

CR-132391  
Vol. 1B

(NASA-CR-132391) FEASIBILITY STUDY OF AN INTEGRATED PROGRAM FOR AEROSPACE VEHICLE DESIGN (IPAD). VOLUME 1B: CONCISE REVIEW (Boeing Commercial Airplane Co., Seattle) 211 p HC A10/MF A01	N78-16011  Unclas CSCI 01C G3/02 02565
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**FEASIBILITY STUDY OF AN INTEGRATED  
PROGRAM FOR AEROSPACE VEHICLE DESIGN (IPAD)**

Volume IB: Concise Review

D6-60181-1B

September 21, 1973

Publicly Released  
February 10, 1978



Prepared under Contract No. NAS1-11441 by  
Boeing Commercial Airplane Company  
P.O. Box 3707  
Seattle, Washington 98124

for

Langley Research Center  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



ERRATA PAGE

D6-60181-1B

On Page 34, Figure 2.16, title should read "HUMAN INVOLVEMENT"

On Page 108, right-hand side of page, notes should read:

"From nodes CA, HA...See figure 2.50"

and

"From nodes G, H...See figure 2.50"

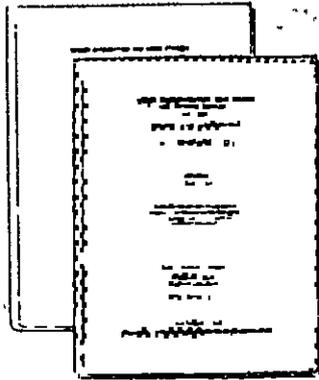
On page B32, Paragraph B.2.4, first sentence should read:

"Figure 2.3 illustrated...."

1 Report No DA-11441-1B	2 Government Accession No	3 Recipient's Catalog No	
4 Title and Subtitle FEASIBILITY STUDY OF AN INTEGRATED PROGRAM FOR AEROSPACE VEHICLE DESIGN (IPAD VOLUME IB CONCISE REVIEW OF IPAD FEASIBILITY STUDY		5 Report Date September 21, 1973	6 Performing Organization Code
		8 Performing Organization Report No D6-60181-1B	10 Work Unit No
7 Author(s) R. E. Miller, Jr.                      A. S. Kawaguchi J. W. Southall                         D. D. Redhed		11 Contract or Grant No NAS1-11441	
9 Performing Organization Name and Address Boeing Commercial Airplane Company P. O. Box 3707 Seattle, WA 98124		13 Type of Report and Period Covered Contractor Report	
		14 Sponsoring Agency Code	
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		15 Supplementary Notes Project Manager, Dr. R. E. Fulton, Structures and Dynamics Division, NASA Langley Research Center, Hampton, Virginia 23365	
16 Abstract Volume IB of the Boeing report on the IPAD feasibility study is a concise review of the following detail reports: Volume II - The design Process; Volume III - Support of the Design Process; Volume IV - IPAD System Design; Volume V - Catalog of IPAD Technical Program Elements; Volume VI - IPAD System Development and Operation; Volume VII - IPAD Benefits and Impact.  The approach used to define the design process is described. Major activities performed during the product development cycle are identified. The computer system requirements necessary to support the design process are given as computational requirements of the host system, technical program elements and system features.  The IPAD computer system design is presented as concepts, a functional description and an organizational diagram of its major components. The cost and schedules and a three phase plan for IPAD implementation are presented.  The benefits and impact of IPAD technology are discussed.			
17 Key Words (Suggested by Author(s)) Design Process Computer System Design Data Base Management		18 Distribution Statement	
19 Security Classif (of this report) Unclassified	20 Security Classif (of this page) Unclassified	21 No of Pages 211	22 Price* ██████████

**FEASIBILITY STUDY OF AN INTEGRATED  
PROGRAM FOR AEROSPACE VEHICLE DESIGN (IPAD)**

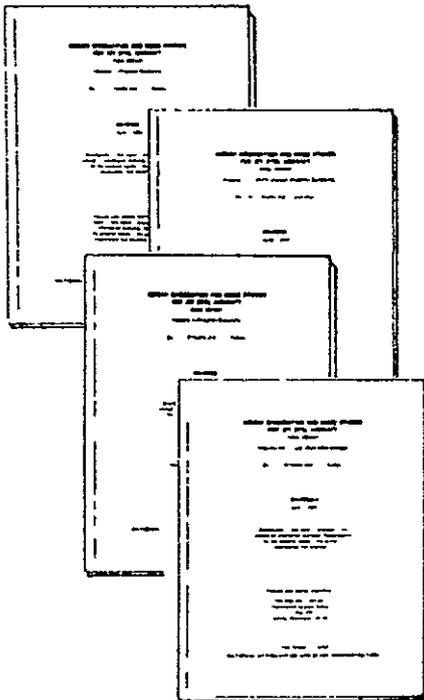
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**Volume IA**  
Summary of IPAD Feasibility Study  
D6-60181-1A

**Volume IB**  
Concise Review of IPAD Feasibility Study  
D6-60181-1B

**Part I—Final Report, Tasks 1 and 2**



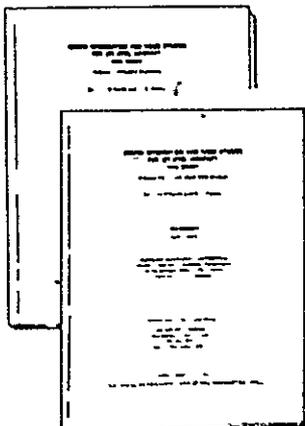
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**Volume III**  
Support of the Design Process  
D6-60181-3

**Volume IV**  
IPAD System Design  
D6-60181-4

**Volume V**  
Catalog of IPAD Technical Program Elements  
D6-60181-5

**Part II—Final Report, Tasks 3 through 8**



**Volume VI**  
IPAD System Development and Operation  
D6-60181-6

**Volume VII**  
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## SUMMARY

The intent of this feasibility study of an integrated program for aerospace vehicle design was to:

- focus on the product design process;
- seek feasible ways to improve utilization of men and computers in their support of the design process;
- design a hardware/software system to support, in general, design processes;
- prepare implementation plans and assess impact and benefits of use of such a new system in product design.

This volume represents a concise review of all the IPAD study work which is reported in seven other volumes.

Volume IA	Summary of IPAD
Volume II	The Design Process
Volume III	Support of the Design Process
Volume IV	IPAD System Design
Volume V	Catalog of IPAD Technical Program Elements
Volume VI	IPAD System Development and Operation
Volume VII	IPAD Benefits and Impact

This volume is organized along the lines by which the IPAD work developed. As such it reviews first the work on the design process identification.

During this phase of the work, case studies of actual airplane design were utilized. Two projects were chosen for study. These were a subsonic commercial transport (Project 1), and a supersonic commercial transport (Project 2). In addition, a brief study was made of a naval hydrofoil. Prior to establishing the design process for these Projects in detail, the general environment was divided into nine levels, arranged into three sections. These levels provide the interface with the total time related activities for aerospace products and provide a framework for control of the technical activities.

Four Levels are concerned with the preliminary design of the product. The four Levels in this section are: Design Mission and Criteria Selection, Design Sizing, Design Refinement, and Design Verification. Detail design and manufacture of the product, is also comprised of four Levels. They are: Product Detail Design, Product Manufacture, Product

Verification and Product Support. For each of these Levels, the extent of design and analysis, the computational resources required, and the resultant accuracy of the answers will be known to management. After review of the results of each Level, management may commit the design sequences to the next Level. One additional Level was identified for research from which procedures and methods will be developed to support advancement of technology.

The design networks for the Preliminary Design Levels are developed in detail for Projects 1 and 2. Each element of technical code, denoted Technical Program Element, is identified and is presented in Volume V. This catalog provides a list of required technical capabilities, and supports the determination of computing hardware requirements.

The information drawn from the study of Projects 1 and 2 is used to prepare requirements for the computing support of the design process.

These user requirements, to be satisfied by the hardware/software system design, are described in terms of user interface functions for maintaining the data and code bases, preparing to do a job, executing the job and examining the results. A user language is developed as a further means of describing this interface. The user-terminal environment is discussed and suggestions are presented for peripheral equipment and the manner in which the equipment should be arranged. The need for a Management Information System is presented. The required computational capabilities of the host hardware are developed from the design networks of the aircraft case studies.

The IPAD system design is based upon the requirements identified in the aircraft design process and computational requirements studies. Tables 1 through 4 in section 2.4.6.3 summarize the relationship of these requirements to the IPAD system design features, the IPAD software requirements and host operating system requirements.

These requirements reflect the user's environment. His tasks are not completed in a day or with a single run on the computer. His interface with the computer should be with language and devices that give him capabilities he needs without loading him with jargon and irrelevancies. He works in large organizations where free communication is essential. But he also works with vast volumes of data that must be controlled and kept in a high state of integrity. The organization he works for has a vested interest in his work and an interest in maintaining some security on the results of his work. At the same time, the user is a creative individual and requires some

privacy for thought and invention. The product he is designing is highly complex and he must work under rigid schedules. Reliability of the computing system and the data base is critical. These factors are dealt with in the design of the IPAD system.

The IPAD system is designed to manage data on the project level. Project data and application software are treated as an entry in the data base. The organization of application software into sequences to perform some particular task is supported by executive type routines. The execution of module sequences and the handling of data are supported by the host operating system and the IPAD data manager. Personal terminals are the principal interface and dialogue language is the principal means of communication.

Top-down structured programming is the method used for system design. In this method, the system is systematically refined from the most general statement of requirements to the most specific. The IPAD system design was refined to where host system hardware and operating system software, not yet specified, began to have a major impact.

Human factors, security, and standards were studied in detail and recommendations are given. A survey was made of manufacturers of large scale computing hardware to obtain performance and size characteristics of basic hardware components. The results of this survey were utilized to formulate a CDC 6600 (CYBER 74) and an IBM 370/168 configuration adequate for a large aircraft design project.

The implementation strategy proposes the development of a baseline system for delivery to NASA/Langley Research Center and a parallel effort to transfer IPAD technology from the development environment to the industrial aerospace-vehicle design environment. A three phase plan is presented, the first phase of which results in an initial operational system in four years.

The Phase 1 implementation of IPAD will provide a suitable balance between technical capability and system capability. Adequate technical modules will be available to support development and checkout of the IPAD concepts on some meaningful design case studies. The Phase 1 implementation of IPAD will provide some analysis capability for Project 1 subsonic class airplanes (see Volume II). This technical capability will provide the basis for vehicle analysis/design calibration since it will be possible to relate the subsonic class of airplane to both existing in-service airplanes and to studies which are continually in progress for this class of airplane. The Phase

1 implementation will also provide some analysis capability for Project 2 supersonic class airplanes (see Volume II). This technical capability will orient IPAD to future vehicle design problems. It is expected that technical capability for Phases 2 and 3 will reflect NASA and industry experience with Phase 1 capability.

The initial operational system developed during Phase 1 will provide the principal IPAD design feature of continuity of task and time. Continuity will be supported through the development of the user/IPAD interface, and subtask and community libraries. During Phase 2, the system will be extended to include limited information control through the capability of defining project plans and reports. The full capability of the IPAD system design will be completed during Phase 3. This includes full support of project planning and reporting, specialized interactive capability, and full privacy and security provisions.

The successful transfer of IPAD technology from the NASA development environment to the industrial problem solving environment is mandatory. A technology transfer strategy which considers both the commercial, proprietary interests of industry and the broad public interests of NASA is presented as follows:

NASA will contract for the evaluation of the IPAD system software in realistic product design studies,

Contractors will be required to perform these studies utilizing the IPAD system with the contractors own technical modules and deliver only reports covering technical and economic evaluation of their use of IPAD.

Cost and schedule estimates for two implementation plans are presented. The first plan, in which Phases 1, 2 and 3 are developed sequentially, requires nearly nine years and 13.2 million dollars for full IPAD development. The alternate plan, in which Phase 1, 2 and 3 development is overlapped, results in a fully developed IPAD in six years, but the cost is increased to 13.7 million dollars. For both plans, Phase 1 implementation is expected to be completed in four years and is estimated to cost 6 million dollars for IPAD system development and 3 million dollars for the development of the technical modules.

The primary benefit of IPAD will be increased productivity of the designer. This increased productivity will accumulate to better product design as time and cost savings are reinvested into the design process. It will become visible at the company level as (a) accumulated cost and flowtime savings and (b)

'reduced' risk or increased competitiveness in the market place. At the national level, increased productivity will enhance the competitiveness of United States industry in the world market.

These conclusions on potential benefits of IPAD technology are developed through the following process:

- an analysis of time and labor utilization in the design process,
- an evaluation of flowtime and cost savings being experienced using currently available systems,
- an extension of these savings to IPAD technology,
- a projection of the effect of these savings upon designer productivity and company effectiveness,
- a projection of IPAD technology as a national resource.

The emerging concept of the computer as the basic handling device for all information, not just that associated with calculations, is causing the emergence of an information technology. Information technology is the combined application of the computer, telecommunications, and methodology to information handling. IPAD technology is essentially information technology. The primary impact will be:

- Acceptance and conversion to information technology as the basic method of handling information.
- A trend towards centralization in task and organizational structure.
- The impact of this trend upon management and technical personnel.

IPAD executive and data base management software, associated with information handling, is expected to be of such a general nature, that it will have wide application such as marine, land transportation, construction industries, and finance.

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## 1.0 INTRODUCTION

This document is a concise review intended to familiarize that reader who has had some background in computing and will serve as a guide to locate additional information on the various aspects of the IPAD work contained in Volume II through VII as noted on page (ii). The reader is referred to Volume IA for a summary of the state-of-the-art and the IPAD work.

Section 2 of this volume contains a review of Part 1 and Part 2 of the IPAD feasibility study. The purpose of Part 1 was to identify a design process suitable for an integrated program for aerospace vehicle design (IPAD), and to develop a design of an IPAD System to support the design process. The purpose of Part 2 was to assess potential benefits, impact and possible alternate uses for IPAD and to develop a strategy for IPAD implementation, including development cost estimates and operating cost estimates. The review covers development of the general design process and its required computing support, the IPAD System requirements and concepts, the benefits and impact of an IPAD System and finally the implementation aspects.

Section 3 conclusions and Section 4 recommendations are repeated from Volume IA.

Appendix A contains the tables of contents for all volumes in the study, Appendix B contains a summary review of the design process for the preliminary design phase of the products studied and Appendix C contains the answers to all task questions.

## 2.0 STUDY RESULTS

### 2.1 THE DESIGN PROCESS

Task 1 of the IPAD feasibility study was to establish the extent to which IPAD should support the design process. The technique to achieve this goal was to examine two aerospace products in some detail, and to characterize the tasks, activities, information and decision-making processes involved. These case studies provided the IPAD team of design and analysis engineers with the basis for discussion of interdisciplinary problems, for appraisal of computational capabilities and for identification of strategies for design iterations and optimization. From these specific case studies, the generalized requirements for an IPAD environment have been developed.

The case studies selected involved products for which a large base of design and analysis experience was available within Boeing. The first project was a subsonic commercial transport. The total design involvement, from research through preliminary and detail design through manufacture to use by the customer was studied to characterize the design process. The maximum detail was developed for the preliminary design phase for which detailed design task and decision networks were developed and the computer programs required to support the networks were identified and collected into a catalog. A generalized design network was developed for the detail design phase of a product.

The second project was a supersonic commercial transport, which was examined to the same degree as was the first project. The design task and decision networks and the related catalog of computer programs were also documented.

A naval hydrofoil was considered in less detail and after some preliminary evaluation, it was determined that this project would be essentially of the same nature, but somewhat smaller, than the first project. Therefore, only a partial design process was developed.

A summary of the design process for these projects is presented in Appendix B of this volume and a detailed description is presented in volume II. The following sections summarize the major elements of the design process.

### 2.1.1 Typical Product Development Cycle

Figure 2.1 shows a sequence of the major development activities of the product development cycle. The four continuous activities at the top form the industrial background from which the product development originates. The top line is the research and development to provide new design concepts and technology. The resource control of a company provides its capability to support a new product in terms of manpower, facilities and finances. The marketing, finance, and preliminary design groups combine these resources with continuing studies of new products. Management will authorize a preliminary design effort when these marketing studies reveal a product with a large enough sales potential to warrant further study. The process then enters several successive stages of design which lead to firm offers for the sale of the product to potential customers. If sufficient sales response is generated by the potential product, management will authorize a go-ahead for detail design, manufacture, verification and support.

Figure 2.1 also shows that a potential product may fail to survive the preliminary design process. Some may be outmoded by advancing technology, and some may have been based on a poor assessment of the market potential.

The development cycle for a typical subsonic transport aircraft will require several years from preliminary design go-ahead through airplane type certification and the preliminary design phase will require approximately 25 to 30% of the total development cycle time. More complex products such as a supersonic transport and a space shuttle will require several more years and the preliminary design effort may require a larger percentage of the development cycle. IPAD must be capable of accepting these time related highly flexible development processes and must provide continuity of the data development which is required to support integrated design task relationships.

In summary, the primary functions of the design process are as follows:

- Provide management with control of projects, plans, schedules and budget;
- Provide management with information such as technical capability, progress reports and resources used, etc.;
- Support design and analysis functions such as mathematical modeling of the configuration, flexible sequence of tasks, interface with other organizations and departments, etc.;

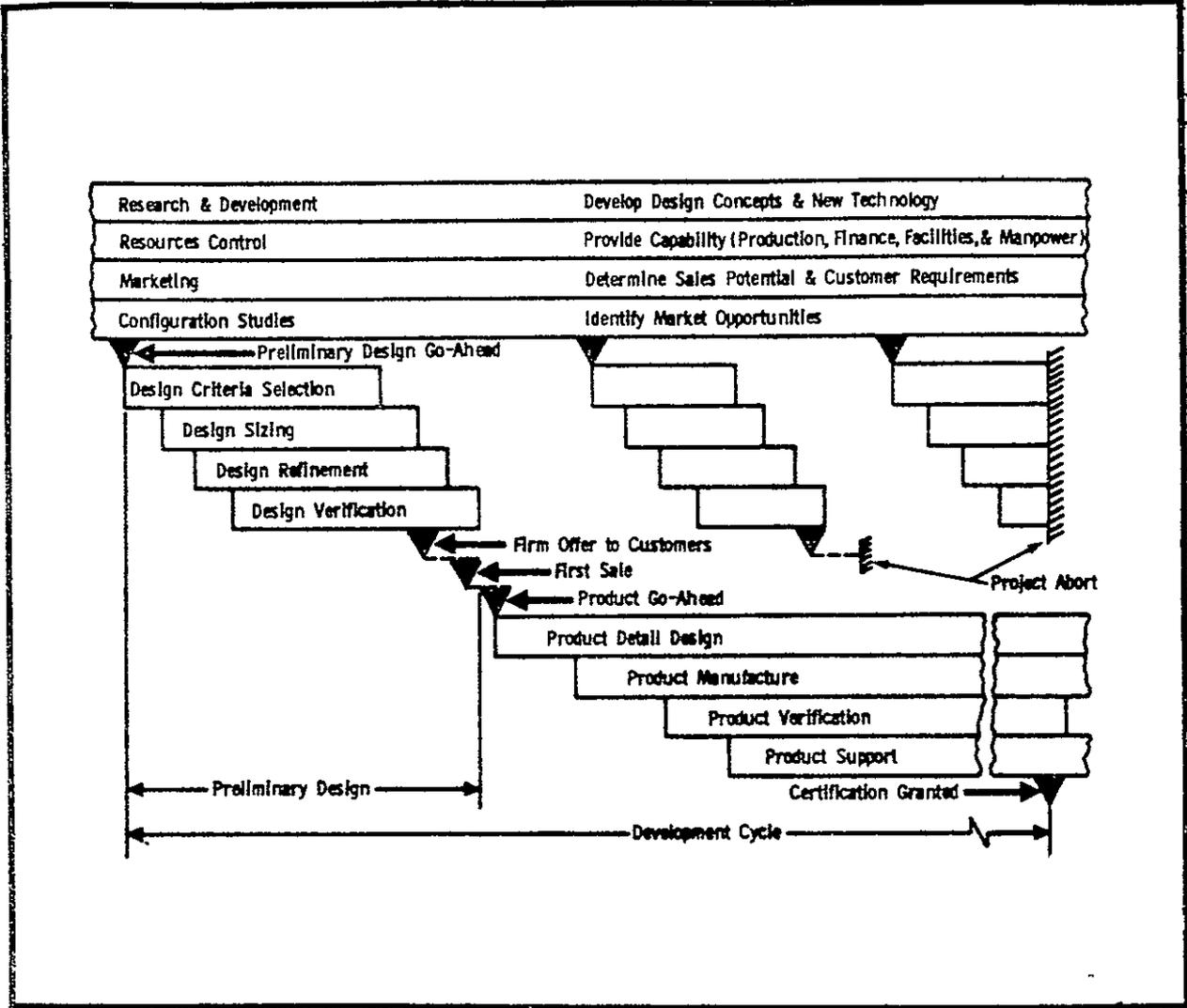


Figure 2.1 Development Cycle - Typical Aerospace Product

- Support the capability to respond to continuing changes through feedback and update and to identify any resulting schedule delays;
- Support data management with automated capability for such items as data storage, data transfer, data retrieval, data records, etc.;
- Support evaluation of competing products with comparative display of such items as performance, efficiency, operating costs, etc.

### 2.1.2 Product Design Levels

The subsequent description of product levels is to be interpreted only as a basis for description of the design process. In no way is IPAD limited to, or constrained to supporting users in the specific manner as described. Such specific uses of IPAD as may evolve may be as arbitrary as the need demands.

The basis for organization of the design process study was to relate the design process to the product development cycle. This identified a hierarchy of time related activities required to design aerospace vehicles. Design control will be provided in IPAD by dividing the development of technical information into levels.

It was considered essential to group these activities in a manner which permits rigorous management control of the engineering resources required to identify a potential product and to systematically develop a technical definition of that product. In this context, generalized design levels were developed to include both phasing which provides the required schedule (time) relationships and increasing depth of design and analysis information which provides the required computing and engineering cost control relationships.

The characterization of the design process by levels provides a subdivision of the environment within which IPAD will relate to a product and its design process. During the study of each design process this division by levels was found to be product independent for the aerospace class of product, and that the levels could serve as a guide for the classes of man and machine involvement with a product. It was considered essential to include all of the design activities of the product development cycle which use or could use computer support and to establish a relationship with all other activities which influence a product design such as marketing, finance, and

manufacturing. The number of levels required to control the development of a product design may vary for different products. Some products may require less and, for example, some very complex spacecraft systems may require more. As IPAD use evolves, more levels may be added for aircraft design. However, for the purpose of the IPAD feasibility study, the generalized levels shown on figure 2.2 were used to develop the IPAD design process. There are nine product levels divided into three sections.

The first section is comprised only of Level I, Continuing Research. This represents the research activities of a long-term nature that are done independent of IPAD. In the IPAD environment, these research activities will be continually monitored to provide new design procedures, technical analysis capabilities and to improve the technology data bases. Both computer programs and data will be received into IPAD.

The second section is made up of the Preliminary Design Levels. The four levels in this section are design criteria selection, design sizing, design refinement and design verification. Design goals for the four levels must be chosen to balance analysis versus computing time. This will prevent a conflict between the level of analysis and computer time. Control of the required engineering resources is the principal criterion for the establishment of the preliminary design levels. Accordingly, the activities relating to preliminary design will be collected by types of activities and hierarchies of analysis capabilities to achieve the objective of meaningful design results in a usable time period. Thus the capability will be provided to develop a product design and consistent data base definition in a time sequence which is responsive to management control of costs, schedules and technical depth of analysis for each competing configuration under investigation. To further emphasize the time relationship, activities which require long flow times such as wind tunnel testing were placed in Level V. Using this concept a manager may develop very complete technical data on several configurations before selecting the specific configurations to be tested in the wind tunnel which requires approximately three months flowtime and a large budget expenditure.

Once the design has been committed to Level VI, the activity enters the third section in the IPAD design process. The four levels in this section are detail design, manufacture, verification and in-service support of the product. These levels are collectively referred to as the Product Levels and are parallel activities that continue as required for the life of the product. Within each product level sequential activities

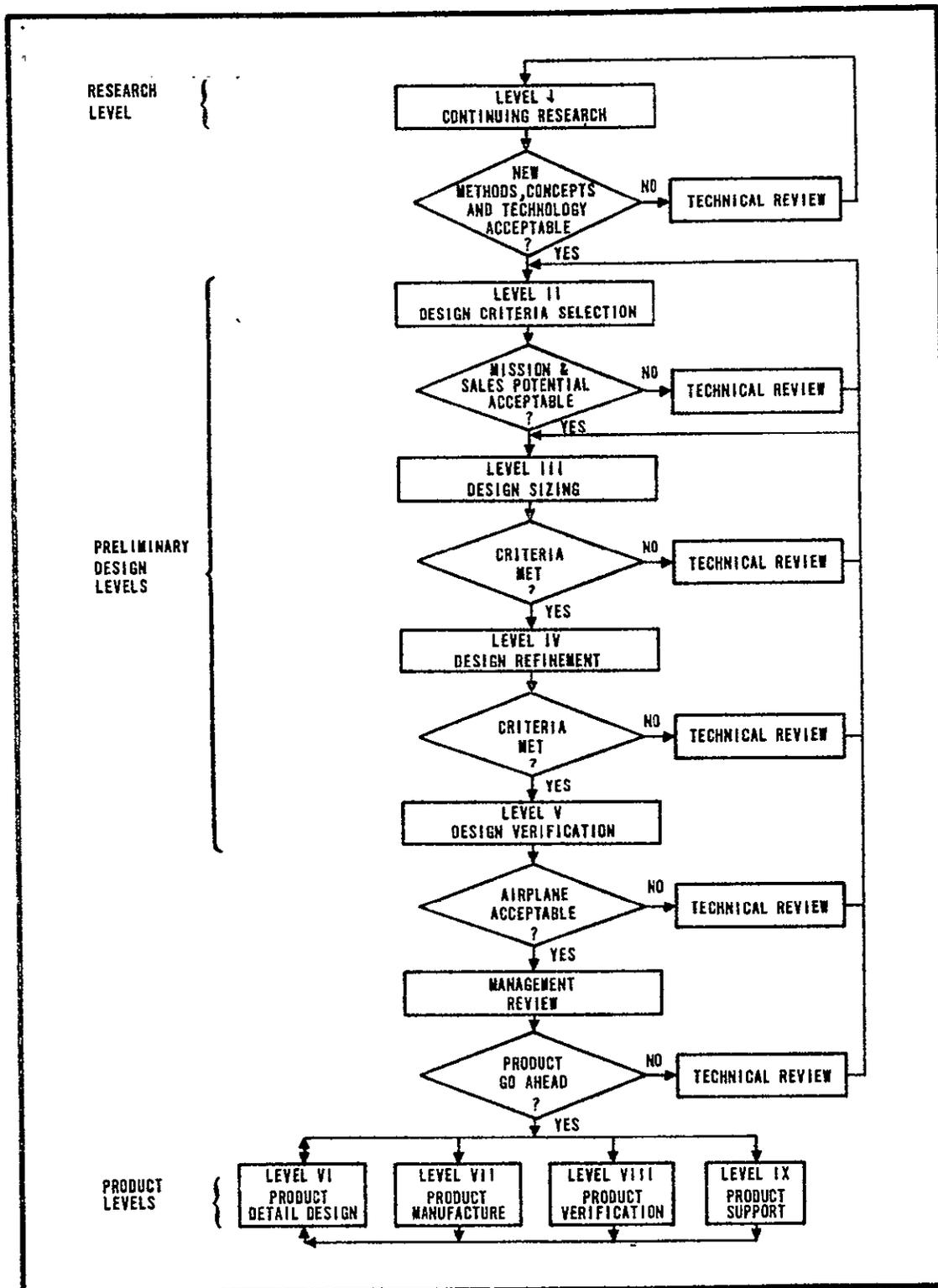


Figure 2.2 IPAD Product Design Levels

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will occur and the control will be similar to the preliminary design levels.

For the airplane studies, the technical design and analysis functions of Level II and III identify the major items which influence the gross sizing of the vehicle and match its design configuration size to the mission and design requirements. These levels treat the configuration as a unit and the propulsion analysis deals only with development of engine thrust and engine cycle requirements or matching the configuration to a specific engine. Both cases require a pre-selected propulsion design concept which includes number and location of the engines. Level IV refines the sized configuration by developing a more complete definition of structure and non-structure items and by providing greater confidence thru increased analysis. This level also treats the configuration as a unit and a parallel propulsion study is conducted to monitor the propulsion installation and performance requirements. The propulsion study determines the feasibility of meeting the propulsion requirements with an existing engine or by a proposed new engine and that the nacelle integration is valid.

The configuration development is finalized in Level V and the product detail design is finalized in Level VI. The detail in both Levels V and VI require that the design and analysis activities be divided by major components and systems, thus, providing management control and responsibilities for the design activities. Therefore, design groups consisting of the wing, body, empennage, propulsion, landing gear, payloads, systems, etc., are established and each group is supported with the appropriate analysis activities.

Finally, competing configurations may be evaluated for relative merit based on Level II and Level III data provided that similarity between the configurations is sufficient to insure that consistent analysis techniques have been used. Therefore, only the best configuration of each type will be selected for configuration refinement in Level IV and subsequent configuration verification in Level V.

### 2.1.3 Design Networks

Design networks were identified for each IPAD level. These networks are used to plan design logic and to sequence the solution of technical problems so that the required information would be available to support the design process. The networks are presented in Volume II and represent a formal effort to organize the entire design process into an identified set of tasks. This was accomplished by a group of experienced people.

These people, based on their experience and interviews with others in their fields, identified many of these tasks. For two of the case studies, a subsonic and a supersonic commercial transport, the tasks were identified in detail for the preliminary design and analysis activities and in general for the detail design and analysis activities. For the third case study, a naval hydrofoil, only the tasks for part of the preliminary design and analysis activities were identified.

The procedure used for the preliminary design studies was to identify the tasks which were required to meet the following general goals:

- determine market and design requirements;
  - flowtime - 2 to 3 days (subsonic and supersonic transport)
- size the product and determine its economics;
  - flowtime - 2 to 3 weeks (subsonic transport)  
- 4 to 5 weeks (supersonic transport)
- refine the design and analysis to increase the accuracy of the performance, weight and economic predictions;
  - flowtime - 1 to 2 months (subsonic transport)  
- 2 to 4 months (supersonic transport)
- verify the design and analysis with specific test data to increase confidence in the solution.
  - flowtime - 1.5 to 3 months (subsonic transport)  
- 3 to 6 months (supersonic transport)

The tasks required to achieve these goals were divided into the four levels of preliminary design and a logical sequence of the tasks was developed within each level. In practice, the design tasks can be arbitrarily ordered in IPAD and interaction between levels is anticipated. Provisions were identified within each level to loop the sequence of tasks to achieve a converged design solution. Major decision goals and flowtime goals were also established for each preliminary design level and are presented in Volumes II and III. Other considerations included the required modeling of geometry for technical depth and the quality and accuracy of the analysis for confidence.

For the subsonic and supersonic transport case studies, the capability to support the preliminary design networks with computer programs was identified and a catalog of computer

programs was prepared. Also, in a few sample cases, computer programs were identified for the product levels in group three. The catalog of programs is presented in Volume V. Figure 2.3 is a sample page taken from the Level IV networks for the Project 2 Supersonic Commercial Transport. Based on a common understanding of individual tasks established during the development of these project networks, team members prepared narrative descriptions of activities identified with each network block. These narratives generally describe the application of particular technical elements in performing the specific tasks.

The concepts of engineering cost control (cost-to-design), and identification of production costs and direct operating costs have been integrated into the design networks. Engineering costs are controlled by management reviews throughout the networks which include identification of cost performance relative to budget. Goals for cost-to-produce are identified as an initial requirement for each problem under investigation and will become cost targets. Each management review will compare production cost estimates to the cost targets. Cost-to-support estimates are included in all the direct operating cost (DOC) evaluations.

#### 2.1.4 Technical Elements for Design and Analysis

Technical Elements required to perform the desired design and analysis function have been identified in detail for a subsonic transport and a supersonic transport. The elements of technical computer code were denoted Technical Program Elements and were identified from a survey conducted within Boeing for the preliminary design levels for each of these studies. The Technical Program Elements were collected into a catalog and are presented in Volume V. The catalog includes a reference to usage and status of each Technical Program Element. Figure 2.4 is a sample page taken from Volume V. The reference to the network block numbers shows the proposed usage of nine of the Boeing computer programs which are in current use to support the design and analysis of the flight control system. Each Technical Program Element may be used one or more times for each project and also on one or both projects. However, the source code will only be stored once in the data base which will reduce the required size of the data base. The status of each program is shown in one or more of three categories; 1, operational, 2, in development and 3, not programmed.

Approximately 300 Technical Program Elements are identified to support the detail design networks for Projects 1 and 2. These have been summarized in the Catalog. Figure 2.5 is a

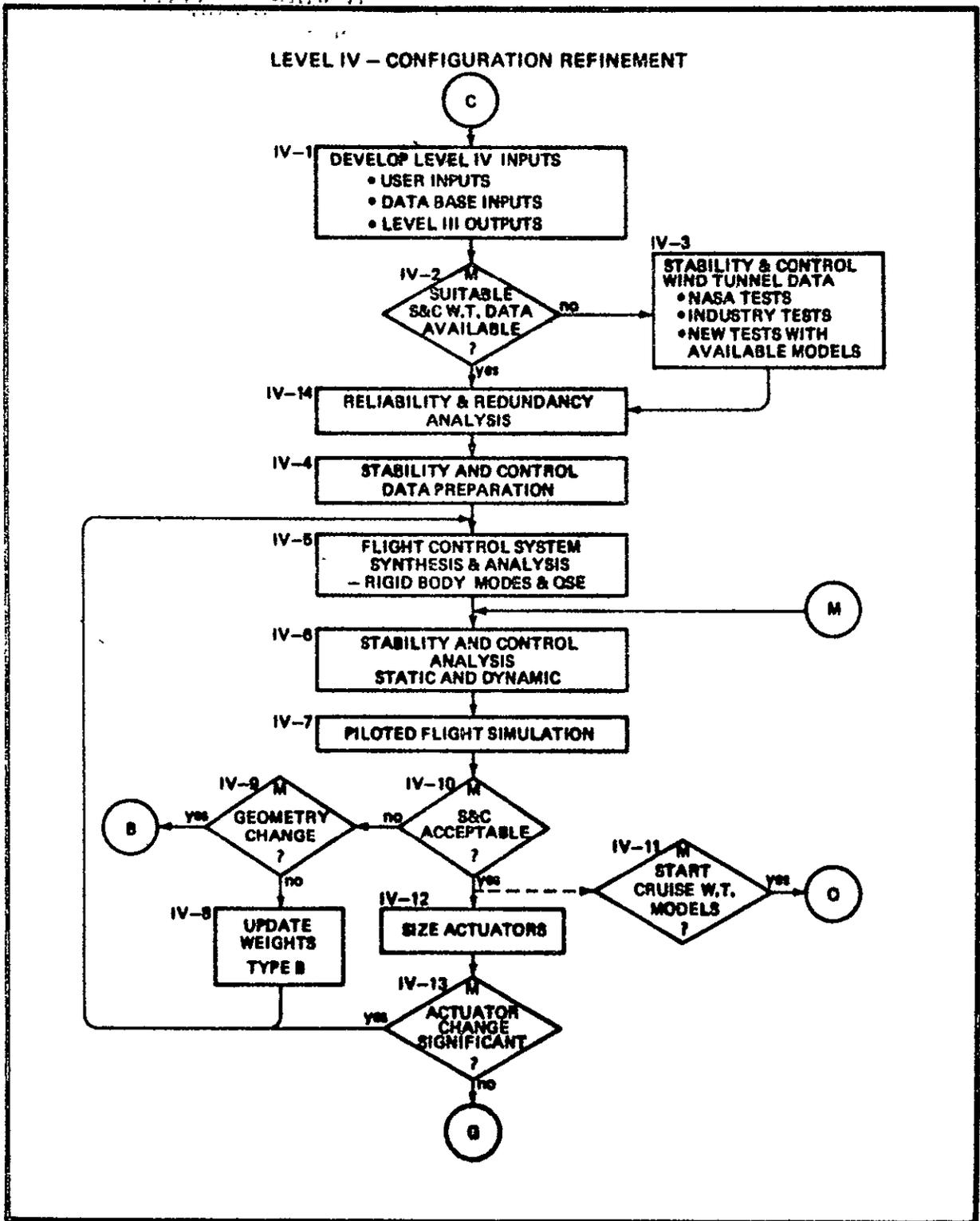


Figure 2.3 Example - Design Network - Project 2

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FCS

USAGE & STATUS OF TECHNICAL PROGRAM ELEMENTS  
FLIGHT CONTROLS

NO.	TITLE	STATUS			APPEARS IN DESIGN NETWORK BLOCK NUMBERS :	
		1	2	3	PROJECT 1 SUBSONIC TRANSPORT	PROJECT 2 SUPERSONIC TRANSPORT
FCS-1	Control System Analyses QR Program	X			IV-6,12,29,53 V-6,11 VI-2,3 VIII-2	IV-5,6,36,63 V-6,10,11 VI-2,3 VIII-2
FCS-2	Control System Analyses MDELTA Program	X			IV-6,29,53 V-11 VI-3 VIII-2 IX-4	IV-5,36,63 V-10 VI-2,3 VIII-2
FCS-3	Control System Opti- mization-LORPS Program	X			IV-12,29,53 V-11 VI-3	IV-5,36,63 VI-3
FCS-4	Control System Opti- mization -Generalized Inverse	X			IV-12,29,53 V-11 VI-3	IV-5,36,63 VI-3
FCS-5	Control System Opti- mization-Gain Scheduling	X	X		IV-12,29,53 V-11 VI-3	IV-5,36,63 VI-3
FCS-6	Control System Opti- mization-Modal Program	X			IV-12,29,53 V-11 VI-3	IV-5,36,63 VI-3
FCS-7	Control System Opti- mization-Decoupling	X	X		IV-12,29,53 V-11 VI-3	IV-5,36,63 VI-3
FCS-8	Digital Simulation - GD Program	X	X		V-11 VI-2,3 VII-2 IX-4	V-10 VI-2,3 VIII-2
FCS-9	Digital Simulation NONSIM Program	X			V-11 VI-2,3 VII-2 IX-4	V-10 VI-2,3 VIII-2

STATUS: ① OPERATIONAL    ② IN DEVELOPMENT    ③ NOT PROGRAMMED

Figure 2.4 Example - Usage and Status - Technical Program Elements

## TECHNICAL PROGRAM ELEMENT

TITLE Control System Analyses - QR ProgramFORM PREPARED BY T. M. Richardson DATE 7/11/72LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 4 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC 6600)INPUT VOLUME 10<sup>3</sup> (Words)OUTPUT VOLUME 10<sup>4</sup> (Words)BASIS FOR TIMING, INPUT, AND OUTPUT 1 flight condition with 10 degrees of freedom, 1 root locus, 1 frequency response and 1 time response.STATUS: Operational X, Programming In Development    , Not Programmed    REFERENCE Boeing Document D6A11656-1TN, "QR User's Guide", T. M. Richardson, July 1969.OWNERSHIP: Public    , Private X, Owner The Boeing CompanyABSTRACT

Classical control systems analysis and synthesis techniques (root locus, time response, and frequency response) can be performed using this program. Laplace transformed differential equations form the basic input data.

MATRIX EQUATIONS OF MOTION WITH  
FLIGHT CONTROL SYSTEM (QUASI-STEADY  
OR FREQUENCY DEPENDENT AERODYNAMICS)

QR PROGRAM

- ROOT LOCUS
- TIME RESPONSE
- NYQUIST & BODE
- POWER SPECTRAL DENSITY
- FLUTTER  $V-g$  &  $V-f$
- RESIDUAL STIFFNESS REDUCTION
- NYQUIST & BODE FROM UNSTEADY AERODYNAMICS  
(NOT PROGRAMMED)

Figure 2.5 Example - Technical Program Element

sample page which shows the type of information provided for each Technical Program Element. The information includes the source code language, the program size in terms of boxes of source cards (where one box contains 2,000 cards), the input output volume, documentation, status, ownership and an abstract.

#### 2.1.5 Design Cycle Time

The design cycle time in the IPAD environment has been defined as the total elapsed working time from the beginning to the end of a single examination through one Level for a given design.

The design cycle time to develop a configuration size matched to market requirements should be greatly reduced. For example, the sizing analyses for a subsonic airplane in Level III should only require about two and a half weeks compared to approximately eight weeks today. Such reduction in time will be accomplished by reducing the input data requirements, through linking Technical Program Elements using the facilities of the IPAD System and by establishing a set of default values for variables which do not routinely change for specific classes of problems.

#### 2.1.6 Converged Design Cycle Time

The converged design cycle time in the IPAD environment has been defined as the total time from the beginning of the first design cycle until the end of a design cycle that has developed a design which meets all the objectives and constraints. At Levels II and III the converged design time will be the same as the design cycle time. At Levels IV and V, the complexity and number of users involved increases greatly, therefore, management will control the number of design cycles at these levels. It is anticipated that the preliminary design solution for a subsonic airplane will not be changed by the initial IPAD and will require approximately 12 to 15 months. This illustrates that the critical path for the development of a subsonic airplane is not established by the calculated data required to define the aircraft. Items such as customer coordination, developmental testing, management assessment of technical risk, flight testing, etc., are expected to form the critical path. However, quality of the design solution should be greatly improved by completing more design cycles in the same time period. For more complex design problems such as a space shuttle or a supersonic transport, the time to reach a preliminary design solution should be reduced, and the solution for high risk items should be sufficiently improved so that the

management confidence in these solutions should permit an earlier commitment to production.

#### 2.1.7 Development Cycle Continuity - IPAD Environment

The development cycle of figure 2.1 is repeated on figure 2.6 to emphasize the correlation between the proposed IPAD general levels and the events of the development cycle. It is of primary importance that the IPAD System provide continuity over both task and time. The arrow pointing to the right illustrates the importance of schedule control and the relationship IPAD must have with time. The arrow pointing down illustrates the importance of design control and the relationship IPAD must have with the technical depth of design tasks. These relationships of schedule and design control will provide the capability to produce the required design information in a time sequence which is responsive to management control of both the engineering costs and schedules and the computing costs for each competing design configuration under investigation in preliminary design phase of the development cycle.

#### 2.1.8 Optimization

The capability to optimize an airplane configuration is a primary IPAD requirement. In addition, IPAD must support the general design optimization problem which is discussed in the section on suboptimization. The elements of the overall airplane optimization problem can be identified in the following three categories.

1. Independent Design Variables. The independent design variables are controlled by the designer and determine the overall general arrangement of the aircraft. The following are examples of independent variables for several major components of the aircraft.

##### Wing and Empennage

Airfoil section, aspect ratio, taper ratio, sweep angle, thickness forms, camber form and loading of the aerodynamic surfaces.

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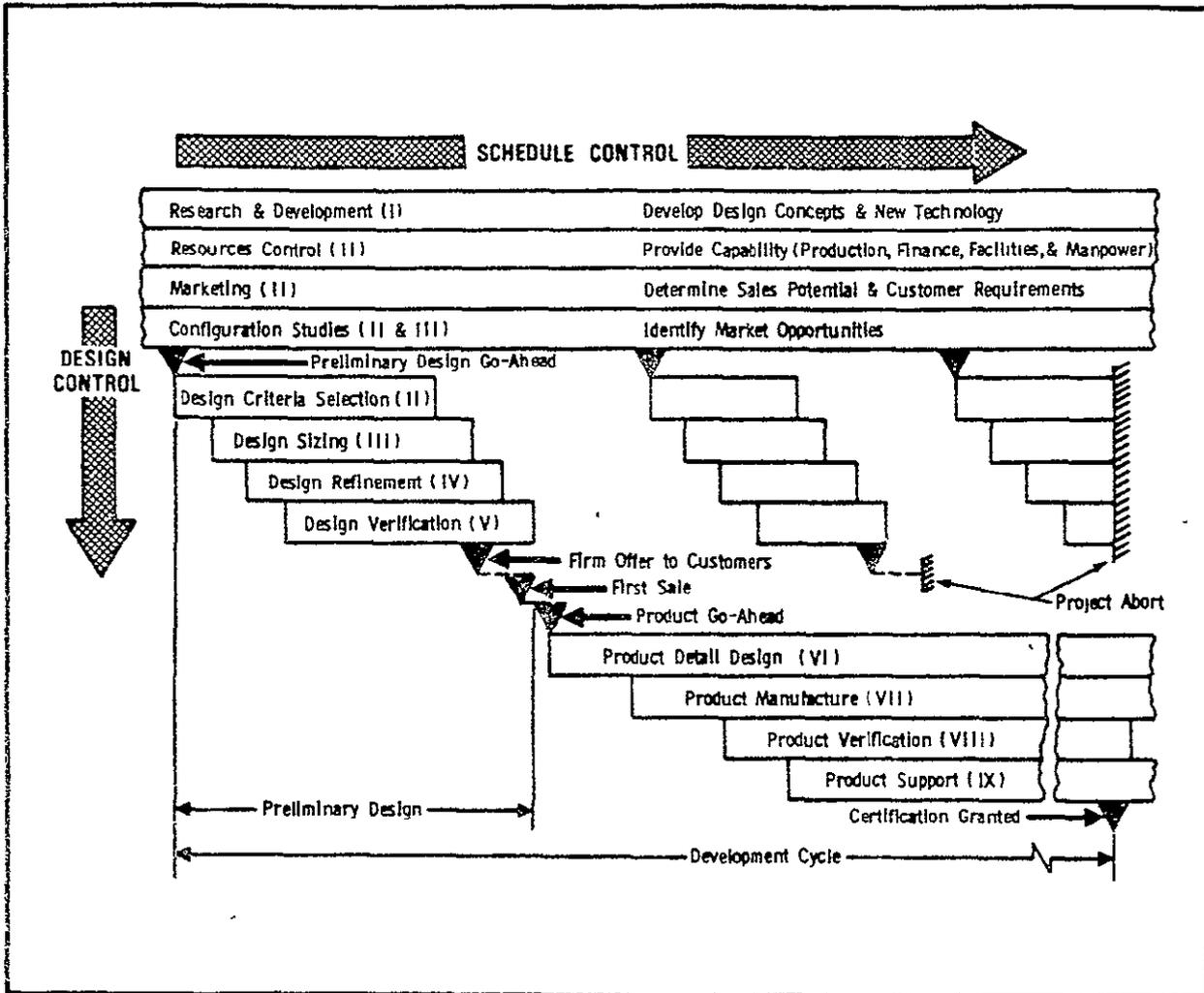


Figure 2.6 Development Cycle - IPAD Environment

## Fuselage

Payload, control cabin, body cross section, body fineness ratio, empennage arrangement and propulsion arrangement.

## Propulsion

Engine cycle, sea level static thrust, cruise thrust, number of engines, and propulsion arrangement.

2. Equality and Inequality Design Constraints. Design constraints are generally performance requirements which are derived by marketing from customer requirements or are requirements established by regulations and good design practices. To reduce the cost of the optimization problem, it is desirable to express these as inequalities. The following are examples of design constraints.

Range, payload, field length, approach speed, initial cruise speed, initial cruise altitude, buffet margins, engine out altitude, etc.

3. Dependent Objective Variables. The dependent objective variables are generally measures of efficiency or merit and fall into the following categories.

### Variables to be minimized

Takeoff gross weight, operating empty weight, wing area, drag, specific fuel consumption, direct operating cost, etc.

### Variables to be maximized

Lift to drag ratio, payload to maximum gross weight ratio, airline return on investment, etc.

There are three basic strategies of optimization proposed for IPAD. First, the strategy of direct (explicit) optimization uses mathematical processes to perform automatic optimization. Various algorithms are collected into a "driver" that controls the process of the solution to an optimum. The number of variables is restricted to a small number (less than 10) and there is only one figure of merit. This class of optimization may require nonlinear programming. Second, the strategy of trade-off studies has the user exploring some range of solutions around the local optimum. These solutions are needed because of multiple objectives that cannot be stated, or because there are too many variables for the direct optimization process. Third, the user optimizes the design thru a process of successively

more accurate analytical modelling. This process is termed sequential model refining.

These strategies will be used differently in the various Levels of IPAD. Direct optimization will be used in all of the Levels, but most heavily in Level II and III. Trade-off studies will be performed throughout all design Levels. Sequential model refining does not begin until the Structure Sizing part of Level III.

The optimization techniques described here will be made available to the user in the IPAD environment. It will be the responsibility of the user to formulate the optimization problem and to monitor its execution. It will be possible to accomplish automated optimization searches but it will be the involvement of the user and the users judgment which will lend credibility to the answers.

The principle objective of preliminary design is to determine an airplane configuration (defined by design variables) that meets a set of specified performance requirements (design constraints). It is also desirable to maximize or minimize a selected set of objectives (objective or merit functions). The formulation of the optimization problem is discussed in section 5 of Volume II.

#### 2.1.8.1 Configuration Optimization

Figure 2.7 shows the application of the optimization strategies to the Design Levels of Projects 1 and 2. In Level II and the geometry sizing portion of Level III, the entire configuration will be optimized. Mathematical programming (direct) techniques will be used as the main optimization tool and will be supplemented by trade-off studies to explore the neighborhood of a locally optimal solution. The purpose of trade-off studies is to identify a range of designs in this neighborhood and determine their sensitivity to changes of the design variables and problem formulation (performance requirements and objectives).

Figure 2.8 relates configuration optimization to the detail design networks for Projects 1 and 2. In Level II, the process of finding the most desirable design criteria and mission will be aided by determining an optimum configuration. This will provide reasonably optimistic performance data for the marketing analysis. In the first part of Level III (Configuration Sizing), the configuration optimization will benefit both from a more thoroughly defined configuration and from a more exact performance analysis. The latter is important in that the Level

IPAD DESIGN LEVEL	APPLICATION	STRATEGY
II DESIGN MISSION SELECTION	CONFIGURATION OPTIMIZATION (Given Arrangement)	<ul style="list-style-type: none"> <li>● DIRECT (EXPLICIT)</li> <li>● TRADE-OFF STUDIES</li> </ul>
III GEOMETRY SIZING	CONFIGURATION OPTIMIZATION, (Given Arrangement)	<ul style="list-style-type: none"> <li>● DIRECT (EXPLICIT)</li> <li>● TRADE-OFF STUDIES</li> </ul>
STRUCTURE SIZING	SUBOPTIMIZATION	<ul style="list-style-type: none"> <li>● DIRECT (EXPLICIT)</li> <li>● TRADE-OFF STUDIES</li> <li>● SEQUENTIAL MODEL REFINING</li> </ul>
IV CONFIGURATION REFINEMENT	SUBOPTIMIZATION	<ul style="list-style-type: none"> <li>● DIRECT (EXPLICIT)</li> <li>● TRADE-OFF STUDIES</li> <li>● SEQUENTIAL MODEL REFINING</li> </ul>
V CONFIGURATION VERIFICATION	SUBOPTIMIZATION	<ul style="list-style-type: none"> <li>● DIRECT (EXPLICIT)</li> <li>● TRADE-OFF STUDIES</li> <li>● SEQUENTIAL MODEL REFINING</li> </ul>
VI PRODUCT DETAIL DESIGN	SUBOPTIMIZATION	<ul style="list-style-type: none"> <li>● DIRECT (EXPLICIT)</li> <li>● TRADE OFF STUDIES</li> <li>● SEQUENTIAL MODEL REFINING</li> </ul>

Figure 2.7 Optimization Strategy - Project 1 and Project 2

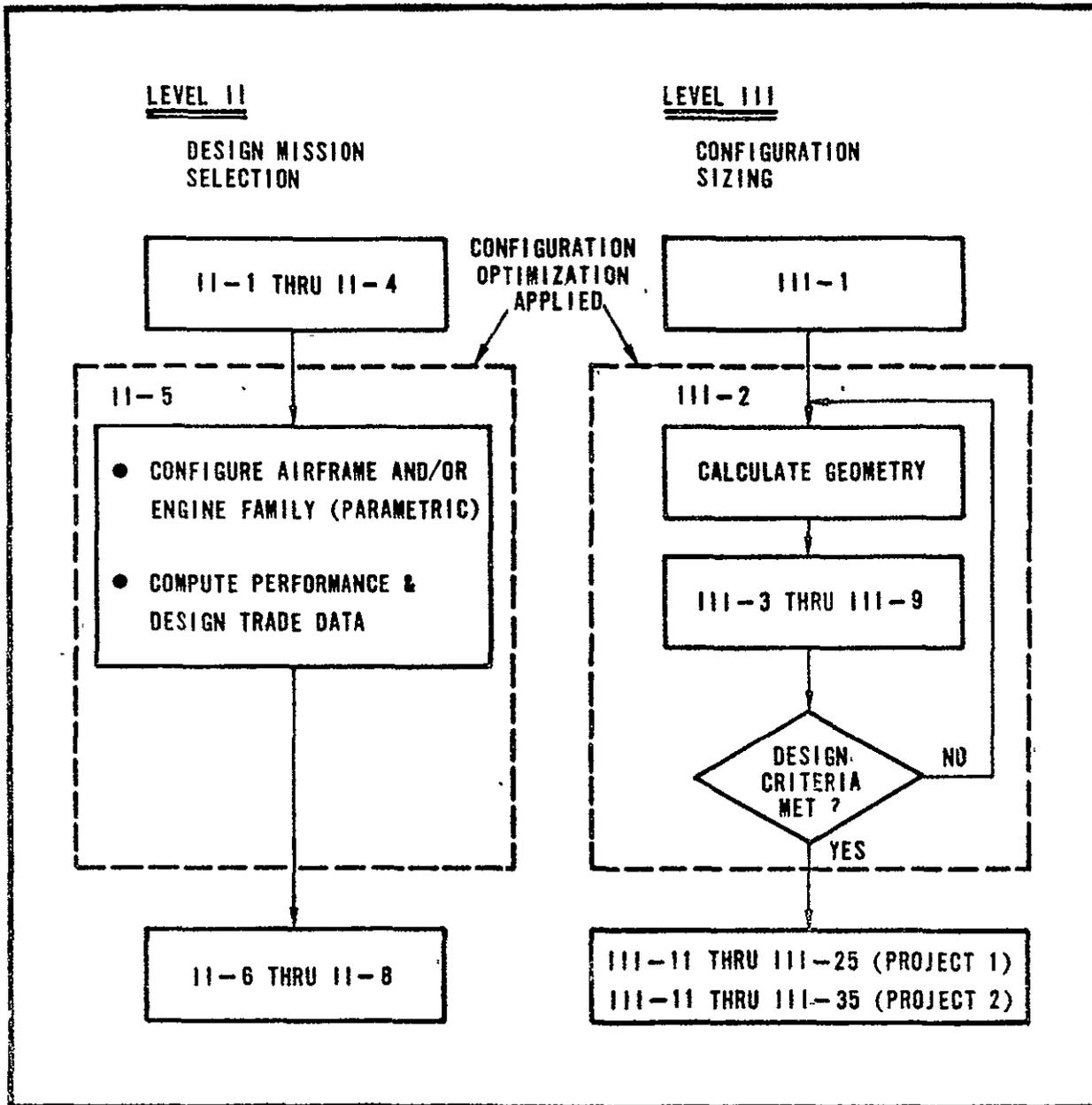


Figure 2.8 Configuration Optimization - Project 1 and Project 2

II approximations in performance methods can result in underestimation of vehicle capabilities. However, it must be pointed out that the computer cost for an optimization solution will be much higher in Level III than in Level II.

Figure 2.9 shows the type of information required for a configuration optimization problem. The configuration arrangement is given first. The basic geometry, for example, the number and location of engines, or the wing technology, is selected and defines the class of configuration being optimized. The objective function is selected and will be the measure of the optimization process. This may be a single variable, for example, direct operating cost or airline profits. There may also be several other partial objectives to be optimized, in which case one of them is selected as a principal objective function, and others are constrained (added to the set of constraints).

The design variables which are automatically adjusted by the optimization driver are selected, for example, wing area and wing aspect ratio. Variations in these design parameters will control the configuration sizing as an optimum is sought. Lastly, the constraints and requirements bounding the range of the solutions are given. These may be expressed as either equality or inequality constraints. Examples would be airplane range and field length.

#### 2.1.8.2 Suboptimization

Beginning with the second part of Level III, optimization will be applied within separate technical disciplines and subdisciplines. It is therefore defined as suboptimization, which will use direct optimization methods, trade-off studies, and techniques of sequential model refining. Typical examples of the suboptimization problems in the design process are:

1. Optimization of engine performance - the specific fuel consumption is optimized for given flight conditions.
2. Optimization of wing structures - drag, weight, natural frequency and geometric limitations are minimized.
3. Optimization of stability and control - a control vector is searched such that the performance index is minimized.
4. Optimization of flutter prevention designs - the structural weights and fixed weights which are added

- GIVEN CONFIGURATION ARRANGEMENT
  - BASIC GEOMETRY SELECTED
    - NUMBER AND LOCATION OF ENGINES
    - WING TECHNOLOGY
    - ETC.
  
- CHOOSE OBJECTIVE FUNCTION
  - (MIN) DIRECT OPERATING COST OR  
(MAX) PAYLOAD TO MAX. GROSS WEIGHT
  
- SELECT DESIGN VARIABLES
  - WING AREA
  - WING SWEEP
  - ETC.
  
- INDICATE EQUALITY AND INEQUALITY CONSTRAINTS (PERFORMANCE REQUIREMENTS)
  - RANGE
  - FIELD LENGTH
  - ETC.

Figure 2.9 Example - Configuration Optimization

to the structure in order to obtain a desirable flutter performance are minimized. Principal design variables are rescaling factors of the structural stiffness and corresponding structural weights. Constraints of the problem include the configuration limitations and the specified flutter speed.

The results of suboptimization within disciplines and subdisciplines are coordinated and synthesized to yield an optimal (or nearly optimal) solution for each major design unit. An example might be the wing design which involves several disciplines such as aerodynamics, structures and weights, stability and control, and flutter analysis (see fig. 2.10). The basic idea behind the concept of suboptimization is to decompose design problems which are too large to be solved in one place. The decomposition of this type results in:

1. Reduction of the complexity of analysis and related optimization problem,
2. Separation of objective functions and design variables into smaller groups within one discipline or subdiscipline.

Furthermore, the formulation of a major design unit such as a wing can be considered as a suboptimization problem related to the design of an entire airplane. Thus, the airplane design can be viewed as a pyramid-structured multilevel analysis and optimization process.

From the preliminary design viewpoint the highest in the hierarchy is the configuration optimization problem where the major decisions defining an airplane are made. Results of this optimization are inputs to the lower level suboptimization problems whose outputs in turn define in more detail the subsystems (parts) of the total design. This multilevel optimization and design process is executed essentially from the top of the pyramid to the bottom. It is, however, possible to have a looping effect, where a lower level optimization causes the repetition of analysis and optimization at higher levels.

## 2.2 SUPPORT OF THE DESIGN PROCESS

The study of several specific projects and the resulting characterization of the general design process provided information concerning the required support of the design process in the IPAD environment. Two principal categories were recorded, with several items of support in each category.

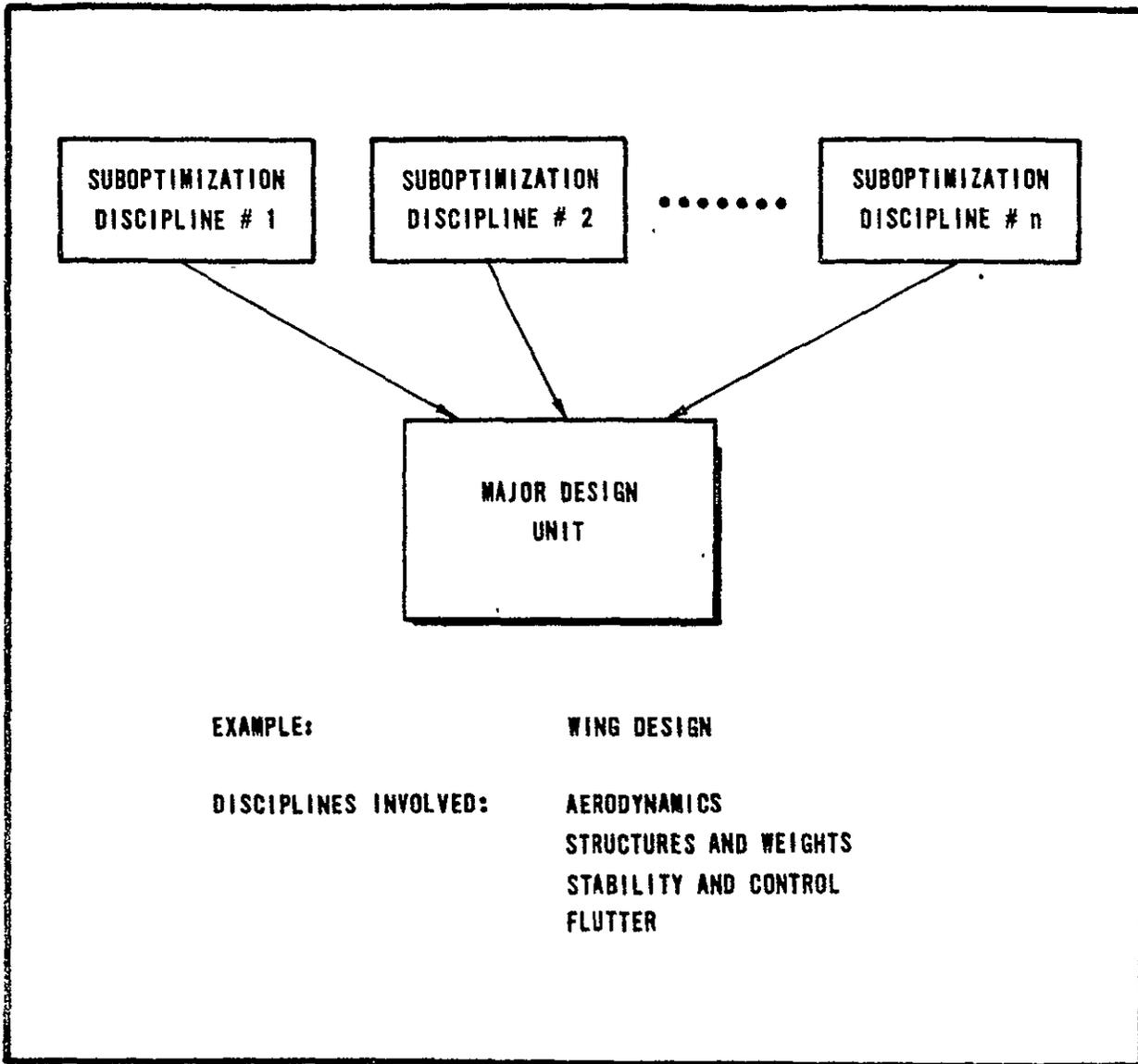


Figure 2.10 Suboptimization Concept (Decomposition and Multilevel Optimization)

Figure 2.11 shows this information, along with the area primarily impacted by the item of support.

The first general category is comprised of two items that were measured from the design process. These are the computational requirements of the host hardware and the status and needed development of the Technical Program Elements (TEP's) required to perform the calculations in the design process.

The second general category is made of those items that were observed during the characterization of the design process. In this instance, quantitative indications could not be developed. Rather, qualitative needs for the support of the design process were found for human involvement; continuity over task and time; user interface; privacy, security, control and integrity of the data base; and reliability. These all provided requirements for the IPAD System design. The desired peripheral equipment and facilities arrangements were also indicated.

Both categories of information will be discussed in the following sections and a more detailed description is presented in Volume III.

### 2.2.1 Computational Requirements

Figure 2.12 shows the first step in measuring the computational requirements for the design projects that were studied. This step is to postulate a scenario for the time-relations of the design levels and the number of design cycles within a particular level during the preliminary design phase of an airplane development cycle. The following tabulation shows the number of design cycles that were used to estimate the computational loads for two projects. Each design cycle involves the design, analysis and testing (where required) of one specific configuration.

		<u>PROJECT I</u>			
LEVEL:	II	III	IV	V	
DESIGN CYCLES	30	100	30	8	
		<u>PROJECT II</u>			
LEVEL:	II	III	IV	V	
DESIGN CYCLES	45	115	40	8	

Category	Main Impact On:
<p><u>MEASURED FROM THE DESIGN PROCESS</u></p> <ul style="list-style-type: none"> <li>● Computational Requirements</li> <li>● Technical Program Elements (TPE's)</li> </ul>	<p>Host Hardware TPE Development</p>
<p><u>OBSERVED FROM THE DESIGN PROCESS</u></p> <ul style="list-style-type: none"> <li>● Human Involvement</li> <li>● Peripheral Equipment</li> <li>● Continuity over Task &amp; Time</li> <li>● User Interface</li> <li>● Privacy, Security, Control, Integrity of the Data Base</li> <li>● Reliability</li> </ul>	<p>IPAD System Design Facilities</p> <p>IPAD System Design</p>

Figure 2.11 Support of the Design Process

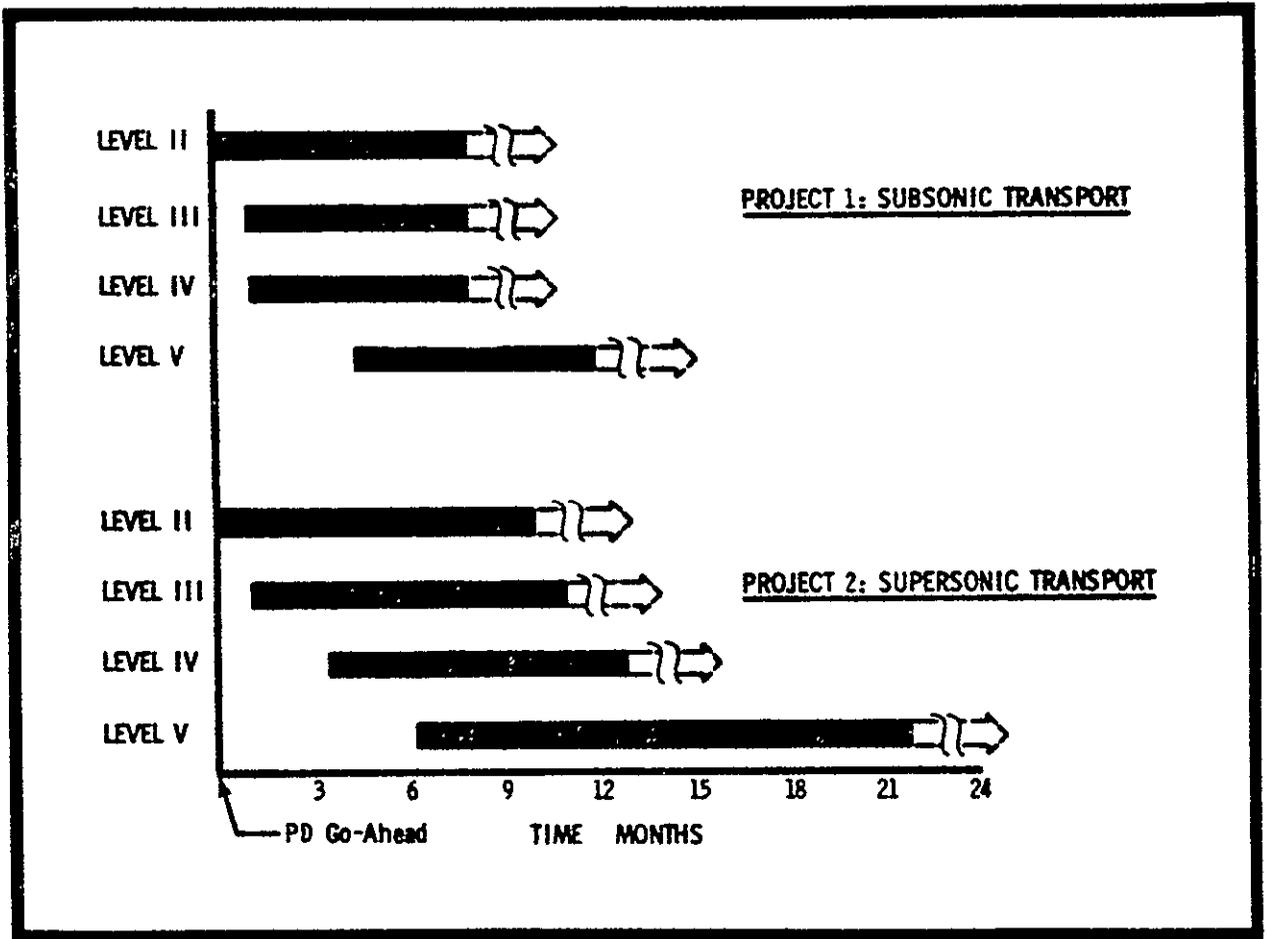


Figure 2.12 Project Level Phasing - Preliminary Design

### 2.2.1.1 Computational Loads for Preliminary Design Levels

The scenario of the design levels and number of design cycles for each level is combined with the detail design network and the associated Technical Program Elements to produce the computational load for the items of central processor time, data storage and data transfer rate. To account for the product levels not shown in the scenario, each technical discipline estimated the activity of their respective Technical Program Elements, from which the same items of computational load could be developed.

Figure 2.13 shows one of these items, that of the central processor (CP) hours per month for the time line of the product preliminary design. The data are relative to the CDC 6600 (CYBER 74). They show two interesting features, for example. First, the computational load for an SST is much larger than for a subsonic transport, as would be expected. Second, the overlap of Levels III and IV for the SST produces an extended peak load that may present significant problems to a computer facility.

These presented computational loads are unconstrained by such a computer resource limitation. In an actual situation, the CP time available may be less than the CP time required, and consequently, the design flowtimes would lengthen.

### 2.2.1.2 Hardware Performance Requirements

The computational loads can be used to develop host hardware performance requirements. Figure 2.14 shows the CPU power, data storage, and input/output rate for the following three examples:

1. One continuous Project 1,
2. One continuous Project 2,
3. A continuous company mix effort, made of:
  - 7 continual Project 1 preliminary design efforts,
  - 1 Project 1 product detail design effort, begun at two year intervals,
  - 1 continual Project 2 preliminary design effort,
  - 1 Project 2 product detail design effort, begun at 8 year intervals.

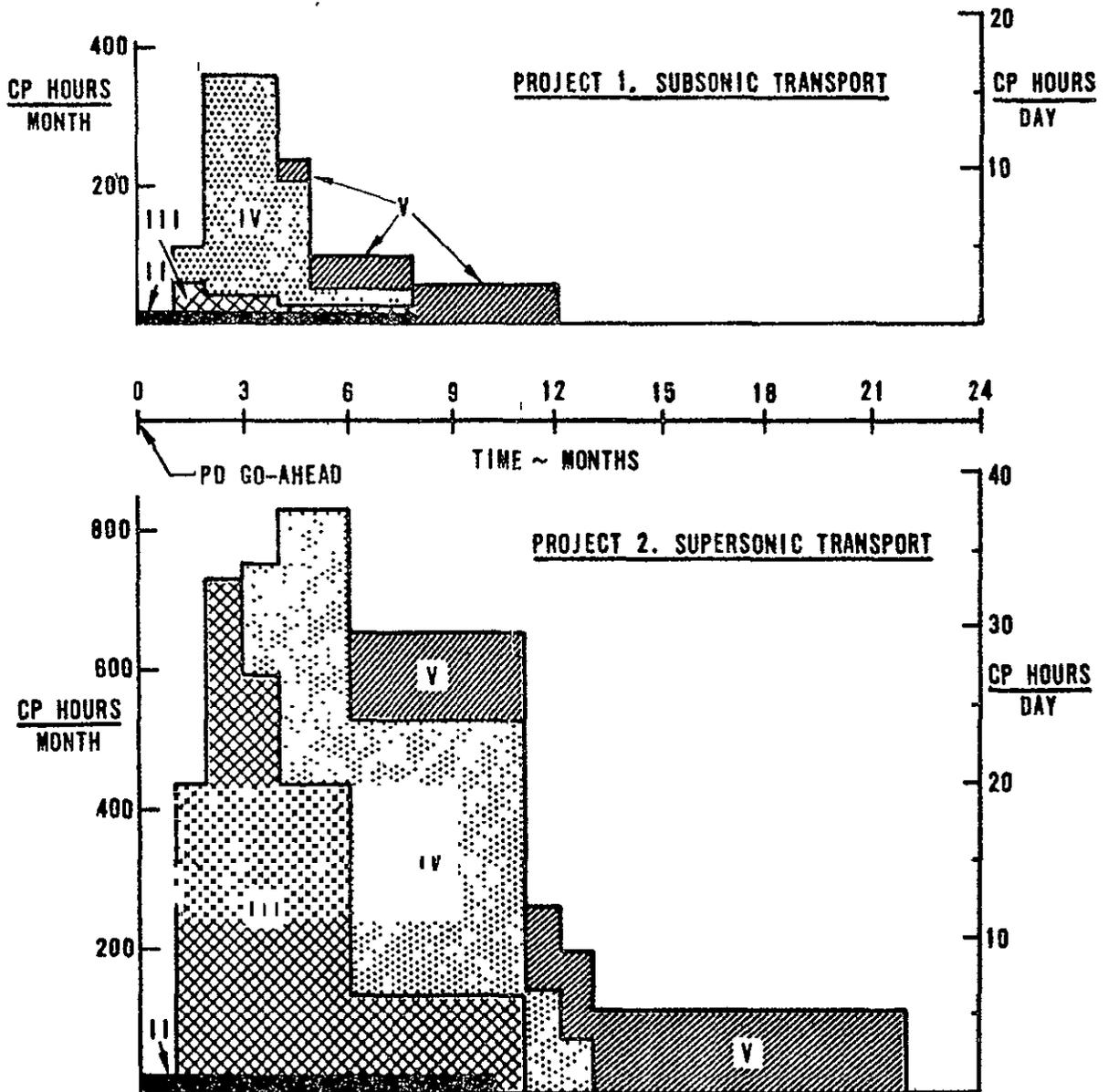


Figure 2.13 Project 1 and Project 2 Computational Loads for Preliminary Design Levels

PERFORMANCE CHARACTERISTIC		PROJECT 1	PROJECT 2	COMPANY MIX
● CPU Power	● 3rd Generation Scientific Machine	.5 CDC 6600	.9 CDC 6600	3.8 CDC 6600
	● Instruction Rate ( $10^6$ Instructions / Sec)	3.5	3.5	3.5
	● 4th Generation Vector / Array Processor	.04	.08	.32
	● Instruction Rate ( $10^6$ Instructions / Sec)	40	40	40
● Data Storage (Billion Bits)		28	141	270
● I/O Rate ( Words/6600 CP Sec )		57,000	59,000	50,000

Figure 2.14 Hardware Performance Requirements

The CUP power required is expressed both in terms of present third generation hardware, (CDC 6600) and estimated fourth generation vector/array processors. The requirements presented are based on extensive estimates from existing Technical Program Elements, which may be candidates for first implementation.

The information shown for the company mix is considered realistic for a large aerospace company. It compares to the Boeing Company requirements for the 1966 through 1969 time period when two CDC 6600 computers were used to support the engineering development of commercial airplanes. One CDC 6600 was dedicated to the SST development effort. Other design organizations within the company were using additional computing facilities.

### 2.2.2 Boeing Technical Code Survey

A survey was conducted within Boeing to identify the technical code required to support the IPAD design networks in section 4.0 of Volume II. The timing and depth of this study did not permit extending this technical code survey outside of Boeing. The purpose of this survey was to identify existing code suitable for incorporation into IPAD and to identify the areas where suitable code does not exist. A catalog of 304 technical elements denoted Technical Program Elements (TPE) were collected by the team and are presented in Volume V.

Appendix A of Volume VI lists a subset of the Volume V catalog consisting of 65 TPE's which are recommended for initial implementation into IPAD. Approximately 75% of this code exists at Boeing and it is assumed that similar code is available elsewhere. However, approximately 90% of this Boeing code has been executed in an integrated design system and the data interface has been developed between these programs. The Volume VI cost estimate for implementation of the phase 1 operating modules (OM's) is based on incorporation of these 65 TPE's.

The status of the entire Boeing TPE survey is presented in section 2 of Volume V for the 20 technical disciplines recognized during the task 1 activities. The status of each TPE has been identified in one of three categories: Category 1 (code available) indicates that the TPE is in current use or has been used. Category 2 (code under development) indicates that a TPE is being developed but is not yet operational. Category 3 (code not started) indicates that a TPE is required for IPAD but is not currently being developed at Boeing. In addition, a fourth category (cannot be coded) has been estimated. The fourth category cannot be measured and represents an estimate of that

portion of the total man activities which cannot be brought into the man-machine environment in the sense that supporting code cannot be written for these activities. For example, this category includes judgmental decisions, day-to-day verbal and written communication, development testing, and sundry activities which require personal attention such as study, research of library information and trade journals, travel, etc.

Figure 2.15 shows a summary of the status of code identified for Project 2, the supersonic commercial transport. This status includes the code required for the preliminary design Levels II, III, IV and V and a few sample cases are included for the product levels. The measure of the three categories which can be coded is based on the number of cards of source code required and was extracted from Volume V. Therefore, this TPE survey represents the status of Boeing technical computer code for preliminary design as viewed by the members of the IPAD team. It is further pointed out that this TPE survey relates to that portion of the total design effort which should be brought into the man-machine environment and in this sense relates primarily to the effort which identifies design requirements and sizing criteria. Detail design activities such as the interactive design of frames, floorbeams, system diagrams, wire diagrams, etc., are identified to a lesser degree and much development work is underway in these areas. However, there are many areas of detail design which generally do not follow patterns and it would be difficult to provide supporting code. These areas include selection of items such as emergency equipment, special electronics items, color schemes, standard equipment, mounting brackets, etc. Much work is still required in the area of information retrieval to support a selection process in the areas of standard items, standard design practices, standard tooling information, standard parts release, factory planned instructions, etc. The complete survey is presented in numerical form in Section 2 of Volume V, the Catalog of Technical Program Elements.

### 2.2.3 Human Involvement

The category of items observed from the study of the design process begins with the nature of human involvement in the IPAD environment. The major categories of human involvement are shown in figure 2.16.

#### 2.2.3.1 Personal Terminal .

The primary user access to IPAD will be using a personal terminal. This does not mean that each user will have a

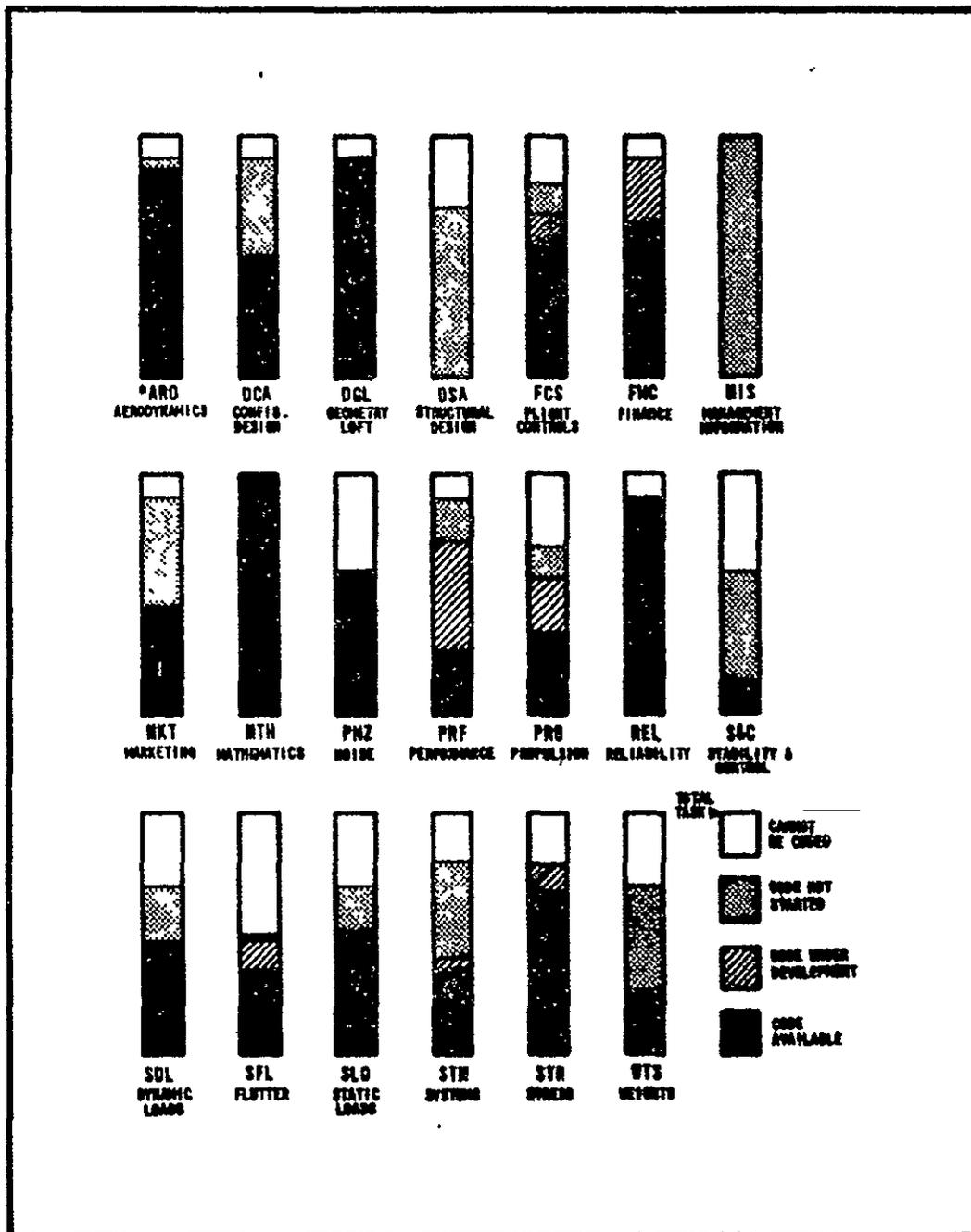


Figure 2.15 Technical Program Elements Status - Project 2 - Supersonic Commercial Transport Preliminary Design Levels

- **Personal Terminal--Primary IPAD Access**
  - **Flexible Selection & Sequence of Programs**
  - **Interactive Design & Job Execution**
  - **Selective Data Retrieval & Display**
  - **Maintenance of the Data Base**
- **Management Information System**
  - **Technical Depth of Design & Analysis**
  - **Sequence of Design & Analysis**
  - **Tracking of Product Costs**
    - **Cost of Design, Production, Support & Operation**

**Figure 2.16 Human Development**

terminal but rather than the IPAD System will recognize both the user and the terminal while the user is on-line. The personal terminal will provide the user the flexibility to interactively select the Technical Program Elements and their sequence to perform the desired job. A job is defined as one or more Technical Program Elements combined to form an executable program. The IPAD System will aid in this process, by performing library searches and by providing documentation of available programs. The set-up and verification of input data will be made easier in the terminal mode. During execution, the user may want to observe the job, in order to follow the progress of the solution. This will be especially useful during optimization exercises. Or, the user may desire to interactively control the job. Once execution is complete, the user will want to selectively retrieve some of the data for display, in order to determine quickly the validity of the solution.

#### 2.2.3.2 Maintenance of the Data Base

The maintenance of the data base is a fundamental objective of IPAD. The development, qualification, and retrieval of data from large data banks must be possible with minimum effort required by the user. There will be local data bases, consisting of company historical data as well as new information. There will be central data banks of standard information available, possibly maintained by governmental agencies. Each data set must contain information that will insure the preservation of its integrity. This could be in the form of qualifiers that contain sufficient information to support the resolution of any questions that may arise concerning the contents and use of that data set. There will be well-defined human and automated management functions regarding purging of old data sets. The IPAD System must provide support for all these activities.

Each IPAD installation will contain a substantial collection of coded programs or program elements. Each set of code will have to contain information in the form of qualifiers that will preserve the integrity of that code. The IPAD System must not allow unrecorded modifications of code to be made. Each set of code should also contain a brief description and key words to help the user in finding suitable code in the code base. This should reduce the amount of redundant code.

### 2.2.3.3 Doing Work with IPAD

The basic method of accomplishing work using the IPAD System will be to prepare and execute jobs. The preparation for a job will begin with collection of the proper code. The IPAD System should assist the user to locate a suitable job already in the code base. If a suitable existing job cannot be found, the user must construct the form of his job. In doing so, he will construct logical networks of code, and will insert instructions into the networks that will support his interactively monitoring and controlling the job during execution. Preparing the input for the job has two steps. First, the sets of variables for the job must be determined. Then, values are provided for these variables. The IPAD System should assist the user to assemble the required data sets available in the data base which were developed by the lower levels or other jobs. Some of the input data will have to be provided. Once the data is collected, the IPAD System must support efforts by the user to verify the contents of the data sets before initiating the job execution.

The execution of a job in IPAD will be a relatively simple matter. The execution process should be able to run unaided, or the user must be able to monitor, interrupt or interact during the execution of the network sequences. The capability must be provided to execute a job both by batch processing or by active monitoring at a personal terminal without sacrificing any of the data management characteristics of the IPAD System.

### 2.2.3.4 Information Display

The IPAD System should have a general display capability for examining results. This must support the display requirements of the typical user and the display requirements for Management Information. This capability should be based on a method of accepting specific display formats and the user need only specify the format and the qualified data sets to be plotted.

### 2.2.3.5 Data Consistency

Perhaps the most important result of the IPAD environment will be to bring a consistency and a discipline to the user community. This discipline means consistency both in the definition of variables and in the processes that produce values for the variables. This discipline will be achieved partly through the management structure of the user's organization, and partly through design features of the IPAD System.

### 2.2.3.6 Management Information Display

Display of Management Information will be provided by special jobs which provide preformatted displays of data. In addition, the capability for management to establish plans and schedules and to monitor them is an IPAD System design requirement. As the design progresses, the plans will be updated to show the completion of each step. This will provide management with a well-supported capability to track the costs of the product design. In addition, estimates of the production cost, product support cost, product operation cost and other product evaluation information may be monitored.

Management Information will be available to management through personal terminals. Also, project control rooms may have large-screen display devices which project preformatted displays of the latest information from the data base. When information is in question, it may be possible for a manager to interrogate data in successively increasing detail until the source of the discrepancy is found.

### 2.2.4 Peripheral Equipment Capabilities

Efficient use of the capabilities provided by the IPAD System will require a variety of peripheral equipment. There are three distinct categories for this equipment. Personal terminals will provide the user with means to communicate on-line with the computer. Off-line equipment will provide services where time is not the prime factor. Certain special devices will be needed to support the activities involved in the design of the product.

#### 2.2.4.1 Personal Terminal Equipment

The largest and most important category within the IPAD environment will be for personal terminals. Careful consideration will be required at each IPAD installation to provide the most effective type and number of the specific pieces of equipment. The following list defines the types of equipment to be considered.

1. Keyboard and printer - the traditional teletype, for use primarily in data and code manipulation.
2. Interactive text scope - a text scope, with keyboard. This device does not have plotting capability but will display text and provide interaction via the keyboard.

3. Keyboard-interactive graphics scope - a scope with both vector plotting and text display capability. The interaction will be through the keyboard.
4. Display-interactive graphics scope - a scope with vector plotting and text display capability. The interaction will be through devices such as light pens or "control sticks," as well as through the keyboard.
5. Card reader - a low volume card reader for inputting low card volume data.
6. Tape reader - a small on-line tape reader, probably a cassette type. Certain data sets and programs where portability is desired may be efficiently stored and loaded in this method.
7. Digitizers - a manually operated device to read curves and introduce them into the system.
8. On-line printer - required to produce immediate hardcopy of text. Document quality is not required.
9. On-line x-y plotter - required to produce immediate hardcopy of graphical displays. Document quality is not required.

#### 2.2.4.2 Off-Line Equipment

This category considers that equipment which is not usually a part of a personal terminal. The common host system equipment will be required, in addition to some devices that are not part of the typical installation. The following types have been indicated as necessary to support the design process.

1. High volume card reader - the typical input device in present host installations.
2. Automatic digitizer - a large capacity digitizer with automatic line following capability, for inputting large volumes of data from drawings.
3. High volume printer - the typical "chain-print" device for producing large volumes of printed output.
4. Document quality printer - required to allow utilization of the IPAD capability for having display formats that prepare reports directly from the data

base. This may be a type-setting device or a high-quality typewriter.

5. High volume plotter - a device to produce large numbers of plots for internal company communication. Accuracy is not a high requirement.
6. Drafting quality plotter - to produce highly accurate drawings for design and manufacturing purposes.
7. Tape drive - the typical tape read/write device for entering information and producing copies onto magnetic tape.

#### 2.2.4.3 Special Devices

A category of special devices has been identified from requirements established both by the design networks and by the user. The list below gives two examples of this category. Other devices will be required by additional applications of IPAD.

1. Hybrid simulator - this represents the occasions when the IPAD System will drive any simulation process using an analog computer.
2. Microfilm storage - a system where documented results would be microfilmed. Location information would be maintained as a part of the IPAD data base, and users would employ the IPAD System to retrieve a particular microfilm record.

#### 2.2.4.4 Terminal Equipment Arrangements

The best use of personal terminals in the IPAD environment will come from careful arrangement of the user's facilities. There should be different types of work arrangements, dependent on the size of the using unit, their class of activity, and the particular equipment to be used.

For example, figure 2.17 shows an engineering organization of approximately 225 people. The 3 central rooms will contain the on-line terminal equipment and off-line printers and plotters to support the using organization and its interface with IPAD. The equipment density represents projections for the time period of 1976 through 1979.

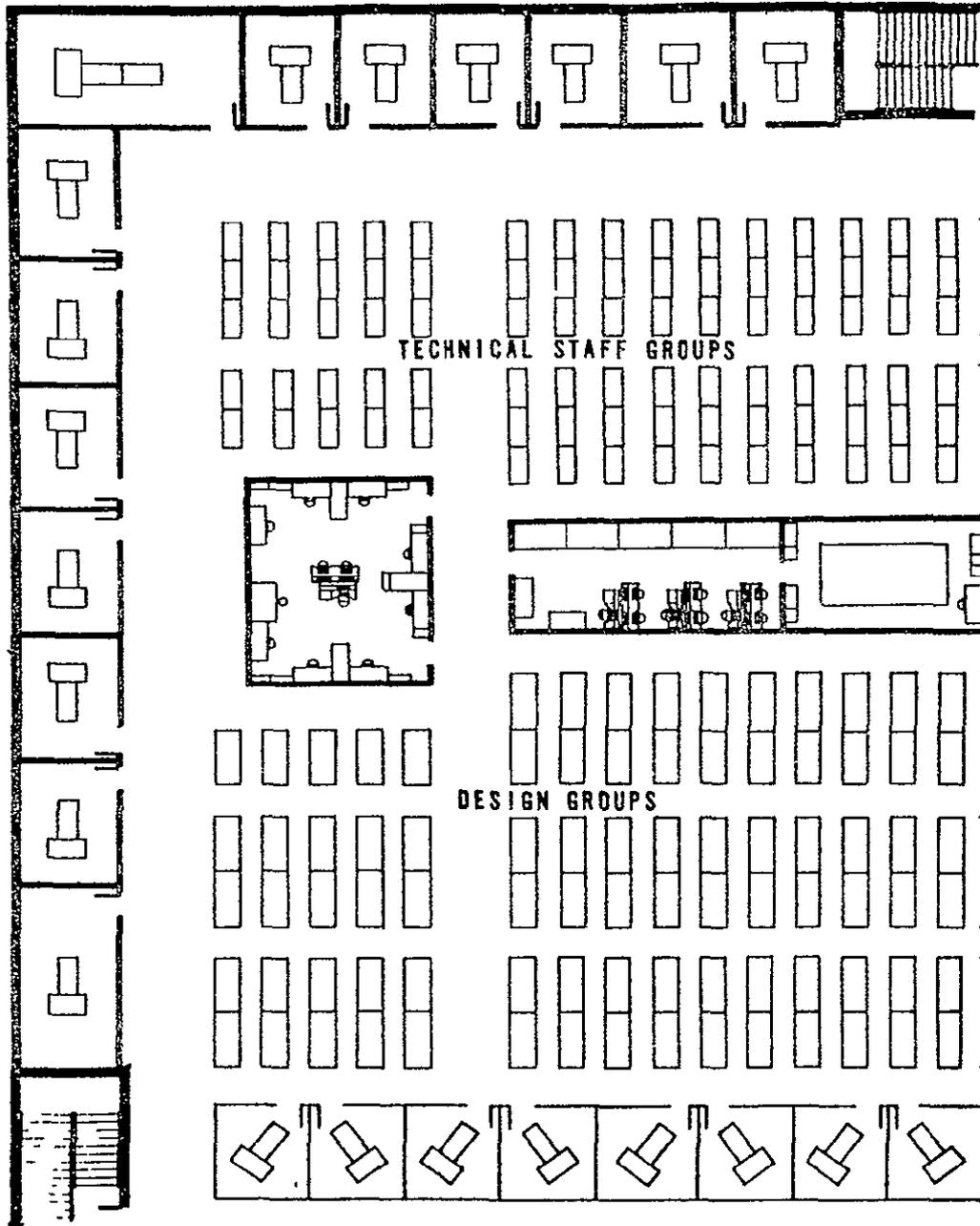


Figure 2.17 Terminal Equipment Arrangement

The square room to the left of center is for eight skilled users who would represent the principal technical disciplines. This room is shown in greater detail on figure 2.18.

The room in the center shows an arrangement of on-line terminal equipment to support approximately 150 other engineers having less terminal support requirements. This room has six silent teletype units and three interactive graphics consoles with vector plotting capability. This room also has two manual digitizers and three work tables.

The room to the right of center shows a central arrangement of off-line plotting equipment to support the entire organization. This room has one high volume low accuracy plotter, two medium volume high accuracy plotters and one very accurate drafting plotter. High volume printers and medium accuracy film plotters are assumed to be in a central facility remote to the using organization.

Figure 2.18 shows an arrangement for a unit composed of eight users. These eight users would be a basic group which represents the major technical disciplines required to support each design network identified in section 4 of Volume II for the preliminary design levels. Their IPAD terminals would consist of two silent teletype units and one interactive graphic console with vector plotting capability. With the equipment centered in the work area, access would be convenient, and terminal availability could be determined without having to get up and go to another area. Furthermore, a job that would require sequential execution by different members of the unit, such as an examination of a configuration in Level IV, could actually be done in a sequential manner at the terminal. Continuity of the solution would be present in the user's mind as well as in the IPAD System.

This arrangement is only one example of many ways to provide the user access to IPAD. The important point is that effective utilization of IPAD will require facility planning, as well as the more obvious selection of the peripheral equipment itself.

### 2.3 IPAD SYSTEM REQUIREMENTS

The IPAD System design requirements have been extracted from the study of the design process and the capabilities required to support the design process. The following sections relate to categories identified for support of the design process (see fig. 2.11).

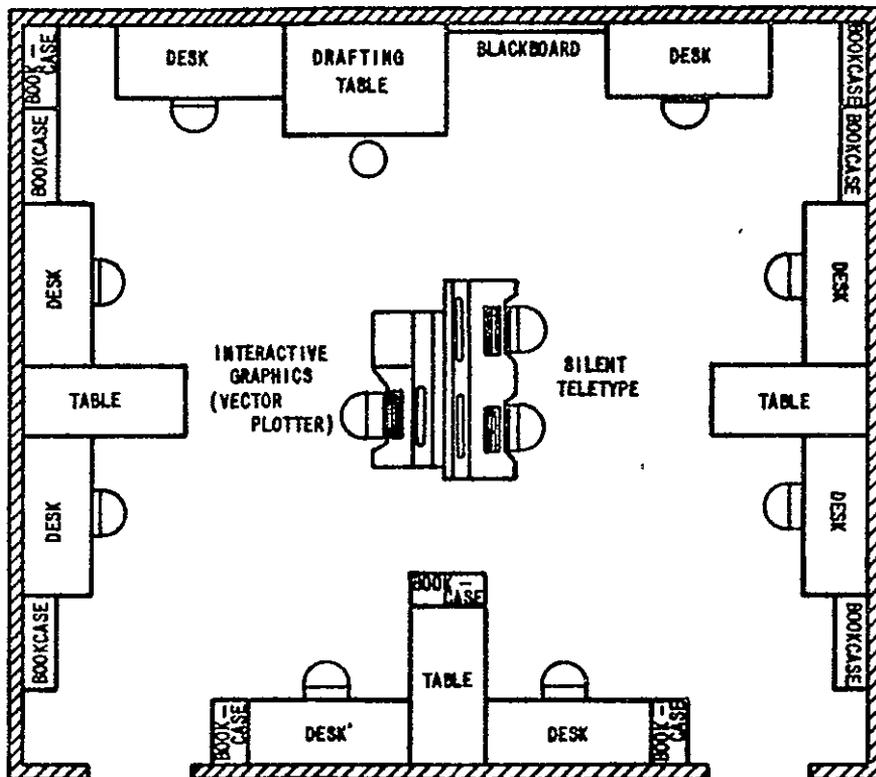


Figure 2.18 Basic User Group Equipment Arrangement

### 2.3.1 Effects of Volume - Computational Requirements

Within large design organizations, the communication of information between specialized groups is essential. The critical factor in communication is the volume of information being controlled, transmitted or interpreted.

The first effect related to volume is longer response times. In figure 2.19, response time is plotted against volume of information for several transfer rates. There is a band of response times that is effective for a given activity. Response times above this band result in information being transferred too late to be useful to the receiving organization. Below this band, the information is transferred faster than it can be utilized. Response time is a characteristic of the device used. The constant rate lines on the figure represent different devices for communicating data. The choice of device is determined by that combination of transfer rate and volume that lies within the acceptable response time band.

The second effect related to volume is decreasing reliability. As the volume of information increases, the ability for humans to maintain adequate reliability decreases. Hence, a capability must be sought that will provide nearly perfect reliability and still have the transfer rate necessary to produce the required response times.

The third effect related to volume is decreasing control. An organization is managed by a small number of individuals. Data is generated and used by a large number of individuals. Control of creation and changing of the data base is dependent upon the ability to collect and contain the data in a manageable form. Hence a capability is required to store the data base and provide control methods.

The fourth, and most difficult effect related to volume, is obscuring of information. A thousand order flexibility matrix, coupled with a load matrix, contains the deflections for a thousand points, but it does not communicate those deflections to a user unless acted upon in some way. Hence, for high volumes, methods are necessary to manipulate, extract, and display the precise information needed by the user to make a decision.

The problem is aggravated and compounded when several disassociated groups become involved such as two or more companies or a company and a government agency. In these instances, local jargon and definitions, local methodology, local data formatting and local preferences become part of the problem.

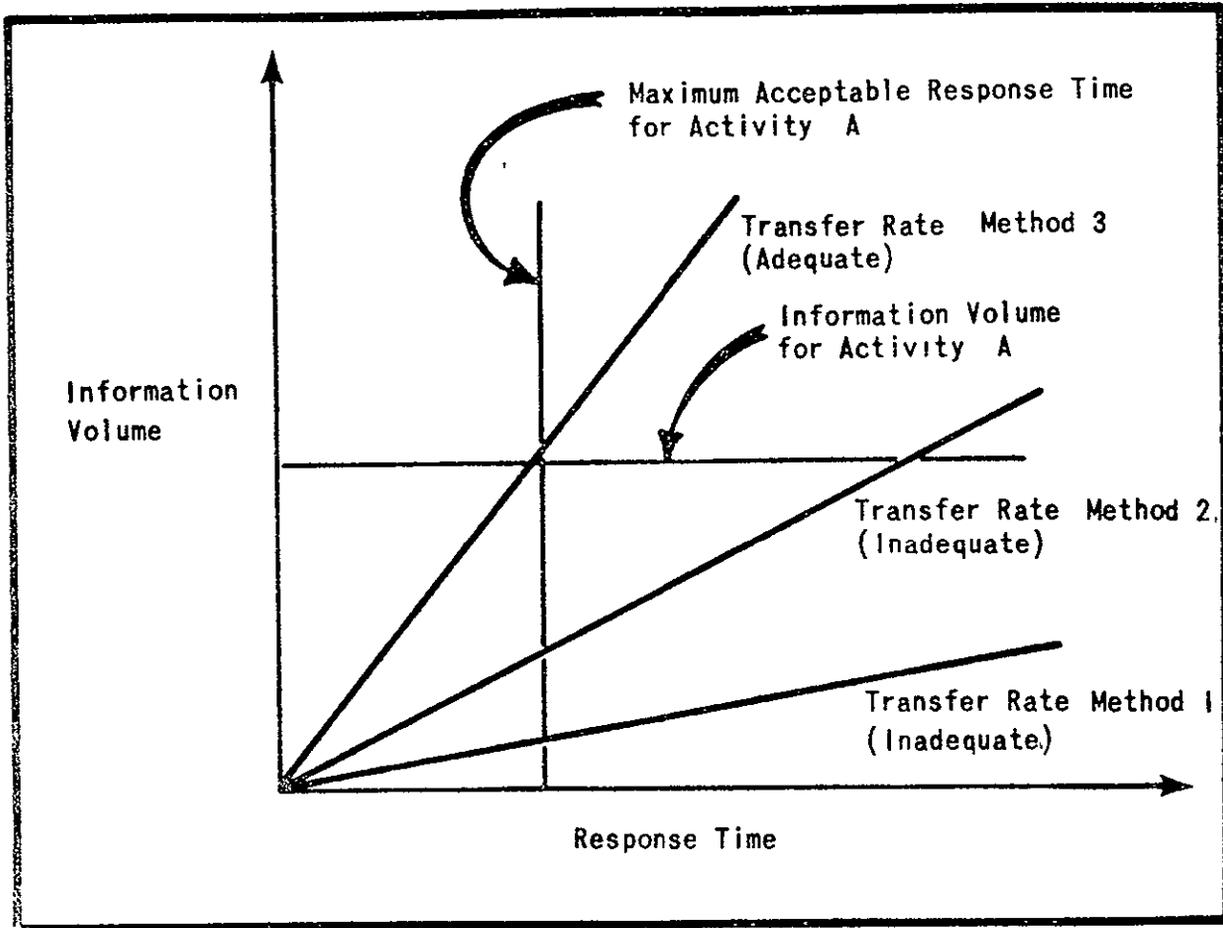


Figure 2.19 Effect of Information Volume Increase

The IPAD System design must provide the capability to meet the required response times, to provide reliability of the data base, to provide control and access to the data base and to improve data communication between disassociated organizations.

### 2.3.2 Technical Program Elements

The technical capability outlined in Volumes II and III will be provided through modules of application code entered into the data base as library entries and executed under control of the IPAD System. The IPAD System must be able to:

1. Accept and manage an adequate volume and variety of technical code;
2. Provide for change control; and
3. Interface existing code with the data bank and other modules without major reprogramming.

There will be no specific relationship between the IPAD system code and any particular piece of application code. The code will be called from the data bank, organized into groups or sequences, and started executing. During execution, with the exception of interfacing with the data bank, the application code will perform in the same manner as it would external to IPAD.

### 2.3.3 Human Involvement

The IPAD System will be controlled by a community of users having a wide range of capabilities and responsibilities. Therefore, the relationship of the user to his job, and to other users and the physical capabilities of users have been carefully considered and accounted for as requirements for the IPAD System design.

#### 2.3.3.1 Job and Data Base Growth

A user of IPAD will execute a job, several jobs, or the same job several times in order to complete a subtask. The same user and other users will complete other subtasks, which, together, will form a task. Many tasks may be required to complete a project. Figure 2.20 illustrates this relationship. Consideration must be given to the characteristics of the individual user as a human and to groups of users as an organized community of people. The important human factors are

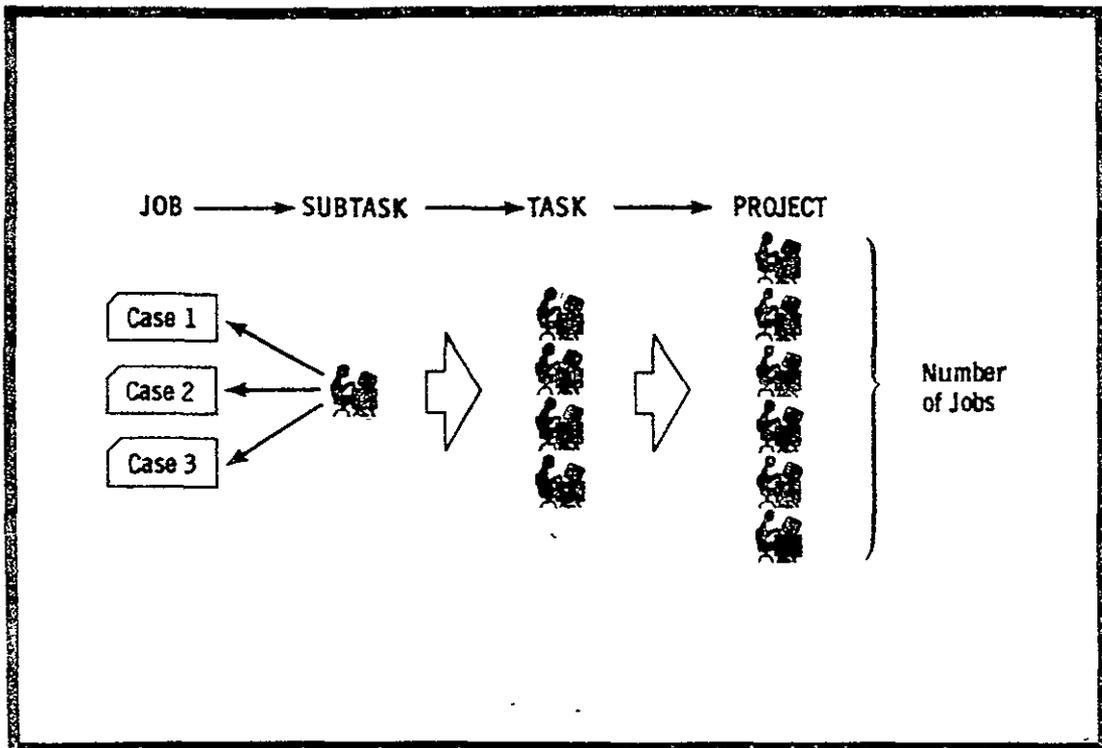


Figure 2.20 Job Growth

the memory and response characteristics of the mind. The important community factors are the continuity of the organization and work with respect to time and the coupling of the work of various subgroups within the organization.

#### 2.3.3.2 Human Factors

The characteristics of the man as well as the computer must be considered in the design of a man-computer dialogue. The ability of man to adapt to a wide range of circumstances directs the designer of a man-computer dialogue to give greatest consideration to the least adaptive of the two - the computer. Too often, the needs of the man are determined from a value-based definition which leads to the ultimate conclusion that the real needs of man are only associated with food, water, and shelter. A more useful basis is a rational definition wherein a "need or requirement is some demonstrably better alternative in a set of competing known alternatives that enable a human purpose or action to be implemented." This definition deliberately ignores the argument of value versus cost, an argument that is never conclusive in the design of a man-computer dialogue. It does allow for an exploration of alternatives and their implications on the quality of work, efficiency, and general creativeness of man.

Language is the principle vehicle in a dialogue. Since man is the dominant element in the dialogue, the following observations about the behaviour of man are pertinent:

1. Behaviour is strongly time associated.
2. Behaviour is conditioned by familiarity and expectation.
3. Familiarity and expectation are the result of experiences.

For the purposes of this study, these behaviour characteristics will be treated in six categories:

1. User Behavioral Characteristics. Reduction in computer response time from several days to several minutes by going from a batch system to a terminal system may be an adequate improvement if the objective is to provide a more efficient operation through remote job entry. However, if the objective is to establish an environment in which the computer is part of a continuous thought process, the improvement in response time from days to minutes is not sufficient because the human mind requires response times in the order of seconds for

continuous thinking. Hence, the following observed characteristics of the mind play an important part in the design of a computing system. Figure 2.21 illustrates these characteristics.

Short Term Memory - When tasks are performed, a body of information is held in the mind at conscious level, termed "short term memory". Two characteristics of short term memory, both associated with waiting, are important.

- a. Short term memory is never passive. Noise from within the mind or distractions from without can cause change of its contents.
- b. During creative or highly innovative periods, large amounts of work are performed within continuous, concentrated, and relatively short time periods. Interruptions of less than a minute during one of these periods can cause loss of the entire line of thought.

Closure - Humans spontaneously organize their activities into "clumps" that represent an action that is concluded with a definite result. At the end of these activities there is a sense of completion. Psychologists call this sense of completion a "closure".

Closures come in different degrees depending upon the importance of the result. A person is much more tolerable to interruption when an important closure has been reached than he is at an intermediate closure.

Step-Down Discontinuities - The rate at which thought processes decrease in efficiency as the number and length of response delays increase is not continuous. Ordinary conversational dialogue becomes awkward with response times greater than 2 to 4 seconds and is not possible with response times in excess of 15 seconds. Hence, for conversational dialogue, a response time of 30 seconds is no better than a response time of 5 minutes.

2. Interactive Response Times. The response times given are those for which the user will be comfortable and continue to utilize the terminal for his purposes. They are a quantitative expression of a qualitative phenomenon and, as such are subject to interpretation. However, they are based upon study and observation (see Volume IV for references) and, while the association between response time and activity may not be precise, such an association does exist and is of the order given. Response time is defined as the time elapsed between the

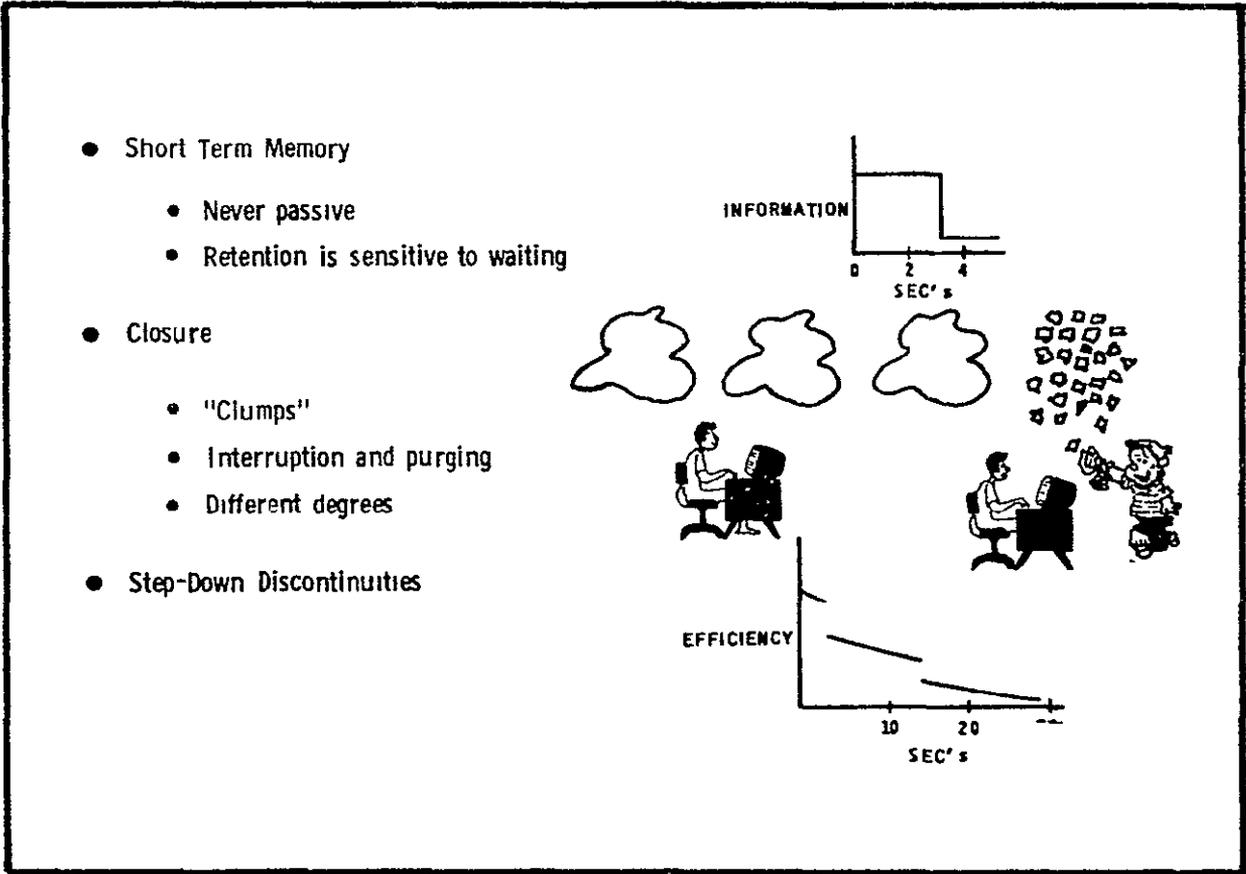


Figure 2.21 User Behavioral Characteristics

last input by the user and the first character displayed by the computer.

Permissible deviations in response times vary. In general, the permissible deviation depends upon the seriousness of the closure to the user. Response times in the 2 second and less category should not vary by more than 100%. Figure 2.22 illustrates the diminishing user capability as response time increases.

3. User Classification. Familiarity and expectation influence the classification of users.

Familiarity - The complexity of each problem step a user is able to handle decreases proportionately, if, through unfamiliarity, a user's short term memory is filled with personal concern or memorized step-by-step procedures. Hence, the unfamiliar user may be helped by decreasing the complexity of each step, increasing the number of steps, and increasing the volume of reminder information supplied.

Expectation - Responses strongly dissimilar to the user's expectations are the same as an interruption. Less obvious and less critical, but still important, is the style of the language. Quick cryptic language statements may appear coarse and rude to the manager who's day-by-day business requires close attention to a smooth interface with people. On the other hand, language that is polite and uses full English may be boring and time consuming to the technical specialist. Dialogue design must "steer a course between operator boredom and bewilderment".

These factors lead to the following classification of users.

- a. Totally Untrained or Novice - This user is consciously defensive and is easily frustrated by unclear terminal responses or unusual response times. He requires tutorial dialogue with display messages that maximize his confidence in himself and in the system.
- b. Casual - This user spends most of his time doing something other than operating a computer terminal. He is trained in terminal usage and feels at ease using it. He requires descriptive cues and prompts to remind him of missing information, errors in command structure, etc.
- c. Dedicated - This user spends most of his time operating a computer terminal and has near instantaneous recall of command structure. He is

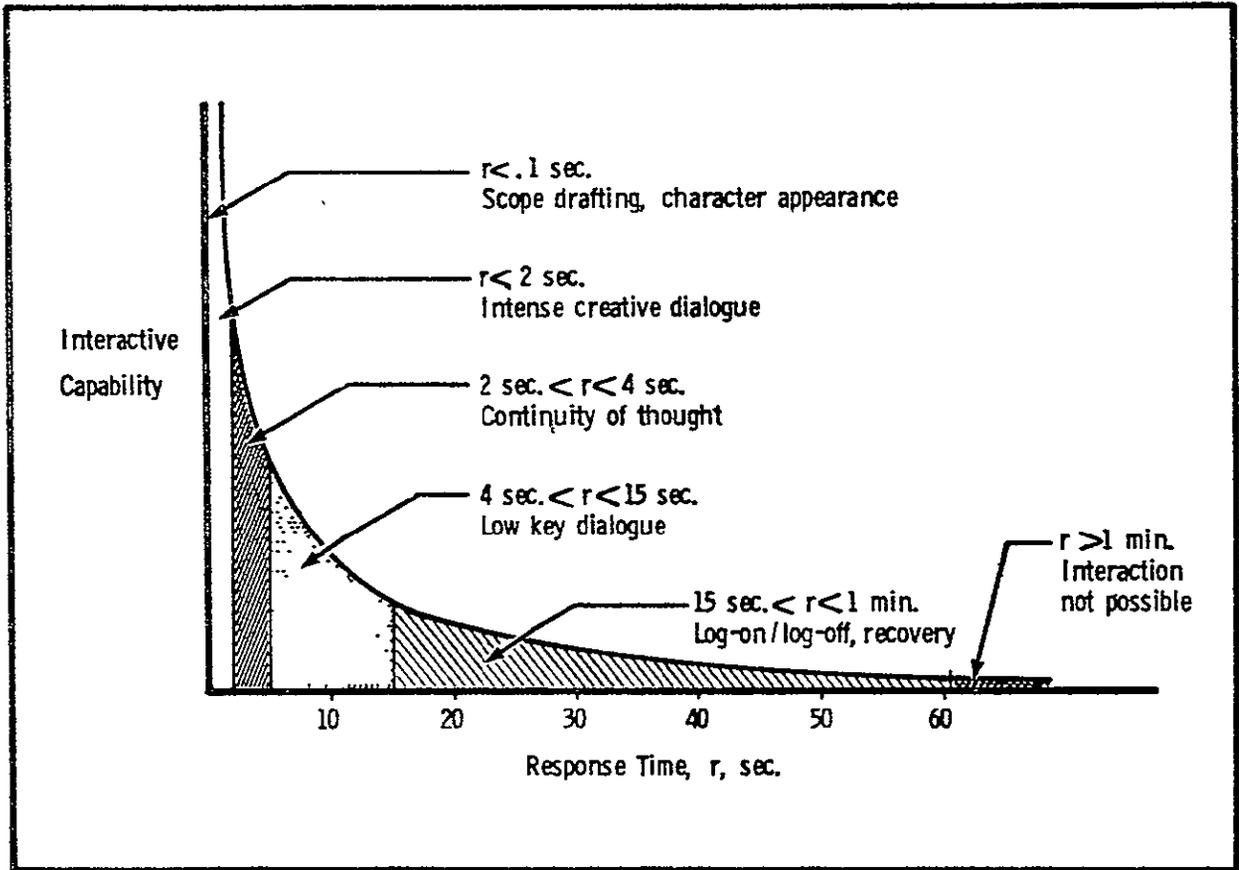


Figure 2.22 Interactive Response Times

psychologically tuned to the response pattern of the terminal and is intolerant to language structure beyond the minimum required for uniqueness. He requires abbreviated cues and prompts, maximized use of mnemonics, and faster than normal response times.

4. Man-Machine Dialogue. The man-machine dialog can be classified as user or computer initiated and by a hybrid combination of both.

User-Initiated - User initiated dialogue implies a dedicated user, or at least a user of such frequency that the dialogue commands are instantaneously recalled. Classes of user initiated dialogue are given below. It should be noted that the user is leading and the computer is interpreting and responding.

a. Full English - Because of the alternate meanings of words and the context dependency of English statements, interpretation of full English syntax by the computer is difficult. Further, full English is responsive to characteristics of the human mind that are not present when the computer is a party to the dialogue. Hence, full English is not a viable language for the user initiated part of the man-machine dialogue.

b. Limited English Input - English words and phrases can be used where distinctive meanings can be assigned. However, use of full English statements where some of the words are read by the computer and the rest are ignored is often confusing to the user. For example,

PLEASE DISPLAY ALL BEAM ELEMENT NAMES AND MARGINS OF SAFETY WHERE THE MARGIN OF SAFETY IS GREATER THAN 0.95.

In this example, the underlined words are the only words interpreted by the computer. The above command would be better given as

DISPLAY BEAM ELEMENT NAMES AND MARGINS WHERE MARGINS GT 0.95.

In this command, every word is read and has meaning to the computer, and the entire phrase has meaning to the user. This type of language (i.e., limited English without extraneous words, user initiated) is probably the most useful language form for the casual user of IPAD.

- c. Mnemonics - Mnemonics is the most efficient language for the dedicated user. They give great flexibility and forego extraneous characters not required to uniquely identify the command to the computer. The disadvantage is that they must be remembered and present little in the form of memory aid. The above command might appear in mnemonics as

D / 2 B ID, M / \* M GT 0.95.

- d. Graphic - This dialogue is initiated by the user drawing lines, shapes, or symbols; or graphically supplying instructions to change the size or location of the same either through the CRT face or via an electronic tablet.
- e. Pictorial - This dialogue is initiated by the user by manually or optically tracing and marking a drawing to be stored in the computer. It may also be initiated through calls for display of stored picture catalogs with corresponding commands for paging and selection.

Computer Initiated - Computer initiated dialogue is necessary where the user is unfamiliar with the command structure or data input formats and must be directed or "led through" the procedure. It should be noted that the computer is leading and the user is following.

- a. Full English - Full English commands with limited English or mnemonic user responses is the most appropriate dialogue where the user is entirely unfamiliar with the procedure. Menus, lists of alternatives, explanations, and helps are all a form of this command.
- b. Limited English - Same as full English.
- c. Mnemonic - Where the user is entirely familiar with the mnemonic set but unfamiliar with order of input, a computer initiated dialogue using mnemonics can be used.
- d. Form Filling - A form can be displayed giving appropriate blanks and headings.

Hybrid - Combinations of user initiated and computer initiated dialogue can be useful.

5. Errors and Failures. The three primary causes of errors and failures are the language, erroneous input data and interruptions.

Effect of Language - The language response must be consistent with the mode the user is in. If the user is making a single inquiry, he will probably have note of it, and a request for re-entry is adequate. If the user is making a complex inquiry, it will be necessary to display an index of categories or parameters he previously input to place him back in context. If the user is in a conversational problem solving mode, the model he has constructed to the point of error or failure must be available to him. Reconstructing a model is one of the most arduous and unreliable activities he performs. Loss of a batch run means only that the job must be rerun. Loss of a creative terminal job means the model must be reconstructed. Reconstruction is a demoralizing activity. Hence, error correction or restart after system failure must be responsive to the user's need to (1) retain confidence in the work thus far completed and (2) retain confidence in the terminal as a problem solving medium.

Diversity of Source - The integrity of a data set will generally be less when multiple independent users are inputting to it than when the data is received from a single controlled source. Hence, procedures for achieving integrity of the contents of data sets increase in importance in a multiple user community. The following procedure is recommended.

1. Real time dialogue to detect and correct errors.
2. Software for performing scans, sums, cross file checks, etc., of the entire data set.
3. Intelligent methods of correcting errors and the effects of errors discovered at a time subsequent to input and first usage.
4. Designation of ownership responsibility to some member or manager of the user community.

Interruptions - Interruption of the user to inform him of errors or to warn him of impending system failure should occur, if possible, at closure rather than during activity. Further, unusual delays should be preceded by a message to the user, where possible, so that he is released from mental and physical captivity.

6. Product Development Organization. There is a hierarchy of planning and control associated with the development of a

product. Information flows through the hierarchy as shown in figure 2.23. The labels of company, product, etc. are somewhat arbitrary. The terms in the parenthesis are basic descriptors of the primary interest at each level. These descriptors are only representative and are not accurate for all organizations. There are, however, several characteristics that seem universal.

- a. There is a level at which real work on the product design is accomplished. Above that level, work is centered around planning and management control. Below that level, work is centered around preparation of tools and methods. In the hierarchy shown in the figure, the level of real work on the product is at the subtask level.
- b. Each level tends to transmit information above and desire action from below.
- c. Those above tend to be interested in what is being done; those below tend to be interested in how things are done; while those doing concentrate on the actual work, varying their interest between what and how depending on the immediate situation.
- d. The number of levels shown in the figure is not uniquely six, but it is neither large nor small compared to six.

In summary, the user of IPAD works at the subtask level. Those above this level normally give direction, review results, and exercise control. Those below this level prepare computer tools. However, anyone executing a job in IPAD will do so at the subtask level. An example might be a program manager accessing the data base through the management information system to obtain data on budget expended to date for a particular phase of his program.

### 2.3.3.3 Continuity Over Task and Time

The design case studies reported in Volume II show that there are both levels and phases in the design process: each performing a different function and each having its own characteristics of time, data volume, technology required, etc. The following significant characteristics of the using environment have been identified to support continuity over task and time:

1. There is continuity in the day-by-day work,

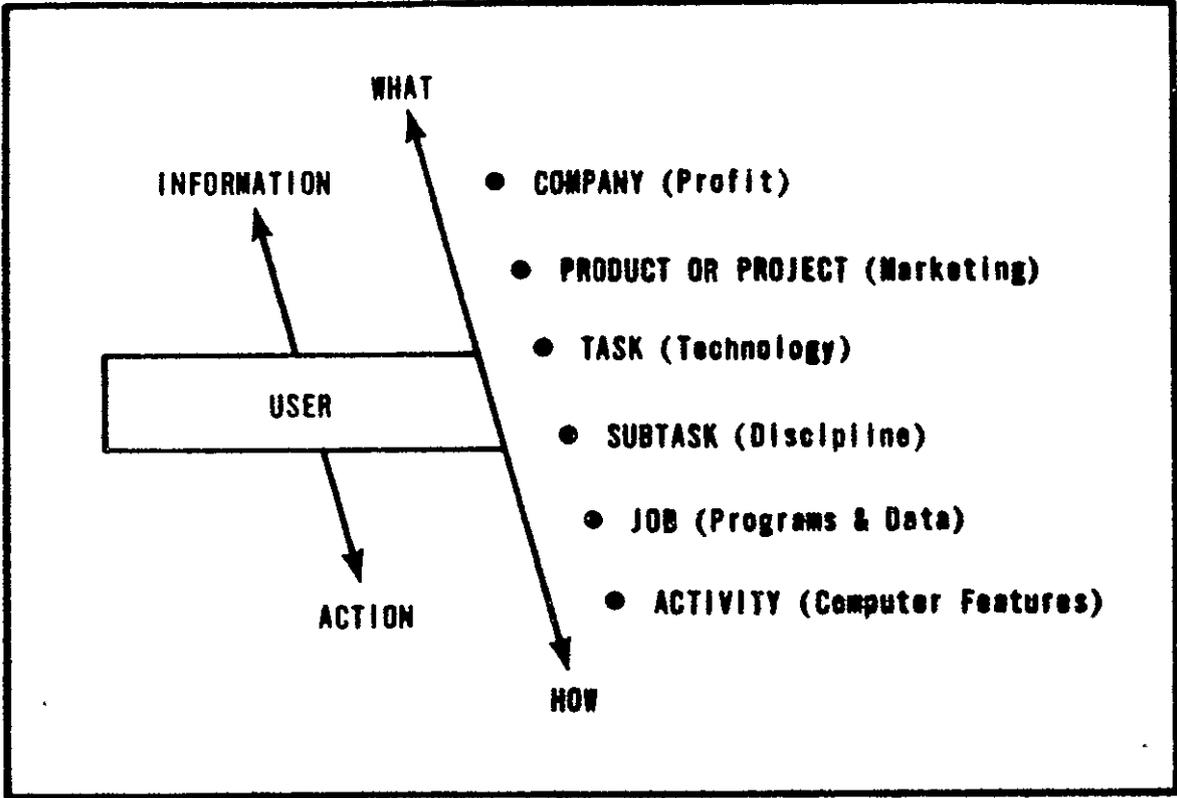


Figure 2.23 Hierarchy of Product Design

2. There is a flow of information throughout the user community,
3. There is a direct association between plans made, work done, and tools on a day-by-day basis,
4. The activity is ongoing over periods of time extending into years.

It is a user requirement that IPAD be compatible with and provide direct software and hardware support to this environment. The relationship of projects, tasks, subtasks, and jobs was shown on figure 2.23. In IPAD these relationships may be large, small, or nonexistent depending on the circumstances. On large projects, the number of users may be many hundreds and the volume of data may be of the order of billions of words. Figure 2.24 shows several classes of projects, and the relationship to tasks, subtasks, then example job executions. The intent is to show that a project is not necessarily a very large undertaking. It is, instead, the highest level above which there is no meaningful division, and at which, all reporting would become complete. Also, examples are shown which do not relate to any defined project or task. It is also possible to execute a job without any relationship to a subtask. For these smaller activities, the time for reporting may not be specified and a report may not be required.

#### 2.3.4 User Interface

The user interface with the IPAD System has been identified by the development of a general work flow model, an accessing concept, required capabilities and command language and a communications concept.

##### 2.3.4.1 General Work Flow Model

Although the project flow diagrams presented in Volume II represent the specific procedure a typical design organization might follow, they do not represent the general activities users perform. An understanding of the general activities a user performs is necessary to design the IPAD System. To help gain this understanding, a problem solving work flow model was developed at a very general level as shown in figure 2.25 and in detail as given in Appendix B of Volume IV. This model was useful in isolating particular capabilities so that the system design could be modularized effectively and general language statements could be developed.

<u>PROJECT</u>	FIND BEST SST	FIND BEST DELTA-WING SST	FIND USES FOR S.A.S. ON AN SST	NONE
<u>TASK</u>	FIND BEST DELTA-WING SST	CONFIGURE IN LEVEL III	USE S.A.S. TO IMPROVE RIDE QUALITY	NONE
<u>SUBTASK</u>	CONFIGURE IN LEVEL III	FIND BEST CONFIGURATION WITH SUBSONIC L.E.	CHANGE S.A.S. ELECTRONICS ONLY	DEVELOP GENERAL SWEEP THICKNESS TRENDS USING WIND TUNNEL DATA
<u>JOB</u> (Execution)	SUBSONIC L.E. 4 ENGINES ETC.	4 ENGINES ETC.	SYNTHESIZE RIDE QUALITY GAINS & FILTERS	ANALYZE ONE SET OF WIND TUNNEL DATA

Figure 2.24 Examples of Projects, Tasks, Subtasks, and Jobs Subtasks

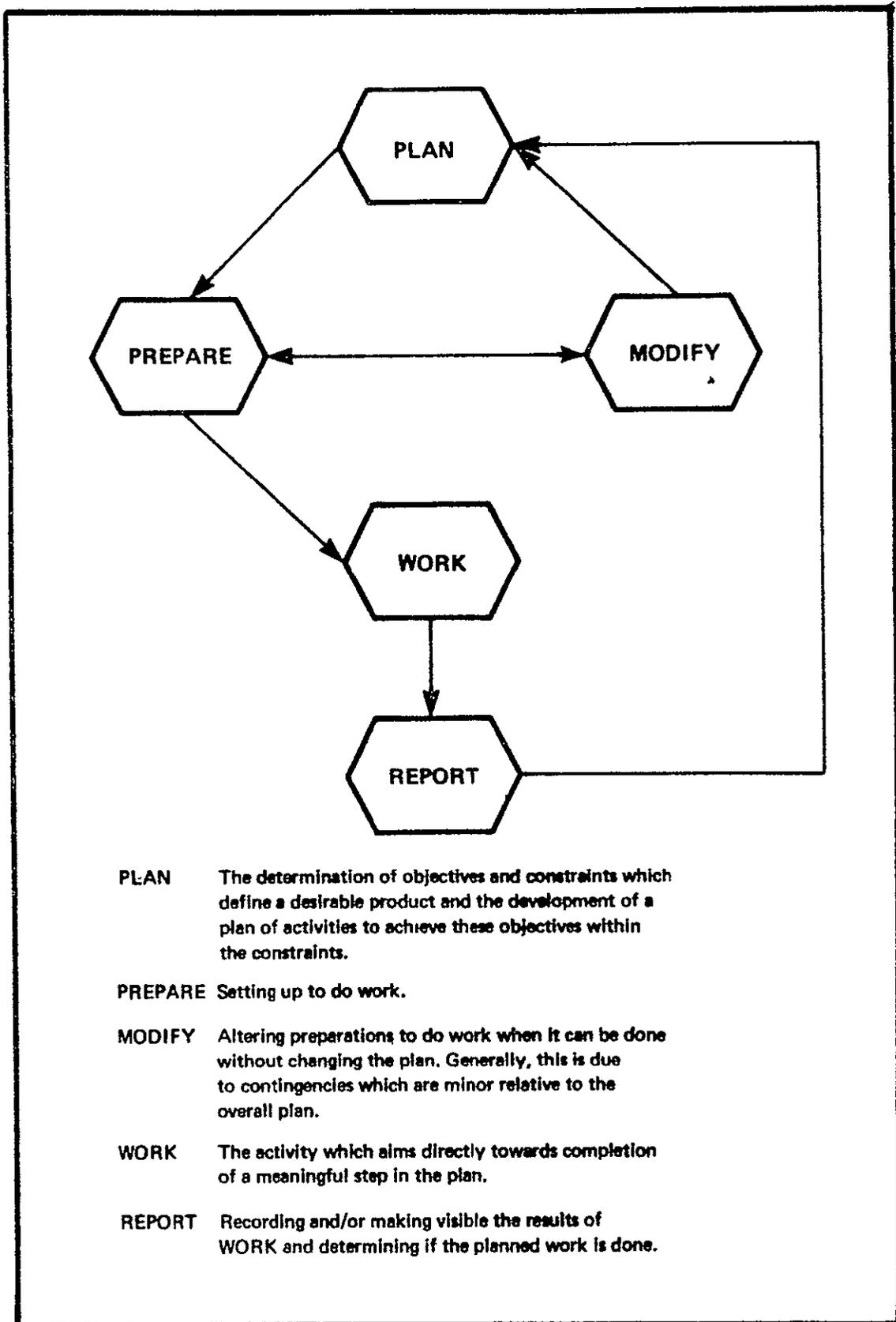


Figure 2.25 General Work Flow

#### 2.3.4.2 Accessing

Accessing will be through a personal terminal, i.e., a terminal associated only with one user at a time during the entire course of his activity. Ideally, the minimal personal terminal will be an alphanumeric CRT with passive, low resolution graphics. High resolution interactive graphics, hardcopiers, remote job entry devices, and other equipment will vary from installation to installation.

#### 2.3.4.3 User Command Capabilities

IPAD is primarily a design tool. Hence, its basic organization is for a human hands-on operation using a command language that makes the computing system essentially transparent to the user. As a consequence, the user will be placed in a design environment entirely compatible with his own behavioural characteristics and the characteristics of the task he is performing. These general characteristics must be supported by the IPAD System at the user subtask and a command interface language must be developed. Requirements for a command language are presented in Volumes III and IV and are summarized below.

1. DEFINE - Entering or modifying definitions or elements to be entered into the IPAD libraries. The definitions include abstracts, variable names, correspondence tables, and other information necessary to interface the element with the data base and provide descriptive information to the user. An element is a data set, a module of application code, a display format, etc. DEFINE is separate from ENTER to allow, for example, predefinition of variables pertaining to a data set by a single focal point followed by the actual entry of data by other persons who must then conform to the predefinition.

2. ENTER - Entering the actual library element. This command permits the user to enter information which conforms with the definition made using DEFINE. Many sets of information may be entered following a single DEFINE, but each will have qualifiers supplied by the user and the system to fully identify and distinguish them.

3. TRANSFER - Moving elements between libraries within IPAD. This command allows movement of elements between private and community libraries. It does not allow movement of information to a location remote to the IPAD installation within which it is located.

4. SEND - Sending library elements to a location remote to the IPAD installation in which the element is located.

5. EDIT - Locating and modifying existing library elements. Automatic version changes will be made by the system to accurately trace antecedents and preserve integrity for other users.

6. PURGE - Erasing entire library elements. Carefully designed system controls will exist to ensure against purging of elements still being used or saved by some segment of the user community.

7. COMPARE - Making comparisons between sets of information or between information within the system and information supplied by the user. This command would allow, for example, a check of all moduli of elasticity within a data set to ensure they are within a given range.

8. CONSTRUCT - the construct command triggers a dialogue language through which the user may form executable code from groupings or modules of code previously entered into the system.

9. EXECUTE - Execution of code. This command causes a particular set of code formed through CONSTRUCT to be executed. If the executing code has a language structure of its own, the user will interact with that language with complete transparency of the IPAD System. Subcommands will be available to interrupt an executing code set to review its progress, change its direction, or discontinue execution.

10. DISPLAY - Bringing information for an IPAD library to a display device in a defined display format. Display formats may be entered separately through a DEFINE and ENTER. There will be many display formats, each providing a particular class of display. Generally, activation of the display will trigger language dialogue to guide the user in inputting necessary parameters.

11. FIND - Locating information within the libraries. This command provides two capabilities: (a) locating particular sets of information such as technical code or data sets, and (b) locating particular items within a data set.

12. MESSAGE - Sending messages through the IPAD system to a user located at another terminal.

13. LEARN - A tutorial state that provides a programmed learning course in the use of IPAD.

14. General Commands - In addition to the specific capabilities defined above, the system will also provide commands for (a) short term pauses and returns allowing

execution of other commands between the pause and the return, (b) long term interruptions extending over log-offs and log-ons, (c) help commands from the system to the user that prompt the user, tell him of missing information, explain commands which the user has obviously misunderstood, and otherwise smooth and assist the execution of work. Using these commands, a user may interrupt an activity, complete a second, third, etc., activity, and then return to the first.

#### 2.3.4.4 Communication

The transfer of data between Operational Modules or between Operational Modules and the system libraries will be transparent to the user except through the command language outlined above. The actual locations of stored information will not be known to the user. Rather, movement or communication of information will be accomplished by the user through the use of generic names and adjectives.

#### 2.3.5 Privacy, Security, Control, Integrity

A review of the design projects studied in Volume II and the manner in which an organization would proceed to work these projects indicate requirements for privacy, security, control, and integrity of system code, application code, and data. These requirements are outlined as follows:

1. There is a need for both private data regions where an individual user can do scratch work, correct personal errors, etc.-- and public data regions--where data important to many users can be stored, accessed, and controlled.
2. There is a need to protect information against unintentional access or intentional illegal access.
3. There is a need to control use of the system and of the data base.
4. There is a need to provide integrity of the code and data.

Many of the features of IPAD in themselves provide privacy, security, control, and integrity. Other features are specifically designed to support these requirements. The capabilities within the IPAD System design which support this area are listed below:

1. Subtask and Community Libraries
2. Controlled Access to Data Base
3. Controlled Permission to use System Commands
4. Uniqueness of Versions
5. Trace of Antecedents
6. Trace of Data or Code Leaving IPAD Control
7. Personal User Identification
8. Protection Against Self-Inflicted Accidents
9. Security of the IPAD System Code
10. Security of the Security Features Themselves
11. Controlled Relationship Between Jobs, Subtasks, Tasks, Projects
12. Government and Company Security Provisions

Government or defense security provisions are provided by law or by requirement from the specific agency involved and are not considered here. Likewise, special security provisions necessary for a company to protect proprietary material are not considered. However, the mechanisms provided by IPAD will make it possible to provide for government and/or company security requirements.

### 2.3.6 Reliability

The reliability of the IPAD system, hardware, and operating system should be such that system unreliability need not be a specific planning consideration for IPAD users. No definitive studies have been made to establish the precise parameters and ranges within which this criteria is satisfied. Nevertheless, it is an essential criteria.

The reliability of the application code is outside the control of the IPAD system. However, standards can be established and a rating system developed and implemented whereby application code can be classified according to its established level of reliability.

## 2.4 THE IPAD SYSTEM

Task 2 of the IPAD feasibility study was to generate a design of the IPAD System.

The IPAD System is based upon the requirements identified in the aircraft design process and computational requirement studies documented in Volumes II and III respectively. The basic requirements identified in these studies cover:

1. Continuity over task and time;
2. User interface;
3. Privacy, security, control, integrity; and
4. Reliability.

These requirements reflect the user's environment. His tasks are not completed in a day or with a single run on the computer. His interface with the computer should be with language and devices that give him capabilities he needs without loading him with jargon and irrelevancies. He works in large organizations where free communication is essential. But he also works with large volumes of data that must be controlled and kept in a high state of integrity. The organization he works for has a vested interest in his work and an interest in maintaining some security on the results of his work. At the same time the user is a creative individual and requires some privacy for concentrated thought and invention. The product he is designing is highly complex and he must work under rigid schedules. Reliability of the IPAD System and the data base is critical. These factors are dealt with in the design of the IPAD System.

Early methods of organizing computing tasks involved batching work of a similar nature and relying on well trained operators to maintain a reasonably efficient operation. As volume and complexity increased, many of the administrative functions were shifted to the computer, leading to the present day "operating" and "monitor" systems. Each new operating system development had two basic objectives:

1. more efficient processing, and
2. new capabilities to aid the professional programmer.

In general, software has not been generated which helps the applications user organize and manage his work. Moreover, most operating systems are "one run" and "one user" oriented while

typical design projects require numerous runs, spanning several days or months and involve many people performing inter-related activities. IPAD will provide continuity in doing work on the computer even though the work may involve many separate work sessions extending over long time periods and requiring communication with other users also working on the computer. The following are primary features of the system design.

Full Project Support - A project is a set of tasks and a task is a set of subtasks. Within any project the sequence of tasks and subtasks are scheduled and require a flow of information or interdependence between them.

There are specific items in the data base for "plans" and "reports" associated with projects that support management control and definition of the work flow. Each project, task, and subtask will be given a report skeleton at the time planning data is entered in the data base. Hence, completion of each subtask is a formally recognized event in IPAD. That is, the completion of the subtask can be recorded in a project report. If a pert-chart type logic is used for planning, the sequence of subtasks can be controlled through permission codes in the system. Managers and technical users can also interrogate the status of projects, tasks, or subtasks from the project reports.

Continuity of Work - Subtasks are the prime working interface between IPAD and the IPAD user. Subtasks are generally associated with one user and are organized within IPAD to provide continuity of activity.

A subtask is a user's private domain in which he works individually without impacting other users. He has access, through the data base libraries, to application programs, utility programs, and data common to all users. His accessing of information in the data base libraries is controlled or restricted as necessary because of the community nature of the data base.

Continuity of activity means that from the time the user initiates a subtask until he terminates it, he works with the sense of continuity of a single session. That is, having interrupted his activities for lunch, sleep, or thinking, he will resume activity with a subtask status identical to that at the time of his interruption. This continuity will be true for either interactive or batch type work.

Continuity between subtasks (and hence between users) will be provided by the data base. As each subtask is terminated,

the user will transfer entries of common value into the community library.

#### 2.4.1 The Library Concept

Uniqueness of terms and their definitions, variables and their units and all other information which requires precise control within a large community of IPAD users is major design requirement of the IPAD System. Two types of libraries are provided within IPAD. The first library is used to establish formal identification of information required by the entire community of users and is designated the community library (CL). There is only one community library in an IPAD System. The second library type is used by an individual user for personal work prior to entering data or code into the community library. The users personal library has been designated the subtask library (STL) and there is one subtask library for each user in the IPAD community.

##### 2.4.1.1 Library Organization

The IPAD libraries contain library entries which may have one or more library variables. A variable is any item which has basic engineering meaning in the technical sense. A library entry consists of one or more variables which have a particular logical relationship. Typically the user collects sets of variables together into a single library entry for convenience in handling.

An IPAD user communicates with the IPAD data base through the community library and his subtask library. He may also transfer data and application modules which are outside IPAD's control into his subtask library. These libraries are formed from two basic items--variables and entries. Any entry may be data, source code, object code, or system commands. Variables are the individual items in a library entry containing data. Variables and entries are organized into dictionaries and directories. The dictionaries describe the meaning or functional use of a variable or entry. The directories point to the storage location of the entry as shown in figure 2.26.

Both variables and entries are defined in dictionaries, typified by the following information:

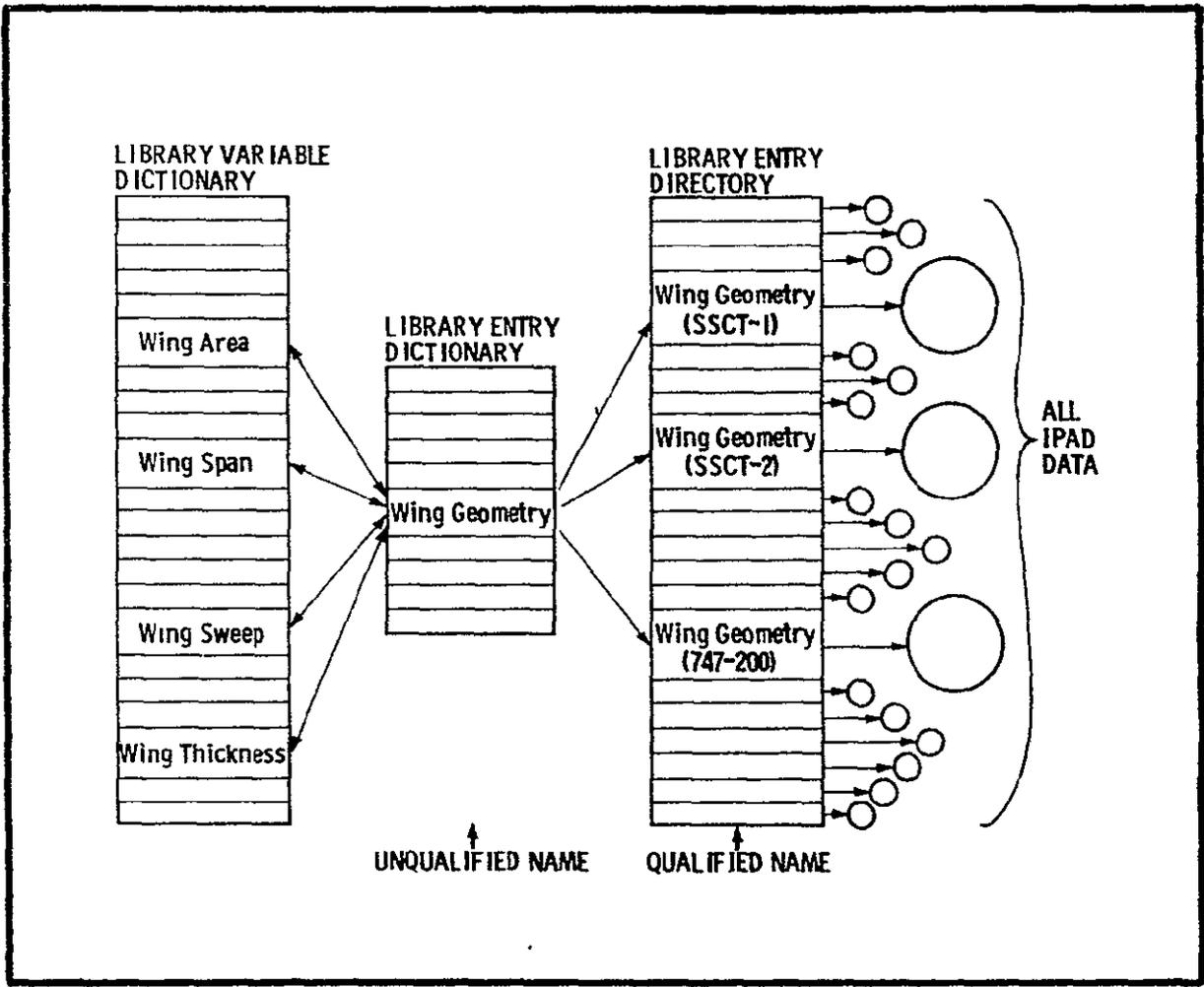


Figure 2.26 Library Organization of Data in IPAD

<u>Variables</u>	<u>Entries</u>
Engineering significance	Engineering use
Units	List of variables
	Logical structure

The dictionaries provide a clearing house for nomenclature and a means for searching for items through keyword lists.

The user is linked to each item in the library entry dictionary by an unqualified name for the item. When specific data is associated with an entry, the unqualified name is combined with a qualifier (associated with the particular data) to produce a qualified name. Any unqualified name may be associated with many qualified names. The collection of qualified names forms the basis of the library entry directory which points to all data in the library. The qualifier is the user's primary means of data identification.

Qualified and unqualified names must be unique within a library.

#### 2.4.1.2 Library Structure

The community and subtask libraries have been defined in the IPAD data base. Their relationship is shown in figure 2.27. The basic characteristics of each library are:

##### 1. Community Library (CL)

- Long term continuity of information.
- Contains all programs and data available to IPAD users.
- Active library items will be online.
- Archival library items may be offline.

##### 2. Subtask library (STL)

- Contains all information associated with one user's working domain for a subtask.
- Community library items may be attached, copied, or transferred to the subtask library.

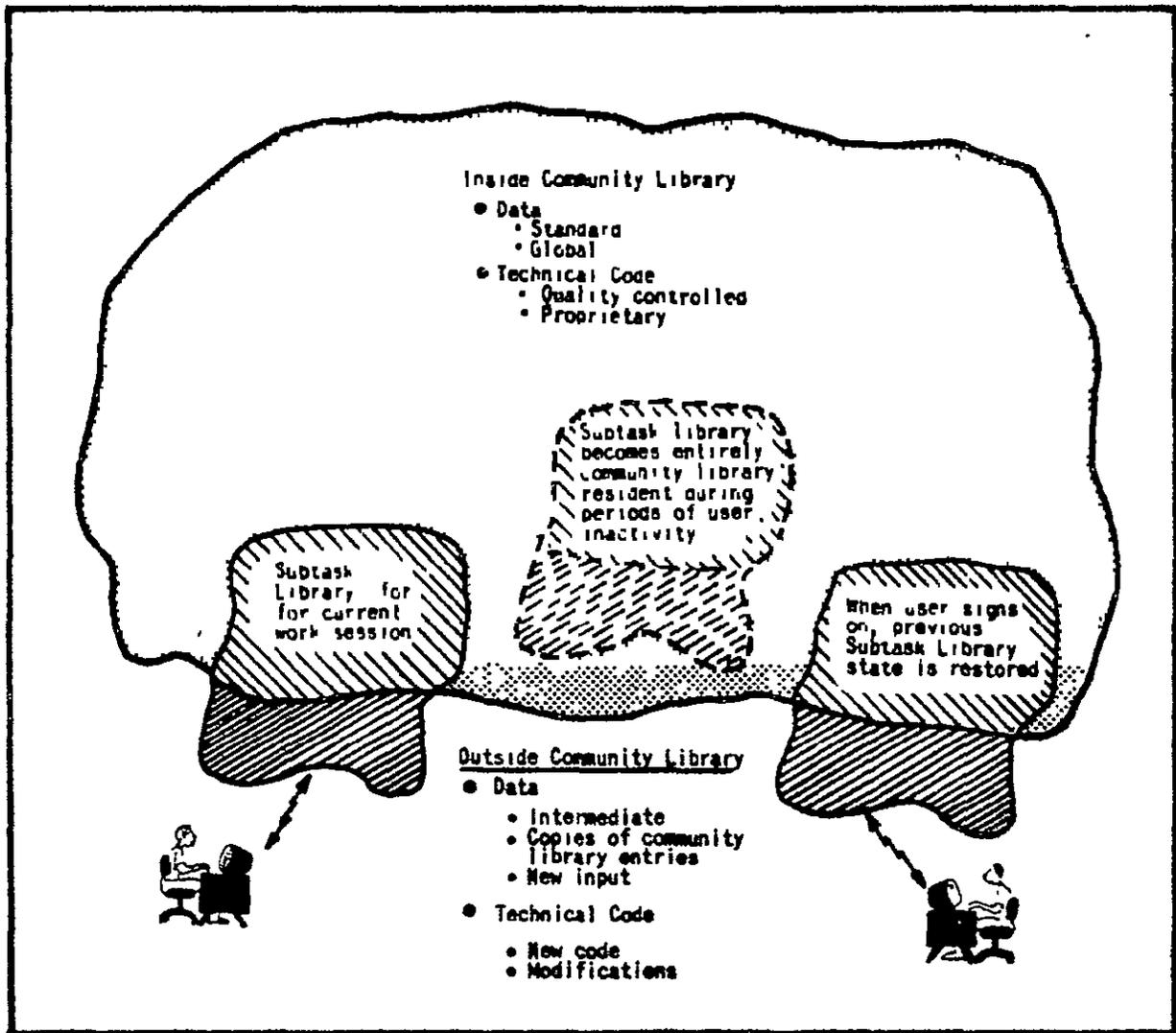


Figure 2.27 Attribute of IPAD Community and Subtask Libraries



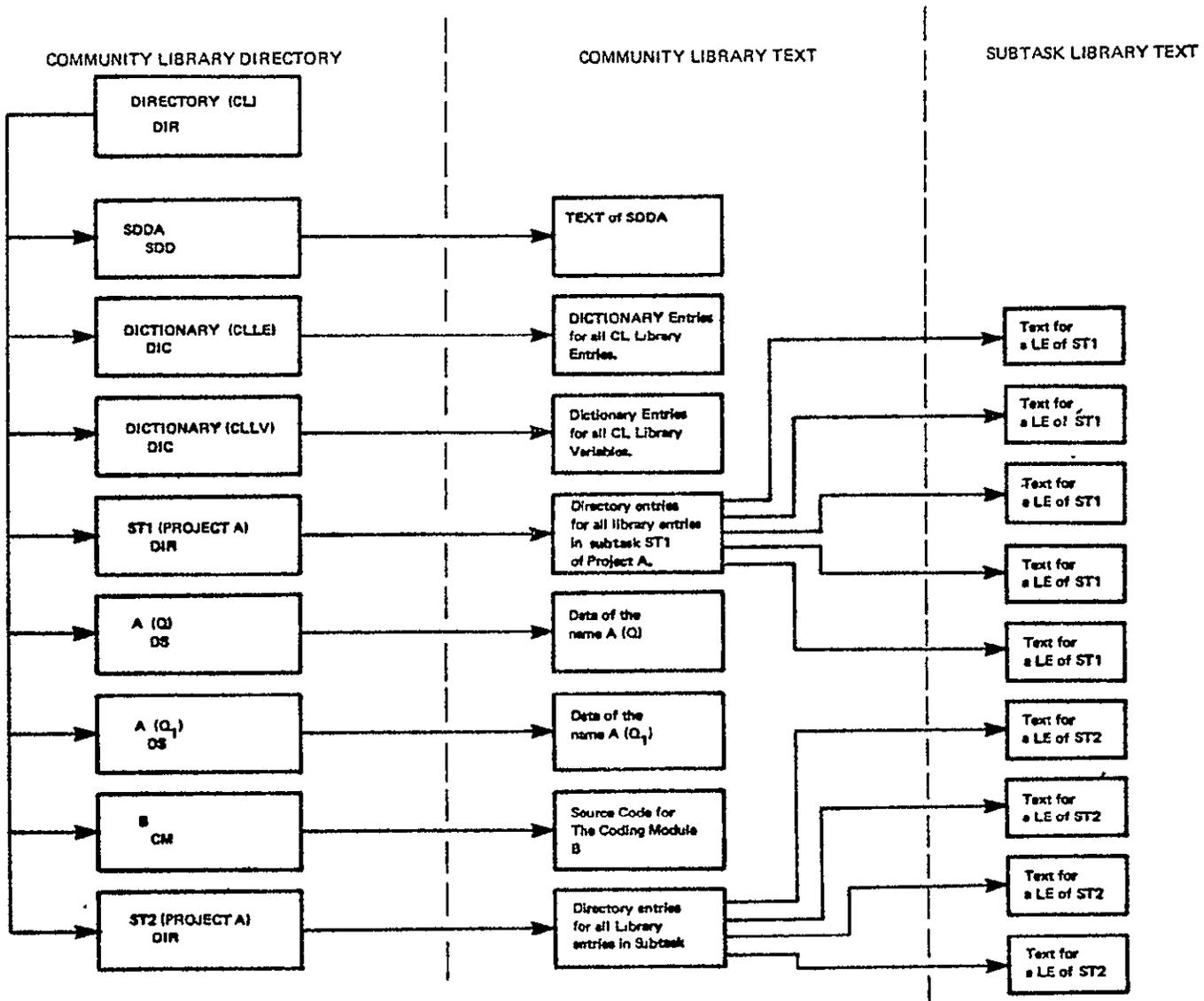


Figure 2.28 IPAD Library System

1. Code  
2. Data Manager Information

- Code
  - Data Manager Information
  - System Control Information
3. Each library must have
- One directory type library entry
    - Index to all library entries
  - At least one dictionary type for:
    - Library variables
    - Library entries
4. All information enters through the subtask library

#### 2.4.2 The Job Concept

Application modules and utility functions will be executed as one or more jobs. A job is a selected set of Operational Modules (OM) and/or other jobs organized by the user as part of a subtask. An OM consists of a selected set of subroutines organized as Coding Modules (CM) to execute in a sequence as defined in a "main program." Without regard to execution sequence, the above relationships are shown in figure 2.29. Any set of source code used in several OM's should be entered as a CM to make it more visible to the user community. The same rule applies in the OM to job relationship.

##### 2.4.2.1 Entering Coding Modules (CM)

Source code and descriptions are entered as Coding Modules as shown on figure 2.30.

##### 2.4.2.2 Building Operational Modules (OM)

Developing OM's is a building process where one or more CM's are assembled into an executable form. See figure 2.30. A complete OM must have one main control program, i.e., only one main program may exist in the CM's being packaged into an OM. Also, if no main program exists in the CM's to be used, then one must be written as part of the OM building process. Some library entry information must also be defined at OM build time,

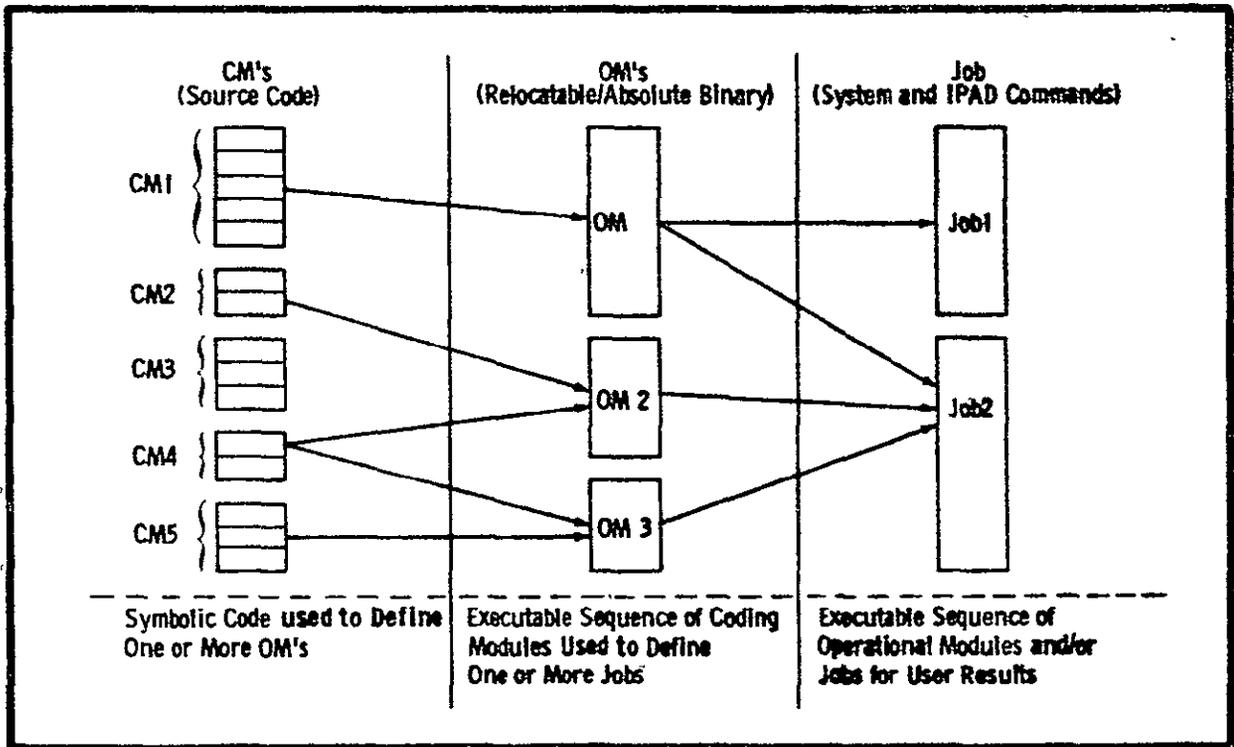


Figure 2.29 Sequence of Job Definition

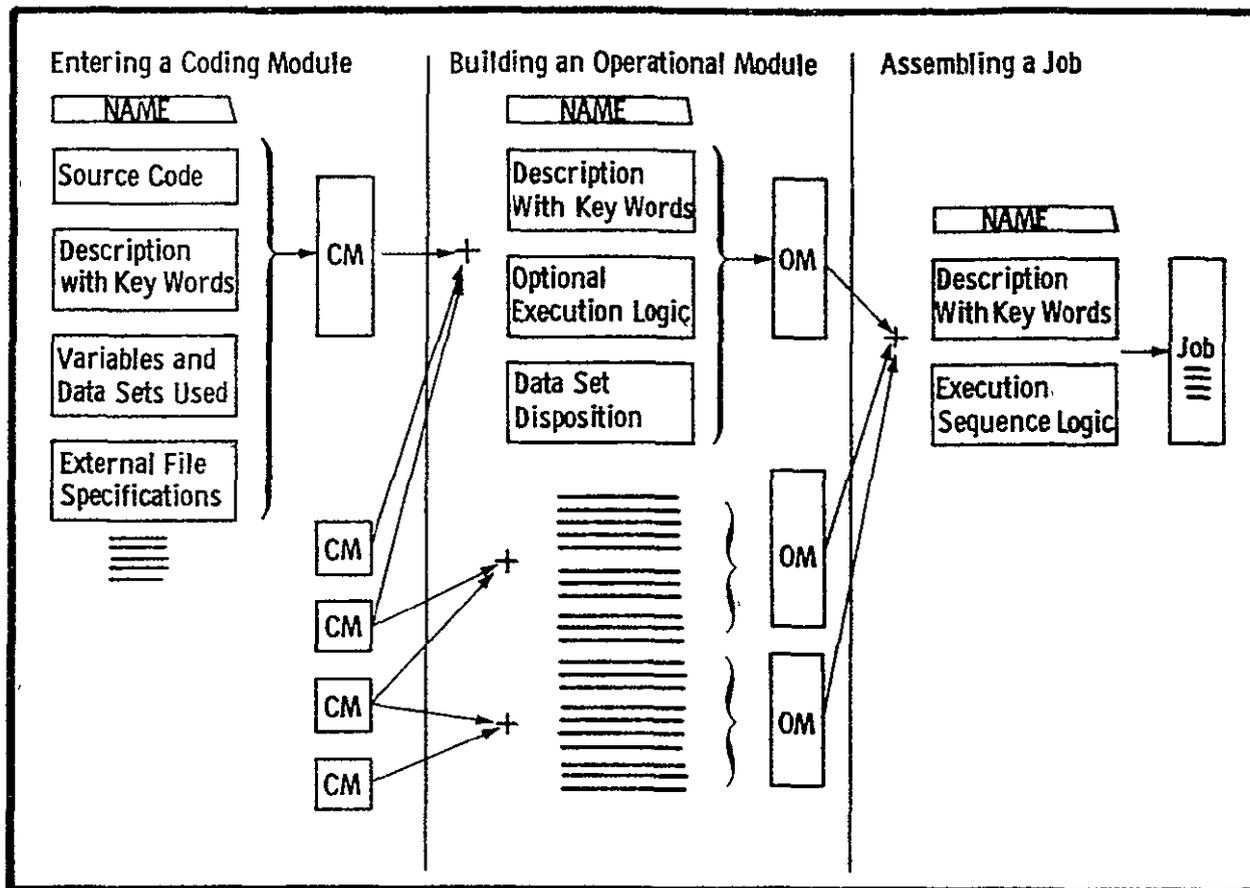


Figure 2.30 Steps in Job Construction

such as library entry use and disposition. Any files used by the OM and not linked to library entries by the CM's must be linked at this time. If an OM is placed in the community library, all its component CM's must be in the community library also.

#### 2.4.2.3 Constructing Jobs

Constructing a job is similar to building an OM. An execution sequence with optional logic at OM boundaries is specified. The executable units in a job are OM's. During job assembly the qualifiers for all output library entries will be partially constructed. Information supplied at job execution time will complete the qualifier. Job construction is illustrated in figure 2.30.

#### 2.4.2.4 Execution of Jobs

When job execution is requested, the subtask library and community library are searched for the correctly qualified input library entries. The library directory entries for all intermediate and output library entries are set up in the subtask library and are qualified by both the set of qualifiers generated at job assembly time and the set received with the request for execution. All file linkages to actual locations (as specified in the job definition) are set. The status record information for this job request is written and the system commands required to execute the job are delivered to the operating system for execution.

#### 2.4.3 The Subtask Concept

The user interface with the IPAD System has been established from a unique concept called the subtask.

IPAD must support the general work relationships existing in hierarchy of product design and development. The system design focus is thus at the user subtask level. This design must recognize the demands made on the user from above and below his domain of interest. A user's subtask will be supported in a community of such users. Figure 2.31 repeats the information shown on 2.23 to emphasize the user/subtask relationship.

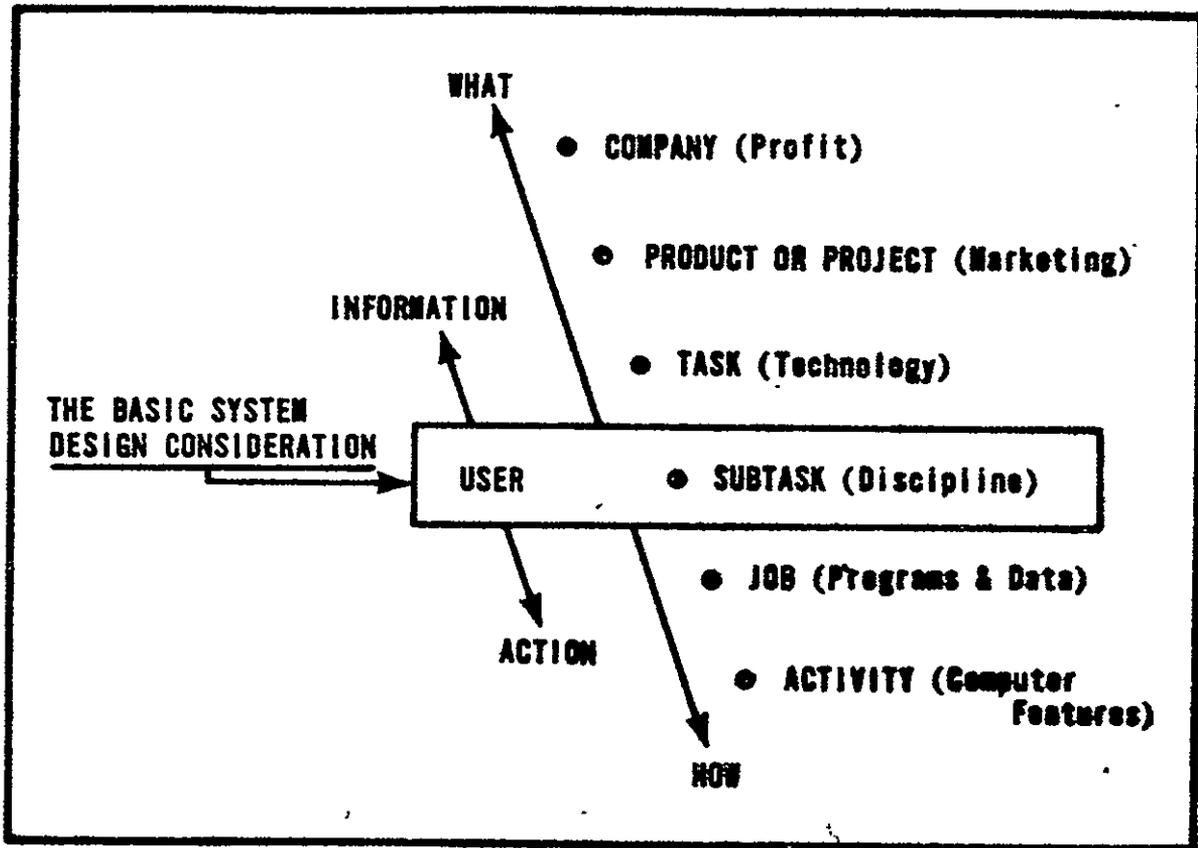


Figure 2.31 Hierarchy of Product Design

#### 2.4.3.1 Subtask Characteristics

Subtasks are the primary working interface between the IPAD System and the IPAD user. The characteristics of the subtask are as follows:

1. One user oriented
2. Limited domain of work
3. Access to the community data base
4. Logically continuous throughout the subtask life

Subtasks are associated with one user and are organized within IPAD to provide continuity of activity. A subtask is a user's private domain in which he works individually without impacting other users. He has access, through the data base libraries, to application programs, utility programs, and data common to all users. His accessing of information in the data base libraries is controlled or restricted as necessary because of the community nature of the data base.

Continuity of activity means that from the time the user initiates a subtask until he terminates it, he works within the continuity sense of a single session. That is, having interrupted his activities for lunch, sleep, or thinking, he will resume activity with a subtask status identical to that at the time of his interruption. This continuity will be true for either interactive or batch type work.

Continuity between subtasks (and hence between users) will be provided by the data base. As each subtask is terminated, the user will transfer entries of general interest into the community library.

#### 2.4.3.2 Subtask Activities

Activities of a user during a subtask fall into the following general categories:

- Initializing a subtask
- Entering data and code
- Constructing jobs
- Executing jobs
- Examining results
- Modifying data and code
- Disposing of data and code
- Interrupting a subtask
- Terminating a subtask

### 2.4.3.3 Work Relationships

Figure 2.32 shows a schematic relationship of the data base and work within IPAD. A project consists of:

1. Project Plans
  - Overall Project Plans
  - Individual Subtask Plans
2. Project Reports
  - Project Summary Report
  - Individual Task Reports
  - Individual Subtask Reports
3. Subtasks
  - All user activity in IPAD occurs in a subtask.
  - The mode of communication in a subtask is primarily interactive.
  - Batch mode is available. Continuity is retained in the subtask whether accessing is interactive or batch.
  - A user may have an arbitrary number of subtasks active at any one time.
  - A subtask has three meaningful states in IPAD: defined, active, or terminated.
  - Records of subtask library and are used to formulate project reports.
  - Users communicate subtask data through the community library.
  - Protocol is defined to maintain integrity of data in the community library.

It may be desirable to have complete project and task plans available before subtask definition, but it may not be practical to do so. However, it is necessary that a subtask be defined before it is activated so that accounting and reporting can be done by the system. IPAD provides a framework within which

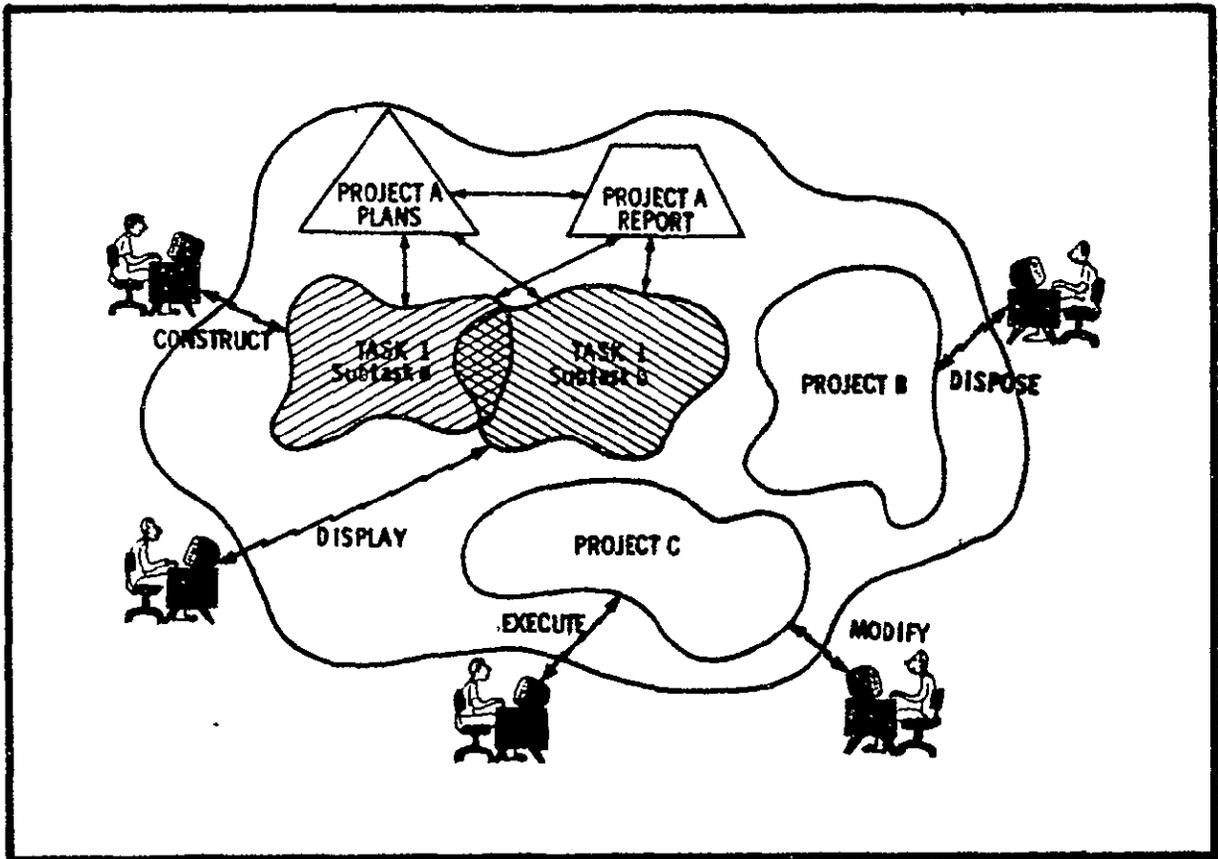


Figure 2.32 Data Base and Work Relationships in IPAD

control and reporting may be defined to meet the needs of the using organization. IPAD will not require a user to record his progress in the project report unless control has been defined in project plans by his management.

#### 2.4.4 The Executive Control Concept

IPAD is organized like many computer programs which consist of a set of semi-independent utility programs tied together by an executive program. The utility programs are relatively fixed, prepackaged operational activities and they communicate with each other and the executive program through a limited number of communication paths.

##### 2.4.4.1 The IPAD Executive Functions

The IPAD Executive must handle all user requests and transform them suitably for action by either the data base manager or the host operating system. This will allow the user language to be independent of the actual working software. In addition, the Executive has the total capability to identify users; to allow or disallow the user access to the data base; to control the execution of the OMS as prescribed by the user; to consistently document the activities of the user and maintain the necessary records to provide continuity.

The basic executive functions are as follows:

1. User Interface
  - Access control
  - Activity control
  - Activity documentation
2. Data Base Manager Interface
3. Host Software Interface

##### 2.4.4.2 User Interface

###### 1. Personal Terminal

The primary interface between the user and IPAD will be a "personal terminal." A "personal terminal" is uniquely associated with a given user while he is active. Each user will

be identified to the system via his identification code. Since the IPAD System will not have terminal handling software, the user's first contact will be with the operating system. If IPAD is the only system requiring terminal support, the operating system will be a transparent message carrier.

## 2. Command Flow

In general, each command to IPAD will be mapped into one or more operating system commands. Control will then be given to the operating system. When the operating system has completed a set of commands, IPAD will be recalled to determine if all commands have been processed. If not, the above process will be repeated. When all commands have been processed, appropriate entries will be made in the subtask records and all items will be disposed of as requested by the user. An activity in progress may be interrupted and another activity initiated. Upon completion of the second activity the user may continue the first activity. This sequence may be nested. The sequences for execution of data and programs may be stored as job descriptions in the IPAD libraries. The general flow of control for IPAD and system commands is shown in figure 2.33.

Subtask reports will be compiled giving data sets used and generated, application modules used, and commands executed from information in the IPAD libraries. Recovery is accomplished from information contained in the libraries. The user determines the point of recovery by considering the logical organization of his job.

While many languages may exist within the total IPAD domain, the IPAD executive itself needs a relatively limited language capability. The basic commands are modal statements, i.e., the command indicates the basic intent of the user. These commands are the means of executing all application modules, executive utility functions and data base management functions. Recommended basic commands were given in section 2.3.4.3.

### 2.4.5 The Data Management Concept

Within IPAD data communication will be under the control of a Data Management System (DMS).

#### 2.4.5.1 Data Management Functions

The Data Management System (DMS) coordinates and controls all data activities in the IPAD System. Users, OMs, and the IPAD Executive access the data base through DMS. Administrative

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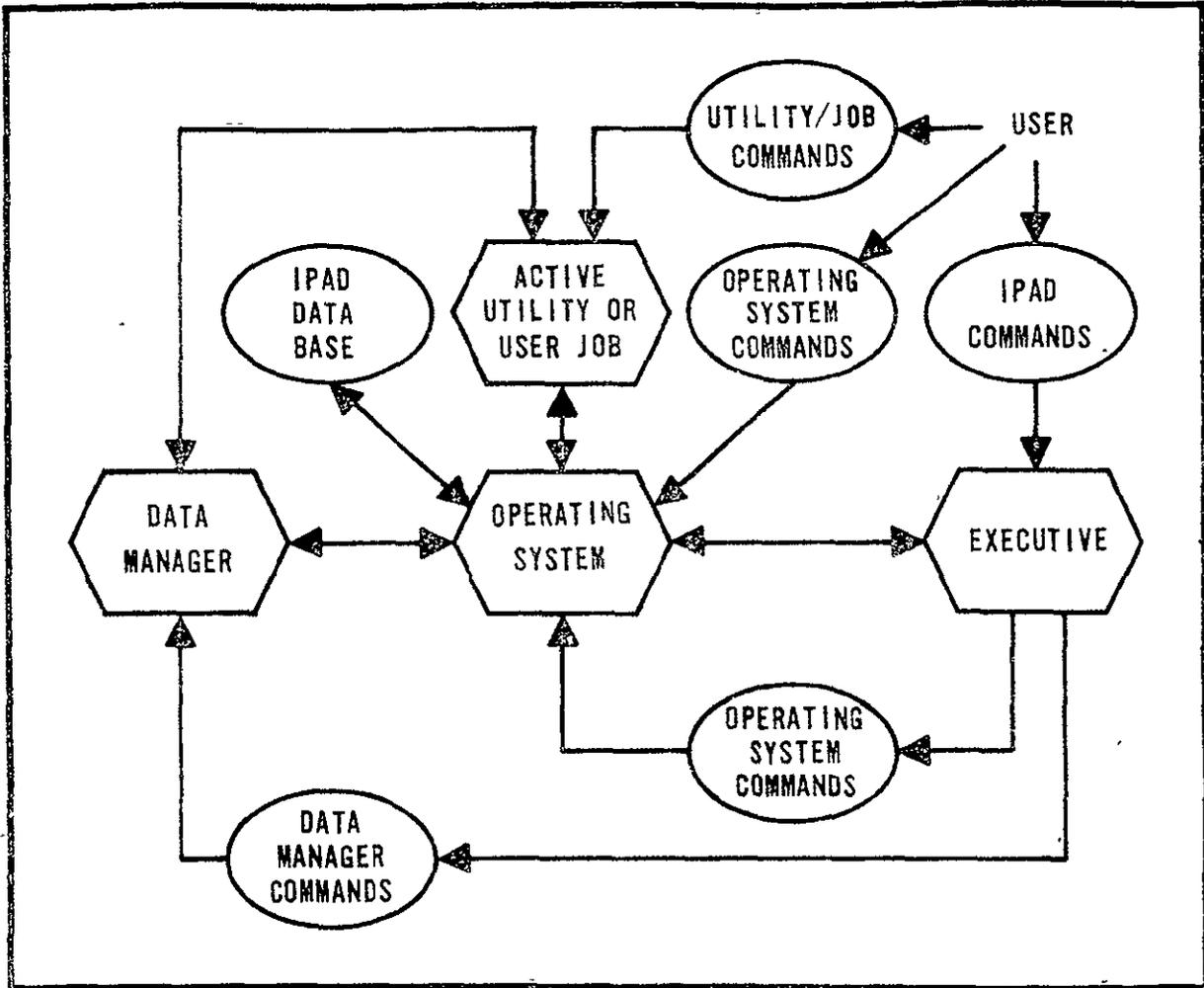


Figure 2.33 IPAD System Command Flow

policies and strategies dealing with access privileges and retention control will be carried out by the DMS. The major functions of the DMS are as follows:

1. Maintain a Dictionary of Variables, OM's and Data Sets
2. Provide the Mechanisms for the Physical Storage and Retrieval of Data
3. Support a Set of IPAD System Data Structures
  - Libraries which reference common data elements
  - Cross references and relationships among different library types
  - Checks of cross references and tests of relationships.
4. Provide Interface Between OM's and Data Base

#### 2.4.5.2 Elements of the Data Base

Many elements of data will be accommodated in the data base. Some of the data elements will be used by the data base manager to carry out the data management functions. However, most of the data elements are directly related to user activities. Figure 2.34 defines the basic elements of the IPAD data base.

#### 2.4.5.3 IPAD Data Base Libraries

Information organization is fundamentally by individual users. They may communicate via the data base and still retain individual identity. Each logical session at the machine may be separated from each other to help the user keep organized and give management the ability to observe project status at any time. Once an activity is completed, the data of historical importance can be kept while eliminating the non-useful data, activity by activity under the direct control of the users. The primary purpose of the IPAD libraries is to provide partitions of the data base which allow the following capability:

1. Organization of Work by Individual User
2. Separation of Activities by User

DATA ELEMENTS	DEFINITIONS
Directories	Locations for storage and retrieval of IPAD data
Dictionary	Variable definitions with cross references to OM's and data sets
SDD	Stored data definitions of logical organization of sets of variables; specifications of internal and external units for transformations; cross references to dictionary
Data Sets	Values of variables used and produced by OM's, and input from external sources
OM's	Organized set of coding modules that form a unit of execution
Plan	User project planning and system coordination and control data
Job	User defined OM execution sequence
Coding Module	Source and object code

Figure 2.34 Data Base Elements

### 3. Continuity of Related Activities

- Product design
- Tasks within product design

### 4. Management Visibility

- Status of design activity
- Review of design process
- Critical path detection

### 5. Historical Data Source

The libraries described in section 2.4.1 contain two categories of data structures; system defined and the user defined. No formal distinction is made between these categories by the data manager, but system structures are not generally accessed directly by user programs. The system structures are used to store application modules, referencing information, control information, etc. User structures contain data produced and manipulated by application programs. The user is not restricted to a fixed set of data structures. Figure 2.35 shows the general contents of the data base.

There are two basic modes of access to data by application modules:

1. Explicit I/O - the user's code is written with detailed knowledge of the data structure of the library entry.
2. Implicit I/O - the user's code references variables within an entry by name, letting IPAD do all storage and retrieval.

In the first case, the user names the required library entries, and they are made available at execution time. The data manager assumes that the user's code will handle read/write operations.

In the second case, the user's code contains declarations naming stored data definitions, and explicit I/O statements are replaced by commands to the data manager to fetch and store data. The data manager carries out the required I/O as specified by the appropriate stored data definition. Figure 2.36 shows a schematic of the two I/O modes and figure 2.37 is a table of comparisons.

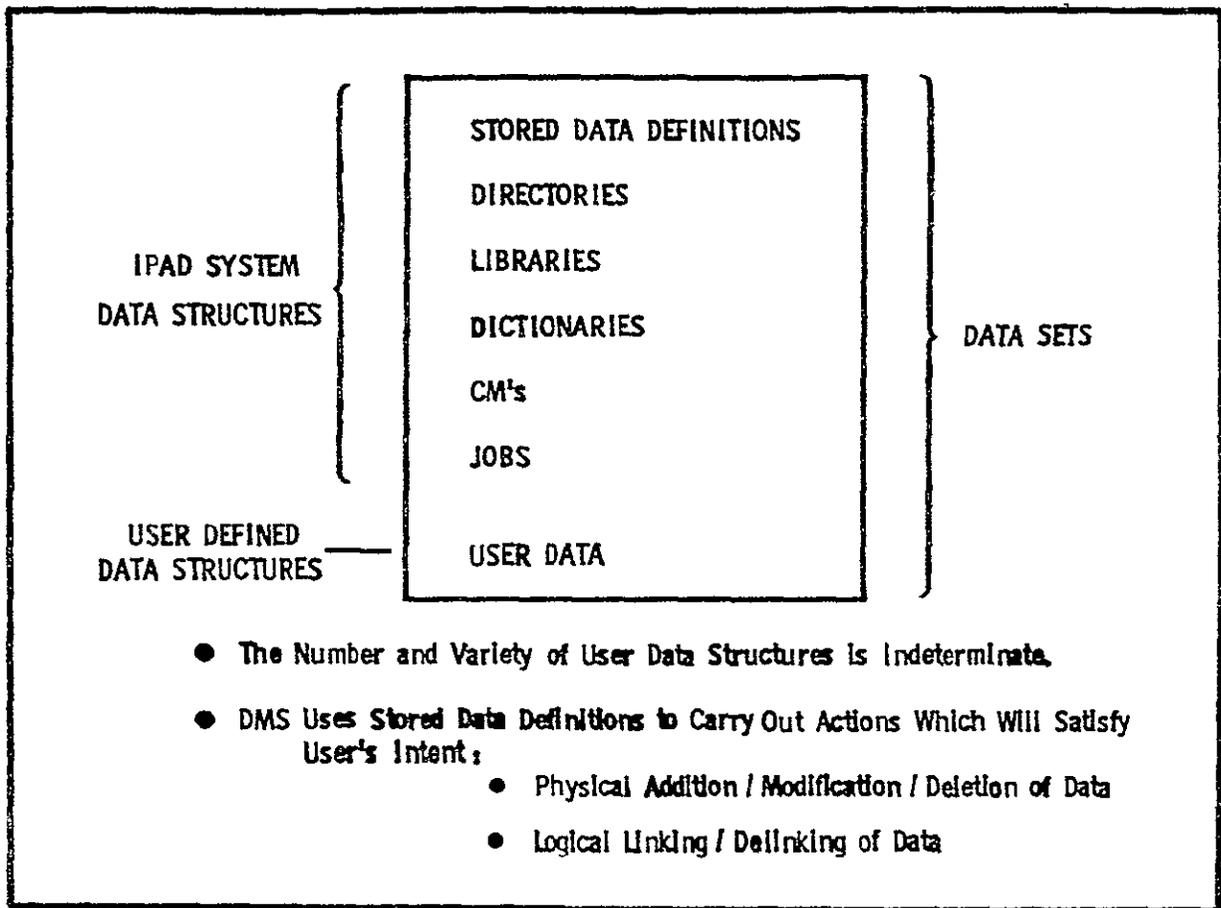


Figure 2.35 Data Base Contents

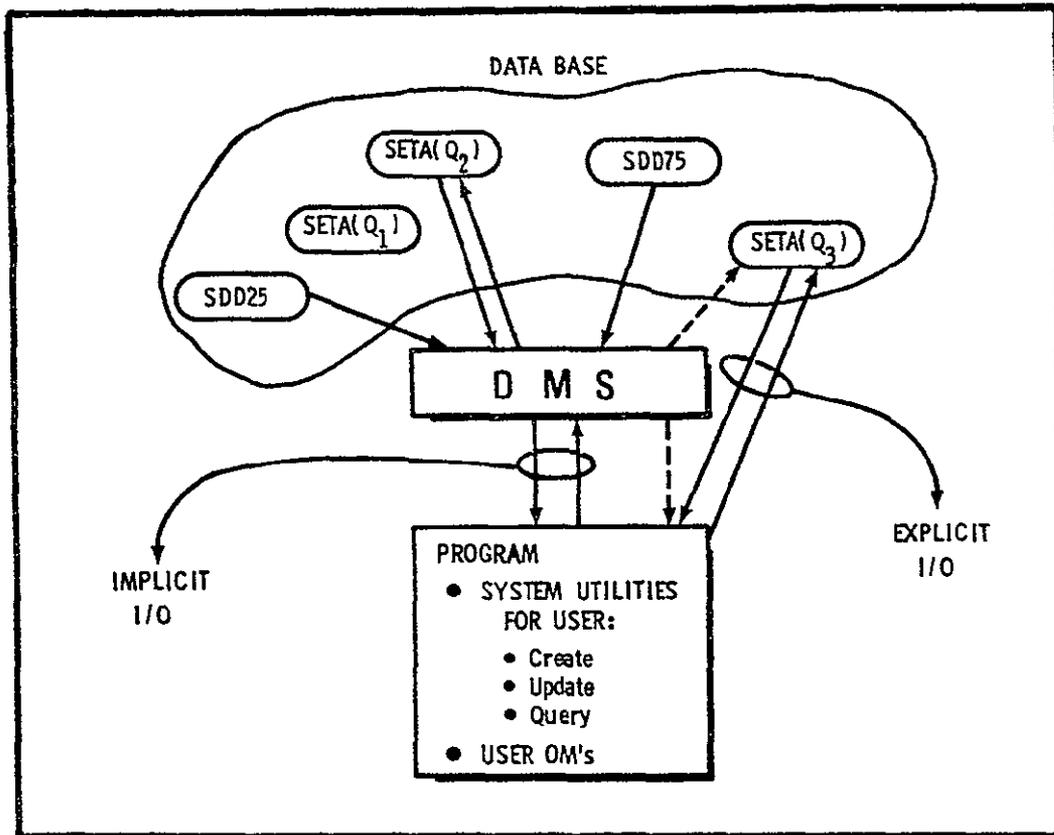


Figure 2.36 Relationships of Implicit and Explicit I/O to the Data Base

EXPLICIT I/O	IMPLICIT I/O
<ul style="list-style-type: none"> <li>• DMS Connects OM to an Entire Data Set</li> </ul>	<ul style="list-style-type: none"> <li>• DMS Connects User to All or Part of Specified Data Sets</li> </ul>
<ul style="list-style-type: none"> <li>• OM Performs all I/O Operations Without IPAD Intervention</li> </ul>	<ul style="list-style-type: none"> <li>• User Requests Data               <ul style="list-style-type: none"> <li>• By Library Variable (Data Item Key)</li> <li>• By Position                   <ul style="list-style-type: none"> <li>• Sequential Data Sets</li> <li>• Logical Chains</li> </ul> </li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>• DMS Functions Performed only on Entire Data Set</li> </ul>	<ul style="list-style-type: none"> <li>• DMS Functions Performed on Individual Library Variables Within Data Sets</li> </ul>

Figure 2.37 Relationships of Implicit and Explicit I/O to the Data Base

#### 2.4.5.4 Stored Data Definition (SDD)

All information in the IPAD libraries is accessible through a stored data definition (see figure 2.38). The SDDs for user data are user supplied, avoiding the problem of forcing users to change their data formats and structures to conform to a single standard.

Each library entry in IPAD may have one or more formats associated with it. When described by a single SDD, multiple formats imply the use of subsets of the whole library entry or possibly different unit conversions. Multiple format SDDs also allow external formats (e.g., punched cards) to be described. SDDs are mandatory when using implicit I/O and optional for library entry used in explicit I/O only.

#### 2.4.5.5 Implicit Input/Output

SDDs require each variable to have a definition in the variable dictionary and a corresponding global name. The utilization of global names in the SDD eliminates many of the ambiguities that could arise when different people are interpreting data variables or when decisions are made regarding the selection of a coding module for a specific computation. The SDD also permits variables to be given local names for different subroutines. During execution, calls on the data manager will result in data being moved from the storage media to the user's working area. Data will be positioned in the user's working area so that local name references to variables in the user's code will be correct. Data structures can be varied without jeopardizing user code although recompilation may be required.

#### 2.4.5.6 Explicit Input/Output

When the data handling logic is explicitly present in the source code, (as it is with all source code generated without data manager type functions available) the data manager's function is limited to OM boundaries; i.e., the data manager will prepare the data linkage prior to OM execution and dispose of the data after execution. Knowledge of the library entry internal structure by the data manager is not required during program execution.

#### 2.4.5.7 Physical Distribution of Data in Data Base

- AN SDD DESCRIBES A DATA STRUCTURE WHICH IS USER'S MODEL OF REAL WORLD
- AN SDD FILED IN THE DATA BASE IS A TEMPLATE USED BY DMS WHEN ACCESSING DATA

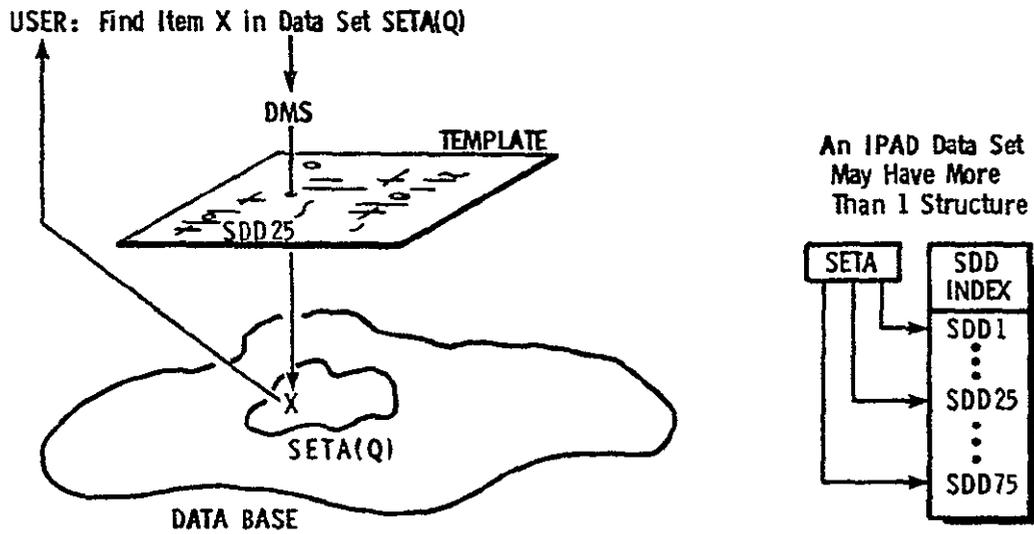


Figure 2.38 Stored Data Definition Illustration

Physical storage of data on the available storage devices is under DMS control (see fig. 2.39). Decisions relative to the distribution are made by both the users and the DMS. Users may desire to keep data at a particular storage level consistent with expected access requirements. DMS in managing available space utilizes user requests and internally gathered usage statistics.

Data sets must have logical relationships preserved across devices. DMS will handle the mappings required when the physical representations change so as to allow, for instance, a relational data structure on a random access device to be moved to magnetic tape and re-loaded at a later time. DMS capability to manage such storage mappings in conjunction with SDD's can be applied to problems of data back-up, archive storage, and data portability.

#### 2.4.5.8 Pre-Existing Application Code

Considerable concern has been expressed over the handling of application modules already in existence and modules that will be developed independent of the IPAD system standards. The Control Data Corporation studied this question and their report is included as Appendix C to Volume IV. The following is a brief summary.

The General Problem--The IPAD software migration problem can be stated as follows: given an open-ended set of programs, called Operational Modules (OMS), written in several languages for different computers, design a machine independent system, IPAD, in which the OMS are linked by an executive program through a data management subsystem to a common data bank. The system should execute as a job in batch mode under the standard operating system at any installation having the minimum equipment configuration required.

Solution Proposed by CDC--A solution of the general IPAD problem includes, as one of its principal parts, development of methods for moving operational modules (OMS) freely among the various IPAD based computer systems. Since most of the OMS are written in some form of FORTRAN, a solution for this case alone can be expected to be useful.

A number of methods for solving this migration problem, at least in principle, have been examined. Of these, only two showed sufficient promise to be retained for further consideration. The first requires that each source language program be translated to a common language before compilation and execution. The second is based on a pairwise set of source

- Data will be Stored by DMS on Different Levels of Storage Devices
- Decisions will be Made by User and DMS
  - User
    - Project Status
  - DMS
    - Storage Availability
    - Usage Statistics
- DMS will Automatically Map Storage Structures Across Devices
- DMS Use of SDD's and Storage Structure Mapping Capability are Mechanisms That Provide Data Base Portability
  - Introduction of Foreign Data Sets to IPAD
  - Provide IPAD Data for Other Systems

Figure 2.39 Physical Distribution of Data in Data Base

- host translators. The principal advantage of the first method is that the common language becomes, by definition, the IPAD standard. The advantage of the second method is that its initial cost is probably lower, but as new dialects enter the system, new translators must be written, and documentation standards would be difficult to enforce. The first method has been recommended by the Control Data Corporation as a result of their study.

The design of the common IPAD language is the next concern. Three requirements are basic. It must be possible to translate existing programs to it, the translated programs must not contain machine dependent code, and the language must be extensible to accommodate fourth generation computers entering the IPAD System.

It follows from examination of FORTRAN dialects in current use that the common IPAD language can be machine independent only if it requires that the same amount of detail that is now implicit in the computer environment for which the program was written be specified explicitly. The architectural differences between third and fourth generation machines is so fundamental that it can be assumed that most OMS will in time be reprogrammed for the newer computers.

The conclusion reached by CDC was in this study is that the IPAD software migration problem is best solved by translating current OMS into, and writing all future OMS in a common machine independent FORTRAN based language, developed especially for IPAD, that can be extended to include vector and string processing in its fourth generation version.

#### 2.4.6 The IPAD System Design

The IPAD System design involves development of two basic system software functions. The first is an executive program and the second is a data base management system. The language of these programs is to be as machine independent as possible to provide the maximum portability of IPAD. The following section summarizes the basic approach to the IPAD System design.

##### 2.4.6.1 Executive Design Approach

Figure 2.40 outlines the basic design criteria for the IPAD executive program. There will be one executive per each active subtask. The executive will use the host operating system utilities.

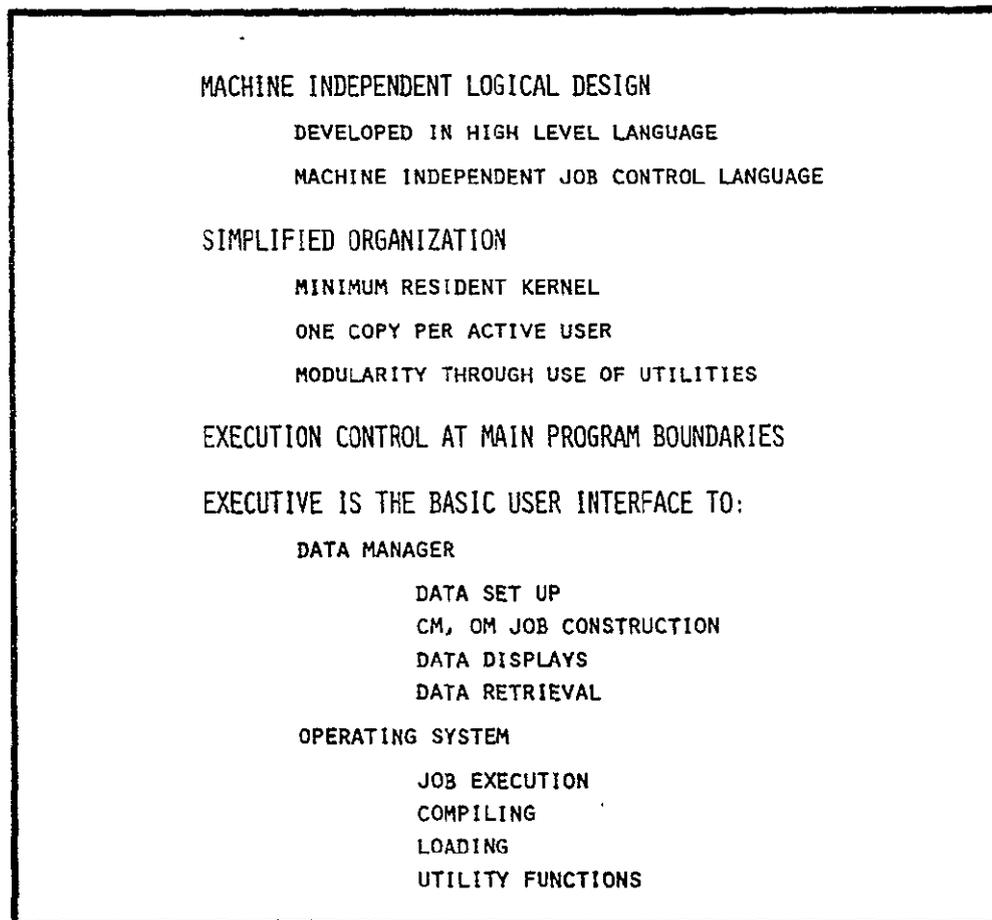


Figure 2.40 Executive - Design Approach

#### 2.4.6.2 Data Management System Design Approach

Figure 2.41 outlines the basic design criteria for the IPAD data base management system. The approach to the DMS design is to provide the means for users to define their data structures. This information will be saved and referenced by the DMS when access to data is needed.

Consistent with the design approach of the IPAD Executive, the DMS is being design so that there may be many simultaneous users accessing the data base, each with his own copy of the DMS. Interlocks and coordination among users will be through the data base. A higher level language will be used for the actual development of DMS which reflects the intent to keep the design machine independent.

Because of the large volume of data anticipated for an IPAD system, the overall design must allow different types of storage devices to be used. The DMS design approach calls for the control of the distribution of data across a hierarchy of storage devices to rest with DMS rather than the operating system. (This permits DMS to use IPAD usage statistics and IPAD user commands to determine where data should and may be stored. It also permits DMS to cope with the problem of maintaining logical relationships in data when the physical storage structure changes with devices.)

#### 2.4.6.3 Principal IPAD System Design Concept

The IPAD System is designed principally as a data management system. Application modules, i.e., user software, are treated as an entry in the data base. The organization of application modules into sequences to perform some particular task is supported by executive type routines. The execution of module sequences and the handling of data are supported by the host operating system and the IPAD data manager. Personal terminals are the principal interface and dialogue language is the principal means of communication. Tables 1-4 summarize the relationship of the basic user requirements to the system design features and the IPAD system and operating system software requirements.

#### 2.4.6.4 System Design Methodology

Structured Programming is a formal work dealing with software engineering and hardware-software system design and development. The objective of this work is to transform the development of computer systems from a seat-of-the-pants art, to

- SYSTEM MUST ACCEPT DATA STRUCTURE DEFINITIONS
  - NOT ALL DATA STRUCTURES KNOWN IN ADVANCE
    - System
    - Engineering
  - DATA STRUCTURES REQUIREMENTS CHANGE IN TIME
    - Variety from Large Body of Users with Individual Ideas
    - Data Structures are not Rigid and Develop with Technology
- MANY SIMULTANEOUS USERS IN DATA BASE
- EACH USER HAS OWN COPY OF DATA MANAGER
- HIERARCHY OF STORAGE DEVICES
- DEVELOPED IN HIGH LEVEL LANGUAGE

Figure 2.41 Data Management System - Design Approach

Table 2.1 IPAD Design Requirement--Continuity Over Task and Time

CONTINUITY OVER TASK AND TIME			
DESIGN REQUIREMENTS	IPAD SYSTEM DESIGN FEATURES	IPAD SOFTWARE REQUIREMENTS	HOST OPERATING SYSTEM REQUIREMENTS
Continuity of day-to-day work	<ul style="list-style-type: none"> <li>• Subtask interruption and restart</li> </ul>	<ul style="list-style-type: none"> <li>• Unique identification of subtasks</li> <li>• Saving/retrieving subtask library</li> <li>• Subtask setup</li> <li>• User log off with job executing</li> </ul>	<ul style="list-style-type: none"> <li>• Time sharing system               <ul style="list-style-type: none"> <li>— multi tasking</li> <li>— relationship to IPAD executive</li> <li>— allowable terminal disconnect during execution</li> </ul> </li> <li>• Permanent file system</li> </ul>
Flow of information throughout the user community	<ul style="list-style-type: none"> <li>• Community library and its associated support routines</li> </ul>	<ul style="list-style-type: none"> <li>• Data display</li> <li>• Information retrieval</li> <li>• Explicit/Implicit I/O</li> <li>• Unique names</li> <li>• Qualifiers</li> <li>• Data management discipline and conventions</li> </ul>	<ul style="list-style-type: none"> <li>• Permanent file system</li> <li>• Data management utilities</li> </ul>
Project plans and progress related to the user's day-to-day work	<ul style="list-style-type: none"> <li>• Subtask setup and termination linked to project plans and reports</li> </ul>	<ul style="list-style-type: none"> <li>• Connecting user log-on/off to plans and reports</li> </ul>	
Continuous user capability while migrating across computers	<ul style="list-style-type: none"> <li>• Machine independent high level design</li> </ul>	<ul style="list-style-type: none"> <li>• High level code in the IPAD system written in machine independent source statements</li> </ul>	<ul style="list-style-type: none"> <li>• Compiler for a machine independent language</li> </ul>

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Table 2.2 IPAD Design Requirement — User Interface

USER INTERFACE			
DESIGN REQUIREMENTS	IPAD SYSTEM DESIGN FEATURES	IPAD SOFTWARE REQUIREMENTS	HOST OPERATING SYSTEM REQUIREMENTS
Personal Terminal	<ul style="list-style-type: none"> <li>• Unique user ID for each person</li> <li>• Support for typical terminal activities</li> </ul>	<ul style="list-style-type: none"> <li>• User ID tables</li> <li>• Logic to support terminal type activities</li> </ul>	<ul style="list-style-type: none"> <li>• Time sharing system supporting the appropriate type of terminal</li> </ul>
Functional Capabilities <ul style="list-style-type: none"> <li>• Define Variables</li> <li>• Enter code and data</li> <li>• Transferring information within IPAD</li> <li>• Sending information outside IPAD</li> <li>• Edit code and data</li> <li>• Purge information</li> <li>• Compare information</li> <li>• Construct jobs for execution</li> <li>• Execute jobs</li> <li>• Display information</li> <li>• Find information</li> <li>• Learning about IPAD</li> </ul>	<ul style="list-style-type: none"> <li>• Defining library entries or variables</li> <li>• Creating library entries</li> <li>• Disposition of library entries</li> <li>• Modifying library entries</li> <li>• Disposition of library entries</li> <li>• Displaying results</li> <li>• Construct an OM sequence as a job</li> <li>• Execute a Job</li> <li>• Displaying results</li> <li>• Searching through the libraries</li> <li>• Displaying results</li> <li>• Searching through the libraries</li> <li>• Learning about IPAD</li> </ul>	<ul style="list-style-type: none"> <li>• Executive and data management software</li> <li>• Teaching software</li> </ul>	<ul style="list-style-type: none"> <li>• Executive and data management software support</li> </ul>
General Control Commands for <ul style="list-style-type: none"> <li>• Pausing</li> <li>• Continuing</li> <li>• Log-off</li> <li>• Log-on</li> <li>• Assistance</li> </ul>	<ul style="list-style-type: none"> <li>• Interrupted states</li> <li>• Operating system log-off, IPAD log-off</li> <li>• Operating system log-on, IPAD log-on</li> <li>• Learning about IPAD</li> </ul>	<ul style="list-style-type: none"> <li>• Executive logic working with the operating system</li> <li>• Subtask setup and interruption logic</li> <li>• Teaching software</li> </ul>	<ul style="list-style-type: none"> <li>• Roll out, roll in controllable by a user program</li> <li>• Terminal interface for log-on and log-off</li> </ul>
Handling of information inside IPAD is invisible to the user	<ul style="list-style-type: none"> <li>• Stored data definition</li> <li>• Coding module, operational mode, and job organization</li> </ul>	<ul style="list-style-type: none"> <li>• Support for the stored data definition and automatic library entry handling for constructed jobs</li> </ul>	<ul style="list-style-type: none"> <li>• File assignments changeable by a user program</li> </ul>
Human Factors	<ul style="list-style-type: none"> <li>• Interactive dialogue emphasis with helps to aid users at various levels of proficiency</li> </ul>	<ul style="list-style-type: none"> <li>• Interactive logic in the code</li> <li>• Monologue, dialogue and teach modes</li> </ul>	<ul style="list-style-type: none"> <li>• Interactive support to the user</li> <li>• Proper response time characteristics</li> </ul>

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Table 2.3 IPAD Design Requirement — Privacy, Security, Control, and Integrity

PRIVACY, SECURITY, CONTROL, AND INTEGRITY			
DESIGN REQUIREMENTS	IPAD SYSTEM DESIGN FEATURES	IPAD SOFTWARE REQUIREMENTS	HOST OPERATING SYSTEM REQUIREMENTS
Private and public data regions	<ul style="list-style-type: none"> <li>• Subtask library</li> <li>• Community library</li> </ul>	<ul style="list-style-type: none"> <li>• Data management support for this library structure</li> </ul>	<ul style="list-style-type: none"> <li>• Permanent file system</li> <li>• Data management utility routines</li> </ul>
Protection against illegal access to information	<ul style="list-style-type: none"> <li>• Data access Permission codes</li> <li>• Command access permission codes</li> <li>• Security control of access codes</li> </ul>	<ul style="list-style-type: none"> <li>• Access code checks</li> <li>• Permission code checks</li> <li>• Specialized procedure for setting codes</li> </ul>	<ul style="list-style-type: none"> <li>• Permanent file system with security lockout</li> <li>• Central memory read/write protection</li> </ul>
Assurance of the integrity of the data base	<ul style="list-style-type: none"> <li>• Unique names for all library entries</li> <li>• Mandatory version numbers for all altered library entries</li> <li>• Automatic qualifier generation to record the origin of the data</li> <li>• Trace of information leaving IPAD</li> <li>• Protection against self-inflicted accidents</li> <li>• Setting of permission and access codes</li> <li>• Controlled relationship between the project and its subtasks</li> </ul>	<ul style="list-style-type: none"> <li>• Checks for name uniqueness</li> <li>• Version number generator</li> <li>• Qualifier generator</li> <li>• Keeping records for all information leaving IPAD</li> <li>• Warning about the implications of certain actions</li> <li>• Provision for handling such codes in project plans</li> <li>• Ability to control subtasks on the basis of information in the project plans</li> </ul>	<ul style="list-style-type: none"> <li>• Permanent file names with qualifiers and version numbers</li> </ul>

Table 2.4 IPAD Design Requirement--Reliability

RELIABILITY			
DESIGN REQUIREMENTS	IPAD SYSTEM DESIGN FEATURES	IPAD SOFTWARE REQUIREMENTS	HOST OPERATING SYSTEM REQUIREMENTS
<p>System unreliability negligible compared to user's unreliability</p>	<ul style="list-style-type: none"> <li>• Recovery of subtask libraries after a system shutdown</li> <li>• Recovery of the entire community library after a system shutdown</li> <li>• Automatic incremental dumps of the system during normal running</li> <li>• Full community library dump capability</li> <li>• Intermittent errors of small effect infrequent</li> <li>• Small error recoverability</li> </ul>	<ul style="list-style-type: none"> <li>• Logic to recover a subtask library that was interrupted out of IPAD's control</li> <li>• Logic to recover a community library directory after a system shutdown</li> <li>• Controls for making incremental dumps at specified intervals</li> <li>• Records of when dumps were taken</li> <li>• Check sums allowing correction</li> </ul>	<ul style="list-style-type: none"> <li>• Recovery of the subtask library file and all files associated with it</li> <li>• Recovery of all permanent files after a system shutdown</li> <li>• Incremental dump feature for the permanent files</li> <li>• Permanent file dump capability</li> <li>• Fault detection hardware</li> <li>• Check sums in all data transfers</li> </ul>

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a disciplined technology. This approach has been utilized to develop the IPAD System design.

Structured Programming is a relatively new programming technology which provides a top down design method in which the design proceeds from the general to the specific. Each refinement is a level in the system design and the system is systematically refined from the most general statement of requirements to the most specific. The IPAD System design was refined to where host system hardware and operating system software, not yet specified, begin to have a major impact.

Two design tools provide management capability in structured programming. The first tool is called a tree diagram and provides control of the relationship between system design levels. The second tool is called the state diagram and provides transition relationships between functional groups within each level. The functional groups within a level are called nodes. The following examples explain the application of these concepts to a simple time sharing system.

Tree Diagram--An example of the tree diagram concept is shown on Figure 2.42. The first level breakdown of a system is the user interface and it should directly relate to the user requirements. These nodes are the only direct capability the user has - they limit his domain of work. Succeeding levels are only used to show greater detail about what is meant. The design at each level is complete in scope, and lacking only in detail. The four nodes under COMPILER explain the meaning of COMPILER and more precisely or indicate how it will be accomplished. In turn, the next level under ANALYZE will explain how the source code analysis will happen.

One may take the position that the design should be completely specified at each level before moving on to the next, in practice it appears to be an iterative process.

It is a requirement that this diagram be a true mathematical tree; i.e., there can be no connections between branches.

State Diagram--An example of the state diagram concepts is shown on Figure 2.43. While the design tree, figure 2.42, related the vertical structure of the design, the state diagram deals with the horizontal relationship at any given level and provides finite state machine descriptions which relate modes.

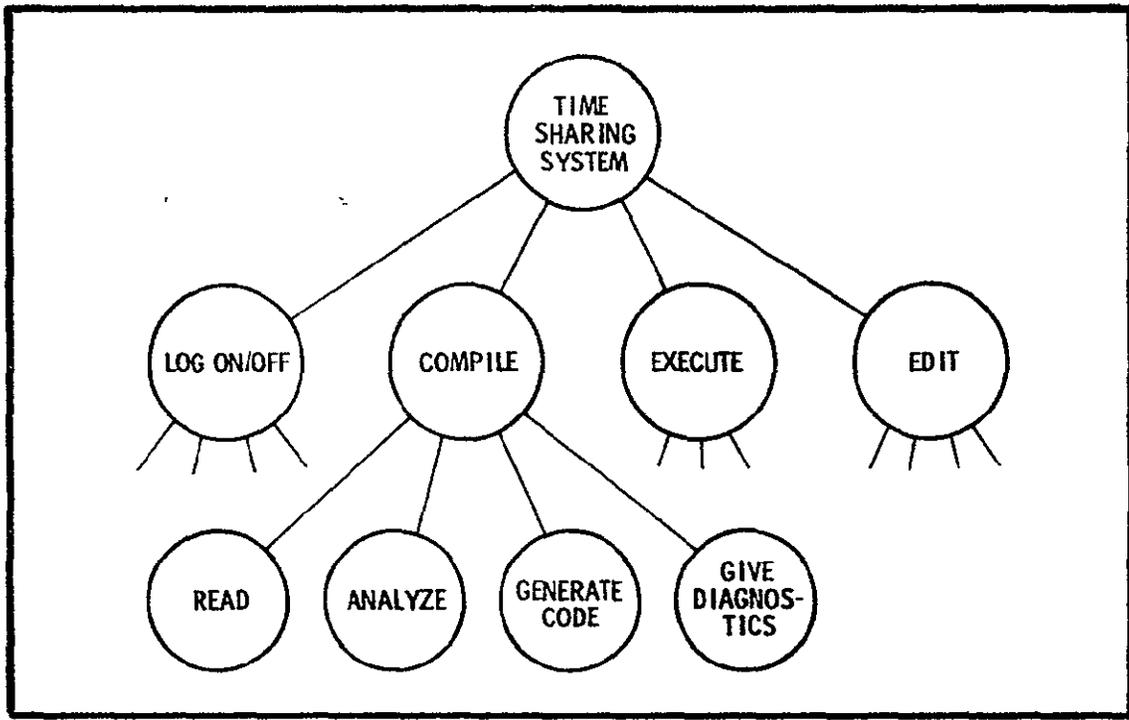


Figure 2.42 Example - Tree Diagram

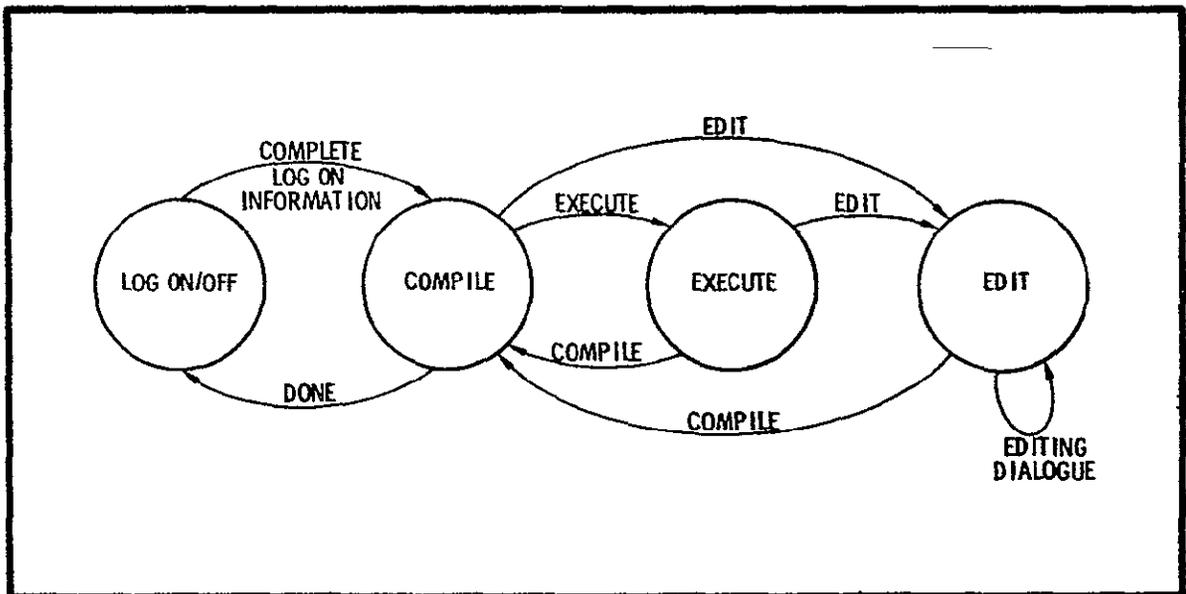


Figure 2.43 Example - State Diagram

Each node is considered to be a state in which the system may be active in serving the user. The active state will be changed when a certain set of inputs is received; e.g., when the user inputs the proper log on information he is then changed to the compiling state. With each of the lines on this diagram, there is an associated input specification. Also available, but not shown, is the set of outputs from each state.

This diagram tells the user about all the activities he may engage in, and the sequence in which they may be executed, but it does not give details, such as the editing language. Note that in this system there is no path directly from EDIT to LOGOFF.

Every state diagram is mathematically related to a corresponding flow chart. The state diagrams are more compact and help manage the programming activities.

#### 2.4.6.5 User Interface Design - IPAD Functional Summary

Figure 2.44 illustrates the five nodes which summarize the IPAD system structure at the highest level and show the possible transitions during a subtask.

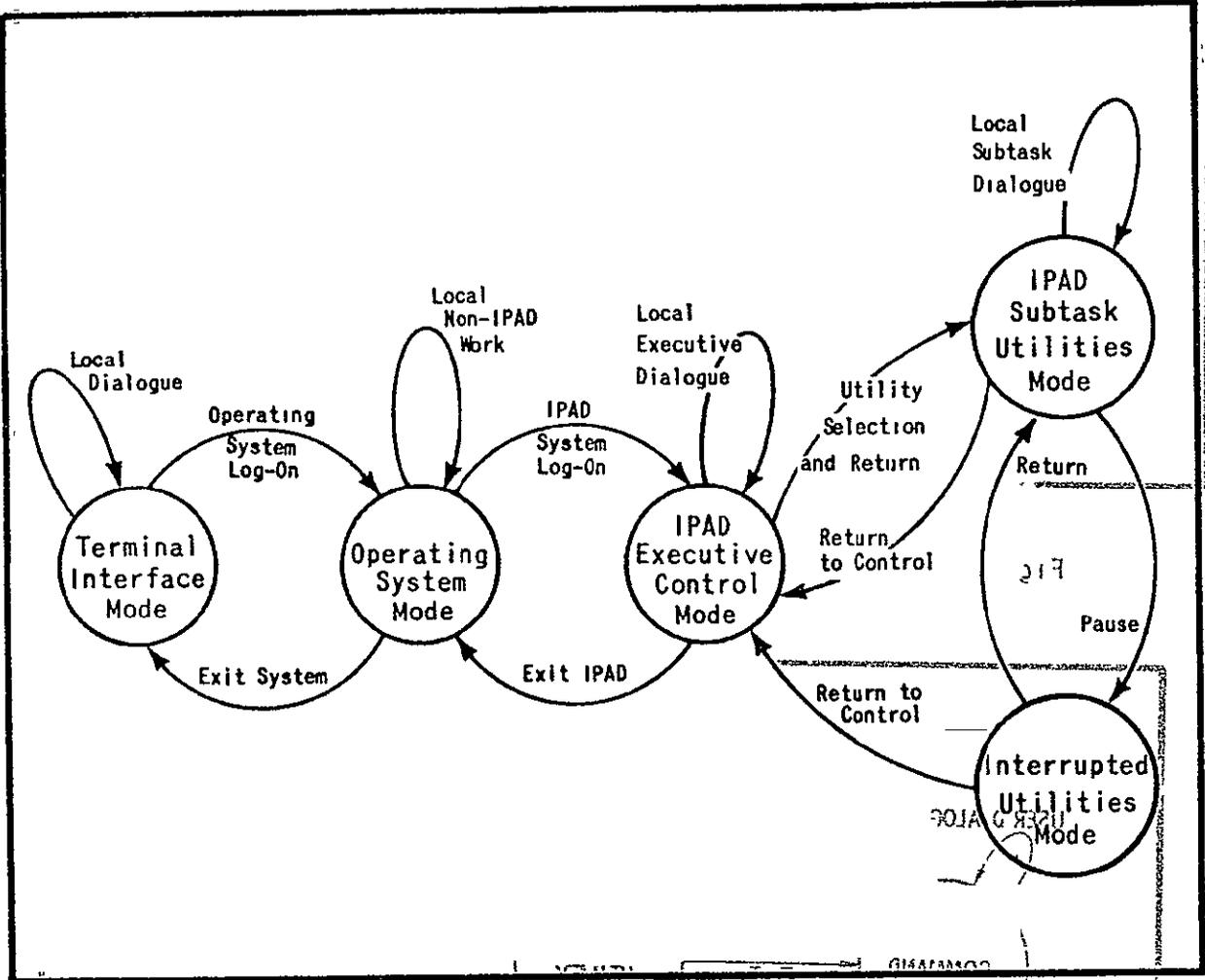
#### 2.4.6.6 User Interface Design - IPAD Executive Control

Figure 2.45 illustrates the five states that comprise the control portion of the system design. Subtasks are initiated, terminated, and interrupted and utility operations for the user are controlled.

#### 2.4.6.7 User Interface Design - Access to IPAD Utilities

Figure 2.46 illustrates IPAD access to utilities. All IPAD utilities are accessed from node F (Subtask Command Mode) through a basic command of the type SEARCH, DEFINE, etc. Once in execution a utility will return to F when the desired action is completed. Otherwise a user may interrupt at any time with a PAUSE. If he desires to do something else, he enters the appropriate basic command and the current utility will be interrupted in progress and the new one activated. When the new one is through, the user is free to issue another basic command or give a RETURN. This will re-activate the previously interrupted activity. This process is nestable.

The following list of nodes shows the utility operations currently defined in the IPAD System.



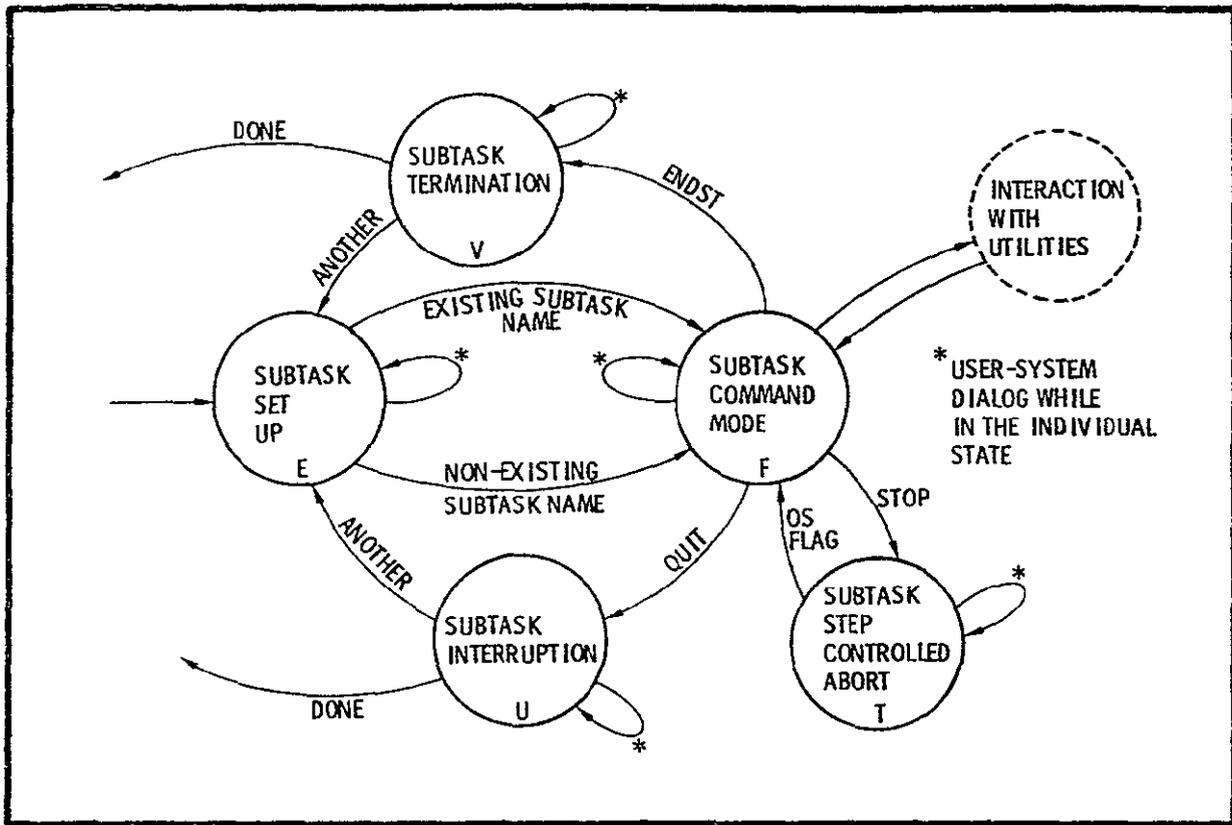


Figure 2.45 User Interface Design - IPAD Executive Control

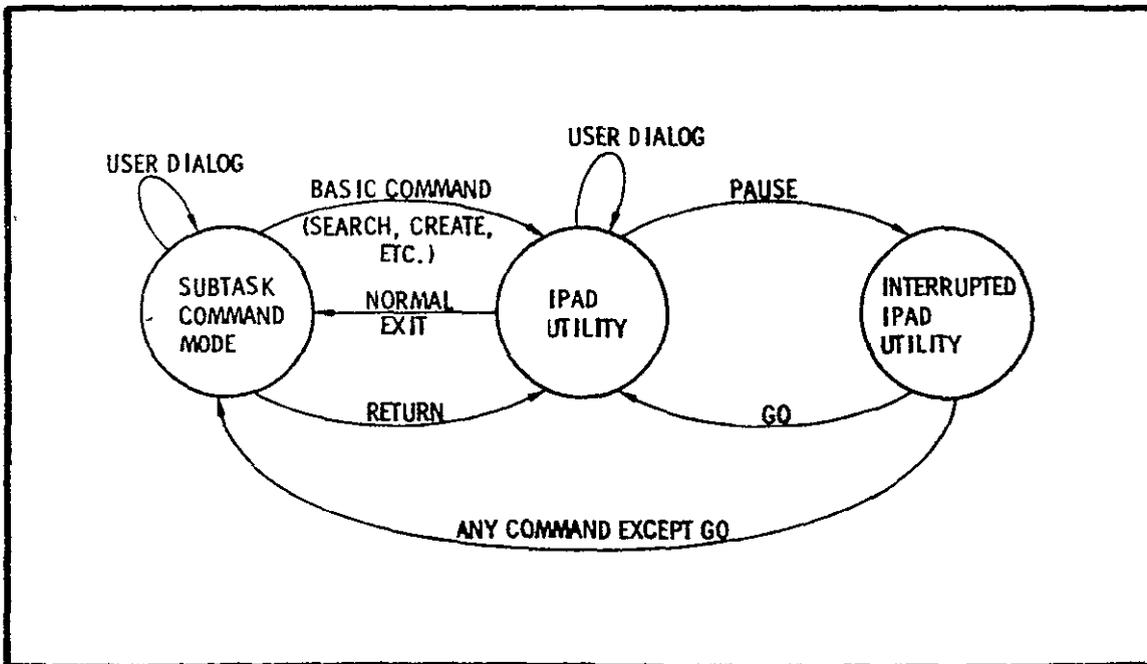


Figure 2.46 User Interface Design - Access to IPAD Utilities

<u>NODE</u>	<u>TITLE</u>	<u>(BASIC COMMAND)</u>
G	Learning about IPAD	(HELP)
H	Searching through the libraries	(SEARCH)
I	Creating library entries	(CREATE)
K	Modifying library entries	(MODIFY)
M	Constructing a job	(CONSTRUCT)
N	Executing a job	(EXECUTE)
P	Displaying results	(DISPLAY)
Q	Disposition of library entries	(DISPOSE)
W	Defining library entries or variables	(DEFINE)

#### 2.4.6.8 System Members

The tree structure representation of the system along with the transition diagrams depict how the system functions while carrying out various activities for the user. From the viewpoint of planning software packaging for implementation, it is convenient to identify aggregates which have common functional interfaces. Figure 2.47 identifies four software system members. They are defined as follows:

1. Active Job - A set of computer operations performing work for the user. Jobs include the execution of user supplied programs as well as IPAD utilities.
2. Operating System - The collection of software which controls the host computer.
3. IPAD Data Manager - The collection of unique IPAD software which controls and manages access to data in the IPAD data base.
4. IPAD Executive - The collection of unique IPAD software which interprets, controls, and manages user activities.

Figure 2.48 shows the relationship between the primary system members shown on figure 2.47 to the user interface level

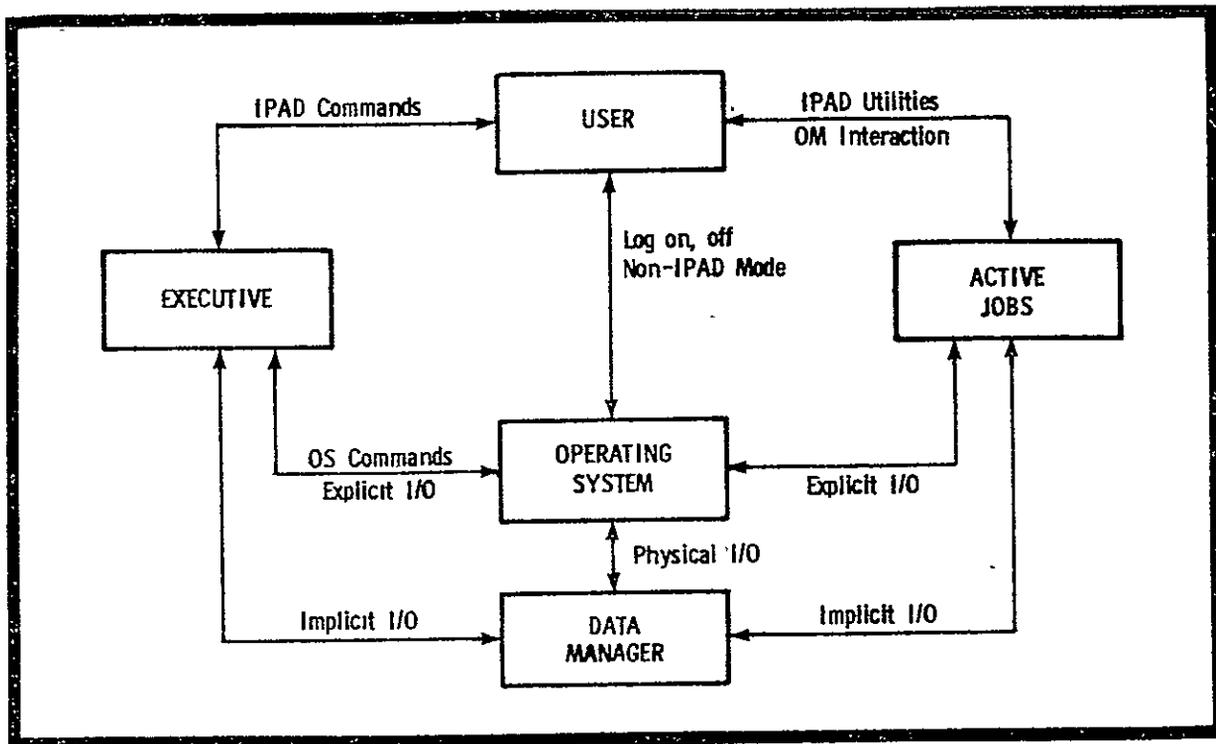


Figure 2.47 System Members

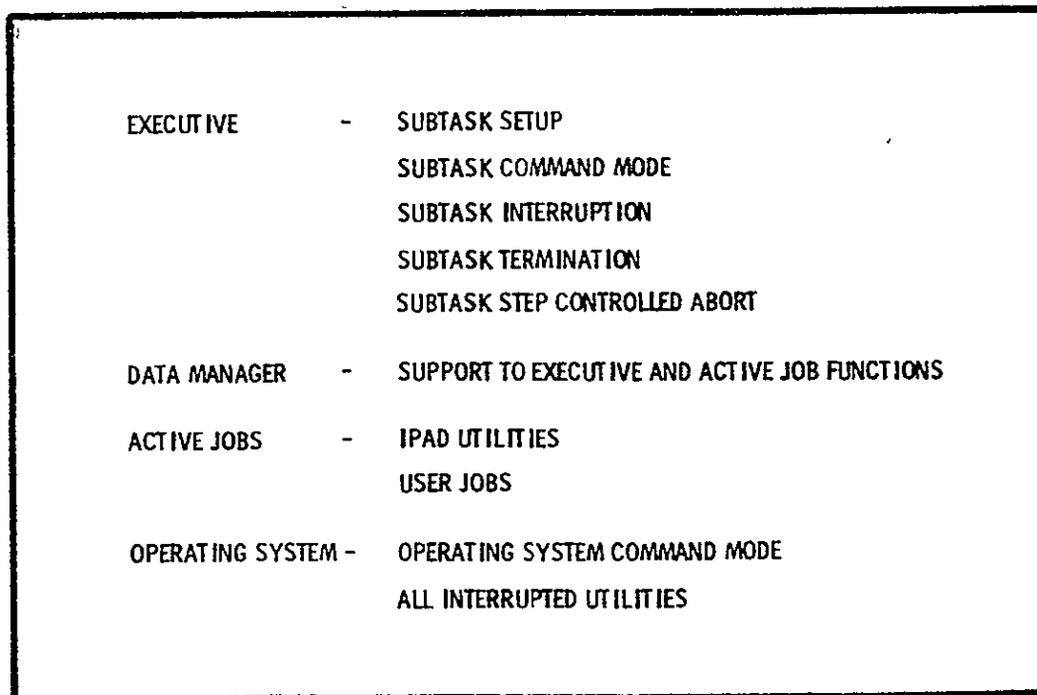


Figure 2.48 System Member - Design Tree Relationships

of the design tree. Since the user does not directly interface with the data manager, the relationship is purely supportive.

The IPAD system design follows the general form described. Figures 2.49 and 2.50 illustrate the twenty-nine level 1 nodes or states. Except for a few level 1 states dealing with hardware or host operating system protocol, the level 1 states are each refined into level 2 states. The level 2 states are, in turn, broken out into level 3 states, and so on. The emphasis in the design was placed upon consistency in detail rather than consistency in levels documented. Hence, there are differences in the depth or number of levels reached in some of the tree branches. The complete design is presented in section 6.0 of Volume IV.



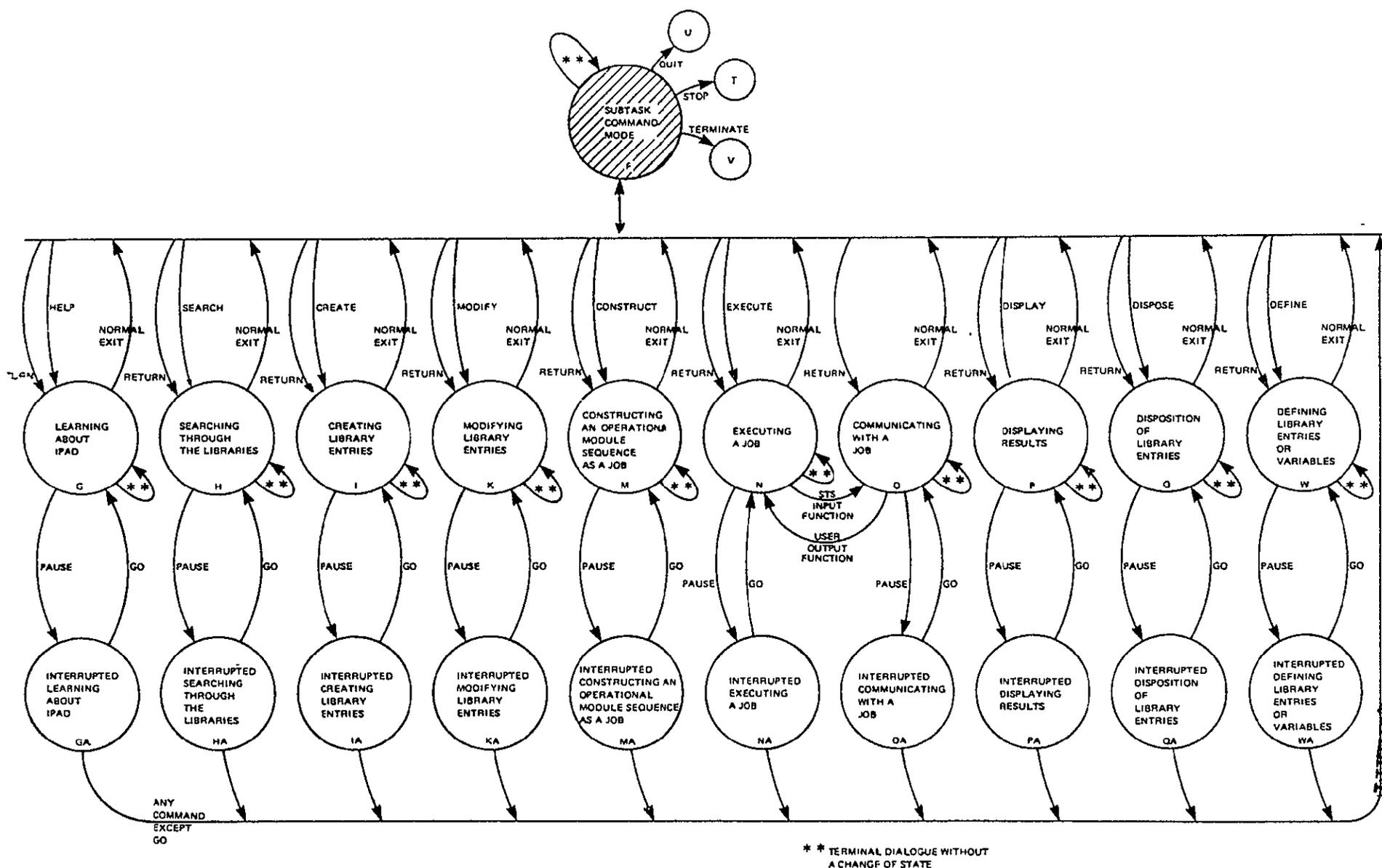


Figure 2.50 IPAD System Design Level 1 State Diagram (cont'd.)

## 2.5 IPAD BENEFITS, IMPACTS AND SPINOFF

The benefits, impact and spinoff which may result from development of an IPAD System are presented in Volume VII. They have been identified from the IPAD study and from research in related fields.

### 2.5.1 Benefits

The primary benefit of IPAD will be increased productivity of the designer. This increase will result from the utilization of system software and design methods that require less flowtime and labor cost, extend the technical scope of current methods, or improve the opportunity for creativity. An evaluation of the potential benefits of IPAD was made through an analysis of time and labor utilization; an evaluation of flowtime and cost savings; the affect upon company effectiveness; and a projection of IPAD as a national resource.

Time and Labor Utilization--All design activity can be placed in one of the following categories:

- o Routine information exchange, data preparation, and calculations,
- o Judgmental procedure development and results evaluation.

A flowtime and labor analysis of Level III of the design process was made for the current system of batch standalone computer programs and noncomputer-aided information exchange. A comparison was then made with an integrated system. The results, as shown in figure 2.51, are:

- o Man-weeks are reduced to 20%,
- o Significant redistribution of time spent in the routine and judgmental activities,
- o Significant redistribution of activity between analysis and design, principally resulting from the increased computational power given to the designer.

Flowtime and Cost Savings--The flowtime and labor cost savings being experienced in the usage of current systems on widely different problems was investigated. The results are summarized below:

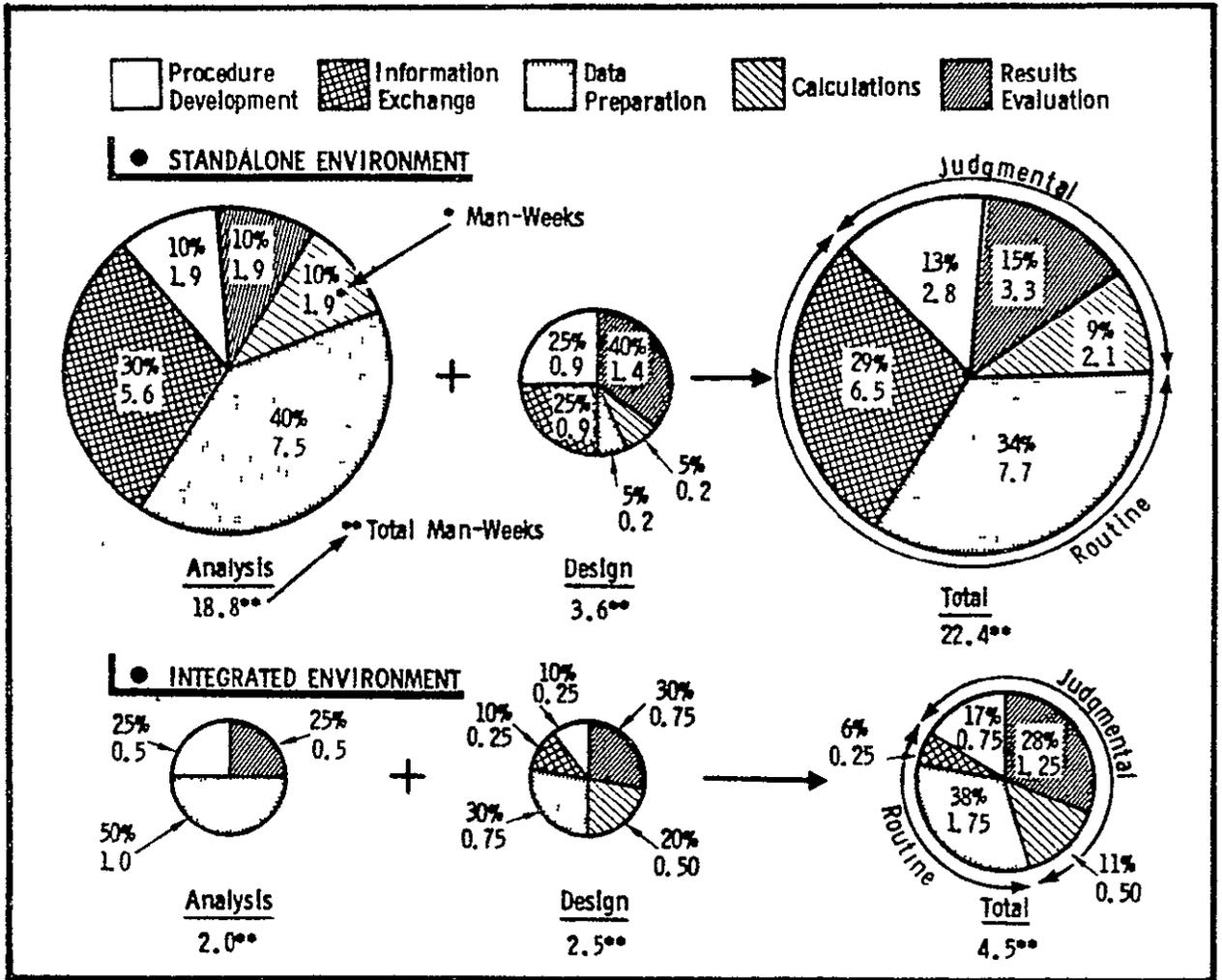


Figure 2.51 IPAD Level III, Subsonic Transport, Division of Effort

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System	Cost Saving	Flowtime Saving
NSRDC ISDC		90%
Lockheed CADAM (electrical)	78%	80%
Boeing CPDS	80%	67%
Boeing ATLAS	50%	50%
Lockheed CADAM (floor beams)	62%	46%
Lockheed CADAM (bulkheads)	33%	25%
Adequate Computational Devices	20%	

Existing systems have gained their effectiveness by automating or computer-aiding information handling at the interfaces between computer programs. IPAD will increase effectiveness by providing an information handling environment especially compatible with the day-to-day continuity required in the design organization. Hence, the cost and flowtime savings being experienced with existing systems on small tasks can be feasibly obtained, for the company as a whole, using a suitable IPAD System.

Company Effectiveness--Company benefits from the potential flowtime and cost savings from IPAD depend on how management elects to reinvest them. The following are some of the options:

- o Direct flowtime and labor cost savings. Management may elect to reduce labor costs and shorten product development schedules. An estimation of the magnitude of savings is given in figure 2.52 where flowtime and cost savings being experienced with current systems are extrapolated to a larger design organization.
- o Reduction of risk. Management may elect to reinvest savings into improved product design in order to reduce their risk.
- o On-time design. Potential cost savings downstream from product design may be realized as shown in figure 2.53. Typical cost reductions in this area are reduced tooling changes and reduced retrofitting of manufactured aircraft by elimination of late or inadequate engineering design.

IPAD as a National Resource--The benefits of IPAD will accumulate at the national level as:

- o Increased competitiveness of United States industry in the international market place;
- o Stimulation of information technology development;

SYSTEM	MANAGEMENT ABOVE FIRST LINE	TECHNICAL JUDGEMENT	TECHNICAL ROUTINE	TOTAL DOLLARS	FLOWTIME
Standalone Batch	6%	34%	60%	100%	100%
	\$1,800,000	\$10,200,000	\$18,000,000	\$30,000,000	
Multiple Devices	7%	34%	59%	81%	
	\$1,800,000	\$8,160,000	\$14,400,000	\$24,360,000	
CPDS	14%	65%	21%	42%	33%
	\$1,800,000	\$8,160,000	\$3,600,000	\$12,480,000	
ISDS					10%
ATLAS	9%	43%	48%	63%	50%
	\$1,800,000	\$8,160,000	\$9,000,000	\$18,960,000	
CADAM (Bulkheads)	8%	34%	58%	79%	75%
	\$1,800,000	\$8,160,000	\$13,900,000	\$23,860,000	
CADAM (Floor beams)	10%	49%	41%	56%	54%
	\$1,800,000	\$8,160,000	\$6,830,000	\$16,810,000	
CADAM (Electrical)	13%	59%	28%	46%	20%
	\$1,800,000	\$8,160,000	\$3,960,000	\$13,920,000	

\* All dollar values figured on basis of 2000 men, \$15,000 per manyear

Figure 2.52 Potential Annual Relative Labor Cost and Flowtime Using IPAD Technology

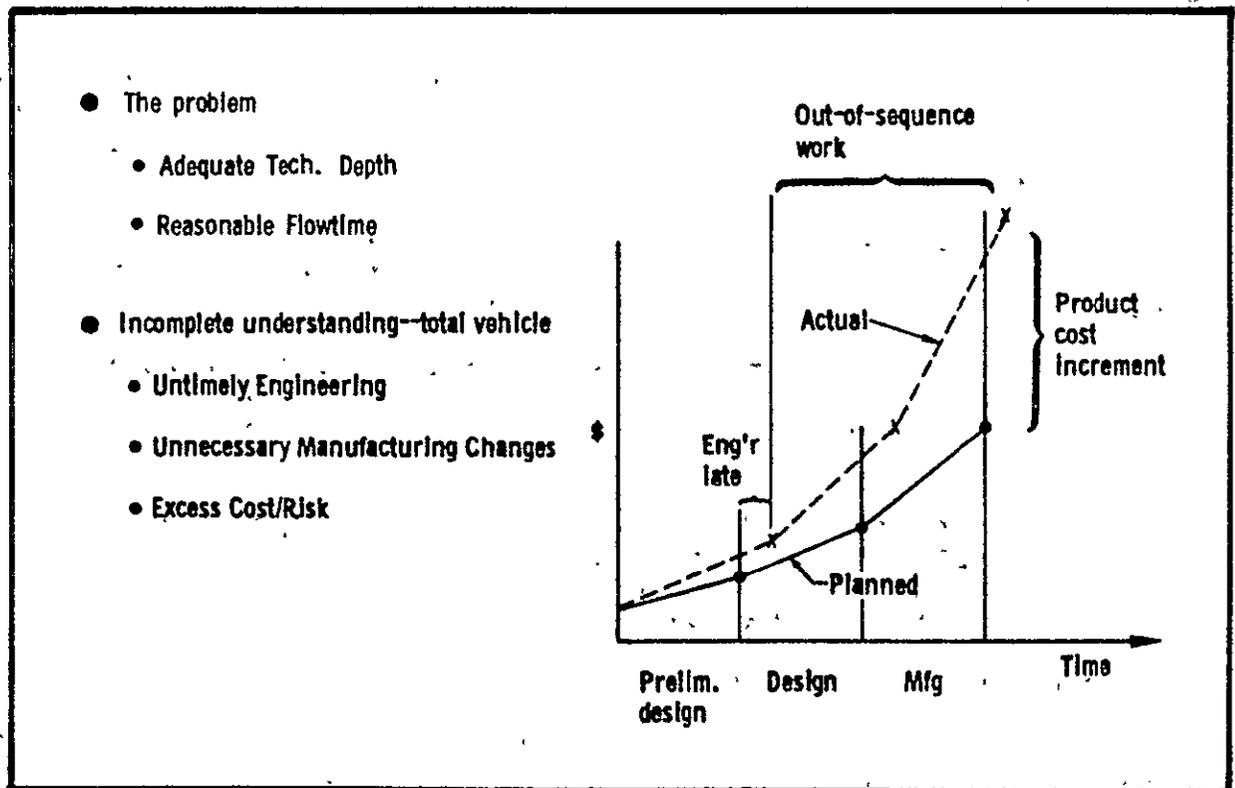


Figure 2.53 Downstream Effects of Late Engineering Design

- o Utilization of IPAD to increase the effectiveness of government procurement procedures.

### 2.5.2 Impact

The developing concept of the computer as an information converter, processor, and library is resulting in an information technology. IPAD is essentially information technology. The primary impact will be:

- o Acceptance of computerized information handling as opposed to manual handling;
- o A trend towards centralization in task and organizational structure with its corresponding impact on people.

Acceptance--The principal factors motivating the acceptance of IPAD are competition, contract requirements and directives. Internal inertia such as lack of skill, current method success and current resources, work against acceptance.

Impact on People--Changes in task structure will require different forms and levels of individual initiative. New standards of work performance will emerge consistent with the change in task structure and the requirements of information technology.

Individuals will make new identifications with the product and with the changed objectives of their immediate organization. These identifications will be of two forms:

- 1) Where activities are automated and centralized, individuals will have reduced identification with the company product. The demand for professional people in these organizations will diminish.
- 2) Where activities are broadened in scope, individuals will have an improved identification with the company product. Professional people will tend to seek out these organizations.

The introduction of centralized information in data banks will increase the span of control for those managing this information. It will also increase the opportunity for communication, creativity and innovation by those accessing the information.

The eventual impact of information technology upon people will depend largely upon how it is managed within individual organizations. Like all fundamental developments, its effect can be either motivating or oppressive.

### 2.5.3 Spinoff

The spinoff from IPAD aerospace technology will impact two areas.

- 1) Direct use of IPAD system and technical elements. Many of the system features such as data management, executive, some utilities, and many technical elements will have direct application outside the aerospace industry.
- 2) Motivate similar technical advances. The presence of IPAD will generally motivate advances in industrial design environment, computing technology applications and engineering design methodology.

## 2.6 IPAD SYSTEM IMPLEMENTATION

### 2.6.1 Strategy

The IPAD system design implementation is build around a strategy which recognizes three principal factors: (fig. 2.54)

- o Development Environment
- o NASA (langley) Usage
- o Industry Usage

The development environment provides for a phased effort which produces an initial IPAD System in about four years with two plans for implementing the complete IPAD system design as described in Volume VI.

The initial system capability provided in phase 1 includes software for continuity of day-to-day activities, entering programs and data into data base, constructing jobs, executing jobs, modifying programs and data, and displaying data base contents.

Enrichments to the IPAD system software in phases 2 and 3 will be in the areas of project management aided by computer

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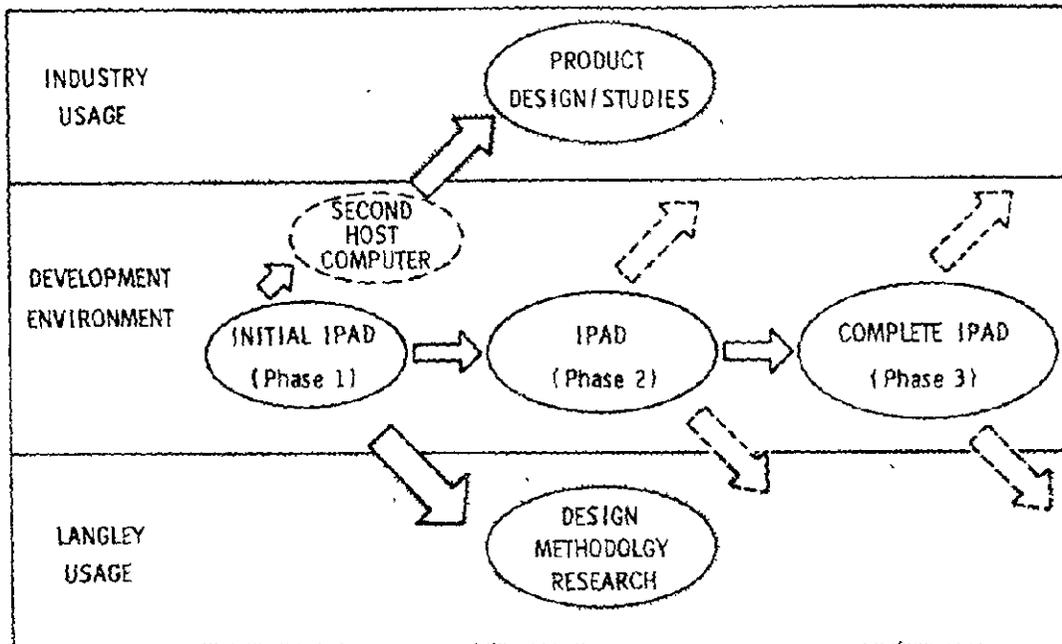


Figure 2.54 IPAD Implementation Strategy

stored plans, privacy/security protection in data base, interactive graphics, specialized interactive commands, expanded utility functions.

The product design capability that is proposed will provide for preliminary design sizing of subsonic transport Levels II and III and supersonic transport Level II and part of Level III. In addition an initial capability will be provided to do interactive detail part design including a data interface between IPAD and the automated functions in manufacturing (CAM).

The IPAD System development environment will provide, at Langley Research Center, the baseline from which both usage by NASA, and usage by industry can begin at the end of Phase 1.

This strategy recognizes that even though the initial IPAD is expected to be implemented for NASA at the Langley Research Center, implementation on a second host may be desirable near the end of Phase 1 to accommodate particular industry interests.

#### 2.6.2 Development

The IPAD capability offers a significant improvement in engineering computing. Consequently, its implementation will require a significant development period. Therefore the proposed development plan is in three phases. The delivery of some useful initial capability early in the total plan permits the major innovative concepts to be available for early evaluation and can provide feedback for the later development stages.

Two plans for development of the IPAD System design are proposed.

Plan 1 (fig. 2.55) indicates an approximate nine year development period to produce the complete IPAD System design described in Volume IV. This alternate provides:

- o No overlap of the development phases,
- o Maximum opportunity for feedback to Phases 2 and 3 from NASA or industry usage,
- o A significantly lower yearly cash flow.

The major development events, together with estimated costs and schedules for plan 1 are given in figure 2.55. The OM costs are separated from the system costs since the degree of OM development is still arbitrary. The OM costs assume certain

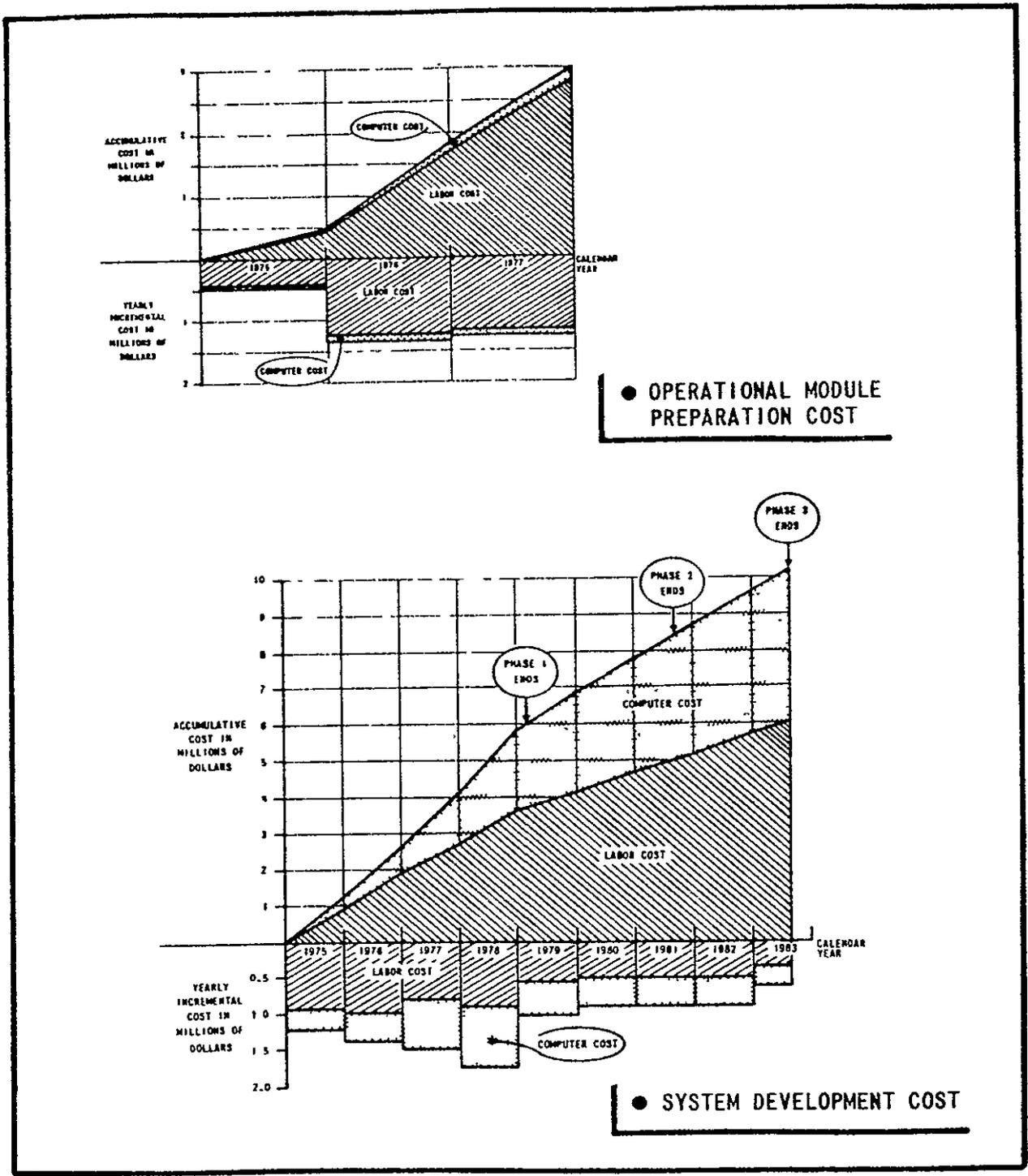


Figure 2.55 IPAD Development Costs and Schedules Summary - Plan 1

existing modules available from the government and new modules to be contracted.

During Phase 1 development, the complete IPAD System design is produced and the Phase 1 subset of the system design is coded. This Phase 1 system subset is the minimum IPAD System capability required to support the air vehicle product design process through the automation of the major portions of the routine information handling functions. The executive and data management function, as discussed in section 3.2, form the backbone of this Phase 1 development. In Phases 2 and 3 additional system capability will be added. The OM capability at Phase 1 will be limited to Levels II and III. In later phases this will be increased to more levels and broader product support.

The major system development events, estimated costs and schedule for plan 2 are given in figure 2.56. In plan 2, some degree of overlap of the phases is proposed to achieve a minimum development time to produce the complete IPAD System design. As a consequence there are:

- o Markedly higher yearly cash flows than plan 1,
- o Anticipated extra costs due to the potential for re-doing work as the overlapped work produces technical conflicts.

### 2.6.3 NASA (Langley Research Center) Usage

NASA usage will be initially founded upon the development and implementation of IPAD at the Langley Research Center.

This is expected to provide a focal point installation which can accommodate IPAD exploratory activities by government organizations and provide a nucleus effort in design methodology research.

Design methodology research is at a pioneering stage. During the IPAD Feasibility Study, it became painfully clear that if the "Design Process" was to be discussed it would be necessary to:

- o Create a visual representation of the design process (Design Networks - Vol. II);
- o Create a vocabulary for discussing the design process (Design Levels and Activities - Vol. II).

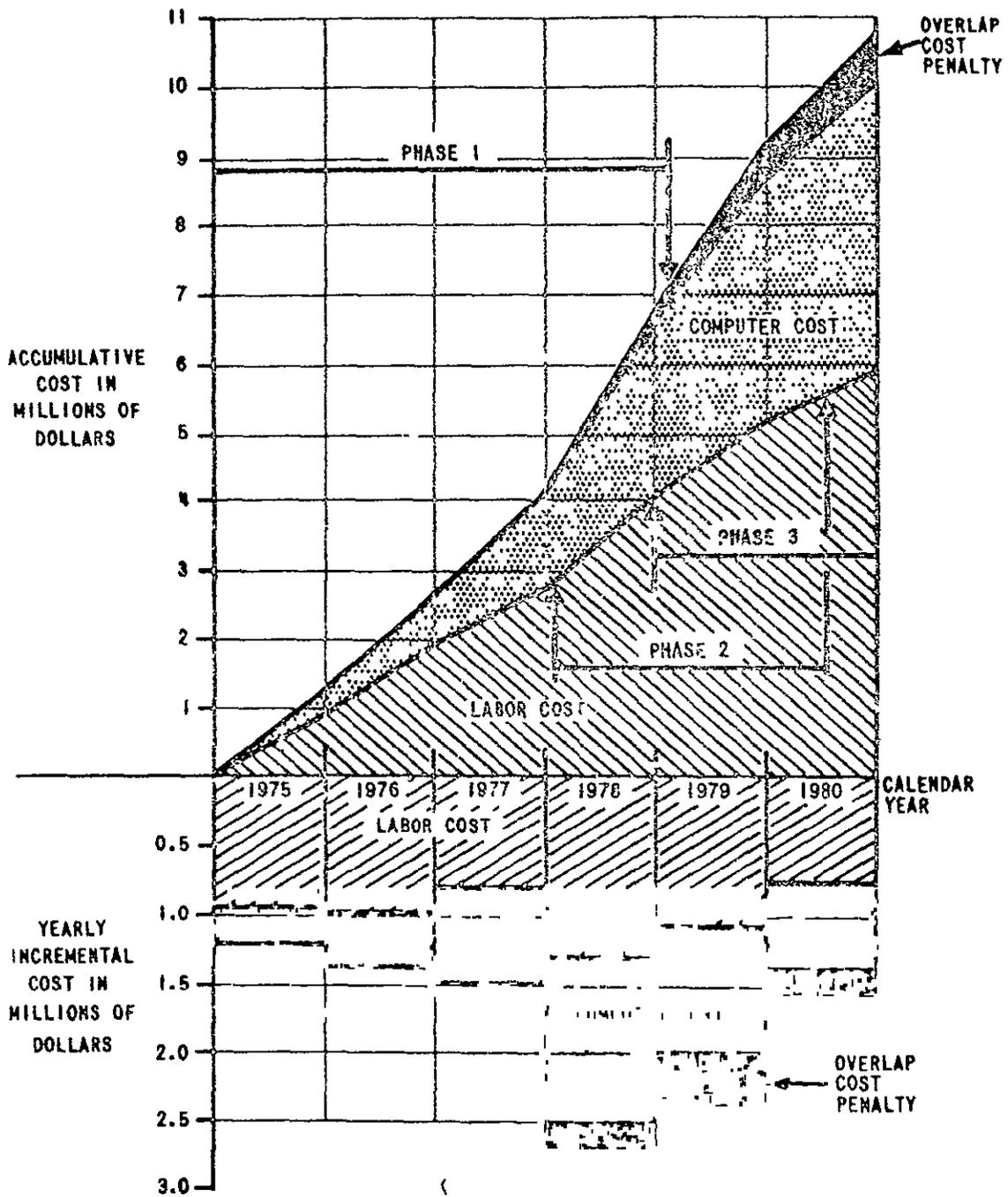


Figure 2.56 IPAD System Development Costs and Schedules - Plan 2

This activity required gathering in one place those technical specialists and managers spanning the vehicle design functions. This activity produced the design process representation and vocabulary. It also created an awareness of what each speciality does and how they do it to achieve a composite design goal.

Such activity as described above is expected to be continued, especially as the IPAD System and design capability evolve. With the completion of Phase 1, both industry and NASA will be equipped to conduct design studies and research.

#### 2.6.4 IPAD Technology Transfer to Industry

Formulation of additional contracted effort will parallel the Phase 1 development. These contracted efforts are aimed at transferring the IPAD technology into industrial organizations. These efforts are expected to be specific government contracted studies which require use and evaluation of IPAD within selected industrial organizations.

To achieve this technology transfer:

- o NASA is expected to issue RFPs for design studies using IPAD and installing the IPAD System software at the sites of successful contractors.
- o Contractors are expected to use IPAD with their technical modules, propose design studies and deliver evaluation reports.
- o The results expected are the establishment of IPAD industry technical/economic value, positive transfer to industry, and early contractor experience with IPAD.

The Phase 1 development has been planned to accommodate both primary implementation at Langley Research Center as well as implementation on a second type host computer. Implementation on a second host could begin approximately halfway into Phase 1 and be completed prior to the end of Phase 1. The added costs for a second type host implementation are shown in figure 2.57.

These additional costs assume the same system and OMs as implemented in the Phase 1 baseline implementation at Langley Research Center. The principal effort is related to OM conversion to second host, system implementation of host

dependent software, (i.e., operating system modifications, etc.) and finally, OM system checkout and integration.

	Code and Certify System	OM Conversion	System/OM Integration	Total
Computing	\$940,800	\$30,000	\$925,600	\$1,896,400
Labor	\$983,000	\$500,000	\$983,700	\$2,466,700
Total	\$1,923,800	\$530,000	\$1,909,300	\$4,363,100

Figure 2.57 Additional Implementation Costs - Phase I  
Second Type Host Computer

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### 3.0 CONCLUSIONS

It is concluded from the study that:

1. It is feasible to significantly reduce cost and flowtime in the product design process. If new plateaus of productivity are to be attained, then a computer-based system is required which recognizes the central role of the individual designer and his tasks.
2. It is feasible to design a computer-based IPAD System. Such a system should be time-shared, interactive, and terminal oriented. Significant advances in executive and data manager software are required and feasible to provide. The current third generation large computers are suitable hosts for an IPAD System, however, fourth generation computers will eventually be required to provide the large volumes of rapid access storage and the support of hundreds of terminals.
3. The current technical analysis programs (OM) are a feasible base upon which to build an air vehicle design capability. However, additional significant development is required to augment the analysis programs with new design programs.
4. The six million dollar, four years time required to implement an initial IPAD System are consistent with the scope of the task and the benefits expected. The benefit to cost ratio is expected to exceed 10 to 1.

#### 4.0 RECOMMENDATIONS - TECHNICAL

IPAD System and technical capability should be implemented in a 3 phase plan. The goals of each phase should be:

##### Phase 1

- o Demonstrate the utility of the IPAD concepts on total vehicle design studies,
- o Demonstrate the task/time continuity capabilities of the IPAD System design,
- o Develop a strategy for transferring Phase 1 IPAD technology from the development environment to an industrial environment.

##### Phase 2

- o Extend the Phase 1 system capability,
- o Expand IPAD usage to industry,
- o Demonstrate effective man/machine methodology on aerospace vehicle problems at Langely Research Center,
- o Determine the impact of 4th generation computers on the development during Phase 3.

##### Phase 3

- o Demonstrate the full capability of the IPAD System design.

#### 4.1 PRODUCT APPLICABILITY

##### Phase 1 - Implementation

Figure 4.1 illustrates the technical areas of the design process recommended as the minimum technical capability for Phase I IPAD implementation.

##### Preliminary Design Capability

The initial implementation of the Project 1 subsonic class of airplanes should include Levels II and III of the design networks. This technical capability should be adequate to support the development and check out of the IPAD system. It

will also provide a basis for calibration since it will be possible to relate the subsonic class of airplane to both existing in-service airplanes and to studies which are continually in progress for this class of airplane. The initial implementation of the Project 2 supersonic class of airplanes should include Level II and the geometry sizing part of Level III of the design networks. This technical capability would orient IPAD to future vehicles. This should help demonstrate the value of the IPAD System for evaluation of complex design studies for which past experience is limited.

#### Detail Design Capability

The detail design process utilizing interactive graphics concepts should be done for several representative parts. Typical parts could include floor beams, body frames and wing ribs. These will be useful in understanding the nature of the development of a preliminary design concept into a manufacturable part. These representative parts will also establish the cost savings potential of the enhanced design environment provided by IPAD.

#### IPAD/CAM Interface

It is recommended that the interface with manufacturing at Level VII be initiated during the Phase I implementation. This interface will be similar for both Project 1 and Project 2 and should make IPAD complement the development of Computer Aided Manufacturing (CAM) Systems. Many present manufacturing facilities are highly computerized and for these, CAM Systems are in various stages of study, implementation, or are presently in use. The IPAD System should provide technical information at the interface between design and manufacturing which can be transferred directly to computing facilities that support manufacturing.

#### Phase 2 and 3 Implementation

The product technical capability for Phase 2 and 3 are expected to primarily reflect the experiences of NASA and industry with the Phase 1 capability. No specific technical module developments are recommended at this time.

### 4.2 SYSTEM SOFTWARE AND HOST COMPUTER

The 3 phase implementation of the system software follows the goals for product technical capability (section 4.1). An overall implementation strategy is recommended which:

- o Provides an initial baseline system software capability at NASA-Langley Research Center,
- o Extends the initial baseline capability in response to NASA and industry experience and needs,
- o Responds to the pace at which 4th generation computers become viable in the industry.

### Phase 1 Implementation

System capability is recommended in the areas of Executive, Data Management and Host Computer.

#### Executive Software

The development of the executive capability to support the continuity of the users activities using the subtask concept and to support construction and execution of jobs.

#### Data Management System

The development of the data management capability to support the subtask and community libraries including data transfer capability between OM's.

#### Host Computer

A dedicated CDC 6600 computer system located at NASA-Langley Research Center is recommended for Phase 1 implementation of IPAD. The operating system should be modified to support the continuity requirements of the system design.

### Phase 2 Implementation

Phase 2 baseline implementation extends the Phase 1 baseline capability at NASA. During this phase it is recommended that the Executive and Data Base Management capability be extended to include information control via portions of the project plans and report functions.

It is anticipated that the Technology transfer efforts may require a Phase 1 capability installed on host computers other than NASA-Langley Research Center.

### Phase 3 - Implementation

Phase 3 baseline implementation will complete the project plans, report functions of the system design, and initiate an interactive graphics capability.

#### 4.3 TECHNOLOGY TRANSFER TO INDUSTRY

It is recommended that contracted efforts be the basic means of transferring IPAD technology from the development environment to the industrial environment.

These contracts should provide innovative firms the opportunity to place themselves in the forefront with IPAD technology. The contracts should require:

- o Competitive bidding to select those firms who will have the first opportunity,
- o NASA to provide the IPAD system software operational on the successful bidders host computer system,
- o The successful bidder to utilize the IPAD System with their technical modules on product design problems proposed by them,
- o NASA to receive reports which evaluate the technical and economical aspects of the contractors experience with the IPAD System.

It is recommended that these evaluation reports become the basic guidance for the future development of the baseline system capability.

APPENDIX A

READER INDEX - CONTENTS OF ALL IPAD VOLUMES

The Tables of Contents for each volume of the IPAD feasibility study are duplicated in this appendix to help the reader locate additional information.

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## APPENDIX B

### SUMMARY - CASE STUDIES

The design processes for the preliminary design phase of the design projects studied during the IPAD feasibility study are summarized in this appendix. The detailed design network for each project are contained in Volume II and a catalog of computer programs required to support Projects 1 (subsonic transport) and project 2 (supersonic transport), are documented in Volume V.

The summary descriptions of Project 1 and Project 2 are very similar, however, each description is complete and the reader is advised that there will be much repetition between these narratives.

#### B.1 PROJECT 1 - SUBSONIC COMMERCIAL TRANSPORT

##### B.1.1 Project Definition

At the start of the feasibility study contract, a specific specification was established for a particular airplane in the category of intermediate range subsonic commercial transport. As the design networks evolved, the procedures and technical tasks placed into the network were found to be as applicable to the general category. Consequently, the project defined as Project 1 is constrained only to be a typical, high subsonic speed, moderate aspect ratio wing, commercial transport, with two to four engines located in conventional arrangements. This does not mean to imply that the Project 1 network will not support the design and analysis of unusual configurations, only that the computing times developed in Volume III will be representative of typical geometries.

##### B.1.2 Design Networks

The general Product Level concept of figure 2.2 applies to this Project. The following are the objective time relationships for the preliminary design phase of a subsonic transport:

<u>Level</u>	<u>Design Cycle</u>	<u>Converged Design</u>
II	2 days	--
III	2 and 1/2 weeks	--
IV	1 month	2 months
V	1 and 1/2 month	3 months

Figures B.1, B.2 and B.3 present the summary work flow network relating technical tasks, major man decisions and technical and management reviews for the preliminary design phase of a subsonic commercial transport. The technical tasks and reviews are presented as rectangular blocks and the man decisions are shown as diamonds. The preliminary design activity has been divided into four levels beginning with selection of the design mission and ending with verification of the configuration prior to management review for product go-ahead.

#### B.1.2.1 Level II

The goal of Level II is to determine the best design mission for the subsequent configuration design process. This begins with a management selection of an airplane class, for example, an intermediate range airplane or a long range airplane for low passenger density routes. The analysis to select the best design mission uses airline operational requirements and histories, route information and performance data to estimate the market suitability and to forecast potential sales. The configuration used to provide performance and design trade data is parametrically generated. Level II requires short execution times so that many airplane mission options, and airplane family concepts can be investigated.

#### B.1.2.2 Level III

The goal of Level III is to size a candidate configuration to the design mission and to select "best" from similar competing configurations. Thus, the design and analyses of Level III must be more accurate than Level II.

The first part of Level III sizes the airplane geometry of a candidate configuration. The external geometry is specified parametrically as in Level II, except more thoroughly defined. The configuration is balanced and the airframe weight is established, using statistical weight estimation techniques. The cruise drag and the flaps-down lift and drag are parametrically estimated. The cruise and field performance are calculated with methods similar to those used for certification.

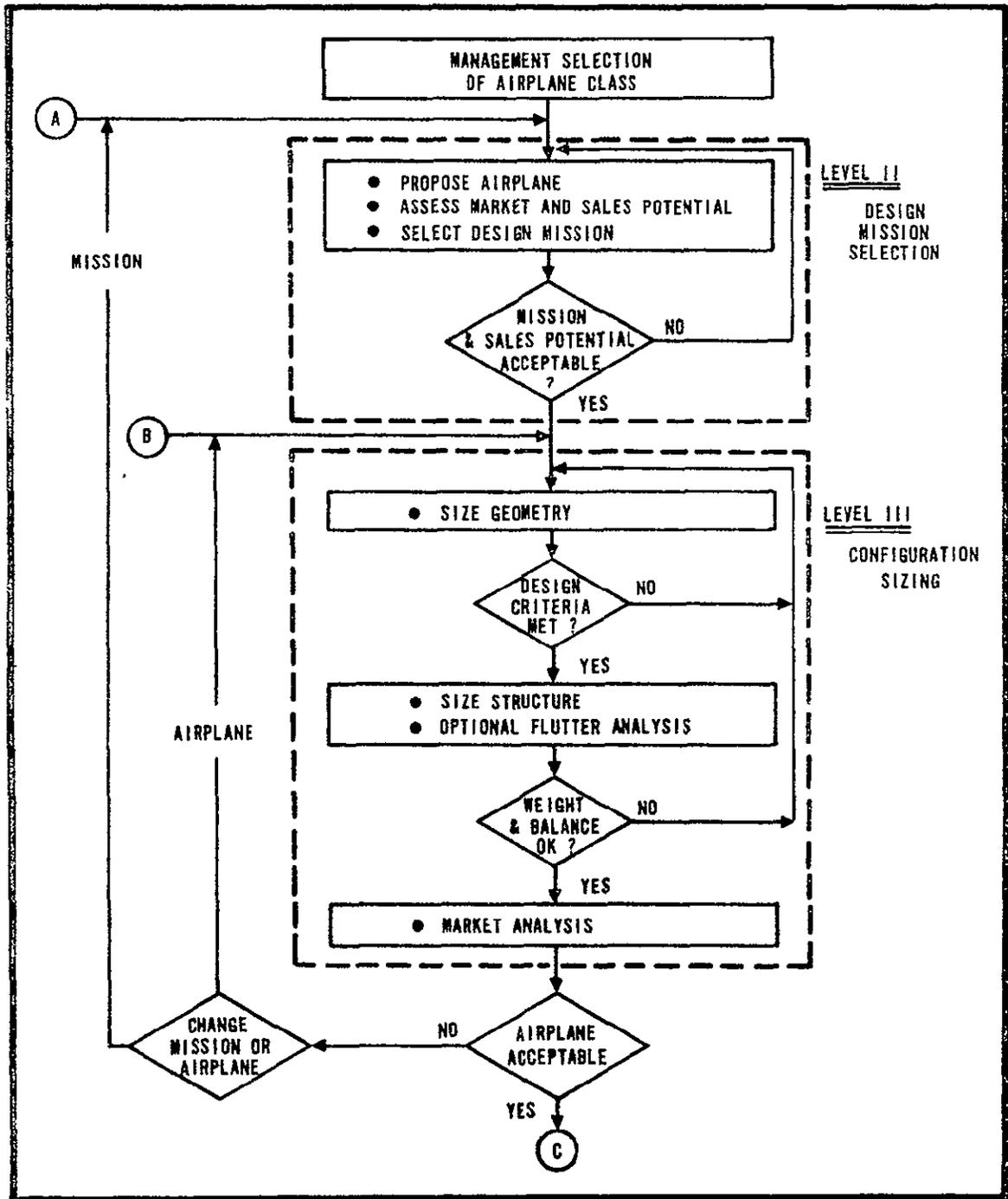


Figure B.1 Preliminary Design - Subsonic Commercial Transport - Levels II and III

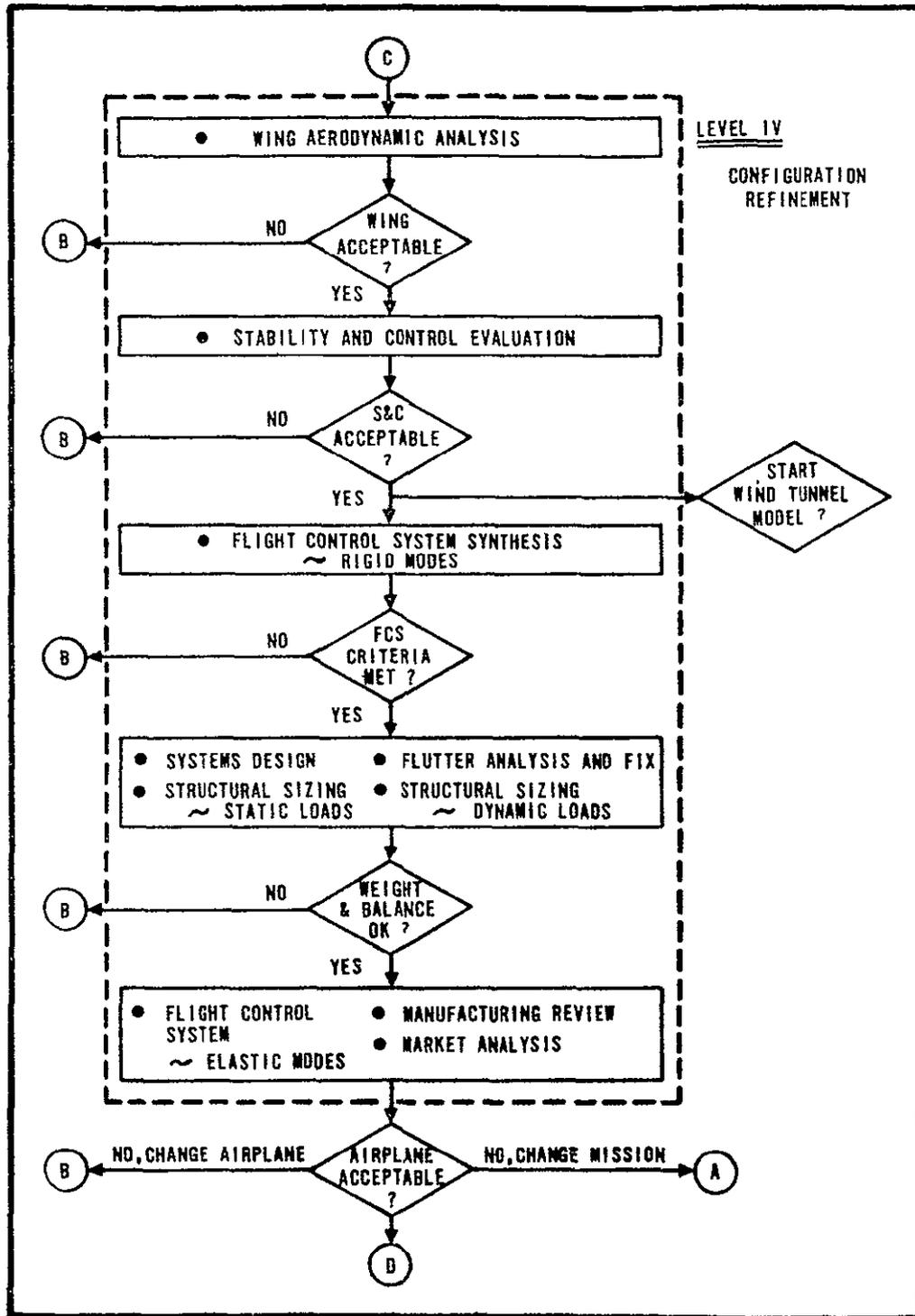


Figure B.2 Preliminary Design - Subsonic Commercial Transport - Level IV

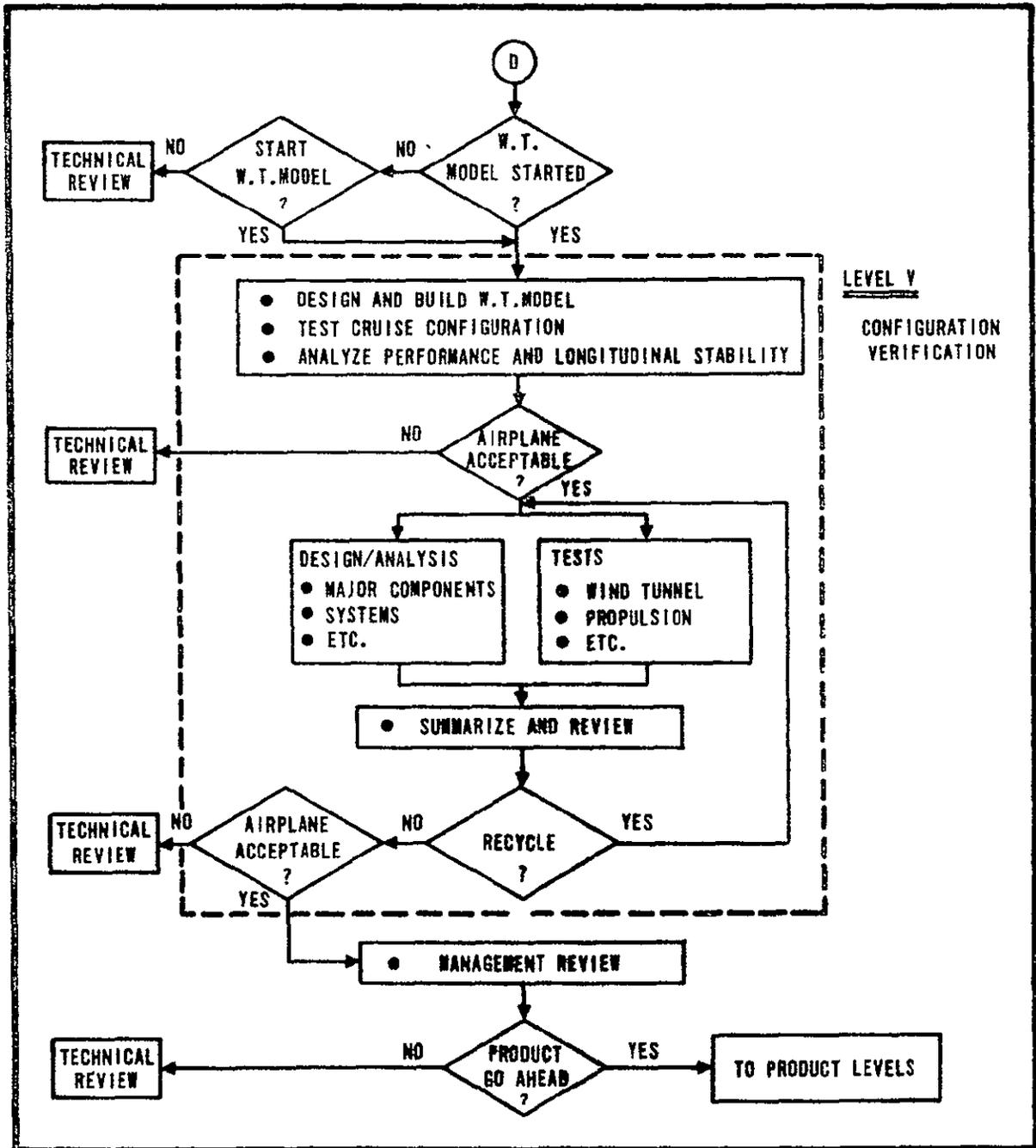


Figure B.3 Preliminary Design - Subsonic Commercial Transport Level V

The wing area and engine thrust are sized to the mission and satisfy inequality constraints such as approach speed, field length and initial cruise altitude. The solution is continued until all constraints are satisfied. Community noise footprints are calculated.

The second part of Level III sizes the primary structure to satisfy the static loads, and gusts. The sizing is for strength and fatigue. Since the structural sizing yields a better weight estimation, the resulting change in airplane weight or balance may require that the airplane geometry be resized. This looping within Level III continues until the structural sizing to static loads and the airplane geometry sizing to the design mission are consistent. A flutter check may be done as a guide in rating competing configurations. Sufficient marketing analysis and configuration evaluation is done to decide if the configuration is to be carried to Level IV.

#### B.1.2.3 Level IV

The goal of Level IV is to refine a Level III configuration in a short time so that increased confidence may be gained in the configuration. This refinement is done with improved analysis capabilities that can better assess the geometrical and structural effects of aeroelasticity, static and dynamic loads, flutter, systems design and flight control system synthesis. The results are a better weight estimation and more reliable information about the configuration. With these results, the performance is known with more certainty, and problems with the configuration are exposed before a large investment in manpower and time has been made. The analysis programs are linked across their data interfaces, and this provides the capability for a reduced flowtime. Manual monitoring and control of the technical activity is an essential part of Level IV.

The first technical task in Level IV is a partial design of the wing. Potential flow techniques are used to analyze parametrically generated wing contours. The design will proceed only far enough to establish that the wing contours can be later finished for testing as a wind tunnel model. If camber, and twist distributions can be found to produce acceptable upper surface isobars and the desired span loading, the wing will be acceptable. If not, planform or form thickness modifications are required, and the design process must return to the start of Level III.

Next, the stability and control aspects of the configuration are examined to determine if the airplane has adequate stability margins and is controllable. The analysis

uses Level III corrections for aeroelastic effects initially, until calculated corrections are available on later passes through Level IV. If the airplane is determined not to be controllable, then configuration changes are required and the design must return to the beginning of Level III.

The flight control system to provide or augment the airplane stability is now synthesized. The equations of motion expressing rigid body modes with static aeroelastic corrections are used for this synthesis. The gains and other aspects of the resulting system are examined and, if acceptable, the design proceeds. If not, configuration changes are in order and the design must return to the beginning of Level III.

Hydraulic, electric, pneumatic and other systems are now sized and designs are initiated to provide a more accurate estimate of the system weights. Structural sizing to static loads for strength and fatigue is done and the configuration weights are updated. The sizing to static loads includes an allowance to satisfy FAR formula gusts. A flutter analysis using lifting surface unsteady aerodynamics is made and a design loop using geometry, stiffness or mass changes or suppressing with control surfaces is performed until the required flutter margins are met. The structure is sized for strength and fatigue to spectral flight gust loads and to landing impact and taxi ground loads. Once again, the configuration weights are updated.

After each weights update, the balance and weight of the configuration are compared with the situation at the end of Level III. If the differences are sufficiently large to invalidate the Level III performance analysis then configuration resizing is required and the design must return to the beginning of Level III. Otherwise, the flight control system synthesis performed early in Level IV is repeated using the airplane's elastic modes in the equations of motion. A performance calculation and market analysis is made with the refined configuration resulting from Level IV. The first manufacturing review in the design process is held to consider facilities, resources and unusual design techniques. An estimate of costs and product program schedules is made and these are compared to the cost and schedule targets established in Level II and III.

The design sequence of Level IV is not generally performed straight through. Normal usage has most tasks being done several times in a series of loops whose paths depend on the previous result. After Level IV has been in work long enough for confidence to be established that the geometry of the configuration will not change, the design and fabrication for the wind tunnel model to be tested in Level V may begin.

Finally, the configuration is evaluated and the results are presented to management to decide if the configuration should be committed into Level V. If the configuration is not acceptable, the management may elect to retain the design mission and criteria and return to the beginning of Level III to resize using alternate sizing rules or the management may elect to return the design sequence to Level II to evaluate the effects of an alternate design mission.

#### B.1.2.4 Level V

The goal of Level V is to verify a configuration so that management commitment to production status can be done with minimum risk. The information for the management review is developed from wind tunnel tests, detail design and analysis, manufacturing evaluations and other tasks. The risk is reduced by improving the airplane weight estimation, by using measured drag data in the performance calculations and by doing sufficiently detailed design and analyses so that no surprises will be found in the product detail design phase (Level VI).

The status of the wind tunnel model design is reviewed. Modifications to the wind tunnel model design may be required as indicated by analyses done late in Level IV. If the model design has not begun, a review is held to decide whether to begin design or not. If not, then a technical review is required to determine the next action.

The wind tunnel model design will result in a complete external loft of the geometry to be tested and used in Level V. The parametric scheme of geometry generation used in previous levels will no longer be adequate. The wind tunnel model test establishes the cruise drag, provides wing airloads and measures the longitudinal stability and control characteristics. If the cruise drag levels and the longitudinal stability and control are acceptable, then the remaining activities of Level V may begin. If not, then a technical review must establish the next action.

The remaining activities of Level V are performed in parallel with periodic reviews and recycles. Tasks new to the design sequence include a computerized space mockup, a low-speed wind tunnel model design and test, and a high speed lateral and directional derivatives wind tunnel test. Design activities are done by teams of designers working on specific parts of the configuration. The design and analyses activities are updated by incorporation of wind tunnel data and results of parallel design activity into a common data bank. The depth or completeness of design activity depends on the specific detail

design task. Other activities in Level V include scheduling and resources reviews and a manufacturing examination of the configuration geometry. An important consideration in this examination would be a comparison between the tested wing contour and a producible contour. Serious disagreement would require one additional wing to be tested.

These activities are expected to occur over an eight month period. Once these tasks have all converged, a review determines if the airplane is acceptable. If not, a technical review is held to choose the next action. If the airplane is acceptable, and there is sufficient customer interest, then a management review board is presented with the competing configurations that have successfully completed Level V. The management review board may choose a configuration for production commitment, and the design process goes to Level VI. If not, then a technical review considers the configurations and any recommendations from the management review to determine the next action.

### B.1.3 Results of the Design Levels

The principal results of the preliminary design levels for a subsonic transport are summarized in the following sections.

#### B.1.3.1 Results of Level II Design Mission Selection

Figure B.4 shows the principal results of Level II. The goal of this level was to determine the design mission for the configuration design that follows. The analyses of this level are done primarily by marketing. Configuration information such as operating costs, mission performance and design trades are required to support the marketing analysis. The configurations are parametrically controlled and represent a projected technology level for the time period of interest. The configuration is sized and the performance characteristics are estimated. Weight and drag are estimated by statistical methods and the performance calculations are also statistical in nature. The intended market is established, and the best design mission for that market is determined. This mission is the one that results in a configuration with the largest sales potential, both in volume of sales and in market share.

#### B.1.3.2 Results of Level III Configuration Sizing

Figure B.5 shows the principal results of Level III. The goal of Level III is to size a candidate configuration to the

NEW INFORMATION PROVIDED BY LEVEL II

- CONFIGURATION SIZING (PARAMETRIC ESTIMATE)
- PERFORMANCE ESTIMATE
  - SIMPLIFIED WEIGHTS AND DRAG METHODS
  - SIMPLIFIED PERFORMANCE METHODS
- SELECT DESIGN MISSION
- MARKET ESTIMATE (SALES POTENTIAL)

Figure B.4 Results of Level II Design Mission Selection  
Subsonic Commercial Transport

NEW INFORMATION PROVIDED BY LEVEL III

- PRIMARY STRUCTURE CONCEPTS & ARRANGEMENTS
  - STRENGTH/FATIGUE SIZING TO STATIC LOADS (GROSS)
- NOISE FOOTPRINTS
- LATERAL CONTROL CHECK
- INITIAL FLUTTER CHECK

INFORMATION IMPROVED BY LEVEL III

- CONFIGURATION SIZING
  - AIRPLANE BALANCE/LOADABILITY
  - WEIGHTS BASED ON STRUCTURAL ANALYSIS
- PERFORMANCE ESTIMATE
  - IMPROVED WEIGHTS & DRAG ESTIMATION
  - IMPROVED PERFORMANCE METHODS
- MARKET ESTIMATE

Figure B.5 Results of Level III Configuration Sizing  
Subsonic Commercial Transport

design mission selected in Level II. In general usage, Level III begins with the best configuration selected for the design mission studies of Level II. New information is developed in Level III as a result of additional analysis capabilities. Structure concepts and arrangement are developed for the primary structure. The primary structure is then sized for strength and fatigue to gross static loads, with beam theory being used as the method of analysis. A flutter analysis may be conducted at the option of the designer. Finally, noise footprints are generated to assess local environmental effects.

The analysis methods used in Level II are improved for Level III and are based on more complete physical modeling of the airplane and its primary structure. For example, the mathematical definition of the exterior geometry is calculated in more detail and the payload arrangements including the location of all passenger seats are calculated. When used with the methods new to this level, the configuration sizing to the design mission is done to an improved accuracy. The primary structure weight is now based on structural analysis. This in turn allows better design for balance and longitudinal control.

The improved weight estimate along with a more thorough drag estimation procedure support the configuration performance calculations. These calculations are of the same type as used for airplane certification. The new performance estimates allow a better estimate of the market, including a more accurate prediction of sales potential.

#### B.1.3.3 Result of Level IV Configuration Refinement

Figure B.6 shows the principal results of Level IV. The goal of Level IV was to refine a Level III configuration so that increased confidence may be gained in that configuration. The refinement occurs as a result of additional design and analysis capabilities.

Stability and control for all three axes are examined with the inclusion of calculated aeroelastic effects. A flight control system is designed for the flexible airplane. The systems (ECS, avionics, hydraulics, etc.) are sized by analysis of operational requirements and loads. Flutter margins are computed and deficiencies are corrected by mass, geometry or stiffness changes, or by design of a flutter suppression system. Structural sizing of both primary and secondary structure for strength and fatigue is done for dynamic as well as static flight loads. The dynamic loads predictions include spectral gust representations. Structural sizing for a flutter fix by

NEW INFORMATION PROVIDED BY LEVEL V

- ⊗ DETAILED STRUCTURAL SIZING TO DYNAMIC GROUND LOADS
  - STRENGTH/FATIGUE
- WIND TUNNEL MODEL TESTING
  - CRUISE & LOW SPEED PERFORMANCE
  - MEASURED AIRLOADS
  - STABILITY DERIVATIVES
- ⊗ SPECIAL TESTS FOR UNUSUAL CONFIGURATIONS (ENGINE GROUND TEST, ETC.)
- SIMULATOR STUDIES (PILOT EVALUATION)
- ⊗ COMPUTERIZED SPACE ARRANGEMENT MOCKUP
- MANUFACTURING FEASIBILITY EVALUATION

INFORMATION IMPROVED BY LEVEL V

- CONFIGURATION SIZING
  - DESIGN OF MAJOR COMPONENTS
  - WIND TUNNEL TESTING
  - SIMULATOR STUDIES
- PERFORMANCE ESTIMATE
  - DETAILED WEIGHTS
  - WIND TUNNEL MODEL DRAG COEFFICIENTS
- MARKET ESTIMATE

Figure B.7 Results of Level V Configuration Verification -  
Subsonic Commercial Transport

are primarily based on beam theory, but finite element concepts are introduced at major structural discontinuities.

The results of these design and testing activities provide for a better weight estimate, and when used with the measured drags, produce a very reliable airplane performance calculation. This and the simulator studies serve as a verification of the configuration sizing to the design mission established in Level II. The final market analyses and sales prediction are made as the last technical activity in Level V before management review.

#### B.1.4 Design Task Relationships

Figure B.8 shows an example of the relationship of applying an engine location trade study task to the design network developed for the subsonic commercial transport. The Level II design mission selection and Level III configuration sizing functions use drag estimation methods which can only provide information for selection between similar configurations, i.e., twin versus trijet with engines on the wing and twin versus trijet with engines on the body. Therefore, the best configuration of each type becomes the basis for the configuration refinement Level IV and the configuration verification Level V. Only when the design has progressed to Level V is information of sufficient detail available to permit selection of the single best configuration. The chart also shows that the desired level of design and analysis for an all-flying horizontal stabilizer places that task in Levels IV and V because wind tunnel data available in Level V is required to substantiate the assumptions made in the analytical analysis.

### B.2 PROJECT 2 - SUPERSONIC COMMERCIAL TRANSPORT

#### B.2.1 Project Definition

Project 2 is defined to be a general supersonic commercial transport. The wing geometry would be fixed or variable. Different structural concepts would be utilized, and the geometry could be control-configured. The most important limit is that the cruise Mach number be low enough that cooling by using the fuel as a heat sink would be adequate. The range and payload are unspecified.

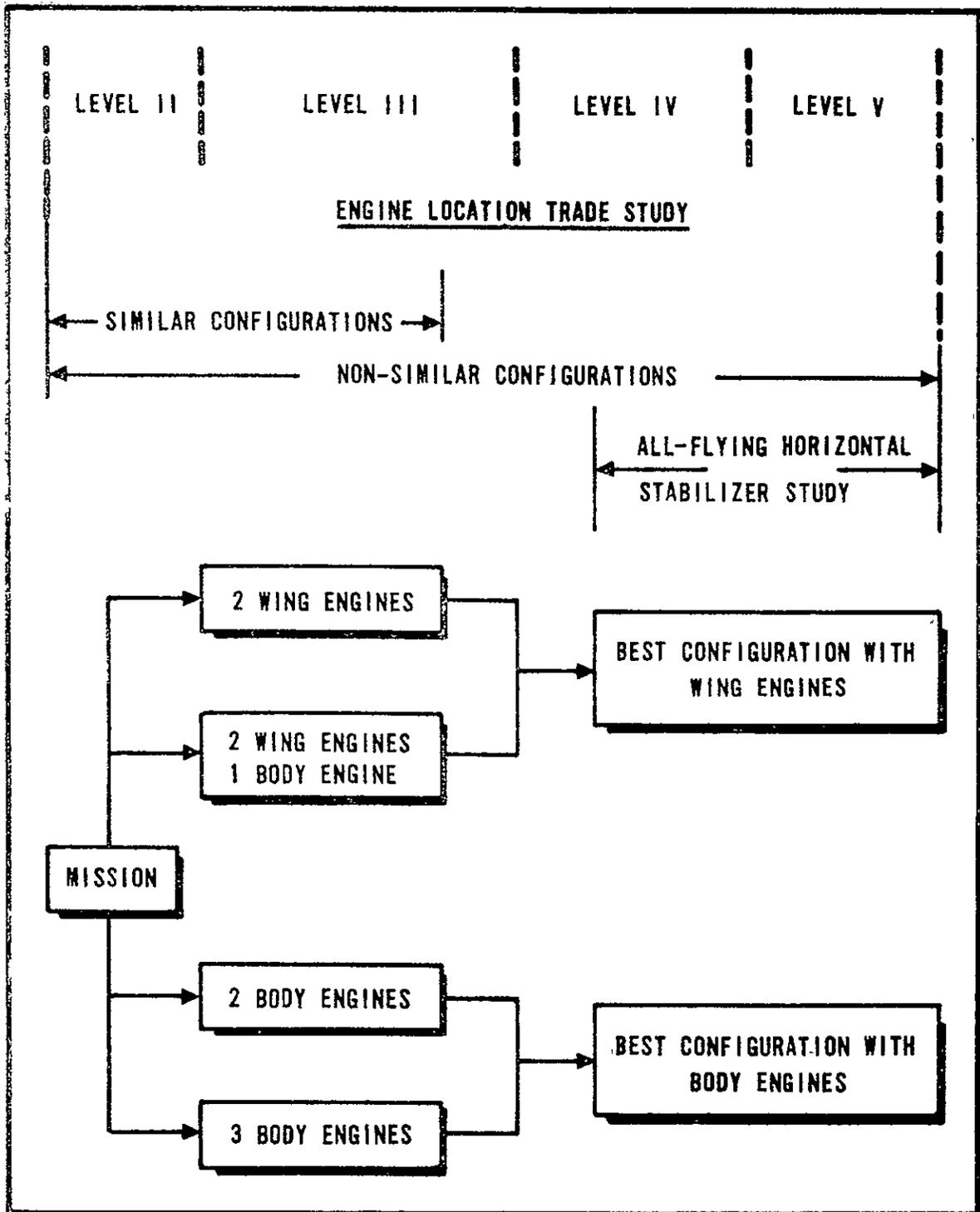


Figure B.8 Example Design Task Relationships - Subsonic Commercial Transport

### B.2.2 Design Networks

As in Project 1, the general Product Level concept of figure 2.2 also applies to this Project. The following are the objective time relationships for the preliminary design phase of a supersonic transport:

<u>Level</u>	<u>Design Cycle</u>	<u>Converged Design</u>
II	2 Days	--
III	1 Month	--
IV	2 Months	4 Months
V	3 Months	6 Months

Figures B.9, B.10 and B.11 present the summary work flow network relating technical tasks, major man decisions and technical and management reviews for the preliminary design phase of a supersonic commercial transport. The technical tasks and reviews are presented as rectangular blocks and the man decisions are shown as diamonds. The preliminary design activity has been divided into four levels beginning with selection of the design mission and ending with verification of the configuration prior to management review for product go-ahead.

#### B.2.2.1 Level II

The goal of Level II is to determine the best design mission for the subsequent configuration design process. This begins with a management selection of an airplane class, for example, a 5,500 n.m. range, Mach 2.7, supersonic commercial transport. The analysis to select the best design mission uses airline operational requirements and histories, route information and performance data to estimate the market suitability and to forecast potential sales. The configuration used to provide performance and design trade data is parametrically generated. Level II requires short execution times so that many airplane mission options, and airplane family concepts can be investigated.

#### B.2.2.2 Level III

The goal of Level III is to size a candidate configuration to the design mission and to select the "best" configurations from similar competing configurations. Thus, the design and analysis of Level III must be more accurate than Level II.

The first part of Level III sizes the airplane geometry of a candidate configuration. The external geometry is specified parametrically, as in Level II, except that it is more

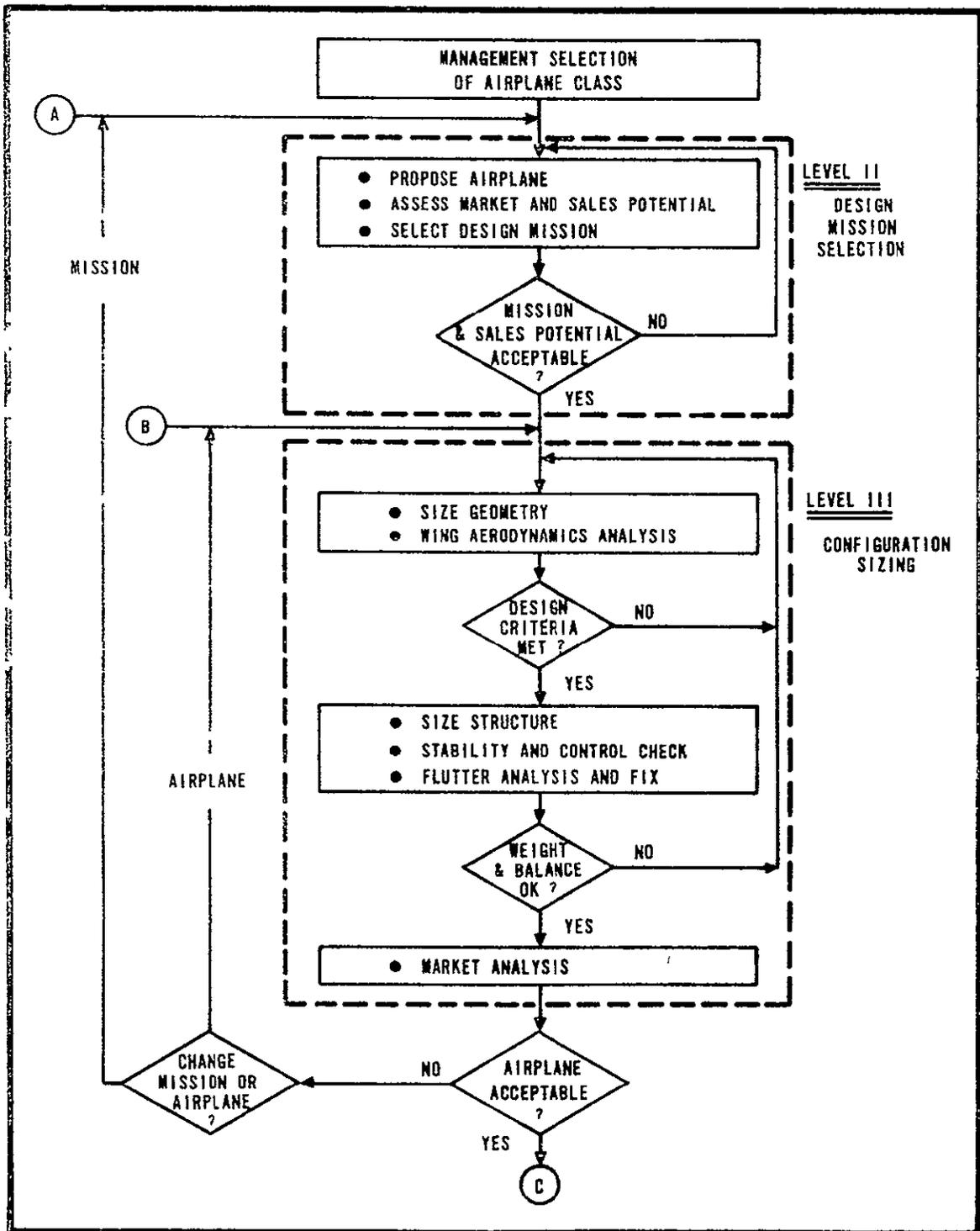


Figure B.9 Preliminary Design - Supersonic Commercial Transport - Levels II and III

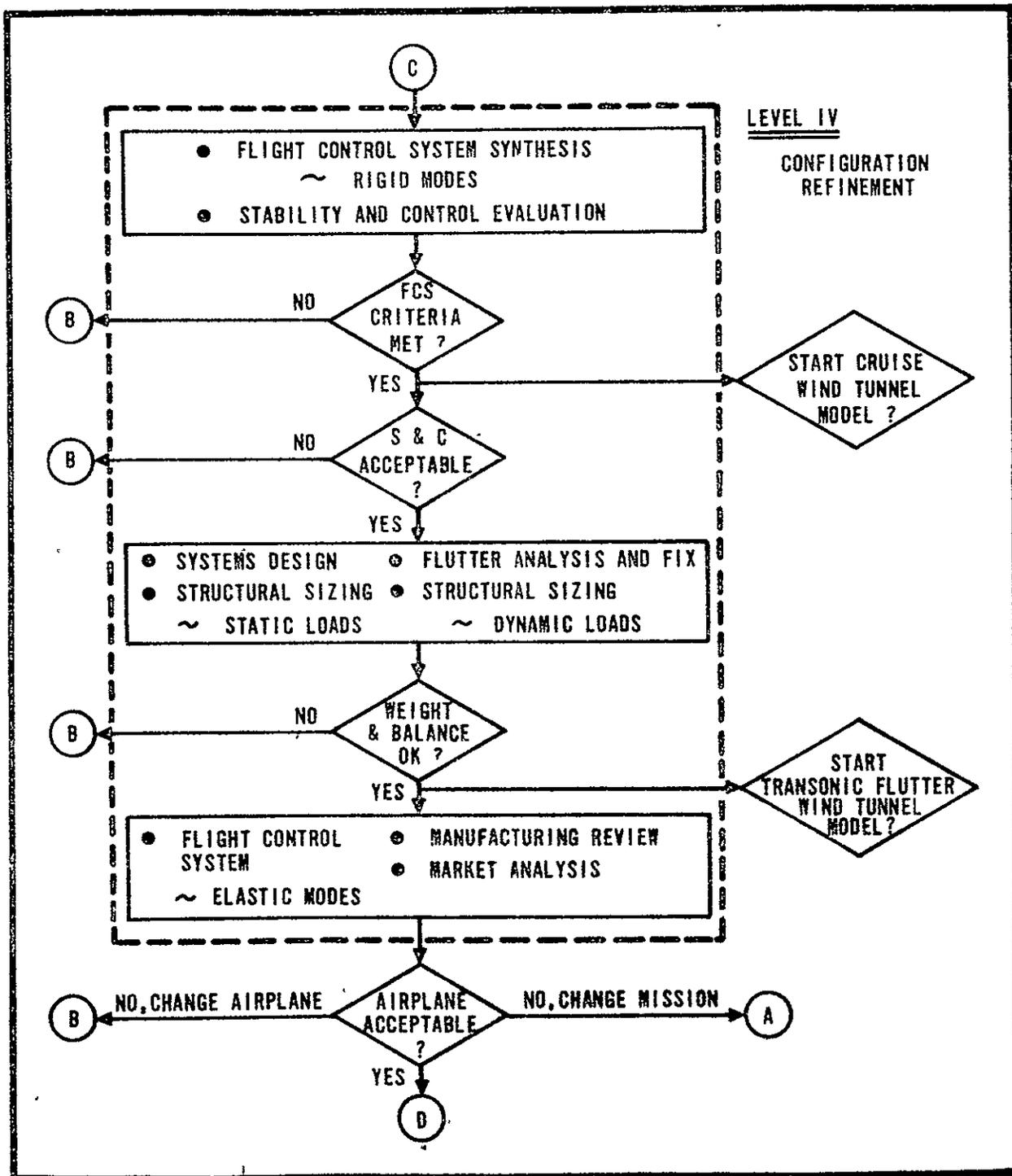


Figure B.10 Preliminary Design - Supersonic Commercial Transport - Level IV

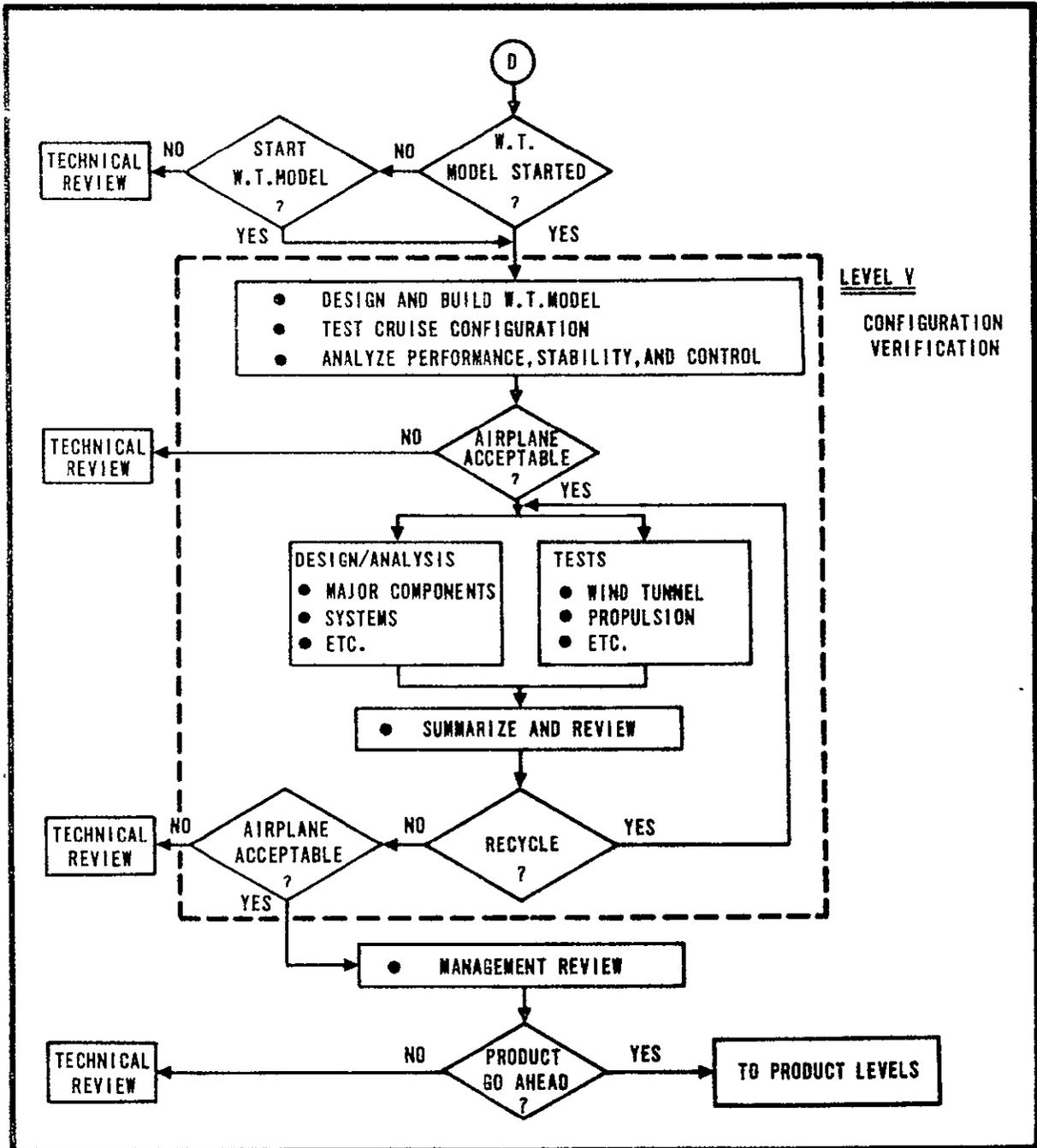


Figure B.11 Preliminary Design - Supersonic Commercial Transport - Level V

thoroughly defined, and it insures that the requirements for area ruling are met. The configuration is balanced and the airframe weight is established, using statistical weight estimation techniques. The cruise drag is analytically determined and the flaps-down lift and drag are parametrically estimated. The wing pressures at cruise may be obtained as a consequence of calculating the cruise drag. The wing shape is reviewed to insure that it is close to an acceptable design. The cruise and field performance are calculated with methods similar to those used for certification. The wing area and engine thrust are sized to the mission and satisfy inequality constraints such as approach speed, field length and initial cruise altitude. The solution is continued until all constraints are satisfied. Community noise footprints and sonic boom estimates are calculated.

The second part of Level III sizes the primary structure to satisfy the static loads and gusts. The sizing is for strength, fatigue, and thermal effects using finite element analysis. Since the structural sizing yields a better weight estimation, the resulting change in airplane weight or balance may require that the airplane geometry be resized. This looping within Level III continues until the structural sizing to static loads and the airplane geometry sizing to the design mission are consistent. A simplified flutter analysis will be done to assess flutter characteristics and the configuration may be recycled to eliminate flutter problems. Sufficient marketing analysis and configuration evaluation is done to decide if the configuration is to be carried to Level IV.

#### B.2.2.3 Level IV

The goal of Level IV is to refine a Level III configuration in a short time so that increased confidence may be gained in the configuration. This refinement is done with improved analysis capabilities that can better assess the geometrical and structural effects of aeroelasticity, static and dynamic loads, flutter, systems design and flight control system synthesis. The results are a better weight estimation and more reliable information is known about the configuration. With these results, the performance is known with more certainty, and problems with the configuration are exposed before a large investment in manpower and time has been made. The analysis programs are linked across their data interfaces, and this provides the capability for a reduced flowtime. Manual monitoring and control of each technical activity is an essential part of Level IV.

The first technical task is a flight control system synthesis and stability and control evaluation which is conducted to establish if the stabilizing surfaces and control surfaces sized in Level III are adequate. The flight control system to provide or augment the airplane stability is synthesized using equations of motion expressed by rigid body modes corrected with static aeroelastic factors. The stability and control evaluation includes a check of control surface effectiveness, an analysis of the airplane dynamic response characteristics and a preliminary handling qualities evaluation using both computerized pilot simulation and real pilot simulation. Preliminary sizing and rate requirements for all control surface actuation is made. If the airplane is determined not to be stable or controllable, then configuration changes are required and the design must return to the beginning of Level III.

Hydraulic, electric, pneumatic and other systems are now sized and designs are initiated to provide a more accurate estimate of the system weights. Structural sizing to static loads for strength, fatigue, and thermal effects is done and the configuration weights are updated. The sizing to static loads includes an allowance to satisfy FAR formula gusts. A flutter analysis using lifting surface unsteady aerodynamics is made and a design loop using geometry, stiffness or mass changes or suppressing with control surfaces is performed until the required flutter margins are met. The structure is sized for strength and fatigue to spectral flight gust loads and to landing impact and taxi ground loads. Once again, the configuration weights are updated.

After each weights update, the balance and weight of the configuration are compared with the situation at the end of Level III. If the differences are sufficiently large to invalidate the Level III performance analysis then configuration resizing is required and the design must return to the beginning of Level III. Otherwise, the flight control system synthesis performed early in Level IV is repeated using the airplane's elastic modes in the equations of motion. A performance calculation and market analysis is made with the refined configuration determined in Level IV. The first manufacturing review in the design process is held to consider facilities, resources and unusual design techniques. An estimate of costs and product program schedules is made and these are compared to the cost and schedule targets established in Levels II and III.

The design sequence of Level IV is not generally performed straight through. Normal usage has most tasks being done several times in a series of loops whose paths depend on the previous result. After Level IV has been in work long enough

for confidence to be established that the geometry of the configuration will not change, the design and fabrication for the wind tunnel models to be tested in Level V may begin.

Finally, the configuration is evaluated and the results are presented to management to decide if the configuration should be committed into Level V. If the configuration is not acceptable, the management may elect to retain the design mission and criteria and return to the beginning of Level III to resize using alternate sizing rules or the management may elect to return the design sequence to Level II to evaluate the effects of an alternate design mission.

#### B.2.2.4 Level V

The goal of Level V is to verify a configuration so that management commitment to production status can be done with minimum risk. The information for the management review is developed from wind tunnel tests, detail design and analysis, manufacturing evaluations and other tasks. The risk is reduced by improving the airplane weight estimation, by using measured drag data in the performance calculations and by doing sufficiently detailed design and analyses so that no surprises will be found in the product design phase (Level VI).

The status of the design of the wind tunnel models is reviewed. Modifications to the wind tunnel model design may be required as indicated by analyses done late in Level IV. If the design of the models has not begun, a review is held to decide whether to begin design or not. If not, then a technical review is required to determine the next action.

The wind tunnel model design will result in a complete external loft of the geometry to be tested and used in Level V. The parametric scheme of geometry generation used in previous levels will no longer be adequate. The wind tunnel cruise model test establishes the cruise drag, provides both wing and body airloads and measures the longitudinal, lateral and directional stability and control characteristics. If the cruise drag levels and the longitudinal, lateral and directional stability and control are acceptable, then the remaining activities of Level V may begin. If not, then a technical review must establish the next action.

The remaining activities of Level V are performed in parallel with periodic reviews and recycles. Tasks new to the design sequence include a computerized space mockup and low-speed, wind tunnel models for transonic flutter, pressure and cruise stability and control testing. Design activities are

done by teams of designers working on specific parts of the configuration. The design and analyses activities are updated by incorporation of wind tunnel data and results of parallel design activity into a common data bank. The level of design activity depends on the specific detail design task. Other activities in Level V include scheduling and resources reviews and a manufacturing examination of the configuration's geometry. An important consideration in this examination would be a comparison between the tested wing contour and a producible contour. Serious disagreement would require one additional wing to be wind tunnel tested.

These activities are expected to occur over a sixteen month period with a one cycle flowtime of two months. Once these tasks have all converged, a review determines if the airplane is acceptable. If not, a technical review is held to choose the next action. If the airplane is acceptable, and there is sufficient customer interest, then a management review board is presented with the competing configurations that have successfully completed Level V. The management review board may choose a configuration for production commitment, and the design process goes to Level VI. If not, then a technical review considers the configurations and any recommendations from the management review to determine the next action.

### B.2.3 Results of the Design Levels

The principal results of the preliminary design levels for a supersonic transport are summarized in the following sections.

#### B.2.3.1 Results of Level II Design Mission Selection

Figure B.12 shows the principal results of Level II. The goal of this level is to determine the design mission for the configuration design that follows. The analyses of this level are done primarily by marketing. Configuration information such as operating costs, mission performance and design trades are required to support the marketing analysis. The configurations are parametrically controlled and represent a projected technology level for the time period of interest. The configuration is sized and the performance characteristics are estimated. Weight and drag are estimated by statistical methods and the performance calculations are also statistical in nature. The intended market is established, and the best design mission for that market is determined. This mission is the one that results in a configuration with the largest sales potential, both in volume of sales and in market share.

NEW INFORMATION PROVIDED BY LEVEL II

- CONFIGURATION SIZING (PARAMETRIC ESTIMATE)
- PERFORMANCE ESTIMATE
  - SIMPLIFIED WEIGHTS AND DRAG METHODS
  - SIMPLIFIED PERFORMANCE METHODS
- SELECT DESIGN MISSION
- MARKET ESTIMATE (SALES POTENTIAL)

Figure B.12 Results of Level II Design Mission Selection -  
Supersonic Commercial Transport

#### B.2.3.2 Results of Level III Configuration Sizing

Figure B.13 shows the principal results of Level III. The goal of Level III is to size a candidate configuration to the design mission selected in Level II. In general usage, Level III begins with the best configuration selected for the design mission studies of Level II. New information is developed in Level III as a result of additional analytical capabilities. Structure concepts and arrangements are developed for the primary structure. The primary structure is then sized for strength, fatigue, and thermal effects to gross static loads, using (course grid) finite element analysis. Noise footprints and sonic boom estimates are generated to assess local environmental effects. The lateral control situation is checked using computed structural stiffness and the tail sizes are confirmed. A flutter analysis is performed to ensure that the required flutter margins are met.

The analysis methods used in Level II are improved for Level III and are based on more complete physical modeling of the airplane and its primary structure. For example, the mathematical definition of the exterior geometry is calculated in more detail and the payload arrangements including the location of all passenger seats are calculated. When used with the methods new to this level, the configuration sizing to the design mission is done to an improved accuracy. The primary structure weight is now based on a finite element structural analysis. This in turn allows better design for balance and longitudinal control.

The improved weight estimate along with a more thorough drag estimation procedure support the configuration performance calculations. These calculations are of the same type which would be used for airplane certification. The new performance estimates allow a better estimate of the market, including a more accurate prediction of sales potential.

#### B.2.3.3 Results of Level IV Configuration Refinement

Figure B.14 shows the principal results of Level IV. The goal of Level IV was to refine a Level III configuration so that increased confidence may be gained in that configuration. The refinement occurs as a result of additional design and analysis capabilities.

Stability and control for all three axes are examined with the inclusion of calculated aeroelastic effects. A flight control system is designed for the flexible airplane. The configuration is subjected to an analytical piloted flight

NEW INFORMATION PROVIDED BY LEVEL III

- PRIMARY STRUCTURE CONCEPTS & ARRANGEMENTS
  - STRENGTH/FATIGUE SIZING TO STATIC LOADS (GROSS)
  - STRUCTURE CONCEPTS CHANGE TO FIX FLUTTER
- NOISE FOOTPRINTS AND SONIC BOOM ESTIMATES
- INITIAL STABILITY & CONTROL CHECK
- INITIAL FLUTTER CHECK & FIX

INFORMATION IMPROVED BY LEVEL III

- CONFIGURATION SIZING
  - AIRPLANE BALANCE/LOADABILITY
  - WEIGHTS BASED ON STRUCTURAL ANALYSIS
- PERFORMANCE ESTIMATE
  - IMPROVED WEIGHTS & DRAG ESTIMATE
  - IMPROVED PERFORMANCE METHODS
- MARKET ESTIMATE

Figure B.13 Results of Level III Configuration Sizing -  
Supersonic Commercial Transport

NEW INFORMATION PROVIDED BY LEVEL IV

- DYNAMIC EFFECTS ON STABILITY & CONTROL
- FLIGHT CONTROL SYSTEM SYNTHESIS & DESIGN
- ESTIMATED HANDLING QUALITIES
- SIMULATOR STUDIES (PILOT EVALUATION)
- SYSTEMS DESIGN
- FLUTTER ANALYSIS & FIX
- DETAILED STRUCTURAL SIZING TO STATIC AND DYNAMIC FLIGHT LOADS
  - STRENGTH/FATIGUE AND STIFFNESS TO FIX FLUTTER

INFORMATION IMPROVED BY LEVEL IV

- CONFIGURATION SIZING
  - DETAILED STRUCTURAL SIZING
  - SYSTEMS DESIGNS
  - SIMULATOR STUDIES
- PERFORMANCE ESTIMATE
  - IMPROVED WEIGHTS
- MARKET ESTIMATE

Figure B.14 Results of Level IV Configuration Refinement -  
Supersonic Commercial Transport

simulation. The systems (ECS, avionics, hydraulics, etc.) are sized by analysis of operational requirements and loads. Flutter margins are computed and deficiencies are corrected by mass geometry or stiffness changes, or by design of a flutter suppression system. Structural sizing of both primary and secondary structure for strength, fatigue, and thermal effects is done for dynamic as well as static flight loads. The dynamic loads predictions include spectral gust representations. Structural sizing for a flutter fix by changing stiffness is also done. All the structural analyses of Level IV are based on finite element analysis.

The calculations done by the analyses new to Level IV provide an improved evaluation of stability and control characteristics and an improved weight estimation, because of the system design and because of the detailed structural sizing. The improved weight estimate provides for a more reliable performance prediction. Also because of the improved weight estimation, the configuration sizing to the design mission of Level II is more reliably determined. The cost estimates are improved by the more refined and more complete technical information. Finally, the market analyses is repeated, and a more accurate prediction of sales potential is made.

#### B.2.3.4 Results of Level V Configuration Verification

Figure B.15 shows the principal results of Level V. The goal of Level V is to verify a configuration so that management commitment to product status can be done with minimum risk. The analysis techniques of Level V are the same as those used for Level IV except for a more refined usage of finite element analyses for structural sizing. The verification of the configuration occurs primarily as a result of physical tests and of more detail design activity.

Wind tunnel model testing begins with the cruise configuration. The cruise drag is measured, wing and body pressures are recorded, and the longitudinal stability and control aspects are evaluated. Satisfactory drag, pitch characteristics and lateral and directional stability and control contribute to configuration verification. The measured wing and body pressures are used to improve the airloads prediction. Low speed wind tunnel model tests follow to measure the low speed configuration lift and drag and to examine the stability and control characteristics. A transonic wind tunnel model is tested to evaluate flutter characteristics. Special tests such as engine rigs, structural rigs or systems mockups, are done for unusual configurations. Systems installations are verified with a computerized space arrangement mockup. A

NEW INFORMATION PROVIDED BY LEVEL V

- DETAILED STRUCTURAL SIZING TO DYNAMIC GROUND LOADS
  - STRENGTH/FATIGUE
- WIND TUNNEL MODEL TESTING
  - CRUISE & LOW SPEED PERFORMANCE
  - TRANSONIC FLUTTER
  - MEASURED AIRLOADS
  - STABILITY DERIVATIVES
- SPECIAL TESTS FOR UNUSUAL CONFIGURATIONS (ENGINE GROUND TEST, ETC.)
- COMPUTERIZED SPACE ARRANGEMENT MOCKUP
- MANUFACTURING FEASIBILITY EVALUATION

INFORMATION IMPROVED BY LEVEL V

- CONFIGURATION SIZING
  - DESIGN OF MAJOR COMPONENTS
  - WIND TUNNEL FLUTTER TESTING
- PERFORMANCE ESTIMATE
  - DETAILED WEIGHTS
  - WIND TUNNEL MODEL DRAG COEFFICIENTS
- MARKET ESTIMATE

Figure B.15 Results of Level V Configuration Verification -  
Supersonic Commercial Transport

detailed manufacturing review of the configuration is done to reveal contours that would be difficult to fabricate. Detail structural sizing for strength and fatigue to dynamic ground loads is added in this level.

Along with these new activities, design groups proceed with detailed design on all the major components of the airframe. The analysis techniques for the most part are the same as those used in Level IV, with a more detailed definition of input information and modeling being provided. Structural analyses are primarily based on finite element analysis with increased emphasis placed on major structural discontinuities.

The results of these design and testing activities provide for a better weight estimate, and when used with the measured drags, produce a very reliable airplane performance calculation. This and the wind tunnel flutter testing studies serve as a verification of the configuration sizing to the design mission established in Level II. The final market analyses and sales prediction are made as the last technical activity in Level V before management review.

#### B.2.4 Detail Design Example

Figure B.16 illustrated one page of the detail design networks for the supersonic transport. There are 19 similar pages shown in Volume II to describe the design networks for a supersonic transport. The example shown on figure B.16 illustrates how a portion of the detailed design networks could support a separate study. The example chosen is for a small examination of the use of a stability augmentation system to improve ride quality. The study begins in Block IV-48, where the equations of motion are generated. There would likely be a suitable set of aerodynamic, mass and stiffness matrices available in the data bank. The next step is to predict the dynamic loads in Block IV-49 and evaluate the ride quality.

The solution then skips down the network to Block IV-63 where the equations of motion are established again. Then in Block IV-63, a control law is postulated, the gains and filters synthesized, and the effect of these modifications to the flight control system are analyzed. This analysis would consider only the worst conditions in the ride quality. The final form of the revision to the flight control system is checked thoroughly in Block IV-49. This loop of IV-49, IV-62, back to IV-49 continues until either the limit to a practical flight control system has been realized, or until the ride quality has been made acceptable.

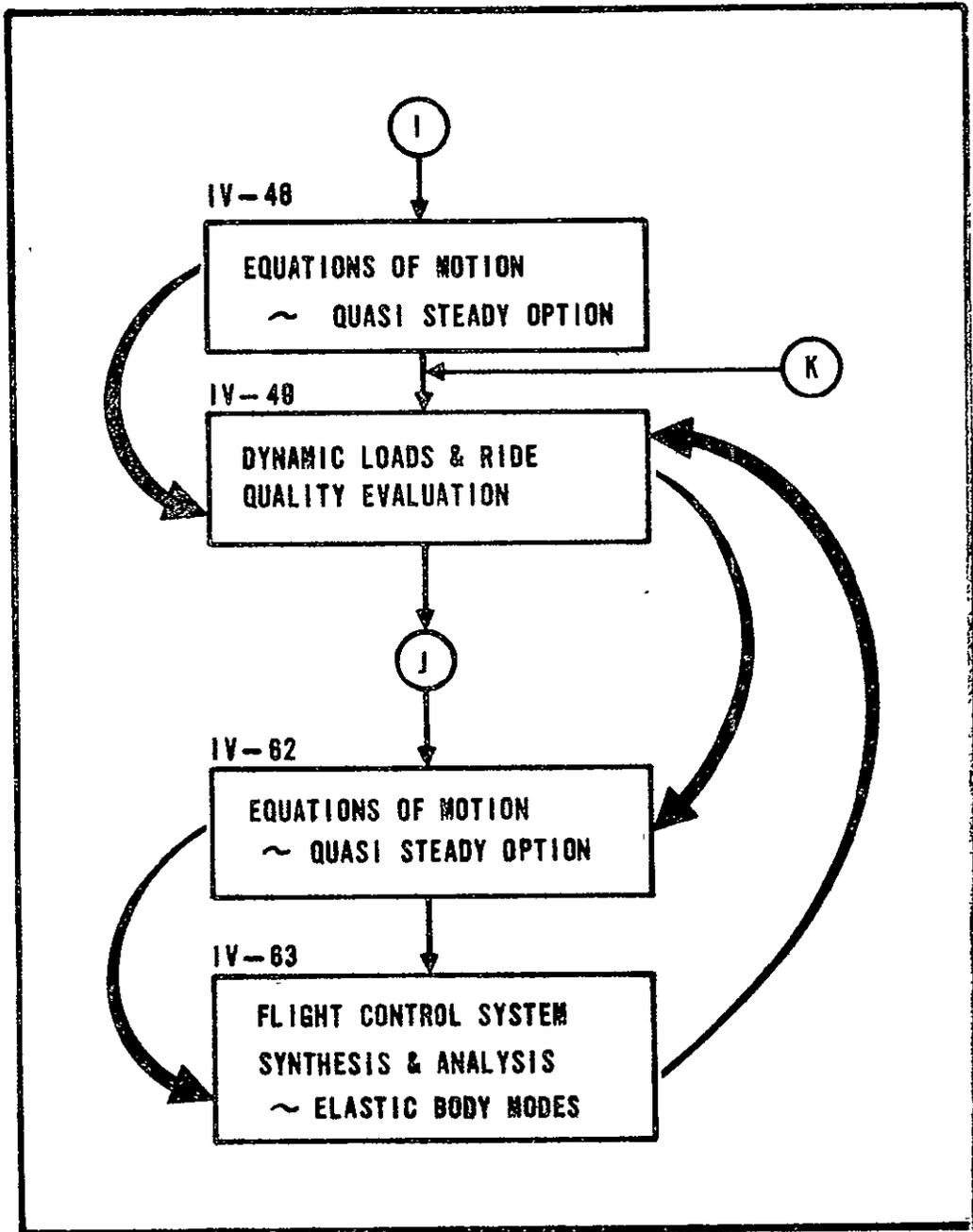


Figure B.16 Detail Design Example - Ride Quality SAS  
Supersonic Commercial Transport

## B.3 OTHER - NAVAL HYDROFOIL

### B.3.1 Project Definition

A brief study was made of a naval hydrofoil, intended primarily for patrol and antisubmarine assignments, powered by a water-jet system both when hullborne and when foilborne.

This study was made because it is not an aircraft geometry yet is a complex, highly integrated vehicle for which considerable experience was available locally within The Boeing Company.

### B.3.2 Design Networks

The design networks for preliminary design levels II, III and IV were established, with the result that the general Product Level concept of figure 2.2 also applies to hydrofoil. The computing resources required to support this project were not evaluated. It was felt that this project would be smaller in required computing resources than Project 1 or 2, and that initial emphasis would be on aircraft design.

Figures B.17 and B.18 present the summary work flow network relating technical tasks and major man decisions for the preliminary design phase of a naval hydrofoil. The design process is shown for some of the same product levels (Level II to IV) as were used for the subsonic and supersonic commercial transport. This serves to support the conclusion that approximately nine product levels are required for the general product.

#### B.3.2.1 Level II

The goal of Level II is to select the design criteria and mission for the subsequent configuration design process. This begins with a management selection of the hydrofoil class, for example, a coastal patrol hydrofoil or a fleet protection hydrofoil. The analysis to select the best design mission uses threat analyses, battle zone climatic histories, and performance data to predict superiority and survivability. The configuration used to provide performance and design trade data is parametrically generated. Level II requires short execution times so that many hydrofoil options can be investigated.

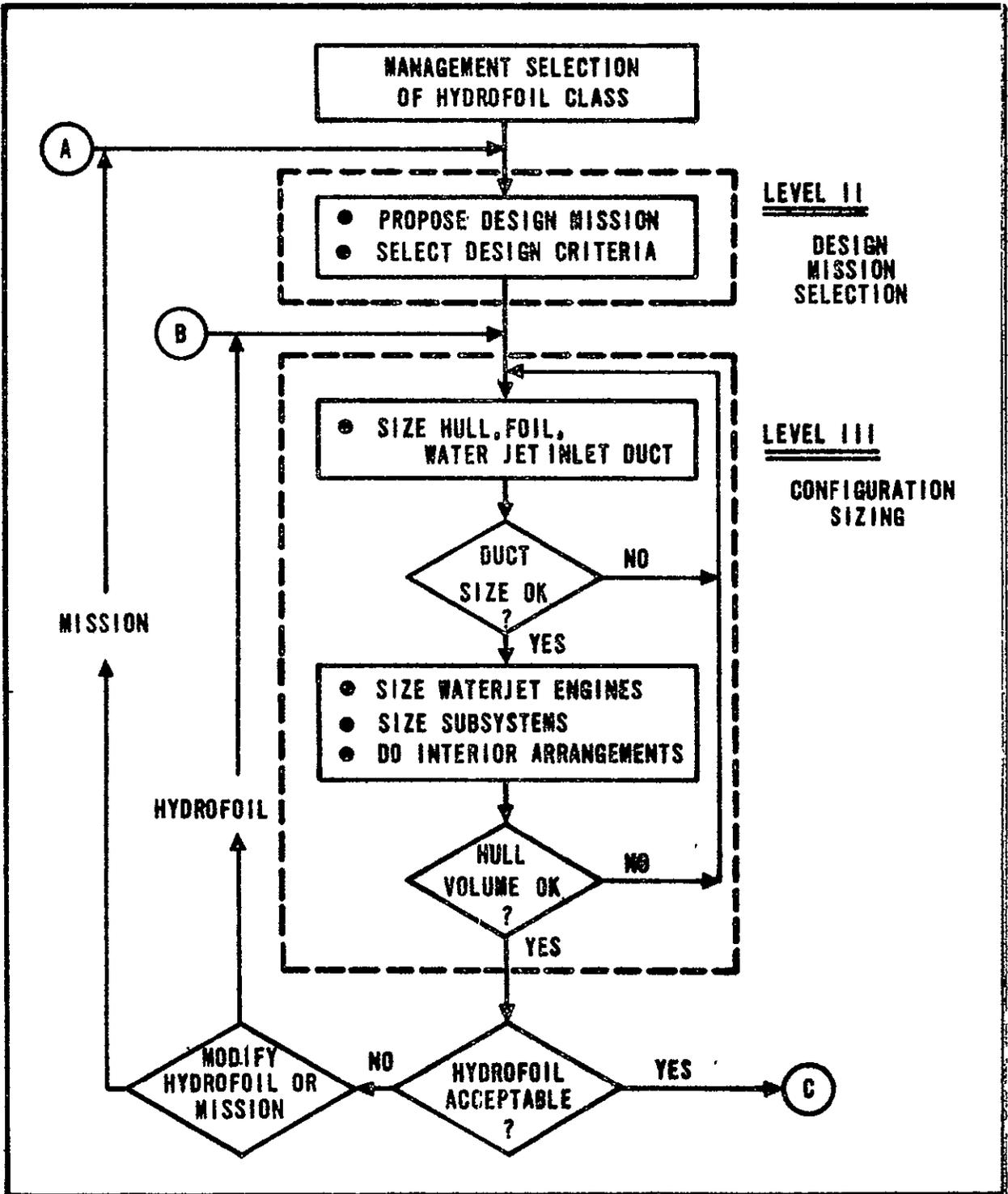


Figure B.17 Preliminary Design - Naval Hydrofoil

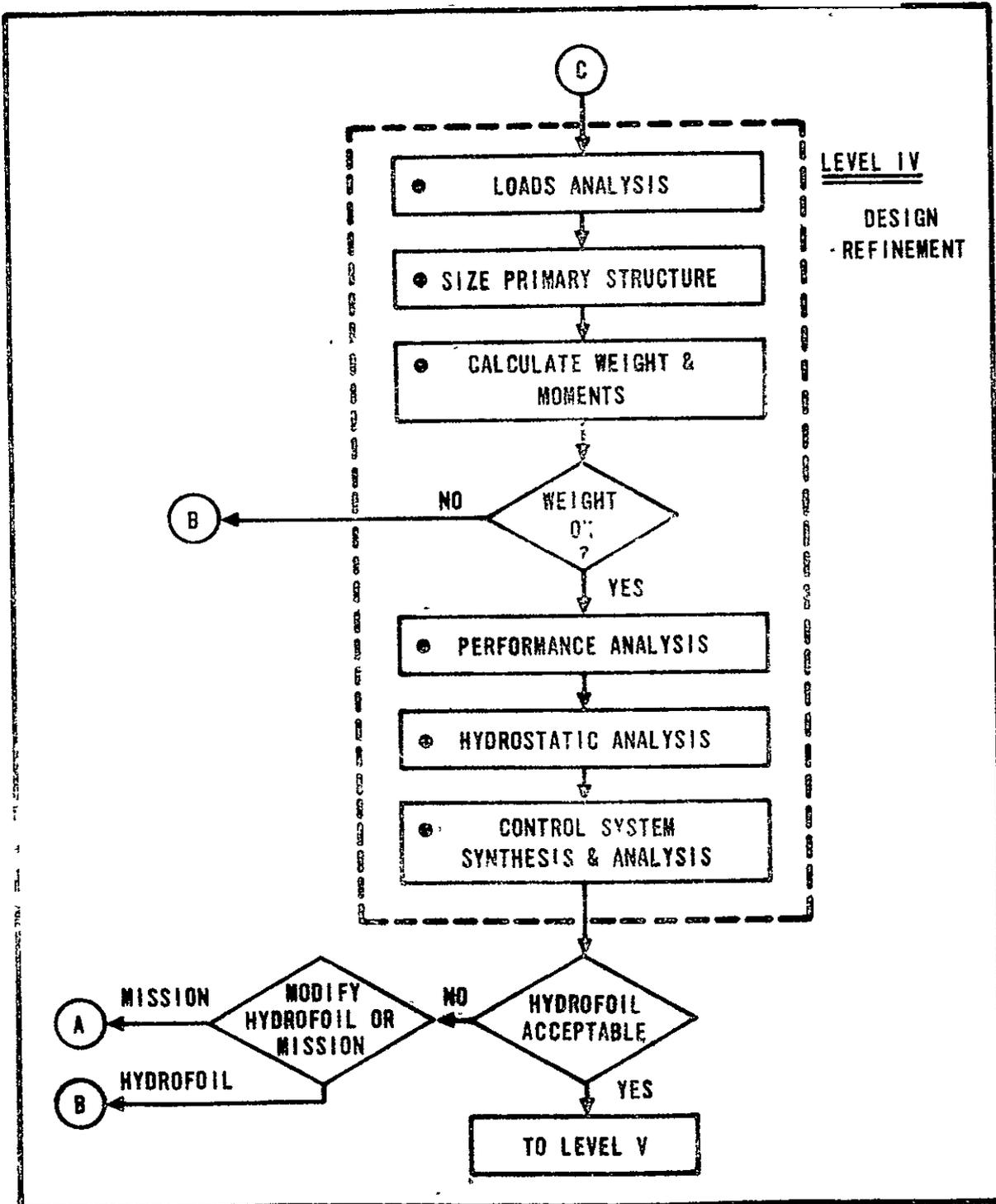


Figure B.18 Preliminary Design - Naval Hydrofoil

#### B.3.2.2 Level III

The goal of Level III is to size a candidate configuration to the design mission and to select the "best" configurations from competing configurations. Thus, the analyses of Level III must be more accurate than those of Level II.

The first part of Level III sizes the hull, foils and waterjet inlet ducts. The geometry is parametrically specified as in Level II, except more thoroughly defined. The hull is developed from a set of parent hull lines. The foil-strut-water duct-inlet geometry is sized, and the total drag is estimated. The waterjet thrust requirements are determined, and the ducts are checked to see if they are adequate. If the ducts are too small, then the geometry is resized.

The second part of Level III sizes the propulsion and interior systems and does an interior arrangement. The weight of the configuration is calculated. If the hull is not large enough to contain the systems, fuel and other required interior arrangements, the geometry must be resized.

#### B.3.2.3 Level IV

The goal of Level IV is to refine a Level III configuration in a short time so that increased confidence may be gained in the configuration. This refinement is done with improved analysis capabilities that can better assess the geometrical and structural effects of static and dynamic loads, primary structure sizing and control system synthesis and analysis. The results are a better weight estimation and more reliable information is known about the configuration. With these results, the performance is known with more certainty, and problems with the configuration are exposed before a large investment in time has been made.

The first technical task in Level IV is to estimate the static loads. This allows a sizing of the primary structure to be done. The weight and moments of the configuration are then determined with better accuracy. This weight can be compared to the weight of the configuration at the end of Level III. If the change is significant, the design must revert to Level III and be resized.

Following convergence on the hydrofoil weight, a complete performance analysis is done. An analysis of impact loads, wind loads and high sea state loads is made. Finally, a stability analysis examines the directional stability, controllability and sea state response and synthesizes a control system.

### B.3.3 Results of the Design Levels

The principal results of the preliminary design levels for the naval hydrofoil are summarized in the following sections.

#### B.3.3.1 Results of Level II Design Criteria Selection

Figure B.19 shows the principal results of Level II. The goal of this level is to determine the design criteria and mission for the configuration design that follows. A design mission is proposed, along with design criteria for structure, materials, stability, and parent hull and foil shapes. A configuration parametrically representing these characteristics is generated, and weight, drag and performance are predicted by statistical methods. The best design mission and criteria are those that produce the most favorable combination of superiority and survivability for the selected threat situation. The configuration and interior arrangement for this design mission is available to start the Level III calculations.

#### B.3.3.2 Results of Level III Configuration Sizing

Figure B.20 shows the principal results of Level III. The goal of Level III was to size a candidate configuration to the design mission and criteria selected in Level II. New information is developed in Level III as a result of additional analysis capabilities. The waterjet propulsion system and the strut-foil-inlet geometry are sized by analysis. A hydrostatic analysis is performed, and various subsystems are sized.

Analysis methods used in Level II are improved in Level III. When used with the methods new to this level, the configuration sizing to the design mission is done to an improved accuracy. The size and number of engines and interior arrangements are improved. The weight of the configuration is predicted to better certainty.

#### B.3.3.3 Results of Level IV Configuration Refinement

Figure B.21 shows the principal results of Level IV. The goal of Level IV was to refine a Level III configuration so that increased confidence may be gained in that configuration. The refinement occurs as a result of new analysis capabilities.

Configuration loads are analyzed and the primary structure is sized. This enables an improved weight estimation, which in turn, improves the performance analysis. A control system is synthesized and analyzed. The hydrostatic analysis of Level III is updated using improved methods.

NEW INFORMATION PROVIDED BY LEVEL II

- ⊙ PROPOSED MISSION
- ⊙ DESIGN CRITERIA
  - ⊙ STRUCTURE
  - ⊙ MATERIALS
  - ⊙ STABILITY
  - ⊙ HULL & FOIL GEOMETRY
- ⊙ INITIAL CONFIGURATION & ARRANGEMENT

Figure B.19 Results of Level II Design Mission Selection - Naval Hydrofoil

NEW INFORMATION PROVIDED BY LEVEL III

- ⊙ WATERJET INLET GEOMETRY
- ⊙ STRUT-FOIL GEOMETRY
- ⊙ SUBSYSTEM SIZES
- ⊙ HYDROSTATIC ANALYSIS

INFORMATION IMPROVED BY LEVEL III

- ⊙ CONFIGURATION SIZING
- ⊙ SIZE AND NUMBER OF ENGINES
- ⊙ INTERIOR ARRANGEMENT
- ⊙ WEIGHTS

Figure B.20 Results of Level III Configuration Sizing - Naval Hydrofoil

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NEW INFORMATION PROVIDED BY LEVEL IV

- LOADS ANALYSIS
- PRIMARY STRUCTURE SIZING
- PERFORMANCE ANALYSIS
- CONTROL SYSTEM SYNTHESIS & ANALYSIS

INFORMATION IMPROVED BY LEVEL IV

- WEIGHT & MOMENTS
- HYDROSTATIC ANALYSIS

Figure B.21 Results of Level IV Design Refinement -  
Naval Hydrofoil

## APPENDIX C

### ANSWERS TO TASK QUESTIONS

The answers to all task questions are included this appendix. These answers are also included in section 2.0 of Volumes II, III, IV, V, VI and VII as they apply to the subject matter.

#### C.1 TASK 1 QUESTIONS AND ANSWERS

Task 1, Question 1--What different disciplines should be involved?

Answer--The characterization of the design process for Project 1 and Project 2 indicate that a large number of disciplines are involved to varying degrees in Design Levels II to VI. The titles for each discipline may vary from company to company, but the activities will remain the same. The list of disciplines is as follows:

- |                             |                                    |
|-----------------------------|------------------------------------|
| (1) Aerodynamics            | (11) Noise                         |
| (2) Configuration design    | (12) Performance                   |
| (3) Dynamic loads           | (13) Propulsion                    |
| (4) Flight control systems  | (14) Reliability & Maintainability |
| (5) Finance                 | (15) Stability and control         |
| (6) Flutter                 | (16) Static loads                  |
| (7) Geometry lofting        | (17) Stress                        |
| (8) Management info. system | (18) Structure design              |
| (9) Marketing               | (19) Systems design                |
| (10) Mathematics support    | (20) Weights                       |

Task 1, Question 2--What disciplines are already adequately represented by existing codes? Which ones are missing?

Answer--The disciplines of geometry lofting, mathematics, noise and product assurance (reliability) are adequately represented by existing codes. The discipline of structural design and the preliminary design management information system are missing. This is based on a Boeing Company survey.

Task 1, Question 3--What disciplines have to be represented primarily by experimental data?

Answer--Stability and control, static loads and noise are highly dependent on experimental data in Design Levels V and VI. Aerodynamics and flutter are dependent to a lesser degree in these levels. The propulsion system will be represented almost totally by experimental data, beginning with Design Level IV. Nearly all disciplines require statistical data in Levels II to IV. Statistical data is considered separately as Task 1, Question 6.

Task 1, Question 4--How should experimental data be handled in the system operation?

Answer--Experimental data should be stored in the appropriate community data bank in coefficient form, not in the raw engineering or instrument measuring units in which it was recorded. The reduction to coefficient form should ideally be done by personnel at the facility where the testing was done.

Task 1, Question 5--What aspects of the design are not quantifiable and what impact do they have on the design process?

Answer--Certain critical aspects of management control, design evaluation and design optimization cannot be automated. The IPAD System must support, in terms of data retrieval and display, the user requirements to perform these critical aspects.

Task 1, Question 6--What is the proper place and role of statistical information in the system?

Answer--Each technical discipline will use statistical information in order to produce its best estimate of the ultimate result at any point in time until that information can be replaced by specific experimental and analytical information. These replacements will vary by technical discipline and by project as to their location in the Design Networks.

Task 1, Question 7--In the case of structural weight, how should the non-optimum and secondary weights be assessed?

Answer--The non-optimum structure weights will be predicted using statistical information in the early preliminary design levels. Because of the expense involved, the lack of sufficient detail design information, and the limited experience available, the statistical non-optimum weights will be used in the design networks until the weights can be calculated from detail part layout drawings generated in the product design levels. The

secondary structural weights will have a similar history throughout the design process.

Task 1, Question 8--What should be the IPAD level of application?

- a. Preliminary design?
- b. Detailed design?
- c. Final analysis?
- d. Can all be included in the system as a natural progression of the design process?

Answer--IPAD should be applied to all parts of the product design process and manufacture interface. If the IPAD system is well designed, it will support any one level as well as all of the levels. Therefore, development of all design levels should be undertaken as a natural progression.

Task 1, Question 9--What should be the range of IPAD applications?

- a. Commercial vehicles?
- b. Military vehicles?
- c. Aerospace vehicles?
- d. All?

Answer--IPAD will benefit any product large enough to support the computer cost to use the IPAD System. First implementation should be in the area of commercial aircraft, specifically, an advanced SST. Indeed, the design of that class of aircraft offers an outstanding requirement for multi-discipline technical integration, thus providing primary motivation for IPAD. It could be a decisive factor in achieving a high quality product with reduced technical risks, and a means to control development costs and to meet schedules. In addition, other commercial and military aerospace vehicles simply await development of the necessary Technical Program Elements.

Task 1, Question 10--How can one resolve the unavoidable conflict between the level of analysis and computer time? What is the optimal level of analysis at each stage of the design? How can one measure and determine it?

Answer--With the nine Product Levels as provided in figure 2.2, the conflict is avoided. For each of these levels, the extent of analysis, the computational resources required, and the resultant accuracy of the answers will be known to management. After review of the results of each Level, management will commit the design sequence to the next higher level.

The nine design levels have been chosen with the goal to permit the optimum trade between computing resources, time to get the result and accuracy of the result. The design levels so chosen integrate the use of statistical data, analysis and experimental data in order to balance the accuracies of the various technical disciplines within each level. The overall accuracy of any single design level is influenced by the management need of an answer to that accuracy within a certain time period.

Task 1, Question 11--What choice of design strategy should be available to the designer in seeking the optimum design? For instance, how can trade-off data be generated and used to speed up the design process?

Answer--The design strategy is completely represented by the nine design levels of figure 2.2. This forms an orderly sequence of design steps that increase the accuracy and reliability of the design for a known additional cost. Because of the orderly development of the product design arising from the design levels, the generation of trade-off data should be carefully controlled. Trade-off data should be collected from generalized studies thus providing related parametric data having established trends. Designers may extract specific information from data in this form and with reasonable accuracy predict the capability of specific cases. This data will be used in Levels II, III and IV and should speed up the design process. A trade study plan must be implemented and continually updated to achieve the final optimum design selection.

Task 1, Question 12--How could one judge the efficiency of independently developed codes relate to their efficiency when incorporated into the IPAD framework? At what point would it be more economical to rewrite the independent code before incorporation into IPAD?

Answer--The data base management features of the IPAD system will provide for very efficient data communication between code within IPAD. Inefficiencies will arise when codes brought together in IPAD have significant engineering overlaps. As this situation raises the question of integrity of the results, editing the overlaps in the code is more than a

question of economics, and should be eliminated whenever possible.

## C.2 TASK 2 QUESTIONS AND ANSWERS

Task 2, Question 1 -- How should the (IPAD) system be organized to provide sufficient flexibility to accommodate independently developed codes, pre-existing and/or those created in the future?

Answer -- The system organization should be able to accommodate multiple language processors, either compilers or translators and provide a mechanism for data structure transformations.

Task 2, Question 2 -- What computer languages will be admissible in the pre-existing codes?

Answer -- As a minimum there will be the language of the IPAD system itself. Additionally, any language that is acceptable to the host operating system is acceptable to IPAD, although the user may have interfacing problems between codes of different languages. IPAD will execute any code compiled on the host system, but cannot automatically interface data between codes having different input/output conventions (see task 2 question 1).

Task 2, Question 3 -- What degree of machine independence is acceptable to IPAD?

Answer -- Machine dependent code should be restricted to those areas concerned with the host system interface. No portion of the IPAD system communicating directly with the user should be machine dependent; i.e., the user interface logic should be independent of the host system. Machine dependent code for efficiency purposes should be done only after the performance of machine independent code is clearly demonstrated to be unacceptable.

Task 2, Question 4 -- To what extent and how should the human element be retained in the system control in order to utilize engineering "intuition", judgment and experience?

Answer -- The basic operating mode for IPAD will be based on the personal remote terminal. With this mode, the human element, that is the user, will always be present. The general level of user control will be to monitor the progress of a solution with interdiction capability. A step up to the interactive mode will be done as specific Technical Program

Elements activate that mode during the course of their execution.

Task 2, Question 5--What set of design variables defines the vehicles to which IPAD is to be applied?

Answer--Of the total set of variables describing the product, each variable becomes a design variable at some level. The number of design variables expands from a few at Level II to many at Level IV to all of the variables at Level VI.

Task 2, Question 6--Should the set of design variables be divided into subsets of basic ones (i.e., wing aspect ratio) and local ones (i.e., skin thickness of a specific panel)?

Answer--There is no advantage to be gained by special identification of variables as being either local or basic. The IPAD system and Data Base Manager allow Technical Program Element input-output identification and data set definition. These will give the user the flexibility to handle his data efficiently.

As each Element is introduced into the community library, the variables that appear at the boundaries of that Element will be entered into the community library dictionary. Thus, all of the design variables corresponding to the current design and analysis capability will be known throughout the user community. As a separate entry, a user may package these design variables in any order into groups, or data sets. Different users will be able to collect the same variables into different sets. Or, the same user may reorder his data sets over a period of time.

Task 2, Question 7--How should the number of vehicle design variables be reduced to a tractable number?

Answer--The division of the whole product activity into nine levels establishes a natural relation between number of variables and the time the user has to do the solution. At Level II, which has a short time frame, the user will use a very small subset of the total set of variables. At Level VI, which has a long time frame, the user community will need nearly all of the variables known to the IPAD system. As the design proceeds through the levels and the number of active variables grows, collection into data sets will make data handling much easier.

Task 2, Question 8--How can one resolve the associated problem of the organization of an optimization process in the form of an overall loop and suboptimization loops?

Answer--Suboptimization will not be done concurrently with overall optimization. There is a definite order to the optimization sequence. First, the overall optimization loop is restricted to the total problem. A small number of general variables will be used in a direct, or mathematical, optimization process. Once the large loop has been cycled to completion, additional detail must be developed for that configuration. With this enhanced detail, selected parts of the overall optimized solution can then be locally improved with suboptimization techniques, whether direct or by trial and error.

The suboptimization process is a sequence of loops within loops. Once a given suboptimization loop is completed, it is developed in further detail, then suboptimization at the new level can be done. This cascade effect will continue until the level is reached at which all the detail parts are designed.

Task 2, Question 9--How can one establish a merit function for various types of aircraft?

Answer--Merit functions are required only for the evaluation process associated with direct, or mathematical, optimization. The easiest case is to select a single variable. If this is not possible, then a weighted functional relationship, expressed as a single equation must be specified. Ideally, the customer for the product would specify the weighting. If the customer cannot do so, then the designer must make the weighting selection. There is no formal process for doing this selection.

Task 2, Question 10--What degree of flexibility should be given to the system operator in arranging available OM's into different sequences according to the needs?

Answer--The user should have complete flexibility in arranging the available OM's. The IPAD System should support the user by keeping records of key words, input-output, and internal engineering descriptions to facilitate the selection of the proper OM's. This flexibility will reduce the total number of Technical Program Elements, from which OM's will be made, in the dictionary to do the task. Reducing the number should enhance the credibility and integrity of the result, simply because a small number of Elements can be more thoroughly certified than can a large number.

Task 2, Question 11--What I/O devices will best serve IPAD?

Answer--The most important class of devices will be those required to support the user at his personal terminal. Large volume and special purpose offline devices will complement these personal terminals.

Task 2, Question 12 -- What will be the impact of the next generation computers on IPAD?

Answer--Quantitatively the question is not answerable at this time. Qualitatively the following areas could be affected:

- increasing size and reliability of the data base,
- introduction of new source language capability matching new hardware logic,
- larger number of simultaneous users possible,
- greater involvement in multi-machine networks .

Task 2, Question 13--What is the first release capability for IPAD which should be developed for subsequent extension?

This answer is in two parts.

1. Answer--The first release of IPAD should include the following technical capability:

- Operational Technical Program Elements for design and analysis of a subsonic commercial transport for Levels II and III of the design networks for Project 1.
- Operational Technical Program Elements for design and analysis of a supersonic commercial transport for Level II and the geometry sizing part of Level III of the design networks for Project 2.

2. Answer--The first release of IPAD should provide system support for libraries, continuity of task and time, construction of jobs and execution of jobs. Table C.1 in Volume IV shows the design features which should be part of the system on which further development would be based.

### C.3 TASK 3 QUESTIONS AND ANSWERS

Task 3, Question 1--Can IPAD be developed by a single organization (company)?

Answer--For development purposes, the IPAD system and OMs should be considered separately. The system development should be done by a single organization since it must have a unified structure and logic throughout all the components. However, the OMs may be developed and contributed by a large (and even diverse) set of organizations. One of IPAD's goals is to make the use of OMs developed under such conditions more common in the future.

Task 3, Question 2--Is it appropriate or desirable to divide the development work among industry, government, university? Should anyone of the three develop it alone?

Answer--As noted in section 2.1 of Volume VI, the system should be developed by a single organization and further to ensure an adequate emphasis on the requirements of the air vehicle design process, an aerospace firm should be the IPAD system developer.

From the OM point of view, no single company, university, or government agency has a monopoly on technical design and OMs. Thus, the OM development should take advantage of the expertise throughout the U.S.A. and should be contracted for on a broad basis.

Task 3, Question 3--What problems are associated with the inclusion of proprietary codes and ideas into the development?

Answer--Allowing proprietary codes and ideas to reside in IPAD poses two primary concerns for OM owners:

- Will I be adequately compensated for code and ideas which I am willing to release?
- Can I be assured of control of the code so that I am protected from
  - use by unauthorized user
  - copies being made of code which is not for sale.

The concern about adequate compensation applies only to "pre-existing" proprietary code which is desired for the IPAD technology. Some kind of cost reimbursement NASA procurement practice will be required if these codes are to be made part of the "public" IPAD technology.

The concern about control of the use of proprietary code will have to be met in the IPAD system design. Today every commercial computing service faces a similar problem in

permitting computing customers to use their services simultaneously. Experience to date does not indicate that a totally secure system is possible. IBM is near the end of a \$40 million security study (reference 7) which has produced some valuable recommendations and procedures, but no "final answers" to the security and control problem. In principle, the user with proprietary code can restrict the use of his code as he desires, (i.e., the IPAD design has security and control features which can protect the owner from all "normal" security violations). However, it must be finally noted that no system has been shown to be secure from the dedicated thief.

#### C.4 TASKS 4, 5, 6, 7 and 8 QUESTIONS AND ANSWERS

Tasks 4 and 5, Question 1--What are the important economic factors associated with IPAD development and operation relative to:

- a. An industrial company?
- b. A government organization?
- c. Military goals?

Answer--The primary benefit of IPAD will be an increase in productivity through automation and computer aiding of the routine information handling chores in a design organization (see Volume VII, section 4.3). This increase in productivity will result from decreased flowtime, increased technical power and increased creative power of individual designers (see Volume VII, section 4.4). The effect of this increase in productivity will be a substantial increase in the labor and flowtime available. This is the primary economic factor associated with IPAD technology.

Since the primary impact of IPAD technology will be upon routine information handling chores, the benefits may be realized by any organization; industrial, government or military.

The primary economic cost is associated with the initial development of IPAD technology to a useful status. This includes practical refinement of IPAD concepts and system design as well as implementation with system and technical module software on a suitable host computer. Once this initial development is achieved the productivity of IPAD technology will appear and provide adequate motivation for growth of acceptance.

Once the productivity of IPAD technology is realized within an organization, management will have the option of reinvesting its gains as

- 1) direct savings in labor cost and flowtime,
- 2) improved product design, or
- 3) more timely design.

Tasks 4 and 5, Question 2--What is the impact of future computers on question 1?

Answer--IPAD technology. is part of a larger national trend towards information technology. Information technology is the utilization of computers, telecommunications and organizational methodology to convert, process, store and communicate all recordable information, not just that associated with calculations. Future generations of computer hardware, software systems and data nets are expected to exploit this trend. Hence the impact of future computer systems should be a substantial improvement in technology and reduction in cost relative to information handling, thus aiding the IPAD technology.

Machine independence and the impact of the next generation of computers were treated in the answers to questions 3 and 12, Task 2.

Tasks 4 and 5, Question 3--What level of skill will be required of a user of the system?

Answer--The introduction of IPAD will provide a requirement and an opportunity for more general skills in overall technical scope. For example, an integrated system for the total aeroelastic cycle, while not negating the need for individual specialists within the cycle, would encourage the development of skills inclusive of the entire cycle.

A requirement will be created for skills to work with and feed information to the system. While much of the routine information requirements of a design organization will be automated, a requirement will exist to input data into the data banks and use the system facilities for obtaining specific reports or displays.

There will be a general requirement for increased management awareness of computers as broad information handling devices

A minimal training requirement is anticipated for the vast majority of technical personnel within a design organization. From 10 to 30 hours of formal basic system training should be adequate.

Tasks 4 and 5, Question 4--What is the level of the skill of the people that may be replaced by system?

Answer--The automation or computer aiding of the routine information handling chores within a design organization will result in the reduction of personnel, technical and management alike, whose primary function lies in these areas.

Tasks 4 and 5, Question 5--What are the associated trade-offs of the computer and operator costs versus pay saved, including impact of the design process on calendar time reduction?

Answer--An estimate of the ratio of dollars saved in engineering labor to the additional cost of computing can be made. In figure 4.22 of volume VII, it is shown that, by extrapolating current system savings, the potential engineering direct labor savings is 20% to 60%. A reasonable value for these savings for IPAD technology is from 20% to 40%. Hence, for the 2000 man organization (\$30,000,000 annual direct labor budget) used in figure 4.22, the savings would be from \$6,000,000 to \$12,000,000 annually. As shown in section 4.3 of Volume VI, the cost of operating IPAD will be about 80% greater than current operating costs. The current cost of computing is about 4% to 8% of the aerospace engineering direct labor costs, or between \$1,200,000 and \$2,400,000 annually. Hence the ratio

$$\begin{aligned} \frac{\text{Engineering dollars saved}}{\text{Additional Computing dollars required}} &= \frac{6 \text{ to } 12 \text{ million}}{80\% \text{ of } 1.2 \text{ to } 2.4 \text{ million}} \\ &= \frac{3}{1} \text{ to } \frac{12}{1} \end{aligned}$$

Thus every new dollar spent using IPAD computing technology should create a saving of 3 to 12 dollars in engineering labor.

In addition, as shown in figure 4.22 of Volume VII, the potential design process flowtime savings are projected to be above 20%.

TASK 6, Question 1 -- What tangible evidence do you have that would suggest that an IPAD system would improve performance of military aircraft or return on investment of commercial aircraft?

Answer--There is no direct economic correspondence between IPAD technology and improved aircraft performance. However, the

complex and voluminous calculations and data handling requirements associated with the design and manufacture of modern high performance aircraft make the use of high speed digital computers mandatory. IPAD technology will provide software to enhance the effectiveness of computer use by attacking the general information handling requirements of the total product development organization. The resulting increase in the productivity of designers, increased technical power, and greater visibility and control of information, will provide an opportunity for management to apply these new resources to seeking improvements in product performance(see section 4.5 of Volume VII).

Task 6, Question 2--Given the present engineering work organization, what is the likelihood that engineers will be able to do more creative work when tedious and routine tasks are taken over by IPAD?

Answer--Task time compression and increased technical power provide substantial opportunity for engineers to improve their creativity. These resources increase the ability of individuals to investigate creative ideas by reducing their dependence upon the organizations other manpower resources (see section 4.4.3 of Volume VII).

The problem of converting other people to an embryo idea is alleviated. The "not invented here" syndrome is an inability of people to change or alter their mental and emotional commitments. The computer knows no such constraints and is as willing to function on one problem as another. Hence IPAD will give the designer more opportunity to mature his creative ideas before exposing them for review or requesting organizational resources.

Task 6, Question 3--Will the system bring closer cooperation between the people from different disciplines? With what results?

Answer--The integration of technologies in current systems (such as the integration of loads, stiffness and flutter into an aeroelastic system) is already introducing a new level of communication between technology groups. IPAD technology will accelerate this trend by providing improved communication and control of technical information through a data base.

The sharing of problems, ideas, solutions and information that will result from IPAD technology will stimulate a broader outlook on the product design. For example, the integration of loads, stiffness and flutter technologies into the Boeing ATLAS system has resulted, by common agreement, in a single structural

model in the place of separate loads, stiffness, mass and flutter models previously required. IPAD technology will make many such efficiencies possible in the total aircraft development cycle.

Task 7, Questions 1, 2--What are the ramifications of traditional company design organizations and procedures relative to the acceptance and utility of IPAD? How will company design organizations likely change to use IPAD most effectively?

Answer--Organizations generally reflect task structure. Since the fundamental information produced by tasks within a design organization will remain essentially unchanged, the design organization will not be fundamentally altered by information technology. However, elements of the organization, corresponding to changes in task structure, will change. These changes will be of the following types:

- 1) New power centers will be formed as tasks are centralized or widened in scope.
- 2) New human communication paths will be formed in order to accommodate changes in elements of the organization structure and the existence of a centralized data base.

In general, the increased productivity of IPAD technology will provide adequate motivation for acceptance. However, in those instances where the benefits are not believed or understood, where a manager feels "control" of his operation is threatened, or where the resources are not available for conversion to an IPAD technology, acceptance will be resisted. However, the solution to these problems requires sensitive management and is independent of the IPAD technology itself (see section 5.0 of Volume VII).

Task 8, Questions 1, 2--Will experience gained in the implementation of a system like this open the way to the creation of similar interdisciplinary systems in non-aerospace fields? What are these fields?

Answer--As shown in the discussion of existing systems in Volume VII, section 4.2 and in the IPAD survey in Volume VII, Appendix A, integrated systems are becoming increasingly available. The ISDS/COMRADE system being developed by the Naval Ship Research and Development Center (NSRDC) and the ICES system developed at MIT are two examples of relatively broad systems outside aerospace. However, none have attempted the scale of development envisioned by IPAD technology. The principal barrier to development at this level is the nonexistence of

suitable host computer operating systems software, data base management, and executive control software. This IPAD software, when developed, will be of such a general nature that it will be utilized wherever extensive routine information handling is required (see section 6.0 of Volume VII). The fields in which this software will be utilized are:

- 1) Maritime industry
- 2) Automotive industry
- 3) Land management
- 4) Population and resource analysis
- 5) Construction industry
- 6) As operating system software extensions in data nets.