

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

by C. A. Garrocq, J. J. Hosek, et al.

VOLUME III

ENGINEERING CREATIVE/EVALUATION PROCESSES

(PHASE I, TASK 2)

August 30, 1973

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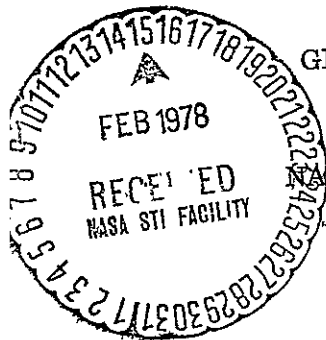
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INTEGRATED PROGRAM FOR AEROSPACE-VEHICLE  
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PHASE 1, TASK 2 (General Dynamics/Convair)

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

VOLUME I - SUMMARY

VOLUME II - CHARACTERIZATION OF THE IPAD SYSTEM  
(PHASE I, TASK 1)

VOLUME III	- ENGINEERING CREATIVE/EVALUATION PROCESSES (PHASE I, TASK 1)
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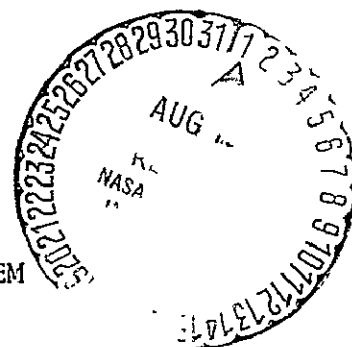
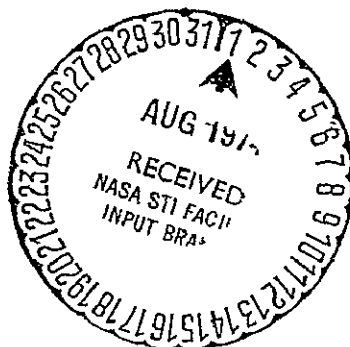
VOLUME IV - DESIGN OF THE IPAD SYSTEM  
PART I - IPAD SYSTEM DESIGN REQUIREMENTS  
(PHASE I, TASK 2)

VOLUME V - DESIGN OF THE IPAD SYSTEM  
PART II - SYSTEM DESIGN  
PART III - GENERAL PURPOSE UTILITIES  
(PHASE I, TASK 2)

VOLUME VI - IMPLEMENTATION SCHEDULE  
DEVELOPMENT COSTS  
OPERATIONAL COSTS  
BENEFIT ASSESSMENT  
IMPACT ON COMPANY ORGANIZATION  
SPIN-OFF ASSESSMENT  
(PHASE II, TASKS 3 to 8)

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VOLUME II  
CHARACTERIZATION OF THE IPAD SYSTEM  
(PHASE I, TASK 1)

30 August 1973

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DESIGN (IPAD) SYSTEM

VOLUME I - SUMMARY

VOLUME II	- CHARACTERIZATION OF THE IPAD SYSTEM (PHASE I, TASK 1)
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## FOREWORD

This investigation was conducted for the NASA Langley Research Center by the Convair Aerospace Division of General Dynamics Corporation under Contract NAS 1-11431.

The NASA Technical Monitor was Dr. Robert E. Fulton, Head, IPAD Technology Section, Design Technology Branch, Structures and Dynamics Division, assisted by Dr. Jaroslaw Sobieszczanski and Mrs. Susan J. Voigt. The Convair Project Leader was Mr. C. A. Garrocq, assisted by Messrs. M. J. Hurley, M. Dublin, J. J. Hosek, O. E. Wheeler, R. A. Westerwick, R. H. Trelease, J. S. Barron, G. W. Bradfield, J. D. Sutliff, W. J. Moran, A. Karemaa, R. T. Schemensky, L. A. Evans, D. S. Osterle, R. G. Huntington, J. L. Howse, H. Roland, R. W. McMickle, K. C. Bonine, J. E. Meyer, R. H. Schappelle, D. Kurpiewski, S. K. Pederson, R. Howe, N. E. Tipton, A. H. Cooper, G. M. Oing, J. M. Maughmer, W. E. Jenkins, T. M. Wooster, J. C. Mallory, B. H. Oman, D. W. Peterson, P. K. Shih, D. R. Diaddigo, R. E. Kenyon, B. J. Kuchta, J. D. Neilson, J. T. Gordon, and W. W. Buckner.

The Control Data Corporation participated in the performance of this study as a subcontractor to the General Dynamics Corporation.

The period of performance was from 15 March 1972 to 30 August 1973.

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## GLOSSARY OF IPAD ACRONYMS

A. C.	AERODYNAMIC CENTER
AGE	AEROSPACE GROUND EQUIPMENT
ALGOL	ALGORITHMIC LANGUAGE
APT	AUTOMATICALLY PROGRAMMED TOOL
APU	AUXILIARY POWER UNIT
BATCH	BATCH MODE PROCESSING
CAD	COMPUTER AIDED DESIGN
CAM	COMPUTER AIDED MANUFACTURING
CEP	CREATIVE/EVALUATION PROCESS
CER	COST ESTIMATING RELATIONSHIP
CM	CENTRAL MEMORY
COBOL	COMMON BUSINESS ORIENTED LANGUAGE
CPU	CENTRAL PROCESSOR UNIT
CRT	CATHODE RAY TUBE
DBA	DATA BANK ADMINISTRATOR
DBMS	DATA BASE MANAGEMENT SYSTEM
DDL	DATA DESCRIPTION LANGUAGE
DML	DATA MANIPULATION LANGUAGE
DVST	DIRECT VIEW STORAGE TUBE
ERB	ENGINEERING REVIEW BOARD
EXEC	IPAD EXECUTIVE
FMECA	FAILURE MODES EFFECTS- CRITICALITY ANALYSIS
FORTRAN	FORMULA TRANSLATING SYSTEM
FRC	FIRST RELEASE CAPABILITY (IPAD'S)
GDM	GENERAL DESIGN MODULE
GGL	GENERAL GRAPHICS LIBRARY
GGP	GENERAL GRAPHICS PLOTTER
GPU	GENERAL PURPOSE UTILITY
GSE	GROUND SUPPORT EQUIPMENT
I/O	INPUT/OUTPUT
IPAD	INTEGRATED PROGRAMS FOR AEROSPACE-VEHICLE DESIGN
JOVIAL	JULES' OWN VERSION OF THE INTERNATIONAL ALGEBRAIC LANGUAGE
MAC	MEAN AERODYNAMIC CHORD
MACRO	LARGE OR OF THE HIGHEST ORDER
MAXI	LARGE SCIENTIFIC COMPUTER SYSTEM
MDB	MULTIDISCIPLINARY DATA BANK
MEA	MAINTENANCE ENGINEERING ANALYSIS
MENU	A TABLEAU OR LIST OF ITEMS

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## GLOSSARY OF IPAD ACRONYMS (Cont'd.)

MICRO	SMALL OR OF THE LOWEST ORDER
MINI	SMALL COMPUTER
OM	OPERATIONAL MODULE
OPTUM	IPAD OPTIMIZER GENERAL PURPOSE UTILITY
OR	OPERATIONS RESEARCH
RFP	REQUEST FOR PROPOSAL
SCHEMA	A CODASYL CONCEPT
SPU	SPECIAL PURPOSE UTILITIES
STATUM	THE IPAD STATISTICAL UTILITY MODULE
STOL	SHORT TAKE OFF AND LANDING
SUBSCHEMA	A CODASYL CONCEPT
TCS	TASK CONTROL SEQUENCE
TOGW	TAKE OFF GROSS WEIGHT
USER	ANY IPAD USER
V/STOL	VERTICAL/SHORT TAKE OFF AND LANDING
VTOL	VERTICAL TAKE OFF AND LANDING

## SUMMARY

The purpose of this study was to determine the feasibility of an IPAD system, define its operating philosophy and organization, and generate an IPAD system design featuring the best approach identified during the study.

The study was divided in two phases encompassing eight tasks. An overall study summary is reported in Volume I. The detailed results of Phase I (Tasks 1 and 2) are reported in Volumes II to V. Volume VI includes the results of Phase II (Tasks 3 to 8).

An evaluation of the design process, as viewed through the activities of various design and engineering disciplines, was performed to segregate the basic creative and evaluation procedures used in the design of an aircraft project. Volumes II and III present the results of the evaluation. This effort yielded a specific set of disciplinary functions required, and identified available automated procedures that can be used in an IPAD system. It also identified a series of procedures presently carried out by hand and further developments that are needed to automate these latter analyses and to conduct the whole design process in a more efficient, cost-effective manner. By reviewing the participation of various disciplines within a project design team, a usage philosophy was evolved whereby the user - the engineer - is the focal point of the IPAD concept. This concept involves two major ingredients; an Engineering Capability consisting of a battery of Operational Modules, and a Computer Software/Hardware Complex where that capability will be installed and exercised. The engineering capability is modular and will be tailored to the specific needs of the project team, while the computer complex could be essentially the same for all teams, barring differences among computing systems.

The principal mode of operation is using interactive graphics equipment. The system also includes less sophisticated interactive terminals as well as the common batch mode operation. Details can be found in Volumes IV and V.

A First Release Capability for IPAD is recommended consisting of engineering operating modules, computer systems software and required computer hardware and peripheral equipment. Details of this recommendation can be found in Volume I, Section 2.4.

This volume discusses the aircraft design process and the degree of participation of the various engineering disciplines considered in this feasibility study.

## 1 INTRODUCTION

The design of a new aerospace vehicle is presently a complex, long-term process. At the onset, a set of objectives is identified in the areas of mission, weight, performance, payload, range, etc., which are specified with a fairly good knowledge of the available design technology and constraints. The designer's goal is to minimize cost, while meeting basic project objectives. The designer possesses a fund of accumulated experience and knowledge which he applies, with intuition, to the requirements and constraints he has been given. The knowledge and experience of the designer are more and more frequently being delegated to the computer; the intuition and imagination can never be. Some of the purposes of the IPAD feasibility study were to determine what sections of the design process are amenable to automation; how much monitoring must the automation have; how can the design process be effectively organized; and, most important, how can the management/designer/engineer team members retain the visibility and control necessary to exercise their intuition and imagination in the design process.

The introduction of automation is a significant change in the design process; however, the important management aspects of this change are not only related to the technical details of engineering disciplines, programming, data bases, etc., but the key to success also depends upon managing the adaptation required of the people involved in the use of the automated process.

Automation of any process requires not only a thorough knowledge of the process, but of the pivotal factors that drive and control it. When the process involves the myriad details of project team data flow and communications, many programs and subroutines, thousands of variables, and the ramifications of computer operating system characteristics, it is easy to lose sight of the fact that it is still the designer - the engineer - who is the key driver and decision-maker in the process.

Although the various volumes of this report describe some of the considerations necessary for the technical basis needed to successfully automate the design process, the underlying, guiding philosophy has been that of providing a tool adapted to the needs of the members of a management/designer/engineer team--the ultimate users--and that is a truly useful tool. The acknowledged principle has been that the engineer and his management are generally more interested in solving the design problem than in becoming a better communicator with the computer.

The scope of the total IPAD feasibility study is illustrated in Figure 1-1. The study was divided into the following eight tasks within two study phases:

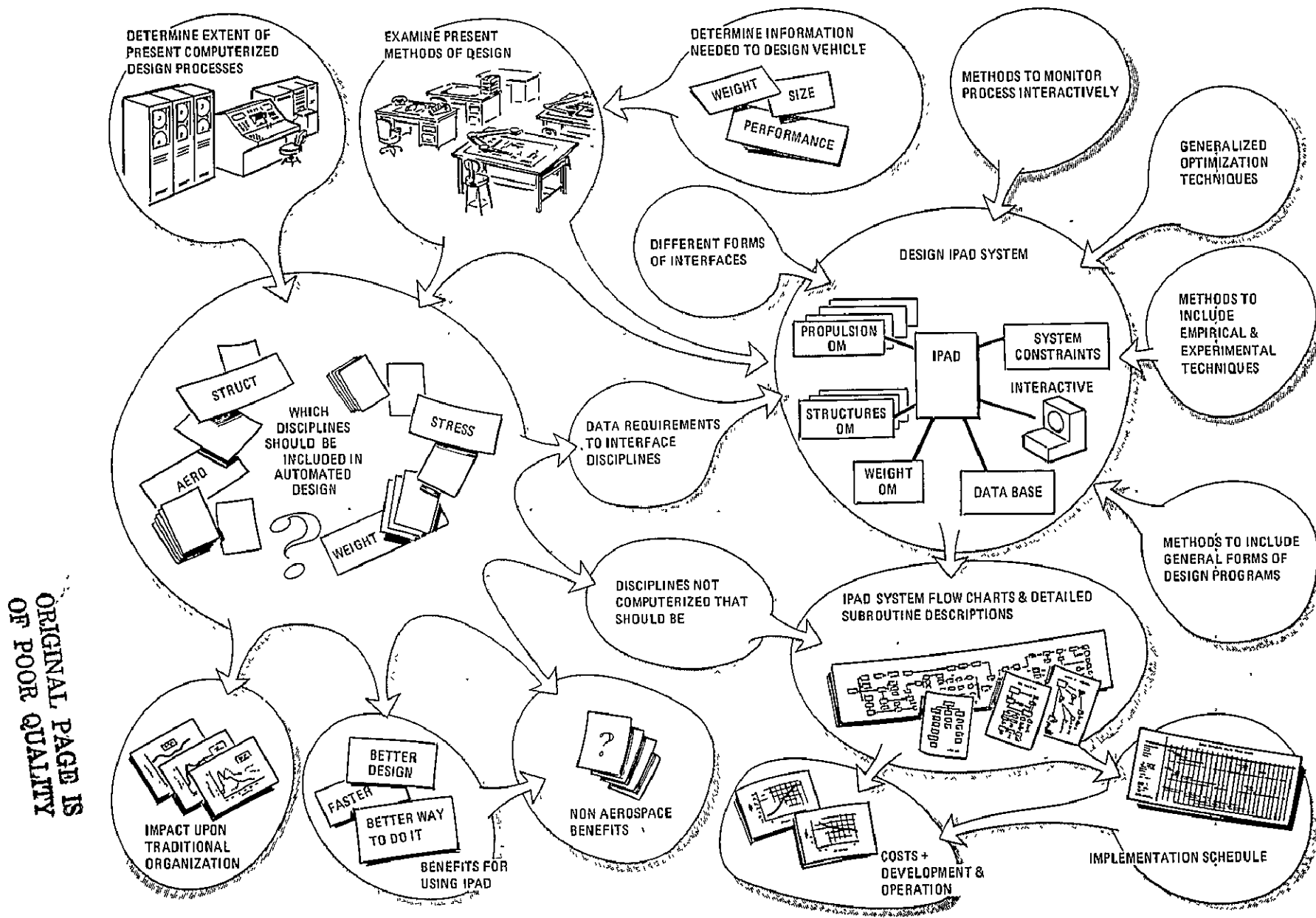


Figure 1-1. IPAD Study Flow Chart

## PHASE I

### STUDY PLAN COORDINATION

#### TASK 1 - CHARACTERIZATION OF IPAD SYSTEM

- Define an IPAD Engineering Usage Philosophy
- Identify Feasible Automated Design Procedures
- Evaluate Adequacy of Existing Computer Programs
- Recommend Areas for Further Development
- Determine IPAD Feasibility and Applicability
- Recommend IPAD's First Release Engineering Capability

#### TASK 2 - DESIGN OF IPAD SYSTEM

- Define a Systems Operating Philosophy
- Evaluate System Design Options
- Identify Elements of IPAD's Utility Library
- Investigate Organization and Management of Data Bank
- Determine Number and Type of Input/Output Terminals
- Determine Host Computer Complex Configurations Adequate for IPAD
- Recommend IPAD's First Release Computer System Capability

## PHASE II

#### TASK 3 - IPAD IMPLEMENTATION SCHEDULE

#### TASK 4 - IPAD SYSTEM DEVELOPMENT COST

#### TASK 5 - IPAD SYSTEM OPERATIONAL COST

#### TASK 6 - IPAD SYSTEM BENEFIT ASSESSMENT

#### TASK 7 - IPAD IMPACT ON COMPANY ORGANIZATION

#### TASK 8 - IPAD SPIN-OFF ASSESSMENT

Figure 1-2 summarizes the main features of an IPAD system as presently conceived and described elsewhere in this report.

**IPAD IS:**

- AN INTEGRATED SYSTEM OF AUTOMATED MODULES.  
EACH DISCIPLINE IS RESPONSIBLE FOR ITS OWN CAPABILITY DEVELOPMENT,  
UPDATE & GROWTH
- A USER-ORIENTED & DIRECTED MODULAR SYSTEM WITH FLEXIBILITY FOR CHANGE,  
ADAPTATION & EXPANSION
- A HARDWARE/SOFTWARE COMPUTER SYSTEM DESIGN APPROACH  
TO PERFORM ENGINEERING DESIGN PROCESSES MORE EFFECTIVELY,  
ECONOMICALLY & SWIFTLY
- A COMPUTER SYSTEM STRUCTURE  
USABLE IN MANY ENGINEERING & SCIENTIFIC FIELDS
- ITS DATA BANK IS THE REPOSITORY FOR ALL DESCRIPTIVE & INFORMATIVE DATA  
GENERATED BY THE ENGINEERING/SCIENTIFIC TEAM FOR A SPECIFIC PROJECT
- A MANAGEMENT TOOL  
TO PROVIDE IMMEDIATE VISIBILITY INTO PRODUCT STATUS & PROGRESS
- INITIALLY, A REASONABLE ENGINEERING CAPABILITY (SET OF AUTOMATED  
MODULES) MOUNTED ON A STATE OF THE ART HARDWARE/SOFTWARE STRUCTURE  
THAT CAN BE READILY IMPLEMENTED
- ULTIMATELY, A COMPREHENSIVE, DYNAMIC ENGINEERING TOOL SUPPORTED BY  
EFFICIENT, COST-EFFECTIVE HARDWARE/SOFTWARE CAPABILITY
- AN EDUCATIONAL AID FOR TRAINING NEW ENGINEERS IN THE USE OF VARIOUS  
DESIGN PROCESSES

**IPAD IS NOT:**

- A SINGLE, HARDWIRED COMPUTER PROGRAM
- AN AUTOMATED, SINGLE-PURPOSE PROCEDURE
- A DISLOCATED ARRAY OF RANDOMLY COLLECTED COMPUTER PROGRAMS
- A SYSTEM OF PROGRAMS TO BE RUN BY A SINGLE DISCIPLINE
- A SYSTEM OF PROGRAMS IMPOSED BY AN AGENCY (OR COMPANY) ON THE  
AEROSPACE INDUSTRY COMMUNITY

Figure 1-2. Major IPAD Features

## 2 THE IPAD SYSTEM DESIGN. AN OVERVIEW

The overall goal of IPAD is the automation of appropriate sections of the design process to shorten design time, reduce cost, and improve the ultimate product.

The objectives of the present study were to:

- Develop IPAD's Operational Philosophy
- Establish Extent of IPAD Support of the Design Process
- Investigate System Organizational Options
- Determine the Feasibility of an IPAD System
- Generate an IPAD System Design
- Recommend IPAD's First Release Capability

A series of studies were performed in pursuit of these objectives including the following:

1. Design Process
  - a. Characterize the design process dividing it in various design phases, and segregate the basic functions performed by several representative design/engineering disciplines in each phase.
  - b. Identify the interdisciplinary data flow for manual/automated procedures and man-machine interfaces occurring in the design process.
  - c. Evaluate the adequacy of existing computer programs and operating modules for use in IPAD.
  - d. Define an IPAD usage philosophy from the engineering user point of view.
  - e. Identify optimization techniques to be included within an IPAD system.
  - f. Recommend IPAD's first release engineering capability.
2. Computer System.
  - a. Define the system operating philosophy and evaluate system design options.
  - b. Investigate the organization and management of the Data Bank.
  - c. Identify and describe the software elements of a Utility Library for IPAD.
  - d. Determine the number and type of Input/Output Terminals.
  - e. Determine host Computer Hardware/Software Complex configurations adequate for IPAD.
  - f. Evaluate language and size limitations of existing operational modules.
  - g. Recommend IPAD's first release computer system capability.



## 2.1 IPAD Organization

An IPAD system is defined herein as consisting of four major components, as shown in Figure 2-1: (1) A Management Engineering Capability represented by a battery of automated Operational Modules for various management/design/engineering disciplines, (2) an IPAD Framework Software which supports and augments the Engineering Capability, (3) an Operating System Software, which features a comprehensive Data Base Management System, and (4) A Computer Complex Hardware, on which all the Engineering, IPAD, and System software will be mounted and exercised. From this statement, it can be inferred that the Management/Engineering Capability can and should be tailored to the specific needs of the management/design/engineering team (i.e., the battery of Operational Modules for aircraft design would be different than that for missiles, or navy vessels, or terrestrial vehicles, or civil engineering projects, although many common elements could be identified). On the other hand, the IPAD Framework Software, the Operating System Software, and the Computer Complex Hardware could have essentially the same basic capabilities for all users, with freedom of choice in specific software, and type and quantity of equipment desired within each computer complex.

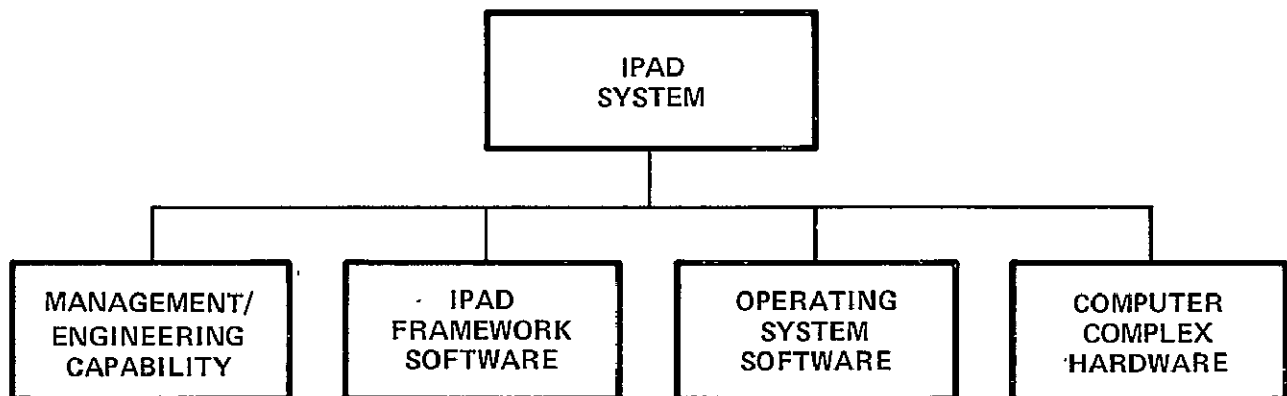


Figure 2-1. Major IPAD System Components

The organization, engineering usage philosophy, and the accompanying IPAD design concept developed in this study provide the flexibility required to satisfy the project needs of any management/design/engineering team which will use and exploit the IPAD system's capability in any way it sees fit.

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## 2.2 Engineering Usage Philosophy

Figure 2-2 gives an overview of the interrelationships among the four major components of IPAD and illustrates the engineering usage philosophy. The more important elements of those components and the usage philosophy itself are discussed in the following paragraphs:

### 2.2.1 Management/Engineering capability. - The elements in this area are:

1. The User. IPAD has been conceived and designed around a Project Team as its main user, to enhance team creativity through effective communications and interaction among its members. An individual user will participate in the design process using the IPAD System in either of four different modes:
  - a. Interactive monitoring, which puts at his disposition the most capable interactive devices, mini-computers, host computer, and all features of the IPAD System. This mode will be used mostly with interactive Operational Modules to monitor input/output (alpha-numeric, graphical or both) by either: (1) single project team members in performance of their individual tasks, or (2) several members interacting with each other in sequential or iterative activities involving one or more design/engineering disciplines.
  - b. Batch spin-off, whereby the user starts a task in the interactive mode and ends it by requesting an immediate batch processing (perhaps requiring long execution time) while he performs other tasks.
  - c. Interactive typewriter, which enables him to access a reduced set of the IPAD System capability. This mode will be mainly used with interactive Operational Modules requiring small amounts of input/output data transmission.
  - d. Batch, which from the operations point of view provides a capability similar to present usage of computers, although with the benefits of data base management and other features of the IPAD System. This mode will be principally used with non-interactive Operational Modules or production jobs that do not require a man in the loop. The batch processing can be requested either from an interactive device, a remote terminal, or by direct submittal to the computer operations desk.
2. Automated Operational Modules. The total automated capability of the engineering/science community is resident in a library of automated operational modules consisting of both a public domain library, accessible to all parties,

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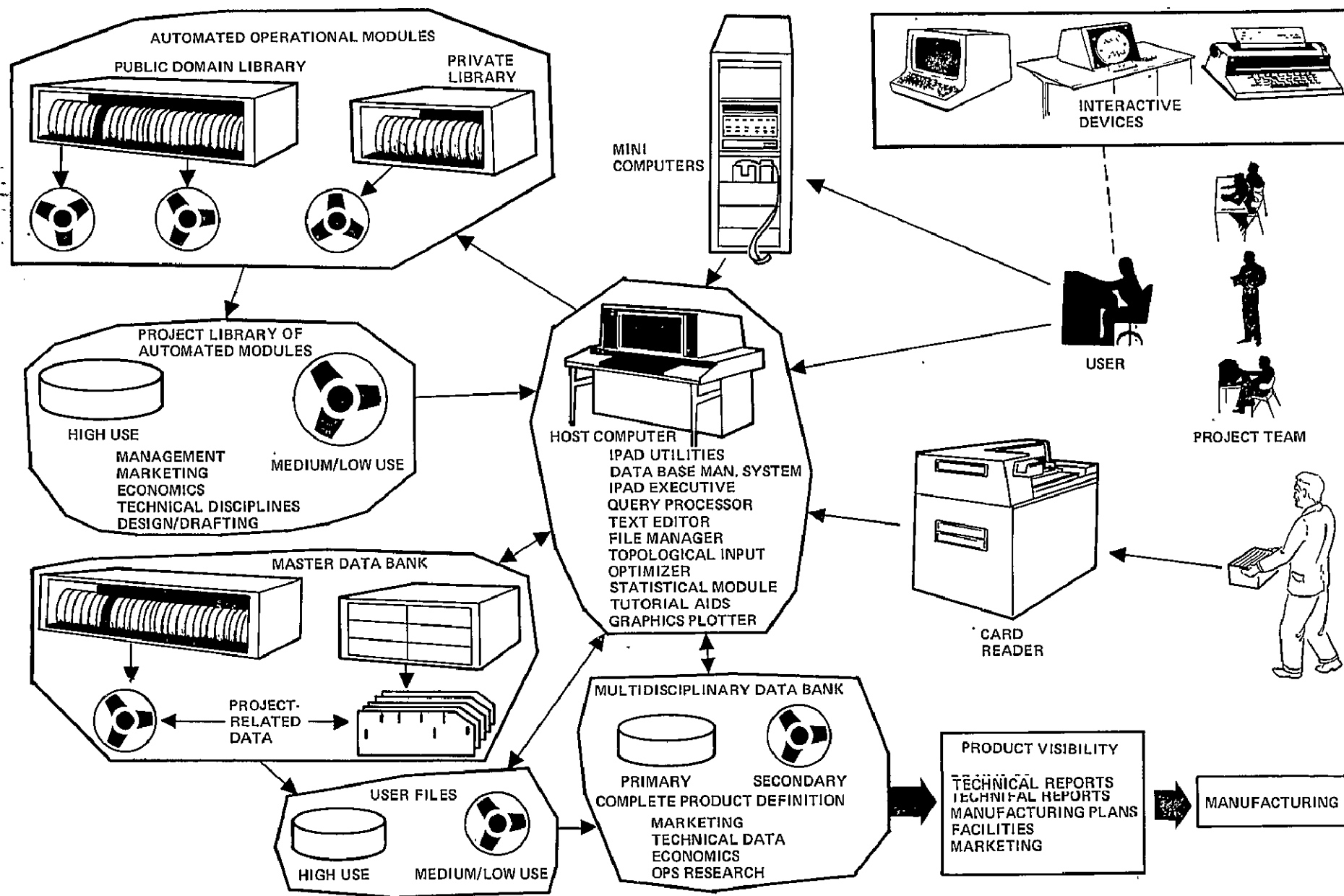


Figure 2-2. IPAD Overview

and private libraries containing modules with limited or restricted availability due to the nature of its contents being private data, classified information, or the like. From the total gamut of available modules a project team will select those which are applicable to their specific project to assemble a project library of automated operational modules that will be installed on the IPAD Computer Complex. The contents of this library are dynamic in the sense that programs are added or removed from it as the need arises, and are resident on disk or tape depending on their usage rate. All project related activities such as management, marketing, economics, technical disciplines, and design/drafting will have their respective automated capabilities installed in the system. The position of this software in relation to other computer software required for IPAD is shown in the first two columns of Figure 2-3.

3. Master Data Bank. This bank is the repository of all historical, statistical, and other data that has been accumulated from previous studies and which are a vital part of the experience of a design team. The contents of this bank are both of the public-domain and the private-data type but most predominantly of the latter one. Typical contents of this bank would be weight statistical data, raw or curve fitted test data for aerodynamics, propulsion, structures, etc; engine data; design criteria and specifications; standard parts; subsystems data; and many others. The project team members will select from this bank that data which is pertinent to their project and place it in residency on disk or tape, depending on the extent of the data and its usage rate.
4. The Multidisciplinary Data Bank. Now the user - with the engineering know-how described in 2. and 3. above and the rest of the IPAD System components described in paragraphs 2.2.2 to 2.2.4 - is ready to devote his attention to generating the data that will completely define the product, including all technical groups, marketing, economics, operations research, etc. Most of this data will be contained in the Multidisciplinary Data Bank for proper access by all parties concerned. The inflow of data into this bank is supervised by the project Data Bank Administrator, who ensures that the data is reviewed and approved before it is inserted in the bank.
5. Product Visibility. Data contained in the Multidisciplinary Data Bank at any stage of the design can be used to provide product-related visibility in terms of drawings, technical reports, manufacturing plans, facilities, marketing, etc. The final set of data defines the product that goes to manufacturing.

2.2.2 The IPAD framework software. - From the user's point of view, IPAD is a framework which supports and augments the capabilities of his computerized management, design/drafting, and analytical tools. From this viewpoint, the framework is composed of a number of utilities and interfacing capabilities, as shown in Figure 2-3. The elements of this software are:

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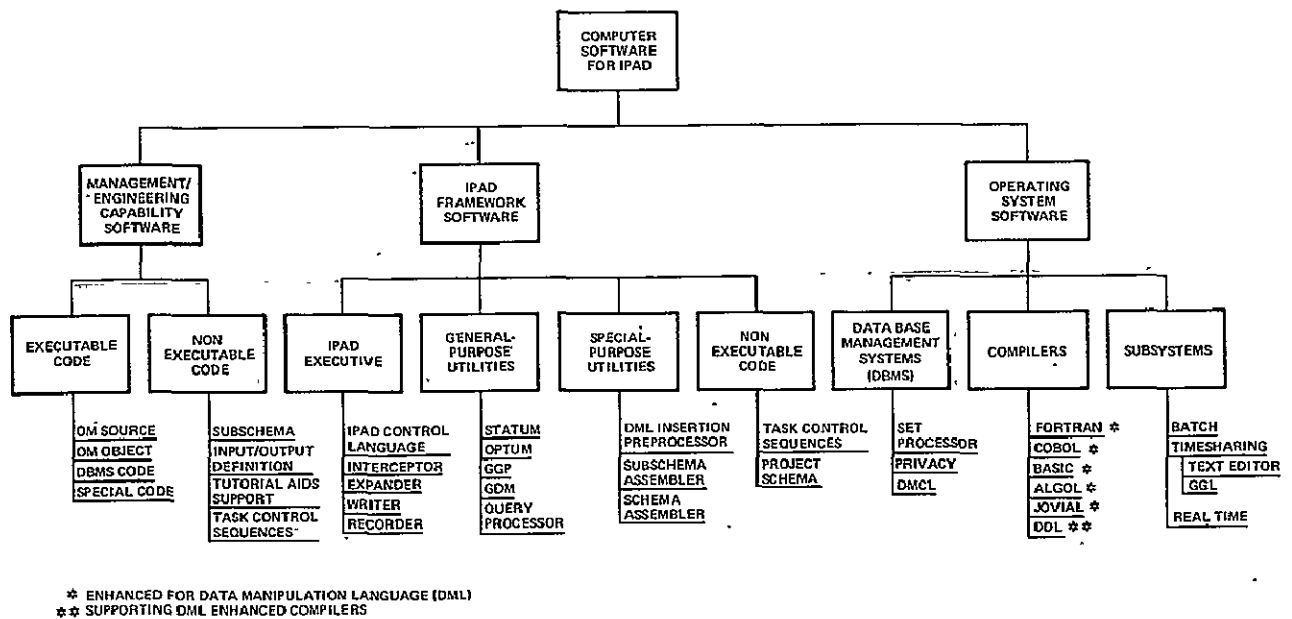


Figure 2-3. Computer Software Associated with IPAD

1. The IPAD EXECutive function, which provides control of the full capability of the host operating system/timesharing subsystem and is interfaced by: tutorial aids and the ability to code, save, and execute pre-established task sequences.
2. The General Purpose Utilities, which include:
  - a. The Query Processor, which provides interface with a project-oriented Multidisciplinary Data Bank and the Data Base Management System. To the user, the Data Base and Query Processor provide for accurate and efficient communication with respect to task assignments and task status, and efficient access to pertinent design data, design tools, and operating modules.
  - b. A statistical utility (STATUM) and a general-purpose optimization utility (OPTUM), which provide general engineering capability in these areas.
  - c. A General Graphics Plotter (GGP), and a General Drafting Module (GDM), which provide multipurpose plotting and design/drafting capabilities, with access to hardcopying equipment.

The foregoing three major groups of general purpose utilities make up the basic capability. Additional utilities could be added in the future, or, conversely, some elements of this capability could be absorbed by the operating system.
3. The Special Purpose Utilities, which provide a capability to incorporate Operational Modules and to assist the user in preparing existing modules for operation within the IPAD Framework.

4. Non-executable Code, which provides a task integration capability and permits the construction of a task oriented user file appendage to the data base, and the construction of a Data Base Management System interface to share data among the Operational Modules.

2.2.3 The operating system software. - This software usually resides in disk and consists of: system utilities to support the user, such as compilers, assemblers, translators, file managers, etc; the operating system library, containing system-support entities such as the resource allocator, the job scheduler, the record manager, the loader, etc.

Features of the operating system software which are considered important to IPAD include: random access files, which are deemed to be required by current and projected mass storage hardware for fast access/retrieval times; index sequential files, which combine both random and sequential features; permanent files, required for continuous availability of information contained in IPAD's data banks; and UPDATE utility, to selectively update while retaining prior data; and interactive communication subsystem, including time and memory sharing features to provide fast response times; and an interactive graphics subsystem, to provide capability for making graphs, drawings, pictures, etc. In relation to the latter feature, it is important to point out a pressing need within IPAD for a standard graphics language.

2.2.4 The computer complex hardware. - A particular host computer (i. e., a CDC CYBER 70 series) is used herein to illustrate a typical installation and its major components, as shown in Figure 2-4. The host computer is shown schematically in the center surrounded by the peripheral equipment. The illustrated host computer consists of the Central Processor Unit (CPU) and the Central Memory (CM), which form the high speed computing core of the unit; Peripheral Processors, which are small self-contained computers to handle peripheral tasks; optional Extended Core storage, which can be used to expand storage up to several million locations; Input/Output channels to communicate with the peripheral equipment; and the Operators Console, which provides the interactive interface with the host computer operating system software.

Disk storage holds the operating system, support utilities, and provides job residency, user residency (in the form of permanent files, accounting and system files), and disk packs for private user data, results from previous studies, etc.

The peripheral equipment includes: input/output handling equipment such as card readers/punches, magnetic tapes, paper tapes, and microfilm recorders, removable disk packs; interactive remote terminals, with hardcopying capability such as typewriters, alpha-numeric graphics consoles, direct view storage tubes, and the more sophisticated large-screen, vector-drawing, refreshed terminals, usually serviced by a mini-computer; and remote units, typically fed from magnetic tapes, such as remote plotters, paper-ink plotters, drafting machines, and numerically controlled machines.

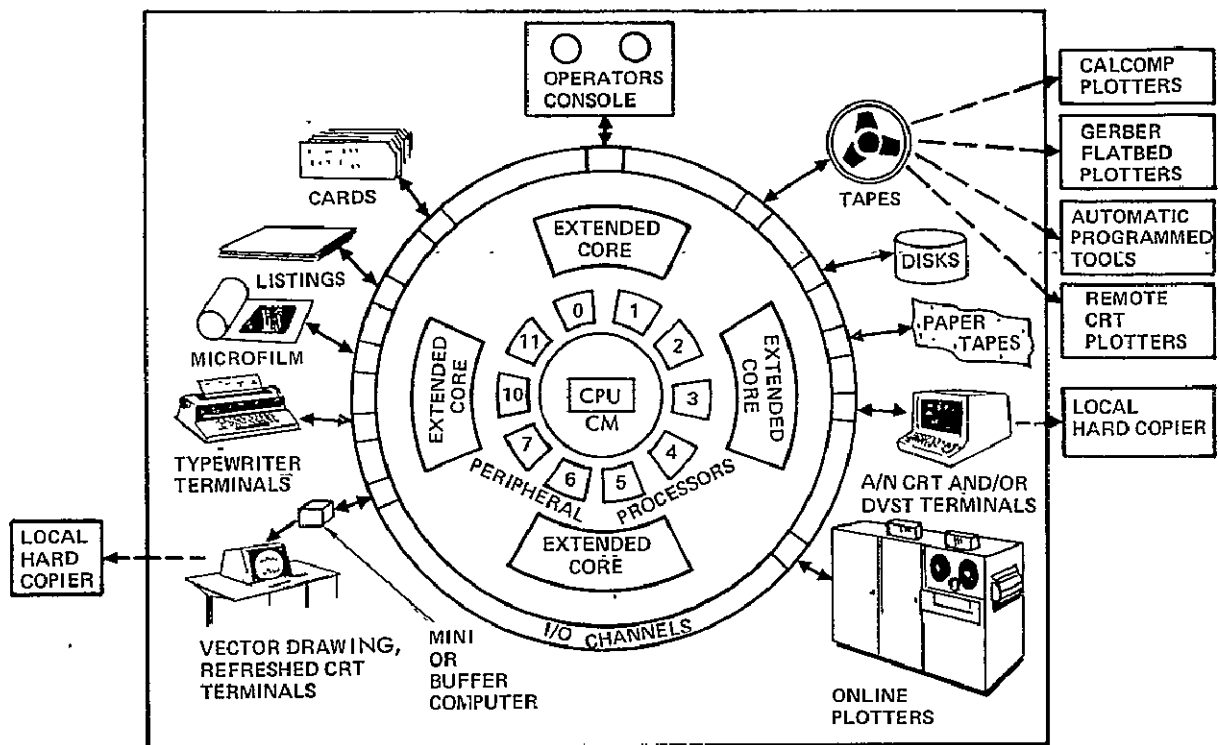


Figure 2-4. Typical Host Computer Complex Hardware

### 2.3 IPAD's Operating Philosophy

A set of IPAD operating philosophy features deemed important for an IPAD system were defined at the onset of the study. These features are shown in Figure 2-5.

A conceptual design evolved from these considerations, which embodies all the engineering usage and operating system features presently envisioned for an IPAD System. The major components of such design are identified in Figure 2-6, which shows it centered around interactive graphics terminals as being the principal (albeit not the only) mode of operation. The data base, shown in the dotted box, consists of the following entities:

1. Engineering Review Board (ERB) Action File, a communications file summarizing the action requests placed on the various engineering disciplines by the ERB as the principal representative of project management/engineering.
2. Task Status File, a communications file summarizing the current status of action requests placed by the ERB. The entries in the Task Status File are correlated with entries (action requests) in the ERB Action File and are linked to these.
3. Multidisciplinary Data Bank (MDB), that portion of the IPAD data base reserved for project approved data. This data bank is under the supervision and control

**TO BE EVOLVED AROUND:**

- MAN IN THE LOOP. APPROPRIATE MAN-MACHINE INTERFACES
- COMMON MULTIDISCIPLINARY, SAFEGUARDED DATA BANK
- FLEXIBLE SYSTEM ORGANIZATION AND TCS(s)
- MODULAR SYSTEM AND ENGINEERING APPROACHES
- EASE OF ADAPTATION TO CHANGE AND GROWTH
- USER ORIENTED FEATURES
- EASE OF IMPLEMENTATION IN VARIOUS COMPUTER SYSTEMS
- RANDOM DATA ACCESS
- TIME SHARING OF CPU
- PROGRAM ROLL IN/ROLL OUT (SWAP IN/SWAP OUT)
- ACCEPTANCE OF EXISTING OM SOFTWARE
- LANGUAGE VERSATILITY

Figure 2-5. IPAD Operating Philosophy Features

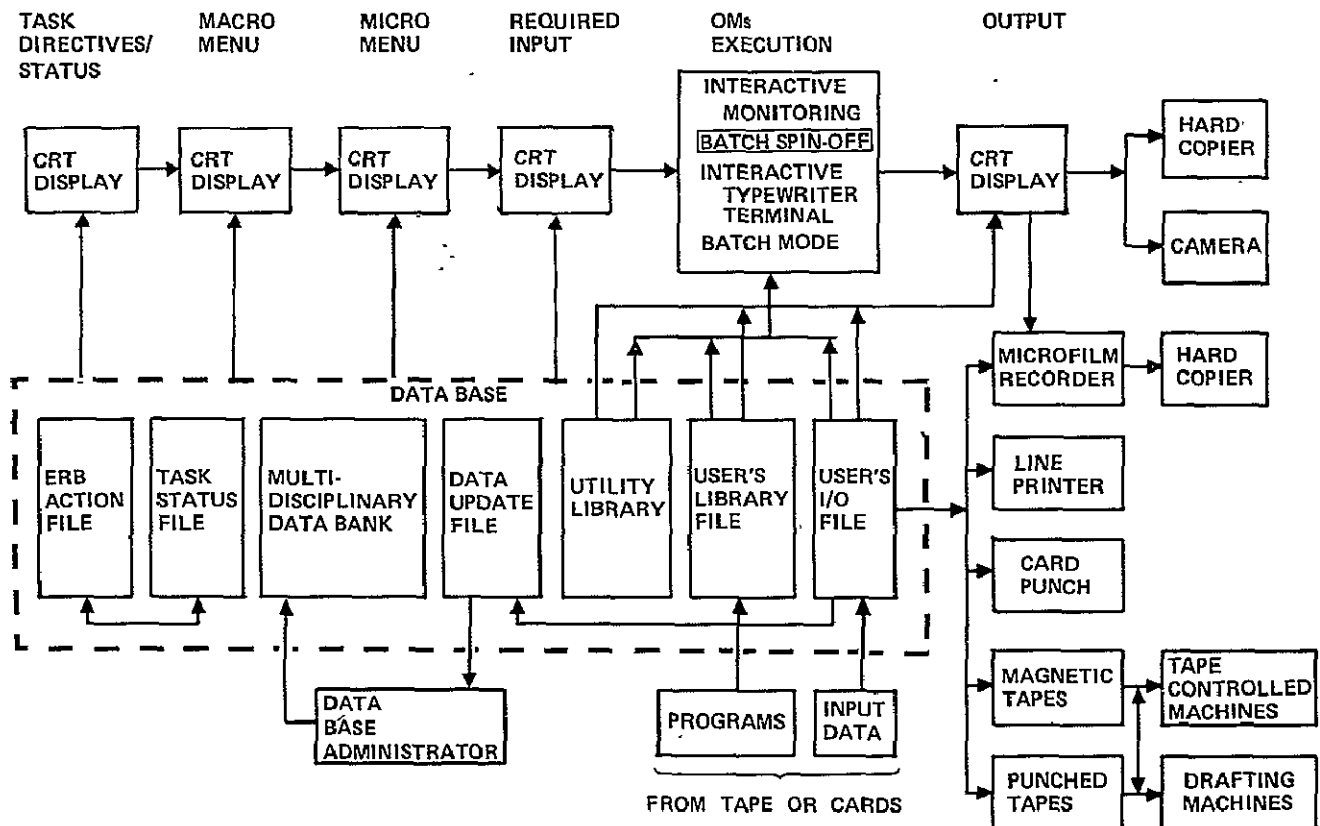


Figure 2-6. Interactive CRT Monitoring and Batch Spin-off



of the Data Base Administrator who ensures that the project's data is reviewed and approved before being inserted into the MDB. This is intended to prevent the insertion of erroneous data invalidating a sequence of studies drawing from this data, and the subsequent "chain reaction" of resulting (erroneous) data being fed back into the MDB.

4. MDB Data Update File, the input queue for data to be inserted into the MDB. The Data Base Administrator reviews and approves this data before actual insertion. An illustration of this process is presented in Figure 2-7, including a sample of the disciplines to be represented within the MDB.
5. Utility Library, the collection of IPAD system code supporting IPAD users in general. Utilities are to be distinguished from specific OMs supporting individual users.
6. User's Library File, the collection of OMs and special utilities supporting the individual users. It also can contain special data supporting several users. It is envisioned that this file's organization will be at the discipline level (lumping the OMs or special data utilized by users within a given engineering discipline). Additional infrequently-used programs (OMs) may temporarily reside in the User's Library File, being read into the system from cards or magnetic tape when needed.
7. User's Input/Output (I/O) File, that collection (for a given user) of intermediate results, partially constructed inputs, partially processed outputs, and related data that the user requires for the purpose of conducting his task. The User's I/O File can be considered as the user's "scratch" area in the data base. Infrequently-used data may also come from (or go to) cards or tape and only temporarily reside in the User's I/O File.

The last three files are illustrated in more detail in Figure 2-8.

The user, in performing his tasks, will interface with the system proceeding along the following major steps (refer to top of Figure 2-6):

1. Examine any new task directives in the ERB Action File and the current task status summarized in the Task Directives/Status File. This process is personalized to the user or his disciplinary area (through his sign-on identification) in order to eliminate unrelated information.
2. Selecting a task to be worked on during the current interactive session, the user acquires an individual OM through the Macro/Micro Menu selection process. The Macro and Micro Menus are display data supporting the OMs (and special purpose utilities) contained in the User's Library File. The form is a logic tree (or more complex) structure which stepwise refines the selection process until the actual OM to be used has been selected.

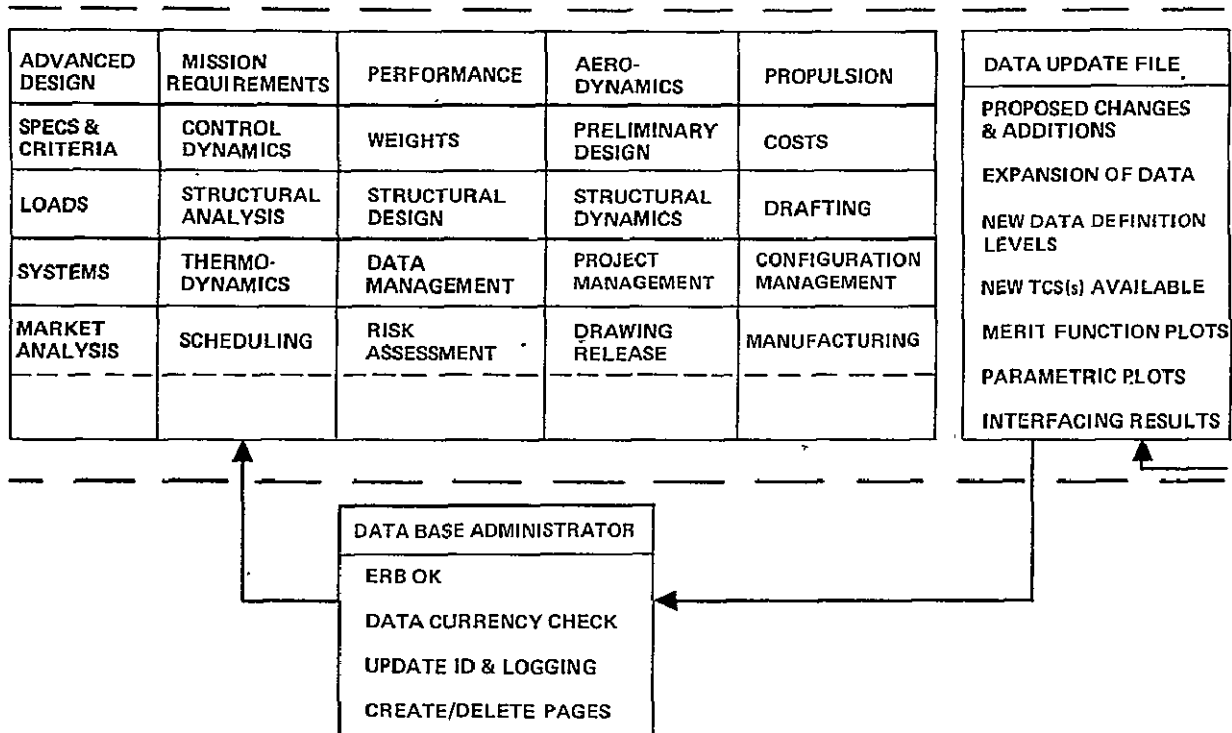


Figure 2-7. Multidisciplinary Data Bank (All Disciplines)

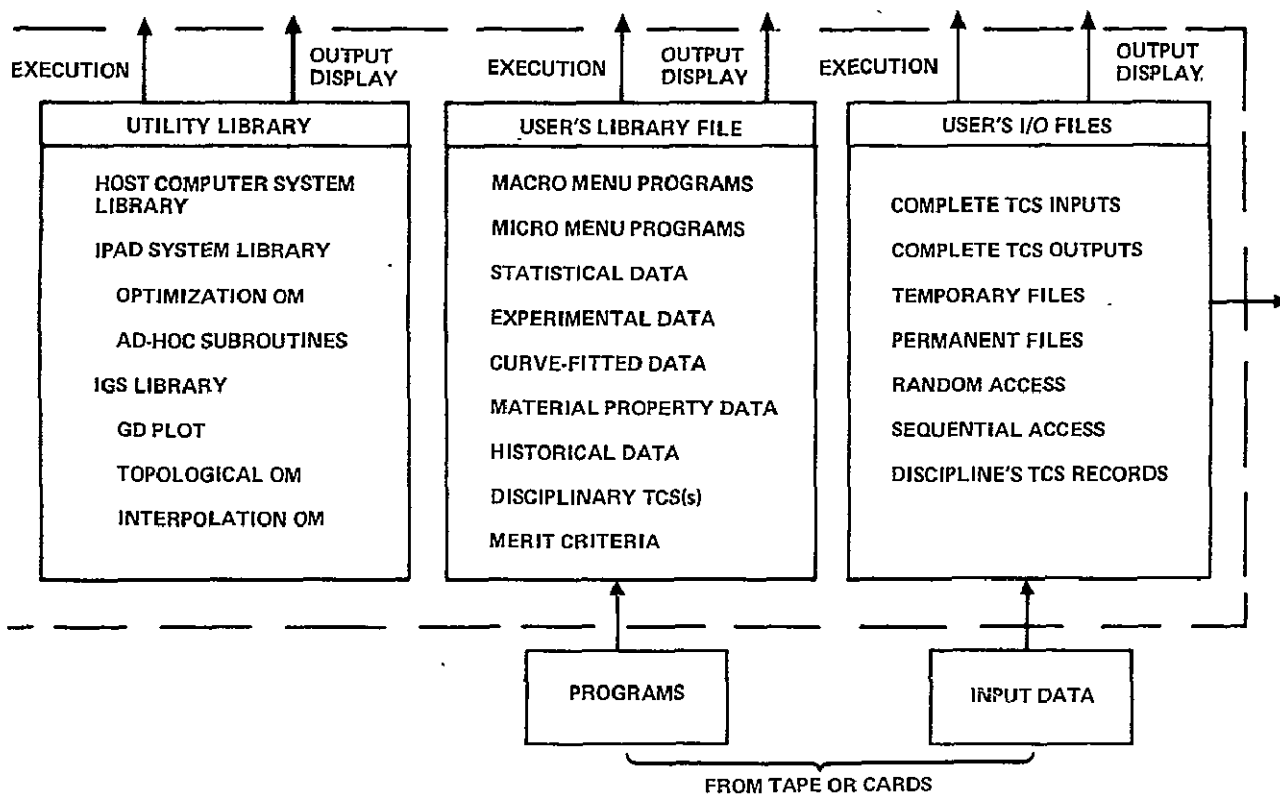


Figure 2-8. Utility and User's Libraries, I/O Files (All Disciplines)

3. The required input for the selected OM is then examined from display data stored with that OM in the User's Library File. From that user-oriented display information, the user directs the system to configure the required input data for that OM, selecting data from the Multidisciplinary Data Bank (MDB), the User's Library File and/or his User's I/O File. The selection process for input data is similar to that for OMs.
4. The user then selects the type of OM execution desired.
  - a. Interactive monitoring, if the OM selected is an interactive OM with large amounts (or graphical) output to be monitored (either requires use of CRT terminals).
  - b. Batch spin-off, which is a request for immediate (high-priority) batch processing while the user performs other, perhaps related, tasks.
  - c. Interactive typewriter mode, if the OM selected is an interactive OM with minimal I/O data requirements.
  - d. Batch mode, which is a request for deferred batch processing.
5. Following OM execution (figure 2-6 illustrates the case of batch spinoff) the resulting output from the OM is examined via display data stored with that OM in the User's Library Files. From that user-oriented display information, the user directs the system to configure and present the required display - usually for viewing if on a CRT terminal - and perhaps recording on any of the devices indicated in figure 6. Figure 2-9 illustrates currently available devices in more detail.

Having completed the output of that OM (or perhaps leaving a partially completed task in his User's I/O File), the user has the option of signing off or returning to the Macro or Micro Menus for another OM or returning to the Task Action or Status Files for another task. Prior to signoff, however, it is envisioned that the user will be given (by the IPAD system) the Task Status File to update based on the tasks (sub-tasks) performed.

An example of the displays that a Structures' user might see as he conducted a wing definition study is presented in Figures 2-10 through 2-13. (Note that these figures represent details of corresponding blocks in Figure 2-6.) In response to an ERB request for "Proposed Wing Changes", the user is displayed the related tasks in his Task Status File and selects "Wing Definition Study" (Figure 2-10). (Note that the checked tasks in the figure are those completed and await ERB review before being removed from the Task Status File.) In response to the "Wing Definition Study" selection, the user is presented a Macro Menu to select a category in which an OM (which he is envisioning using) resides (Figure 2-11); he selects the category "Wing". In response to the selection of Wing, the user is presented a Micro Menu of the cross-reference category type

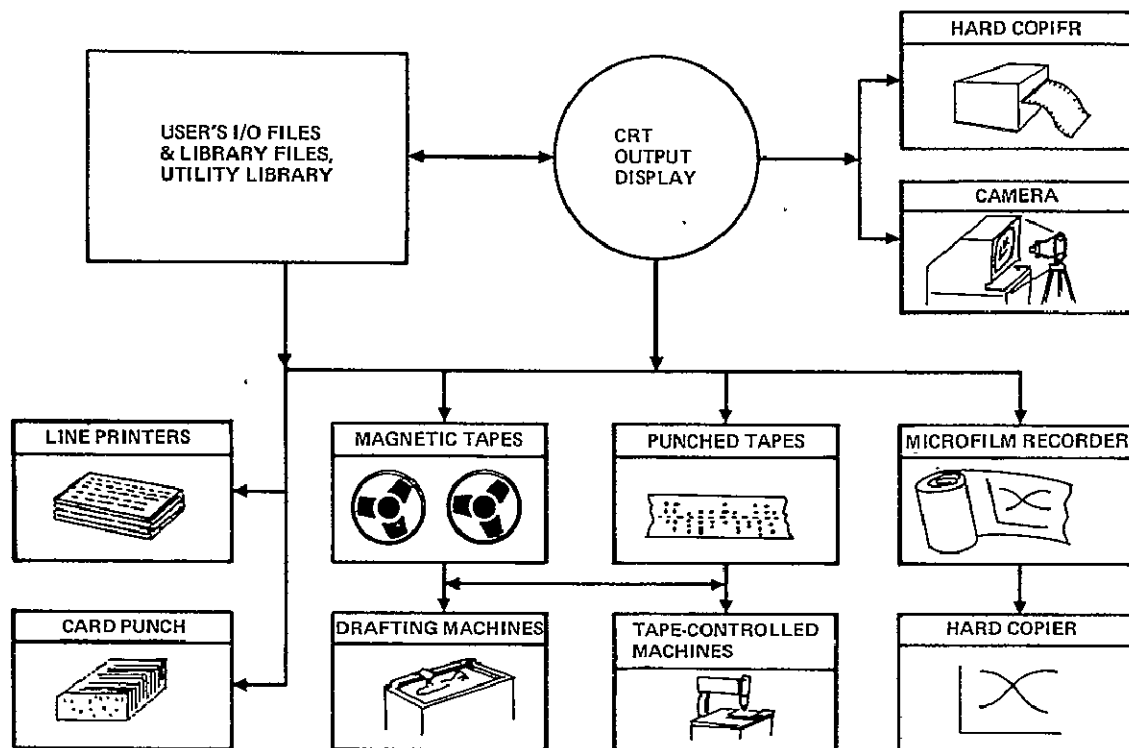


Figure 2-9. IPAD System Output Options (all disciplines)

(Figure 2-12); here he selects "Multiple Station", "Synthesis" and "2nd Level" resulting in the selection of a specific interactive OM to be used. With that OM comes a summary of the required input data with which the user interacts in constructing an input file for that OM (Figure 2-12). Selecting "Interactive Monitoring" (Figure 2-13), the user is presented a menu of available output parameters to view while monitoring and selects "Rigidity Data", "Stress Levels", "Deflections" and "Wing Box Weight vs T/C Plots" for graphical presentation. The user would then set up the plot grids and arrangements, and call for OM execution which would be monitored interactively.

Figure 2-14 is similar to Figure 2-6 and presents a near identical operation using interactive typewriter type terminals for which the hardcopy is the typed sheet produced. Figure 2-15 presents the batch mode for which no interactive display is required; note however that the hard copy capabilities (summarized in Figure 2-9), except for those available only through the interactive terminal, are still available (through IPAD) in a batch mode providing these have been requested.

The foregoing operating philosophy and the accompanying IPAD design concept just described provides the flexibility required to satisfy the project needs of any management/design/engineering team which will use and exploit the system's capability any way it sees fit.

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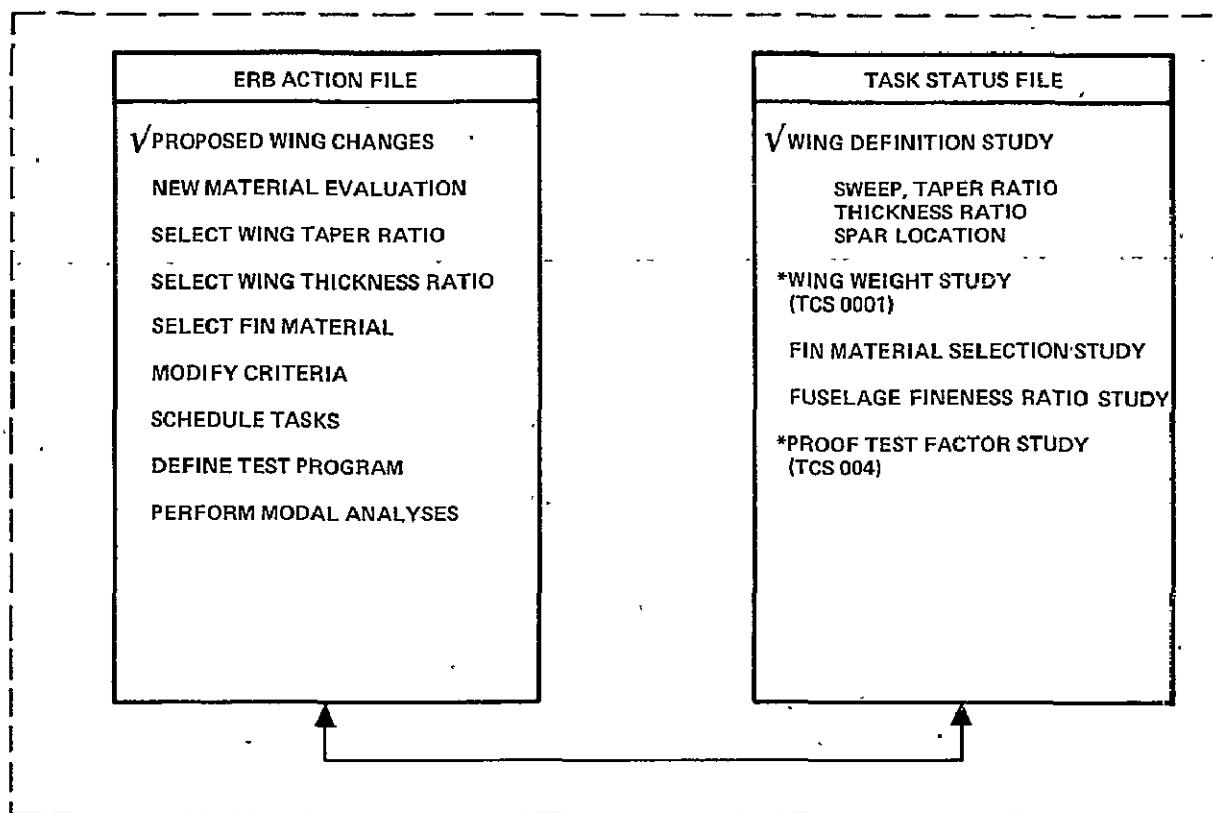


Figure 2-10. ERB Action File and Task Status File (Structures)

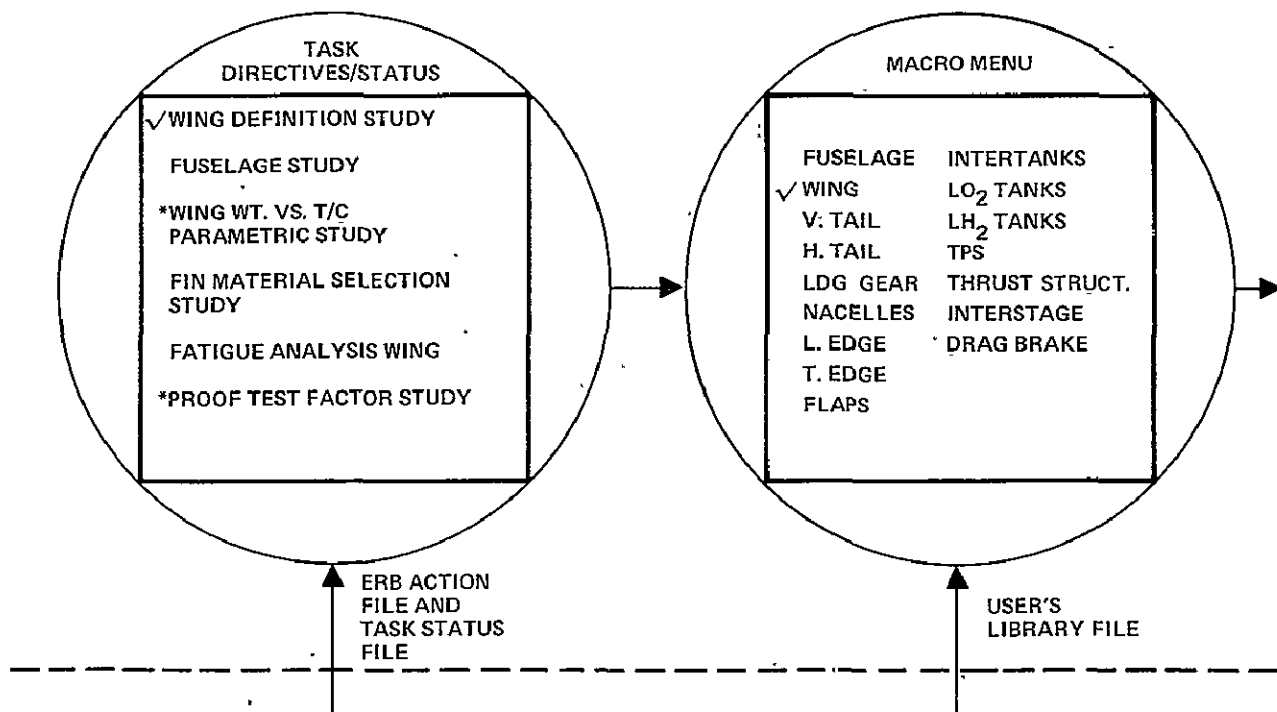


Figure 2-11. Task Directives/Status and Structures Discipline's Macro Menu

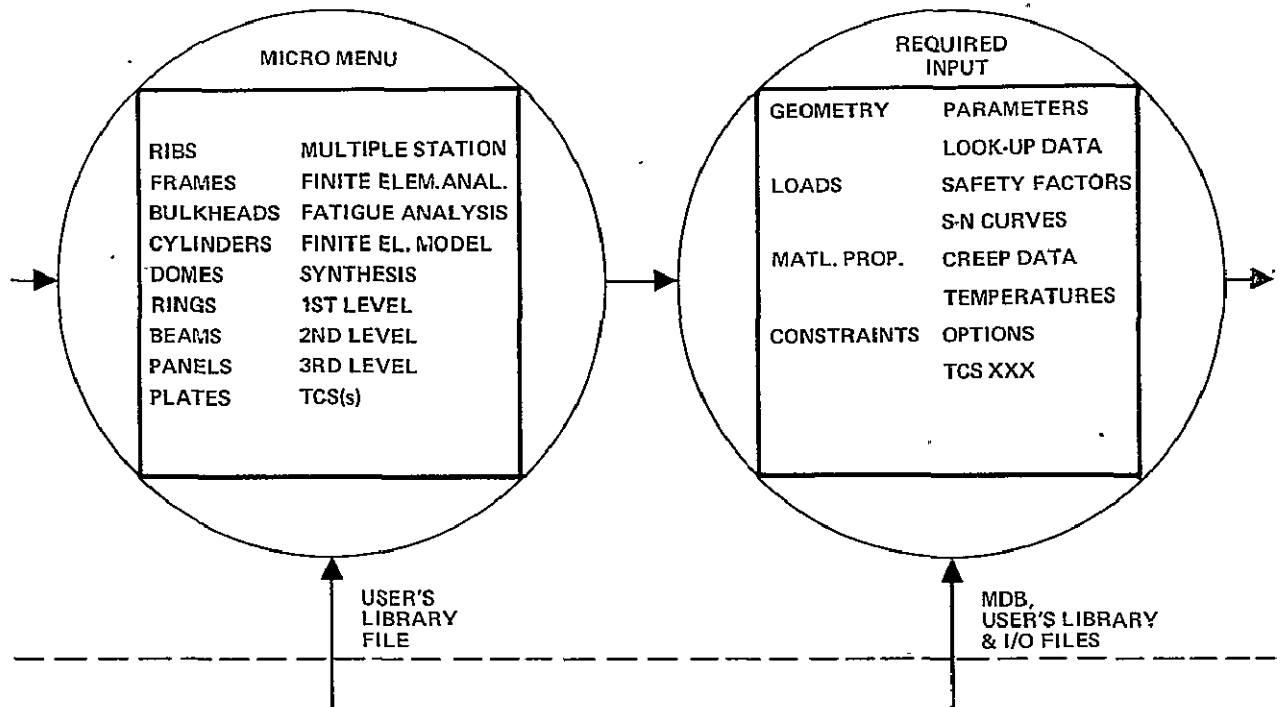


Figure 2-12. Structures Micro Menus and Required Inputs

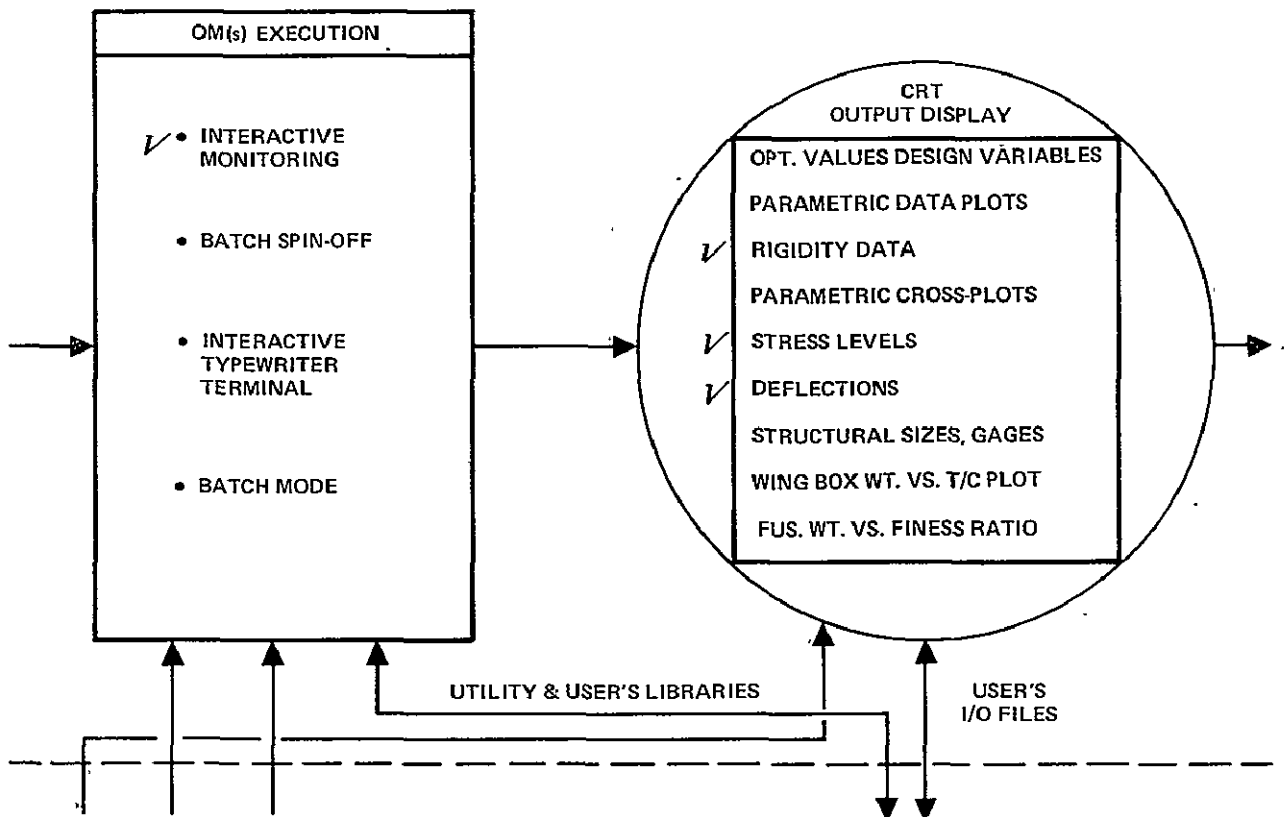


Figure 2-13. Disciplinary OM Execution. Structures Output Menu

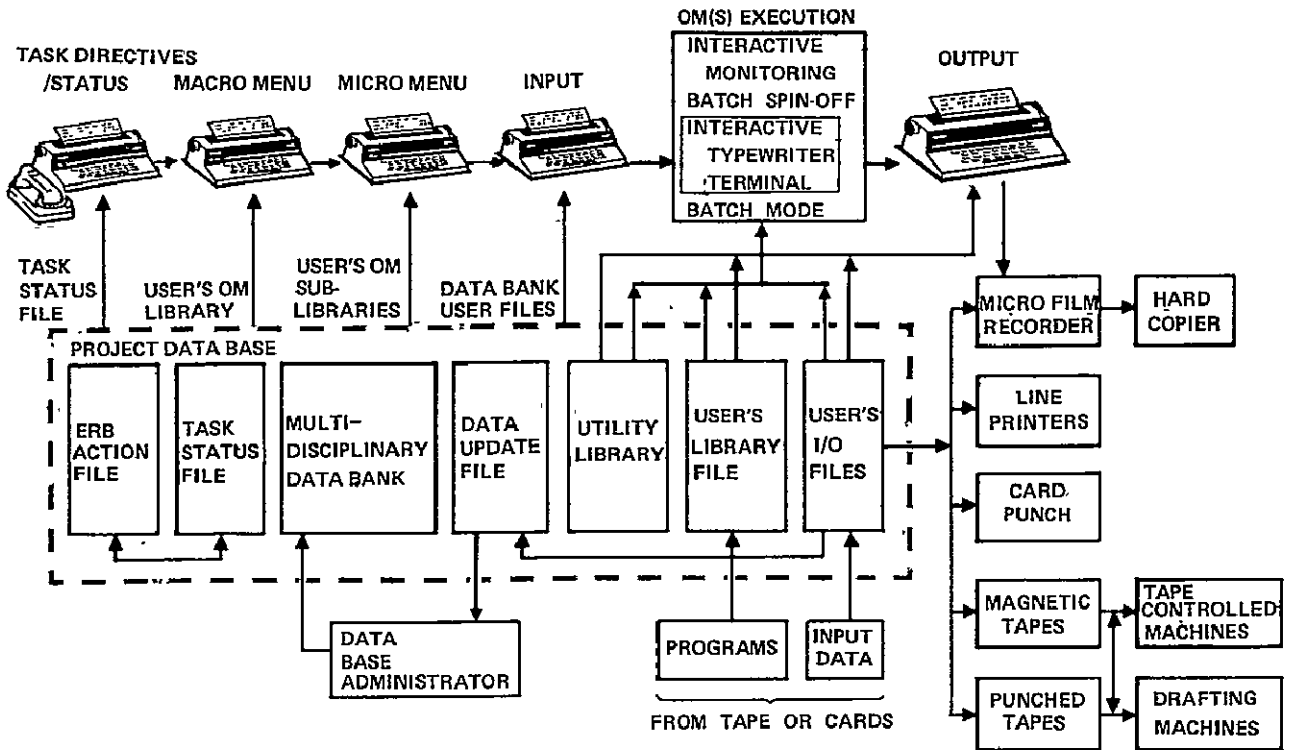


Figure 2-14. IPAD , Interactive Typewriter Terminal

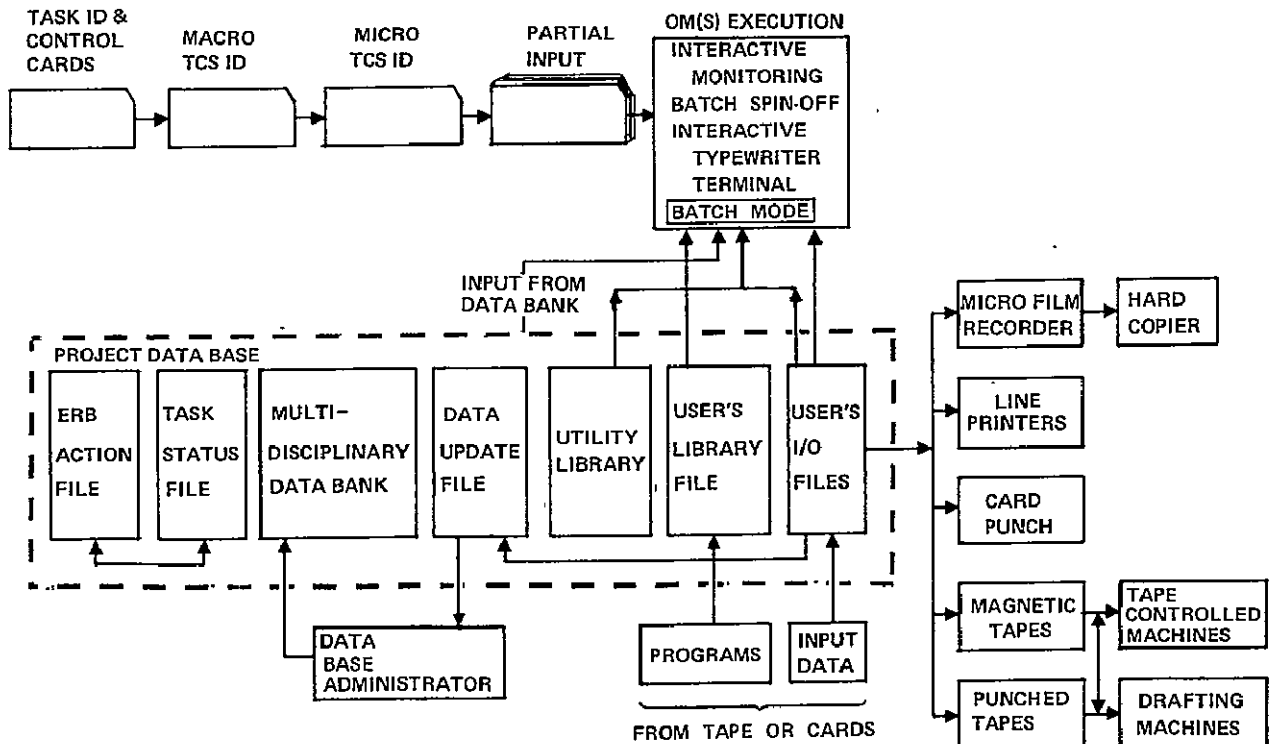


Figure 2-15. IPAD, Batch Mode

## 2.4 A Design/Engineering Feasibility Window

The design of an aerospace vehicle is a complex process, requiring the intervention of many specialized disciplines that define the myriad of details that make a product perform successfully. To have considered all aspects of the design process within this feasibility study was judged both unnecessary and unwarranted. Unnecessary, because the objectives of this study could be met by looking into the design process through a "window", provided it afforded enough insight to depict the detailed engineering functions that must be performed, and provided it enabled definition of the computer system size and equipment required to handle the whole design process. Unwarranted, because it would have led to "more-of-the-same" type of information without a real return in investment.

The design/engineering disciplines included in this "feasibility window" and their respective functions within the design process are detailed in Section 3 of this volume. The basic study plan carried out in each of the selected disciplines is presented in Figure 2-16.

Figure 2-17 shows the general organization of a typical OM that makes use of the features envisioned for IPAD's First Release Capability. This organization has evolved from experience gained within Convair and from projections of operating features offered by the conceived IPAD System.



- IDENTIFY 3 LEVELS OF REPRESENTATION

CONCEPTUAL DESIGN  
PRELIMINARY DESIGN  
DETAILED (PRODUCTION) DESIGN

- INVESTIGATE DEGREE OF AUTOMATION IN EACH DISCIPLINE

- DETERMINE ADEQUACY OF AVAILABLE PROGRAMS

- IDENTIFY FOR EACH REPRESENTATIVE OM

CORE STORAGE REQUIREMENTS  
OVERLAY STRUCTURE  
SYSTEM SUBROUTINES CALLED  
TYPICAL RUN TIMES  
DATA DISPLAY REQUIREMENTS  
IDEF AND ODEF CHARACTERISTICS  
IGS DISPLAY CODING NEEDS  
POTENTIAL IPAD SYSTEM SUBROUTINES NEEDED

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- DEFINE INPUT AND OUTPUT DICTIONARIES, DIMENSIONS, FORMAT

- IDENTIFY SUB-OPTIMIZATION TECHNIQUES USED

- IDENTIFY AND RECOMMEND AREAS FOR FURTHER DEVELOPMENT

Figure 2-16. Study Plan in Selected Disciplines

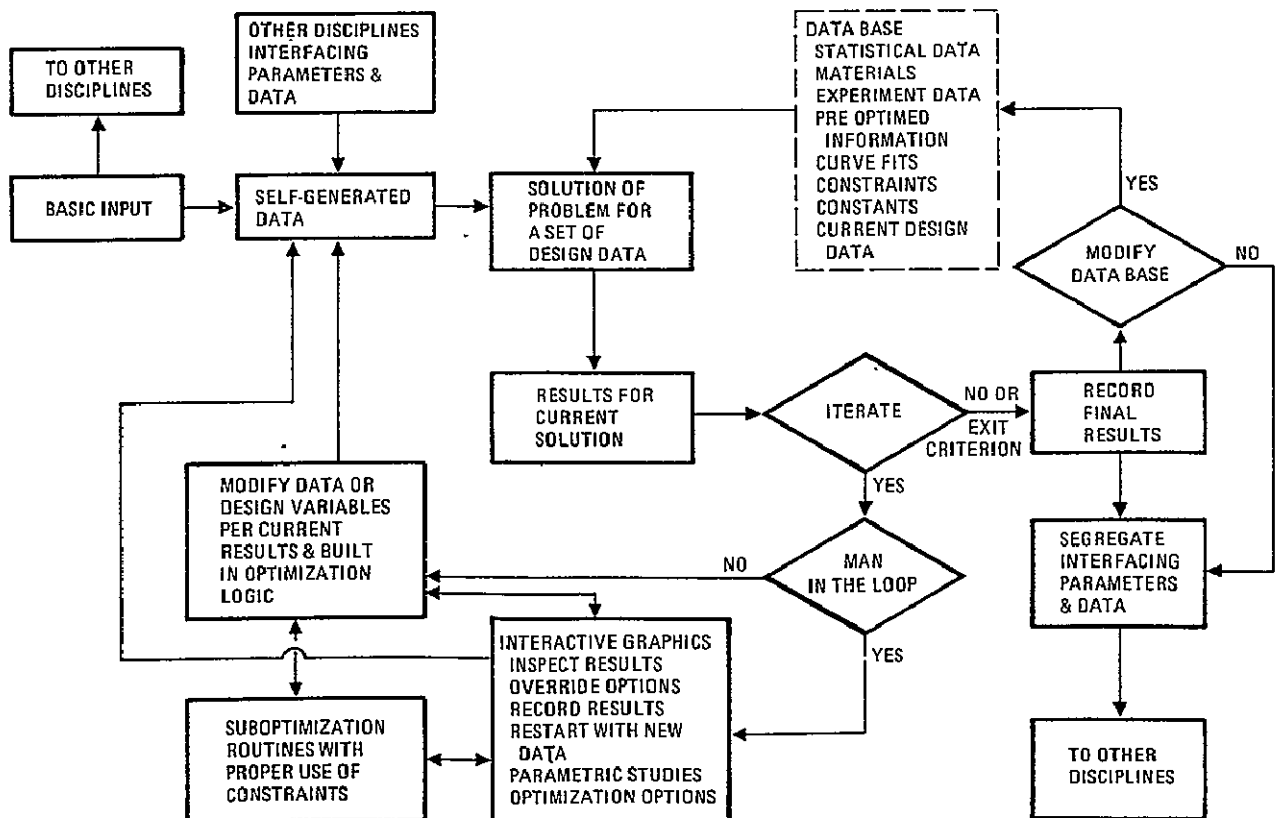


Figure 2-17. General OM Organization

## 2.5 Answers to NASA's RFP Questions

This section presents answers to key questions posed in the RFP by NASA in relation to Task 1. Although many aspects of these questions have been answered implicitly or explicitly elsewhere in this report, additional consideration is given to each question individually in the following paragraphs.

2.5.1 What different disciplines should be involved? - The IPAD system, as presently conceived, is receptive to having all disciplines represented in it by means of their respective Operational Modules and appropriate interfaces with Multidisciplinary Data Bank and other Operational Modules. The question should be qualified in terms of discipline involvement in the various phases of the design process and, furthermore, in terms of specific project requirements since no two projects are alike, although similar creative design processes and evaluations may be performed by some disciplines. Since the IPAD System is designed with the required flexibility to accept any set of disciplines with their own degree of sophistication, then the basic issue posed by this question becomes immaterial in the long range. But, if a specific implementation is in mind, such as a First Release Capability for IPAD, then the disciplines and the contents of their Operational Modules should be defined. In this respect, the list of disciplines and the present automated capability described in Section 2.4 of volume I should be considered as the initial goal for IPAD's First Release Capability.

2.5.2 What disciplines are already adequately represented by existing codes? Which ones are missing? - Most of the engineering disciplines (such as aerodynamics, performance, structural analysis, propulsion) have developed, through the years, a wealth of automated procedures ranging from simplified analyses to comprehensive treatment of physical phenomena. Although many specialists can make a justified case for further development, an adequate capability is available in many of these disciplines, in particular for conceptual and preliminary design phases.

On the other hand, design disciplines (such as vehicle configuration and subsystem design) have not had, until recently, the benefits of adequate equipment and software to perform their functions more effectively. Among these are the creative functions, which can hardly be delegated to any equipment or computer, and the routine functions, most of which can and should be automated. By taking the drudgery out of the design and by providing special equipment and aids, the designer can dedicate his effort and talents to the more challenging creative activities and contribute to a more effective design process. The design functions are presently underdeveloped and offer a fertile ground for cost-effective automation.

Management is another area in which adequate automated tools are missing. It is envisioned that the general and special purpose utilities offered by IPAD would afford almost instantaneous visibility in all tasks being performed in a given project by

accessing files and data stored in the project's Multidisciplinary Data Bank. A series of Operational Modules specifically designed to perform management tasks should be added.

The areas of operations research, reliability, maintainability, safety, logistics, and economics could benefit from the development of additional automated capability.

2.5.3 What disciplines have to be represented primarily by experimental data? - The use of experimental data is commonplace in most of the disciplines involved in aerospace-vehicle design, particularly materials, aerodynamics; stress analysis, weights and several subsystems. The need for experimental data and the basic drivers for generating it will not be changed by IPAD, but the means of reducing, interpreting, curve fitting, and finally applying the data to the design could be substantially improved by the use of interactive equipment and general and special purpose utilities to be available within IPAD.

2.5.4 How should experimental data be handled in the system operation? - Experimental data is usually generated because of lack of appropriate analytical methods to predict behavior under specified environmental conditions, or to identify the environment itself. The number of interacting variables could be large and, typically, many experimental points are required to cover the possible ranges of the variables and the scatter in test results. A large amount of raw data could result from a test program, and it is cumbersome to use it in that form. The raw data is usually interpreted, reduced, and curve-fitted to make it more amenable for use within analytical evaluation procedures. The IPAD system should provide expeditious means of reducing and curve fitting experimental data so that the user does not need to store it in raw form, and therefore save prime storage space.

2.5.5 What aspects of the design are not quantifiable and what impact do they have on design process? - The non-quantifiable aspects of the design are many and form the body of intangibles and artistry that cannot be delegated to a computer. Many design decisions are not quantifiable because they are never brought to the surface for that purpose, and are imbedded in established design practice, availability of stock or parts, experience of the designer, etc. Although the effects of those decisions on the end product could be measured in terms of weight, drag, and costs, their impact on the design process itself is not significant.

2.5.6 What is the proper place and role of statistical information in the system? - Statistical information should be contained in local user's data banks and they should be easily recalled, updated, and categorized. A general-purpose utility (STATUM) is provided by IPAD to help in analyzing, reducing, and applying statistical data in any discipline. The role of statistical information in the system is to be determined by the discipline using it.

2.5.7 In the case of structural weight, how should the non-optimum and secondary weights be assessed? - Many automated structural sizing procedures determine the theoretical gages (with proper consideration of manufacturing constraints) required to sustain various loading conditions and to preclude several failure modes. The resulting structural element dimensions can easily be translated into theoretical weights. The actual part, though, once it is processed through design and manufacturing teams will weigh more than the calculated theoretical weight. Many reasons exist to account for the difference (called non-optimum weight by many), the main one being that not all the significant design factors (besides loads and failure modes) are included in the structural sizing procedures. The so called non-optimum weight becomes, hence, a function of how comprehensive the sizing procedures are in including all the important design and manufacturing realities. The area of structural weight estimation needs a stronger marriage between structural sizing, design details, mass properties, and manufacturing to produce automated procedures that account for all significant factors by means of grass-root approaches. This type of information is also usable in cost estimating procedures. A similar grass-root approach seems to be the only reliable approach to identify the sources and account for secondary weights.

2.5.8 What should be the IPAD level of application? - The level of application of IPAD should be progressive, starting with a management/engineering capability for conceptual and preliminary design phases, and gradually expanding to other fields and phases of design as a result of a planned evolution of IPAD and the levels of funding available.

2.5.9 What should be the range of IPAD applications? - A distinction must be made here between IPAD's system software and IPAD's engineering Operational Modules. The system software is applicable to any set of Operational Modules and as such is applicable to any type of vehicle or design project. On the other hand, the engineering software is tailored to the evaluation of specific phenomena, which is very dependent on the type of vehicle or design at hand. The set of Operational Modules and the pertinent automated procedures used for the design and evaluation of an aircraft are different than those required for a ship, or for a bridge. The selection of the appropriate set of Operational Modules should be made to satisfy the most immediate plans of the agencies involved in the development of an IPAD system.

2.5.10 How can one resolve the unavoidable conflict between the level of analysis and computer time? What is the optimal level of analysis at each stage of the design? How can one measure and determine it? - The cost of analysis (computer time and man-hours) is known to increase with the level of analysis, whether due to degree of sophistication and thoroughness or because of evaluation of behaviour under different conditions. The level of analysis to be used in a particular evaluation is determined by specialists in each discipline, and the conflict most frequently is not between the analysis level and the computer time required (they very well know how much it costs), but

rather between the cost of the needed analysis and the budget available. It is true that the level of analysis should be in balance with the degree of definition of the product, and unnecessary analysis should be avoided; but a competent design team already has built-in within its modus operandi judicious selections of adequate levels of analysis for each stage of the design. It is doubtful that an optimum level of analysis could be established a priori and, furthermore, that it could be measured. Confidence on the results of a proven procedure may be the deciding factor, or a detailed level of analysis may be justified to substantiate a weight savings that permits meeting minimum performance or payload constraints. A gamut of special situations, even within a single project, can invalidate any preconceived ideas or the statistics of previous cases, so that the selection of the most adequate level of analysis should be left to experienced members of the design team.

2.5.11 What choice of design strategy should be available to the designer in seeking the optimum design? For instance, how can tradeoff data be generated and used to speed up the design process?— Many optimization and suboptimization loops take place in the various phases of design, ranging from overall vehicle sizing to design details such as panel stringer spacing. Most disciplines participate in one type or another of optimization study. Conceptual and preliminary design vehicle synthesis programs have built-in optimization loops, where major configuration and subsystem quantities are the design variables, and the merit functions are measured in terms of overall vehicle performance or in meeting a given set of requirements. Familiar tools such as these must be preserved, and IPAD can further enhance this capability by providing an interactive, general purpose optimization utility (OPTUM), whereby the user can specify his design variables, constraints, and objective function as well as participate (interactively), if he wishes, in monitoring the progress of the optimization. This same utility can be used as a parameterizer to obtain tradeoff data, either interactively or in a batch mode. The availability of this general-purpose optimization utility will provide the core for all optimization and tradeoff data generation required to speed up the design process, from multidisciplinary studies to local sub-optimization within a single discipline.

2.5.12 How could one judge the efficiency of independently developed codes relative to their efficiency when incorporated into the IPAD framework? At what point would it be more economical to rewrite the independent code before incorporation into IPAD? The efficiency of a code must be considered in terms of total costs; that is to say, both user and computer-related costs. The involvement of the user in setting up a computer run in the present computing environment is, typically, the largest portion of the problem-solving activity, and as such offers a sizable target for streamlining and cost savings. One means of accomplishing this objective is by interactive graphics (e.g., checking of input and output data, automatic plotting of results, monitoring progress of iterative procedures, etc). So, the relative efficiency of existing code, as

compared when incorporated into IPAD, could be measured in terms of investment required to make it more efficiently usable versus the savings to be accrued during operations. The projected usage rate, of course, is an important factor in this evaluation. On the other hand, there is code efficiency in terms of computer costs. An existing code that was developed to run efficiently in one system does not necessarily run efficiently in all systems. Even the charge algorithm used within a company may dictate changes to reduce the running costs of specific programs, since these algorithms weigh differently the use of central processor, peripheral equipment, tape handling, memory units, etc.

Convair Aerospace has experienced cost savings merely by interfacing two or more programs (unmodified). This improvement was due to (a) avoiding manual handling of input/output, and (b) automatic generation of data from one program to the next.

In conclusion, it is felt that each agency or company using IPAD should develop its own standards as to extent and type of changes that are justified for efficient use of independently developed codes. This statement is made with the understanding that the problem-solving algorithm within the code is not altered.

2.5.13 What set of design variables defines the vehicles to which IPAD is to be applied? - This question suggests the existence within IPAD of specific sets of design variables for one or more type of vehicles. If IPAD were a hardwired multidisciplinary computer program this could be possibly necessary, but the presently conceived IPAD system is softwired and has the flexibility to accept any set of design variables consistent with computer-time constraints. Any other approach will short change the project design teams and detract from wide acceptability of the system.

2.5.14 Should a set of design variables be divided into subsets of basic ones (i.e., wing aspect ratio) and local ones (i.e., skin thickness of a specific panel)? - Experience gained in the use of many vehicle and subsystem iterative redesign processes indicates that the total set of design variables is typically, and conveniently, divided in several subsets according to the stage of design development. During conceptual and early preliminary design phases, most vehicle sizing requirements are met by using basic design variables from various disciplines and there is little need or enough design definition for inclusion of local design variables. In many cases the effects of local design variables are already "built-in" in one or more basic design variables (i.e., unit wing weights including preoptimized structural concept proportions with proper manufacturing constraints) and they are not needed explicitly in the vehicle redesign process. As the design evolves into more detailed phases the need for local design variables increases, but this need usually can be confined to the operational modules peculiar to each discipline. The results of this sub-optimization are usually reflected into basic design variables which typically are kept within the overall vehicle optimization loops.

2.5.15 How should the number of vehicle design variables be reduced to a tractable number? - The number of design variables typically used in conceptual stages is small. They include wing aspect ratio, wing area, wing loading, thickness/chord ratio, body fineness ratio, etc. A larger number is used during preliminary design and a substantially larger number must be considered in detailed design. Typically, in a non-computerized environment, the detailed design variables are manipulated in groups involving one or more disciplines, and are never considered simultaneously, since it would be a slow and complex process. Automation makes it possible to speed up this process but a large number of design variables is still undesirable. Due to the implicit relationships tying these variables together and the existence of highly nonlinear and discontinuous functions within each discipline, the mathematical optimization problems associated with a large number of multidisciplinary design variables could be formidable. The number of vehicle design variables must be kept as small as possible while still retaining enough "visibility" for the more strongly interrelated effects. On the other hand, approaches using optimization algorithms with design variable linking schemes and the subdivision of the overall optimization problem into various suboptimization loops (including taking a reduced number of variables at a time) offer some possibilities for efficient vehicle optimization loops. Another means of reducing the number of design variables treated simultaneously is to convert them to parameters which are varied by the responsible specialist from an interactive terminal. In this case, the specialist can use his judgment and experience in directing the vehicle optimization process.

### 3. CHARACTERIZATION OF THE DESIGN PROCESS

The major objective of Task 1 was to establish the extent to which an IPAD System is to support the design process. This objective was pursued by investigating the basic functions performed by various engineering disciplines involved in aircraft design, by segregating their present capability in terms of automated and hand-performed procedures, and by identifying areas for further developments needed to operate within an IPAD environment. To this effect, an "engineering window" was defined first under the premise that if this window provided adequate insight to assess the needs and automation potential of enough disciplines the expansion of this window would have led to more of the same without a justifiable return on effort and investment. The engineering window selected for this feasibility study consisted of the following disciplines: Configuration Design, Aerodynamics, Performance, Propulsion, Mass Properties, Flight Control and Stability, Operations Research, Reliability, Economic Analysis, Structural Loads, Structural Analysis/Synthesis, Structural Dynamics, Thermal Analysis, and Various Subsystem Designs.

The participation of each of these disciplines in the design process is discussed in Section 3.1 while the specific procedures used in performing the tasks are detailed in Section 3.2.

Task 1 culminated with a recommendation for the engineering capability required in a First Release Capability of IPAD as reported in Section 2.4. of Volume I.

For the convenience of the reader most of the figures and tables called out in this section have been bound separately in Volume III, "Phase I, Task 1: Engineering Creative/Evaluation Processes".

#### 3.1 Design Phases

The aircraft design process is typically divided into various phases or levels of design. Some aerospace companies use conceptual, preliminary, and detailed design phases while others further break down these basic phases into additional levels. Furthermore, each of these phases is not precisely defined and the division lines vary among companies. The moral behind this existing situation is that semantics does not design aircraft and that the real backbone of the design process lies in the engineering functions or processes that must be performed from conception to operational use of an aircraft.

In this study, emphasis has been put in identifying grass root design/engineering functions, their logical place and sequencing in the total process, and their inter-communication needs. Because of this, all partitions of the design process become immaterial and the choice of one or another phase breakdown can be made on the basis of convenience or accepted practice within a company, without affecting the design process



itself. With the foregoing considerations in mind the design process was divided into conceptual, preliminary, and detailed design phases. This selection was done in order to:

1. Avoid another fictitious breakdown of the design process into ad hoc phases for IPAD, and
2. Provide a common basis for understanding and communications among personnel from the various disciplines participating in the study at Convair.

The flow charts of Figures 3-1 and 3-2 (refer to Volume III, Chapter 3) provide the insight needed for this study. They show the various disciplines participating in conceptual and preliminary design tasks, identify the methodology used in performing the tasks, and outline the major flow and sequencing of activities. The various letter-number identifiers shown in the boxes of both charts refer to the specific procedures that are used at that point in the design process and which are detailed in Section 3.2 of this volume. These two charts present an overall view of the design process as well as a proper cross referencing for "telescoping" into each discipline's task to find out the type of input data required, details on the methodology used, output of the task, and recipients of the end results obtained. These details are given in the functional flow charts of Volume III. Many of the disciplinary functions depicted in Figures 3-1 and 3-2 are also performed during the detailed design phase, although using more detailed input data and interfacing with a larger number of disciplines. The basic function per se is the same and the identification of additional detail was judged unnecessary for the purposes of this study.

### 3.2 Engineering Disciplines

In order to participate in the design process an engineering discipline, in general, needs Input Data originating outside and/or within the discipline, which is used with Creative/Evaluating Procedures (CEP) (Executed by hand/brain, computerized, or a mixture of them) to generate Output Data which is used by other disciplines downstream in the overall design process (or upstream if a part of a multidisciplinary iterative CEP). A CEP is defined herein as a sequence of steps, the execution of which will either define part of a product, or generate additional data for use in other CEP's, or yield a measure of goodness, or permit to reach a conclusion or make a decision. Typical examples of CEP's are the sequences of steps required to: create a configuration design; perform a flutter analysis, a performance analysis, or an engine selection; make a weighted comparison of alternate designs; estimate the cost of a part; etc. The CEP's must be appropriate and sufficient for the immediate design definition goals at a given point in the design process such as to avoid both underkill and overkill. The type and amount of data associated with the Input and Output of a given CEP is very dependent on its complexity and relations to other disciplines. As the design evolves the degree of participation of a discipline changes from phase to phase and involves many CEP's. Also, the amount of data mushrooms and flows in many directions.

A series of Functional Flow Charts were developed in order to properly identify and record the degree of participation of the disciplines considered in this feasibility study and the type of data required in the design process. This task was accomplished by generating the following information:

1. A list of typical CEP's which are within the responsibility of each discipline, classifying the CEP's according to being used in conceptual, preliminary or detailed design phases.
2. A list and brief description of computer programs selected by each discipline as appropriate for use within an IPAD system, identifying in what phases they are used.
3. Functional Flow Charts for the CEP's identified in 1. The form shown in Figure 3-3 was used for a consistent presentation of data in all disciplines. Each flow chart gives the required information classified in five columns. The first column identifies the disciplines interfacing with the input required for the CEP. The second column identifies, in the form of Input Data Blocks, the information required from those disciplines. The third column describes the Creative/Evaluation Process performed by the responsible discipline shown in the chart heading, including a brief description of the function of each box and showing if the function is presently executed by hand (H) or by automated procedures (A). The fourth and fifth columns are similar to columns one and two, but refer to Output Data Blocks generated by the CEP and the disciplines receiving the data.
4. Identifiers attached to the Input and Output Data Blocks to indicate the form of data transmission presently used in each case. The following nomenclature was used for this purpose:

C:	Card decks	L:	Computer listings
d:	Drafting machine drawing	M:	Magnetic tapes
D:	Hand-made drawings	R:	Report, documents
g:	Machine-plotted graphs	r:	Written text, memos
G:	Hand-made graphs	T:	Hand written tables

The functional CEP flow charts and engineering capability described in the following sections have been extracted from present modus operandi of the respective disciplines at Convair Aerospace, San Diego and Fort Worth Operations, and as such are partially representative of the total capability available in each area. For the purposes of this feasibility study, they collectively define the "engineering window" used to assess the major ingredients that enter into the conceptual, preliminary, and detailed phases of an aircraft design process. Although this window was limited in scope it has provided a more than adequate measure of the degree of involvement of key design engineering activities, their respective interfaces, and has helped in defining the size and magnitude of data banks and requirements for computer hardware and associated equipment.

3.2.1 Configuration Design. - This section contains a detailed outline describing the configuration design process as it is now accomplished, the description of a general type of computer equipment that would permit its efficient use by the configuration designer, and a second detailed outline to describe an approach to the automation of the configuration design process using this computer equipment. A series of Creative Evaluating Process (CEP) functional flow charts were developed to break the process down to the individual elementary steps involved. These CEP's show the data input requirements necessary to perform each elementary design task and the data output as a result of the task. The discipline source of the input data is listed as well as the destination discipline for the output data. An overall flow chart of the configuration design process is shown in Figure 3-4, Volume III.

3.2.1.1 Present capability: A step by step description of the configuration design process, as presently used, is given in the following paragraphs:

1. From performance engineer, get estimate of gross weight and fuel volume, engine thrust required, and general wing characteristics such as wing loading, aspect ratio, taper ratio, sweep airfoil.
2. Compute the coordinates for the wing and draw wing template to layout scale.
3. Obtain an engine drawing and draw engine template to layout scale - include engine c.g. - of each engine to be considered.
4. Obtain drawings of payload items ( bombs, missiles, guns, ammo, people, seats, galleys, etc.) and make templates to layout scale.
5. Obtain estimates of weight and volume requirements for avionics equipment; also antenna "look" requirements and size for radar, IR, etc., antennas.
6. Start "arranging" or "composing" a configuration concept to satisfy as many of the mission requirements as practical. Accomplished by placing templates of parts (e.g. engines, wing, payload, crew, avionics, etc.), on drafting table under a vellum sheet in a reasonable (based on past experience) arrangement.
7. Sketch a shape (fuselage) around the parts as applicable and make a rough estimate of weight buildup and balance.
8. Rough size tails to fit the configuration concept based on statistical data (volume, etc.), or on "what looks right" for that particular configuration concept.
9. Relocate parts to achieve balance, if necessary.

10. Size landing gears (wheels, etc.) and draw a concept for folding and stowage.
11. "Harden up" the lines to fit the parts taking into account area curve/cross sectional area distribution, if applicable.
12. Cut a few cross sections through the fuselage and other parts as necessary, at critical locations, to start defining the area curve fit if applicable.
13. Rearrange components as necessary to achieve better area curve fit, but remain cognizant of balance requirements as defined by the first balance estimate.
14. When reasonably satisfied with rough area curve fit, define fuel tanks in side view, plan view, and cross sections. Add intermediate cross sections as necessary.
15. Check fuel volume by plotting fuel tank cross sectional area against fuel tank length (fore and aft) and integrating this curve for volume. Also, establish fuel C.G. from this curve.
16. Bulge, stretch, rearrange as necessary to get fuel volume required if a reasonable match between this volume and the one established at original sizing, has not yet been achieved.
17. Calculate wetted-surface areas of components by plotting component peripheries (from cross section cuts) against fuselage length and integrating this curve for surface areas.
18. Using these surface areas, fuel volumes, and other dimensional data available at this stage, update the structural and system weights estimates and make another weights buildup and balance check, both with and without fuel.
19. Move components as necessary to achieve a desirable balance (based on  $1/4$  MAC at this point), both with and without fuel.
20. Derive necessary data (weights, fuel volumes, wetted areas, surface areas, etc.) necessary to make a preliminary performance check.
21. From this performance check, adjust wing area, wing loading, wing geometry, thrust, gross weight, fuel volume, etc., to achieve desired performance. (This task is done by the Performance Group).
22. Start second pass layout: adjust wing area, fuel volume, engine size, etc., to conform to new estimates.
23. Request the Flight Control and Stability group to size tails and estimate A.C. position and desirable static margin.
24. Perform a weight and balance update and re-position the wing if required.

25. Adjust lines of fuselage, etc., to give proper area curve match if applicable.
26. Cut cross sections through all components and develop:
  - a. fuel volume
  - b. wetted-surface areas
  - c. cross-sectional areas
  - d. dimensional dataas required for aerodynamic lift and drag analysis, structural weights analysis, systems weight analysis, and performance analysis.
27. Repeat 22 through 26 as necessary to achieve performance.
28. Make three view drawing of the configuration and dimension all pertinent external features necessary to permit evaluation of the vehicle by an independent party, as when submitting a proposal to the customer.
29. Make an internal arrangement drawing (inboard profile) of the configuration with sufficient internal detail to permit evaluation of the vehicle by an independent party.
30. Make an external lines drawing of the vehicle for same reason as above and for making wind tunnel models.

The present capability in terms of CEP's and existing computer programs at General Dynamics/Convair is given in Table 3-1. This capability is in a continuous state of expansion and adaptation to the needs of present and near future aerospace-vehicle programs. The CEP flow charts that were previously called-out in Figures 3-1 and 3-2 are explained in more detail in the following paragraphs.

1. Concept Layout and Basic Design Data Development (CD1), Figure 3-5. This CEP represents the initial configuration composition. It is based to a large degree on past airplane history and statistical data. It provides the starting data for the initial gross sizing exercises and tests the basic beginning concepts for validity of arrangement.
2. Parametric Configuration Concept Evaluation (CD2), Figure 3-6. The parametric evaluation CEP is the beginning of the optimization process for a specific concept. Layouts are made for two basic purposes:
  - a. to establish feasible limits for the variation of parameters, and
  - b. to generate descriptive geometric data for the analysis part of the parametric evaluation.

3. Initial Configuration Layout (CD3), Figure 3-7. This CEP details how the first time full-blown, detailed layout of the concept is made. It uses as inputs the sizing and geometry data (e.g. wing planform, engine type and size, gross weight and fuel volume, cross-sectional area distribution) generated in the parametric evaluation. Its primary purpose is to test the validity of the emerging design. It also generates data required for analysis as part of this test and provides the necessary lines, 3-view, and internal arrangement drawings needed to communicate the design data to other groups.
4. Risk Assessment (CD4), Figure 3-8. This task is performed during sensitivity studies to assess the impact on cost, performance, weight, and scheduling in case the assumed technology and performance levels, and the selected design features cannot be achieved.
5. Trade Study Layouts (CD5), Figure 3-9. Trade studies are conducted to define the sensitivity of the configuration to various design and operational aspects as the design progresses. Layouts are made to assess the physical impact of these trades on the configuration and to generate data for any analysis required for this assessment.
6. Selected Configuration Layout (CD6), Figure 3-10. A configuration selection is made and a second detailed layout of this selected configuration will generate the required data for test of its validity. Three-view, interior arrangement, and lines drawings are made of this configuration as part of the evaluation process and to portray the details of the design. The design process may require several layouts of the type made here, to work out solutions to any problem areas that emerge.
7. Configuration Control Studies (CD7), Figure 3-11. The beginning of the preliminary design phase sees the start of design studies being conducted by the various structural and systems design areas. As these studies progress, alterations to the configuration are often suggested. Layouts are made of these suggested alterations to generate data required to assess their desirability. If this assessment indicates acceptance, the configuration control drawings are updated to reflect this alteration.
8. Configuration Description (CD8), Figure 3-12. This CEP is in reality a configuration publishing point. It provides an opportunity for all design and analysis disciplines involved in the process to get updated to a configuration resulting from some fairly detailed design and analysis studies. The configuration itself is "real" in that it has "survived" or "evolved" from these studies. This point represents a "hard" proposal point.

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9. Final Configuration Control Studies (CD9), Figure 3-13. Major alterations to the configuration will not occur after this point. As the design refinement studies continue prior to hardware design the suggested minor alterations are tested by layout and analysis before being incorporated on the configuration control drawings (3-view, internal arrangement and lines).
10. Configuration Design Studies (CD10), Figure 3-14. This CEP is a summary/overview of the Configuration Design tasks in relation to the input data required, the originating groups for this data, and the primary groups that receive the output of these studies.

3.2.1.2 Further developments: The following paragraphs describe the type of equipment needed for configuration design, and outline an approach to the computerization of the configuration design process.

1. Interactive Graphics Equipment Needed. In order for computer equipment to simulate or duplicate the use of the drafting table and drafting equipment currently used by the designer in the "configuration composition" process without an extraordinary relearning process on his part, the equipment must have a graphics display unit that is highly interactive with the operator, is dimensionally accurate, and which presents a stable but erasable image in a size, format, and scale with which he is familiar. The current Light-Pen/CRT units represent a crude form of this type of equipment; however, their "working surface" is too small, is curved, and the image produced is not dimensionally accurate enough and is made up of line widths too great. If the basic concept of the Light-Pen/CRT is retained but the working surface is altered so that it is approximately three by five feet, flat, and has an image that is dimensionally accurate with line widths similar to that of the drafting pencil on vellum, then the configuration designer could work with the new tools in a reasonably familiar environment and could perform his "composing" task with confidence and without distraction.
2. Computerization of the Configuration Design Process. The following paragraphs describe an approach to the computerization of the step by step design process given in 3.2.1.1.

Step No. 1. If the performance engineer provides these sizing data estimates, they will be done on his OMs using the conceptual design level OM. If the designer derives this data, he probably will rely on a survey of historical and statistical data of previous airplanes. This would require a comprehensive library of data on historical and contemporary aircraft. Data similar to that contained in "Janes" would be required although more detail would be

valuable. This library probably could be stored on disk or tape by categories of aircraft and read in when required.

Step No. 2. Several programs written in APT language are available. Variations occur in the type of input data and in what output is required -- number of chord-wise and spanwise sections cut -- whether the wing is a variable sweep wing or fixed, whether it is a variable incidence horizontal tail or fixed, etc. The post-processor currently used at General Dynamics/Convair is for the Gerber NC Drafting Machine using punched paper tape. The graphics display device to be used will determine the necessary interface equipment.

Step No. 3. Engine drawings have been made using the APT language and the Gerber NC Drafting Machine. Probably what would be done is to program the basic engine installation drawing and retain it in an engine drawing library to be recalled as required. In the early stages of an aircraft program development, engines are often scaled to provide different thrust levels. In scaling, the engine diameter and length are often scaled to different factors. This capability would have to be built into engine "drawing" programs so that when a basic engine is recalled from the library, it can be scaled to the desired thrust level as required..

Step No. 4. All of the payload items such as crew, people, cabin equipment, bombs, guns, ammo, etc., would be handled like the engines. The pieces would be programmed and stored in a library in the various categories and read back into the system as the problem required. Very few of these items are currently programmed, but the task would be simple using the APT language.

Step No. 5. The avionics items would be handled like the engines and payload items: programmed, and stored in the library for recall as required.

Step No. 6. The designer initiates the "composition" process by calling from the library the "drawings" of the standard parts such as crew, engines, payload items, etc., and arranging them on the "board." He would call the wing drawing program, insert the required parameters such as area, aspect ratio, taper ratio, sweep, and airfoil and "draw" the wing on the board and move it into the approximate position.

Step No. 7. With the primary parts arranged in side and plan views from Step 6, "draw" the fuselage shape control lines in, the upper and lower profile in side view, and the maximum half breadth in plan view. These lines are approximate at this stage and will be altered many times in the succeeding steps. Several existing programs in both Fortran and APT languages are available for curve fitting of cubics, conics, and polynomials up to the tenth degree. The



technique would probably be for the designer to spot points at critical clearance areas on the scope "board" and let the machine fit a curve through these points.

A rough weight and balance check can be achieved at this time by means of computerized procedures used within a mini computer, within a desk calculator mode or within the main machine, depending on the complexity and detail of the calculations desired.

Step No. 8. If tail volumes or volume coefficients are the starting information, simple programs can be arranged for storage in the designer's local data bank/library for recall. These programs compute a tail area required, given a volume or volume coefficient and a  $\overline{C}/4$  position for the tail surface. A tail "draw" program is then used to draw the tail. This program is the same as the wing "draw" program and uses area, aspect ratio, taper ratio, sweep, and airfoil as input data. If a simplified method of sizing the tails is used, a tail will be drawn by spotting the leading edge and trailing edge of the root and tip chords on the board then drawing straight lines between these points. The characteristics of the tail (area, aspect ratio, taper ratio, sweep, MAC, etc.) will then be computed.

Step No. 9. The relocating of parts to achieve a balance or to satisfy other requirements such as engine blast, bomb drop, crew vision, etc., will mean that entire units such as engines, wing, crew, etc., will have to be moved around on the "board" to different locations for trial looks at the new position. The fuselage upper and lower profile lines and maximum half breadth lines probably will require alteration in whole or in part. Tails may have to be altered in size and shape. Even wings may be altered in size and shape. The equipment and computer system should have the capability of temporarily storing a wing, tail, or even a whole rough configuration for later recall for comparison. Full or reduced scale hard copies of the "board" should be obtainable at most any intermediate stage desired.

Step No. 10. A program is available in Fortran to size landing wheels. This program requires gross weight and landing field surface characteristics as inputs. Programs to draw these wheels will have to be made. Included in these wheel "draw" programs should be the capability to move or translate the wheels to a stowed position as the first step in determining the retraction method. The wheels, when sized, are "drawn" on the board in position, both up and down, and become another one of the "parts" of the emerging vehicle to be worked with. The wheels will be moved several times and the retraction method altered during the subsequent design process.

Step Nos. 11, 12 and 13. These steps represent the major "lines" development task of the design process and will be based on computerized lines procedures already in use, using the APT language with the computer and the numerically controlled drafting machine as the graphic output device. In the IPAD system, the drafting machine would be replaced with the already discussed "on line" board. Two different methods can be used; the Polyconic Surface System (which is three dimensional using the x-y-z format) and a two dimensional, x-y format, system using conic development. The 2-D system is generally faster and is adequate for the preliminary design stage with conversion to the 3-D system occurring at the transition to the detailed design phase. The lines are developed as follows. At areas of critical clearance such as crew station, weapons, wheels, engines, etc., construct a cross section shape using the conic which requires five controls: three points, and two slopes. Check the cross-sectional area against the area curve. Rearrange the internal components if necessary (but do not forget balance) and reconstruct the sections until a reasonable fit is obtained. Check the longitudinal fair of the five controls for the conic cross sections (upper or lower profile line, maximum half breadth, a shoulder point, and slope controls for the profile and maximum half breadth). Alter as necessary to fair. Construct intermediate cross sections as required and check cross-sectional area against area curve. Alter longitudinal controls as necessary to match area curve with cross sections but keep fair. Reconstruct cross sections to new controls and check cross-sectional area. Repeat as necessary to achieve desired match and shape.

Step Nos. 14, 15 and 16. The fuel tanks are generally bounded, partially by the external surfaces already established and partially by new internal boundaries. The internal boundaries are generally simpler shapes than the external ones and are defined with simple straight lines, circles, etc. These boundaries are established in the plan and profile views, then in the cross section cuts to agree with the plan and profile views. The cross-sectional area of the fuel tank portion of each cross section cut is measured, plotted against tank length and the resulting curve integrated to determine fuel tank volume. If the resulting volume does not match the required volume established in Step 1, all or a portion of the steps 9 through 16 will be repeated to achieve the match. A balance check at this point is helpful, accomplished as described previously.

Step No. 17. Wetted-surface area is computed by measuring the exposed periphery of each of the cross section cuts, plotting these peripheries against fuselage length and integrating this curve to obtain surface area. Existing lines programs derive arc-length data in the Gerber Drafting Machine post-processor, therefore other means will have to be incorporated to derive this data.

Step Nos. 18 and 19. Structures and systems weights will be updated at this point using the preliminary design structures and systems weight estimating OMs. Another balance check will be made at this point and mass moments of inertia will be estimated using the mass properties OM. Components will be moved as necessary and steps 9 through 19 repeated as required.

Step Nos. 20 and 21. The aeroanalysis and performance OMs will operate to analyze the configuration developed to this point. The necessary input data will be derived from the configuration as designed.

Step Nos. 22 through 27. These steps are repeats of Steps 1 through 21 in greater detail each pass through.

This completes the second level of definition as shown on the Configuration Design Process flow chart, Figure 3-4.

3.2.2 Aerodynamics. - This section describes the role of the Aerodynamics group in a typical advanced aircraft design process. The sequence of steps in the aerodynamic evaluations are shown, along with the interaction with other disciplines through input and output data flows. The degree of automation of the design process is identified along with the appropriate computer programs for conceptual, preliminary, and detailed design phases. The IPAD system is conceived of a set of interacting operational modules which correspond to the major disciplines. A proposed structure for the aerodynamics portion of the IPAD system is described along with recommended computer programs it should contain.

3.2.2.1 Present capability: The typical aircraft design process involves several stages ranging from conceptual, preliminary, and detailed design phases. The Aerodynamics group is involved in all phases of aircraft design and the nature of its tasks and interactions with other disciplines changes from one phase of design to another. Table 3-2 presents a list of the aerodynamics tasks involved in the three aircraft design phases. Figures 3-15 through 3-20 present generalized CEP flow charts depicting the sequence of steps required to perform several of the tasks listed in Table 3-2. The flow charts also identify the disciplines which originate the inputs for each aerodynamic task and the disciplines which receive the results of the analysis. Practically all of the input data that is received from other disciplines involves a manual transfer of data into the aerodynamic evaluation process and most of the data resulting from the evaluation process is transmitted to the other disciplines by way of hand drawn graphs or tables. Most of the aerodynamics evaluation processes are automated although some steps in the evaluation processes are executed manually. Table 3-2 lists some of the computer programs available in the Aerodynamics group and the likely design phase where these programs are generally used.

At the conceptual level of an aircraft design study very little is known about what exact kind of aircraft will best satisfy the mission requirements and system constraints specified by the customer. Several different design concepts which appear to meet the design requirements may be laid out by the Configuration Design group based on simple state of the art sizing charts. The conceptual design may include a conventional configuration, which probably is based on an existing aircraft design, and several alternate configurations which incorporate several advanced technology concepts. The advanced technology concepts carry greater technical risk and higher development costs which must be weighed against the expected payoff in the performance of the aircraft. Some examples of the design requirements which may lead to the use of an advanced technology concept are:

1. STOL or VTOL requirements may suggest several powered lift concepts.
2. Transonic cruise may require supercritical wing technology.

3. Supersonic acceleration and transonic maneuverability requirements may lead to the selection of a thin wing with leading edge flaps and/or trailing edge jet flaps.

A large number of perturbations of the conceptual baseline configuration wing platform, engine size, wing loading, etc., are then studied as part of an interdisciplinary multi-variable optimization study.

In the conceptual design phase, the major interactions of the Aerodynamic group is with the Configuration Design, Propulsion, Mass Properties, and Performance groups. The Configuration Design group provides basic geometric data for lift and drag analysis. Very little detailed geometric data is needed in the conceptual level of aerodynamic analysis since the accuracy of the levels established for drag trade studies are not very critical. Decisions on design selection are made on a relative basis such that the aerodynamic trends become more important than the baseline levels.

In the preliminary design phase a greater level of configuration detail is required and a larger number of disciplines and interactions are involved. The primary interaction of the Aerodynamics group are with the Configuration Design, Performance, and Structural Design groups. Other interactions occur with the Propulsion, Stability and Control, Mass Properties, and the Model Test groups. The preliminary design phase requires a higher level of precision and detail in the aerodynamic evaluation of the baseline configurations. The preliminary design phase can be further divided into two subphases, the phase before wind tunnel testing and the phase with wind tunnel test data. Before wind tunnel data is available on the study configurations, the aerodynamicist must rely on the theoretical and empirical procedures for lift, drag and loads estimates. The test data is used to increase the level of confidence in the aerodynamic predictions and becomes a source of data to replace many of the earlier preliminary design estimates.

In a preliminary design study, the availability of test data lags behind the state of the actual configuration. The configuration is constantly changing as each discipline completes its detailed analysis and impacts the external lines or weight of the configuration. By automating the design process and involving a greater participation of all disciplines earlier in the design process the lag between test model and actual configuration can be decreased.

The detailed design phase is characterized by one well defined baseline configuration with detailed wind tunnel testing required for a high degree of accuracy. Typical aerodynamic tasks during the detailed design phase consists of:

1. Predicting drag differences due to changes in external lines.

2. Predicting drag of various external stores.
3. Detailed loads data.
4. Drag study of manufacturing irregularities, and
5. Preparing a complete set of aerodynamic data for the performance substantiation report and flight operation handbooks.

Another phase of detailed design occurs when flight test is underway. At this point Aerodynamics is concerned with flight test data reduction and analysis. Also, engineering changes need to be analyzed to assess their effect on the aerodynamics of the aircraft.

3.2.2.2 Further developments: The Aerodynamics Operational Module (AOM) should be a self-contained set of programs which would interface with the other Operational Modules (OM) in the IPAD system. The AOM and the other OM's would be under the control of an executive module and coupled through the executive module to a common data base. The AOM would obtain its needed geometry data for design evaluation from the data base and transfer the result of its evaluation back into the data base. The executive module would control the operation of the AOM to provide lift-drag data to the Performance OM, loads data to the Structures OM, and additional aerodynamic data to the other OM's. The executive module also could operate the AOM to refine the configuration design within a set of constraints so that aerodynamic parameters such as  $(L/D)$ , maximum lift, wave drag, would be optimized.

The aerodynamic programs in the AOM should be a combination of theoretical and empirical methods which will interact together to produce a continuous prediction of lift and drag in the subsonic, transonic, and supersonic speed regimes. The AOM should also be capable of using wind tunnel data, when it is available, as a means of generating the data required for other OM's. The combination of empirical and theoretical prediction methods along with model test data will provide a sufficient level of detail and computational accuracy as the design process moves through the stages of conceptual, preliminary, and detailed design. The AOM should be open-ended in nature so that computer programs could always be added.

The methodology in the AOM should be consistent with the level of detail needed for a particular phase of design. In the conceptual phase of design, detailed aircraft geometry is not needed since the aerodynamic parameters for performance evaluation are based only on the major design variables of the concepted aircraft such as aspect ratio, wing area, volume, etc. The conceptual level of aerodynamics analysis uses minimum bound estimates based on the fundamental physical characteristics of the system. For a given set of major design variables a minimum bound exists whereby minimum drag,

induced drag, and wave drag are theoretically limited. Statistically determined factors are used with the theoretical bounds to provide realistic predictions compared with the "state of the art" in aircraft design. The conceptual level of the AOM procedure is intended to give the designer early guidance, show trends, define interactions between major design variables, and provide aerodynamic data for performance potential and sizing. In the conceptual trades studies, all configurations are assumed to have an equally good detailed design so as to approach the theoretical lower bounds of drag.

In the preliminary design phase, external geometry for several baseline aircraft concepts would be available to the AOM from the IPAD data base. The baseline aircraft would be layouts of several design concepts such as a conventional design and another employing advanced technology. The baseline aircraft would then be analyzed using a combination of the area rule wave drag procedure, the finite element lifting surface procedure, and the empirical lift and drag prediction procedure (AeroModule). The wave drag procedure and the lifting surface procedures provide more exact answers to the AeroModule procedure to use with its empirical factors to derive non-linear and transonic lift and drag. After the baseline lift and drag levels are established, aerodynamic trade studies using the AeroModule procedure would then be performed. The empirical methods in AeroModule are based on fundamental theoretical principles and provide an efficient method of analyzing a large number of design perturbations while maintaining a sufficient level of accuracy to measure the aerodynamic differences relative to the baseline configuration.

In the later phases of preliminary design and into the detailed design phase, the character of the programs used in the AOM would change from a theoretical-empirical approach to a theoretical-test data approach. The configuration geometry is much more detailed in the later phase of preliminary design and the number of configurations is limited to a select few based on the earlier preliminary trade studies results. The area rule and lifting surface procedures are used to provide detailed fuselage area ruling and wing twist and camber distributions, to meet the design lift and drag requirements implicit in the earlier preliminary trade studies. Wind tunnel force models are constructed and tested from the detailed geometric data. The wind tunnel test data is used to substantiate the aerodynamic predictions that were made earlier in the preliminary design phase. The test data also would be used in place of the empirical prediction procedures to provide a greater detail of aerodynamic data to be transferred into the IPAD data base for an updated baseline configuration. The performance of the updated baseline would then be re-evaluated and additional parametric studies would be performed to re-size and optimize the configuration.

The wind tunnel force data and loads data analysis programs in the AOM would allow the aerodynamicist to view, analyze, manipulate, and make corrections to the wind tunnel data read directly from the tapes obtained from the wind tunnel facility. The use of inter-

active graphics in the wind tunnel analysis programs would provide the most effective means of reducing a large mass of wind tunnel data to provide the full scale aerodynamic data required for the other OM s.

In the detailed design phase of aircraft design the aircraft configuration is relatively fixed, only minor design changes are usually encountered. Wind tunnel data would be the primary source of most of the aerodynamic data that is contained in the IPAD data base. The theoretically based program in the AOM would be used to evaluate minor design changes prior to wind tunnel testing.

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3.2.3 Performance. - During the three phases of the design process, the emphasis on the performance tasks changes. Sizing studies based on nominal configuration geometry and state-of-the-art assumptions dominate the conceptual design phase. In the preliminary design phase, parametric configuration studies are used to refine the external geometry. Once the geometry is fixed, the Performance discipline assumes a supporting role with emphasis on mission performance and flight mechanics analyses to determine the effect of alternate missions, changes or compromises in design, materials, payloads, subsystems, etc.

The Performance discipline engages in five primary tasks in the design process: (1) concept selection, (2) mission performance, (3) sizing and parametric configuration studies, (4) flight mechanics analyses, and (5) summary charts and documentation. The following subsection briefly discusses these primary tasks, computational state-of-the-art of the Performance discipline, and major interfaces with other disciplines.

3.2.3.1 Present capability: Table 3-3 lists the Creative/Evaluating Procedures (CEP's) and computer programs used by the Performance discipline with an indication of the design phases in which they apply. Five major areas of endeavor are identified as follows:

1. **Concept Selection.** Concept selection refers to the Performance discipline's contribution to the cooperative and, to some extent, intuitive effort by all of the disciplines to choose one or more aircraft concepts to be used as the starting point in the iterative design process. This includes identification of the primary design variables for each concept, selection of the range of design variables to be examined, and gross estimates of the aircraft and engine sizes required to meet the design requirements.
2. **Mission Performance Analyses.** Mission Performance Analyses are the fundamental task of the Performance discipline, and it must be included in all synthesis and sizing programs. It involves determining the capability of an aircraft to perform a sequence of mission segments, i.e., cruise, climb, acceleration, refuel, etc. Design mission definitions are usually different for each aircraft to be designed because the desire for a new performance capability is the most frequent reason for designing a new aircraft. A representative example of a military bomber mission is shown in Figure 3-21.

Aircraft missions are built up from standard operational segments that are governed by Military Specifications or Federal Air Regulations. A list of segment types is shown in Figure 3-22, and each of these involves many variations depending on the aircraft type. A number of segments may be combined in any way to form a mission definition. For determining mission performance, each segment must be characterized by a fuel-distance relationship with whatever additional dependencies are

required, such as duration, speed, schedule, external-store drag, and initial or terminal conditions. These data may then be combined according to mission rules to determine overall mission performance capability.

Specialized, simplified methods, rather than detailed trajectory simulations, are used because of the large number of calculations required. Reference 1 contains descriptions of the types of methodology involved in both performance calculations and mission integration. These methods form the minimum requirements of a general aircraft Performance OM and are shown in the flow diagrams of Figures 3-23 through 3-26, CEP's PE01 to PE04.

3. **Sizing and Parametric Trade Studies.** With the support of the Aerodynamics, Mass Properties, Propulsion, Flight Control and Stability, and Configuration Design groups, the Performance discipline engages in sizing and parametric configuration studies whereby the configuration geometry is held constant while the combination of engine and aircraft (and sometimes wing) sizes which satisfy the design requirements are determined. The geometric parameters (i.e., wing and airframe shape) are varied to establish tradeoffs, determine sensitivities, and select optimum configurations. Each configuration is usually sized to meet the design requirements. Satisfaction of the design mission requirements determines the amount of fuel to be carried by the aircraft, which makes mission performance the computational element that closes the aircraft sizing loop. Since it is not meaningful to compare aircraft in the configuration selection process unless they have been sized to meet the same mission requirements, it is appropriate to include the sizing logic in the Performance OM. Figure 3-27 and 3-28 provide a flow diagram of the sizing procedure, CEP PE05. The logic for surveying configuration geometry, computing design variable sensitivities, and selecting optimum configurations, however, should be in a separate Control OM. In the case of configuration optimization, the sizing could be handled more efficiently along with the other constraints within the optimizer, but this can cause difficulties that hinder convergence.
4. **Flight Mechanics Simulations and Analyses.** In addition to the determination of design mission capability, the Performance discipline is required to compute other types of performance such as takeoff and landing, maneuverability, and air combat simulation, Figure 3-29. Runway requirements, for instance, are usually placed on the design, and these do not enter directly into the determination of design-mission performance capability. Maneuverability requirements are now commonly included in the design mission definition or used as a figure of merit in the configuration selection process for fighter aircraft. These and other performance analyses have been assembled into a list under the Flight Mechanics task in Table 3-3, and are shown in the flow diagram of CEP PE06, Figure 3-30. This list is open-ended, and the Performance OM must be constructed in such a way that new types of analyses and simulations can be added as they are needed.

5. Summary Charts and Documentation. The output of the Performance OM is used in three ways:
  - a. It is fed back into the configuration selection process as figures of merit and constraint values,
  - b. It is given to the Operations Analysis discipline in the form of mission trade data for the determination of costs, effectiveness, risk, etc., and
  - c. It is transmitted as an end product to the customer.

A typical format used in presenting this data is shown in the flow chart of CEP PE07, Figure 3-31.

The Performance discipline has an easily identifiable set of interfaces with the other disciplines. These interfaces are essentially identical at all levels of design, but the data transferred through them takes on greater depth and scope as the design progresses. In order to analyze the performance of a configuration, the Performance discipline must obtain information through the following primary interfaces:

1. Aerodynamics/Flight Control and Stability. This interface provides either:
  - a. the total drag of the configuration and control deflections for trim, given the flight condition, gross weight, center-of-gravity location, and lift required; or
  - b. the total lift and drag of the configuration, and control deflections for trim, given flight condition, gross weight, center-of-gravity location, and angle of attack.
2. Propulsion. This interface provides either:
  - a. thrust and fuel flow (or SFC) for the configuration, given the flight condition and power setting; or
  - b. fuel flow for the configuration, given the flight condition and thrust required.

If inlet, nozzle, and other engine-associated drag is not accounted for here, then it must be reflected in the drag obtained through the aerodynamics interface, which will require power setting or thrust as inputs.

3. Mass Properties. This interface provides the dry and maximum gross weights of the configuration along with whatever fuel, tank, and payload weights are necessary to compute the mission capability of the configuration. It also provides the center of gravity location, given the loading (fuel and payload) of the configuration.

Simply stated, the first three interfaces provide the forces needed to solve the equations of motion for a point-mass aircraft. The remaining interfaces are:

4. Configuration Design. This interface provides the few geometry parameters needed in performance calculations, such as wing area for lift and drag calculations, wing incidence, thrust angle, static ground attitude for takeoff and landing calculations, etc.
5. Customer. The mission requirements, which are based on either Federal Air Regulations or Military Specifications, are supplied by the customer. He, in turn, eventually receives the output of the Performance Discipline in the form of a Flight Manual and, in the case of military aircraft, a Performance Data Substantiation Report.

3.2.3.2 Further developments: Performance is a discipline with relatively clear-cut inter-disciplinary interfaces, but it is faced with an ever increasing diversity of computational tasks. The methods used in performance calculations, however, are "exact" which eliminates the need for much basic research other than mathematical research associated with a few abstruse performance tasks like dynamic flight path optimization. Performance problems lend themselves well to computerization, and the absence of basic physical and computational problems in mathematical modeling has allowed greater effort in the development of sophisticated approaches that have enhanced versatility and generality in performance computer programs. Because of this situation, the Performance discipline is better prepared to contribute to a system such as IPAD than most disciplines. Since performance methodology is highly computerized, the continually expanding spectrum of performance characteristics to be examined has resulted in a proliferation of programs to handle similar, but not identical, tasks for various types of aircraft. A list of those computer programs pertinent to the design process were presented in Table 3-3. The programs shown were generally developed for use on military aircraft projects, but some of them have been adapted for use on commercial aircraft also.

The Mission Analysis and Performance System (MAPS), Figure 3-32, Reference 1 is the result of such a programming effort extending over the past five years. Although it is the primary tool for flight manual and performance substantiation data calculations on production aircraft at Convair, it has been developed with a system such as IPAD in mind as its ultimate application. It has clear, general interdisciplinary interfaces and is extremely modular and open-ended in design. Provisions have been made for alternate levels of detail and an essentially unlimited variety of performance methods. An adaptation of MAPS would be ideal as the Performance OM for the Preliminary and Detailed Design Phases.

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The use of interactive graphics in a program such as MAPS is a further development which could provide additional configuration design capability. Interactive graphics is a relatively new capability, and current applications are largely experimental in nature. Its enhancement of computational efficiency as a direct I/O device - where very large amounts of data are not involved - is without question. It can be used quite effectively in checking for valid trends in data through graphic displays. Attempts to use interactive graphics to put a man in the computational sequence in performance calculations (as in cruise optimization, for example) have resulted in a reduction of the amount of computation required, but an increase in the time required to obtain the end results. Eventual application of this capability to more complex problems, such as dynamic flight path optimization and configuration selection, should prove much more effective. Such problems are characterized by catastrophic "bomb-outs" and convergence failures, and great savings could be made simply by eliminating batch-processing turnaround time even if no computational savings were achieved.

3.2.4 Propulsion. - The philosophy used in the evaluation of propulsion systems involves a progressive condensation of data transmittal as the process proceeds downstream. Otherwise, the amount of data and the level of complexity that would be required in the Propulsion Operational Module (OM) could, for example, render the OM unmanageable. Similarly, the tests, analyses and sundry specialized programs that go into the background for the OM are not required in the OM itself. There is, in effect, a pyramid of evaluation procedures rather than a single block. Some of the procedures in the pyramid have been automated, others are amenable to automation and still others require a man in the loop. It is important to realize that the same evaluation processes are generally employed in the conceptual, preliminary design, and the detailed design phases. The difference lies in the depth (detail) of effort.

At the level required for conceptual studies the primary trades determine whether one has a viable aircraft, in consequence of which estimates based on prior aircraft are used, as are ratios to scale the aircraft propulsion system to the current study iteration. Also it should be noted that very little of design data is required for the conceptual phase.

The preliminary design phase answers the critical questions raised during the conceptual phase but does not become encumbered by anymore detail than necessary. From the point of view of propulsion, this phase uses real (or nearly real) engines, initiates those test programs leading to practical inlets and exhaust systems, fills out the flight profile propulsion performance using preliminary test results (above), and translates the test findings into configurational constraints for the enlightenment of the designer.

The detailed design phase may, of course, use similar programs or even the same programs, but will exercise these in much greater detail both by quality of input and quantity of output required.

3.2.4.1 Present Capability: Table 3-4 gives a list of the principal tasks undertaken at each phase of the design process followed by a list of the computer programs currently in use. The design phase in which each task is performed has been identified as well as a cross reference to the CEP functional flow chart on which each task and/or computer program appears.

CEP P01, Figure 3-33, depicts a conceptual process for choosing an engine size and type. In this approach propulsion system data is developed or estimated outside of this task and then integrated into the vehicle synthesis by means of a propulsion subroutine called PROPUL. This subroutine contains engine data in a standard block format and employs a table look-up approach to satisfy the synthesis program call. Engine data is an integral part of the propulsion system identified in PROPUL. This data may be installed or uninstalled. If installed, the subroutine will respond to a call directly from the table. If uninstalled data is read into the table, the PROPUL subroutine will

use its installation routines to respond with installed propulsion system performance data. This requires that a separate table be established for each engine and a separate set of installation factors for each type of installation. Thus, the flexibility of the propulsion subroutine is limited to enhance the flexibility of the vehicle synthesis program it serves. The first source of engine data is, of course, the engine manufacturer(s). If appropriate, the engine manufacturer's data can be used directly. If an engine cycle similar to an existing engine is desired, a simulated engine may be built from the propulsion group files. Note that rough estimates of maximum engine air bleed and horsepower extraction are customarily used in conceptual design phase calculations, but these figures are derived from the accumulation of design requirements. The subroutine is called from an airplane synthesis program used by the Aerodynamics Group. The synthesis program provides the altitude, air speed, and temperature conditions as input to the PROPUL subroutine. Note that the choice of engine cycle is made external to this program and the result of that choice determines the engine data package to be included in PROPUL. Similarly the results of PROPUL calculations are compared with prior results to confirm or deny that choice of cycle. Installation practicality (in an obvious case, an engine too large for the fuselage) is also checked by hand, i.e., by review of program output. The PROPUL subroutine does have the capability for scaling the engine and does this on call from the synthesis program. The output of the subroutine consists of installed propulsion system performance (e.g., thrust and specific fuel consumption versus flight condition), and physical characteristics of the propulsion system (e.g., weight and dimensions).

CEP P02, Figure 3-34, serves a more general interest than the PROPUL subroutines. The input and output are virtually the same as in CEP P01. Note that each contained program was written as a subroutine in the interests of flexibility. A simpler driver is used when either of the programs (INST or EPIC) are to be run separately which is the more common case. EPIC is used to generate internal losses for a cycle in the absence of an engine deck. It can be used as a modifier or in lieu of an engine deck for the purpose of generating valid bare engine data. Program INST computes installed engine performance by correcting the bare engine performance for the several installation penalties, e.g., inlet, exhaust, power and bleed. The comparisons with desired results are made by visual examination of tabulated data or machine plotted data. These comparisons determine the necessity for the approximate magnitude of recycle input for another iteration. Note that since these programs are frequently used as main programs the output does not feed directly into a synthesis, but is more likely delivered as either machine plotted curves or punched cards, "squared off", to fit a performance routine.

The series of CEP's P03 through P12, Figures 3-35 to 3-44, cover the same ground for predesign and design phases as CEP P02 does for the conceptual phase, but in greater detail. It will be noted that there is considerable interlacing of these input/output as shown in Table 3-5. Consider first the prediction of the flow field at the inlet location.

TABLE 3-5. PROPULSION. INTER-RELATIONSHIP OF THE CEP FLOW CHARTS

INPUT	CEP	OUTPUT	INPUT	CEP	OUTPUT
P001	P03	P031	P001	P08	P082
P041		P032	P081		P084
P043			P083		
P044			T032	P09	P091
P052			P001		
P072			P125	P10	P101
P062			P001		P102
P125			P125		P103
P001	P04	P041		P11	P112
P051		P042	P110		P113
P052		P042	P041		P114
P053		P043	P042		P115
P072		P044	P082		P116
P124			P102	P12	
P125			P111		P124
P001		P051	P117		P125
P062		P052	P103		P126
P124		P053	P123		P127
P125	P05		P001		
P001			P041		
P062			P042		
P001	P06	P062	P102		
P061			P122		
P001			P123		
P062	P07	P072	P117		
P071					

This is covered on CEP P06. The input is shown as mission requirements and configuration constraints, especially the configuration upstream of the inlet. Computer program SF7-A solves the flow equations for supersonic flow and the listed output parameters P062 are further used in CEP's P03, P05, and P07.

Next, consider the selection of compression surfaces and the degree of variability that is required. This is shown on CEP P07. The input is the choice of inlet type and location, P001, and as noted above P062. The computer programs listed by number are not connected automatically but depend on selection, by the aerothermodynamicists, of the path to follow. Maximum speed requirements in conjunction with other operational considerations, such as a requirement for good takeoff performance or a need for stable operation at high angles of attack, guide the inlet selection. Programs A5T, A5M, A1V, SL6, and A6C represent different types of inlets so that the choice of inlet type

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would determine which of these programs is applicable. The chart shows this sequence of programs where more than one is required e.g., combination inlets such as EC-IC types. The output of the chart goes to both design data and to CEP's P03 and P04. The next step is the selection of engine cycles and control characteristics. This is shown on CEP P12 and it is noted that this will be a somewhat more complicated procedure since some of the input is derived from downstream calculations. Some of the input will stay such as P001, P122 and P123 since mission requirement and engine extraction (bleed and power) are not in the cycle selection iterative loop. Performance calculations are undertaken for each cycle under consideration using the engine manufacturers computer decks or comparable programs. The output shown is considered rough for the first run until outputs P124 and P125 can be used as input for CEP's P04 and P05 to update CEP P12 inlet performance and through CEP P10 to update CEP P12 exhaust system performance. Consider CEP P10 first, which is the selection of the exhaust system and exhaust system performance. The input in P001 and P125. Both internal exhaust system performance data and external drag are generated. The internal performance influences cycle selection and is fed back to CEP P12 for iteration. When the accuracy requirements are satisfied, the nozzle configuration is delivered to design, the nozzle internal performance to CEP P12 and both internal performance and external drag to CEP P11.

Similarly the inlet performance is iterated with CEP P12. In the case of the inlet two CEP's are required: CEP P04 which is inlet performance and CEP P05, which is inlet design. Considering first the inlet design, the input is P001, P062, and the output P124 and P124 from CEP P12. Calculations are performed from this inlet design to arrive at the inlet size (P051), geometry (P052) and the bypass geometry and bleed rates (P053). These design data are then input into inlet performance calculations (CEP P04) along with P001, P124 and P125. The output of inlet performance calculations is pressure recovery (P041), drags (P042), boundary layer bleed and bypass rates (P043) and inlet pressures (P044). Of these, P041 and P042 are required for the loop with CEP P12. When the iterative accuracy requirements are satisfied, block P041 is supplied to CEP P03, P11, and P12; blocks P041 and P042 are supplied to CEP P12; block P043 is supplied to CEP P03 and P044 is supplied to the loads group. The last set of calculations can now be performed in CEP P12 and the output block P125 supplied to CEP's P03 and P09 in addition to those previously described. Output blocks P126 and P127 are supplied to the vehicle performance and the design groups affected. Consider next the inlet control system which is CEP P03. As input we have the previously described blocks P001, P125, P041, P043, P044, P052, and P062. The selection of sensor location and sensitivity may be calculated from inlet flow-data, but the preferable course of action is to support this selection with tests. The output becomes part of the purchase specification to the vendor. Consider next CEP P09, the secondary air system, i.e., air that must be brought aboard for use by other systems but which having different air-flow requirements than the engine air inlets are more efficiently treated separately even with less efficient air inlet systems. The input to this CEP is P001 plus the requirements

for secondary air. Some of the sources for these airflow needs may be automated, e.g., environmental cooling system (ECS) but due to the fact that secondary air inlets are usually configuration sensitive, automation is not at this time envisaged for this total CEP. As an example of this configuration sensitivity, postulate a ventilation requirement for equipment located in the vertical stabilizer. The alternative sources for this air are the engine air inlet, which takes air aboard at the least penalty and a separate inlet near or on the vertical stabilizer. If the ventilation requirement does not increase with Mach number the sizing condition will be at low velocity which can penalize the engine air inlet performance at high velocity. There is also the problem of ducting the air to the place where it is needed. These penalties weighed against the penalty of a separate inlet, e.g., flush scoop, will provide basis for a good decision. The output of this block is configuration and internal drag (momentum loss). Configuration details are supplied to the design group and internal drag is supplied to CEP P11.

Consider next the nozzle loads, CEP P09. Input consists of P001 and the exhaust system pressures from P125. External and internal pressure distributions are calculated and supplied to the loads group.

The propulsion system performance summary CEP P11 is considered next. Input consists of blocks P001, P042, P082, P102, P103, P123, P117, and engine data bank which is called P111. At this point all of the factors influencing propulsion system performance should be reasonably defined and the more exacting analysis is appropriate. This would include both on-design and off-design performance over a range of power settings and probably for hot day (or tropic) as well as cold day. The range of operating conditions for the inlet and exhaust systems would be predicted as would the performance predicted upon these variations. Propulsion system transients and interface conditions, e.g., bleed temperature and pressure would be specified. Some of the engine manufacturer's data would pass through this CEP with little or no action required of the CEP. Typical of these are the engine case temperatures and heat rejection rates and the various engine signatures (IR, Radar, Noise). The output is supplied to diverse groups; some, like the propulsion system transient response, are useful principally to Flight Dynamics for stability and control analysis; others, like the propulsion system signatures, may be initially supplied to one group but other groups such as Systems Operational Analysis and Preliminary Design will subsequently find need for this data. Note also that it is more accurate to use the expression "thrust minus drags" than net thrust since several drag items are included in the summation that are not truly related to propulsion, e.g., equipment cooling air drag, etc., but are included with propulsion for reasons of bookkeeping.

CEP P13, Figure 3-45, serves much of the same purpose as CEP P01, i.e., conceptual propulsion performance. The CEP P13 approach, however, is more rigorous, the program generating an engine cycle. Cycle selection becomes more flexible since it is not limited to cycles for which engine manufacturers have generated performance data. This flexibility enhances the ability to optimize the engine cycle. Input to the program consists of flight conditions, component efficiencies, installation factors, etc., as shown on the flow chart. The program defines an engine cycle from this data and calculates

installed propulsion system performance. The program may then be used again with different cycle parameters until the "engine" is near optimum for the mission. Output data is provided to the vehicle performance and aerodynamics groups for their further use in optimizing an aircraft.

CEP T02, Figure 3-46, shows the affected disciplines and the input/output for adverse weather systems analysis. The input consists of P001 plus customer required climatic conditions. The analysis is not automated at this time, but is amenable to automation. These analyses include windshield and canopy de-fog and cleaning, rain clearing of the windshield and anti-icing or de-icing of the required surfaces, e.g., leading edges of wing and tail, radome, engine inlet, windshield. The output from these analyses will be the performance and physical description of these systems and the requirements these systems place upon the propulsion system in terms of bleed and power extraction.

CEP T03, Figure 3-47, shows a generalization of the ambient cooled equipment, i.e., those areas which can survive hot, but which require flow of air to carry away the heat being generated and/or insulation required to protect aircraft components situated in proximity to these heat sources. The input to these programs consists of P001, the climatic conditions desired by the customer and the heat loads of the various equipment, e.g., engine skin temperature and heat rejection characteristics at selected flight conditions. Several examples are shown: the engine, for example is a common source of heat; especially severe is the supersonic aircraft with afterburning or duct burning; hydraulic systems, particularly at high power tend to accumulate heat unless some provision is made for carrying off the heat; again, most aircraft require generator and drive cooling and any source of heat has the potential for damaging the structure unless protection of the structure is undertaken. In some cases insulation is required, e.g., the F-106 shroud, and in others a change of material may be indicated. The output of T03 consists of physical characteristics (weight and volume) of the system, and airflow requirements for the purposes of sizing secondary inlets or increasing the size of engine air inlet to accommodate total requirement (Ref. CEP P08).

CEP T04, Figure 3-48, shows the functional flow for cooling with conditioned air. The input is P001 and T021 as before plus the heat loads due to avionics, electrical, and physiological heat sources. There is presently a computerized approach which solves for the air conditioning source and a balanced distribution system. The output consists of distribution system characteristics which are vital to the design of that system, physical characteristics and performance. The performance characteristics apply both to the refrigeration system and the bleed, power (CEP P12), and secondary inlet (CEP P08) constraints which must feed back into propulsion system performance calculations within CEP P11.

3.2.4.2 Further developments: The demands upon the propulsion group may be classified into three basic areas:

1. Provide an optimized propulsion system for a specified vehicle.
2. Evaluate changes which may affect any part of the propulsion system and update the data bank with those changes showing merit.
3. Pursue development goals both internal (inlet or ejector testing) and external (new engine studies by an engine manufacturer).

A great deal of flexibility is required to satisfy these needs. This flexibility has been enhanced through use of available automated processes, and the capability exists to further improve this position. It is also recognized that lack of visibility may obscure improvements which may lie well within the existing state of the art. In the general case the propulsion OM could be referred to as one of energy conversion. In this way there would be no conflict of ideas in adapting IPAD's Propulsion OM to other forms of transportation. For this report, however, such generalization is not required. The goals of flexible response and evaluation of changes are not satisfied in the same way. Flexible response infers optimization at a low level and visibility of the effects of the choice of system or propulsion system output. Evaluation of changes, on the other hand, must consider the effects of some change on a vehicle as a whole. To this end, a logical development would be a synthesis program containing simplified aerodynamics and rather comprehensive propulsion systems in much the same manner as a current synthesis program optimizes the aerodynamics around a simplified propulsion system. Below that level of desire the improvements that should be made fall into two categories:

1. Improving the system through extension of the automated processes.
2. Updating the system through continual revision of data contained in the system, e.g., new engines or perhaps new inlet data.

Category 2 needs little elaboration so the remaining discussion will review those areas of category 1 where improvement is indicated.

CEP P01 is a subtle case since the subroutine has purposefully been kept small in order to allow a maximum of flexibility in the synthesis of a vehicle. Comparisons of engine cycles or installation variables are therefore made external to the program and at some inconvenience. Much greater flexibility would be achieved through the use of the CEP P13 program or similar, but special means are required to fit such a program to the machine. In addition, there is a visibility problem in that the installation procedure now used in either CEP P01 or CEP P13 is adequate for a conceptual phase study at this time. If, at some future time, the conceptual phase demands a more sophisticated approach this will have to be reconsidered and an installation program written to satisfy the requirements.

CEP P02 shows a case in which there is presently a good deal of flexibility but that flexibility is functionally the engineer's flexibility in "mix or match" programs. Work is required to improve both programs EPIC and INST to be able to perform more of the task automatically, i. e., improve flexibility. This would permit read-in of each program once and optimization of the engine cycle and installation would be made internally. Furthermore, an evaluation program is required to determine when an optimum has been achieved.

The next design phase, preliminary design, is covered in CEP's P03 through P12. In CEP P03 it was previously noted that however the sensor location is selected it is very desirable to verify this location with test. Also, any flow program written to predict the flow conditions in the duct would be unique to the configuration so it is likely that a program will not be required to support P03. CEP P04 illustrates a situation that has gone from hand calculations to computerization and back again. As far back as 1955 Convair had a computer simulation of inlet performance which analytically stepped through the shock geometry (F-106) to predict total inlet performance. The problem has been that theory does not adequately represent the physical article so preliminary design and detailed design phase inlet performance is derived directly from test data with only a minor assist by computers. The computer programs shown in CEP P07 are used for much of the prediction. What is required at this point is a means of modifying the theory with test data such that a computer model will be suitable for performance while retaining the flexibility to respond to changes. Assuming that this is a likely development the next step would be to include that program as a part of the package that makes up CEP's P12 and P11. CEP P05 shows the design process for inlets. While an assist will be rendered by the computer programs of CEP P07, a general program to be part of CEP P11 is not contemplated at this time. Except for updating, CEP's P06 and P07 are adequately computerized. CEP P08 shows the secondary air system which is configuration sensitive and therefore not included in immediate plans for computerization. Short programs for inlet ducting and several types of secondary inlets have been used in the past and will be rewritten and updated but there are no present plans for incorporating these programs into a comprehensive overall program such as CEP P11. CEP P09 shows essentially a design process which can use computers effectively for the small tasks within the CEP but is probably not amenable to becoming a part in a larger program. CEP P10, on the other hand, should be part of CEP P11. To do this, nozzle performance and selection should be programmed. The capability exists at present to accomplish this. CEP P11 shows the master propulsion performance program. For most purposes this master program could be described as an OM but there are significant gaps in its flexibility. The engine manufacturer's deck may be used either as a main program or as a subroutine. At this point in the preliminary design or detailed design phases an engine will have been chosen (CEP P12) but further modification may be permissible in inlet and exhaust systems. For this reason program packages previously mentioned in the discussion of CEP's P04 and P10 should be written into

the CEP P11 program. CEP P12 is the engine cycle selection program. In the conceptual phase it is desirable to use "rubber" engines but in preliminary design or detailed design phases real engines are desired. This is presently accomplished by pre-selection of an engine and changing if indicated. It would be advantageous to store the engine programs so that one or more real engines may be compared to an idealized cycle and compared with other real engines in contention. T02 shows fertile ground for computerization. Present knowledge requires that systems choice be made by an engineer external to the program but much of this task can and should be computerized. Capability also exists at present for computerization of CEP T03. The standard heat transfer program would be used to define the heat loads on components and modification of existing programs would permit definition of cooling requirements. CEP T04 shows a system already computerized and one for which only updating is visualized in the foreseeable future.

In summary, there are several CEP's which may now be computerized advantageously as a systems improvement and there are areas where communication between CEP's may be improved for the specific purpose of enhancing the IPAD capability.

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3.2.5 Mass Properties. - In general, the Mass Properties Group is responsible for the estimation and control of weights, center of gravity, and inertias from the conceptual to the detailed design phase and on to actual hardware production.

In the conceptual design phase of a new aircraft, the mass properties group activities concentrate on weight and center of gravity estimation with only cursory studies of inertial properties. Initially, the weight estimates depend primarily upon empirical equations derived from statistical analysis of existing vehicles. As the design progresses, the initial estimates are refined with inputs from aerodynamics, design, propulsion, etc. After the initial weight analysis is performed a center of gravity estimate is made, based upon layout drawings. If the center of gravity is not within the prescribed limits then either subsystem components are moved around or the wing location is changed. A computation of the aircraft inertia is made by dividing the vehicle in twenty to one hundred discrete elements and computing the moment of inertia. Weight control during this preliminary design state is a most vital function, with weight savings of large magnitude possible. These weight savings are obtained by optimization studies selecting the best combination of two or more parameters.

In the detailed design phase, the mass properties group is primarily responsible for keeping track and controlling the weight of the aircraft. Detailed weight records of each part and fastener must be maintained and summed for the entire aircraft.

During the production phase, the mass properties group must substantiate weight estimates with actual measured values, and must prepare the aircraft weight and balance report.

Throughout the design and development period the mass properties data is provided to other engineering groups, such as the Structural Dynamics Group for analysis of dynamic problems, the Loads and Stress Analysis groups for calculation of structural loads and stress, and the Performance, Aerodynamics and Flight Control groups for calculations of vehicle performance and control characteristics. In addition, component weights, material identity, and airframe dissimilar part and total piece count data is furnished to the Cost Estimating department.

3.2.5.1 Present capability: The Creative/Evaluating Procedures (CEP) used within the Mass Properties Department are tabulated in Table 3-6. These sixteen areas are elaborated on in the following paragraphs and the corresponding functional flow charts. The computer programs listed in Table 3-6 provide the backbone of the analytical work.

1. Configuration Geometry Definition (WO1), Figure 3-49. The initial definition of the overall geometric configuration has many potential starting points, such as;

- a. Similar Designs
- b. Project Office
- c. Design Group
- d. Mass Properties Group
- e. Customer

The reason the Mass Properties Group sometimes does the initial sizing is because of a technology overlap. Aircraft Weight Sizing computer program (P5525) has been developed mainly for providing a way of resizing the entire aircraft when any of the components are changed. The input for this program requires overall aircraft characteristics (wing loading, payload, etc.). Therefore, this program can also be used to do initial aircraft sizing with the type of input data shown in Figure 3-49. The output is sufficient to draw a 3-view of the aircraft. This CEP has been completely computerized and is in current use.

2. Preliminary Gross Weight Estimation (WO2), Figure 3-50. Weight estimation is based upon equations that model each of the subsystems. These equations are driven by the output of the geometry CEP WO1 plus additional input such as load factor and so on. This CEP has been completely computerized and is coupled together with CEP WO1 forming the Aircraft Weight Sizing Program P5525.
3. Development of Weight Equations for Specific Configurations (WO3), Figure 3-51. These weight equations are developed to model specific features of an aircraft and for subsequent use in trade and refined weight estimation studies of that aircraft configuration.
4. Parametric Weight Definition (WO4), Figure 3-52. In order to develop the parametric equations used in CEP WO2 one must develop a large data base. This hand gathered data for Mass Properties work is composed of detail aircraft weight, overall vehicle configuration and design data.
5. Weight/Size Relationship Development (WO5), Figure 3-53. The development of weight size relationships are the backbone of the activities performed by the Mass Properties group. These relationships model the weight of a subsystem (such as wing structural weight) as a function of the major driving parameters (such as wing area, span, load factor, and so on).
6. Point Design Weight Estimation (WO6), Figure 3-54. This estimate is basically a refinement of the work done in CEP WO2 whereby the weight statement developed in WO2 is revised by hand to account for special features or nonstandard features.



7. Mass Property Data Refinement (WO7), Figure 3-55. The execution of this CEP represents the summation of all previous work into a point design aircraft. This procedure entails incorporating the refined subsystem weights into the group weight statement and resizing the vehicle. The center of gravity of each element in the weight statement is defined from the inboard profile drawing. These locations are used to determine a composite aircraft center of gravity. The MIPI (Moment of Inertia, Product of Inertia) computer program P5619 is used next to determine the overall inertial properties of the vehicle.
8. Trade Studies Effects on Mass Properties (WO8), Figure 3-56. This CEP computes the changes in mass properties due to changes in the baseline aircraft.
9. Weights, Size, Geometry Update (WO9), Figure 3-57. This procedure consists of updating the data generated in WO7, using more detailed data with program P5525.
10. Weight Minimization (W10), Figure 3-58. The mass properties computed with CEP WO7 provide a baseline datum for tradeoff and sensitivity studies. Relationships that provide valuable design information are developed by perturbing the baseline input data to minimize weight (e.g., what does a one pound increase in ammunition cost in terms of increased gross weight).
11. Detailed Weight Estimation (W11), Figure 3-59. This CEP is basically a hand operation for which the weight of each detail component is individually calculated. These component weights are then summed by subsystem and replace the weights estimated by means of CEP WO7.
12. Development of Detailed Balance and Loading Data (W12), Figure 3-60. This is a refinement of the balance work done in CEP WO7 using the new detail weights developed in CEP W11. This can be either a hand calculation or a computer analysis using program P5619.
13. Detailed Mass Distribution and Inertias (W13), Figure 3-61. This is a refinement of CEP WO7 using the new detail weights of CEP W11 and center of gravity data of CEP W12. This is a computerized analysis, covering many loading conditions.
14. Weight Penalties due to A/C Features (W14), Figure 3-62. This procedure is a hand operation in which the Mass Properties group determines the weight penalty for various special features (e.g., landing gear fairings).
15. Cost Elements (W15), Figure 3-63. This CEP depicts one of the studies performed by the Mass Properties group in support of cost analysis. This can be either a hand analysis (during predesign) to a detailed computer analysis (during design). It is a grouping of all the parts by fabrication method and material form that are manufactured both in house and outside. It has been found that strong cost relationships depend on this type of data.

16. Weight Substantiation (W16), Figure 3-64. This is a documentation of all previous CEP analysis to satisfy company and customer requirements.

3.2.5.2 Further developments: In order to effectively use the full capabilities of the IPAD system the entire mass properties tasks outlined in the previous section must be computerized. This current technology for conceptual and preliminary design phases is approximately forty to fifty percent computerized while the detailed design phase technology is approximately ten to twenty percent computerized. Furthermore, the mass properties task must be expanded to new technology horizons. This includes the following areas to be developed:

1. Advanced Composite Structures. Composites are the materials of the present and as such merit the development of mass properties analysis tools, similar to those discussed in the previous CEP's. Many theoretical studies and tests on composite components and flight hardware exist. Yet the results have not been adequately evaluated and analyzed (collectively) for their present and future worth.
2. V/STOL Thrust/Balance Capability. V/STOL designs, especially those which utilize multi-purpose engines (both lift and cruise thrust) create a unique problem of requiring a three-way balance of aerodynamic forces, thrust forces, and inertia forces. Since these are not mutually independent quantities, an iterative solution is necessary. The results frequently constitute major constraints on the configuration arrangement. At present, special programs have to be developed for each problem and/or a great deal of hand calculations must be accomplished to define the configuration.
3. Finite Weight Analysis. This entails the development of mass properties subroutines to interface with structural finite element programs. This will provide the mass properties department with support data on many of the aircraft structural features and provide a sound analytical base.
4. Aircraft Surface Area Distribution Program. This program would generate a total aircraft surface area distribution curve that would include major components as wing, body, tail and canard. This would allow a more efficient and better packaged aircraft. Also the Aerodynamics Group fuselage area rule analysis would use this program.

In addition, the Mass Properties discipline can greatly benefit from exploitation of the interactive environment to be provided by IPAD, for the purpose of tying programs together, using graphic display packages, and better communications and data transmittal with other groups.

**3.2.6 Flight Control and Stability.** - This functional group determines and specifies those systems which will provide aerospace vehicles with adequate stability and control characteristics. In order to develop the system specifications, analysis is performed by computer simulation, wind tunnel tests, and computer aided empirical and analytical prediction methods. Stability requirements dictate vehicle external configuration, mass properties or flight restrictions. Control requirements dictate specification for controllers, avionics systems, power supplies systems, and engines. This functional group has overall responsibility for control system development which covers analysis, mechanical design, avionic design, and testing.

**3.2.6.1 Present capability:** In aircraft conceptual design studies the primary function on the Flight Control and Stability group is to provide: (1) vertical and horizontal tail volume coefficients, and (2) lateral and longitudinal control surface size to the Preliminary Design, Aerodynamics and Mass Properties groups. This data is computed using small desk-top computers. The computational process includes estimating: (1) aerodynamic stability characteristics at takeoff and high speed; (2) tail and control surface characteristics; (3) nose gear unstick characteristics; (4) longitudinal short-period frequency and damping; (5) dutch roll frequency and damping; (6) engine-out characteristics; and (7) roll performance. CEP SC1, Figure 3-65, depicts this capability and the required flow of input and output data in functional blocks.

For launch vehicle conceptual design studies the primary function of this group is to provide: (1) the type of control (thrust vectoring, secondary injections, etc.); (2) the amount of control (gimbal angle, volume of fluid, etc.); and (3) time histories of angle of attack and dynamic pressure under high wind conditions. This analysis is conducted using the LAUNCH computer program which is a six-degree-of-freedom simulation of a launch vehicle during ascent flight. This program can operate in either a batch or an interactive graphics mode.

In spacecraft conceptual design the function of this group is to define the control system in a gross sense (i.e. reaction motors, control moment gyro, reaction wheels, spin stabilization, gravity gradient, or some combination). These conceptual system descriptions are based on hand computation and past experience.

Preliminary design activities require a more in-depth analysis and design tasks. During aircraft preliminary design a detailed layout is made of the mechanical flight control system. At the same time an in-depth stability analysis using wind tunnel data is performed to establish automatic flight control system requirements. A block diagram of the avionics system is developed from these requirements. Control surface requirements are developed from simulator generated data. Wind tunnel data is developed for the simulation. The maximum control surface rates of deflection and hinge moments are used to determine the hydraulic power requirements. Stores

separation analysis is performed to optimize the stores location based on good separation clearance and store trajectory. Simulated catapult launches are developed to define the lift, landing gear and control system requirements if the aircraft is a carrier aircraft. The objective is to provide an aircraft which can be catapulted without high pilot loads and work load.

For launch vehicle preliminary design a detailed function layout of the control system is developed. Sensor requirements are specified by analyzing simulated flights in wind and turbulence and by conducting root-locus stability analysis of an elastic model of the vehicle. Trajectory shaping is performed to define loads and controller requirements.

If a preliminary design is being conducted for a spacecraft the Flight Control and Stability group will develop simulations of the vehicle in orbit to determine the control system functional requirements and equipments needed to perform the defined functions. Power requirements such as reaction control propellant or electrical power are developed from the simulation, past experience, and specific mission tasks. Sensor requirements are developed in a like manner. The preliminary design activities for this group revolve around: (1) vehicle-oriented non-real-time simulation; (2) computer programs TRIM-STAB, LAUNCH, CATAPULT and D3270, see Table 3-7 and Figures 3-66 to 3-70, CEP's SC2 to SC6; (3) past experience; (4) hand computations; and (5) real-time man-in-the-loop simulations, see Figure 3-67, CEP SC3. For real-time piloted simulations the pilot interacts with the computer through cockpit displays and controls, visual television displays, and motion cues. The engineer interprets the pilot's comments to modify the control system. These modifications are iterated until an optimum control system is obtained.

3.2.6.2 Further developments: Further development should be in the direction to more rapidly estimate the aerodynamic characteristics of a vehicle during the conceptual and early preliminary design phases. Computer mechanization of DATCOM would greatly improve the estimation of aerodynamic stability and control characteristics of aerospace vehicles.

Much of the analysis tools are currently available and any attempt to generalize them could produce complicated and expensive programs. Many attempts have been made to develop general six-degree-of-freedom simulations. However, they become too large, difficult and time consuming to run. The interactive capability to be provided by the IPAD System and the creation of a project oriented multidisciplinary data bank offer great potential for further technological developments within this discipline.

**3.2.7 Operations Research.** - Operations Research (OR) serves its most useful function in the conceptual design phase. It is the function of OR to relate the physical performance capabilities of a new aircraft to the operational environment and needs of the user, to develop measures and methods of evaluating airplane effectiveness in performing its missions, and to accomplish that evaluation. Conversely, OR functions to derive and/or interpret operational requirements in terms of airplane design goals. Outputs of OR analyses are used by management in selling company products and in assisting military customers to sell their own programs.

Operations Research encompasses reliability, maintenance and survivability and works hand-in-hand with Economic Analysis in evaluating operations costs. In the conceptual design phase, these functions are accomplished with rather rudimentary mission effectiveness models, most often hand computed, with estimates or gross analyses of the so called "-ilities". As the aircraft and mission parameters variations are reduced in scope, more definitive models are created for use during preliminary and detailed design phases. Models are computerized when their complexity and/or the number of cases to be investigated warrants the effort and expense.

**3.2.7.1 Present capability:** Most of the capability of an Operations Research group rests in techniques which can be stated only in terms of general procedures. It has been Convair's experience that each new problem is sufficiently different from previous ones that only a few sub-models remain usable from one project to the next. Table 3-8 lists the CEP's and computer programs presently used within the discipline. The CEP flow charts accompanying this section, Figures 3-71 to 3-82, describe models which have been used on previous programs. Those models, mostly computerized, concerning survivability, maintenance, basing and operations are usable in existing or slightly modified form on several projects. On the other hand, mission effectiveness models are usually unique and require reformulation for each new project. Different projects and stages of analysis require different levels of detail. Another important fact which affects the approach to be followed is that personnel familiar with one set of models may not be available when a new project appears which might use those models. For new personnel, it is usually easier to design a new effectiveness model incorporating specific new features, than to learn the intricacies of older models and their applicability. This procedure maintains a constant infusion of new techniques and expertise which improves the value of the analysis.

Most of the submodels described in this section are simulations. The vulnerability and survivability models go into great detail to simulate antiaircraft weapons and terminal kill effects. Some of these models employ Monte Carlo techniques; most are expected values, where probabilities are involved. Basing and operations models simulate the flow of airplanes through maintenance and operational cycles,

generally for the purpose of measuring the total effectiveness of a given number of airplanes or to determine the number of airplanes required to perform a fixed task in a real world situation. The only current use of interactive graphics is to check the geometric shape and location of simulated aircraft components in the vulnerability analysis program.

3.2.7.2 Further developments: A major function of Operations Research is to find optimal solutions to operational requirements. This generally involves a great deal of parametric analyses. The relatively simple mission effectiveness models are computerized and exercised for wide ranges of many variables. This is a time consuming process because of the many computer runs required; even though several cases are run together, there is a reluctance to run a really large batch of cases because of the possibility of keypunch errors and wasted computer time. Interactive graphics with real time modification of input parameters would appear like an efficient process for doing parametric analyses provided hard copy records of final results can be obtained.

Generally speaking, however, OR is not directly intertwined with vehicle design. Design requirements generated by OR are stated in terms not necessarily directly convertible into design variables. There is a very definite interactive procedure between the derivation of airplane performance requirements, the design of an airplane, and the evaluation of the mission performance of that design. This procedure continues through the conceptual and preliminary design phases. But since OR involves the analysis and interpretation of mission requirements and the structuring of problems, it is questionable that these functions should ever be automated because of the simple necessity and desire for human judgement in design and evaluation processes.

3.2.8 Reliability, Maintainability, Safety, and Logistics. - This section defines the functional processes associated with four interrelated discipline areas: Reliability, Maintainability, Safety, and Logistics (Supportability). As a program moves from conceptual to detail design phase, the tasks, expertise, and scope of each discipline becomes more specialized requiring different tools and techniques to be implemented. The objective in coordinating these four areas is to provide a smooth, consistent transition from one design phase to another, using analysis results of a preceding phase as a foundation for further studies in subsequent phases.

3.2.8.1 Reliability. - Reliability encompasses those studies and analyses concerned with the frequency of failure at system, subsystem, component and piece part levels. Specific parameters derived from reliability studies are:

1. Mission abort factors or probability that the system will be available to start the mission
2. Probability of mission success, and
3. The prediction of maintenance frequencies as an input to maintainability and supportability studies.

In the conceptual design phase, reliability analyses provide three major contributions to the project:

1. Providing input to the top level tradeoff of selecting one or more basic design concepts, i.e., number of engines, type of control system, etc.
2. Providing aid in determining system feasibility from a reliability standpoint, and
3. Establishing economically justifiable reliability goals (quantitative) on a total system basis to be used as preliminary design requirements for subsequent studies.

In the predesign phase, classical reliability techniques are employed for influencing systems design and initial systems costs and effectiveness studies. Basic to this phase are:

1. Allocation of the quantitative goal established (and perhaps modified) in concept design.
2. Initial system reliability predictions, and
3. A first cut at a functional and component level failure modes, effects and criticality analysis (FMECA).

The level of detail reached in the detail design phase allows a significant refinement to the predictions and FMECA which were performed in predesign. In many cases the task is one of analyzing hardware at the piece part level to arrive at detailed predictions

of equipment reliability characteristics, which then can be compared with subsystem reliability allocations.

3.2.8.2 Maintainability. - The maintainability discipline involves the quantitative aspect of maintenance repair time, manpower, inspection frequency and total maintenance burden of maintenance manhours per operating hour (MMH/OH). It also is concerned with quantitative factors of accessibility, replacement and repair levels and fault isolation all of which influence the design approach. A prime interface is with reliability in the area of expected frequency of various maintenance actions.

In the conceptual phase, the purpose of maintainability analysis is to provide:

1. Initial difference in MMH/OH among the concepts under study as an input to concept selection trade studies.
2. An MMH/OH goal for the system
3. Feasibility of meeting utilization rates and/or operational readiness rates which would be acceptable to the customer.

Additionally, gross level maintenance policies for the system are established as a framework for subsequent design phases.

Specific objectives in the preliminary design phase are:

1. To allocate the system level MMH/OH goal to subsystem levels
2. Perform initial predictions of subsystem maintenance burdens
3. To identify specific problem areas in maintainability of the chosen concept, and
4. To support tradeoffs in subsystems predesign. Primary outputs support economic analysis and design decisions.

The detailed design phase involves an extension in more detail of the tasks performed in the predesign phase. Maintenance time estimates by task are broken down into accessibility, fault isolation, repair and checkout to identify critical provisions required in design. The primary output is support of the maintenance engineering analysis (MEA) performed under supportability (logistics).

3.2.8.3 Safety. - System safety as a discipline is concerned with loss of life (crew or ground personnel), personnel injury, vehicle loss or major damage and destruction of property attributable to the system in question.

During the conceptual design process, candidate designs are analyzed for expected loss and accident rates to determine relative safety characteristics. This quantitative factor is provided as a top level input to overall concept selection trade studies.



In the detailed phase, the level of design allows detailed hazard analyses at system, subsystem, component and system interface levels. Both the fault tree and hazard analyses will be expanded to identify critical hazards, and possible design changes for their elimination.

3.2.8.4 Logistics/Supportability. - This area encompasses many sub-disciplines relating to analysis of resources required to support the system under study. Logistics depends heavily on quantitative analyses of both reliability and maintainability. Outputs of such studies are qualitative and quantitative, the latter having a strong impact on life cycle costs.

Because support analysis is a multi-disciplined area and one which interfaces with reliability, maintainability, cost analysis, and system effectiveness, it becomes a focal point for assembling many variables which determine vehicle utilization and readiness as a function of resource costs.

Support analysis in the conceptual phase is integral with maintainability in identifying the basic environment maintenance concepts and basing concepts under which the system will be operated. Candidate designs are reviewed to determine if any basic incompatibilities exist in relation to the broad maintenance concepts. Analysis is quantified only on a relative basis to arrive at first order life cycle cost effects. Flow charts are prepared to depict the system in the operational support phase.

With specific hardware functions or actual items identified, an abbreviated MEA is conducted during preliminary design to identify and quantify projected operational resource requirements. The general flow chart described above can be converted to a computer simulation model to receive as inputs the MEA data. Such a model provides an initial estimate of vehicle utilization, readiness and base resource requirements.

A formalized MEA process is implemented during detailed design to identify detailed aspects of logistic support including spares, training, GSE, etc. The simulation model described above is expanded to include more detailed levels of support at organizational and intermediate maintenance levels. Repair vs. discard models are used to provide design guidelines at the component level. Simulation runs are continuously updated to periodically evaluate the system from a logistics/cost standpoint.

3.2.8.5 Flowcharts. - The flowcharts for the disciplines included under this section are self-explanatory and are shown in Figures 3-83 to 3-87. The processes depicted reflect those currently used in various design phases. Brief descriptions are included in the following paragraphs:

1. Three basic factors are used to perform analysis during conceptual phase in all four areas: mission definition; weight vs. complexity relationships; and historical data on reliability, maintenance burden and attrition rates. The key words in the evaluation are the relative complexity of each concept which influences the tradeoff of concept selection. In the conceptual phase, all analysis is currently performed manually. See paragraph 3.2.8.6 for desired automation techniques.
2. During preliminary design in all four areas, initial "grass roots" estimates of the various parameters are performed. Note that since the level of effort has increased in each discipline, separate charts have been prepared to illustrate these differences. Computer models are operational to perform the following tasks:
  - a. Analyze a system of series/parallel components and predict overall system reliability using failure rate as input data.
  - b. Predict total maintenance burden of a system given individual maintenance action rates, times to repair and required manpower.
  - c. Predict behavior of a system with fixed resource constraints using as inputs failure frequency, maintenance times, resource requirements by maintenance task type and operational schedules. Resultant outputs give vehicle utilization and readiness over various calendar time increments.

3.2.8.6 Further Developments.- Because the tasks involved in the analysis of reliability, maintainability, safety, and logistics require a day to day, person to person contact with the designer, many aspects of these disciplines are not amenable to an automated system. However, in the analysis of designs for quantitative effects there are certain further developments which would contribute to the IPAD interactive process. These are discussed in the following paragraphs:

1. Conceptual design: Of primary desire during this phase is the development of reliability and maintainability estimating relationships wherein a gross level analysis of mission success probability, manhours per operating hour, and vehicle turnaround could be made. This relationship would be based on such parameters as systems weight, mission avionics weight, design Mach number, number of engines, etc. Although some work has been done in this area over the years by industry, it is felt that an updating and consolidation is necessary for practical application in conceptual studies. It may be possible that such relationship information could be stored in a computer and become a part of an interactive IPAD system. The user would input certain characteristics of each conceptual design and receive as outputs a range of expected reliability, maintenance, and supportability quantitative values associated with each candidate design.

2. Predesign and detail design: Desired developments in these two phases have been combined since the tasks are essentially the same in each phase. The keys to the usefulness of advanced automated capability in these four support disciplines are:

- a. Rapid response to obtaining analysis results following a design change, and
- b. Integrated inputs of design, reliability, weight, etc. so that results of analysis are consistent with the latest design information.

Advanced automated capability must therefore meet the following general requirements:

- a. Ease of input, and
- b. they must be interactive, in that the user should be able to modify the program inputs between executions.

Assuming that the requirements of the above paragraphs are met, it is desirable that a system be set up within IPAD to have the following capabilities.

A provision should be made to identify and store the reliability and maintenance parameters (MTBF's, MTTR's) in the common IPAD data bank. The identifiers would be common to all four areas, so that if a design change is made for a component, system, etc., these would be a single update for all areas. Any reference to an obsolete identifier would show to the reliability, maintainability, etc., analyst that his input or output was inconsistent with current design data. This capability becomes especially important to satisfy that requirement for rapid turnaround during that period of design when a large number of subsystem tradeoffs are being made.

A second desired capability relates to the logistics and support area, and specifically to maintenance and operations simulations. Currently, a cumbersome and tedious process exists for generating operational data, resource estimates (spares, GSE, etc.) and inputting maintenance action frequencies, repair times, etc. for the running of the model. Two features of an advanced program are required. The first is to have all the basic descriptors, numerical values, mission planning data, etc., directly accessible from the IPAD central data bank in the format required for execution of the simulation. The second is the provision for an on-line system wherein the user can make changes to inputs such as number of resources, operating schedules, etc., as a means of testing the sensitivity of interacting parameters. Results from such a rapidly responsive program would be beneficial to contractor as well as customer management in making decisions about a new systems design and operational philosophies.

3.2.9 Economic Analysis. - The principal functions of Economic Analysis within the aircraft design process as it currently operates are:

1. To provide independent estimates of the development and procurement cost of new aircraft systems.
2. To provide estimates of total system cost for alternative systems to form the basis for evaluating cost in recommending a final design.
3. To identify the major cost factors as the basis for design refinement.
4. To develop and maintain an adequate cost data bank to support the development of cost estimating relationships.
5. To maintain cognizance of the state of the art in methodology and maintain adequate internal design-to-cost methodologies.

3.2.9.1 Present capability: A list of CEP's and computer programs presently in use within this discipline is given in Table 3-9. Total system cost is estimated by means of an existing computer program. The computer program list is not static, however, since the program logic is constantly evolving. Changes are made due to improvement in cost estimating relationships and computer programming methods.

Figure 3-88, CEP E01 depicts the overall total system cost estimating methodology. Five separate estimating modules are involved and each of these is comprised of numerous cost estimating relationships (CERs). The Aircraft First Unit Cost Synthesis module is shown in greater detail in Figure 3-89. Theoretical first unit costs are estimated in the categories shown in Table 3-10. Economic factors and aircraft characteristic data, from either an aircraft synthesis model or a design study, are used to generate a theoretical first unit cost in the categories shown. The cost-estimating relationships for the airframe and propulsion categories generate costs as functions of material type and construction, weights, weight ratios, and subsystem performance and physical parameters. A detailed synthesis of cost based on design considerations is accomplished with the first unit cost model, and these unit costs are then used to project recurring production airframe costs for both development test articles and production.

Basic-structure first-unit manufacturing costs are estimated by means of a series of CERs for wing, fuselage, empennage, and nacelles. The methodology is described below using the wing as an example. Figure 3-90 shows the data points from which a general cost estimating relationship is derived. The CER form is:

$FU_w = KaW^b$  where:

$FU_w$  = Wing first-unit manufacturing cost

$k$  = Construction/material complexity factor

$a$  = Derived cost per pound value at pound one for reference type of material and construction

$W$  = Estimated structural weight

$b$  = Cost-sizing scaling exponent

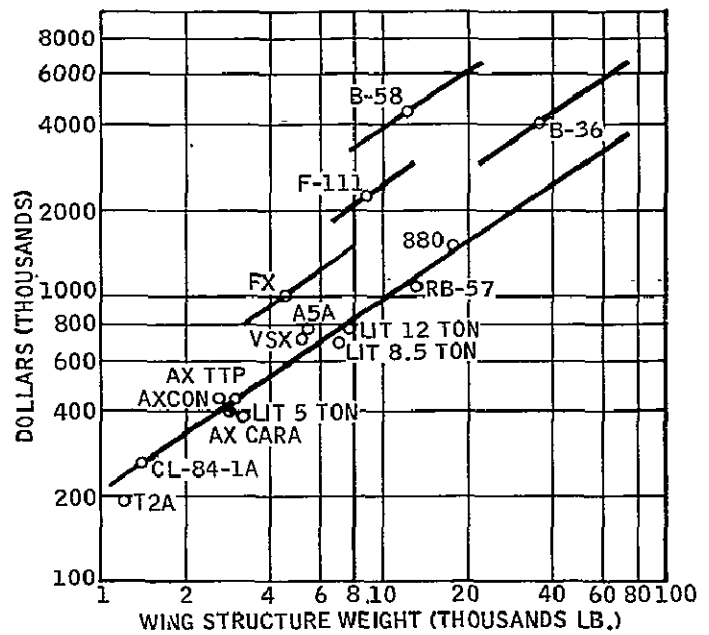


Figure 3-90. Wing First Unit Cost

Complexity factors are determined by various means: analogy, industrial engineering analysis, historical data, and engineering judgment.

Subsystems are estimated in a manner similar to that outlined for basic structure. This methodology is described using the environmental control system as an example. Figure 3-91 shows available data points. The CER is of the same general form as the basic structure. Complexity is defined in terms of characteristics such as Mach No., air flow rate, number of passengers, and electronic cooling requirements.

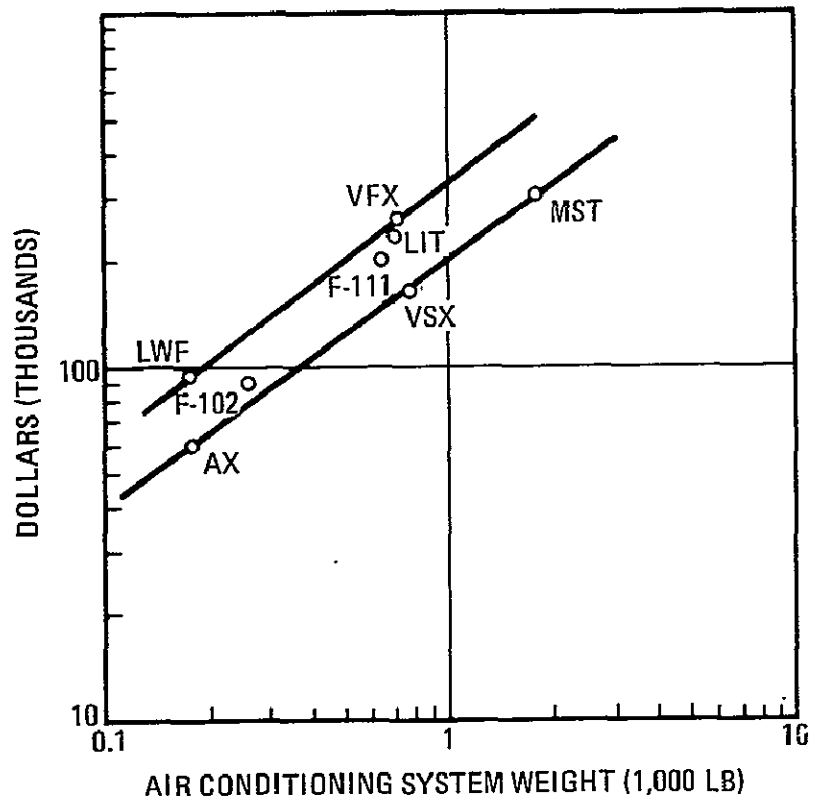


Figure 3-91. Environmental Control System First-Unit Cost

Propulsion costs are estimated using generalized cost-versus-thrust curves and data points for specific aircraft updated with a projection of cost for latest technologies based on interface with engine contractors.

Avionics costs are estimated by the development of equipment lists and an analysis of the cost of individual items of equipment. Both GFE and CFE categories are considered. Avionics is further categorized as to whether it is new design or prior production. This is done in order to accurately evaluate avionics development costs and projected manufacturing costs where the degree of cost-quantity improvement is affected by prior production status.

The Design and Development Cost Synthesis module consists of parametric cost estimating relationships for each of the RDT&E cost elements including initial engineering, basic tooling, development support, flight test operations, and ground and flight test hardware. An example of one of these CERs is shown in Figure 3-92. This CER may be stated as follows:

Basic Tool Manufacturing Hours,

$$T_1 = T_c W^b$$

where:

- $T_c$  = Tooling complexity factor
- $W$  = AMPR weight of airframe
- $b$  = Weight scaling relationship

The CER can be simplified since the exponent  $b$  is found to be equal to 1. The tooling complexity factors lend themselves to empirical definition or they can be specified as an analog to a known data point. Basic tooling provides the capability for a low production rate, approximately three aircraft per month. The remaining elements of nonrecurring RDT&E costs are estimated either in a comparable parametric fashion or by means of direct estimates based on an analysis of requirements. Recurring RDT&E costs (test hardware) are estimated in a manner similar to that described for production hardware.

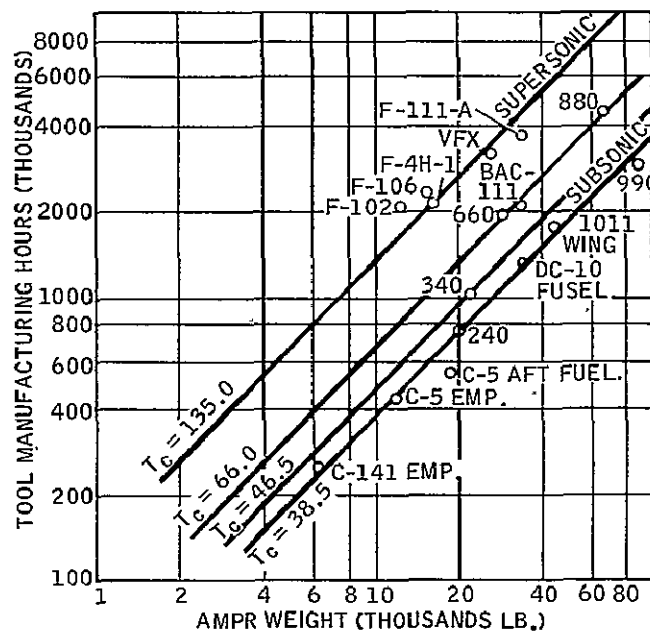


Figure 3-92. Basic Tool Manufacturing Hours

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The Production Cost Synthesis module provides for the run-out of first-unit costs over the specified procurement using suitable quantity-progress curves. The items of support system cost, principally initial spares, AGE, training, and technical data, are developed by analogy to historical data.

The Operating Cost Synthesis has two alternative modes of operation. These are depicted in Figure 3-93. One mode is based on the use of general system characteristics as cost related variables. The other makes use of a detailed simulation of maintenance actions that are aggregated to show simulated maintenance and operation demands. Direct operating costs are estimated and indirect costs are obtained by factors applied to the direct costs.

The Total System Cost Output is provided by a module that performs a summarizing function. This module may be set up to provide the cost output in various management directed output formats.

Each of these modules is presently computerized. They are set up in a flexible cost program that permits treating changes in cost estimating relationships as changes to the input deck. Generalized input codes are assigned so that they can be given alternative definitions appropriate to the estimating relationships.

Figure 3-94, C&EP E02, shows the use of the Total System Cost modules for the investigation of cost sensitivities and the support of design tradeoff analyses. Cost sensitivity analysis is supplemented by ad hoc evaluations since the system parameter of interest is not necessarily treated explicitly as a cost related variable. Its relationship to cost must, therefore, be determined through its relationship to variables that are so treated. Trade cost data consists of the relative differences in total system cost attributable to variations in specific air vehicle characteristics.

3.2.9.2 Further developments: The principal objectives of further developments in the area of economic analysis are: (1) to provide an improved independent parametric total system cost estimating capability, including costs, for weapon systems being evaluated; (2) to better identify the cost sensitivity of cost and/or performance significant system design features; and (3) to identify the program factors or parameters that account for major costs. Economic analysis interest has been in the direction of trying to tie cost estimates more closely to design characteristics. There is a need for identifying cost sensitivity to design features and to understand how design choices generate the cost effects estimated for them. This is prompted in general by the notion of design-to-cost. This notion is not at all clearly defined, but it implies the use of cost as a design parameter and the timely feedback of cost effects to the hierarchy of decision makers involved in weapon system acquisition. Further development is required to provide the cost estimating logic needed for support of the overall design process and to specifically meet the above objectives.

Providing an improved total system cost estimating procedure, which would lend itself to computerization, requires improvement in each of the estimating modules used in the present capability. Each of these modules comprises separate costs for airframe, avionics and engines, however, and each of these must be dealt with individually since the estimating methodology that an individual contractor can contribute depends primarily upon his area of expertise. A weapon systems contractor must be knowledgeable in each area. The designer and builder of a particular component should be an expert for that component. Differing levels of expertise will be typically evident in the available cost estimating capability. From the weapon system contractor's viewpoint, areas to be considered for further development are shown in Table 3-11.

TABLE 3-11. AREAS FOR COST ESTIMATING IMPROVEMENT

<u>Major Category</u>	Integrated Air Vehicle (Incl. Airframe)	<u>Avionics</u>	<u>Engines</u>
First Unit Cost	x	x	x
Design and Development	x	x	x
Production and Logistics Support	x	x	x
Life Cycle Operating Cost	x		

Both the Air Force Flight Dynamics Laboratory (Contract F33615-72-C-2083) and the NASA (Contract NAS1-11343) are sponsoring continuing efforts to improve airframe cost estimating techniques. This work is currently being performed by Convair, and the resulting techniques will be available in automated form for use in an IPAD System. The development of techniques for parametric estimation of avionics and engines lags. Development that has been accomplished by avionics and engine manufacturers is of a proprietary nature and not generally available to the weapon system contractor. The Naval Air Development Center, working with Pratt and Whitney Aircraft and General Electric, have developed an improved engine cost estimating capability, which has not been disseminated, however, because of the proprietary data involved. Improved life cycle operating cost estimation is even less within the control of the weapon system contractor since it is dependent upon the availability of reliable actual cost data at the weapon system level. Two important steps would need to be taken to enable the weapon system contractor to provide operating cost estimating techniques: (1) improved weapon system operating cost accounting by the military services is required to obtain factual operating cost data, and (2) this cost data would need to be made available to the agency developing the necessary cost estimating relationships.



3.2.10 Structural Loads. - Information on the task and Creative/Evaluating Procedure (CEP) activities related to the development of structural design loads data is presented in this section. The primary intent of this presentation is to cover implementation of the CEP's to perform Conceptual and Preliminary Design functions. However, several of the CEP's described here are useful in the Detailed Design Phase with the acquisition of more definitive information and data for the systems under development. These CEP's are adaptable and actually applied to a wide range of air vehicle types, each with their particular operational requirements ranging from small, highly maneuverable fighters to large bombers and transport aircraft. This flexibility is achieved by incorporating any customer specified detailed requirements for a subject air vehicle system together with applicable published general specifications and regulations into a criteria base. Also, the basic input data for the CEP's are developed specifically for the subject air vehicle(s). A more detailed description of the CEP's for structural loads is presented in the following subsection.

3.2.10.1 Present capability: The tasks, CEP's and computer programs presently used by this discipline are shown in Table 3-12. A description of each CEP and the corresponding flow charts are given in the following paragraphs.

1. Establish Preliminary Structural Design Criteria (SL1), Figure 3-95. This procedure is used in early preliminary design phase to establish dive envelopes, V-n diagrams and flutter boundaries.
2. Design Critique (SL2), Figure 3-96. This task is mostly of an advisory nature, based on previous experience with similar configurations and established design practices.
3. Formulate Design Criteria (SL3), Figure 3-97. The purpose of formulating design criteria is to provide a matrix of standards and requirements to be observed for a subject design. The details can vary from the simple, rudimentary criteria generally used for early design studies to a comprehensive and fully developed criteria of a quality suited to the final detailed design of hardware. Early conceptual design studies are usually based on preliminary criteria from past experience and/or whatever information and guidance is available from a potential customer. At some point in a systems development, customer agency specifications will give more detailed requirements for inclusion in the criteria.

Formulation of criteria can involve the task of developing standards along the following avenues of approach:

- a. Survey, evaluate, and incorporate applicable portions of published general specifications together with customer stated requirements to develop an integrated design criteria; and

- b. develop/determine specific values for criteria parametric items such as design gross weights, center of gravity limits, speed limits, etc.

The scope and degree of refinement for a criteria should be commensurate with the nature of the efforts (i.e., conceptual, preliminary, detailed, etc.) in analyses, design, test, etc., that are necessary to accomplish a study or program objectives.

Generally, a rudimentary criteria includes design load factors, gross weights and speed limits. These items can be postulated with guidance from the three upper blocks of input data shown on the flow chart. As a design evolves and more is known about the air vehicle characteristics, the criteria can be expanded to incorporate basic data and results from aerodynamics, performance stability and control system analysis, test, etc. With these data, parametric criteria can be developed in more detail.

As shown on the chart, the basic handling and evaluation processes are accomplished by hand (H) with the output in the form of graphs, tables and written text. Therefore, the development and, in general, the implementation criteria for input to analyses and design processes will require man-in-the-loop effort.

4. Structural Layout Loads (SL4), Figure 3-98. Preliminary structural layout loads are the "first pass" calculations of distributed loads to support initial design of airframe major structural components (i.e., initial arrangement and sizing of principal structural elements) and initial structural weight estimates. In a typical routine, the approach is keyed to a "short fused" operation, in which loads are developed within a very short time period. Therefore, simplified theoretical and empirical methods are applied using data from technical publications, normalized data from past programs, engineering judgement, etc. Input information consists of vehicle geometry and dimensions, rudimentary parametric criteria items (gross weight, load factor, speeds) and preliminary mass distribution data. Airloads are estimated on the wing-body combination using design net lift force and empirical values for the horizontal tail balance load (i.e. lift on the tail-body combination). The wing-body lift is arbitrarily distributed either on the theoretical wing planform, or apportioned to the body and exposed wing using parametric relationships based on slender body theory as presented in report NACA-TR-1307. Vertical tail root shears are generally based on rule-of-thumb values developed from past experience with different airplane types (i.e., fighter, bomber, transport) in terms of percent design gross weight. Spanwise airload distributions for lifting surfaces are generally calculated using either an elliptical or Schrenk approximation of the running load, whichever is the most conservative for bending moment. Chordwise center-of-pressures are assumed at a constant percent local chord length along the span based on typical subsonic/supersonic distributions. Distributions with flap effects are calculated based on data and methods presented

in reports NACA-TN-3014 and NACA-TN-3476 for spanwise effects and ANC-1(2) or empirical information for chordwise effects.

Fuselage load distributions are usually calculated using inertia only (i.e. body airloads are neglected) which is generally somewhat conservative for design of major structural parts.

Inertia load factor envelopes, based on Specification MIL-A-8591 or conservative estimates of airplane maneuver translational/rotational response, are developed for calculating store loads.

As shown on the flow chart for this CEP, the evaluation process is accomplished by hand. At this stage of the design process work is directed toward developing candidate designs. As a routine, several configurations are studied and quick response is necessary from input to output. Portions on the evaluation process are amenable to computerization. For example generalized solutions could be programmed for lifting surfaces to obtain design load distributions for conditions not requiring flap effects. Writing generalized solutions for conditions with flap effects (i.e., wing high lift configuration, vertical fin with deflected rudder) would be more complex and require additional evaluations to assess its practicality.

5. Symmetric Maneuver Load Trends Survey (SL5), Figure 3-99. This CEP is used for later stages of analysis when configuration candidates have been narrowed to a working baseline configuration. However, the computer program can be expanded to provide increasing levels of coverage and refinement leading to support of detailed design. The program accomplishes a balanced symmetric maneuver and component loads analysis by solving lift and pitching moment equations and component loads equations.

In addition to airplane geometry and dimensional data, design criteria parameters, and mass distribution data, input also includes predicted rigid aero data (i.e., lift and pitching moment force data with correlated component distributions) and static aeroelasticity corrections to the rigid data.

The program is set up to cover the design flight envelope with a grid of Mach number-altitude points so that component load trends with speed and altitude can be obtained. Results are plotted using a computer subroutine so that critical flight loads conditions are easily determined by visual inspection. Once critical conditions are determined, detailed loads distributions are prepared manually for use in structural design.

The CEP flow chart for the evaluation process shows that two boxes are currently indicating hand operations. However, these are amenable to automation to a considerable degree. Also, the input and outputs of the various disciplines are in

the form of graphs and tables. In relation to IPAD this type of data can be supplied to the data bank.

6. Landing and Ground Handling Design Loads (SL6), Figure 3-100. This CEP is used to determine loads for structural design of the landing gear and related support structure in the airframe. The output is also utilized to design parts of the airframe structure where ground loads are more critical than flight loads. Calculations are accomplished using the criteria and techniques presented in MIL-A-8862. The CEP process is entirely automated with output data on a digital listing format.
7. Wing Panel Point Loads Analysis (SL7), Figure 3-101. Once a design has progressed to a point where the wing box preliminary structural arrangement has been established with member sizes, joints, and fasteners, etc., a more detailed analysis may be accomplished to further refine the design. This CEP is used to support such an analysis by providing external design loads data in terms of panel point loads data to a math model procedure for analyses of internal loads distributions, stress analysis, calculations for margins of safety and structural weight, etc. As shown on the flow chart for this CEP, five of the operations for the evaluation process require some manual effort. Once the panel point arrangements and related unit inertia loads are established, the remaining three operations requiring manual effort need a man-in-the-loop for engineering judgements to assure that local pressures do not exceed reasonable bounds and/or that pressure distribution shapes are reasonable.
8. Fatigue Loads Spectra (SL8), Figure 3-102. Fatigue loads spectra are calculated for use in structural fatigue damage and reliability evaluations. Input data includes aircraft usage in terms of service life, missions, mission profiles, airplane configuration and gross weight; atmospheric turbulence model parameters, maneuver load factor spectra, landing and taxi spectra and fatigue design scatter factor.

Structural component unit loads data in terms of 1.0g loads and loads per "g" are obtained from results of CEP SL5 titled "Symmetric Maneuver Load Trends Survey". These data are used to convert maneuver load factor cumulative exceedances to loads (stress) spectra. Gust load spectra are based on data and methods presented in report AFFDL-TR-70-106, "Design Manual for Vertical Gust Based On Power Spectral Techniques". Results from the CEP SL6 titled "Landing and Ground Handling Loads" are used to develop cyclic loads spectra consistent with the fatigue design criteria.

This is an automated process that supplies input to a fatigue analysis program that is handled by the Structural Analysis section. It also serves as input to CEP SL9 entitled "Fatigue Evaluation".

9. Fatigue Evaluation (SL9), Figure 3-103. This CEP is used to obtain early indications of potential design requirements that are specifically necessary to meet service life criteria. The analysis provides information to determine minimum stress levels to which areas of the airframe structure should be designed, under 1.0g flight loads conditions, in order to meet the required service life.

The fatigue analysis is performed at arbitrarily selected stress levels called reference stresses. Each reference stress is, in effect, an assumed 1-G stress level for the basic flight design gross weight configuration. For a particular structural point being analyzed, fatigue damage is calculated for gust and/or maneuver at the reference stress levels using Miner's Cumulative Damage Theory. Total fatigue damage at each reference stress level is then calculated and a 1-G allowable stress level is determined from a plot of reference stress versus fatigue damage. The 1-G allowable stress for each structural point is also plotted versus service life. When the 1-G stress based on static strength requirements is superimposed on this curve, it becomes readily apparent which requirement sets the design allowable stress.

This CEP can be of considerable value in the early development stages of a vehicle. With the exception of one indicated operation, the process is automated. With additional programming the entire CEP could be automated.

10. Gust Loads Analysis (SL10), Figure 3-104. The purpose of this CEP is to assess the relative criticalness of the air vehicle gust loads criteria for establishing airframe strength requirements. The criteria and methods presented in MIL-A-8861 are applied, which involve analyses and evaluations using three different approaches:

- a. Discrete gust analysis,
- b. Continuous turbulence analysis, and
- c. Design envelope analysis.

Most of the basic input data for this CEP is essentially the same as that used for CEP's SL5 and SL8. The criticalness of results from the gust loads computations is assessed by making comparisons with design loads based on maneuver criteria. Design load distributions are then calculated for any gust conditions determined to be critical.

The processes involved in this CEP are applicable to both Preliminary Design and Detailed Design Phases with generally more refined and upgraded input data available for the Detailed Design phase. As shown on the flow chart, several of the indicated operations are currently accomplished using manual procedures. It is theoretically possible to mechanize this CEP in its entirety. However, the

practicality of not having a man-in-the-loop operation at some points in this process should be determined.

11. Load Model Wind Tunnel Test Program Support (SL11), Figure 3-105. In the course of developing the design of an air vehicle, data from scale model wind tunnel test are necessary to substantiate and upgrade structural design to the specified criteria. The purpose of this CEP is to provide guidance for the formulation of test plans and requirements so that wind tunnel test program(s) can be related to the needs of the structural design process. Depending upon the nature of the model test, and instrumentation (i.e., pressures, calibrated strain gages, etc.), the data acquired from model test is processed by the aerodynamics or structural load disciplines, as appropriate, for input to the applicable CEP's described in this section. This CEP must be accomplished with a man-in-the-loop.
12. Airplane Rigid Body Initial Dynamic Maneuvers Response Parameter Envelopes (SL12), Figure 3-106. In early design phases, detail type of solutions for abrupt (dynamic) maneuver aircraft response characteristics and related inertia load parameter values are not feasible. However certain areas of design, namely the structure for support and attachment of relatively large mass items such as engines, stores, fuel containment, large equipment items, etc., require values for inertia load parameters which are translational and rotational accelerations. Preliminary estimates for these items are based on past experience with similar type of aircraft for maneuvering flight conditions. Crash and non-crash inertia load factors, for miscellaneous items such as crew seats, capsules, equipment, etc., from MIL-A-8865 are also incorporated to complete the inertia load factor package.

The flow chart for this CEP shows the evaluation process to be accomplished by hand. However, once values for the parameters have been decided upon, the process is very simple and could be programmed with generalized coordinates or having outputs in terms of plotted envelopes of local acceleration or load factors. Very likely, optional parameter values could be categorized and selected according to general types of air vehicles.

3.2.10.2 Further developments: The field of structural loads is a fertile ground for additional automation, both in further advancing the state of the art in load prediction and in providing computerized interfaces with sister disciplines such as structural analysis/synthesis and structural dynamics. Among the needed technology are: procedures to enable prediction of external pressure distributions around solid and vented bodies, including interference effects; automated means of translating these pressure distributions into panel point and station loads for a predefined structural model; automated means of combining these panel point loads with translational and rotational inertias; the inclusion of elastic structure effects on the redistribution of loads; the final conversion of all these loads and effects into internal design loads for structural panels and members. In addition, the development of interactive graphics displays of input/output for much of the existing capability (and for new developments) will prove to be an expeditious and cost-effective means of evaluating the many loading conditions that must be considered and help in selecting the critical ones.

3.2.11 Structural Analysis/Synthesis. - This section describes the role of the Structural Analysis group during the various design phases of advanced aircraft development. The structural analysis/synthesis processes are active in the conceptual, the preliminary, and the detailed phases of aircraft design. There are no well defined lines between adjacent design phases and it is sometimes difficult to tell when one has made the transition from one phase to another. As the design cycles progresses the analysis techniques utilized become more detailed and emphasis is placed on a more refined subdivision of components being analyzed.

3.2.11.1 Present capability: Table 3-13 presents a list of the major structural analysis tasks and computer programs involved in the conceptual, preliminary, and detailed design phases. Figures 3-107 through 3-124 present generalized CEP flow charts depicting the sequence of steps required to perform the tasks listed in Table 3-13. The flow charts identify the disciplines which originate inputs for each structural analysis task and those which receive the results of the analysis. A major portion of the analyses performed by the Structural Analysis group is computerized. The bulk of the information transferred to other groups, however, is usually summarized and recorded in tables and on graphs.

Eighteen major Creative/Evaluating Procedures (CEP) were identified for the purpose of this study. These CEP's provide an adequate "window" to evaluate the participation of the Structural Analysis/Synthesis discipline in the design process and assess its impact on an IPAD system. A brief description of each CEP and the corresponding flow chart is given in the following paragraphs.

1. Structural Arrangement and Concept Design Support (CEP SA1), Figure 3-107. This activity is performed during preliminary design to evaluate various candidate structural concepts and materials and to obtain structural element sizes and related data to assist in the selection of best concepts for various aircraft components.
2. Multi-spar Box Material and Structural Concept Trade Studies, (CEP SA2), Figure 3-108. A series of computer programs is available to facilitate material and structural concept trade studies on multi-spar structures. The basic input for each of these programs such as section geometry, section loads, required stiffnesses are interchangeable and the analysis section of each program were designed to be comparable. Spar webs are sized to react the vertical shear distributed equally to all spars and the torsion that is assumed reacted by the box covers and the front and rear spars. Spar caps are sized for minimum requirement to transfer shear between the cover and the spar webs. Box covers are sized for strength, for local failure modes if the concept is sandwich construction, for general instability, and for local instability if the concept is sheet stringer.



Following the sizing of box cross-section members for strength and instability, cross-section bending and torsion stiffnesses are computed and compared with required stiffnesses specified by input. The strength sized members are then re-sized to satisfy the required stiffnesses utilizing a routine that minimizes the weight increase.

The programs are designed to increment various design parameters such as the number of spars, ply orientations, core depth, etc. Section element sizes and weights are printed for each parameter increment made. In addition, a summary sheet of total section weights for each parameter increment is printed at the end of each run to facilitate the selection of the most efficient multi-spar box material and structural concept.

3. Advanced Composite Fuselage Section Optimization, (CEP SA3), Figure 3-109. This is an automated structural synthesis procedure (Reference 2) to size fuselage section elements such as panels, longerons, and stringers and, optionally, to optimize the composite ply orientations for minimum weight.
4. Finite Element Fuselage Synthesis (CEP SA4), Figure 3-110. This automated procedure (Reference 3) can be used for preliminary design of fuselage structures. It uses finite element models including panels, longerons, and frames to determine optimum frame stiffness requirements and internal element loads. It includes strength, deflection, and geometric constraints and determines detailed structural sizes and gages at various fuselage control stations.
5. Material Selection (CEP SA5), Figure 3-111. This procedure is followed to evaluate various candidate materials under general environmental conditions of load, temperature, acoustics, corrosion, etc. for a specific project. The output of this effort is the identification of candidate materials best suited for the application at hand. This procedure is mostly done by hand.
6. Finite Element Structural Analysis (CEP SA6), Figure 3-112. Many computerized procedures for matrix analysis of structures are presently available. This CEP outlines the various functions to be performed in carrying out such an analysis. The selection of the best suited program depends both on the size of the model and the type of elements included in the program. Programs incorporating matrix analysis manipulations which result in short execution times have proven to be very desirable, in particular when used in conjunction with synthesis procedures which require multiple analyses. It is envisioned that a few finite element programs can be selected from the many available, to be a part of the first release capability of an IPAD system.
7. Finite Element Stress and Modal Analysis (CEP SA7), Figure 3-113. This is an automated analysis/synthesis procedure which uses a finite element stress and modal analysis program during the preliminary design stages as a tool to rapidly size

aerodynamic lifting surfaces. The simulation data such as node point geometry, element node definition, material properties, lumped masses, and load distributions lumped at node points is automatically generated and punched on cards for direct input.

The finite element stress analysis portion of the program has the option to either compute the margins of safety for each element based on either a linear or a non-linear stress analysis. In both cases the computed margins of safety are based on strength and structural stability constraints. Prescribed elements are resized, when doing a linear stress analysis, to achieve a zero margin of safety or satisfy minimum sizes. The option is then available to resize the structure as many times as required to obtain a minimum weight structure to react the critical load conditions. To facilitate preliminary flutter and divergence analyses the procedure computes and punches on cards reduced stiffness and flexibility matrices corresponding to prescribed degrees of freedom and mode frequencies and shapes corresponding to prescribed mass distribution.

8. Fuselage Multiple Station Synthesis (CEP SA8), Figure 3-114. This procedure is automated (Reference 4) and is used during early stages of preliminary design of fuselage structures for which box-beam analysis is applicable. It consists of analysis and redesign cycles performed on several fuselage sections. It determines the sizes and gages of panels and longerons for multiple loading conditions and failure modes. Linking of elements and sections can be used to select appropriate number of design variables commensurate with the details required at the time.
9. Wing Aeroelastic Synthesis Procedure (WASP) (CEP SA9), Figure 3-115. This automated procedure generates stiffness and mass matrices for wing structures, calculates rigid and flexible airloads, deflected shapes and natural modes and frequencies, performs flutter analysis, calculates divergence speed and evaluates pertinent constraints. Non-linear programming techniques are used to modify the design as required to obtain convergency in the results.
10. Preliminary Fatigue Analysis (CEP SA10), Figure 3-116. This procedure is used during preliminary design to assess the impact of fatigue on structural components. The output of this activity are allowable fatigue stresses and the cumulative fatigue damage at selected control points.
11. Fatigue Analysis for Unit Damage Data (CEP SA11), Figure 3-117. This procedure is used in conjunction with fatigue test data to establish stress concentration factors  $K_t$  and fatigue damage for unit load spectra at various control points on aircraft components.
12. Fatigue Test Evaluation and Qualification (CEP SA12), Figure 3-118. This is mostly a hand procedure including partial automation of some analysis loops. Its

purpose is to review the fatigue analysis results and load spectra to define the fatigue test plan, instrumentation required, and produce the pertinent documentation.

13. Fracture Mechanics (CEP's SA13, SA14, SA15), Figures 3-119 to 3-121. A substantial amount of effort has been expended in the area of structural synthesis considering strength and deflection constraints and multiple loading conditions and failure modes. It has just been recently, however, that the necessity of including the fracture mechanics discipline in the synthesis procedure has been recognized. This has come about in part due to the emergence of the fracture mechanics discipline as a realistic method of reducing the risk of structural failures. This fact coupled with some recent catastrophic structural failures in primary aircraft components has resulted in an increased emphasis being placed on fracture mechanics analysis by both NASA and the Air Force. With this in mind, an effort was made herein to detail the fracture mechanics analysis procedures, determine how they could be incorporated into a synthesis procedure, and define those procedures which were already automated to some degree.

The information necessary to perform a complete fracture mechanics analysis includes data on material gages, structural configuration, existence of crack stoppers, type of possible flaws, flight loading history, service life requirements, initial flaw size assumptions and inspectability, material properties, proof testing philosophy, stress intensity factors and a retardation philosophy and scheme. Once all of this information has been assembled, a detailed fracture mechanics analysis can be performed. The total fracture control procedure is graphically represented by the flow chart of CEP SA13 shown in Figure 3-119. The evaluation process is by its nature both quantitative and qualitative, which is to say that the total automation of the entire evaluation process is not practical. However, a number of blocks in the evaluation process lend themselves quite nicely to automation and, in certain instances, these automated procedures already exist. The important things to note in the fracture control approach flow chart is the amount of data and the number of disciplines involved in the data input process. It should also be noted that that portion of the evaluation process labeled "Evaluate Component Features" is an extremely important part of the entire process and is heavily dependent upon the input fracture control criteria and requirements and inspection capability. The output data affects many disciplines and can weigh heavily on the eventual structural sizing. In all cases, the entire procedure is very heavily policy and philosophy dependent meaning that any change in the initial policies or philosophies can greatly affect the final results.

One part of the fracture control procedure which is already automated is the determination of the residual strength and residual life of flawed components. This procedure has been automated in a computer program labeled "CRKPROP" developed in house by Convair Aerospace. The procedure is represented graphi-

cally by the flow chart of CEP SA14 shown in Figure 3-120. Those boxes labeled with an "H" in the evaluation process are the only portions of this particular procedure which have not been automated. They include the generation of the stress spectrum which must be done from the applied load spectrum and load history, and initializing the flaw size, type, and shape which is somewhat of a qualitative procedure. In its present form, "CRKPROP" is an extremely useful and powerful program. However, there are a number of deficiencies in the program which prevent it from handling all of the situations which must be accounted for in the analysis procedure. These deficiencies are listed below:

- a. The program cannot account for the fact that surface and embedded flaws, which do not initially have a semi-circular shape ( $a/2c = 0.5$ ), tend to approach a semi-circular shape under cyclic loading.
- b. The program will not operate in reverse from the critical flaw size to obtain a permissible initial flaw size if the loading spectrum possesses any sustained loading above the sustained loading threshold.
- c. Retardation can be accounted for by use of the Wheeler retardation model only, no other retardation scheme is available in the program as it presently exists.
- d. The method of entering growth rate curves ( $da/dn$  and  $da/dt$ ) is restricted to the procedure whereby the curve is entered as a series of discrete points of growth rate ( $da/dn$  versus  $\Delta K$ ).
- e. No present method of accounting for variation in cyclic frequency or for variation in thermal or environmental effects.
- f. Plastic zone correction factors incorporated into the stress intensity factor solutions are for plane strain only; no solutions are available for plane stress.

Although the factors listed here prevent "CRKPROP" from being a truly universal program for residual strength and life calculations, it is felt that all of these deficiencies can be easily overcome if some time can be devoted to these problems.

One procedure in the fracture control process which has not been, but could easily be, automated is the fracture arrest evaluation process CEP SA 15 shown in Figure 3-121. This process is part of the determination of residual strength of flawed components and is used where crack stoppers such as stringers exist. It is an especially valuable tool in increasing the acceptable design stress levels over that which would be allowed if the crack stoppers were not accounted for. The important thing to note about this process is that it has a purely empirical basis with most of the work to this point being done by C. C. Poe, Jr. of NASA Langley Research Center (References 5 and 6).

The result of the automated procedure for fracture arrest could be basically a curve of stress intensity vs. flaw size from which much pertinent output data could be derived such as allowable stress levels, critical flaw sizes, and the like.

14. Nuclear Vulnerability/Survivability Assessment (CEP SA16), Figure 3-122. The purpose of this procedure is to evaluate the response and criticality of various structural components to nuclear overpressure and thermal environment.
15. Structural Test Planning and Testing Support (CEP SA17), Figure 3-123. This procedure describes the functional steps necessary to evaluate the critical design conditions, design test articles, establish test requirements, review test load spectra, and prepare documentation related to structural tests.
16. Detailed Stress Analysis (CEP SA18), Figure 3-124. This procedure summarizes the major function performed in detailed stress analysis of structural components. This CEP encompasses a wide spectrum of activities some of which are automated. This type of analyses are used in final stages of detail design prior to drawing release.

.2.11.2 Further developments: The field of structural analysis has been a fertile area for automation since the advent of large computers. The intensive activity of the last several years has resulted in a proliferation of computer programs with substantial duplication of capability. It is felt at this time that an adequate computerized analysis capability exists for the evaluation of many behavioral phenomena in structures, with a few areas, such as fracture mechanics, still in need of additional development. It is also felt, though, that this capability is, in nature, localized to narrow fields without an overall integrating overview of all the factors that contribute to the structural design process. Structural synthesis approaches have substantially more to offer in this respect, although these procedures are still young and suffer from both fast growing pains and underdevelopment. Synthesis procedures adequate for the various stages of design can and should be developed. Furthermore, while this development is in progress, appropriate steps should be taken to provide the adequate data transmission interfaces with other sister disciplines such as Loads, Structural Dynamics, Materials, Detailed Structural Design, and Mass Properties.

3.2.12 Structural Dynamics. - The Structural Dynamics discipline as it is envisioned to be utilized in the development of an IPAD system is categorized into various subdivisions. These subdivisions are:

1. static aeroelasticity,
2. flutter,
3. dynamic response to gusts, blasts, etc.,
4. dynamic response due to taxi and landing, and
5. acoustics and vibrations.

Thus, it will be the purpose of the subsequent sections to describe each subdivision's tasks and the manner in which each interfaces with other disciplines during the preliminary and detailed design phases of any given vehicle design analysis cycle.

3.2.12.1 Present capability: A typical aerospace vehicle design process involves various stages of development which are:

1. conceptual design,
2. preliminary design, and
3. detailed design process.

The Structural Dynamics group is generally involved, to a large extent, in the latter two stages. A list of Creative/Evaluating Procedures (CEP) and computer programs presently used by this discipline is presented in Table 3-14. The nature of its tasks and interactions with other disciplines is presented in more detail in the following paragraphs.

1. Static Aeroelasticity. In considering static aeroelasticity, the basic tasks shown in Table 3-14 involve computations of surface divergence speeds, aileron and/or control reversal speeds, flexible airplane aerodynamic derivatives, jig shape and/or unloaded airplane shape. For this latter case, the cruise shape is always specified by the Aerodynamics discipline if the maximum L/D for range is required. Other tasks are also performed such as predicting the airplane elastic shape during off-design conditions, determining flexible airplane loads, and providing support during the configuration design stages and wind tunnel model design.

CEP SD1, Figure 3-125, shows the various disciplines that supply the necessary data required for any aeroelastic solution problem. These disciplines are Configuration Design, which furnishes the basic external shape of the airplane; Structural Analysis, which supplies the internal arrangement, member sizes, skin gages, etc.; Material properties; Aerodynamics, which supplies the

aerodynamic characteristics in the form of experimental rigid force or pressure data if available for correlation purposes; Mass Properties, which provides the needed mass properties of the airplane in the form of distributed panel points or weights; Loads and Criteria, which supplies the required load factors and C.G. locations for specified flight conditions trim angles of attack for any desired condition.

The inputs from each of the disciplines are in the form of tables, graphs, computer listings, etc. The basic tasks are summarized in the center column which are then followed by the output of the evaluation process. This output is also presented in the form of graphs, tables and computer listings and then forwarded to the affected disciplines.

The center column shows that the evaluating process is completely automated. The static aeroelastic capability consists of four different programs which are:

- a. A structural program that computes the required flexibility matrix.
- b. An aerodynamic program that computes the aerodynamic influence coefficient matrix.
- c. A corrector matrix program which uses the experimental data to correct the theoretical aerodynamic matrix prior to its input into the aeroelastic program. Naturally, the aeroelastic solution will be based purely on theoretical considerations if no experimental data is available.
- d. An aeroelastic program that combines both the structure and aerodynamics to form the interaction problem. Two options are available in this latter program: (1) the inverse solution which calculates the airplane unloaded shape and/or jig shape when the airplane shape is specified; and (2) the direct solution which calculates the airplane shape when subjected to arbitrary loadings.

Presently, both the structural and aerodynamic influence coefficient matrices are handled as tape inputs. The corrector matrix and pressure data processor, are handled by card inputs while the final output from the corrector matrix is on tape which is input into the aeroelastic module. The programs used in CEP SD1 are listed in Table 3-14.

2. Flutter. Table 3-14 shows the basic tasks performed under this heading. CEP SD2, Figure 3-126, shows the various disciplines that interface with the flutter evaluations. These disciplines are: Configuration Design, Materials, Structural Analysis, Structural Design, and Mass Properties which will supply data similar to that required for CEP SD1. In addition, the Flight Control and Stability group

furnishes black box information in the form of sensor locations and feedback loops, etc.

The Evaluation Process gives consideration to both flutter optimization and flutter suppression. The panel flutter analysis can be accomplished analytically or by use of some acceptable design criteria for prevention of panel flutter. All of the operations in this CEP are automated with the exception of the flutter suppression procedure which does require some hand manipulation. Current attention is being given to that operation to make it fully automated.

3. **Gust Response.** Table 3-14 lists the tasks performed for gust response evaluations. CEP SD3, Figure 3-127, shows the various disciplines that are involved in the gust response analysis. These are: Configuration Design, Materials, Structural Analysis and Mass Properties, which furnish the same inputs into the gust response as they did in the flutter analysis; the Stability and Control discipline, which supplies total airplane life and aerodynamic center, aerodynamic surface derivatives, and the stability augmentation system (SAS); and Structural Dynamics, which provides the input gust power spectral density, discrete gust criteria, human transfer function for ride quality analysis, etc. As in the previous figures the various discipline inputs are in the form of graphs, tables, and computer listings. In the evaluation process column considerations are given to the provisions for gust alleviation systems. All operations shown in this evaluation process are automated. The output data is in form of graphs, listings and tables.

Both the Flutter and Gust Response analysis are performed by means of several programs. The basic flow of these programs is shown in Figure 3-128 for the symmetric analysis and Figure 3-129 for the antisymmetric analysis, respectively. The various programs used in the above analyses are listed in Table 3-14.

4. **Taxi and Landing Response.** The taxi and landing analysis tasks are listed in Table 3-14. The various disciplines that supply the necessary input data for the solution of the problem as well as the output data supplied to their disciplines are shown in CEP SD4, Figure 3-130. This CEP is completely automated. The program used in the analysis is the Continuous System Modeling Program (CSMP) which is a problem-orientated program designed to facilitate the simulation of continuous processes on large-scale digital machines. The problems can be prepared directly and simply from either a block-diagram representation or a set of linear or non-linear differential equations.
5. **Acoustics and Vibrations.** The basic tasks that are performed under the Acoustics and Vibration evaluations are listed in Table 3-14.



The sources of noise and vibration in an aircraft system are many and varied and the input data required to evaluate them must come from the many disciplines concerned with a noise source, its limits of operation and the responding structure. As can be seen from the flow chart of CEP SD5, Figure 3-131, the input data consists of numerical quantities which affect the amplitude, frequency, and duration of noise and vibration sources, and the response of the structure or systems to them. Early inputs are estimates in many cases. Acoustic and vibration analyses consist of predictions of the magnitudes, frequency distributions, and durations of acoustic noise and environmental vibration from every possible source; predictions of the effects of these environments during the service life of the aircraft; comparisons with the established criteria; and recommendations for corrective action where deficiencies are determined. The analyses begin early in the preliminary design phase of an aircraft and are continually updated as details of the design are developed and as qualification and verification test data becomes available. This evaluation activity continues throughout all the design phases until analyses or tests indicate that acceptable conditions will be met in the service life of the aircraft.

The output data consists of design criteria, qualification test criteria, and determination of acceptability of the noise and vibration levels and their effects.

3.2.12.2 Further developments: The Structural Dynamics Operating Module (DOM) to be incorporated into an IPAD system is envisioned as comprising a self-contained set of programs. Table 3-14 presents a list of the existing computer programs that are currently being used in the design process. Any one or a combination of these programs are applicable to the preliminary and/or final design stages of a given vehicle. This means, therefore, that the methodology in the DOM would be consistent with the level of detail needed for the particular design phase.

Based on the requirements of the IPAD system, the DOM can readily admit any of the programs listed in Table 3-14; and programs developed in the future can be easily incorporated into the system. Currently one of the CEP's (SD2) contains an optimization procedure which is capable of finding a combination of significant variables which optimize some merit function which can be weight, stiffness, etc. Similar optimization procedures can be developed and included in other CEP's. Finally, in order to incorporate any of the current programs into the IPAD system, modifications of the input and output formats would be required so that they could draw information from either the data base, user files or direct batch mode input.

3.2.13 Thermal Analysis. - The degree of sophistication and the depth of the thermodynamic analysis in airplane and space vehicle design increases as the design progresses through the conceptual, preliminary, and detailed design phases. During the conceptual design phase, thermodynamic analysis may be limited to establishing the thermal environment. As more design details evolve, a more extensive analysis can be accomplished, and trade studies can be conducted to determine relative merits of various thermal system designs. During the detailed design phase, in-depth thermal analysis of systems and components must be accomplished to define the thermal environment in which they will operate; this data is used to establish material and structural design requirements.

3.2.13.1 Present capability: Table 3-15 shows the list of CEP's and computer programs presently used by this discipline. Three computer programs developed by Convair are available to perform thermodynamics analyses. These are: (1) P5613, Aerodynamic/Structural Heating; (2) P2162, Variable Boundary Heat Conduction Program; and (3) P4560, Thermal Analyzer.

Program P5613 has the most updated method for computing flow field and aerodynamic heating rate at hypersonic velocity. Also included is a simple two-dimensional heat conduction subroutine for calculating structural temperature response. This program is suitable for both conceptual and predesign studies.

Program P2162 is a general purpose numerical procedure for solving problems in heat transfer. This program has the versatility with regard to optional specialized routines which accommodate simulation of various modes of heat transfer, which includes computing of aerodynamic environments. A three-dimensional conduction routine is available for structural temperature computations. This program is suitable for preliminary design studies.

Program P4560 is a versatile heat conduction program which accommodates a broad variety of engineering thermal analytical requirements. This program can be adapted to simple or complex, transient or steady-state conduction applications. This program is best suited for detailed design studies.

A functional flow chart of these procedures is shown in Figure 3-132, CEP T01.

3.2.13.2 Further developments: Additional computer programs to establish thermal environment at wide variety of conditions can be developed as complements to the present programs.

A specific recommendation for IPAD development is an auxiliary program which will calculate the voluminous input data required with a Thermal Analyzer Program.

Input data such as node mass, thermal inertia, thermal diffusivity, and the associated radiation parameters are required for each of the several hundred nodes used in the computer analysis. Currently, these are manually calculated and verified (externally to the computer), and then loaded. Conceptually, this manual process (which is both unusually time consuming and subject to human error) can be eliminated. Since the vehicle configuration, fabrication materials, and thermal characteristics of these materials could be contained within local discipline data banks, an auxiliary program could be used to calculate this data and input it to the Thermal Analyzer program module, given a statement of the desired nodes in terms of vehicle coordinates.

3.2.14 Subsystem Design/Drafting. - This section describes the step-by-step procedures used in the design of a few selected subsystems. These subsystems have been chosen as representative among a variety of design activities to provide a "window" to assess the diversity and magnitude of the subsystem design tasks for potential automation in an IPAD System. This assessment has led to the identification of a series of functions that enter in the design of subsystems and also to the identification of specific features that an IPAD System should provide to improve the lot of subsystem designers in an automated environment. Several of the utilities described in Part II of Volume V have evolved from the design needs identified in this task and previous studies performed by Convair.

The step-by-step procedures are described in subsections 3.2.14.1 to 3.2.14.8, and a list of design function capability required is presented in subsection 3.2.14.9.

3.2.14.1 Preliminary structural design process: This design procedure is illustrated in the flow chart of Figure 3-133 and consists of the following steps:

1. Obtain from the configuration designer a copy of his configuration layout which will have on it preliminary external lines and the location of major components and features such as wheels, engines, cockpit, canopy, bomb bays, etc., including some approximate boundaries for the fuel tanks.
2. Within the physical constraints imposed by the configuration arrangement, i. e., external lines, bomb bays, cockpits, etc., lay in preliminary location of major structural members - bulkheads, longerons, spars, etc. These will be based primarily on past experience.
3. These layouts are transmitted to the Structural Analysis group which in the meantime has contacted the Loads group with a request for a preliminary set of air loads. The Structural Analysis group uses this information to "size" the members for the location shown by the structural designer (e. g., cross section area for spar caps and longerons and thicknesses for skin and webs). These structural members sizes may or may not reflect the influence of flutter requirements but if it does it will be a preliminary analysis and not a detailed flutter analysis.
4. The structural designer checks these member size requirements against the space available at his chosen location and makes a preliminary determination of material.
5. If a gross mismatch of structural member location/size/material appears, the member will be relocated based on the insight gained thus far and steps 3 and 4 repeated until a match is obtained.
6. If repeated passes indicate a match cannot be obtained within the present configuration constraints, the configuration designer will be requested to investigate alterations to the basic configuration layout to correct the situation.

7. When a reasonable "baseline" structural arrangement is thus attained these pictures are transmitted to the stress and flutter analysis engineers to be used as the "starting" parameters for their analysis procedures. A structural deflection analysis will be made for those components affecting stability and control and the results transmitted to the stability and control engineer to be checked against the values to be used in estimating tail and control surface effectiveness and size. A structural weight update will be made using the new structural member data as input parameters.
8. While the various structural analyses are under way the structural designer starts conducting studies:
  - a. to investigate in more detail structural problem areas
  - b. to investigate alternate structural arrangements and materials concepts to reduce weight with a more nearly "optimum" concept and to improve manufacturing approaches to reduce costs.
  - c. to coordinate the structural arrangement with the various systems designers such as crew systems, landing gear systems, weapons accommodations, power plant installations, etc.

These studies will require an analysis to a lesser or greater degree by structural weight estimators, stress analysts, structural dynamics analysts, and manufacturing and tooling engineers. As the design progresses, the results of these studies will be injected into the baseline arrangement as merited.

9. As the results of the various structural analyses on the baseline configuration come in, the structural arrangement drawing is altered and updated to reflect the impact of these results. If an impossible structural design situation appears as a result of the constraints imposed by the basic configuration arrangement, the configuration designer is requested to investigate alternate arrangements to improve the situation.
10. The emerging structural design pictures are transmitted to the various mechanical system designers such as weapons accommodation designers, crew and escape system designers, landing gear designers, power plant installation designers, etc. As these designers proceed with their respective designs, the impact of these efforts on the structural arrangement is transmitted to the structural designer for consideration and/or update action.
11. A formal structural arrangement drawing is eventually made for inclusion in the proposal documents and other similar documents.

3.2.14.2 Propulsion design and installation process: A fair degree of automation and data transfer in the form of card decks for engine characteristics is already in existence. However, a great potential lies in the automatic transfer of data and drawings of the engine from the engine manufacturer to the airframe manufacturer. Such data is used by both the propulsion systems designer and the propulsion systems analyst. The current design procedure is illustrated in Figure 3-134 and is made up of the following steps.

1. Get a copy of the configuration layout from the configuration designer. There will be three major areas of consideration
  - a. inlet/duct design,
  - b. engine-airframe interface, installation, removal consideration, and
  - c. nozzle/airframe interface.
2. Generalized inlet geometry, as it affects the external shape, is probably already defined at this stage, having been defined cooperatively by the internal aerodynamicist and the configuration designer. The details of the exact inlet shape and the mechanics of its operation, if a variable geometry inlet, and the details of any bleed provision are determined by the propulsion system designer. Within the constraints of the established configuration as defined by the configuration layout, the propulsion designer, with consideration for the structural aspect, lays out an initial concept for the mechanical operation of the inlet and provides for inlet boundary layer control bleed, bleed air flow paths, and dump. This layout is transmitted to the internal aerodynamicist for analysis and check of proper flow areas in all modes of operation and to the affected structural and systems designers for consideration. When a satisfactory initial concept is developed, the designer updates his layout by laying in structure, actuators, links, ducts, etc. with re-checks as required by the internal aerodynamicist and structural analyst.
3. A lines drawing is prepared of the inlet for any wind tunnel model tests if applicable.
4. The design is altered and updated as a result of the analysis and any associated wind tunnel tests and as a result of inputs from the associated structural and system designers. The final drawing of the inlet system results from the continued update process.
5. An inlet systems drawing is prepared for inclusion in any report or proposal documents.
6. The initial intake duct shape established on the configuration layout is used as a starting point for more precisely defined duct lines. These duct lines are developed
  - a. to match a flow cross section area distribution as defined by the internal aerodynamicist,
  - b. to clear any internal objects such as weapons bays, landing gears, wing primary structure, etc, and

- c. to provide space for duct structure and any duct boundary layer bleed accommodations.

Programs have been developed, using APT language, that develop duct lines to match a prescribed flow cross-section distribution. Duct bend rates are kept within the allowables determined by the internal aerodynamicist to prevent separated flow.

7. The lines are transmitted to the internal aerodynamicist for analysis and to the structural and any other affected designers for coordination checks on interference. If interferences occur, the duct lines or interfering structure is altered until a satisfactory design is achieved. This may include an alteration to the basic configuration design if the problem warrants this solution.

A real time interactive design/analysis process could be achieved by placing the lines development process on graphics consoles for both the designer and internal aerodynamicist simultaneously.

8. A manufacturer's engine installation drawing is obtained and an accurately scaled engine installation envelope layout is made.

In an IPAD environment the engine data and installation drawings could be computerized. If a computerized drawing were available directly from the manufacturer, this would be used; otherwise, the engine installation envelope drawing from the engine manufacturer would be computerized and stored in the engine drawing library.

9. Using this envelope layout and the airplane configuration layout, an engine installation and removal scheme is developed. Considerations involve an interface with structural design, AGE-engine handling cart or crane, and perhaps the basic configuration arrangement. Alterations of any of these items can occur.
10. When an acceptable engine installation and removal scheme is developed, design layouts are started on the engine driven airplane accessories such as generators, hydraulic pumps, etc., including provisions for cooling these items. The fire protection and engine cavity ventilation systems are investigated by layout. An interaction with the structural designer usually is required, however, the impact of these items on the structure is generally not great enough to require a large number of design iteration cycles.
11. The nozzle integration problem is investigated. Involved in this investigation are layouts, coordination with nozzle aerodynamicists, external aerodynamicists, and thermodynamicists (engine plume, etc.) and coordination with the engine manufacturer. There is a potential for many wind tunnel tests of various basic concepts, particularly for fighter aircraft design where the engine is integrated into the fuselage. The nozzle integration problem offers a great potential for using the computer to perform a coordinated, interactive design/analysis task, provided pressure field analysis OM's are developed that can accommodate the various designs as they are

3.2.14.3 Landing gear preliminary design process: This procedure is illustrated in the flow chart of Figure 3-135 and is described in the following paragraphs.

- | <u>Item</u>   | <u>Source</u>                   |
|---|---------------------------------|
| Flotation/Tire Pressure                                   | - RFP/Program Office            |
| Sink Speed  | - Aerodynamics, Design Handbook |
| Brake Energy  | - Aerodynamics, Mass Properties |
| Steering  | - RFP/Program Office            |
| Auxiliary Gear (Hook, Bumper,<br>Speed Brake, Drag Chute) | - RFP/Design Handbook           |
| Geometry and Space  | - Configuration Layout          |
| Loads and Criteria  | - Design Handbook/Dynamics      |
| Basing Concept (Runway Surface<br>Type)                   | - RFP                           |

- |                |  |
|----------------|--|
| Load:          | 90% Max. gross weight  |
| Location:      | Fuselage station for 15° tip back angle  |
| Size & Number: | Use computer program for dirt, asphalt, or concrete:<br><br>California Bearing Ratio (CBR)<br>Number of passes on CBR and<br>pavement thickness, modulus |

Large single tire (250 psi maximum pressure)  
Twin  
Tandem  
4, 6 and 8-wheel trucks.



Alternate arrangement selection will depend on the retraction space and geometry, and is a cut-and-try procedure, dependent on the designer's experience. Do a preliminary check for brake volume in wheels before finalizing truck geometry.

b. Nose gear tires

Load: 15% of Maximum Gross Weight (MGW) plus  
dynamics braking loads = .6 MGW (C.G. Height/  
Wheel Base)

In an automated environment, such as IPAD, simple OM could establish loads and geometry and feed directly into an existing tire/flotation computer program which could also be modified to draw to scale the truck/bogie alternatives required. By inserting these alternates into the configuration drawing the landing gear designer in turn could quickly determine the most feasible landing gear arrangement.

3. Establish the shock strut size and stroke from the sink speed, the allowable G loading and typical air curves. Check on taxi G allowable for rough surfaces. In an IPAD environment the shock strut sizing would require a simple OM, coupled to a catalog of ground rules and standard parts, to produce both a drawing of the strut and the required air curve (static and dynamic).
4. Structure and Geometry. Obtain a configuration layout and coordinate with other designers to define the retraction space. Synthesize (using methods of Bruss, Reference 7, and Conway, Reference 8) retraction linkages, using direct load paths for drag and side loads, and minimize bending loads as much as possible. Rough in doors, locks and paths of folding members. Coordinate with structural designer to cut as few main longerons as possible. Endeavor to combine landing gear attach points with other main structural members.

Many programs are available to synthesize 4-bar linkages in 2 and 3-dimensions in an IPAD environment. Adding landing gear preferred practice and a simple load/stress subroutine would enable one of these programs to draw a gear to retract into a given location and produce a preliminary weight of the gear structure. This tool would enable the designer to work his way through some of the more exotic (i.e., hard to visualize in 2-dimensions) mechanisms and optimize weight and space required for landing gear.

5. Brakes. Obtain landing and takeoff speeds and gross weights. Do a brake analysis using an existing computer program. Determine heat sink material (iron or carbon) by cost/weight trade study and coordinate with program office. Install heat sink stator and rotor in wheels and check against experience for satisfactory tire change, heat rejection, maintenance and adjustment, anti-skid, single failure safety, etc.

A catalog of component parts, standard practice and scaling rules, added to the existing brake computer program would allow both iron and carbon brakes to be drawn and weighed by automated procedures within an IPAD system. An expeditious and direct comparison of cost/weight would then be possible.

6. Hook and Bumper. Obtain arresting and rotational energy/stroke requirements from basing criteria and aerodynamics. Coordinate hook installation with configuration designer. Check line of action effects on nose gear slap down and in-flight arrestment dynamics.

Hook and Bumper dynamics have been incorporated into a computer program. Adding a draw routine and interactive inputs would allow this step to be automated.

7. Tabulate components and coordinate structural and heat sink weights with weights group.

A weight/draw/tabulate routine developed for other subsystems can easily be expanded to cover tires, wheels, brakes, and landing gear structure.

3.2.14.4 Aerospace Ground Equipment (AGE) preliminary design process: This procedure is illustrated in Figure 3-136 and is described in the following paragraphs.

1. From RFP, Program Office, SOR, etc., obtain mission usage of airplane.
2. From Operations Research, Maintainability, obtain basing and maintenance concepts. As mission usage and basing concepts are developed by other groups, they would be stored in the common data bank for comment and updating. When approved and coordinated with all, they remain in library for reference and usage by all groups. This information could be called up on AGE Designer's display.
3. From designers, obtain inboard profile/3-view and description of major subsystems having AGE interface.

Armament	- Weapon Loading
Propulsion	- Engine Change, Starting, Fuel Servicing
Landing Gear	- Jacking & Towing, Flotation
Crew Station	- Ingress, Egress, APU Start, etc.
ECS	- Ground Air Conditioning
Sec. Power	- Ground Electrical, Hydraulics, Pneumatics
Overall A/C	- Hangar and Runway Compatibility

In the early stages of the design evaluation, the configuration layout is used instead of the inboard profile and 3-view, and only those items such as engine removal, weapons loading, etc. that have a major impact on the overall configuration are investigated. As the structural and systems designers phase in, areas affecting

their designs are then investigated. In an IPAD environment the drawings and other data for each interfacing subsystem would be available from computerized data banks which would be available to the AGE designer on interactive graphics displays and/or hard copies.

4. Postulate the AGE and basing concept.
5. Review concept with designers, program office, "ility" groups, and revise as required. In an automated design environment, after the AGE concept is formulated it would be read into the common data bank, reviewed and updated by designers on their display, and on approval would be left in the library for usage as required.
6. Analyze airplane and system design for compatibility with AGE concept.
7. Review analysis with designers and suggest modifications as required, e.g.,

- Increased ground clearance for standard weapon loaders
- Self-hoist pylons
- Jacking and towing pads
- Quick disconnects for hydraulics
- Engine services to meet QEC time
- APU remote start
- Self-contained ladder
- Tie-down rings
- Nonstructural access doors
- Relocate LOX bottle for faster service
- Etc.

Modifications may be required for compatibility with basing concept or standard AGE or scramble time, turnaround time, self-sufficiency, etc. With the assistance of an IPAD system the analyses and reviews could be performed using interactive graphics equipment. The analysis would consist of calling up standard AGE stored in data banks and comparing interface with A/C and system drawings. Modifications could be coordinated (through the computer) with individual designers on their displays. Approved modifications could be implemented on the scope immediately.

8. Where standard AGE cannot be used, design special items (hi-cost equipment only) for inclusion in cost proposal, or cost tradeoff analysis. (The engine change derrick for the Harrier, or the pod loading trailer for the B-58 are examples of this type of equipment.)
9. List Standard AGE required for inclusion in the list of government furnished equipment portion of the proposal. Selected standard AGE from MIL Handbook 300 can be listed by the computer by means of the report writing capability provided by an IPAD System.

3.2.14.5 Secondary power system preliminary design process: Figure 3-137 illustrates this procedure which consists of the following steps.

1. Obtain requirements and constraints:

<u>Source</u>	<u>Item</u>	<u>Purpose</u>
Aerodynamics Group	Mission Mach/Altitude Profile	Cooling (electrical & hydraulic)
Avionics Design	Services required: Avionics KVA	Electrical Load
Flight Mechanics	Surface Hinge Moment and Surface Rates	Primary and Secondary Flight Controls
Electrical Design Group	Misc. Electrical demands	Flaps, lighting
All Groups	Misc. Actuation	L. Gear, Brakes
Program Office, RFP	Failure Criteria	Fail-safe, vice fail operate
RFP, SOR	Basing & Operational Concept	Self-sufficiency va. Ground Carts. APU? Self-contained engine start?
Program Office	Weight/Cost trade criterion	Actuation Concept Evaluation

As these data are developed by other groups, in an IPAD environment, they would be stored in the central data bank for comment and updating. When coordinated and approved, they would remain in the central data bank for call-up or printout.

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2. Perform initial systems synthesis. This step consists of:

a. Selection of systems

<u>Decisions Required</u>	<u>Basis for Decision</u>
Number of Hydraulic Systems	0 - No large loads 1 - No failure criterion 2 - Fail safe criterion, or 3 - more fail operate.
Number of Electrical Generators	0 - No electrical requirement 1 - No failure criteria 2 - Moderate load fail operate, or 3 - more large load fail operate.
Engine Mounted Pumps & Generators Airframe Mounted Gearbox	Number & location of engines Engine change time limits Weight, Reliability Maintainability.
Hydraulic System Operating Pressure (1500, 3000, 4000 psi)	Load, cost, weight, compliance.
Secondary Power System Cooling	Operating Temperature
Ram Air	Fluid temperature limits
Fuel	Time at temperature
Combination	Cost weight trades
APU Services	Basing and operational concept.

b. Design

On the basis of the above and using the maximum power demand (hydraulic flow rate, electrical KVA, ECS required from APU, engine start, etc.) synthesize one or more systems meeting the requirements, and draw a schematic of each. On a lines layout, install pumps, reservoirs, coolers, etc. from catalog or scaled from existing components. Consult with other designers and establish, using an up-to-date structural arrangement, a routing and component installation control drawing.

For an automated modus operandi within an IPAD system the following capability could be developed:

- a. A system synthesis could be built on the existing HYDSIM computer program by adding: (1) a read-draw OM; (2) subroutines for gearbox, electrical

circuits and the "Fail Safe/Reliability" logic required; and (3) an OM to produce the power system schematic.

- b. The data bank of hydraulic/electrical/ECS/Mechanical Components, in conjunction with a scaling OM would enable the complete routing drawing to be worked on cooperatively by all designers. A common interconnect OM would permit efficient piping layouts and alternatives to be quickly evaluated.
3. Systems Analysis: With line lengths from the routing drawing establish line sizes (HYDSIM Computer Program), adequacy of return and drain lines, pump suction limits, cooler circuitry, reservoir sizes.
4. Weigh and tabulate components and tubing.

Flow and pressure drop OM's in conjunction with the weight OM will make steps 3 and 4 automatic within an IPAD system.

3.2.14.6 Armament system design process: The conceptual and preliminary design processes are illustrated in Figures 3-138 and 3-139. The step-by-step design procedure is described in the following paragraphs.

1. Obtain requirements and constraints:

<u>Source</u>	<u>Item</u>	<u>Purpose</u>
RFP, Program Office Operations Analysis JMM, etc.	Operational Time Frame Mission Profiles Targets Weapons Required Weapons Desired	Weapon Type Desired Weapon Space and Weight Allocation Aero Heating Evaluation Release Limit Evaluation
Mission Analysis Group Aerodynamics Weights	Payload/Range Trade External Drag Penalty CG Limits	Mission Evaluation External/Internal Trade Store Locations

As these data are developed by other groups within an IPAD system they are stored into the central data bank for comment and updating. When coordinated and approved, they remain in the data bank for call up or printout as required.

2. Perform initial system synthesis. This step consists of:

- a.. Weapon List.

Coordinate with the Configuration Design, Operations Analysis Groups and Program Office a tentative list of weapons for internal and external carriage.

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b. Internal Weapons.

Develop a clearance envelope and size a weapon bay for internal carriage weapons. Supply this early to the configuration designer, complete with fall clearance, rocket exhaust clearance, rack and installation clearances. Indicate loading and arming clearances required. Coordinate with the Mass Properties group on CG limits.

c. Gun.

Coordinate with Flight Control and Stability and Configuration Design groups to establish a satisfactory gun installation.

d. External Weapons.

Coordinate with Program Office, etc. and establish the maximum number of external stores for simultaneous carriage.

Fuel Tanks	- (Ferry Mission)
Self-Defense Missiles	
Bombs	
Rockets	
Dispensers	

Locate pylons, wing tip stations, centerline stations and conformal (semi-submerged) store station as required to meet these requirements. Coordinate with Configuration Design, Landing Gear, and Control System Design groups for sufficient ground, landing gear (and door), flap, slat, tail, and speed brake clearances.

A library of weapons, weights and target spectra (combined with operation analysis OM) and a draw-to-scale OM - now partly available - would allow automation of this entire process for an IPAD system. Adding dynamics and separation trajectory OM's would permit computer print/draw of the complete clearance picture in an interactive mode.

3. Armaments System Preliminary Design. This procedure consists of:

a. Internal Arrangement.

Coordinate with structural designer to establish weapon bay hardpoints, door attach points, rotary mechanism requirements, etc. Provide layouts of weapons in bay for evaluation of separation, fall clearance, structural support, dynamics, AGE, weapon servicing and loading, rack interface and services, cooling, etc.

b. Gun.

Coordinating with structures and internal routing; provide ram air purging and cooling of gun and ammunition; locate ammunition storage for minimum twist

and run of chute to and from gun, ease of loading, and to minimize structural and routing interference; route gun drive hydraulics to minimize fire hazard.

c. External Services.

Coordinate hardpoint design with structural designer and routing coordinator to get essential services to each point:

Fuel  
Cooling Air  
Electrical  
Hydraulic  
Etc.

Design pylons, pylon interface, and rack interface.

4. Weight and tabulate components.

Automated drawing and Mass Properties OM's developed for other systems will be adequate for armament to draw, weigh, and tabulate components within an IPAD system.

3.2.14.7 Crew station preliminary design process: This procedure consists of the following steps:

1. Obtain requirements and constraints:

<u>Source</u>	<u>Item</u>
RFP	Type of Aircraft
RFP	Number of Crew and Function
RFP/Program Office	Mission Length
Armaments Group/Program Office	Weapon Carriage & Delivery
RFP/Crew Station Group	Vision
RFP/Program Office	Aircraft Subsystems
All Groups	Space Available
RFP/Program Office	Escape System
RFP/Program Office	Personal Equipment
Aerodynamics Group	Maneuver Limits
Aerodynamics Group	Mach/Altitude Profile
Program Office	Weight/Cost Trades

In an automated environment this data will reside in the common data bank.

2. Establish preliminary cockpit sizing through design layout, working with configuration designer. This task includes establishing location of design eye and determination of vision capability and canopy configuration. Refinement to airplane lines may be required or desirable at this point because of space needs in the cockpit. Some of the decisions to be made at this point follow:



<u>Decisions Required</u>	<u>Basis for Decision</u>
HIAD Geometry or Special	Aircraft Mission & Performance Capability.
Escape System Type	Aircraft Performance Capability
HIAD Vision or Different	Aircraft Mission
Type of Instruments & Equipment	Cost, Weight, Mission Requirements
Shirt Sleeve Flight or Pressure Suit Operation	Structural Weight, Environmental Control System Complexity.
Crew Comfort Provisions Required.	Mission Length.

A cooperative effort with other design groups will be necessary to exploit and modify existing programs for the definition and refinement of cockpit configuration lines within an IPAD environment.

3. Using preliminary cockpit layout, examine critical functions for compatibility with
  - a. Escape system
  - b. Primary and secondary controls
  - c. Candidate displays and controls
  - d. Reach and clearance limits
  - e. Canopy system (normal and emergency mode)

Select a configuration.

In an automated environment, computerized definitions of both the cockpit configuration and the critical element would be available. Using graphic displays of these lines compatibility checks could be made of items such as escape system performance capability (using previously established program for module), ejection seat, rocket extraction system or other system as applicable. Reach envelopes would be evaluated against controls and displays location and a cockpit configuration selected.

4. Coordinate with other designers and technical disciplines to obtain best arrangement. Continue layout and design iteration until a suitable configuration has been established. Depending on the depth of study and any unique features or requirements, a wood and cardboard design aid (static mockup) may be constructed at this point, for use as a 3-dimensional tool in further design iterations.

Computerized graphic displays of cockpit arrangement from any view angle would be used in an IPAD environment, before a mockup is made. This capability could obviate the need for mockups.

5. Weigh and tabulate components and establish performance capabilities for elements such as escape system, controls, etc.

Within an automated capability the weight and other data for each component would reside in data banks. Appropriate programs within this subsystem OM would be used to establish performance for major elements (such as escape system) within the framework of the total airplane environment.

3.2.14.8 Environmental Control System (ECS) design process: The steps involved in this process are:

1. Obtain requirements and constraints affecting Environmental Control System and Life Support

<u>Source</u>	<u>Item</u>
RFP/Program Office	Number of Crew
RFP/Program Office	Mission Length
Aerodynamics	Mach/Altitude Profile
Avionics Design	Avionics Load
Design Handbooks	Cabin Pressure Schedule
Propulsion	Engine Bleed Pressures
Configuration Layout	Space Available
Program Office	Weight/Cost Trades

In an automated design environment this data would reside in the common data bank.

2. Establish (in conjunction with Aerothermodynamics group) heating and cooling loads as a function of the Mach-altitude profile(s) of the mission(s). Add in other features required (e.g., electronic pressurization, anti-icing, bleed air turbine emergency power, etc.).

Standard programs, or adaptation of existing programs to interactive computer equipment, would enable cooperative design/analysis by cooperating disciplines, i.e., the ECS system designer and the aerothermodynamicist interacting with each other through the computer would, using their own design/analysis OM's, establish and coordinate requirements, system design points, etc., and read these data into the central data bank for use by all.

3. Compare loads and duration with conventional heating/cooling cycles. On the basis of experience with similar vehicles and cursory analysis, pick one or two candidate systems for further analysis.

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<u>Typical Candidate Systems</u>	<u>Analysis Parameters</u>
Ram Air Ventilation	Drag Penalty
Liquid Boiling Heat Sink	Engine Bleed/Thrust
Fuel Heat Sink	Mission $\Delta$ Gross Weight
Simple Air Cycle	Complexity
Bootstrap Air Cycle	Safety
Regenerative Simple/Bootstrap Air Cycle	Recurring Cost
Vapor Cycle	Development Cost

In an IPAD system, data libraries contained in user files would contain "catalogs" of existing and previously studies ECS systems, components and capacity numbers. Quick comparison and moderate usage of simplified analysis OM's will enable the comparison parameters to be determined more accurately than by means of present methods.

4. On the selected cycle(s) make preliminary layouts of bleed air system, refrigeration package, cabin distribution and pressurization, and avionics cooling system. Size and weigh components as follows:

Turbo Machinery:	Ratio size and weight by fan laws to airflow ration of existing units.
Heat Exchangers:	Computer programs available to size and weigh cores.
Valves and Controls:	By comparison to existing units.
Water Separators, Density:	Size by airflow and $\Delta P$ required.
Ram Air Inlets & Exits:	Coordinate with Aerodynamics.

5. Obtain layouts/lines drawing of selected portions of vehicle for trial fit of system. Coordinate with other designers, aerodynamics, structures, etc., to obtain best arrangement of: ducting, package, ram air inlet and exits, bleed air inter-cooler, integration of other coolers, avionics cooling. Try alternate packaging concepts; investigate integrating heat exchangers with secondary power and APU.

In an IPAD environment, the designer would use the latest configuration/structural layout from interactive graphics equipment, the data bank of components, and automated scaling OM's, to try various arrangements. An interconnect OM would size and draw the most efficient ducting arrangement which can be accommodated in the space available by the ECS designer, and could be called up for coordination by other designers.

6. Investigate emergency and "off-design" requirements:

- Ram air ventilation
- Open canopy ground cooling
- Taxi and ground engine run conditions
- Single failure safety

Using automated analysis OM's available within an IPAD system the starting conditions of each "off design" or emergency condition would be inserted into the design to modify it as required for comfort or safety.

7. Tabulate Component Data, Weights, etc.

Computerized design OM's would automatically tabulate and weigh components, ducting insulation, etc., within an IPAD system.

3.2.14.9 Design function capability required: The evaluation of the design functions described in Sections 3.2.1 and 3.2.14.1 to 3.2.14.8 were used to segregate basic design functions and data needs for which capability must be provided within IPAD. This roster is not portrayed as a complete one but just as an exemplary list of some of the most important functions and data required. The list has been divided in four major categories which were used in the definition of the General Design Module (reference Volume V) and are detailed in the following paragraphs:

1. Information Storage and Retrieval. Included in this category are: standard parts library; previous design data historical records; subsystem data libraries; specifications and criteria; drawings and geometric data; materials, cost, and manufacturing data; production and usage records; performance and reliability data of parts, components, etc.; availability of commercial parts, stocks, of-the-shelf items, etc; make and buy lists; standard design practice manuals; alternate designs data; etc.
2. Design/Drafting. The required capability must provide for: semiautomatic dimensioning of drawings; text writing and editing; tutorial aids; menus of standard notes, bill of materials, specifications, etc.; drafting of points, lines, arcs, intersections, shapes; various line styles, grid displays; automatic contouring and splinning; deletion of hidden lines; translation and rotation of parts and/or entire assemblies; flat pattern development; total and/or partial erasing, copying, and mirroring of parts and assemblies; pattern repetition; scaling of parts; curve fitting; inboard profile composition; create and store assemblies; tolerancing; isometric and perspective views; hard copying in three different qualities; etc.
3. Analysis Program Library. The system shall provide capability to perform analytical evaluations auxiliary to the design process such as: calculation of perimeters, areas, wetted surfaces, volumes, mass properties, balance, line losses, etc.; usage of scaling laws, kinematics, simplified first-cut analysis procedures; curve fitting routines, etc.; automatic routing of lines (electrical,

hydraulic); coordinate transformations; unit conversions; tolerancing and interchangeability checks; perform parametric sizing and optimization studies; plotting routines; etc. The designer could operate on the desk-calculator mode or access both minicomputers or the main host computer as required with the last two being eventually transparent to him.

4. Computer Aided Manufacturing Interface. This interface will grow in importance as the IPAD system is developed and implemented, and provides the physical transition between the design process and the manufacturing of the parts that define the product. The common denominator of these two activities is the detailed design information in the form of dimensional data and material specifications, which at the end of the design process are contained in the data bank. The extraction and subsequent utilization of this data for manufacturing could be made by generating tapes in the APT program or by utilizing graphical interaction to develop tool cutter path movement (refer to Volume V, Part II, Section 7.1.4).

#### 4 CONCLUDING REMARKS

The conceived IPAD system operates with a well known engineering capability base having project team direction and individual discipline control over their respective tasks as members of the team. In this respect the IPAD system per se does not disturb the responsibilities assigned to project team members.

IPAD brings forward awareness of the benefits afforded by the latest and near future computing technology developments and implements a set of new engineering tools that exploits that technology in benefit of the users. These two developments will foster improvements in the modus operandi of each discipline while retaining control of the changes within themselves. Two major drivers will provide thrust for these improvements: (1) the accomplishments of other disciplines, and (2) the cost effectiveness potential of the new management/engineering tools.

The characterization of the design process has segregated a set of creative/evaluation procedures which provides an adequate engineering capability for the first release of IPAD.

The major characteristics of the conceived IPAD system are it being an interactive system and having an unlimited flexibility to accommodate small or large project teams.

IPAD is a user-oriented, modular system using advanced data base management concepts, which caters to the total design process.

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