design programs to represent numerous pieces of structure, Figure 5. The particular structural model shown was itself a product of automation in that the finite-element model and the card decks for use in the computer analysis were generated by a computer that was given the external geometry and some general modeling instructions. A model such as this contains thousands of elements and degrees of freedom, requiring analysis by a large program such as ASKA, FORMAT, or NASTRAN.

Figure 6 shows a general schematic of the architecture of NASTRAN,[6] a large structural analysis program developed by NASA and used by many organizations. The most recent version of NASTRAN contains about 200,000 source statements and requires a large IBM, CDC, or UNIVAC computer. It was initially defined in 1965 and came into widespread use in 1971. A valuable feature of NASTRAN is the executive that controls all operations and contains rigid formats that make the program easy to use by the analyst as long as he is satisfied with the kinds of structural analysis included in rigid formats. A user more expert in computer programing can do many other tasks with the capabilities of the modules, subroutines, and the internal solution language called DMAP (for Direct Matrix Abstraction Process). Although developed for analysis of space vehicle structures, NASTRAN is used for all types of structural analysis at more than 240 installations, most of them outside the aerospace industry.

Figure 7 illustrates the configuration of a typical aircraft conceptual design program; those listed on Figure 4 may have more or less capability in the pattern shown, the principal difference being in the names and characteristics of the analysis modules. Each has an executive or control system of some type and includes provisions for optimization. Interactive graphic devices which enable the designer to examine results and introduce changes during the computational process are not widely used now, but their use is increasing. Each vehicle design program of this type includes all disciplines or considerations needed to initially define an airplane, but some disciplines, such as structures, may not be specifically included. In the case shown, structural considerations are provided by the weights module.

An integrated structural analysis and design system is illustrated in Figure 8. The Boeing Commercial Airplane Company has been developing ATLAS since 1969 with the objective of integrating related structural disciplines in a common framework with emphasis on automated control of program flow and data communications between modules, to achieve "optimal" processing efficiency. ATLAS has a control module that functions like a design manager to make analysis path decisions and monitor their execution. Module development, a technically oriented language for task definition, and emphasis on automatic input data generation, are among its features. It presently contains 24 technical and utility modules; development of additions is continuing. ATLAS has been applied to several analysis tasks and a comparison of the time and resources required by ATLAS and by conventional methods to do the same structural analysis job on a supersonic commercial transport at the preliminary design level showed that both manpower and flow time were cut in half.

Another system that concentrated on establishing interfaces between accepted analysis programs for final design verification is shown in the simplified layout of Figure 9. Starting in 1967, the Grumman Aerospace Corporation developed an Integrated Design Analysis System (IDEAS).[14] IDEAS is a highly organized system of more than 75 computer program modules interrelated by data packages from a central data bank that stores all calculated data. Sequencing and execution of these modules enables the design team to plan, schedule, coordinate, and control a stream of analyses that provide internal loads, deflections, and temperatures for subsequent analyses by several engineering groups. IDEAS is an integral part of the Grumman design process and was used in the design of the F-14 airplane, requiring over 2000 computer hours. This application verified their initial predictions of substantial reductions in the time and engineering man-hours required to accomplish the same tasks by conventional procedures. Its development was a major step forward in computer-aided analysis and demonstrated that substantial savings in time and cost are attainable. IDEAS continues to grow in capability with the addition of new analysis and design modules.

The programs discussed above are analysis and design programs that are not connected with the computer-aided drafting and manufacturing shown in Figure 3. An operational system that does is illustrated in Figure 10; it is a Computer-Aided Design/Computer-Aided Manufacturing program for cooled gas turbine blades. Started in 1968, it is now in regular use at Pratt & Whitney. Design and manufacturing engineers use interactive consoles to investigate alternative approaches and to check the clearances and intricate geometry of high-temperature, cooled turbine blades. The design of a turbine blade does not have the scope of aircraft design, but this system has most of the features and architecture of an advanced, automated product development system.

The aerospace industry is not the only one that is automating the design process, Figure 11. The U.S. Army is considering a comprehensive automated design system for each class of commodity it uses. The U.S. Navy has been steadily increasing its use of computer-aided ship design and the U.S. Maritime Administration has been encouraging accelerated use of computers in commercial shipbuilding and design. In architecture and civil engineering, extensive international activity in automated design is being coordinated and fostered through technical societies.[15] This is further evidence that integrated, computer-aided design is a growing technology with widely accepted benefits.

The Design Process

Having shown progress made in design automation, the design process itself will be examined to determine its characteristics and define problems that can be alleviated by additional automation.

The process used to design any product is basically simple, Figure 12. Someone sets down a requirement, the designer finds an acceptable configuration and then generates the data required to build, operate, and maintain the product. The selection of the appropriate configuration is not simple, however. The designer first selects one that he thinks, from experience, will meet the need - the idea and innovation stage. Then he analyzes it to determine the characteristics of his product and compares these with the characteristics allowed or required of it - the analysis stage. Initially, the product will lack some essential characteristics so it must be changed - the resize and reconfigure stage. Next, the designer goes through several cycles in which the product is reconfigured and reanalyzed until all required characteristics are obtained. Optimization methods may be used in this phase to achieve some desirable degree of merit in one or more characteristics of the product, for example, low weight or cost. Finally, all data needed to describe the product are compiled and distributed. During the design evolution, many factors and requirements, not shown, such as performance, reliability, manufacturing, maintenance, costs, and sales are included.

The various blocks in Figure 12 represent work to be done or tasks. The arrows represent the flow of data or information. Tasks and data are the elements of the design process which is primarily a data management activity - the generation, flow, and evaluation of data. This data management activity is carried out by people and computers working in an organization. If the organization required to design a product is small, the management of the information flow is easy; in a large design organization it can be slow and cumbersome. The design team for a large airplane employs more than a thousand people at its peak, involves numerous individuals that are designers, and includes large numbers of analysts, draftsmen, test engineers, technicians, administrators, and other specialists. The communication of data and decisions among groups and individuals is of staggering magnitude and is usually inefficient. Automation can speed up this part of the process by reducing the number and duration of human contacts. The largest gains from automation accrue to big organizations with big problems; however, all design organizations can benefit.

Design networks like Figure 12 can be expanded to any level of detail desired, but they soon become extremely complex. Figure 13 presents a general view of the principal elements of the structural design of a flexible airplane. It shows relationships between major tasks and the flow of data where strength, flutter, and stability and control systems interact to configure and size the structure. If aeroelasticity is important, structural deflections affect the aerodynamic loads and thus the stresses in the structure; this interaction must be included in the design for strength. Then, if this structure does not have sufficient stiffness for adequate flutter or control margins, additional design changes are necessary. Each of these activities must be carried out in the proper time sequence and much data transferred among specialists. Many months may be required to finish the first cycle. If design changes are required, several more cycles may be needed to identify appropriate corrective measures and the project can experience costly delays. Because of the complexity and detail involved, automated aeroelastic design is needed now for large, high performance aircraft. The ATLAS program, Figure 8, is a step in that direction.

Optimization has been mentioned above and noted on Figures 7, 12, and 13. Many conferences and publications have been devoted to it (see Refs. 16-25 for examples of structural applications), but it can be discussed only briefly herein. Optimization is a powerful tool for systematically reconfiguring a system or component to obtain the best, one that maximizes or minimizes a prescribed merit function. Automation makes possible application of such techniques to large systems with many variables, but special requirements must be imposed on optimization procedures in an automated system. The user must have great freedom of choice in the methods used and their execution sequence, and have complete control over the process to stop the search, inspect intermediate results, modify the approach, and start again. Therefore, a successful, automated optimum design system must be very fast, very flexible, and very versatile.

The design process passes through several stages or levels as it progresses from an initial concept to the final configuration. Figure 14 is a diagram of the development stages of an aerospace product. Continuing activity in research, development, and marketing periodically identifies new concepts and technology with sales potential. A new idea enters the conceptual design phase to scope its characteristics and, if attractive, moves into a preliminary design phase where it is worked to greater depth. When the design is sufficiently mature, management authorizes the product go-ahead and detail design, manufacturing, and testing lead to first product delivery. Design support for the product in production is a continuing activity to cover changes and modifications. These design stages involve many subtasks and cycles in a variety of sequences over a long period of time.

The three design levels leading to the first airplane delivery are defined approximately in Figure 15. Each organization utilizes different definitions and processes within its design organization so that Figure 15 is an amalgamation from several sources. The levels are defined in terms of the manpower, flow time, and number of configurations examined. The accuracy of weight estimates and short descriptions of the objectives and product are included, too. All numbers are approximate because of the variable scope of design projects, ranging from a small fighter aircraft to a large supersonic bomber or transport. Note the key role played by preliminary design; only one vehicle configuration goes into detail design; however, many components and parts may go through several design iterations during detail design.

Figure 16 presents the three design phases in a decision network, expands the preliminary design phase, and indicates major decision points and recycling routes. The preliminary design phase consists of sizing the product to the marketing criteria, refining it by applying more powerful analyses, and verifying it by more rigorous and detailed analyses plus selected tests. The design is then reviewed to determine if construction should proceed. Note that at each decision point before go-ahead, the process may recycle to as early a level as appropriate. However, once it enters detailed design the major system parameters are fixed and any problem that arises must be solved within that subprocess. Therefore, preliminary design must produce a thoroughly satisfactory configuration for the total system adequate in all subsystem characteristics, including costs, if a successful product is to result.

Each decision point in Figure 16 provides a management opportunity to affect product development cost and anticipated profit. Figure 17 illustrates how this decision leverage decreases with time; it is at its lowest level when the cost accrual rate is highest. By the time the decision to go ahead is made, only about 25% of the management leverage remains. Although the cost of design is only a small part of the total program cost, things done in design establish future costs. Consequently, the best possible design must be developed in the conceptual and preliminary stages; technical excellence must be achieved by any available technique.

The growth in size, performance, and sophistication of advanced vehicles has increased all aspects of the design process - people, data, cost, time, and risk. The process must be changed so that fewer designers can complete their design tasks sooner. Automation can substantially streamline the process and achieve greater technical depth earlier. Fortunately design technology and computer systems have reached a state of development where rapid advances in automation are possible.

The status of and potential for computerization of the analysis and design modules needed for preliminary design of large supersonic and subsonic commercial transport aircraft is summarized in Figure 18. It shows that much must be done to achieve the full potential of computerization and that a significant fraction of design cannot be coded with the present state of the art. Some analyses used in the design process and the extensive testing now required will never be completely automated. Examination of the detailed design phase shows a similar picture.

The approximate design level applicability of selected programs from Figure 4 is shown in Figure 19. It indicates that programs are available to cover all design levels, but detailed review of these programs would show that many parts of the design process are not computerized and few programs have been integrated into an automated design system. The IPAD system, to be discussed next, is planned to cover all design levels in a single, integrated system. To achieve this goal, however, IPAD must use many analysis and design modules, with several levels of sophistication in each technical area, to cover the total scope of the process from an initial vehicle concept to details of a small structural part in the final configuration.

Integrated Programs for

Aerospace-Vehicle Design (IPAD)

The next step in design automation of the aerospace industry is a computer-aided design system for a complete vehicle. NASA has investigated the feasibility of such a system called Integrated Programs for Aerospace-Vehicle Design (IPAD), Figure 20.[26-30] The major software elements of IPAD are the Executive, the Data Base Manager, the Utilities, and the Operational Modules that function with the operating system of the host computer. Remote terminals with interactive graphic devices and other peripheral equipment are used for designer input and computer output.

In IPAD, the Operational Modules (or Analysis Programs), which perform the technical calculations and operations, can be linked together in the computer in any sequence desired by the designer through the Executive. It is the manager that interfaces with the user, provides him control of the process, and generates instructions for carrying out each part of the task. The Data Base Manager and Utilities are the Executives' staff assistants that collect, organize, store, distribute, and display information, computational activity, and task sequences for effective operation and control of the process. The primary NASA goal in IPAD is the development of the IPAD core software - the Executive, Data Base Manager, and Utilities. NASA will develop a few Operational Modules, as appropriate, but most of them will be programs already available to the IPAD user. IPAD will be constructed so that modifications required to fit existing Operational Modules into the IPAD system will be minimal.

NASA envisions IPAD as a versatile and open-ended, multidisciplinary design tool that can handle a wide variety of design situations and be responsive to the needs of the designer. The objectives are not directed toward fundamental changes in the current design process but toward better and more extensive use of the computer in existing organizations.

Two feasibility studies of the IPAD concept have been made for NASA by The Boeing Commercial Airplane Company and General Dynamics/Convair Aerospace Division. The IPAD system development plans resulting from these studies have been evaluated by NASA with assistance for the U.S. aerospace industry. Development of the core software of an acceptable system is planned to begin in about 1 year. As functioning IPAD elements are developed, they will be released to the U.S. aerospace industry for checkout, evaluation, and use on design projects. During 1980, the first complete IPAD core software system should become operational in U.S. industry.

The potential benefits of IPAD have been evaluated by studying the time and labor utilized in the design process, by determining the savings experienced with currently available systems such as those listed on Figure 4, and by estimating the extension of such savings on small tasks to the total system design task in a large organization. The results are presented in Figure 21 (based on Ref. 29) where a range of values are given because characteristics of particular design projects differ. Manpower costs are classified as technical management, technical judgment, and technical routine with the latter two divided into subgroups. The current distribution of effort and that required with IPAD are given along with the estimated cost savings. As expected, the largest savings accrue in technical routine with no cost savings anticipated in technical management. Total cost savings are estimated at 20% to 60%, depending on the project, with 25% to 90% savings in flow time.

The primary benefit expected from IPAD in the highly competitive, low cost environment that exists today, will be new opportunities to increase the productivity of a design staff by using system software and design methods that increase technical capability and creativity and reduce cost and flow time. Reinvestment of time and cost savings can insure greater technical depth before product fabrication and thereby reduce company risk in new product development. Or the chief designer can choose other combinations of time, cost, and quality of product that meet the needs of this project.

The Future Design Environment

Increased automation and new tools used by the designer will change the nature of the design process, the environment in which the designer works, and the designer himself - all for the better. Individuals will work in a more rewarding situation with less routine, less waiting for data from others, greater depth and scope of individual technical activity, and more opportunity for creativity and innovation.

People normally resist change, and objections are fequently voiced to automation. However, favorable experience with automation has occurred when the computerized procedures helped people do their tasks better or easier. The turbine blade design system, Figure 10, has been enthusiastically received by its users who quickly learned to automate additional design activities and to improve further the design processes used.

One outward manifestation of the changes in the design environment will be the appearance of design work areas. Figure 22 illustrates a concept of how project management might interact with an automated system like IPAD. This IPAD executive room for engineering and management reviews would be equipped with a variety of remote terminals and display devices for review of technical and administrative data. Other arrangements of equipment would be used in other IPAD work areas in which individual specialists and interdisciplinary teams could create, review, and change design concepts and details in trade-off and optimization studies. The physical arrangement required would depend on the type and level of projects under way at a particular time.

Design team activity in an interactive mode with an extensive and complex computer-display-designer system is not fantastic or futuristic. Figure 23 shows a large-screen display that has been tested in an interactive mode in air traffic control research at General Dynamics/Convair. Figure 24 is a photograph of the Mission Control Center at the Lyndon B. Johnson Space Center in Houston, Texas. Although the activities illustrated in Figures 23 and 24 differ from design, particularly in their requirements for quick response to problems in a fast moving operation, there are many similarities. Most features expected in an automated design office are already in use in other activities and much applicable hardware, software, and experience are available.

As automation grows, new needs and opportunities for improvements in computers and design procedures will be identified. To prepare for more effective use of men and computers in design, we should be conducting research on the design process itself. We must learn more about combining men and machines in organizations that will produce the best design quickly and economically. Research on the design process must consider both technical and social factors. The technical side of new analyses, optimization methods, and computer hardware and software, is familiar. The social part is only partly understood. A large design organization is a dynamic social system that cannot be managed well without knowledge of the social forces that constantly buffet it. We should apply the same kinds of intensive analysis to the human side of the design process that we do to vehicle technology. Perhaps social and economic factors are the principal deterrents to more rapid design automation; the technology available today is not being fully exploited.[1-3,31]

Concluding Remarks

Great progress has been made in the evolution of computer-aided analysis and design. Automation technology is ready now to revolutionize the design process in the next decade. Integrated systems of comptuer programs will speed the flow of large quantities of data and decisions, providing the designer with the capability to design much better products faster and cheaper.

Automation will change the character of the design process and its practitioners. They will work in a more rewarding environment in which the computer handles most routine work while they apply their intuition, innovation, creativity, and judgment to broad, complex design problems. Research on the design process, including its social aspects, is needed to define optimum man-to-man and man-to-computer relationships in future automated design organizations.

Continuing escalation of vehicle development and production costs can be slowed, if not reversed, by increased automation. Any organization that expects to lead future design and production of advanced vehicles must automate its design and manufacturing activities as fast as the technology permits.

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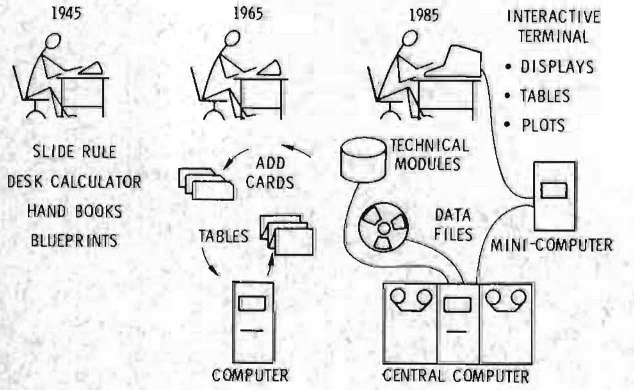

Figure 1. Growth of computerization of engineering.

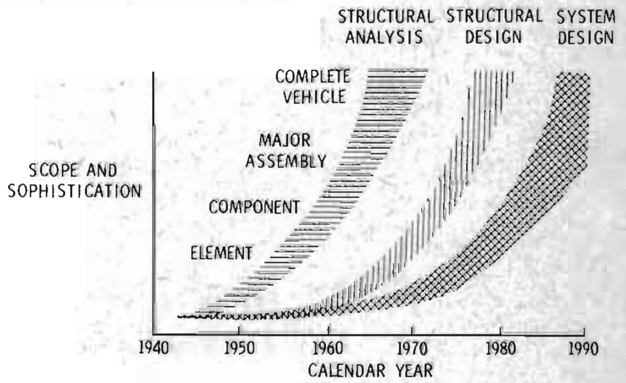

Figure 2. Growth of analysis and design automation.

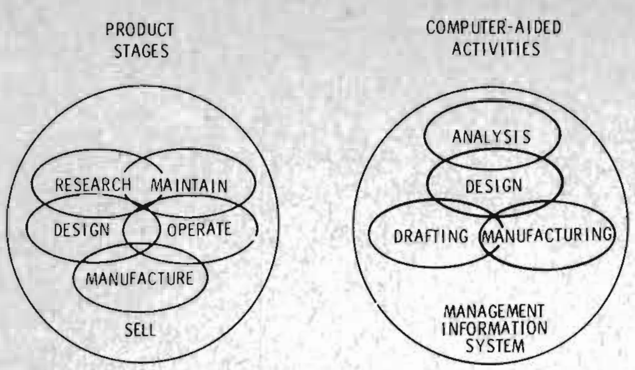

Figure 3. Computer-aided activities in product development.

CONCEPTUAL VEHICLE SYNTHESIS

ACSYNT	NASA - AMES
ADAM	McDONNELL DOUGLAS
AVSYN	RYAN TELEDYNE
CADE	McDONNELL DOUGLAS
CPDS	BOEING
ICAD	USAF - ASD
ODIN	AEROPHYSICS - NASA - USAF
SYNAC	GENERAL DYNAMICS

COMPUTERIZED STRUCTURAL ANALYSIS

NASTRAN	NASA-LANGLEY
ASKA	U OF STUTTGART
FORMAT	USAF-FDL

AUTOMATED STRUCTURAL SIZING

CASD	McDONNELL DOUGLAS
ASOP	GRUMMAN
FADES	NASA - LANGLEY
SPAR	LOCKHEED

INTEGRATED LOADS AND STRUCTURES

ANALYSIS

ATLAS	BOEING
FAMAS	LOCKHEED
IDEAS	GRUMMAN
SPAR	LMSC

SIZING

ARROW	McDONNELL DOUGLAS
RRAPID	NORTH AMERICAN
DAWNS SAVES SWIFT WIDOWAC	NASA - LANGLEY

Figure 4. Progress toward automated design in aerospace.

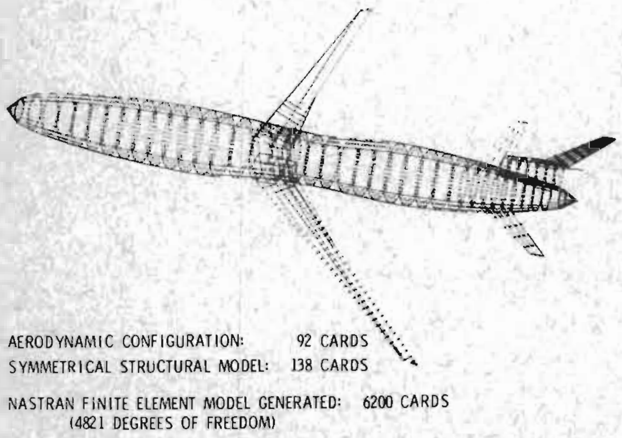

Figure 5. Computer generated finite-element structural model.

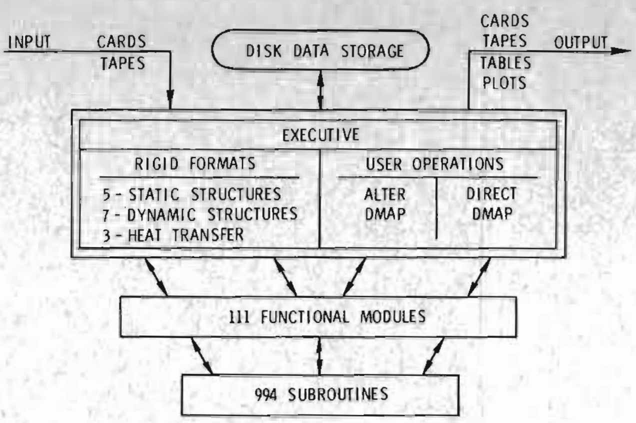

Figure 6. NASA Structural Analysis Program (NASTRAN, Level 15.5).

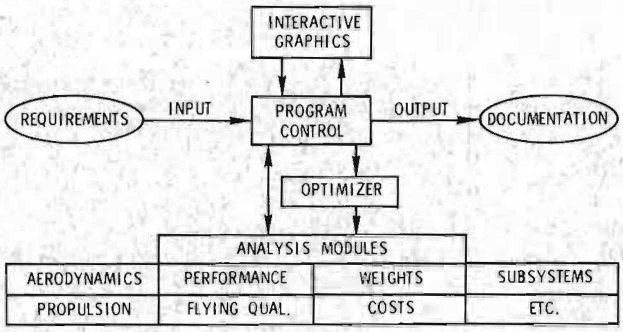

Figure 7. A typical aircraft conceptual design program.

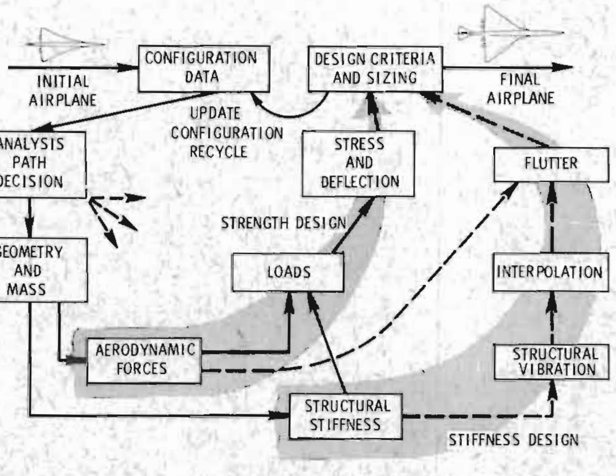

Figure 8. Boeing Integrated Analysis System (ATLAS).

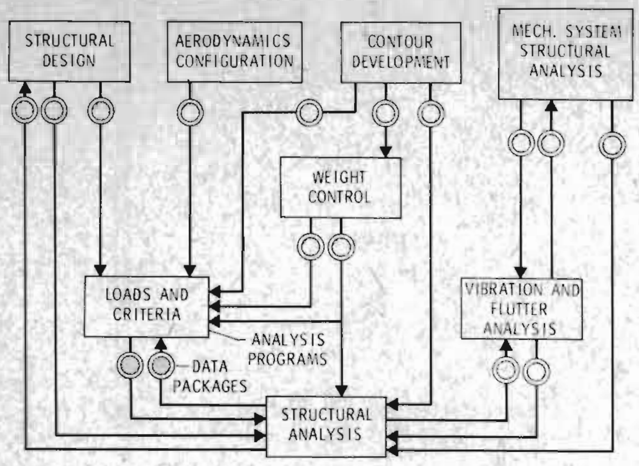

Figure 9. Grumman Integrated Design Analysis System (IDEAS).

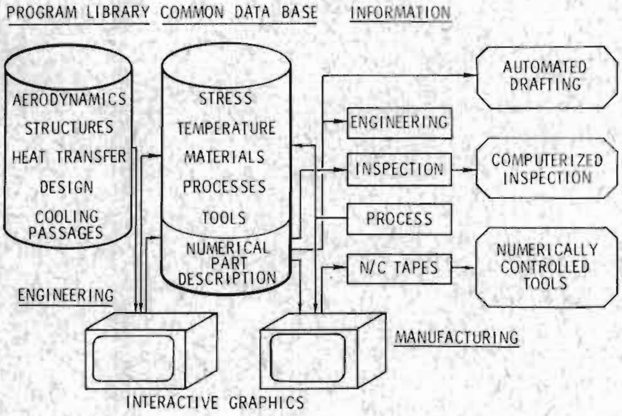

Figure 10. Pratt & Whitney computer-aided design and manufacturing system for cooled gas turbine blades.

U. S. ARMY

- INTEGRATED WEAPONS SYSTEMS SYNTHESIS MODEL (IWSSM) INCLUDES SEVEN COMMODITY CLASS (GUN, VEHICLE, ETC.) VERSIONS

U. S. NAVY

- COMPUTER-AIDED DESIGN ENVIRONMENT (COMRADE)
- INTEGRATED SHIP DESIGN SYSTEM (ISDS)

U. S. MARITIME ADMINISTRATION

- COMPUTER AIDS TO SHIPBUILDING

ARCHITECTS

- ARCHITECTURE MACHINE (URBAN 5)
- COMPUTER-AIDED MODEL FOR ARCHITECTURAL DESIGN (SYNARC)
- SPATIAL ALLOCATION IN DESIGN AND PLANNING (ALOKAT)

CIVIL, BRIDGE & STRUCTURAL ENGINEERS (US & UK)

- COMPUTER-AIDED BUILDING DESIGN SYSTEM
- COMPUTER SYSTEMS FOR BUILDING PLANNING AND DESIGN
- INTEGRATED CIVIL ENGINEERING SYSTEM (ICES)

Figure 11. Progress toward automated design outside aerospace.

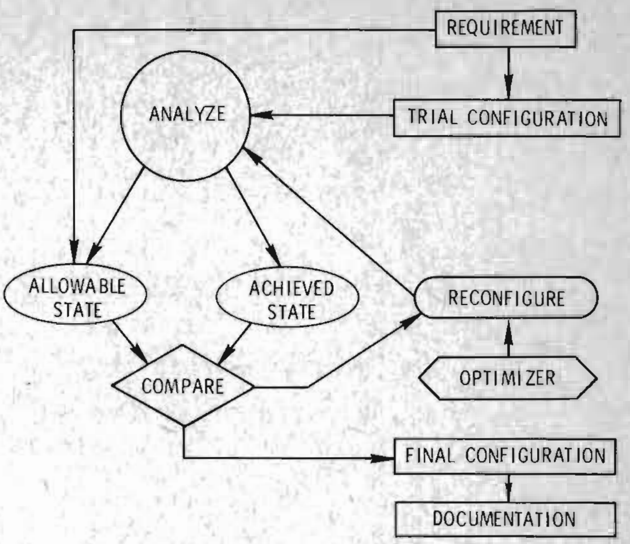

Figure 12. The basic design process.

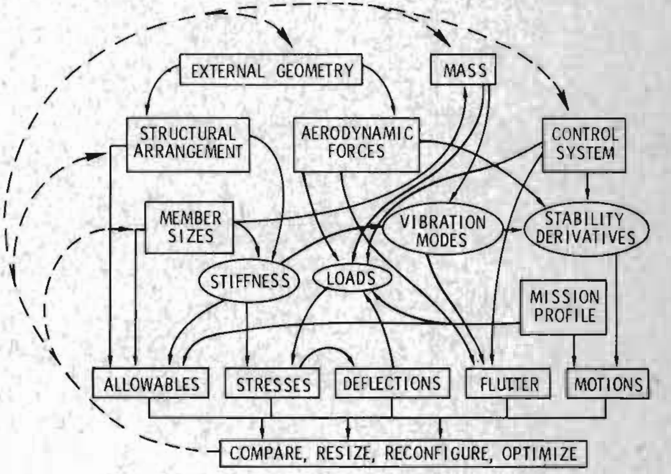

Figure 13. Structural design process for a flexible airplane.

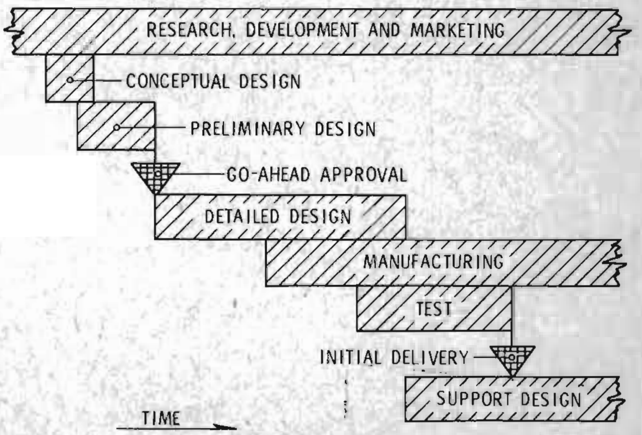

Figure 14. Aerospace product development.

	CONCEPTUAL	PRELIMINARY	DETAILED
• MANPOWER	1 - 5	10 - 200	300 - 2000
• FLOWTIME	1 - 4 WK	3 - 12 MO	1 - 5 YR
• CONFIGURATIONS EXAMINED	30	150	1
• WEIGHT ACCURACY	<92	92 - 98	>98%
• OBJECTIVE	DEFINE MARKET POTENTIAL	SELECT ACCEPTABLE AIRPLANE	PREPARE MANUFACTURING & TEST PLANS
• OUTPUT	POTENTIAL AIRPLANE CONCEPT	VERIFIED AIRPLANE CONFIGURATION	SHOP DATA AND DRAWINGS

Figure 15. Definition of design levels.

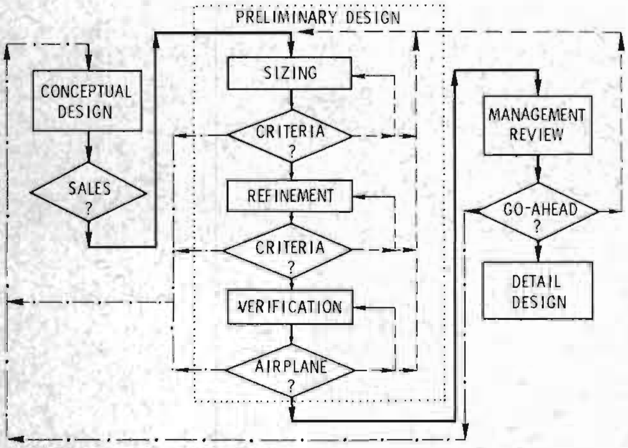

Figure 16. A design decision network.

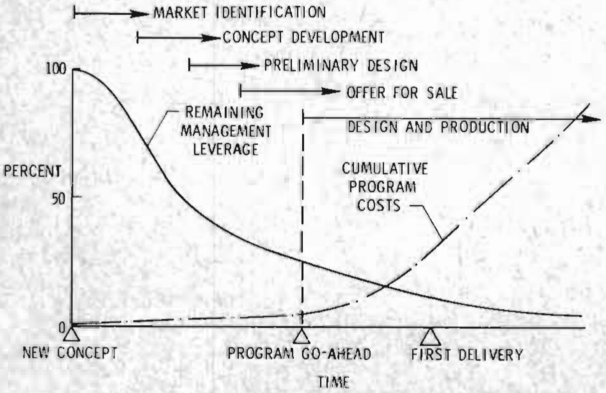

Figure 17. Management opportunities to affect costs during product development.

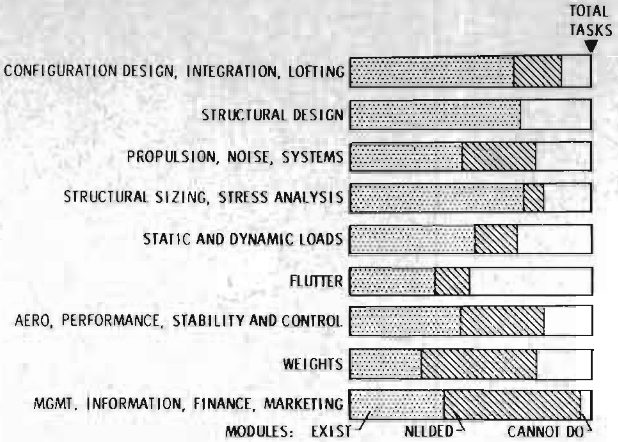

Figure 18. Technical capability for automated preliminary design of subsonic and supersonic commercial transports.

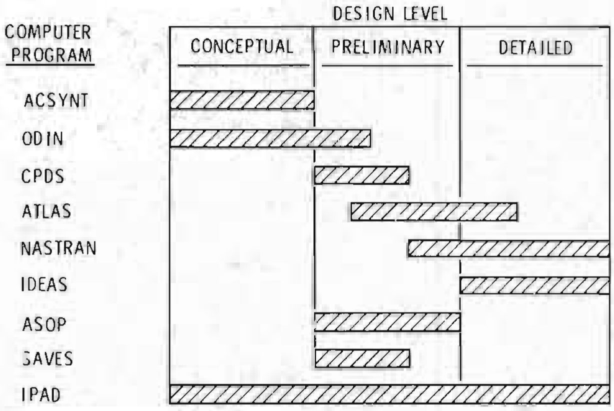

Figure 19. Relationship of aerospace computer programs to design levels.

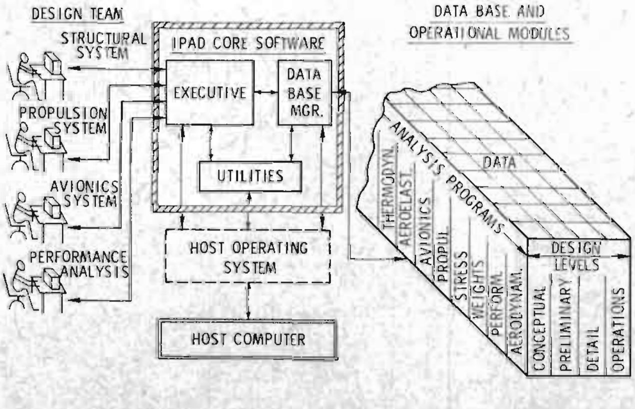

Figure 20. NASA Integrated Programs for Aerospace-Vehicle Design (IPAD).

MANPOWER COST	DISTRIBUTION OF EFFORT CURRENT	DISTRIBUTION OF EFFORT IPAD	IPAD SAVINGS
☐ TECHNICAL MANAGEMENT	6	10 - 15	0%
☐ TECHNICAL JUDGEMENT	34	35 - 65	20%
• PROCEDURE DEVELOPMENT	12		
• CALCULATIONS	9		
• RESULTS EVALUATION	13		
☐ TECHNICAL ROUTINE	60	55 - 20	25 - 90%
• INFORMATION EXCHANGE	26		
• DATA PREPARATION	34		
◇ TOTAL	100	100	20 - 60%
FLOWTIME			25 - 90%

Figure 21. Potential savings from IPAD.

Figure 23. Large-screen interactive display tested in air traffic control research.

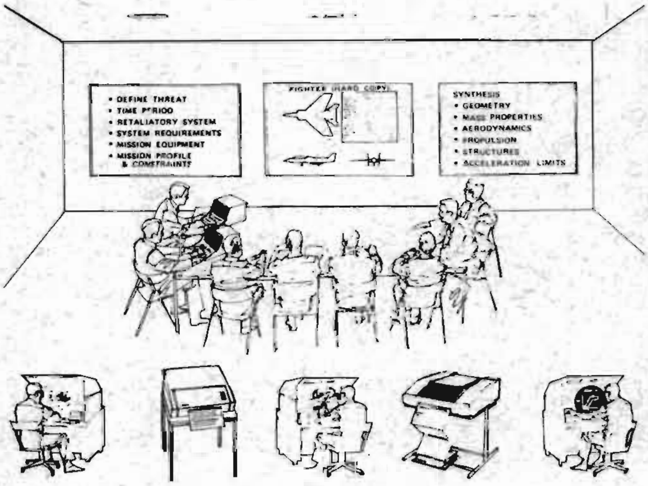

Figure 22. IPAD executive room.

Figure 24. Mission control at NASA JSC.

DISCUSSION

J. Singer (Dept. of Aeronautical Engineering, Technion, I.I.T., Haifa, Israel): 1. Where do tests, such as wind tunnel tests or structural tests of components - which are part of the design process - fit in the system proposed?
2. Would the test links not present bottlenecks in the system, unless more automation is applied to them, too?

M.L. Meyer (The City University, London): Reverting to Prof. Singer's question, if at any stage it is considered necessary to make a model or prototype test for missing data or for reliability, it will take one or several months to obtain reliable results. The consequent mismatch in time between interactive computation and test requirements may make the programme more expensive than foreseen and may create pressures to save on essential new information. How can safe-guards be built into the very impressive programme presented by the author?

Perrier (Avions Marcel Dassault-Breguet, Paris, France): It seems that you have to separate two problems : (1) have a common data base for all the computerized work inside an aerospace manufacturer; the same as if you made communication inside the computer for aerodynamics, structure, flutter... (2) to speed the conception of vehicle - and it is a question of where are the critical points in the sense of PERT - after that you have to choose the best hardware for solving the problems, interactive or not.

R.R. Heldenfels: My paper is concerned primarily with computerization of the information flow and processing that takes place during the design process. Testing and other hardware activities, that cannot be computerized, are essential parts of the design process diagrammed in Figures 14 and 16. Data from experiments is expected to be placed in the design data base, Figure 20, and used, just like much similar information from previous tests, to make empirical engineering analyses whenever theory is inadequate.

In some stages of the design, the critical path could be the test program so that the potential savings from IPAD may not be realized fully unless schedules can be altered. With an automated design process, the required test programs should be defined sooner and design changes required by the test results should be accomplished faster.

In a case where the testing requires much longer times than the required parallel computerized activity, the generation of new experimental data could be discouraged. The automated system itself cannot prevent such a decision since it is the "servant" of the design team and not the decision maker. The project director must control the automated activity and make the judgemental decisions. The automated system can aid him in this by displaying data and numerical evaluations quickly upon demand. Note that no reductions in time devoted to technical management is projected with IPAD, Figure 21.