Part II—Final Report, Tasks 3 through 8

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

Volume VII: IPAD Benefits and Impact

September 21, 1973

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16. Abstract

Volume VII of the Boeing report on the IPAD feasibility study is a description of the potential benefits, impact and spinoff of IPAD technology. The benefits are projected from a flowtime and labor cost analysis of the design process and a study of the flowtime and labor cost savings being experienced with existing integrated systems. Benefits in terms of designer productivity, company effectiveness, and IPAD as a national resource are developed. A description is given of the potential impact of information handling as an IPAD technology, upon task and organization structure and people who use IPAD. Spinoff of IPAD technology to nonaerospace industries is discussed. The results of a personal survey made of aerospace, nonaerospace, government and university sources are given.

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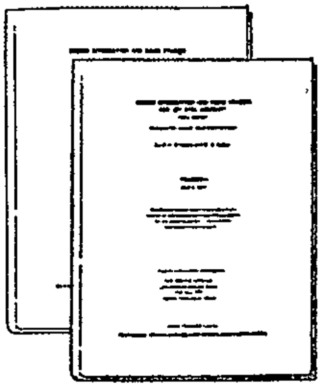

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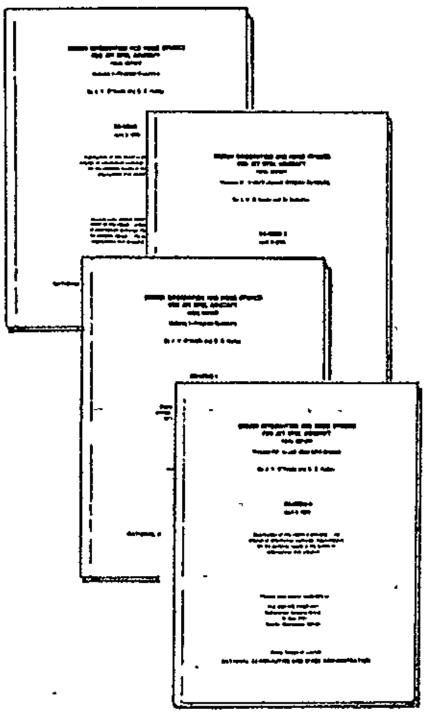

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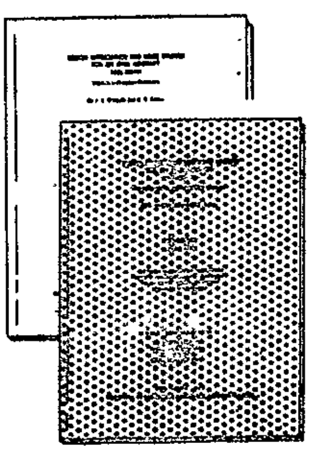

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SUMMARY

This document reports on Task 6 - Benefits, Task 7 - Impact, and Task 8 - Spinoff, of the IPAD Feasibility Study. As part of these tasks, a survey of industry, universities and government agencies was conducted.

TASK 6 - BENEFITS

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:

1) an analysis of time and labor utilization in the design process,

2) an evaluation of flowtime and cost savings being experienced using currently available systems,

3) an extension of these savings to IPAD technology,

4) a projection of the effect of these savings upon designer productivity and company effectiveness,

5) a projection of IPAD technology as a national resource.

<u>Time and Labor Utilization in the Design Process</u> -- An analysis of the direct labor required for a single iteration of Level III of the design process given in Volume II of this study was made for standalone batch computer programs and noncomputer-aided information exchange. This analysis showed that 63% of the labor cost is for routine information exchange and data preparation. The remaining 37% is spent in procedure development, calculation monitoring and results evaluation. These latter categories are considered more judgmental than routine and require extensive human involvement.

Flowtime and Cost Advantages of Current Systems -- As an aid to estimating the potential benefits of IPAD technology, the flowtime and labor cost savings being experienced in the usage of current systems on widely different problems was investigated. The results are summarized in the following table.

System	Cost Saving	Flowtime Saving
NSRDC ISDS	-	90%
Lockheed CADAM (electrical)	78%	80%
Boeing CPDS	80%	67%
Boeing ATLAS	50%	50%
Lockheed CADAM (floor beams)	62%	46%
Lockheed CADAM (bulkheads)	23%	25%
Adequate Computational Devices	20%	-

Extension of Flowtime and Cost Savings to IPAD Technology -- The flowtime and cost savings being experienced with existing systems can be extended to IPAD technology. Basically, existing systems increase productivity by automating or computer-aiding the information handling requirements at the interfaces between computer programs for specialized situations. Productivity will be improved by IPAD by creating an information handling environment directly compatible with the day-to-day continuity of problem solving typical in the design organization. Hence, IPAD technology will bring the productivity being experienced with existing systems to the total design organization. The primary benefit will be an increase in the productivity of individual designers.

Designer Productivity -- The productivity of a designer will be increased by IPAD technology through:

1) Time compression of design tasks by automation or computer-aiding of routine tasks.

2) Increased technical power of individuals by applying the gains from time compression to better design detail, to acquiring more information, and to improvements in communication.

3) Increased creative power of individuals as a result of time compression and increased technical power.

The transition from hand methods to computers is analogous to the transition from the scythe to self propelled harvesting machines. The farmers basic objective of getting grain to the market place never altered and he readily adapted to the change in tools as their productivity became evident to him. In like manner, designers will readily transition to computer tools as the tool productivity becomes evident.

Company Effectiveness -- The increase in designer productivity made available through IPAD technology will provide new flowtime and manpower resources to a company. These resources can be reinvested by the company management as:

1) Direct design labor and flowtime savings. Company management may elect to reduce labor costs and shorten, where feasible, product development schedules. An estimate of the magnitude of these savings was made for the case where flowtime and cost savings being experienced with current systems is extrapolated to a 2000 man design organization. Using this method, it is estimated that a potential of 20% to 40% of the direct labor costs and well above 20% of the flowtime can be saved using IPAD technology.

2) Reduction of risk. Company management may elect to reinvest flowtime and labor cost savings into reducing risk by refining the design or increasing the thoroughness of the analysis.

3) Improved product design. Company management may elect to reinvest flowtime and labor cost savings into a more competitive product.

4) On-time design. Potential cost savings downstream from product design may be realized. 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 Technology as a National Resource -- The benefits of IPAD technology will accumulate at the national level in the form of:

1) Increased competitiveness of United States industry in the international market place.

2) Stimulation of information technology development.

3) Increased effectiveness of government procurement procedures.

TASK 7 - IMPACT

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:

1) Acceptance and conversion to information technology as the basic method of handling information.

2) A trend towards centralization in task and organizational structure.

3) The impact of this trend upon management and technical personnel.

Acceptance -- The primary motivating forces towards conversion to some form of information technology are:

1) competition,

2) contract requirement or administrative directive.

In an organization, the internal inertia working against the adaptation of information technology results from a resistance to change of established methods. This resistance will appear as:

1) lack of skill, knowledge, experience,

2) success with current methods,

3) improvement of current methods,

4) condition of the economy,

5) attitudes, characteristics and motivations of people.

Hence, for acceptance of IPAD technology, the pressures of competition, contract requirement or administrative directive must be sufficient to overcome organizational resistance. In addition, if the resources required to implement IPAD are of the order of magnitude, or greater, than the normal resources available to an implementing organization, funds will have to be supplied from some external source.

Task/Organizational Structure--The dominant trends in task structure resulting from information technology will be the following:

1) Structured (routine) tasks will tend to be consolidated,

2) Unstructured (judgmental) tasks will broaden in scope,

3) New tasks associated with widened scope and feeding information to the system will emerge,

4) Information will be centralized and controlled.

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 to accommodate changes in elements of the organizational structure and the existence of a centralized data base.

Impact on People--The change 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.

New identifications will be made by individuals with the product and with the changed objectives of their immediate organization.

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 effects can be either motivating or oppressive.

TASK 8 - SPINOFF

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.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

1.0 INTRODUCTION

Information handling within a design organization has long been looked upon as a human prerogative. But there are limits to human capacities. As these limits are approached, efficiency declines, communication barriers appear, reliability becomes unacceptable and control is lost. Organizations have been developed to augment the limits in human capacities by providing functional structure. But these, too, have limitations.

The last decade has brought new inventions with enormous potential to extend human and organizational information handling capacities. These inventions include:

Large-Scale Integration -- The ultraminiaturization of computer circuitry provides a means of mass producing computers and computerlike circuitry. This invention offers the potential of extremely small, extremely fast, extremely reliable and very low cost computers.

Real Time Online Computers -- These computers respond to large numbers of remote terminals over telecommunication lines with speeds geared to human thinking. They have the potential of bringing the information handling power of many computers, essentially independent of location, to the personal terminal at the desk of the engineer and the manager.

Digitized Transmission -- Essentially all forms of information, including voice, drawings and pictures, can be converted into a digitized bit stream and transmitted in the same digital stream as numerical data. The conversion of telecommunication lines and switching gear to this form of signal transmission brings the power of the computer to virtually all forms of information handling.

Data Banks -- Vast quantities of digitized information can be stored electronically and indexed, searched, manipulated and recalled by computers in fractions of seconds. These storage devices have capacities of trillions of digitized bits and provide the potential of storing virtually all forms of information currently stored on paper.

IPAD technology is part of a larger industrial trend towards the utilization of these computer inventions to improve productivity by automating or computer-aiding information handling chores. This document seeks to project the potential benefits of IPAD technology to an aircraft design organization. It can be safely predicted that this technology will increase productivity, forge new communication links and remove technology barriers. The extent and form of these changes cannot be so safely predicted. Prediction is done here by extrapolating the benefits from existing systems, applied to limited segments of design, to the entire design organization.

The problems of acceptance and impact on tasks, organizations and people will not be new to IPAD technology. These problems follow a well known and consistent pattern for all basic innovations. The acceptance of innovation is predominantly the result of a sensitive management. Only that impact peculiarly associated with IPAD technology has been included here. For broader reading, references 9, 11, 12, 13 and 14 are recommended.

In this volume, answers to task questions for Tasks 4, 5, 6, 7 and 8 are given. This is followed by a brief summary of the results of a survey of industry, government and university organizations. The full survey is given as Appendix A. Benefits are then developed, followed by impact. Lastly, a brief exposition on potential spinoff outside of the aerospace industry is given.

2.0 ANSWERS TO TASK 4, 5, 6, 7 AND 8 QUESTIONS

The questions associated with Tasks 4 and 5 in the original NASA RFP are mostly related to the subject of benefits and impact. Hence, they have been included here.

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?

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 section 4.3). This increase in productivity will result from decreased flowtime, increased technical power and increased creative power of individual designers (see 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?

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, Volume IV.

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

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 the system?

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?

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 this volume, 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

$$\frac{\text{Engineering dollars saved}}{\text{Additional Computing dollars required}} = \frac{\text{6 to 12 million}}{\text{80\% of 1.2 to 2.4 million}}$$

$$= \frac{3}{1} \text{ to } \frac{12}{1}$$

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, 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?

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).

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?

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).

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 committments. 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?

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 efficiences 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?

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).

<u>TASK 8, Questions 1, 2</u> -- 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 section 4.2 and in the IPAD survey in 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). 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.

3.0 IPAD SURVEY

A survey was conducted in the early part of the IPAD feasibility study. This survey had two purposes:

1) To obtain information and opinion from aerospace industry, nonaerospace industry, university and government sources regarding IPAD concepts, implementation and acceptance.

2) To familiarize these sources with the purposes of the IPAD feasibility study contracts and with the broad concepts of IPAD technology.

SURVEY CONTACTS

The following companies, universities and government agencies were visited:

1) Grumman Aircraft
2) Lockheed-California
3) Lockheed-Georgia
4) McDonnell-Douglas
5) North American Rockwell
6) The Boeing Company
7) Ford Motor Company
8) General Motors
9) Lockheed Shipbuilding
10) Stanford University
11) Massachusetts Institutue of Technology
12) NASA Ames
13) Naval Ship Research and Development Center
14) Wright-Patterson Air Force Base

In addition to the personal visits above, telephone and mail contact was made with Pratt & Whitney, West Palm Beach, Florida.

Every effort was made to make contact with engineers and managers working directly on hardware projects in order to obtain information directly related to the production environment IPAD will impact.

SURVEY RESULTS

Some general conclusions that came out of the survey are summarized below:

1) Integrated systems exist in varying degrees of development and refinement and for varying purposes at all aerospace firms. Their growth, in scope and number, is expected to accelerate.

2) The meaning of the word "integrated" is not universally understood. In one instance, it meant a series of standalone programs with automatic interface data transfer capability through tape or disc files. In another company, it meant the complete automatic hands off execution of a program series. In yet another company, it meant the collecting of modules under the control of an executive program, with human interaction as required in controlling program sequences. These definitions are fundamentally different and result in considerable conflict and confusion.

3) Data base technology, in the general sense anticipated for IPAD, is essentially nonexistent. There is great interest in the development of such technology and a general belief that the communication and coordination efficiencies to be gained through use of a common data base will reduce design flowtimes significantly.

4) There was a general consensus that a principal barrier to be overcome in IPAD technology is language and jargon differences between technologies and between design organizations.

5) All aerospace firms maintain their own computer facility, generally at corporate level, and do their own software maintenance, even on acquired programs such as NASTRAN. There was a strong disbelief that any centralized computing facility, outside their company hardware or software, would give them the control and responsiveness they require. Most technology groups want increased control of computing responsiveness and view an even more remote facility than their in-house facility as synonymous with poorer responsiveness. They did agree however, that data nets utilizing large fourth generation hardware may completely change the economics and make it more practical to buy time than to buy hardware.

6) It was universally agreed that IPAD development should proceed. Not necessarily because they intend to use the system directly, but, in some cases, because they intend to benefit from the technology growth in developing their own systems.

7) There was evidence of willingness to utilize whatever technology software will do the job regardless of origin. However, the advantage of using new software must be considerable in order to offset the cost of conversion, familiarization and maintenance. Most users would rather continue with old software they understand and have confidence in even if it is an order of magnitude less efficient than newer software.

8) Many companies market their engineering as well as their hardware products. One company particularly stated that they market their engineering capability as part of their aircraft sales strategy. Any capability that made them less able to distinguish their engineering organization from that of other companies would be resisted or modified to maintain their image.

9) Some companies involved in government hardware development contracts believe that government review and control is burdening beyond benefit as currently imposed. They fear that IPAD will increase the burden.

10) The most fully developed and operative system witnessed during the survey was the CADAM system at Lockheed California in Burbank (ref. 1, 2).

11) The most comprehensive and technologically advanced system currently under development reviewed during the survey was the ISDS COMRADE project at NSRDC (ref. 3, 4, 5).

A full discussion of the survey results is given in Appendix A.

4.0 TASK 6 - BENEFITS

The primary benefit of IPAD will be increased productivity of the designer. To increase his productivity, a designer must:

1) do the same work in less flowtime,

2) do the same work at less cost,

3) do measurably improved work.

The increase in productivity will result from the utilization of new design methods that:

1) require less flowtime and labor cost than current methods,

2) extend the technical scope of current methods,

3) improve the opportunity for increased creativity.

A "designer", in this context, includes any manager, engineer, technical specialist, etc., directly involved in the design process. An increase in the productivity of the designer can accumulate to better product design through reinvestment of time and cost savings into the design process. The increase in productivity will become visible at the company level in terms of accumulated cost and flowtime savings and in terms of reduced risk or increased competitiveness in the market place. At the national level, increased productivity will appear as an enhancement of the competitiveness of the United States industry in the world market.

The potential for increased productivity and the accumulation of its effects will be developed by treating each of the following subjects:

1) an analysis of time and labor utilization in the design process,

2) an evaluation of flowtime and cost savings using currently available systems,

3) an extension of these savings to IPAD technology,

4) a projection of the effect of these savings upon designer productivity and company effectiveness,

5) IPAD technology as a national resource.

4.1 AN ANALYSIS OF TIME USAGE

The end result of the design process is information used to manufacture a product. Hence, the activity of design is essentially that of generating, evaluating and distributing information necessary to arrive at a product definition that is marketable. Recognizing that the computer is an information handling device, it is useful to define the design process in terms of information handling activities. Doing so suggests the following categories:

1) Procedure Development -- The development (not the selection) of analytical and procedural methods for some phase of product design. Activities in this category include:

   - development of theoretical algorithms,
   - development of computing software,
   - acquisition of computational devices,
   - development of organizational methodology.

   Development of the design procedures in Volume II would be a typical activity in this category.

2) Data Preparation-- The accumulation and ordering of data or other information necessary to approach the solution of a design problem. Activities include:

   - selection of product concepts,
   - selection of procedures,
   - selection of data,
   - preparation of data sets.

3) Calculations-- The transformation and manipulation of data or information in order to obtain other data or information. These include the calculation of:

   - geometry relationships,
   - aerodynamic performance,
   - external/internal loads,
   - aeroelastic characteristics,
   - direct operating costs,
   - etc.

4) Results Evaluation -- The review of the design calculation results and other pertinent information at the technical level in terms of the technical objectives or at the management level in terms of the product objectives.

5) Information Exchange -- The preparation of data in tables, graphs or text for transmittal by letter, memo, report, or electronic device to individuals or organizations.

For the purposes of this study, <u>all labor and time</u> related to the design process within an organization are included in these categories.

A time and labor analysis of Level III of the design process (see section 4.2.3.3 Volume II) is given in figures 4.1 through 4.3. This analysis is for the current conditions of:

1) stand alone batch computer programs,

2) noncomputer-aided information exchange at both the computer program and people interfaces, and

3) noncomputer-aided data preparation.

It is the intent of this analysis to determine:

1) the flowtime and labor required in each of the information handling categories defined above,

2) the division of labor between analysis and design activities,

3) an estimate of the division between "technical routine" and "technical judgment" activities within a design organization.

The time flow relationships for each of the design process categories and the division of labor between design and analysis are given in figure 4.1.

The methodology associated with Level III and indicated in figure 4.1 is an important factor. Level III is preliminary design configuration sizing. The sizing takes place in two stages. In the first stage, the geometry is specified by a designer to meet the mission requirements posed by marketing. This configuration is then analyzed for stability and control, aerodynamics and propulsion and weight. In a typical design organization, these analyses will be performed by technical specialists. In this analysis, the configuration is balanced and the airframe weight is established using statistical weight estimation techniques. The cruise drag and flaps-down lift and drag are estimated parametrically and the cruise and field performance calculated. The wing area and engine thrust are sized to the mission and to satisfy constraints such as approach

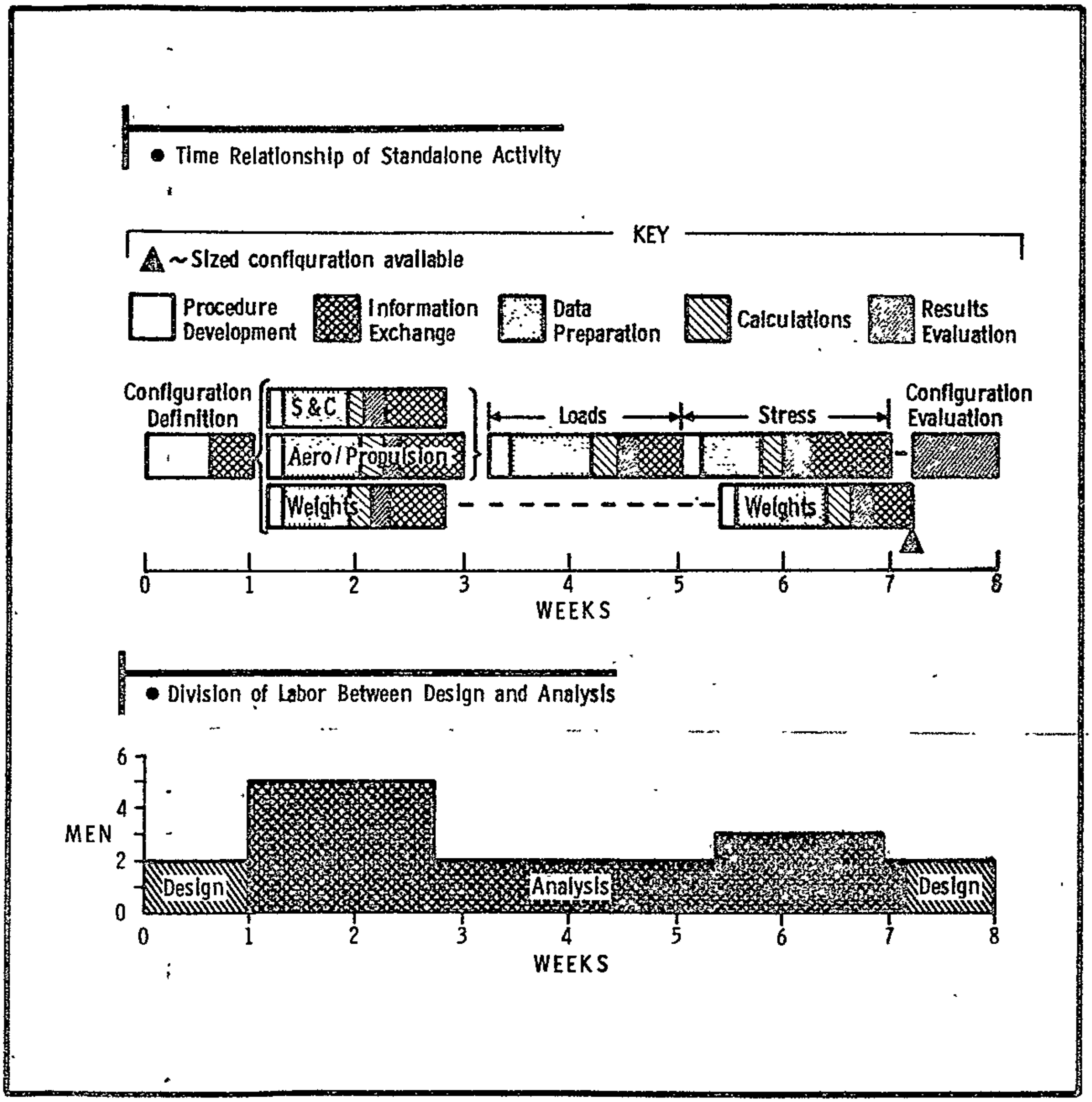

Figure 4.1 Level III, Subsonic Transport, Standalone Environment, Analysis/Design Function Distribution

speed, field length and initial cruise altitude. Community noise footprints are developed. A single iteration of this process takes in the order of three weeks as shown in figure 4.1. Several iterations may be required before proceeding to the second stage.

In the second stage of Level III, the primary structure is sized to satisfy static and gust loads. The sizing is for strength and fatigue. This analysis requires about four weeks of flowtime. Since the structural sizing yields a better weight estimation, the resulting change in weight or balance may require that the airplane geometry be resized by repeating the first stage. This iteration process continues until structural sizing to static and gust loads and geometry sizing to the design mission are consistent. Other technologies, such as a flutter check, may be included as required. Figure 4.1 shows the time and labor associated with a single iteration.

The role of the designer in this methodology is to define the initial configuration, alter this configuration as required for each iteration, and to evaluate the results of the technical analysis. The role of the technical analysts is to evaluate the given configuration for performance or other characteristics relative to a specific technology. As shown in figure 4.1, considerable time is spent in information exchange and data preparation using this methodology.

An analysis of the time spent in each of the design process information handling categories is given in figure 4.2. As shown, 70% of the analyst's time, 30% of the designer's time and 63% of the total time is spent in the categories of information exchange and data preparation. The total man time spent by the analysts is about five times that spent by the designer.

The five design process information handling categories, and the associated percentages from figure 4.2, are grouped into "technical routine" and "technical judgment" in figure 4.3. These percentages are typical for the entire design process and will be used to project the potential flowtime and cost savings of IPAD technology. The "technical routine" grouping includes the bulk of the activities that are routine or structured in nature. These activities are most amenable to rationalization and programming on the computer. Hence, the bulk of any cost and flowtime savings will come from this grouping.

The "technical judgment" grouping includes those categories that are generally unstructured and require extensive human involvement. This group will be affected by IPAD technology in a shift of function resulting from changes of methodology and emphasis. However, the volume of flowtime and cost will not be

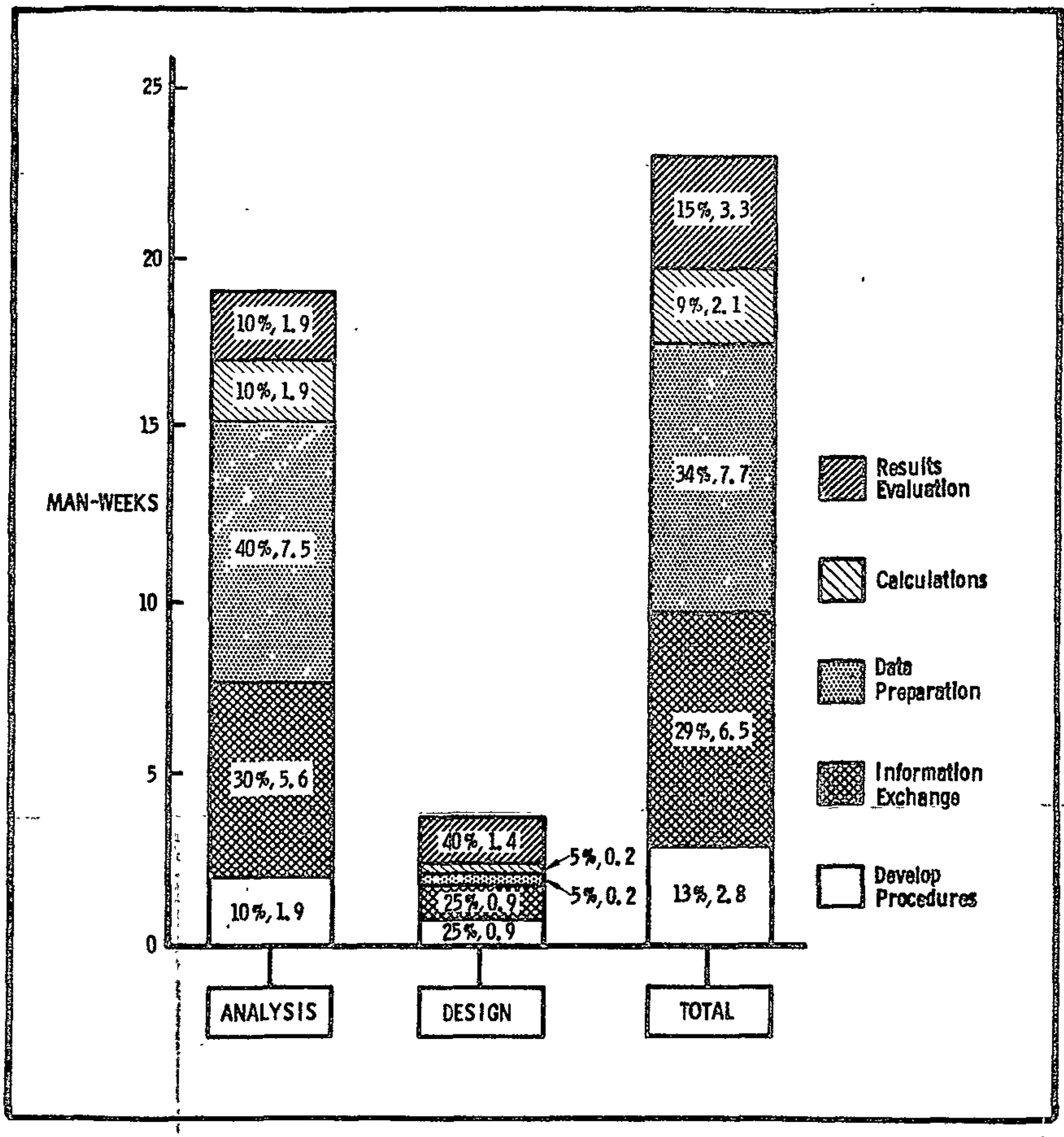

Figure 4.2 Level III, Subsonic Transport, Standalone Environment, Information Handling Distribution

TECHNICAL ROUTINE	
Information Exchange	29%
Data Preparation	34%
Total	63%
TECHNICAL JUDGMENT	
Procedure Development	13%
Calculations	9%
Result Evaluation	15%
Total	37%

Figure 4.3 Level III,Subsonic Transport,Standalone Environment, Routine/Judgmental Activity Distribution

CATEGORY	PERCENTAGE
Management Above First Line	6%
Technical Judgment	35%
Technical Routine	59%

Figure 4.4 Labor Spent in Technical Judgment/Routine Activities in a Design Organization

reduced to the same degree as in the other grouping. The bulk of any improvements in creativity or improved use of technology will come from this grouping.

The calculation category is included in the "technical judgment" grouping because, in the context of this study, this category is associated with the human functions involved in getting the calculations processed through the computer facility. It does not include computer processing costs or labor costs outside the design organization.

Approximately 6% of the direct labor cost of a design organization is for management above first line. The remaining 94% is for technical labor associated directly with the design process in the area of impact of IPAD technology. Applying the percentages for the groupings in figure 4.3 to this 94% gives the percentages shown in figure 4.4. These percentages will be used to project the potential cost savings of a design organization utilizing IPAD technology.

In summary, for the current batch standalone system:

1) Analysis flowtime and labor costs are three to five times greater than design flowtime and labor costs.

2) Nearly two-thirds of the flowtime and labor costs are spent on routine information handling tasks.

4.2 FLOWTIME AND COST ADVANTAGES OF CURRENT SYSTEMS

Having characterized where time and costs are spent in the design process, it is worthwhile to analyze the flowtime and cost savings being experienced with existing systems.

4.2.1 Boeing Computerized Preliminary Design System (CPDS)

A schematic model of the CPDS system (ref. 6) is shown in figure 4.5. This system corresponds to Level III in the design process as discussed in section 4.1. The relative flowtime between Level III in the standalone environment and in the integrated environment is shown in figure 4.6. The flowtime for the first stage in the integrated environment is actual experience. The flowtime for the second stage is estimated based upon the first stage experience.

A manpower distribution comparison is given on figure 4.7. Of the 4.5 manweeks for total manpower using the integrated

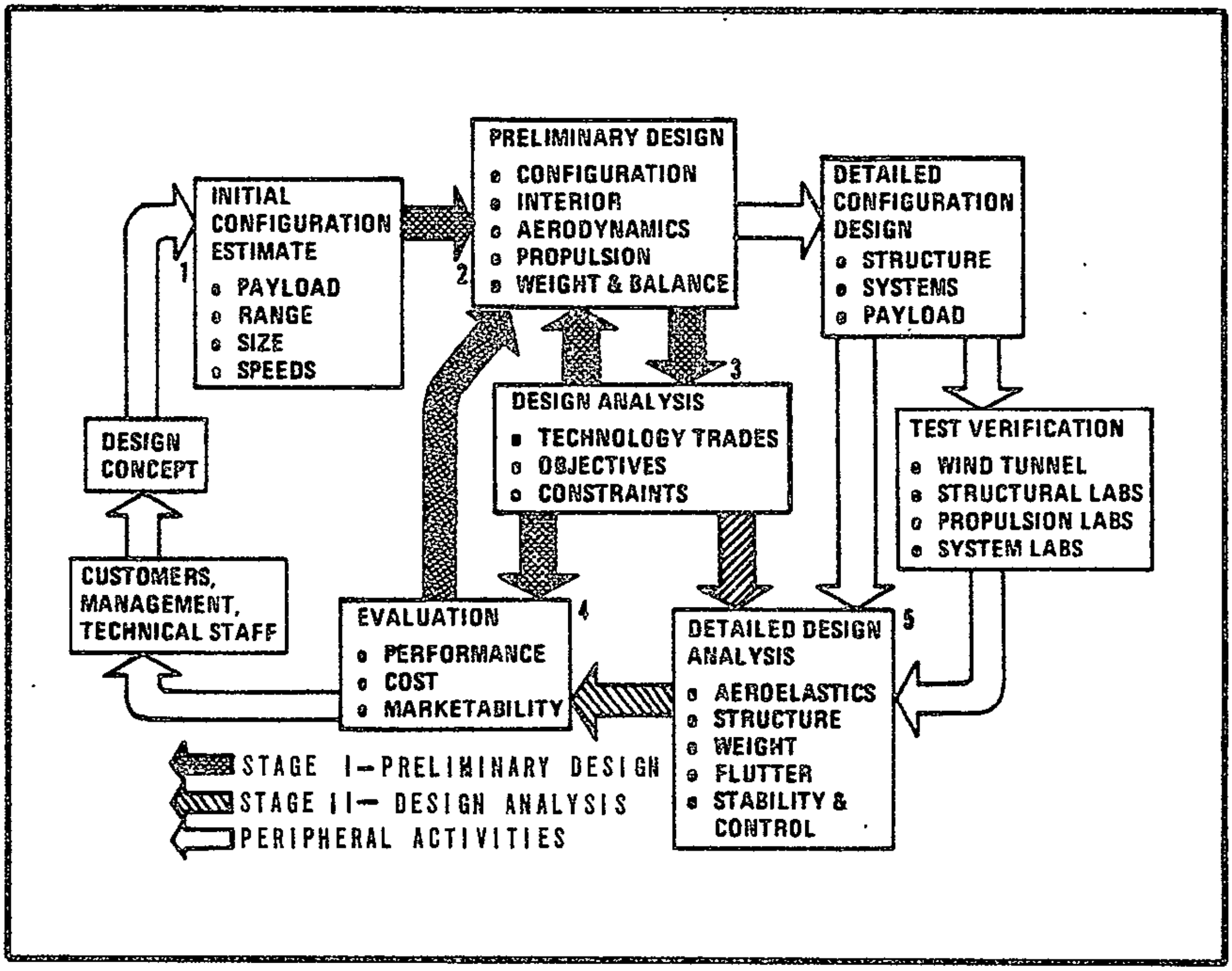

Figure 4.5 Boeing CPDS System

system, design will require 2.5 manweeks and analysis will require 2 manweeks.

A comparison of flowtime and labor costs for the two processes shown in figure 4.6 is given in figures 4.8 and 4.9. The upper row of circles in figure 4.9 is derived from figure 4.2.

A result of the integrated system, as shown in figure 4.9, is the redistribution of time spent. The significance of this is discussed in section 4.4, Designer Productivity.

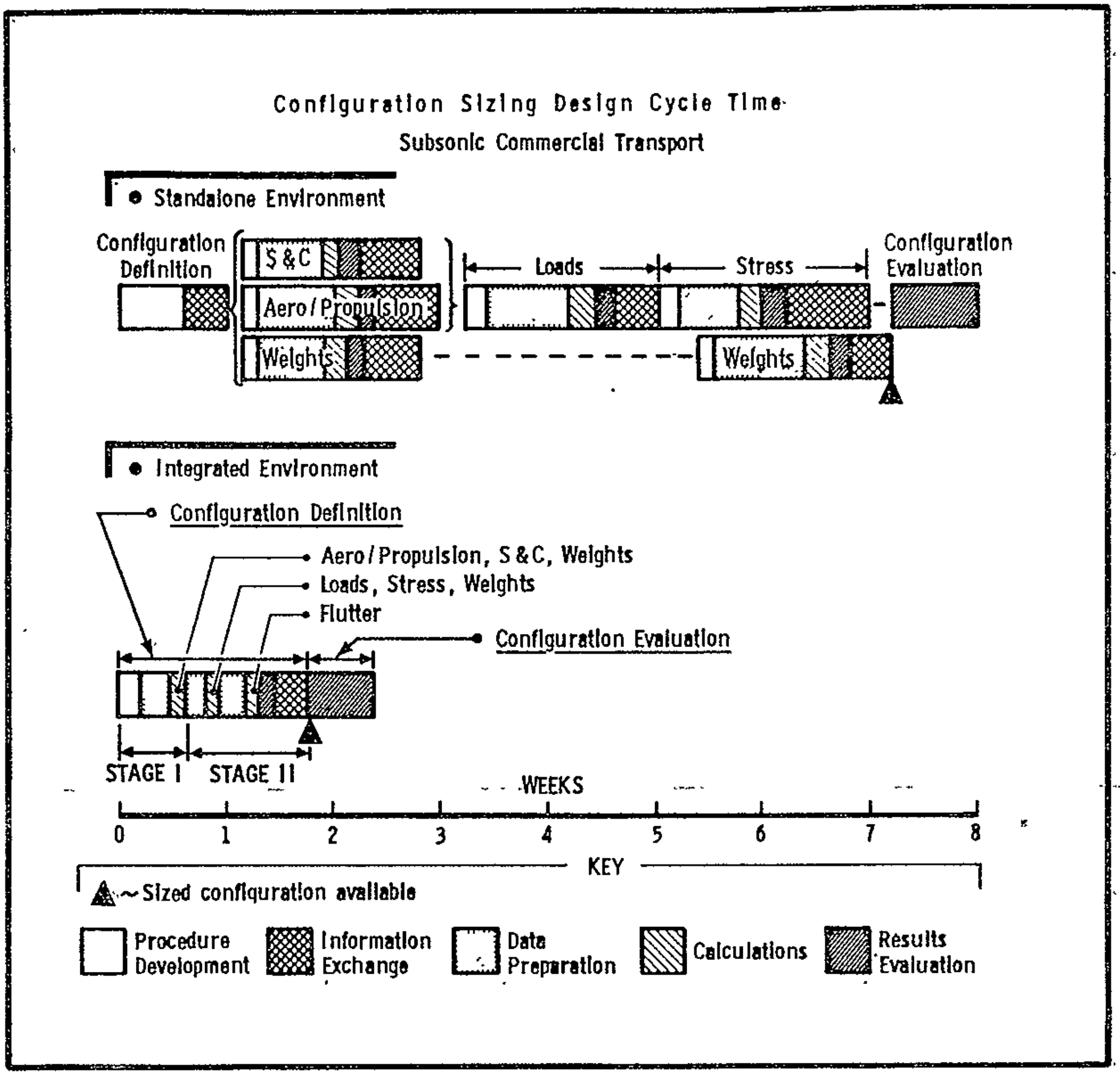

Figure 4.6 Level III, Subsonic Transport, Relative Flowtime, Standalone/Integrated Environment

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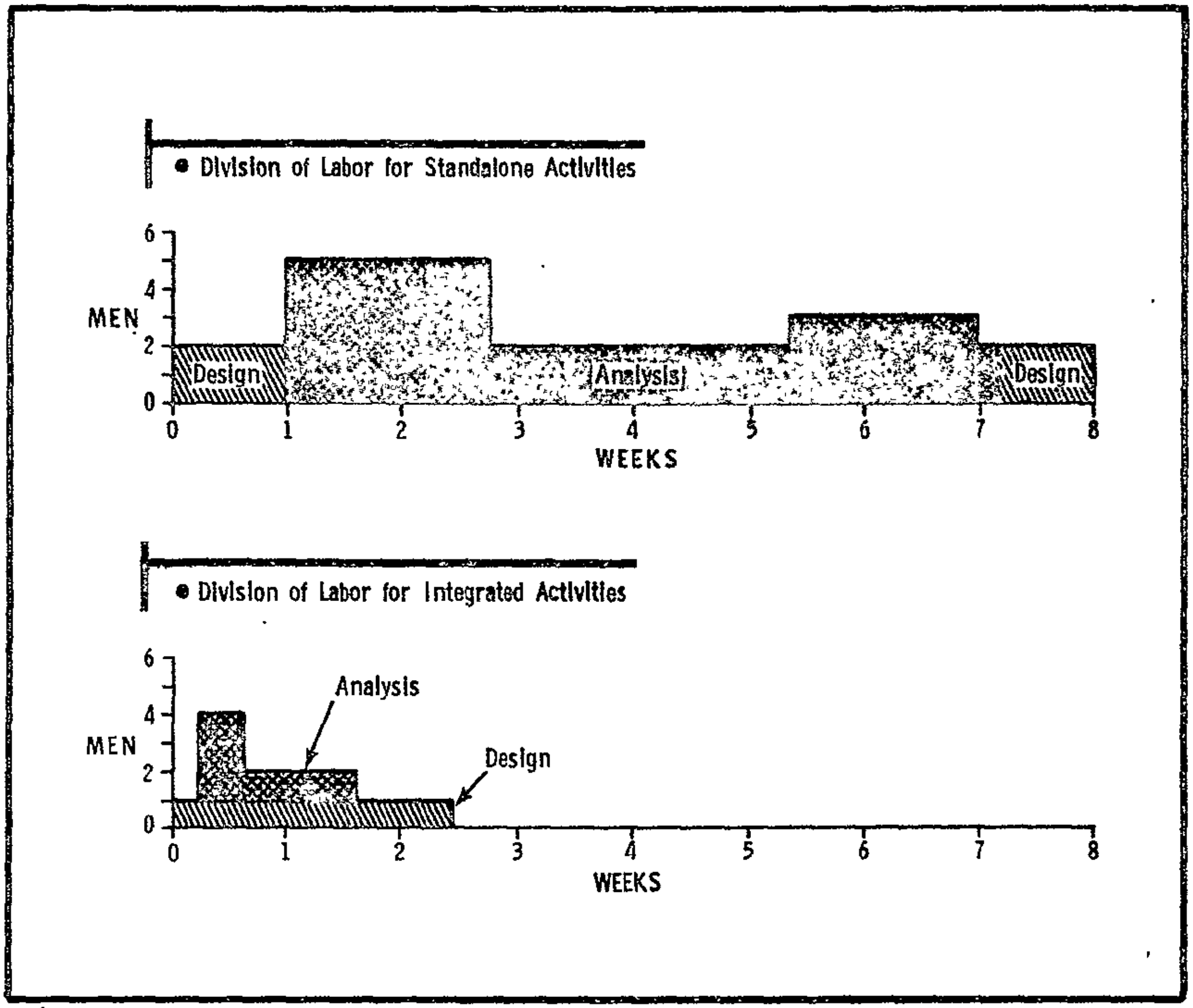

Figure 4.7 Level III, Subsonic Transport, Relative Design/Analysis Distribution, Standalone/Integrated Environment

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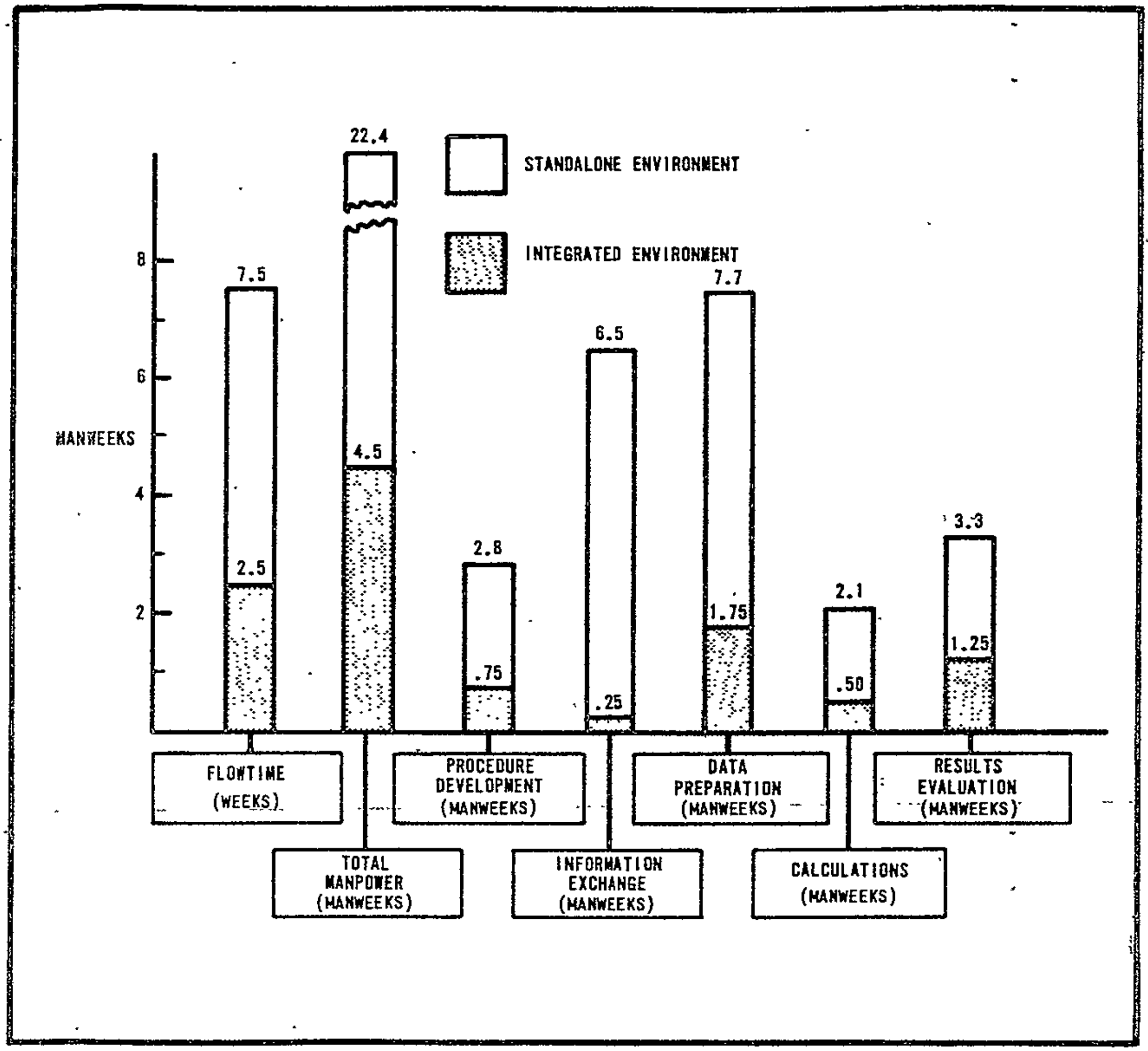

Figure 4.8 Level III, Subsonic Transport, Flowtime and Labor Comparison, Standalone/Integrated Environment

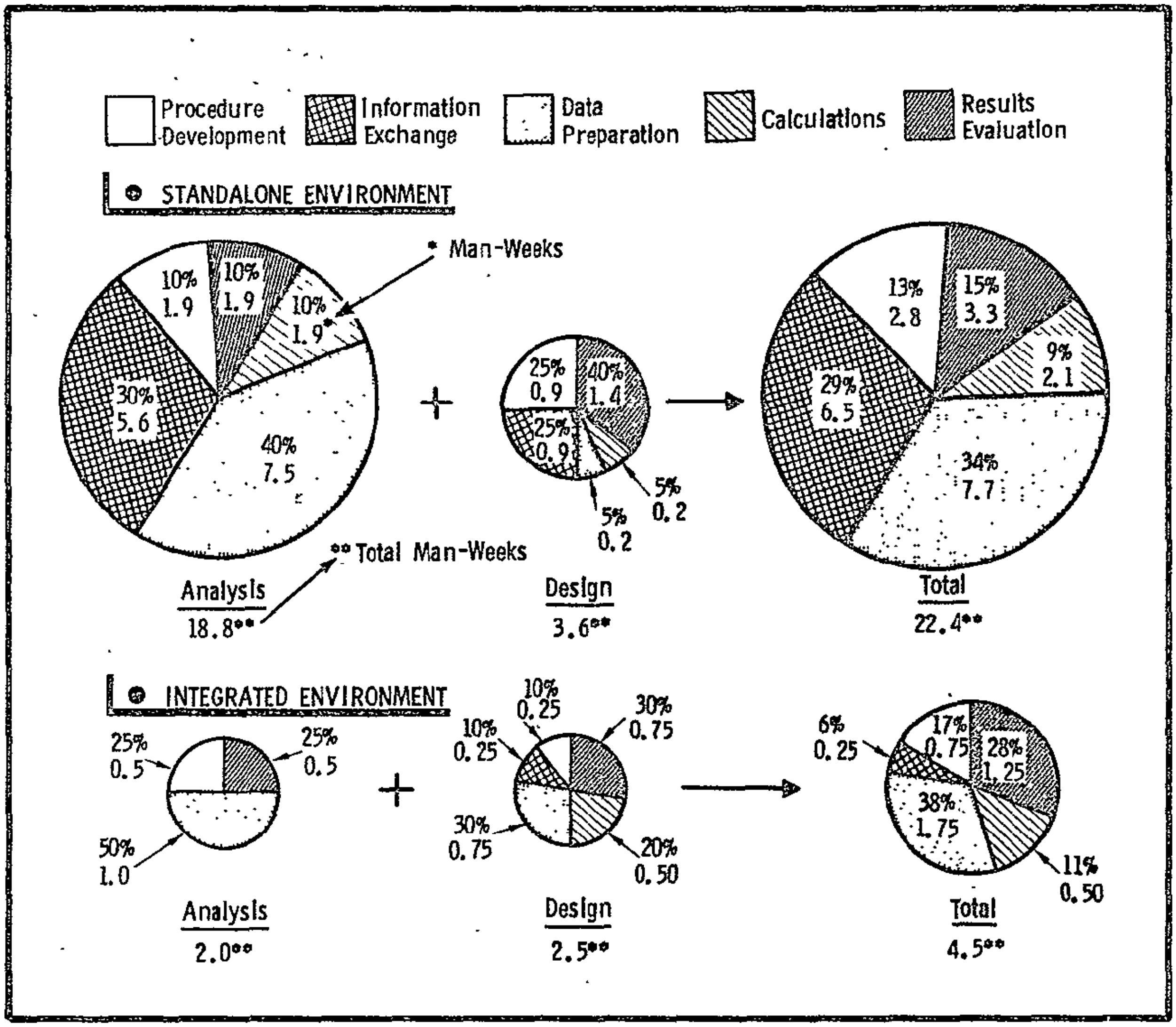

Figure 4.9 Level III, Subsonic Transport, Design/Analysis Labor Distribution, Standalone/Integrated Environment

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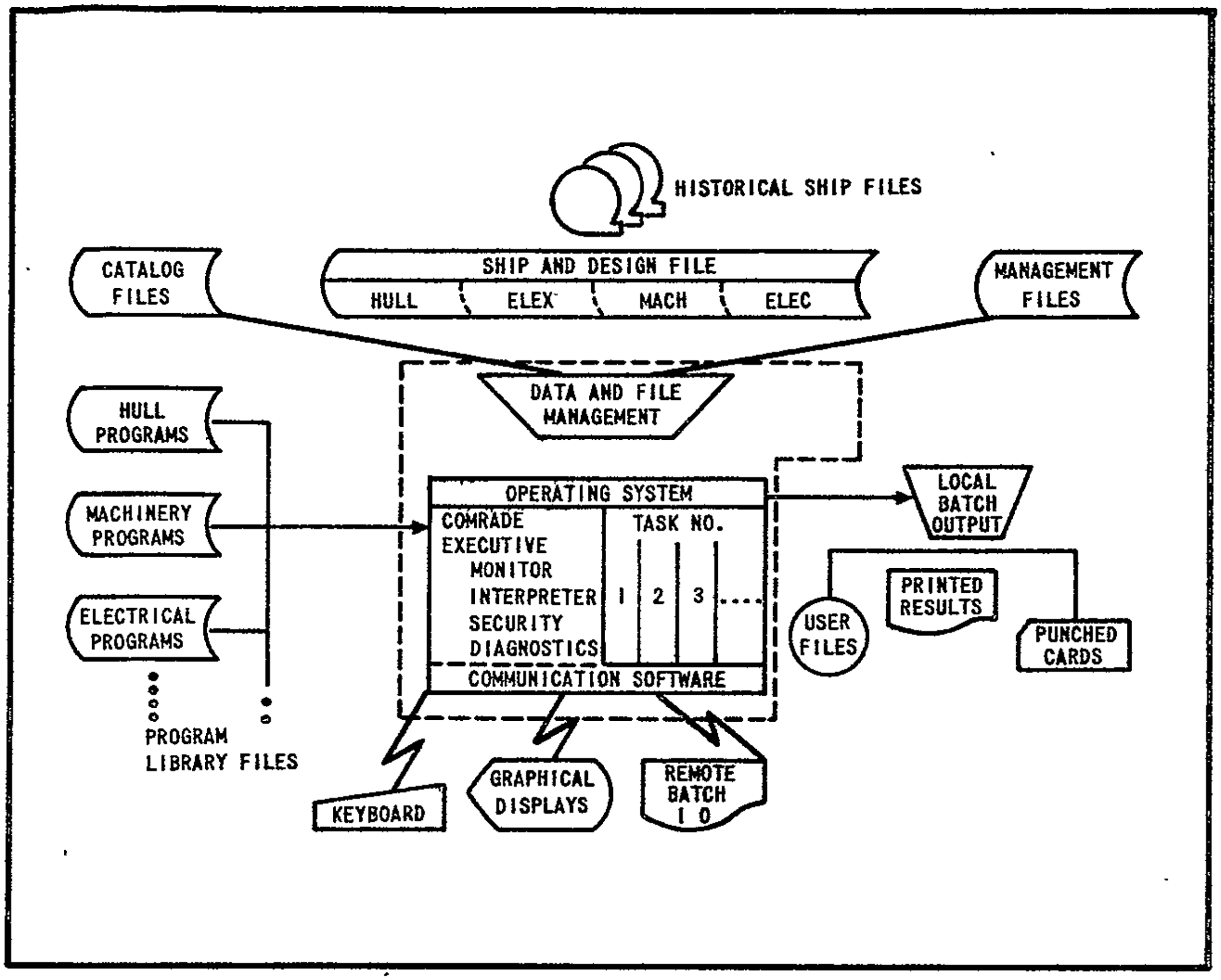


Figure 4.10 NSRDC ISDS/COMRADE System

4.2.2 NSRDC Integrated Ship Design System (ISDS/COMRADE)

With respect to IPAD, ISDS would be equivalent to Level III and to the Boeing CPDS just discussed. COMRADE is oriented toward the IPAD system software. A schematic is given in figure 4.10 (from ref. 4).

ISDS/COMRADE (ref. 3, 4, 5) is being developed by the Naval Ship Research and Development Center (NSRDC) at Bethesda, Maryland to reduce the flowtime required for preliminary design of surface ships. Johnson and Corin (ref. 3) report that, despite the computerization of various parts of the design process, the flowtime required to complete the preliminary design of a ship has actually increased over the last several years. They point out that the increase is due to the large number of intraship tradeoff studies that are now required.

Such results are typical of sub-optimization wherein improvement in some parts may result in a worsening of the whole.

Their analysis of time used shows that it now requires about four months (four man years) to complete the preliminary design of a destroyer. Of this time, about five minutes is spent on calculations and the remainder is spent in information exchange, data lookup and preparation, and error recovery.

Their objective is an integrated system which reduces preliminary design flowtime to about 10% of the current requirement, e.g., the four month flowtime now required to design a destroyer will be reduced to about one week.

4.2.3 The Effect of Computational Devices

Miller (ref. 7), studied the effect of multiple devices upon the cost of problem solving in the design environment. In this study, tasks were modeled as shown in figure 4.11. Note that the model included men as one of the task elements. The choices of computational devices considered are given in figure 4.12. The results of the study are summarized in figure 4.13 and the following conclusions are drawn:

1) A multiple device system would reduce the cost of problem solving by 20%.

2) About 90% of the total cost of problem solving is labor cost. Only 10% is computing cost.

3) The reduction in cost is essentially a reduction in the information handling delays associated with batch systems.

4) There is a 50% to 100% increase in computing costs for the multiple device system as compared to the "current" batch system.

Since this study was completed, time share systems have been installed at Boeing. The flowtime and cost savings being experienced are of the order indicated by the study.

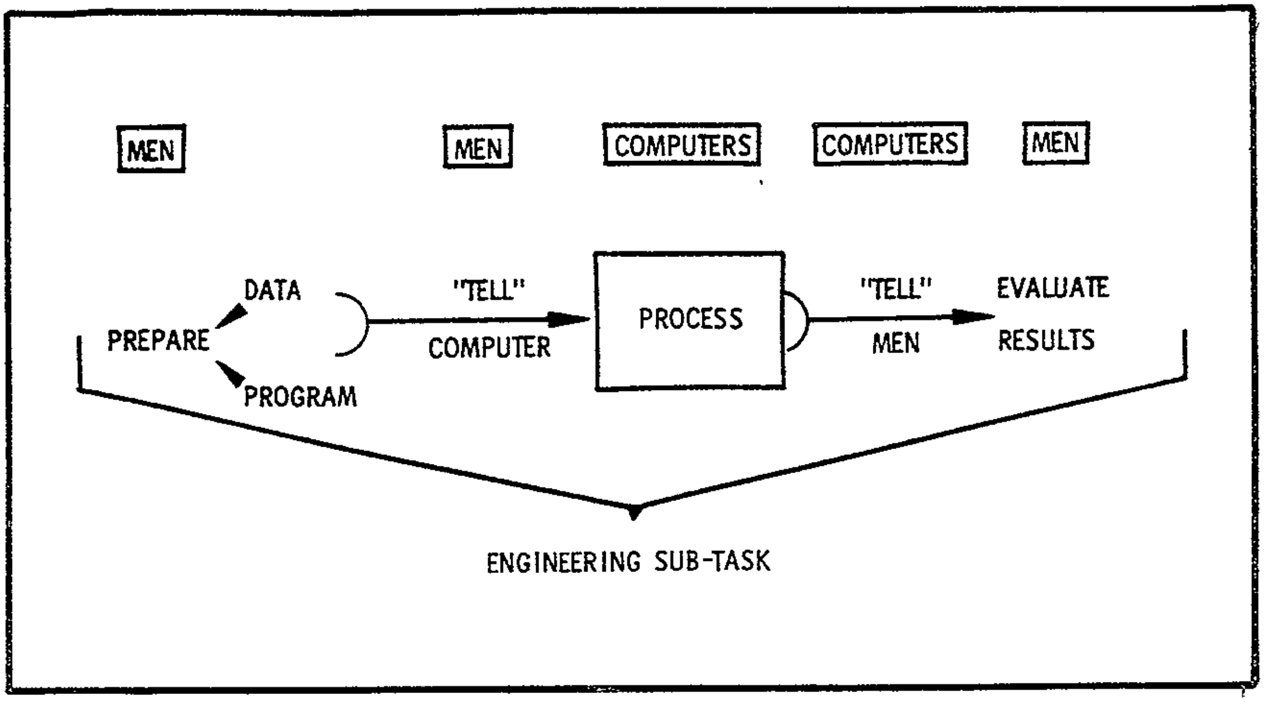


Figure 4.11 Computational Device Task Model

	CURRENT SYSTEM	7 DEVICE SYSTEM	6 DEVICE SYSTEM	5 DEVICE SYSTEM
SLIDE RULE	●	●	●	●
MECHANICAL DESK CALCULATOR	●	●	●	●
PROGRAMMABLE DESK CALCULATOR		●	●	●
SMALL TIME-SHARE SYSTEM		●	●	
LARGE TIME-SHARE SYSTEM		●	●	●
SMALL BATCH COMPUTER		●		
LARGE BATCH COMPUTER	●	●	●	●

Figure 4.12 Computational Device System Definition

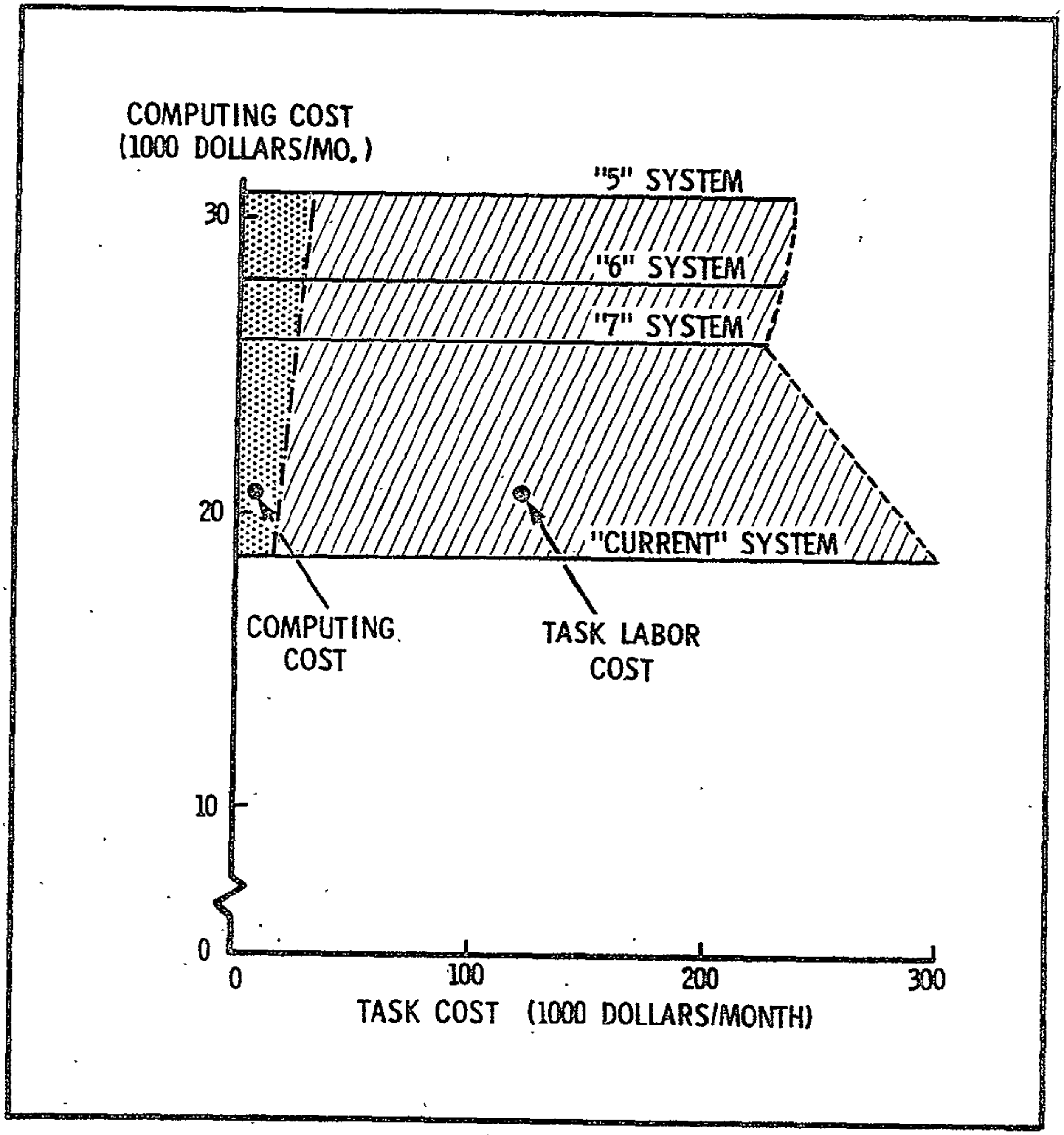


Figure 4.13 Computational Device Study Results

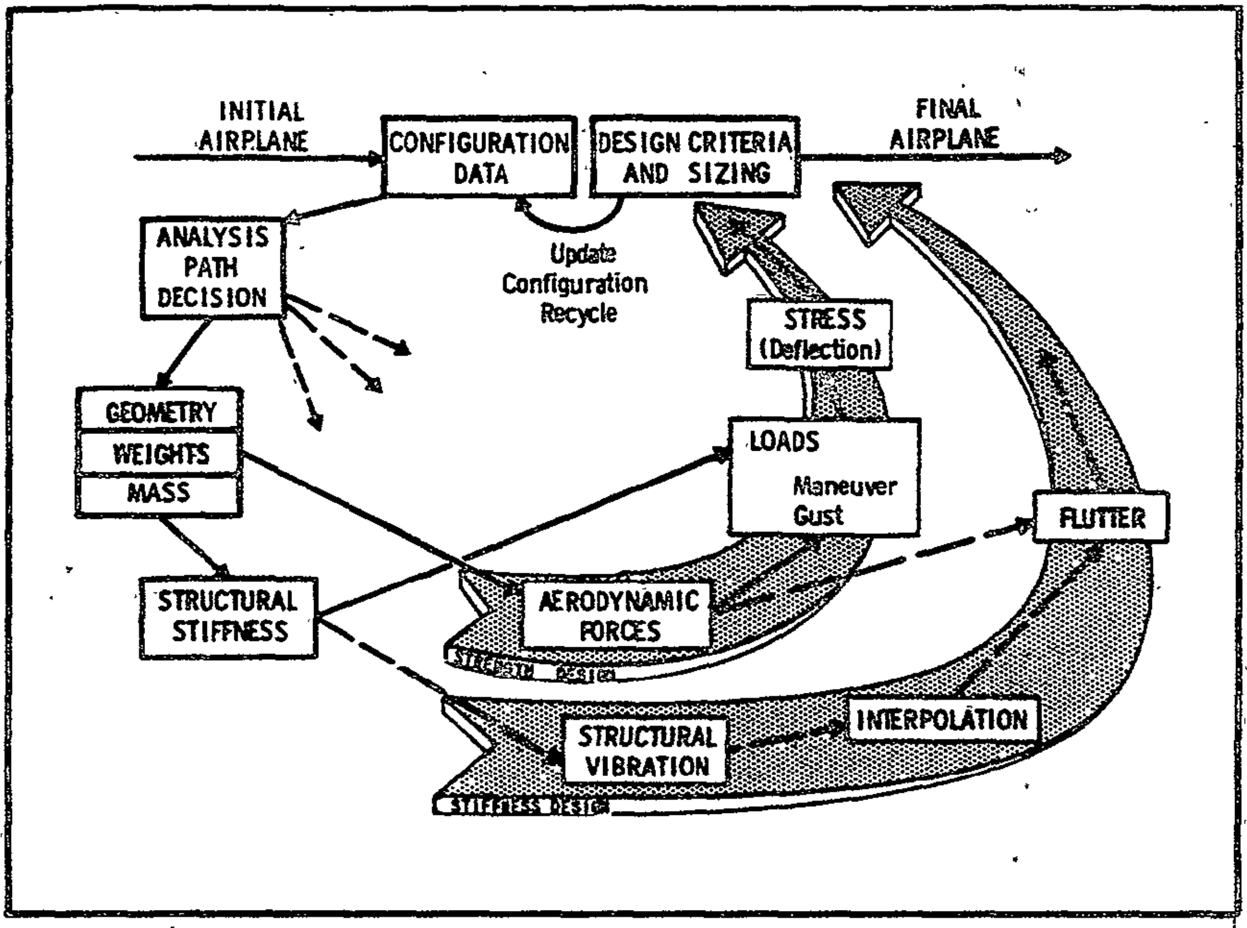


Figure 4.14 Boeing ATLAS System Aeroelastic Cycle

4.2.4 Boeing ATLAS System

The ATLAS System (ref. 8) integrates analysis modules for several aeroelastic technologies by providing an executive control system and computer-aided or automatic transfer of data across the interface of the modules. The system use is modeled in figure 4.14. Manpower and flowtime reductions are shown in figure 4.15. The savings in manpower and flowtime was the result of reducing or automating the information handling requirements between technology groups. ATLAS is a system that would be utilized at Levels IV through VI in the design process developed in Volume II for a subsonic airplane and in Levels III through VI for a supersonic airplane.

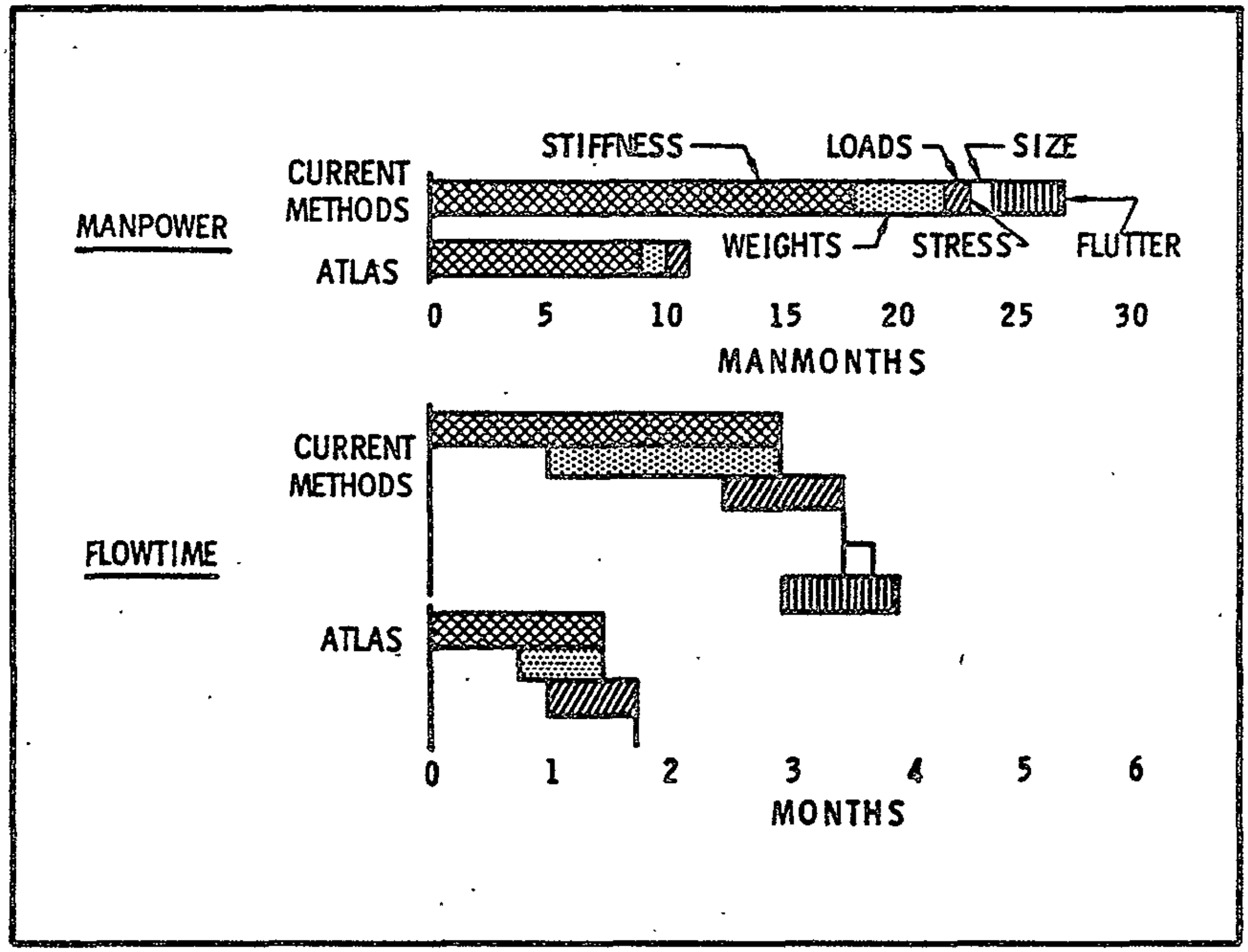
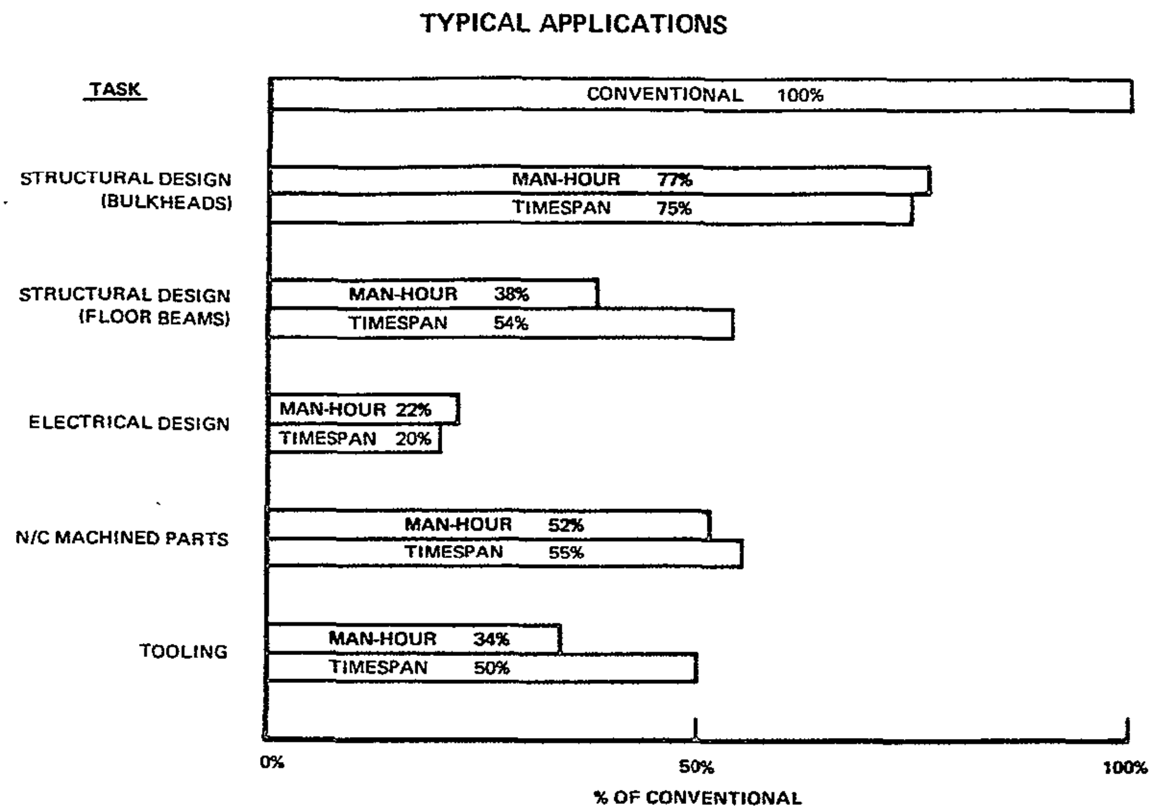


Figure 4.15 Boeing ATLAS System, Flowtime and Manpower Savings



By permission of the Lockheed California Company

Figure 4.16 Lockheed CADAM System,Manpower and Flowtime Savings

4.2.5 The Lockheed Computer Aided Design and Manufacturing System (CADAM)

Figure 4.16 (used by permission of the Lockheed California Company) gives the flowtime and cost savings achieved using CADAM. CADAM utilizes real time interactive graphics terminals and is used for design, computeraided drafting and analysis as shown in figure 4.17. The CADAM System would be utilized at Levels V and VI in the design process developed in Volume II.

During the IPAD survey (see Appendix A), Lockheed reported that the decrease in flowtime, excluding evaluation time away from the terminal, was from five to twenty times. They reported that twenty times seems to be the maximum achievable because, at that point, inputting to the system, system response time and dead time at the terminal during periods of operator contemplation begin to dominate.

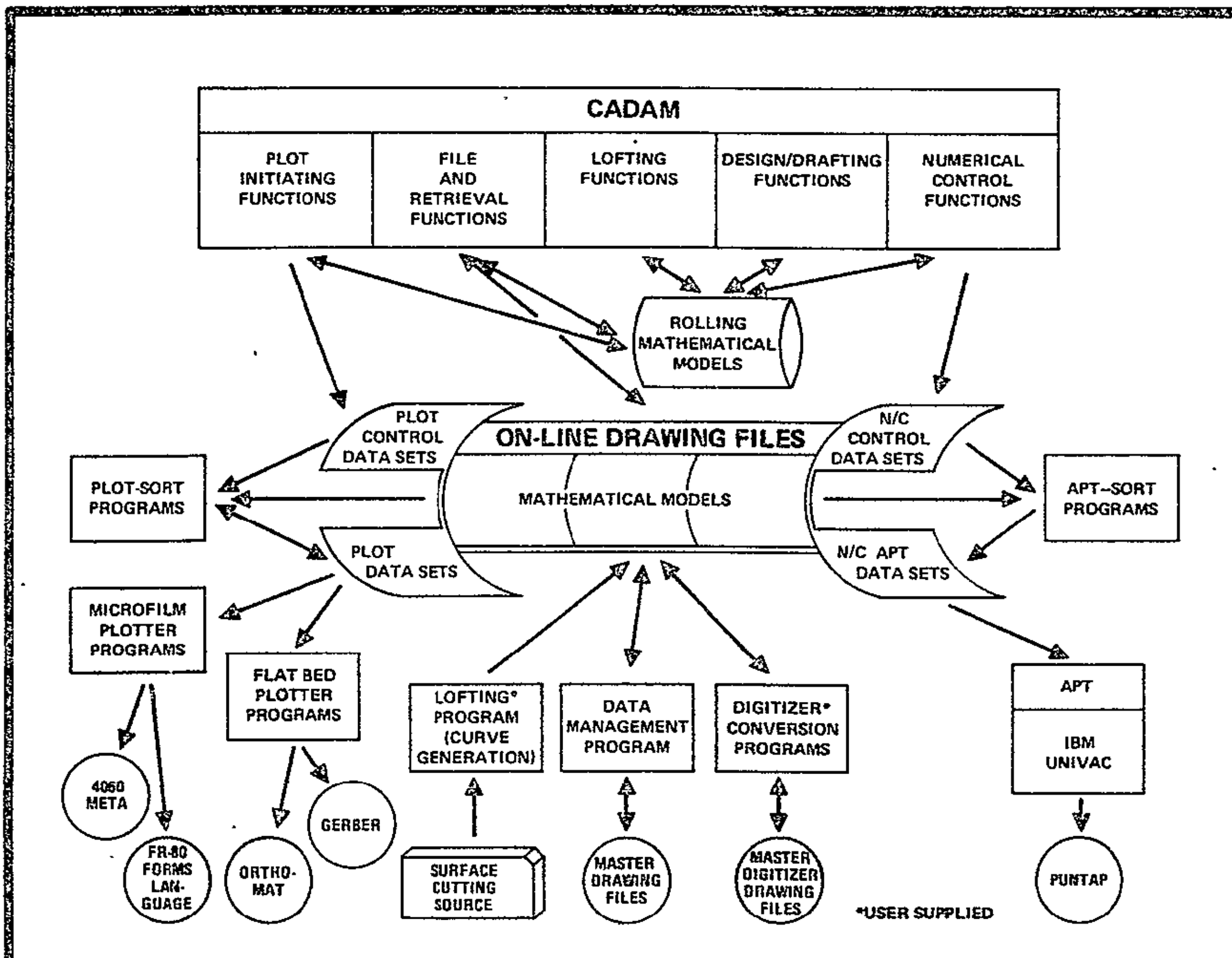


Figure 4.17 Lockheed CADAM System

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4.2.6 Other Systems

The following flowtime and cost savings have been reported in the literature:

1) All glass surfaces for 1971 General Motors cars were designed using their DAC-I interactive graphics system. All GM windshields have been designed using this system since 1965. They report that, for each windshield, styling was completed in one day that formerly required several weeks. Chevrolet uses the system to design windshield wipers, reducing the flowtime from thirty days to five days, (ref. 9, p. I-7).

2) Boeing developed a master dimensioning system through which a mathematical description of aircraft exterior geometry could be expressed. Geometric data is extracted in the following forms:

* Coordinates and components of vectors normal to the exterior surface.

* Mechanized drawings of the surface in any view.

* Mechanized drawings of flat pattern layouts of parts.

* Magnetic tape records of the surface definition used in subsequent work such as analysis and numerical control machining and tooling.

They report reductions in flowtime of five to one and reductions in manhours of ten to one over manual methods replaced by the system, (ref. 9, p. III-14).

3) McDonnell-Douglas has developed an interactive CRT system with which they input curve shapes and parametric data and visually check the results before creating hard copies of drawings using an ORTHOMAT plotter. They report 20% in dollar savings and 50% in time savings, (ref. 9, p. III-16). In reference 10, they report the following time savings:

* Airfoil smoothing reduced from 6 weeks to 10 minutes,

* Flight path optimization reduced from 4 weeks to 1 hour,

* Metering pin design reduced from 4 weeks to 1 hour,

* Control system analysis reduced from 3 days to 1 hour.

In the same reference, they report productivity ratios of 4:1 on wiring and 10:1 on geometry.

4) Lockheed-Georgia has used an interactive 2-D structures program since 1968. It was used extensively on the C-5 aircraft with a reported first year cost savings of $252,000. They estimate that the visual checking capability of the system avoided 500

hours of aborted computer runs during the analysis of a single aircraft wing, (ref. 9, p. III-16).

4.2.7 A Summary of Flowtime and Cost Savings

The labor cost and flowtime savings reported above are summarized in figure 4.18 for the major systems.

In summary, compared to standalone batch processing or hand methods:

1) These systems are achieving labor cost saving ranging from 20% to 80%,

2) These systems are achieving flowtime savings from 25% to 90%,

3) These flowtime and cost saving gains are being achieved through automation and computer aiding of the information handling activities.

4.3 EXTENSION OF FLOWTIME AND COST SAVINGS TO IPAD TECHNOLOGY

The dominant thread in the efficiency gains being experienced with the systems discussed in section 4.2 is the automation or computer aiding of the information handling chores. However the transfer of information within a design organization has remained largely a manual activity, despite the increased use of computers. The factors which limit humans in large volume or complex information transfers are:

1) response time,

2) reliability,

3) control,

4) data display.

The effect of these limitations is illustrated in figure 4.19, adapted from figure 1.1, Volume IV. In this figure, response time is plotted against volume of information for several transfer rates. There is a maximum response time for information transfer in any activity (shown as Activity A in the figure) beyond which the productivity of the activity becomes impaired. Response time is dependent upon the methods used.

SYSTEM	RELATIVE LABOR COST	RELATIVE FLOWTIME
Standalone Batch (Current)	100%	100%
Multiple Computational Devices	80%	
CPDS	20%	33%
ISDS		10%
ATLAS	50%	50%
CADAM (Bulkheads)	77%	75%
CADAM (Floor Beams)	38%	54%
CADAM (Electrical)	22%	20%

Figure 4.18 Summary of Relative Labor Cost and Flowtime for Current Systems

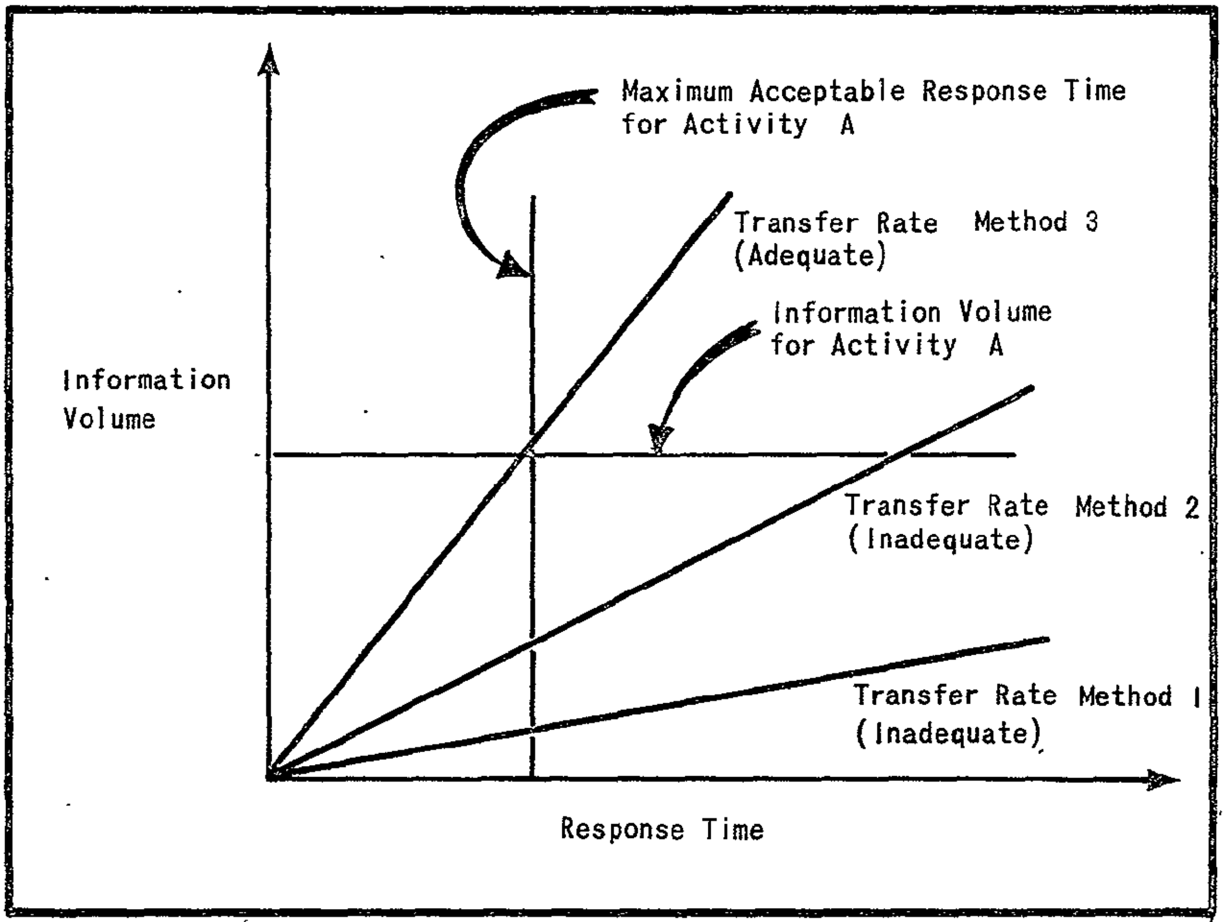

Figure 4.19 Effect of Information Volume Increase on Response Time

When the response time, reliability, control or information display characteristics of a method become inadequate, human productivity using that method becomes limited.

The basic motivating force for a change in method is the limited productivity of the current method in the face of demands for increased productivity. This is illustrated in figure 4.20. As the demand rises, the productivity of the method continues to rise until the limitations of the basic technology supporting the method are reached. At this point, increases in demand have no effect on productivity. An increase in productivity can only be achieved if new technology is developed to support a more productive method.

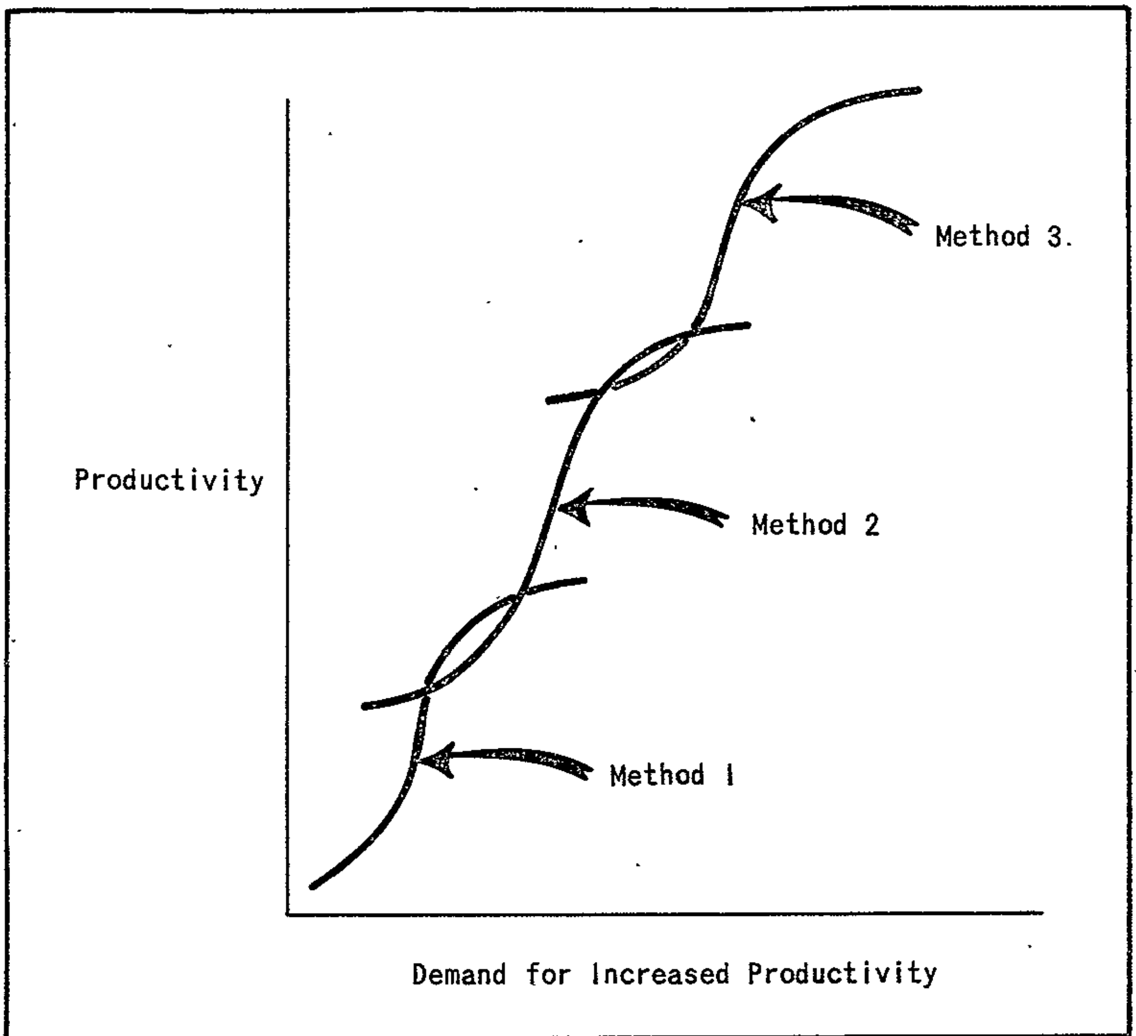

Figure 4.20 · Limited Productivity of Methods

The above limitations are being removed by many of the current systems. However, these systems only attack the information handling problem in isolated pieces of the design process and do not attack the problem within the total process. IPAD technology is the extension of information handling efficiency, as a means of increasing productivity, in the total design process. The full argument of this extension is made in Section 1.0 Volume IA and will not be repeated here.

IPAD technology will bring the information handling flowtime and labor cost reductions being experienced with

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existing systems to the total design organization. These benefits are discussed in the following sections under:

1) Designer Productivity,

2) Company Effectiveness,

3) IPAD as a National Resource.

4.4 DESIGNER PRODUCTIVITY

Design is not a defined process. It is a mixture of invention, discovery, innovation and duplication. It utilizes experience, technology, tools, processes and methods. It involves definition, computation, iteration, search, trial and error, and testing. When the product is complex, it requires organization, management, technical specialists, direction, coordination, communication and control. Yet, all of these factors are constantly changing as new technology is developed, new products are designed, new tools are built, new processes are discovered and new human skills are evolved. Hence, the environment of design is in constant change. Productivity in this environment, while definable, is seldom measurable; its evaluation more often than not is the result of judgment and observation rather than quantitative analysis.

The role of the designer is very subjective. The relationships of individual members of a design organization are so interlocked and interdependent that the contribution of individuals is difficult to differentiate in measurable terms. While we are able to establish labor cost and flowtime savings using current systems, it is difficult to determine the effect of these savings upon the productivity of individual designers in terms of their contribution to the entire design process.

The approach taken in this study is to identify the principal effects of IPAD technology upon the productiveness of the designer. The principal effects are upon:

- time compression,
- technical power,
- creative power.

The accumulation of these effects will be quantitized at the company level in section 4.5.

4.4.1 Time Compression

It was shown in figures 4.6, 4.15 and 4.16 in section 4.2 that time compression resulted from automating or computer-aiding the information handling chores across the module interfaces. Provided the evaluation and decision making functions of the organization can be similarly compressed, the resulting benefit will be a reduction in the design cycle flowtime. In any event, the effect of time compression will be the availability of more flowtime and manpower as a consequence of the increased productivity of individuals. Reduced flowtime is one of the benefits the aerospace industry generally expects from IPAD technology (See Appendix A, IPAD Survey).

An increase in technical power is also an effect of automating or computer aiding the information handling chores of a design organization.

4.4.2 Technical Power

Increased technical power results from:

1) time compression,

2) a redistribution of involvement of analysis vs design,

3) improved computational and data display utilities.

The increase in technical power is evidenced by an increase in the number of iterations and an increase in the scope of the technologies included within the iteration cycle, (decreased task fractionalization).

These factors are in evidence in the Boeing CPDS System as shown in figures 4.6, 4.7, 4.8 and 4.9. A configuration is analyzed in the integrated environment with less flowtime and labor than necessary with standalone programs. Given these additional resources, the designer has the option of:

1) doing more iterations,

2) including more technology (a flutter check for example),

3) increasing the number of configurations investigated.

As shown in figures 4.7, 4.8 and 4.9, there is a redistribution of involvement of analysis versus design when moving from the standalone environment to the integrated environment. When the routine information handling tasks are automated or computer aided, the volume of analysis labor reduces significantly. However, the volume of design labor does not reduce proportionately because this labor is already principally involved in nonroutine tasks.

In the integrated enrironment, in contrast to standalone, the designer is directly involved with the analyst throughout. Since they would have immediate and full access to all data and technical modules, they could alter the design definition or the analysis path as the need arises. Neither the designer nor the analyst is impeded by the requirement for communication, coordination and approval involved in the organizational interfaces dominant in the standalone environment.

At the general level of a design organization, many utilities can be made available that could not be afforded by separate technologies. These include interactive graphics, report generators, libraries of commonly used physical constants, etc. Hence, a general effect of the integrated environment is more powerful computational and data display tools.

Although the specifics of the above examples will vary according to the organization of the design process in different companies, the effects will be similar. Tasks will become less fractionalized because less labor will be required to do the same work. The resulting concentration of data and computational capability with fewer individuals will result in a general increase in the technical power of individuals. Not only will they be able to do more work in the same time period, they will also be able to broaden the scope of their work. The technical power of individuals will be further increased by the general computational and data display capabilities made available through the system.

A benefit of the increase in technical power will be increased responsiveness to management and customer inquiries about product marketability and performance, both in timeliness and in quality.

An important benefit of time compression and increased technical power will be an increase in creative power.

4.4.3 Creative Power

Much of the momentum of a creative thrust is lost when complicated by excessive flowtime, coordination or computational detail. Hence, the generation of new concepts is often more constrained by the tools available to investigate and communicate new ideas than by the unavailability of the new ideas themselves. Many commendable ideas are buried in the maze of organizational coordination and approval associated with the assignment of the additional manpower needed to investigate them. The "not invented here" syndrome is an inability to change or alter the direction of the mental and emotional commitments of individuals. The computer knows no such constraints and is as willing to function on one problem as another. Hence, IPAD technology will remove or soften these constraints through time compression and increased technical power. The effect will be a responsiveness from the design environment (men/tasks/computers) that is more compatible with a creative environment.

As an example, a geometry control system at Boeing has made it possible to obtain lofting for wing surfaces automatically by generation of plot tapes and subsequent plotting on table plotters. With this system, as much can be accomplished in a few minutes of computer time and a few days of flowtime as could previously be accomplished with a draftsman and weeks of flowtime. As a result, a designer may now try many wing shapes without the involvement of more people than himself and without significantly impacting the organizations resources.

4.5 COMPANY EFFECTIVENESS

The increase in designer productivity made available through IPAD technology will provide new flowtime and manpower resources to a company. However, these new resources accumulate as a company benefit only as management elects to invest them. The following are avenues of improved company effectiveness into which company management may elect to channel these new resources:

1) direct design labor and flowtime savings,

2) reduction of risk,

3) improved product design,

4) on-time design.

4.5.1 Direct Design Labor and Flowtime Savings

Company management may elect to reduce design labor costs and shorten product development schedules. Based upon the following assumptions, an estimate of potential savings can be made:

1) The distribution of labor costs between management, technical judgment and technical routine for the current design organization are as given in figure 4.4. This assumes that the current information handling efficiency, throughout the design organization, is at the level of standalone programs.

2) The labor and flowtime savings of the entire design organization utilizing IPAD technology will be similar to those being experienced with the current systems as described and argued in sections 4.2 and 4.3 and as given in figure 4.18.

3) The labor cost reductions in figure 4.18 apply to the technical routine category.

4) There will be a 20% reduction (80% relative) in labor cost in the technical judgment category.

The 80% relative labor cost in the technical judgment category is conservative. There are indications that the savings in this category may be even more. For example, a comparison of the technical judgment elements of the total labor costs for standalone and integrated environments in figure 4.9, shows that the relative judgmental labor cost in the integrated environment is 30% of that in the standalone environment.

The relative labor costs and flowtimes for a 2000 man organization, based upon the above assumptions, are given in figure 4.21. The dollar amounts are based upon a direct (unburdened) labor cost of $15,000 per manyear. The percentages given in the first three columns are the distribution of dollars between the three categories. The percentages given in the Total Dollars column are the relative cost compared to the standalone environment. For convenience, the total dollar and flowtime savings are given in figure 4.22. These were obtained from the complement of the relative cost figures given in figure 4.21.

4.5.2 Reduction of Risk

Company management may elect to reduce the risk of new product design by investing the labor and flowtime resources made available by IPAD technology into improved design. The existence of a total product data base, and the computing capacity, speed and reliability necessary to manage and contain

SYSTEM	MANAGEMENT ABOVE FIRST LINE	TECHNICAL JUDGEMENT	TECHNICAL ROUTINE	TOTAL DOLLARS*	FLOWTIME
Standalone Batch (Current)	6%	35%	59%	100%	100%
	$1,800,000	$10,500,000	$17,700,000	$30,000,000	
Multiple Computational 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 4.21 Potential Annual Relative Labor Costs and Flowtime in the IPAD Environment

it, plus the known deficiencies of localized design, are strong encouragements for investment in improved design. Some typical areas for major payoff are:

1) The aeroelastic cycle -- The coupling of stability and control, loads and flutter is strong enough to preclude satisfactory design by considering each technology singly. The problem is accentuated by requirements for active controls for ride relief and flutter suppression.

2) Engine installation and airframe integration -- The dynamic mating of the engine and airframe has been difficult to perform in a single system because the components are manufactured by separate companies.

3) Inlet controls and airframe integration - The inlet controls on supersonic aircraft are variable geometry and require integration with the airframe.

SYSTEM	TOTAL DOLLARS * SAVINGS	FLOWTIME SAVINGS
Standalone Batch (Current)	Reference Environment	Reference Environment
Multiple Computational Devices	19% $5,640,000	———
CPDS	58% $17,520,000	67%
ISDS	———	90%
ATLAS	37% $11,040,000	50%
CADAM (Bulkheads)	21% $6,140,000	25%
CADAM (Floor Beams)	44% $13,190,000	46%
CADAM (Electrical)	54% $16,080,000	80%

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

Figure 4.22 Potential Annual Labor Cost and Flowtime Savings in the IPAD Environment

4) Total airplane integration -- Assurance, both to product management and technology groups, that the same information is being used by all groups becomes possible with IPAD technology. This control and communication capability will encourage an effective integration of all airplane components and systems. As shown in Appendix A, one of the most important benefits expected by the aerospace industry from IPAD is configuration control.

5) Statistical dependent technologies -- Some technologies, such as fatigue, are dependent upon performance statistics. The collection and communication of these statistics will be helped by the standardization and community library characteristics of IPAD technology.

Dollar amounts associated with these areas are difficult to assess, because they are generally treated as proprietary. However, it is known, for example, that retrofixing flutter and fatigue deficiencies of manufactured airplanes has cost tens of millions of dollars. Hence, the potential savings in this area are substantial.

4.5.3 Improved Product Design

Company management may elect to invest labor and flowtime savings into more competitive products. In retrospect, the commercial jet transport was one such development. Outside the aerospace industry, the Wankel rotary engine may be another. Myriad improvements in design have been made possible by technological developments on a smaller scale. The availability of flowtime and professional labor and increased technological and creative power, will encourage the development of products from a greater analytical base than current aircraft.

4.5.4 On-Time Design

In figure 4.23, the dashed line illustrates the effect of late engineering design and out-of-sequence work early in the design cycle on downstream manufacturing costs and schedules. Planned schedule and costs are represented by the solid line.

A product schedule is developed in response to a market demand. Often, the entire success of the venture depends upon delivery of the product on schedule. Hence, the schedule is

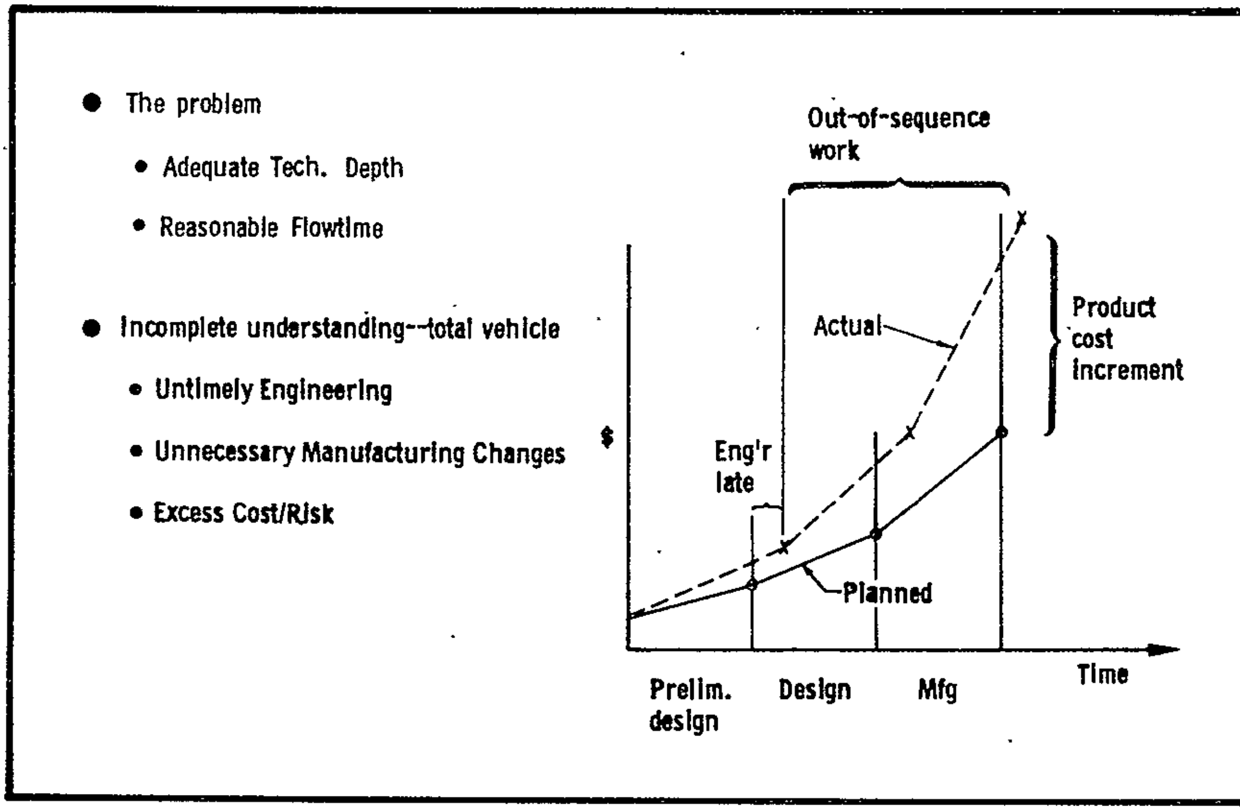

Figure 4.23 Downstream Effects of Late Engineering Design

maintained even though certain elements of the design may not be complete or of adequate standard. This necessitates retooling or retrofitting and complicates coordination and communication.

An effect of the flowtime and labor cost reductions from IPAD technology could be a reduction in late or inadequate engineering, thus reducing manufacturing changes. Although precise numbers are not available, it is known that the costs in this area for a new product can be in the tens of millions of dollars.

As shown in Appendix A, the aerospace industry anticipates an important benefit from IPAD in this area.

4.6 IPAD TECHNOLOGY AS A NATIONAL RESOURCE

The benefits of IPAD technology will accumulate at the national level in the form of:

1) Increased competitiveness of United States industry in the international market place through better products, less expensive products, and products with less associated risk. As shown in figure A.1 (Appendix A), the aerospace industry considered this area of impact to be outstanding in importance.

2) Stimulation of information technology in which information is treated as a resource. Computers and the technologies associated with them provide a means of handling information like a material resource; e.g., storage, inventory, control, dissemination to customers, etc. This technology is beneficial in all areas of aerospace design and manufacture as well as in other industries.

3) Increased effectiveness of government procurement procedures through a more effective information transferral between contractor and agency. This should be looked upon as more effective communication of relevant information rather than an increase in volume and nuisance. As shown in figure A.2, (Appendix A), the aerospace industry expects IPAD to make an important impact in this area.

5.0 TASK 7 - IMPACT

The state-of-the-art in computer applications has been characterized by many isolated programs or systems of programs attacking various aspects of the design process without being integrated or even correlated. This condition resulted from the piecemeal manner in which computer applications developed in engineering areas.

Computers were first applied in engineering as a high speed device to perform arithmetic calculations normally done by hand or as a large capacity device to solve unusually large, complex or difficult problems beyond the limits of hand calculations. This application resulted in some large and sophisticated computer programs and combinations of computer programs (systems). However, the basic concept of the computer as a large capacity, fast, reliable calculator has remained essentially unchanged. This concept has been dominant with both technical professionals and their management. The impact of this narrow concept has been focused primarly upon the technical specialist.

Recently, a more general concept of the computer has been developing. In this concept, the computer is seen as an information converter, processor, transformer and receptacle. This concept of the computer as the basic handling device for all information, not just that associated with calculations, will result in the emergence of an information technology. The impact of this concept will extend well into the management structure.

Information technology is the combination of:

1) the computer,

2) telecommunications, and

3) methodology.

As described by Whisler (ref. 11), the computer is the <u>engine</u> that provides the <u>power</u> for the <u>technology</u>. Where normally an engine is looked upon as an energy converter, in this case it is looked upon as an information converter. Without it, the concept of an information technology becomes operationally unfeasible. The telecommunications component includes data networks, mass storage devices, and input/output ports. Methodology includes the human activities associated with techniques and procedures necessary to meet information handling requirements by utilizing the computer and telecommunications.

IPAD technology is essentially information technology. The primary impact will be:

1) Acceptance and conversion to information technology as the basic method of handling information.

2) A trend towards centralization in task and organizational structure.

3) The impact of this trend upon management and technical personnel.

5.1 ACCEPTANCE

The pattern of acceptance of information technology can be modeled in the following way (ref. 11):

1) External stimuli create pressures for conversion to the use of information technology.

2) When these pressures become great enough to overcome internal inertia, conversion takes place.

3) Information technology contains or implies a logic for organizational and task structure that is incompatible with the system being replaced.

4) Organization and task structure are changed in the direction of a form consistent with the efficient use of information technology.

5.1.1 External Stimuli

The principal motivating forces towards conversion to some form of information technology are the following:

1) indirect through an actual or potential loss of competitive position,

2) direct through contract or administrative directive. These forces were considered in developing the implementation strategy proposed in section 3.0, Volume VI.

5.1.2 Internal Inertia

Internal to an organization, the inertia working against the adaptation of information technology results from a resistance to change of established methods. This resistance will appear as:

1) Lack of Skill, Knowledge, Experience--The training, education and experience of an organization's personnel are generally rooted in present practice. It is unlikely that an organization will have technical skills or knowledge in fields grossly different from itself.

2) Success With Current Methods--The very success of a design method often provides the greatest inertia against changing it. Organizations tend not to originate radical technological advances that invalidate their present success or that wipe out the value of their investments. The tendency is to continue with a method that has demonstrated success for as long as it continues to be productive.

3) Improvement of Current Methods--The development of a new technology that is competitive to existing methods may motivate an immediate improvement in the efficiency of the existing method.

4) Condition of the Economy--The strength of the economy may have positive or adverse effects upon the acceptance of new technology. Profit making organizations tend to be more conservative during periods of economic stress. Conversely, during periods of economic strength, their preoccupation with developing and producing a product may make them reluctant to impose change upon already fully loaded resources.

5) Attitudes, Characteristics and Motivations of People -- Limited knowledge, preconceptions, lack of appreciation, protection of status or prerogatives, habit, fear, etc., all contribute to resistance to acceptance.

6) Availability of Resources--If the resources required to implement IPAD are of the order of magnitude, or greater, than the normal resources available to a design organization, funds will have to be supplied from some external source.

Both the external and internal forces related to acceptance are in a state of constant change. Assessment of the strength and meaning of these forces and the determination of appropriate courses of action in response to them is a prime responsibility of organizational management. Dramatic changes in task and organizational structure will not occur. Rather, as the productivity of information technology becomes evident, and the competitive or directive pressures become great enough, acceptance will evolve. This evolvement will appear as changes in task and organizational structure, shifts in organizational power centers, changes in the job functions of individuals, and changes in informal and formal communication paths.

5.2 TASK/ORGANIZATIONAL STRUCTURE

The dominant trends in task structure resulting from information technology will be the following:

1) Structured (routine) tasks will tend to be consolidated as activities are automated or computer-aided.

2) Unstructured (judgmental) tasks will broaden in scope because of the technical and communication power made possible by information technology.

3) New tasks will be introduced. These new tasks will have two basic forms.

    a) Those associated with more general functions that evolve from the widened scope of technical and communication capability and the increased requirement for planning.

    b) Those associated with feeding data to the system.

4) Information will be centralized and controlled.

Certain information is fundamental to the product being designed. Changes in task structure will improve the efficiency of obtaining and communicating this information by introducing new methods. However, the <u>basic</u> information produced will remain unchanged. For example, the Boeing ATLAS system is designed to improve the efficiency of the aeroelastic cycle, but the cycle itself remains fundamental to aircraft design.

Organizations reflect task structure. Since the fundamental information produced by tasks within a design organization will remain unchanged, the design organization itself 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 organizational structure and the existence of a centralized data base.

5.3 IMPACT ON PEOPLE

The change 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.

New identifications will be made by individuals with the product and with the changed objectives of their immediate organization. These identifications will be of two fundamental 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 effects can be either motivating or oppressive.

5.4 TRAINING

Training will be required. Experience with integrated systems to date indicates that, if the basic technology is understood, from 10 to 30 hours of training will provide adequate skill building. For IPAD technology, this should be interpreted as meaning that 10 to 30 hours will be required for training in the use of the base system. Additional blocks of time of similar magnitude will be required for each major technology area.

In addition to skill building, training in concepts will be required, particularly for management who will be responsible for integrating the system into their organizations. As currently structured, information handling is distributed throughout the organization. IPAD (information) technology will result in the centralization of many information handling functions and in a change of form for many others.

The activity structure and the information structure of an organization are separate and unique. The activity structure is normally highly visible and will continue to be reflected in the organizational structure. However, as information is collected into the data base, the information structure, normally invisible, will become distinct, and very important. The communication between the two structures will be by people through the IPAD system software to the data base. As a result, training will be required in the following areas:

1) Creation and management of the information structure and the data base,

2) Coordination, communication and control of information within the data base,

3) Computer time sharing as a communication medium.

The method of training should be one of the following forms:

1) Active training through simulations in which realistic management or technical situations are role played using the system,

2) Passive training in which the system is not used, but input/output information is described, thus avoiding long training time and high computing costs.

6.0 TASK 8 - SPINOFF

The impact of IPAD technology outside the aerospace industry will be through direct utilization of IPAD software or motivation to develop similar software for specialized applications. As found during the IPAD survey discussed in section 3.0, the problems of information handling are not unique to the aerospace industry. The IPAD executive and data base management software will contain minimal characteristics that are specialized to the aerospace industry. Hence, this software may find wide application in the marine, land transportation and construction industries. As data networks are developed, IPAD executive and data management may be marketed by them as extensions to the system software.

The concepts of IPAD technology have wide application. The development of IPAD software in support of those concepts will result in technology growth that will motivate and support the development of software to perform similar functions for specialized applications. The development of data base technology will be particularly motivating. It was found during the IPAD survey discussed in section 3.0 that, in essentially all areas visited, there is wide interest in the potential productivity from the utilization of general data bases.

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APPENDIX A - IPAD SURVEY

A survey was conducted in the early part of the IPAD feasibility study. This survey had two purposes:

1) To obtain information and opinion from aerospace industry, nonaerospace industry, university and government sources regarding IPAD concepts, implementation and acceptance.

2) To familiarize these sources with the purposes of the IPAD feasibility study contracts and with the broad concepts of IPAD technology.

A.1 SURVEY CONTACTS

The following companies, universities and government agencies were visited. The principal contact during the visit is noted. Most generally, representatives from several technologies were present during the discussions.

Aerospace Companies

1) Grumman Aircraft
   Eugene Baird
   Bethpage, New York

2) Lockheed-California
   Wm. D. Morrison, Jr.
   Rye Canyon Facility, Burbank, California
   Stan Horn
   L1011 Project, Burbank, California

3) Lockheed-Georgia
   S. H. Chasen
   C5A Project, Marietta, Georgia

4) McDonnell-Douglas
   Ed Stanton
   Space Division, Huntington Beach, California
   Dale Warren
   Commercial Aircraft, Long Beach, California
   S. A. LaFavor
   Military Aircraft, St. Louis, Missouri

5) North American Rockwell
   Ellis Katz
   Space Division, Seal Beach and Downey, California

Harvey Hoge
B1 Division, Los Angeles, California

6). The Boeing Company
Ed Widmayer
Vertol Division, Morton, Pennsylvania
R. E. Wallace
Commercial Airplane Division, Renton, Washington

Non-Aerospace Companies

1) Ford Motor Company
Wayne Hamann
Dearborn, Michigan

2) General Motors
Frank Stoneking
Warren, Michigan

3) Lockheed Shipbuilding
R. J. Cook
Seattle, Washington

Universities

1) Stanford University
Prof. Holt Ashley
Aero-Astro Department, Stanford, California

2) Massuchusetts Institute of Technology
Prof. Robert D. Logcher
Civil Engineering Department, Boston, Massachusetts

Government Agencies

1) NASA Ames
Tom Gregory
Mt. View, California

2) Naval Ship Research and Development Center
Jack Brainin, Thomas Rhodes
ISDS Project, Bethesda, Maryland

3) Wright-Patterson Air Force Base
Gordon F. Quinn, ASD; Jim Folk, FDL
Dayton, Ohio

In addition to the personal visits above, telephone and mail contact was made with Dwight Studdard, Pratt & Whitney, West Palm Beach, Florida.

Every effort was made to make contact with engineers and managers working directly on hardware projects in order to obtain information directly related to the production environment IPAD will impact. Contact was avoided with the computing and research groups often associated with the development, rather than the use, of automated or computer aided methods. First contacts were made as high in the organization being visited as possible in order to obtain the active support and cooperation of those visited. In most cases, the first contact was either a vice president, director, or group manager. The actual contact during the visits ranged from high level management through practicing engineers.

A.2 METHOD OF SURVEY

The survey was completed in two trips; one down the west coast and the other through the midwest, east and south. In general, the contacts and visits were made through the following procedure:

1) A series of telephone contacts were made, obtaining the cooperation of the organization and assignment of contact.

2) The summary (Appendix B) and IPAD survey brochures (attached) were then mailed out. These brochures had two purposes. The first was to obtain specific responses from companies currently developing integrated systems. The second was to utilize the actual visitation time most effectively by establishing a basis for discussion prior to the survey visit.

3) A personal visit was made, usually lasting from a half day to a full day.

4) The survey forms were collected and questionable responses clarified at the time of the visit.

A.3 SURVEY RESULTS

Every aerospace company visited is developing integrated computer systems. These systems range from the Boeing CPDS system directed at preliminary design to the Lockheed-California CADAM system, directed at drafting and the numerical control interface. Wherever these systems are being developed, the purpose is to automate or computer-aid the routine information handling chores in order to reduce flowtime, improve reliability and increase productivity.

Specific results of the survey will be given in the following sections for each group of organizations visited.

A.3.1 Aerospace Companies

The aerospace companies are generally the most advanced in the development of systems in the direction of IPAD technology. Consequently, the most relevant survey responses were obtained from these sources. One company did refuse to respond to the survey, stating that the form of the survey implied feasibility while the purpose of our contract was to investigate feasibility. Most companies did not respond to questions regarding the effectiveness of their current systems other than with information available generally in the literature. Very little response was obtained regarding the potential impact of IPAD technology upon people and organizations, although, in discussion, strong sentiments were expressed ranging from very significant to very minor impact.

Nearly all company contacts developed a single composite response to the survey based upon the collected opinions of several members of their organizations. As a result, eleven completed survey forms were obtained from the aerospace companies. Their responses are compiled in figures A.1 through A.3.

In figures A.1 through A.3, the symbols O, I, L and U stand for the following:

O = Outstanding in importance

I = Important

L = Low Importance

U = Unimportant

The number of responses from the eleven survey forms relative to the level of importance of each item are given on the figures. In some instances, the total responses are less than eleven because some companies did not answer all questions.

Figure A.1 compares the importance of some general benefits to the industry with the impact IPAD will have in providing those benefits. As shown, all of the items listed in figure A.1 were considered important to the industry. The most significant

	Importance to Industry				IPAD Impact			
	O	I	L	U	O	I	L	U
1. International Competitiveness	7	3	1	0	1	5	3	1
2. Expanding Product Diversity and Complexity	2	8	1	0	2	4	4	1
3. Communication of Technical Data	2	8	0	0	3	7	1	0
4. Technical Depth/Flowtime	2	9	0	0	3	7	1	0
5. Configuration Control	3	6	2	0	6	4	0	0
6. Technology Transfer	1	7	3	0	2	6	2	1
7. Duplication of Software	2	5	3	0	2	7	0	1
8. Full Vehicle Research	1	9	1	0	0	8	2	0
The following items were added by the respondees:								
9. Government Evaluation of Competitive Proposals	0	1	0	0	0	1	0	0
10. Reduction in Product Development Time	2	0	0	0	1	1	0	0
11. Reduction in Product Development Cost	1	0	0	0	0	1	0	0
12. Reduction in Communication Errors	1	0	0	0	1	0	0	0
13. Common Data Base for Design	0	1	0	0	0	1	0	0

Figure A.1 Survey Summary, IPAD Justification, General Benefits (See IPAD Survey Page 1) contribution from IPAD is expected in configuration control. The least significant contribution is expected in the area of expanding product diversity and complexity. Importantly, some impact from IPAD is expected in all areas. The respondees added some items as noted on figure A.1.

Figure A.2 makes the same comparison as figure A.1, except the items being compared are more specific. As shown all of the items in figure A.2 were also considered important to the industry. IPAD is expected to result in better manpower utilization; however, the average labor skill is not expected to lower because of IPAD. IPAD is expected to make an important contribution to flowtime reductions in all categories listed. It is expected to be of outstanding importance in providing a consistent data base. Significantly, IPAD is expected to make an outstanding contribution in improving manufacturing efficiency as shown in the responses to question 8.

In the questions shown in figure A.3, the respondees were asked to compare their existing systems with some of the capabilities anticipated for IPAD. As shown on the figure, they expect language improvements in IPAD. They also expect routines to help edit, check and display data. They place low priority on computer assistance in selecting execution paths. They do place great importance in direct online participation during optimization cycling. Importantly, even though their current systems do not have them, they place high priority on security safeguards. They also consider the ability to communicate between machines of outstanding importance.

In response to the question on page 11 of the survey about their interest in bidding on system development, five of the respondees said they would be interested in all categories. The others made no reply.

In reponse to the question on page 12 of the survey asking for comment on the level of competitiveness of industrial companies:

1) Five respondees agreed that there should be competition at the product level and cooperation in tool and technology development.

2) Three respondees disagreed, stating that the competition between companies in producing better products results from competition in technology and tool development.

One respondee commented that there should be cooperation in the development of very large systems. Another remarked that the

	Importance to Industry				IPAD Impact			
	O	I	L	U	O	I	L	U
1. Better manpower utilization as evidenced by:								
o Less manhours required to perform the same task.	6	5	0	0	4	2	3	2
o The average labor skill required to do a task may be lowered.	0	5	5	1	0	1	5	5
2. Lowered computing costs per unit of useful result.	1	8	1	1	2	4	2	3
3. Reduced flowtime required:								
o To transfer data/code between locations.	2	7	2	0	3	7	0	1
o To transfer data between technologies.	3	7	1	0	3	8	0	0
o To complete a design cycle.	6	5	0	0	6	3	1	0
o Because of error reduction resulting from automatic data transfers and better control of execution sequences.	2	8	1	0	3	7	1	0
4. Consistent data base resulting in:								
o A common reference system for geometry, modeling, loads, etc.	6	5	0	0	9	2	0	0
o Visibility of changes to both data and technical code.	1	10	0	0	5	6	0	0
5. Computer aided production of document quality reports from data on the data base.	1	5	4	1	2	5	3	1
6. The ability to conduct design research in:								
o Design methodology, i.e. better approaches to the design task.	5	5	1	0	1	4	5	1
o Product configuration, both general and detailed.	4	5	2	0	2	4	4	1
o Evaluating technical capability produced by others and made available as public domain or by sale.	1	7	3	0	1	4	4	2
7. More effective utilization of technical people in terms of less routine and more directly creative work.	0	11	0	0	1	7	2	1

Figure A.2 Survey Summary, IPAD Justification, Direct Benefits (See IPAD Survey Pages 2,3,and 4)

	Importance to Industry				IPAD Impact			
	O	I	L	U	O	I	L	U
8. Improved manufacturing efficiency in:								
o Reduced tooling changes because of more timely or more accurate engineering.	4	7	0	0	4	3	4	0
o Reduced retrofitting requirements because of more timely or accurate engineering.	5	5	1	0	5	3	3	0
o Increased manufacturing and assembly efficiency because of more accurate transmittal of data.	4	5	2	0	4	4	2	1
9. Improved product in terms of:								
o Integrity of structure and systems.	4	7	0	0	0	9	1	1
o Ability to design products beyond the state-of-the-art of today's technology.	3	5	2	0	0	3	4	3
o Increased creativeness of designers because of the availability of comprehensive multitechnology tools that can be utilized by one or few persons.	2	7	1	1	1	4	4	2
o Offering improved performance to customers.	2	8	0	0	0	7	3	0
10. Usefulness to universities as an educational tool that provides:								
o Research opportunity	1	3	4	2	0	2	3	5
o Realistic study of practical problems	0	5	4	0	0	3	3	3
11. Useful to government for:								
o Hardware design evaluation by requiring analytical models as well as wind tunnel models.	2	6	3	0	3	5	2	0
o Aircraft concept research.	2	3	4	1	4	4	3	0
o Reduction of software acquisition costs through elimination of duplication.	2	4	3	2	4	3	3	1

Figure A.2 (Continued) Survey Summary, IPAD Justification, Direct Benefits (See IPAD Survey Pages 2, 3, and 4)

		Your System				IPAD			
		O	I	L	U	O	I	L	U
1.	Accessibility to the degree that the flowtime required to access the system, code and data does not significantly contribute to the flowtime of the design process.	5	2	2	0	5	4	1	0
2.	Language, vocabulary, grammar and syntax directed to the technical task being performed rather than to the file handling and computer processing steps.	1	5	2	1	5	3	1	1
3.	Conversational languages, including prompts, cues, error diagnostics, etc. that lead and assist the user to correct data and execution with minimum flowtime.	3	1	4	1	6	3	0	1
4.	Instructional language using cryptic high level commands for experienced users and allowing calls for explanations, definitions, data formatting, etc., to the level the less experienced user requires.	1	2	3	1	2	2	4	1
5.	Editing routines for online inputting and modifying data or code files.	4	3	1	1	5	5	0	0
6.	Routines to detect errors or inconsistencies in execution sequences or data.	4	3	2	0	8	1	1	0
7.	Online display of test, data items, vectors, or matrices as tabular print, x-y plots, contour plots, etc. as appropriate.	1	4	1	1	4	6	0	0
8.	The capability to input end-products or results of some type or character and have possible or recommended execution paths and alternates returned.	0	1	2	3	1	2	4	1

Figure A.3 Survey Summary, User Comparison of Their Systems and Proposed IPAD Capabilities (See IPAD Survey Pages 7,8,and 9)

		Your System				IPAD			
		O	I	L	U	O	I	L	U
9.	The online ability to devise strings of execution sequences through evaluation of selected results and control the execution and selection of alternate paths.	0	2	3	2	1	5	2	0
10.	The online ability to observe the direction of change of degree of closure during optimization cycling and interdict for purposes of redirection, changing values or stopping.	3	1	2	1	7	1	2	0
11	The online ability to access the data base for purposes of editing, transferring, changing, replacing or purging data files.	2	4	1	1	4	5	1	0
12.	Online accounting for jobs, groups of jobs, projects for computing results used or projected to be used for a particular execution sequence or calendar time period.	0	0	6	1	1	5	3	0
13.	High level security safeguards in terms of passwords, keywords or other such identifiers on code and data files to protect against inadvertent or unintentional access, theft, or spying and to provide managment control of the technical code and the project data base.	0	1	3	3	5	2	1	1
14.	A portable data bank whereby portions or all of a data bank can be removed from the system and be complete in the sense that all descriptors, keys, identifiers, etc. necessary for the IPAD system to re-enter the removed data into the data base are included in the data.	1	3	2	1	3	6	1	0
15.	Inter-machine communication whereby data or code can be transferred between computers of the same or different manufacturer.	1	2	2	2	5	5	0	0

Figure A.3(Continued) Survey Summary, User Comparison of Their Systems and Proposed IPAD Capabilities (See IPAD Survey Pages 7, 8, and 9) competition should be in the utilization of the tools and technology and that cooperation in this development increased the ability of the industry collectively, to compete in the world market.

In answer to the impact questions on pages 13 and 14 of the survey:

1) Five respondees think creativity will increase, one thinks it will decrease and three expect no change.

2) One expects tedium to increase, five expect it to decrease and three expect no change.

3) Four believe higher average skill will be required. Only three expect any obsolesence in skills, specifically naming drawing board layout as a possibility.

4) Nearly all noted some acceptance problems. Five of the respondees selected "fear and dislike of computer intrusion into traditional human activity" as the principal cause of rejection.

5) Seven believed IPAD technology will be accepted by their engineers. Six believe their managers will accept it.

6) In only one instance (Grumman with IDEAS) did a respondee indicate significant organizational changes were required to effectively use an integrated system. Opinion was equally divided on whether or not a requirement for organizational change would be a barrier to the acceptance of IPAD technology.

Some general conclusions that came out of the discussions are summarized below:

1) Integrated systems exist in varying degrees of development and refinement and for varying purposes at all aerospace firms. Their growth, in scope and number, is expected to accelerate.

2) The meaning of the word "integrated" is not universally understood. In one instance, it meant a series of standalone programs with automatic interface data transfer capability through tape or disc files. In another company, it meant the complete automatic hands off execution of a program series. In yet another company, it meant the collecting of modules

under the control of an executive program, with human interaction as required in controlling program sequences. These definitions are fundamentally different and result in considerable conflict and confusion.

3) Data base technology, in the general sense anticipated for IPAD is essentially nonexistent. There is great interest in the development of such technology and a general belief that the communication and coordination efficiencies to be gained through use of a common data base will reduce design flowtimes significantly.

4) There was a general consensus that a principal barrier to be overcome in IPAD technology is language and jargon differences between technologies and between design organizations.

5) All aerospace firms maintain their own computer facility, generally at corporate level, and do their own software maintenance, even on acquired programs such as NASTRAN. There was a strong unwillingness to believe that any centralized computing facility, outside their company hardware or software, would give them the control and responsiveness they require. Most technology groups want increased control of computing responsiveness and view an even more remote facility than their in-house facility as synonomous with poorer responsiveness. They did agree however, that data nets utilizing large fourth generation hardware may completely change the economics and make it more practical to buy time than to buy hardware.

6) It was universally agreed that IPAD development should proceed. Not necessarily because they intend to use the system directly, but in some cases, because they intend to benefit from the technology growth in developing their own systems.

7) There was evidence of willingness to utilize whatever technology software will do the job regardless of origin. However, the advantage of using new software must be considerable in order to offset the cost of conversion, familiarization and maintenance. Most users would rather continue with old software they understand and have confidence in even if it is an order of magnitude less efficient than newer software.

8) Many companies market their engineering as well as their hardware products. One company particularly

stated that they market their engineering capability as part of their aircraft sales strategy. Any capability that made them less able to distinguish their engineering organization from that of other companies would be resisted or modified to maintain their image.

9) Some companies involved in government hardware development contracts believe that government review and control is burdening beyond benefit as currently imposed. They fear that IPAD will increase the burden.

10) The most fully developed and operative system witnessed during the survey was the CADAM system at Lockheed California in Burbank (ref. 1, 2).

11) The most comprehensive and technologically advanced system currently under development reviewed during the survey was the ISDS COMRADE project at NSRDC (ref. 3, 4, 5).

A.3.2 Non-Aerospace Companies

The degree of development of integrated systems at these companies is considerably lower than that found at aerospace companies. However, two developments are accelerating interest within these companies towards increased capability with integrated systems.

Within the maritime industry, increased efficiency of United States shipyards has been identified as the key to survival in the face of competition from foreign ship builders. A conference, held June 2-4, 1971, at the invitation of the Assistant Secretary of Commerce for Maritime Affairs, was conducted specifically to initiate a program of development for computer applications in the ship building industry. The conference was attended by representatives of eleven major shipyards. In the conference report the participants..."agreed that there were significant gains which can be achieved in an accelerated program of computer utilization in ship building and ship design, in order to assist in reaching the reduced subsidy goals of the President's Shipbuilding Program. Further, the probability of implementation and success of such a program can be significantly increased by the joint efforts of the nation's shipyards working towards standardized procedures, systems and objectives." (ref. 6) This activity is being motivated by a shift of government funds away from direct subsidies to research and development of capabilities to increase yard efficiency.

Within the automotive industry, increased safety standards have resulted in a requirement to increase the engineering analysis of automotive vehicles. Automobiles have traditionally been evolved from year-to-year by making minor engineering design changes. As a consequence, total vehicle analysis capability has not been developed. Work is currently underway to develop engineering analysis capability for overall vehicle dynamics, overall vehicle strength, crash resistance, etc. An approach they are using is to develop a general data base of automobile geometry and properties from which finite element models can be developed. They are currently using interactive graphics to develop, edit and evaluate finite element data.

3.3.3 Universities

Little value is envisioned for IPAD in the university classroom. The two possible uses of IPAD in a university are as a research opportunity or for studying realistic problems. Two factors counteract this usefulness.

The first factor is the disparity of interest between the university and the industrial community. Students are generally interested in learning principles and completing their studies. Hence, their span of interest does not extend beyond the completion of a course or thesis. Also their sense of quality or completeness generally does not extend beyond the demonstration of a principle or effect. The long time scales and complexity of industrial integrated system development is at variance with this environment.

The second factor is that most university teachers prefer to have their students study the principles involved and fear that the use of a large system such as IPAD would place a greater burden in learning its use and a greater temptation to use it as a "black box" than the benefit to be gained. Those interviewed did agree that once a student learns a principle he is not helped by having to hand work complex arithmetic related to it. However, they point out that less complex systems available at the universities are adequate.

Professor Logcher of MIT in his paper, "The Development of ICES STRUDL", illuminates many of these problems (ref. 7). He further points out that the maintenance of a system developed by a university for industrial use is counter to the academic interests of the university.

This is not intended to say that universities should not or are not able to contribute to the development of IPAD technology. Their need for viable graduate research projects and the many contributions to technology derived from them are acknowledged. However, the limitations of the university environment should also be recognized.

3.3.4 Government Agencies

Government agencies procuring aircraft generally do not design the vehicle. Their role is in providing mission specifications and in monitoring and evaluating the design as it is developed by an aircraft company. This specification, monitoring and evaluating function requires considerable communication with the contractor involving technical data. This communication would be effectively improved by IPAD technology. One agency stated that it is requiring, in certain contracts, that the contractor provide data for processing through the agencies preliminary design integrated system.

Government agencies procuring naval ships perform the ship design. The Naval Ship Research and Development Center (NSRDC) is developing an Integrated Ship Design System (ISDS) (ref. 3) for the preliminary design of surface ships. This system will utilize a large data base as the principal vehicle for communication of data between various technology groups. The system will be interactive. The principal purpose of the system is to reduce the flowtime required to complete a preliminary design to about 10% of that presently required. They are also generalizing this development to include all phases of ship design. The general effort providing the framework of capabilities for constructing integrated systems is the Computer-Aided Design Environment (COMRADE) project (ref. 4, 5).

JULY 1972

IPAD SURVEY

Copy Number ______

This survey form is intended to be a convenient way for you to respond with information useful to the IPAD Feasibility Study. Please understand that there is no intent to pry into the internal affairs of your company nor is this an attempt to obtain proprietary information from you. If you feel a particular question cannot be properly answered by you, simply pass it by. We do ask, however, that you be as generous as possible with the information you provide. In areas where you wish to elaborate your reply with text, please attach additional pages. Please complete as many items as possible prior to my visit.

Some questions are answered by a choice of weighting symbols. The legend for these symbols is as follows:

- O = Outstanding in importance
- I = Important
- L = Low importance
- U = Unimportant

This survey form is divided into the following sections:

- I. IPAD Justification
- II. Existing Integrated Systems
- III. System Software and Hardware
- IV. Technical Software
- V. Implementation Strategy and Schedule
- VI. Operational Strategy and Cost
- VII. Impact on Man
- VIII. Impact on Organizations
- IX. Impact on Products

Reference is frequently made during this survey to text and figures included in the SUMMARY which was sent with the survey form.

Stanley D. Hansen
The Boeing Company
Commercial Airplane Group
P. O. Box 3707
Seattle, Washington 98124
Telephone 206 237-8142

Your Name ______________________________ Company ______________________________

Date ______________________________ Organization ______________________________

A18

I. IPAD JUSTIFICATION

A. General Benefits - In the SUMMARY under Why IPAD?, several general areas are described where the use of an integrated system on the scale of IPAD could make an improvement. Would you please (1) weight each area in terms of how important improvement in the area is to the aerospace industry today; and, (2) weight the impact IPAD can make upon the area.

		Importance to Industry	IPAD Impact
1.	International Competitiveness	0 I L U	0 I L U
2.	Expanding Product Diversity and Complexity	0 I L U	0 I L U
3.	Communication of Technical Data	0 I L U	0 I L U
4.	Technical Depth/Flowtime	0 I L U	0 I L U
5.	Configuration Control	0 I L U	0 I L U
6.	Technology Transfer	0 I L U	0 I L U
7.	Duplication of Software	0 I L U	0 I L U
8.	Full Vehicle Research	0 I L U	0 I L U

Are there items you would add to the list? Please attach a short descriptive paragraph.

9.	______________________	0 I L U	0 I L U
10.	______________________	0 I L U	0 I L U
11.	______________________	0 I L U	0 I L U
12.	______________________	0 I L U	0 I L U
13.	______________________	0 I L U	0 I L U
14.	______________________	0 I L U	0 I L U
15.	______________________	0 I L U	0 I L U

B. Direct Benefits - The following areas are more direct ways in which IPAD might benefit a using organization. Would you again weight each area as to (1) its importance to the industry as an area needing improvement, and (2) the impact IPAD might have upon the area.

	Importance to Industry	IPAD Impact
1. Better manpower utilization as evidenced by:		
o Less manhours required to perform the same task	O I L U	O I L U
o The <u>average</u> labor skill required to do a task may be lowered	O I L U	O I L U
2. Lowered computing costs per unit of useful result	O I L U	O I L U
3. Reduced flowtime required:		
o To transfer data/code between locations	O I L U	O I L U
o To transfer data between technologies	O I L U	O I L U
o To complete a design cycle	O I L U	O I L U
o Because of error reduction resulting from automatic data transfers and better control of execution sequences	O I L U	O I L U
4. Consistent data base resulting in:		
o A common reference system for geometry, modeling, loads, etc.	O I L U	O I L U
o Visibility of changes to both data and technical code	O I L U	O I L U
5. Computer aided production of document quality reports from data on the data base.	O I L U	O I L U

	Importance to Industry	IPAD Impact
6. The ability to conduct design research in:		
o Design methodology, i.e., better approaches to the design task	O I L U	O I L U
o Product configuration, both general and detailed	O I L U	O I L U
o Evaluating technical capability produced by others and made available as public domain or by sale	O I L U	O I L U
7. More effective utilization of technical people in terms of less routine and more directly creative work.	O I L U	O I L U
8. Improved manufacturing efficiency in:		
o Reduced tooling changes because of more timely or more accurate engineering	O I L U	O I L U
o Reduced retrofitting requirements because of more timely or more accurate engineering	O I L U	O I L U
o Increased manufacturing and assembly efficiency because of a more accurate transmittal of data	O I L U	O I L U
9. Improved product in terms of:		
o Integrity of structure and systems	O I L U	O I L U
o Ability to design products beyond the state-of-the-art of today's technology	O I L U	O I L U
o Increased creativeness of designers because of the availability of a comprehensive multitechnology tool that can be utilized by one or few persons	O I L U	O I L U
o Offering improved performance to customers	O I L U	O I L U
10. Usefulness to universities as an educational tool that provides:		
o Research opportunity	O I L U	O I L U
o Realistic study of practical problems	O I L U	O I L U

	Importance to Industry	IPAD Impact
11. Usefulness to government for:		
o Hardware design evaluation by requiring analytical models as well as wind tunnel models	O I L U	O I L U
o Aircraft concept research	O I L U	O I L U
o Reduction of software acquisition costs through elimination of duplication	O I L U	O I L U

Are there items you would add to the list?

	Importance to Industry	IPAD Impact
13. ______________________ ______________________	O I L U	O I L U
14. ______________________ ______________________	O I L U	O I L U
15. ______________________ ______________________	O I L U	O I L U
16. ______________________ ______________________	O I L U	O I L U
17. ______________________ ______________________	O I L U	O I L U
18. ______________________ ______________________	O I L U	O I L U

A22

II. EXISTING INTEGRATED SYSTEMS

A. Do you now have one or more integrated systems in use or development? yes no

If yes, would you answer the following:

B. What technologies/subtechnologies did you integrate? Example: Structures/Stress.

System 1	System 2	System 3
Technologies ______	Technologies ______	Technologies ______
______	______	______
______	______	______
Subtechnologies ______	Subtechnologies ______	Subtechnologies ______
______	______	______
______	______	______
______	______	______
______	______	______

C. At what level of design are your systems directed? Refer to SUMMARY Figure 4.

	System 1	System 2	System 3
Design Mission Selection	______	______	______
Configuration Sizing	______	______	______
Configuration Refinement	______	______	______
Configuration Verification	______	______	______
Product Detail Design	______	______	______
Other ______	______	______	______
______	______	______	______

D. Do your systems interface directly with any of the following areas?

		System 1	System 2	System 3
1.	Manufacturing	______	______	______
2.	Product Verification (static/flight test)	______	______	______
3.	Product Support (In-service)	______	______	______
4.	Other ______	______	______	______
5.	______	______	______	______
6.	______	______	______	______
7.	______	______	______	______
8.	______	______	______	______

E. What is the status of your system?

1. When did development begin?

System 1	pre 1960	1960-65	1965-70	after 1970
System 2	pre 1960	1960-65	1965-70	after 1970
System 3	pre 1960	1960-65	1965-70	after 1970

2. Were your systems developed from pre-existing technical code?

System 1	yes	no	partially
System 2	yes	no	partially
System 3	yes	no	partially

3. Are your systems used consistently in productuction today?

System 1	yes	no	in development
System 2	yes	no	in development
System 3	yes	no	in development

4. Do you have a continuing research activity directed to the steady evolvement and expansion of your integrated systems?

System 1	yes	no
System 2	yes	no
System 3	yes	no

III. IPAD SYSTEM SOFTWARE AND HARDWARE

A. SUMMARY figures 1, 2 and 3 show possible logical organizations of IPAD system components. If you have any criticism or if you can recommend changes or extensions to these figures, would you please do so by marking on the figures or by supplying alternate figures and text.

B. The following are some of the characteristics that are being considered for the IPAD system as necessary to support the objectives you responded to in sections I, IPAD JUSTIFICATION. Would you please weight them according to (1) the extent you have included the characteristic in you systems, and (2) the extent you believe the characteristic should be included in IPAD.

		Your System	IPAD
1.	Accessibility to the degree that the flowtime required to access the system, code and data does not significantly contribute to the flowtime of the design process.	O I L U	O I L U
2.	Language, vocabulary, grammer and syntax directed to the technical task being performed rather than to the file handling and computer processing steps.	O I L U	O I L U
3.	Conversational languages, including prompts, cues, error diagnostics, etc., that lead and assist the user to correct data and execution with minimum flowtim.	O I L U	O I L U
4.	Instructional language using cryptic high level commands for the experienced user and allowing calls for explanations, definitions, data formatting, etc., to the level the less experienced user requires.	O I L U	O I L U
5.	Editing routines for online inputting and modifying data or code files.	O I L U	O I L U
6.	Routines to detect errors or inconsistencies in execution sequences or data	O I L U	O I L U

		Your System	IPAD
7.	Online display of test, data items, vectors, or matrices as tabular print, x-y plots, contour plots, etc., as appropriate.	O I L U	O I L U
8.	The capability to input end-products or results of some type or character and have possible or recommended execution paths and alternates returned.	O I L U	O I L U
9.	The online ability to devise strings of execution sequences through evaluation of selected results and control the execution and selection of alternate paths.	O I L U	O I L U
10.	The online ability to observe the direction of change or degree of closure during optimization cycling and interdict for purposes of redirection, changing values or stopping.	O I L U	O I L U
11.	The online ability to access the data base for purposes of editing, transferring, changing, replacing or purging data files.	O I L U	O I L U
12.	Online accounting for jobs, groups of jobs, projects for computing results used or projected to be used for a particular execution sequence or calendar time period.	O I L U	O I L U
13.	High level security safeguards in terms of passwords, keywords or other such identifiers on code and data files to protect against inadvertent or unintentional access, theft or spying and to provide management control of the technical code and the project data base.	O I L U	O I L U

A26

	Your System	IPAD
14. A portable data bank whereby portions or all of a data bank can be removed from the system and be complete in the sense that all decriptors, keys, identifiers, etc., necessary for the IPAD system to re-enter the removed data into the data base are included in the data.	O I L U	O I L U
15. Inter-machine communication whereby data or code can be transferred between computers of the same or different manufacturer.	O I L U	O I L U

Others you wish to add?

	Your System	IPAD
16. ______	O I L U	O I L U
17. ______	O I L U	O I L U
18. ______	O I L U	O I L U
19. ______	O I L U	O I L U

IV. TECHNICAL SOFTWARE

A. SUMMARY figures 4, 5, 6, and 7 are an example of a design process flowchart for a particular product. Further refinement of this flowchart will reveal the specific depth and scope of technical software requ red to support this design process. Some of this software will be general. Some will be specialized to this product. A search is being made by the specialists on the Boeing IPAD team for technical software throughout government and industry. They will be making contact separate from this survey. It would be helpful if you can identify persons within your organization and technical software they support.

Name	Technical Software	Documentation Available to IPAD Survey	
______	______	yes	no
______	______	yes	no
______	______	yes	no
______	______	yes	no
______	______	yes	no
______	______	yes	no
______	______	yes	no
______	______	yes	no

B. Do you have any high level design process flowcharts such as SUMMARY figures 4 thru 7 that you are able to release in response to this survey? yes no

C. Automated optimization or parametric studies across broad technology groups is an important part of the IPAD feasibility study. Do you have capability or studies in this area that you are able to release to this survey? yes no

A27

A28

V. IMPLEMENTATION STRATEGY AND SCHEDULE

A. NASA has expressed an intent to achieve as broad an industry participation in the development of the IPAD system as possible in order to achieve a high quality system and to stimulate its use on a broad basis. Which of the following software packages would you expect to bid on?

System executive ________ Terminal Interface ________ Interactive Graphics ________

Data Base Manager ________ Network Interface ________ ________

Technical Software (Please identify technology)

		Reference Available to This Survey?	
1.	________________________	yes	no
2.	________________________	yes	no
3.	________________________	yes	no
4.	________________________	yes	no
5.	________________________	yes	no
6.	________________________	yes	no

B. It is planned that IPAD will be developed as a first implementation somewhere near the 1975-76 period. Do you have a recommendation of what technologies/disciplines/design levels/software packages should be included in the first implementation?

Technologies ____

Disciplines ____

Design Levels ____

Software Packages ____

VI. OPERATIONAL STRATEGY AND COST

A. An argument can be made that the product of the aerospace industry is flight vehicles and that the competitiveness of the industry should be centered upon the invention and manufacture of these vehicles. Hence, the argument goes, the industry is better served by cooperating in the development of computational tools; manufacturing tools and data-communication facilities than in competing over the development of these tools. An example is the industry acceptance of APT for NC tools. Do you

agree   disagree

Comment ____________________

____

____

____

____

B. If your company was to make software available to the IPAD system, would you most likely:

1. Sell the software outright
2. Charge a royalty
3. Make it available for the cost of installing it in the IPAD system.

C. Do you have any published or internal documents on any of the following:

1. Direct cost savings in manpower, computing costs, or manufacturing costs that can be traced directly to the use of an integrated system?

   yes   no   If yes, is it available to the IPAD survey?   yes   no

2. Reduction in flowtime to achieve a design result?

   yes   no   If yes, is it available to the IPAD survey?   yes   no

A29

A30

VII. IMPACT ON MAN

A. In using integrated systems, have you experienced any of the following effects upon your men? Please circle correct answer.

1. Creativeness increased decreased no change

2. Tedium increased decreased no change

3. Noticeable change in manpower skill mix. yes no If yes, answer the following:

   o Average skill higher lower same

   o Average unchanged but requires higher skilled engineers with increase in technical aids. yes no

   o Other ____

   ____

4. Any obsolescence of skills? yes no If yes, would you indicate what skills.

   ____

   ____

B. In implementing computer codes into production engineering organizations, which of the following has occurred?

1. Ready acceptance

2. Rejection as
   o Not required to design product

   o Lacking in display and interpretation capability

   o Fear and dislike of computer intrusion into traditional human activity.

C. Do you believe that a system as broad in scope as IPAD would be accepted within your organization?
o by the engineer yes no
o by the manager yes no

VIII. IMPACT ON ORGANIZATIONS

A. Has the use of computer codes, particularly integrated systems, caused you to significantly restructure your technical organization in order to effectively use the tool?

yes no

B. If yes, did you do any of the following:

- Combine technologies under a single management. yes no (If so, could you include a comment on what was generally done?)

  Comment ____

  ____

  ____

  ____

  ____

- Place the responsibility for technical data computation and communication at a higher management level in your organization. yes no (If so, could you include a comment on what was generally done?)

  Comment ____

  ____

  ____

  ____

  ____

C. Acceptance of IPAD may require some restructuring of your organization in order to use the tool effectively. Would this be a barrier to your acceptance of IPAD?

yes no

IX. IMPACT ON PRODUCTS

A. Do you have any tangible evidence in the form of published papers, documents or reports where the use of integrated computer systems have directly affected your product in a measurable way?

yes   no   Can you release it to the IPAD survey?   yes   no

B. Does your evidence impact any of the following:

_____ Made the design possible

_____ Converged analysis before manufacture

_____ More reliable vehicle

_____ More highly evolved vehicle at time of first production

_____ More highly developed vehicle earlier in the design process because of use

_____ Weight savings

_____ Lower cost vehicle

_____ More durable, greater fatigue resistant vehicle

_____ Less tooling changes

_____ Less retrofitting

_____ Better assembly

Other ____

____

____

____

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APPENDIX B — SUMMARY

FEASIBILITY STUDY OF AN INTEGRATED PROGRAM

FOR

AEROSPACE-VEHICLE DESIGN (IPAD)

July 1972

Prepared as introductory material to an industry wide survey being conducted as part of the study contract.

Contract NAS1-11441

NASA Langley Research Center, Hampton, Virginia

The Boeing Company
Commercial Airplane Group
P. O. Box 3703
Seattle, Washington 98124

B2

IPAD FEASIBILITY STUDY

In early 1972, NASA Langley issued two contracts to study the feasibility of integrating the computational and data management requirements of all of the technologies contributing to aerospace vehicle design within one computing system. One contract was issued to The Boeing Company, Commercial Airplane Group, Renton, Washington. The second contract was issued to General Dynamics, Convair Division, San Diego, California. The study calls for consideration of the following areas:

TASK 1 The extent to which the design process could be supported through analysis programs, optimization, and data presentation within a single integrated computer program system.

TASK 2 The generation of a paper design of the computing system sufficient in detail to show handling of pre-existing code, machine dependency, man/machine interface, executive features, data base management, and optimization looping.

TASK 3 Alternative implementation strategies and schedules including consideration of the involvement of industry, universities and government and the use of proprietary code.

TASK 4 The cost of development associated with the alternatives in Task 3.

TASK 5 The cost of operation including the effect of future generations of computers, training, people obsolescence and effect on product cost.

TASK 6 The tangible and intangible impact of IPAD upon product quality, engineering creativeness, and interdiscipline cooperativeness and communication.

TASK 7 The effect upon existing design organizations and the ramifications of those organizations relative to the acceptance and use of IPAD.

TASK 8 The usefulness of IPAD implementation to non-aerospace organizations in terms of concepts, experience, non-technology software, etc.

THE BOEING APPROACH TO THE IPAD FEASIBILITY STUDY

Boeing is approaching the study in the following steps:

1. Study the general characteristics of the product design process by considering the design requirements of several typical aerospace vehicles.

2. From this study, ascertain technical software, useful optimization procedures, man-machine interface characteristics, system executive functions, data base management functions, system sizing characteristics, etc.

3. Determine the computer system characteristics that will meet the requirements identified in the design process study.

4. Conduct a broad survey of industry, universities and government agencies to obtain as broad a view as possible of potential IPAD use, recommendations on system architecture, potential technical modules, acceptance of the IPAD concept, and a general view of the impact of existing systems upon man, organizations and products.

5. Synthesize a system that includes those characteristics and capabilities that have been revealed by study and by survey.

Boeing has chosen this approach rather than a direct attempt to extend an existing system, believing that a study of extending an existing system would prejudice the study of IPAD feasibility towards the purpose of that system and, further, that no existing system has evidenced the depth of concept necessary to successfully fulfill the objectives of IPAD.

B4

WHY IPAD?

Many integrated systems are currently being developed throughout industry and government to interface previously independent activities. Generally, these systems serve a restricted need in that they integrate divisions within a single technology (e.g., stiffness generation, internal loads, flutter, etc., integrated into a structures program) or they integrate several technologies in some limited part of the design process. The IPAD Feasibility Study is generally directed to a broader scope than these systems in that design at the product level rather than at the technology level will be considered.

Consideration of design at the product level infers development of a system that will impact the areas described below.

Expanding Product Diversity and Complexity - The demand for more varied and higher performing aircraft has been increasing steadily. To meet these demands, the size of engineering staffs has increased and the volume of data generated per engineer has been multiplied several times. In addition, there is an increasing need to perform more analysis on a more timely basis during preliminary design. The ability of the industry to meet these requirements seems increasingly dependent upon the development of capability to control, interpret and communicate data.

Communication of Technical Data - Technical software development has been a hodge-podge of noncommunicating computer codes. The result is the virtual impossibility of transferring hard technical data between technologies or from location to location in an efficient or meaningful manner. This communication is made many times more difficult where hardware or operating systems of different manufacture are involved. The effect of this inability to communicate is felt within design groups, between companies contracting on the same product and within government in attempting to evaluate procurements.

Technical Depth/Flowtime - The increasing complexity of product and the inability to effectively communicate technical data has intensified the competition between adequate technical depth and available flowtime. Hence, it is becoming increasingly difficult to analytically converge the design prior to basic commitments to manufacturing.

Configuration Control - The configuration of a space vehicle is ultimately expressed as digitized geometry. Performance, control, loads, stiffness and strength are similarly expressed. The total volume of data is enormous: billions of words for a modern transport. Control of the creation and changing of this data base becomes an essential part of management of the development of the vehicle. Control of the entire product data base is difficult if it exists as an uncorrelated fractured set and if there is no software to control accessing and change or to monitor contents.

Technology Transfer - A great volume of computing code representing advances in technology is being generated. Considerable amounts of this code is government funded and therefore public domain. The utilization of this technology is dependent upon being able to execute the computer code. Since no effective standardization of computing software or hardware has been established within the industry, most of this technology gives little benefit to other than the company doing the development. There is an increasing tendency for product development to be contracted over several companies. In this circumstance, it is desirable to use common technology and to base the product design upon a common data base. Because of the independent manner in which technical software is developed, this communication is often ineffective or impossible.

Duplication of Software - The uniqueness of local computing facilities makes the evaluation of "out-of-company" software difficult without expensive and time consuming conversion. The current condition is that it is less expensive and more effective to develop technical software locally than to attempt to take advantage of any existing software having similar characteristics. This is a restatement of the technology transfer problem and its effect is duplication of software development both privately and in the public domain. Certainly, private development of software will continue to be necessary, but where the development has the same essential characteristics as existing systems publicly available and the duplication is motivated by an inability to effectively evaluate or convert existing systems, the development is wasteful.

Full Vehicle Research - New product configurations without historical precedence, further optimization of existing configurations or evolvement of more complex products can be advanced with the availability of computational tools for doing full vehicle research. To be effective, these tools must be of such scope and depth that all controlling vehicle performance parameters can be evaluated and optimized within reasonable flowtimes.

International Competitiveness - The development of aerospace products is becoming internationally competitive. Progress in each of these areas described above on a total industry level, would increase the technical competence of the industry as a whole, and, hence, contribute to our ability as a nation to remain competitive in the international aerospace market.

B6

WHAT IS IPAD?

The following general features are being emphasized in the design of the IPAD system as a direct assault upon the problem areas described in the previous section.

Data Continuity - A data base and data base manager are being designed to receive data on a project basis and to provide control of populating, accessing and changing of both technical data and technical code. The effect of this capability will be that the entire data base related to a vehicle design project will be under the direct administrative control of the project manager and will remain the depository for all project technical data throughout the life of the project.

Data Transfer - Network communication facilities and the data base manager are being designed to provide transfer of data between executing modules and transfer of both code and data between locations, remote and local.

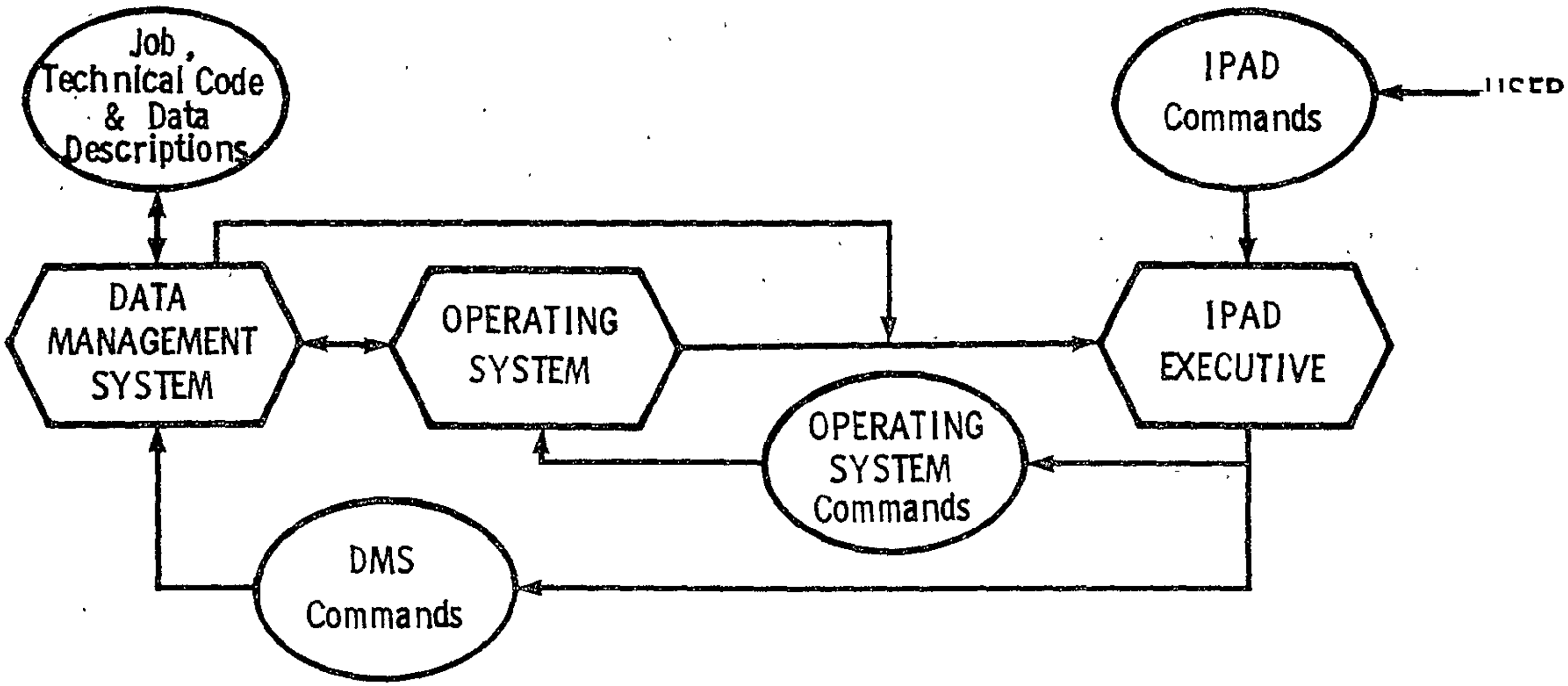
Technical Code - IPAD is being designed with the philosophy that the technical code will be changed frequently to meet the requirements of individual projects. This change requirement will be supported by automated version tracking of coding changes and by software to aid the insertion of new technical code into the system.

Data and Computer Code Security - Proprietary computer codes within the system, accessing of computer codes and data by multiorganizations, several projects using the system simultaneously and management control of the data base will require a high level system of security provisions within IPAD to prevent inadvertent and unintentional accessing, unauthorized changing of code and data, theft and spying.

Pre-Existing Code - IPAD will have to include pre-existing code in order to utilize the enormous investment in existing technical software. A method for interfacing uncoordinated coding packages does not currently exist; however, some software advances to make conversion of existing codes less difficult seem feasible.

Activity Control - The user interface, as shown in Figures 1, 2 and 3, will provide a means of communication and control whereby the designer will be able to pursue the solution of a problem without interruption of his thought processes for activities unrelated to the problem he is solving. It is intended that the flowtime required to access and utilize the IPAD system will not significantly contribute to the flowtime of the design project. A possible organization of activity control is shown in Figure 1.

IPAD System Activity Control



IPAD Commands — Represents a set of activities the user desires to be executed

Descriptions — Defines a set of relations between technical code, data, and jobs

OPERATING SYSTEM Commands — Request on the operating system software for a specific computing function

DATA MANAGEMENT SYSTEM (DMS) Commands — Requests on the DMS for data

Figure B1

IPAD System Software - A possible logical organization of the system software is shown in Figure 2. The host computer operating system provides a supporting medium for IPAD software activities. Access to the IPAD system executive will be via the host operating system. Once accessing is established, some direct communication between the user and some parts of the IPAD system will take place.

The executive will support discontinuous execution of a task over a period of days and weeks. This does not imply restart capability in the conventional sense, but rather recognition within the system that the user will be going on and off the system, as a regular part of his interface methodology, without losing continuity of the task execution within IPAD.

The system data base will be a continuous entity, available on the system at all times. The data base will have multiple purposes including:

- information files containing performance data and catalogs
- product level files containing basic product descriptors such as geometry, loads, etc.
- technology level files housing intermediate data useful only to a specific technology in computing more general data to be placed on product level files.
- archival files for data of long term historical or legal significance.

The data base manager will be responsive to multirun executions, transfer of data between executing modules, security, data integrity, and direct accessing of data for report, display and transfer purposes.

IPAD Technical Software - The technical software is organized into groups of operating modules which contain code related to a particular technology such as structures or controls, for example. The placement of the technical software within the IPAD system may be similar in concept to that of the data base, and, in fact is accessible to the data base manager for transfer as data through the network as shown in Figure 1. It is intended that all of the software necessary to a project be included within the IPAD system in order to maintain management control and to obtain the benefits of fully interfaced technologies in terms of information or data transfer.

IPAD System Software Organization

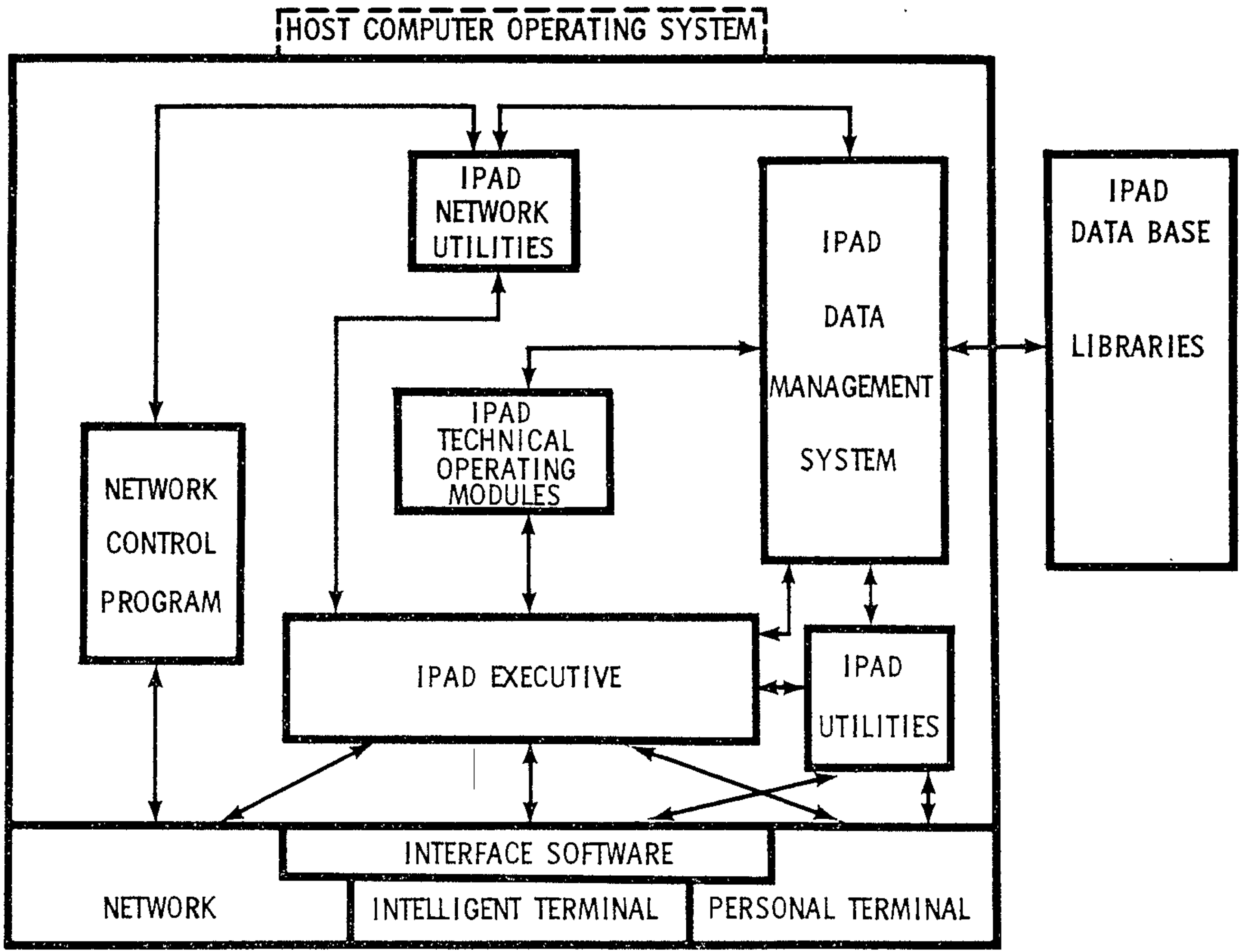


Figure B2

IPAD System Hardware - A possible logical organization of the system hardware is shown in Figure 3. The processing load is distributed among the host CPU(s) and I/O stations. The modularity and multiple connections provide:

- o redundancy in case of failure, maintenance or saturation;
- o expansion and contraction without total reorganization; and,
- o an assignment of the computing work load to devices optimized for the task.

The figure is self-explanatory to the level of definition known at this time.

User Interface - The primary interface with IPAD will be through terminals as illustrated in Figures 2 and 3. A terminal interface will provide the designer with the means to pursue a solution without interruption to his thought processes and without the interference of considerable effort related to accessing the computer but not related to the solution of his problem. A terminal will also provide a means of instantaneously transferring, accessing and changing both data and code and displaying selected data as reports, graphs or plots. It will give the designer the means of evaluating results and redirecting computations through interdiction and interaction on a real time basis. The strength of the user interface will determine the extent to which IPAD is successful in giving the designer a practical means of coping with very large amounts of information.

IPAD System Host Hardware

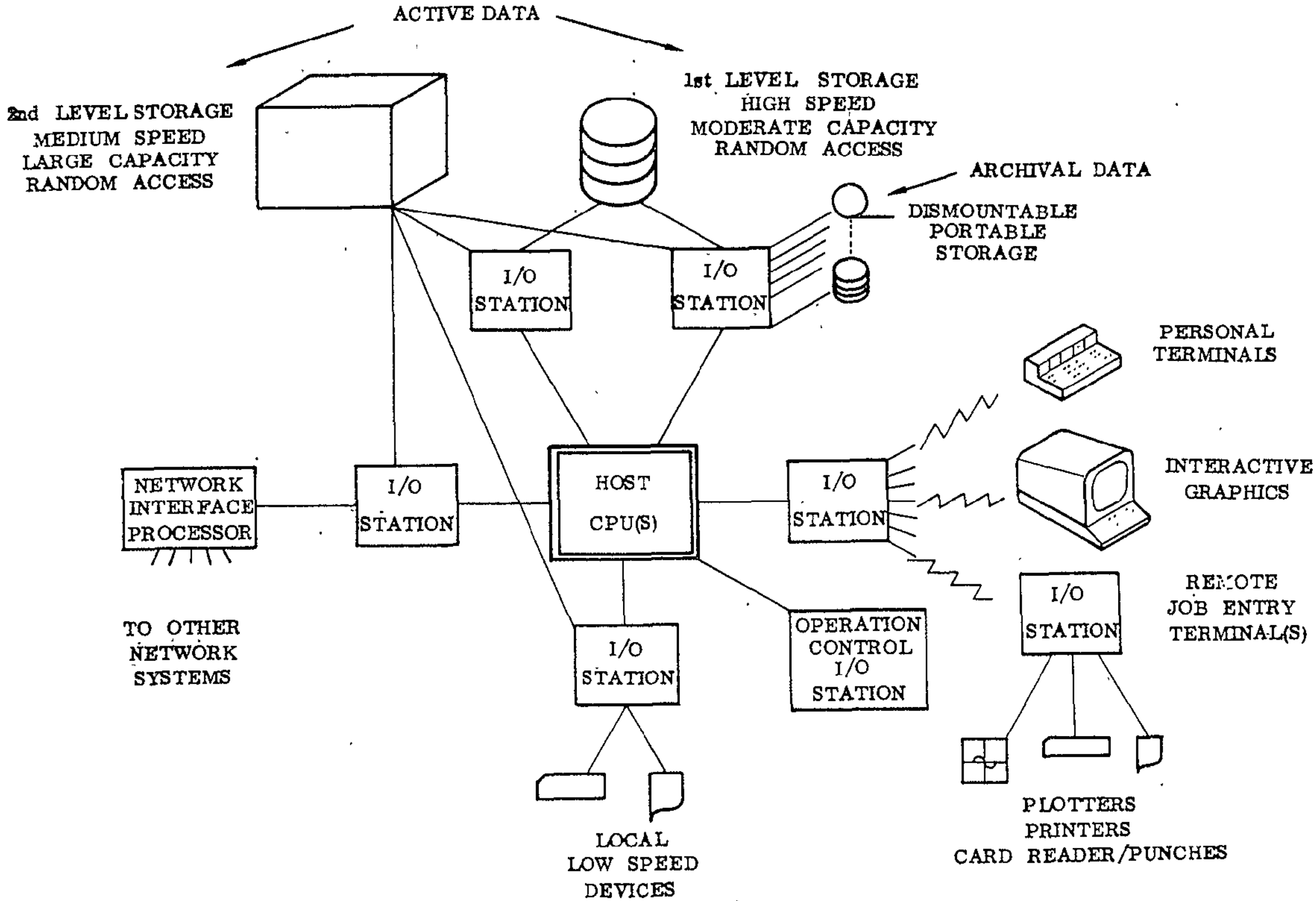


Figure B3

WHAT IS THE PRODUCT DESIGN PROCESS?

Product design is as dynamic as the number of different products to which it is applied and the number of different people involved. It is not intended for the development of IPAD to result in a rigidly defined design process. Rather, IPAD is intended to provide a "tool case" of technology modules and a means of communication. However, to determine what technology modules should be included in IPAD, it is necessary to study typical design problems. Figures 4 through 7 and the accompanying text are the results of such a study for a subsonic transport. The process shown is high level and representative of studies being carried out as part of the IPAD contract to determine what technology modules should be included.

The philosophy of design levels, as shown in Figure 4, is to provide that product design information required at a particular development stage within a useful flowtime. Typical estimates of flowtimes in an IPAD environment are:

LEVEL I	Continuing Research Continuous updating of IPAD technology
LEVEL II	Design Mission Selection Computational flowtime - half hour
LEVEL III	Configuration Sizing Computational flowtime - half day
LEVEL IV	Configuration Refinement Computational flowtime - one week Converged design - one month
LEVEL V	Configuration Verification Computational flowtime - one month Converged design - eight months
TOTAL	Approximately 12-15 months, start of Level II to end of Level V.

In Levels II and III the design process is envisioned to require a small amount of human intervention, therefore, the computational flowtime is the total design time. In Levels IV and V a distinction is made between computational flowtime (one straight computation cycle) and converged design flowtime (several parallel investigations utilizing human intervention).

SUBSONIC COMMERCIAL TRANSPORT

Design Levels

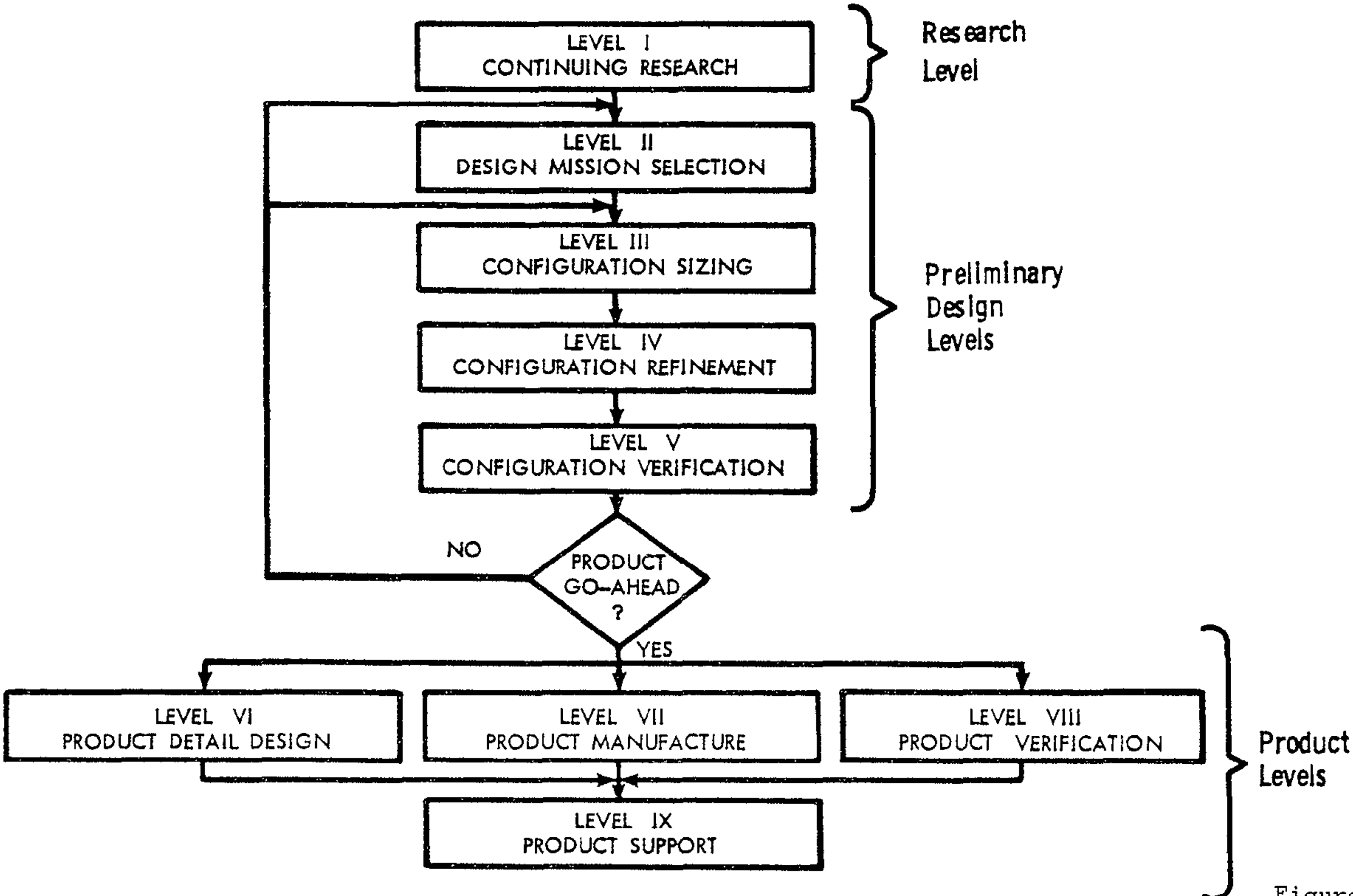


Figure B4

Figures 5 through 7 present the 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.

Preliminary Design Level II and Level III - 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, thin route airplane. The analysis to select the best design mission uses airline operational requirements and histories, route information and performance data for a nominal configuration and projects market suitability and forecasts 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. The required flowtime for one Level II investigation is one half hour.

The goal of Level III is to size a candidate configuration to the design mission and to select "best" from competing configurations. Thus, the analyses of Level III must be more accurate than Level II. The required flowtime for one Level III investigation is one half day.

The first part of Level III sizes the airplane geometry of a candidate configuration. The 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. 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. Noise footprints are produced.

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 is done to decide if the configuration is to be carried to Level IV.

SUBSONIC COMMERCIAL TRANSPORT

Configuration Studies

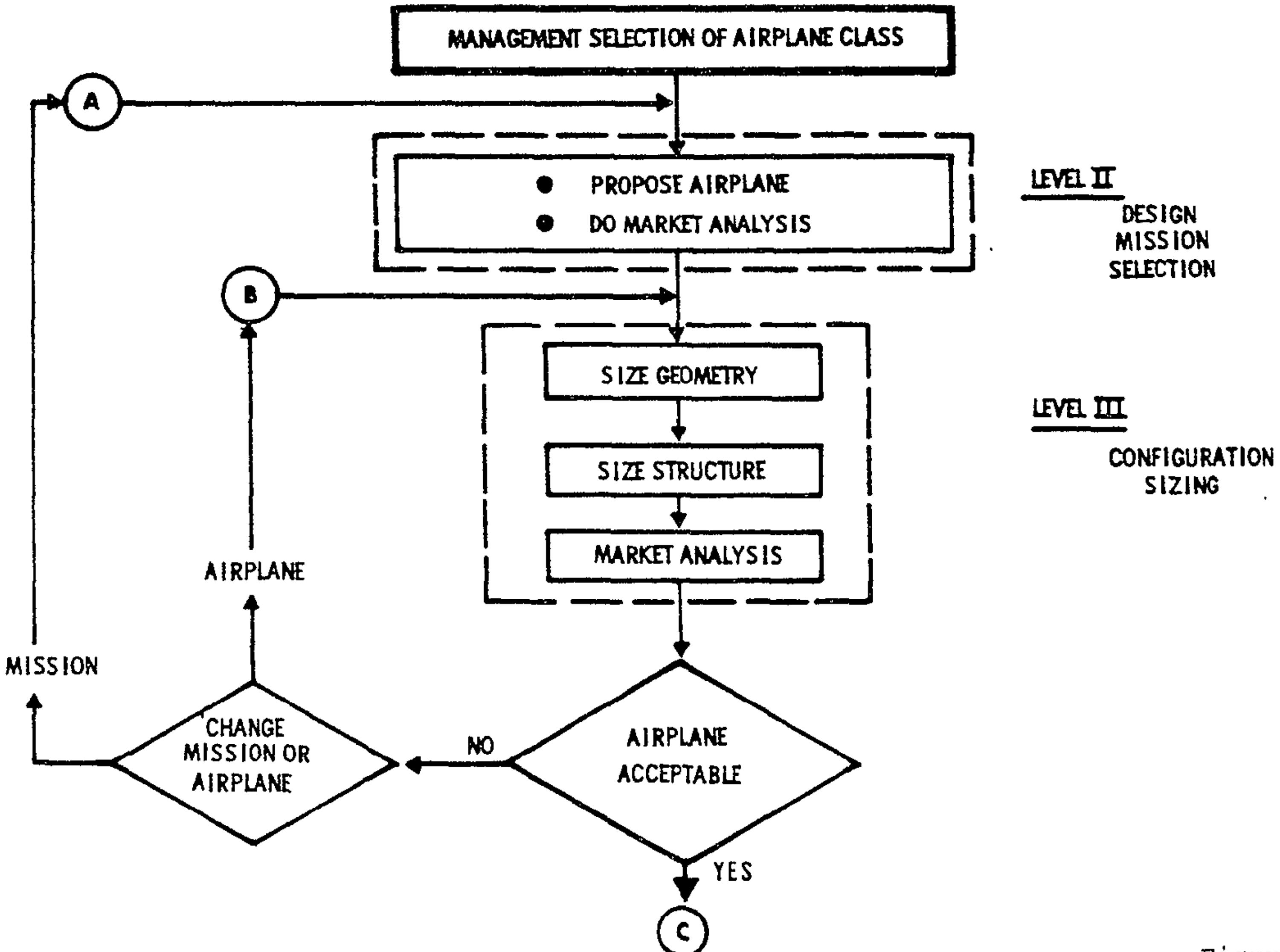


Figure B5

Preliminary Design Level IV - Figure 6 shows the main tasks and decisions of 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 time has been made. The analysis programs are linked across their data interfaces, and this allows a flowtime of a week or less to be accomplished for one pass through Level IV. 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, 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.

(continued)

Hydraulic, electric, pneumatic and other systems are now sized and designed. This provides more accurate 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. A first estimate of costs and product program schedules is made. This is the last activity of Level IV.

The design sequence of Level IV is not generally performed straight through. In normal usage, most tasks are done several times in a series of loops whose paths depend on the previous results. A converged design flowtime of one month is required. 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.

SUBSONIC COMMERCIAL TRANSPORT

Preliminary Design

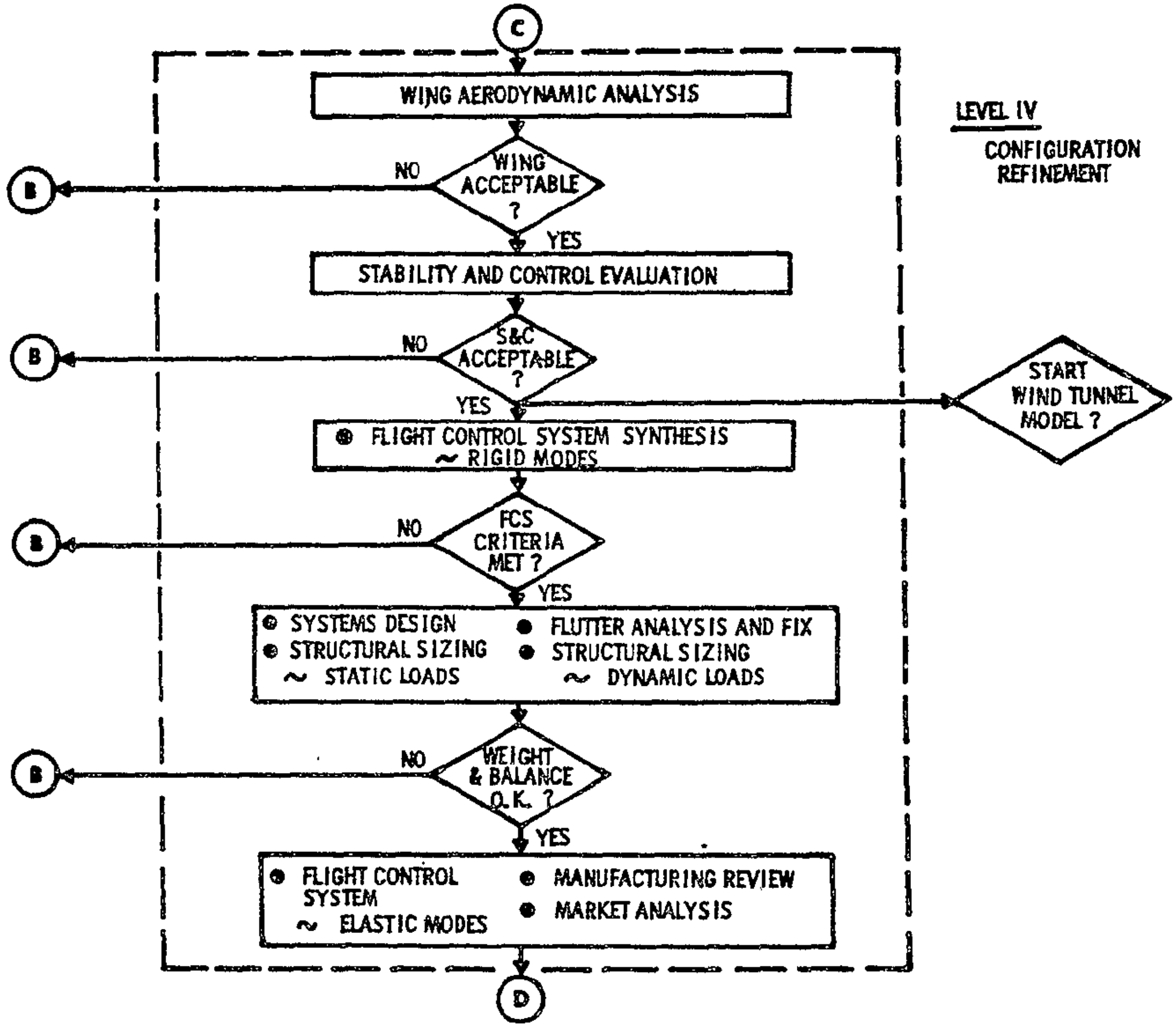


Figure B6

Preliminary Design Level V - Figure 7 shows the main tasks and decisions of 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 analyses so that no surprises will be found in the product detail design phase (Level VI). Some activity precedes the formal tasks of Level VI. The performance and market analyses done at the end of Level IV are reviewed, and if the configuration is not acceptable, then either the configuration is changed (Level III) or the design mission is changed (Level II). If the configuration is acceptable, and the wind tunnel model design was begun in Level IV, then that design activity continues. Modifications to the model design are introduced 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 model design will result in a lofted 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 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. Their analyses are updated by entry 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 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 a twelve month period with one cycle flowtime of four to five 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, 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 commitement, and the design process goes to Level VI. If not, a technical review considers the configurations and any recommendations from the management review to determine the next action.

SUBSONIC COMMERCIAL TRANSPORT

Preliminary Design (cont'd.)

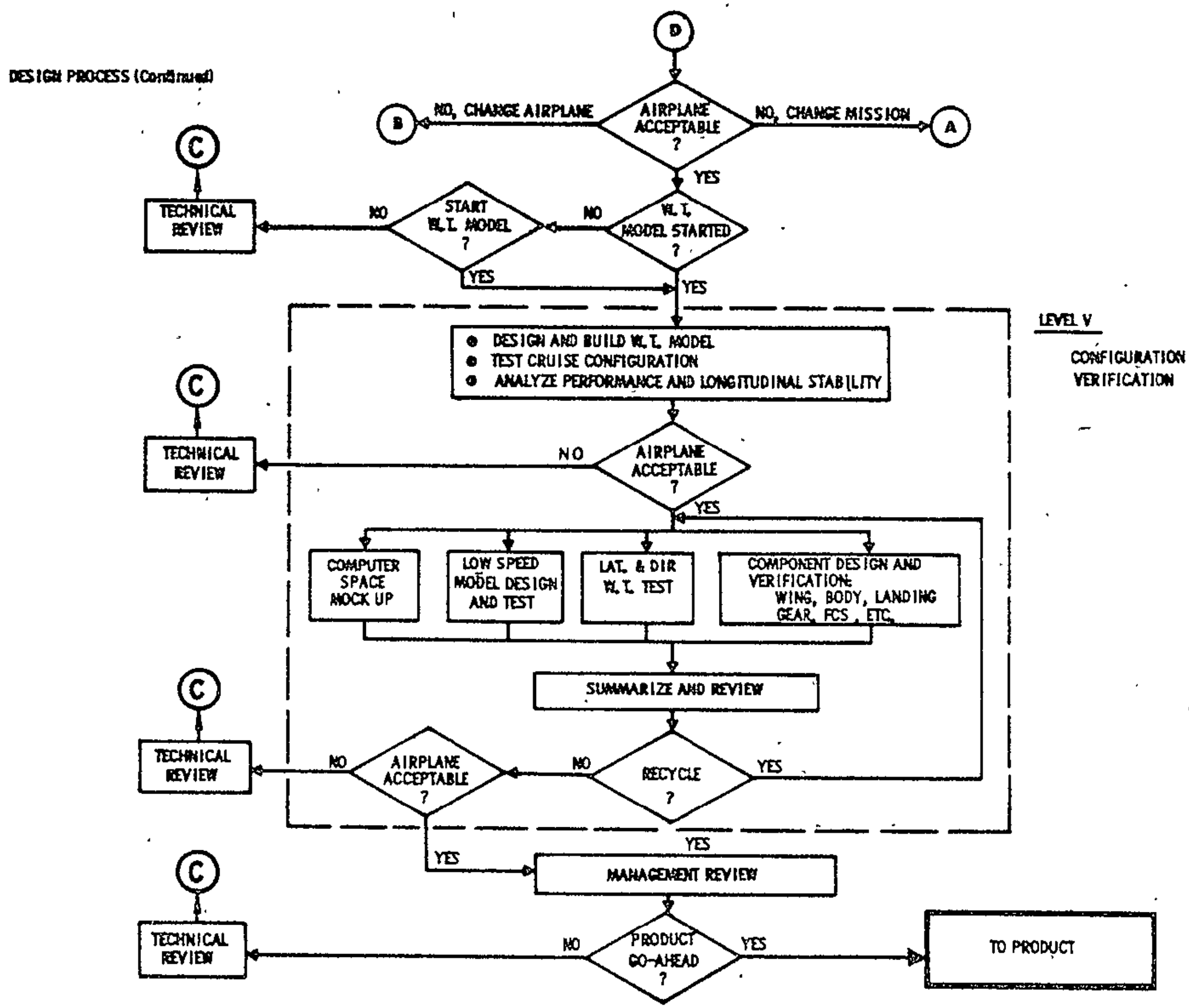


Figure B7