NASA Contractor Report 2981

Development of Integrated Programs for Aerospace-Vehicle Design (IPAD) - Reference Design Process

Donald D. Meyer

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Development of Integrated Programs for Aerospace-Vehicle Design (IPAD) - Reference Design Process

Donald D. Meyer
Boeing Commercial Airplane Company
Seattle, Washington

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FOREWORD

This document was developed as part of the Integrated Programs for Aerospace-Vehicle Design (IPAD) program documentation in accordance with contract NAS1-14700. Other closely related IPAD documents (see fig. 1) are:

NASA CR 2982	Product Manufacture Interactions With the Design Process (D6-IPAD-70011-D)
NASA CR 2983	Product Program Management Systems (D6-IPAD-70035-D)
NASA CR 2984	Integrated Information Processing Requirements (D6-IPAD-70012-D)
NASA CR 2985	IPAD User Requirements (D6-IPAD-70013-D)

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These Boeing engineers contributed portions of the document: Gordon L. Anderton, Eugene Chang, Harold A. Crowell, Jack M. Isenberg, Steven J. Joubert, Donald O. Neilson, Robert K. Robinson, John W. Southall, Leonard L. Steiner, and Irving R. Strauss.

The NASA Langley Research Center Document Coordinator for this document was Jaroslaw Sobieski.

Measurements included in this document were not generated on the IPAD program; therefore, they are shown here in U.S. customary units. A conversion table (U. S. to SI) is included in the appendix.

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1.0 SUMMARY

The IPAD task is to develop a computer-based technology which allows for integration of all aspects of the design process (analysis, design, testing, etc.) into a forceful engineering tool with interfaces to manufacturing computerized methods in order to favorably impact aerospace vehicle performance, development cost, and flowtime.

The Reference Aerospace Design Process Definition given here is one of the building blocks for constructing the IPAD program, others being: "Product Manufacture Interactions with the Design Process Document" (task 1.2, CR 2982), "Integrated Information Processing Requirements" (task 1.3, CR 2984), "User Requirements" (task 1.4, CR 2985), and "IPAD Requirements" Document (task 1.6.2, D6-IPAD-70040-D). Figure 1 illustrates the relationship of this document with other documents developed in task 1 of the IPAD contracts.

A design is a desired arrangement of things and/or activities from a random source. The design process is a procedure for creating a design, where the task is defined (with its environment, restraints, and freedoms) and the best solution is developed during the time span available with minimum task compromise.

This IPAD Reference Design Process document defines a representation design process from the conception of an idea for a vehicle until it has been completely defined and the object built, delivered, and used, including alterations during its service life.

The design process progression is segmented into nine activity levels for visibility and convenience. (See fig. 2.).

In this document, three major subjects are covered: Design Management (section 4.0), Design Support Requirements (section 5.0) and Detail Design Activity (section 6.0).

This document, in accordance with task I in the IPAD Statement of Work (1-15-4934a), updates the IPAD Feasibility Study and the Design Process (D6-60181-2) and develops supplemental networks for detail/sustaining design.

The detail networks illustrated and described give evidence that the design activity network for a system design or a structure design are generally the same, only the terms are varied to reflect the subject concerned.

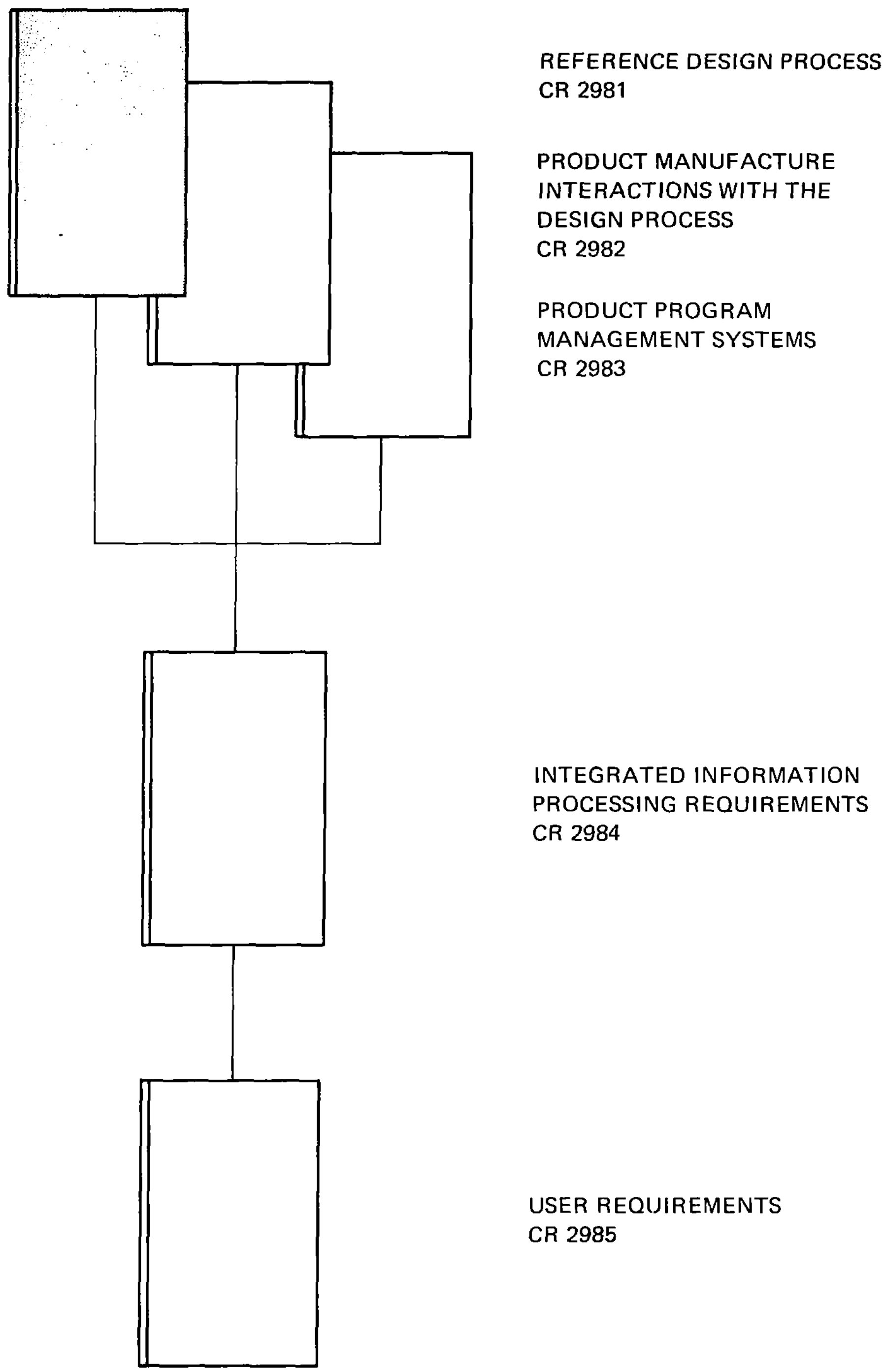


Figure 1.— Relationships of Task I Documents (Shaded Block Indicates this Document.)

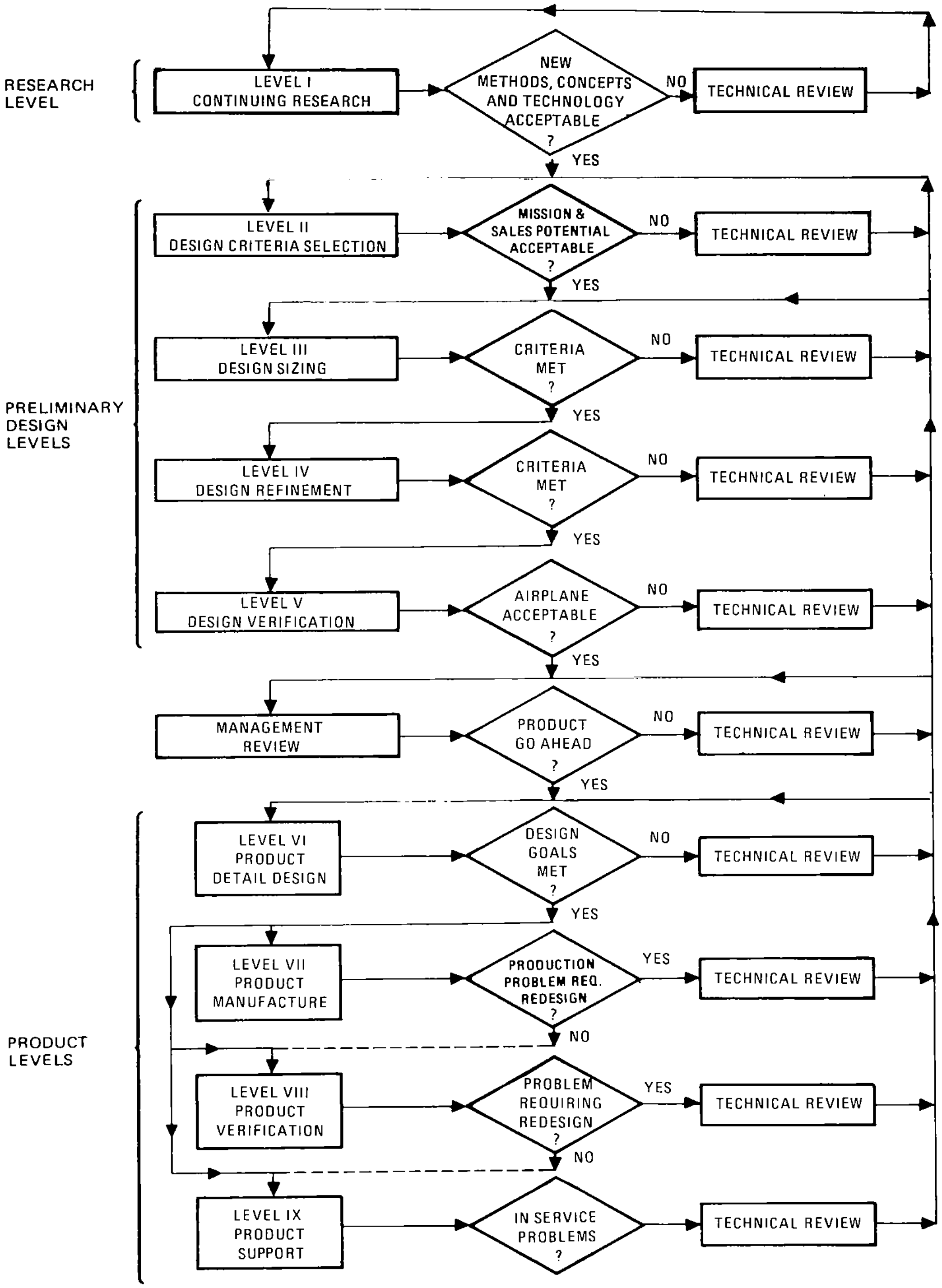


Figure 2.— Activity Levels

2.0 INTRODUCTION

A modern aerospace vehicle is a complex integration of sophisticated technical systems manufactured to the exacting standards required for safety, economy, and mission performance. The complexities of aerospace vehicles and the process of their design and manufacturing have continually increased with time. The design and manufacture of more advanced vehicles is limited by the technology and methods available to develop and manage the required analysis, design, and manufacturing processes. Traditional limited distribution and automation in design constrain the technology that can be designed into advanced vehicles. Further, the productivity limitations of traditional methods result in an increase in manpower required to produce and manage the enormous volumes of necessary information.

Applications of computer-based technology have brought about significant improvements in engineering productivity. These improvements have only partially exploited the potential for computational efficiency and automated data communication by focusing largely on isolated elements of the vehicle design and manufacturing process. There remains the need to provide for expansion and interface to all aspects of analysis, design, testing, and manufacturing in order to lower aerospace vehicle development cost and shorten development flowtime.

The objective of the IPAD technical development is to provide the foundation ingredients of a computer-based information processing system tuned to the aerospace design process needs to serve as the central communication and calculation integrator for large numbers of designers conducting a broad range of design tasks over significant periods of time.

To this end, a description of the design activity is produced to guide construction of an integrated design process.

This document, in accordance with task I, updates the IPAD Feasibility Study Design Process (D6-60181-2) and develops supplemental networks for detail/sustaining design. (Refer to task I in the IPAD Statement of Work 1-15-4934A and in Technical Plan-Final, D6-IPAD-70002-P.)

The design process begins with the conception of a vehicle and continues throughout the production, delivery, use, and alteration of the end item during its service life. The guidance, assists, and restraints encountered during the design process are dealt with as the design develops through several levels of detail and activity.

This document addresses the design process through three major divisions: design management (section 4.0), design support requirement (section 5.0) and detail design networks (section 6.0).

A major and integral part of design process is the management of the design itself. Design process management (section 4.0) deals with the activities management must address itself to:

Engineering resource and schedule control

Configuration management

Design process management

Drawing control and release

Test and analysis

Service support

The second major part of an efficient design process is the general design support available. The design support areas (section 5.0) are:

Product Configuration - technical and geometry

Technical Analysis - staff support of weights, aerodynamics, loads, stress, technology

Computer Aids - computational, graphic, library

Design Intelligence - guides, experience, standards

The third part of the design process is the detail design activity itself (section 6.0). The design process is illustrated first as an activity network followed by a narrative description.

The design process is divided into three basic sections: continuing research, preliminary design, and product development. When describing these areas it is convenient to further divide the process into levels of activity. (See fig. 2.) The first section, continuing research, consists only of level I. Research activities of a long term nature continually provide new design procedures, technical analyses capabilities, and data for the data base. The second section, preliminary design, is divided into four activity levels: design criteria selection (level II), design sizing (level III), design refinement (level IV), and design verification (level V).

The third section, Product Development, is divided into four activity levels: product detail design (level VI), product manufacture (level VII), product verification (level VIII), and product support (level IX).

Product detail design process (level VI) described in sections 6.2, 6.3, and 6.4, is more minutely examined in section 6.6 (structural detail design) and section 6.7 (system detail design). Section 6.5 exposes the information gathering process, which is in continual use throughout all levels of the design process.

A catalog of computer programs is described in section 7.0.

3.0 ABBREVIATIONS

A/C	Aircraft
A/P	Airplane
APU	Auxiliary power unit
BCAC	Boeing Commercial Airplane Company
BCS	Boeing Computer Services
BL	Buttock line
CAD	Computer-aided design
CAM	Computer-aided manufacturing
c.g.	Center of gravity
C,M,C/M	Computer, man, computer/man
DIE	Document industrial engineering
DMR	Diagram manual report
EAMR	Engineering advanced material requirement
ECS	Environmental control system
FCS	Flight control system
GAG	Ground-air-ground
IPAD	Integrated Programs for Aerospace-Vehicle Design
IPC	Illustrated parts catalog
LM	List of materials
MGOS	Maintenance and ground operations system
MPD	Maintenance planning data
OEW	Operating weight empty
PD	Preliminary design
PI	Production illustration

PRR	Production revision record
RFP	Request for proposal
RQSAS	Ride quality stability augmentation system
STA	Station
STRL	Structural
TAT	Total air temperature
TPE	Technical program element
T/W	Thrust/weight
WBS	Work breakdown structure
WL	Water line
W/S	Weight/span
WT	Wind tunnel

4.0 DESIGN PROCESS MANAGEMENT

This section contains representative management plans, controls, and operating procedures necessary to perform the design process. These are intended as guides to promote consistency and, thus, efficiency in the design effort and may be tailored to suit a particular program. Management should give special attention to procedures to accomplish such items as:

Early identification and prompt resolution of technical problems

Scheduling and control of project/staff development milestones

Design budget control

Product cost targets

Management policy

State and Federal laws

Contracts (customer, subcontractor)

4.1 ENGINEERING RESOURCE AND SCHEDULE CONTROL

4.1.1 WORK BREAKDOWN STRUCTURE (WBS)

A work breakdown structure is a product-oriented family tree related to hardware, software, services, and other deliverables that completely define a program.

The work breakdown structure (see document D6-IPAD-70035D, Product Program Management System) is a management tool, starting in engineering and encompassing all program disciplines, including engineering operations, business management, customer requirements, etc.

The WBS is used to plan, control and report:

Budgets	- Identified on program control matrix by organization, WBS element, and significant work order
Costs	- Charged, collected, and reported through a charge number structured to the significant WBS code

Schedules - By WBS element and code number

Technical Performance - Tracked and reported by organization, WBS element, and WBS code

4.1.2 ENGINEERING INTEGRATED SCHEDULE AND CRITICAL PROBLEM RESOLUTION

4.1.2.1 Engineering Integrated Schedule Plan

The purpose of this plan is to integrate all effort into a comprehensive master scheduling framework which will identify:

Start and finish of development tests

Key design milestones for tracking design progress against any desired reference (e.g., budget expenditures,

Start and stop of design tasks for timely identification of manning acquisition and off-load

4.1.2.2 Critical Problem Resolution Plan

This plan is intended to systematically identify and resolve unanticipated problems as they occur as well as high risk problems. It can be expected that the bulk of design problems will be resolved routinely through studies, tests, etc., as the program evolves. In certain cases, however, unanticipated problems will be identified which are deemed critical to the program because of risk or technical performance degradation, schedule slide, or cost overrun. High-risk problems are those which might present themselves if new concepts or processes were employed. Both kinds of problems (unanticipated and high-risk) will be singled out for special attention.

4.1.3 RELEASE SCHEDULE MANAGEMENT PLAN

The purpose of this plan is to implement methods of establishing realistic dates for basic engineering releases and for early, systematic identification of potential schedule problems.

4.1.4 BUDGET ALLOCATION AND CONTROL PLAN

This plan is to establish a task budget and its allocations and tracking and control methods, which will encourage performance within these budgets. The plan should include procedures for:

Project and staff budget allocation

Test budget allocation

Mockup budget allocation

Budget reporting and control

4.1.5 ENGINEERING FACILITIES, EQUIPMENT, ADMINISTRATIVE SERVICES SUPPORT PLAN

Efficient planning for expansion and contraction of a project size and work area, plus timely availability of in-process facilities, equipment, and services, are key influences in meeting the design budget forecasts.

4.1.6 ENGINEERING MANNING PLAN

Plans for a systematic manning acquisition and off-load by design skills and labor grades are key to efficient design performance within established budgets.

4.2 CONFIGURATION MANAGEMENT

4.2.1 TECHNICAL CONTROL DOCUMENTATION

This documentation serves as the technical coordination medium to keep all affected engineering, operations, materiel, finance, and program management organizations abreast of the requirements and current configuration. It also provides a baseline for design trades and assures configuration design control.

4.2.2 DESIGN REVIEW PLAN

This plan is to assure management that the following requirements are accomplished on schedule during the development and design of the product:

The design is meeting or is expected to meet requirements, including cost, and design objectives are being considered.

Prior designs, service experience, method of analysis and test results have been considered.

Technical deficiencies are promptly identified for timely resolution.

4.2.3 TRADE STUDY PLAN

A number of significant configuration issues requiring design decisions remain unresolved at go-ahead. Most of these issues will require trade studies in some form permitting analysis of alternative approaches and arrival at a balanced decision.

Failure to retain trade study data can result in repeated restudy of the same item when configuration features are questioned at various levels of management. In most cases, the trade study data will validate the approach with little or no additional work. The need for reference to earlier trade studies is particularly critical during the transition from preliminary design to detail design. Therefore, care must be taken to ensure recording and retention of significant trade study data as differentiated from everyday decisions.

4.2.4 CHANGE MANAGEMENT PLAN

Engineering change control and processing prior to detail design release may be accomplished through the use of a design memorandum issued by engineering management to authorize and direct a design project to take action on one or more of the following steps, as appropriate:

Coordinate and process changes to the configuration description document.

Coordinate and process changes to the design requirements, criteria, and objectives document.

Record changes in airplane performance characteristics document.

Identify significant design decisions or changes (e.g., significant changes in materials or process specifications, control actuation rates, or design modifications attributed to design reviews) whether or not recorded technical definition data is affected.

4.3 DESIGN MANAGEMENT

4.3.1 MOCKUP PLAN

This plan defines the ground rules and management/procedural techniques employed to control mockup costs and indicates the general magnitude of the planned mockup program. The plan, which is used only for initial planning and budgeting, must be consistent with the budget allocation. Subsequent planning is reflected in a mockup description document maintained initially by the configuration group.

4.3.2 HARDWARE DESIGN COST CONTROL

Since up to 80% of a program cost is committed before the first detail drawing release, it is necessary to establish procedures to:

Assure development of a low cost design

Establish a format for conducting trade studies

Establish a credible cost targeting estimating, and tracking system

4.3.3 WEIGHT PLAN

This plan describes the weight policies, objectives, procedures, and responsibilities to be followed during the design and fabrication of the product. It defines current weight, objective weight, and target weight. It provides for guidelines to be used in making cost versus weight trade decisions on the program.

4.3.4 DESIGN WORK PACKAGE

This plan defines the procedures necessary to segregate the total hardware product into discrete WBS-oriented design work packages. These work packages will define the hardware, schedule, and critical events, and will establish manhour target and material costs. Their purpose is to provide basic information for the design, development, and manufacturing of the product. Each package will be used as the prime tool for:

Developing the complete component (element design)

Identifying potential product improvements including cost reduction

An up-to-date design description

Visibility of concept to encourage product improvement suggestions from the total Company wealth of innovators not directly concerned with the component work package

Establishing and tracking hardware cost targets

Providing up-to-date design review data

Verification of compliance with design requirements and targets (cost, weight, maintainability, reliability) for each component design approach before detail design layout and drawing preparation manpower buildup

4.3.5 AERODYNAMIC CONFIGURATION/GEOMETRIC DEFINITION/NUMERICAL CONTROL COORDINATION PROCEDURE

The purpose of this procedure is to:

Define the scope and coordinating policy for the loft definition process

Establish the procedure for identifying aerodynamic shapes used in performance/cost trades

Outline the procedure for establishing reference planes that can be used throughout the development, design, and fabrication cycle, thus reducing the need for transposing geometric and NC data as the design and fabrication progresses

Define the application of geometric definition and numerical control (NC) support

4.3.6 ENGINEERING/MANUFACTURING TOOLING COORDINATION PROCEDURE

This procedure is intended to:

Provide a coordinating vehicle between engineering design and tool engineering and assure consideration of tooling requirements early in the design process

Identify critical part surfaces on engineering drawings

Minimize the quantity and complexity of tools required

Assure minimum impact on tools after tool fabrication start due to growth and/or resizing of structural members

Set later manufacturing demand dates for drawing/data release

4.3.7 EXCRESCENCE DRAG CONTROL PLAN

This plan is to define slot, gap, hole, and protrusion allowables to assure consistency in design approach between design groups and to permit the maximum possible allowables for low cost but consistent with minimum high speed performance requirements.

4.3.8 SAFETY PLAN

This plan establishes the program activities required to assess the flight safety of the airplane. The safety assessment establishes the level of confidence such that the contractor is assured that the airplane can be released as safe for flight in accordance with the standards applied on current airplane programs.

4.3.9 PRODUCT ASSURANCE PLAN

Product assurance includes reliability, maintainability, and service support data.

This plan establishes procedures that will assist project design groups in designing an airplane that:

Has a basic design that will allow straightforward engineering design development and evolution into a simple, easily maintained, reliable airplane

Has the reliability and maintainability to meet flight schedules without undue problems and delays in its mission environment

Avoids potential mal-maintenance, hazard-causing potentials ("Murphies") in areas of new design

Avoids requirements for special costly ground support equipment or skills to customer

4.3.10 ENGINE MANAGEMENT PLAN

The purpose of the engine management plan is to monitor and control the engine acquisition, engineering development, installation, and test to ensure that the propulsion system will meet the performance, cost, and schedule requirements of the program.

4.3.11 SPACE CRITICAL AREA MANAGEMENT

Critical areas are those containing a number of critical design elements and systems whose interaction requires careful control to assure proper performance of all systems.

The integration of all systems in congested areas will require design rigor equivalent to the detail design of any other major aircraft subsystem. Particular emphasis will be placed on:

Space allocation and priority to various systems

Routing

Access for inspection and maintenance

Mutual protection of systems from each other

Protection against damage from external means

Precautions against failure progression

4.3.12 STANDARD PARTS, MATERIALS, AND PROCESSES CONTROL PLAN

Instruction and criteria must be provided to designers to ensure that the design of the airplane and its components incorporates adequate protection against corrosion and wear for trouble-free service. Special attention should be given to achieving minimum cost.

4.3.13 CORROSION PREVENTION AND CONTROL PLAN

The purpose of corrosion protection and control plan is to assure that the life, safety, and function of a vehicle does not deteriorate from corrosion. Emphasis should be placed on:

Protective coatings, types, uses, application

Isolation of dissimilar metals

Design guides for proper environmental protection, seals, drainage, etc.

Continuing research for improved coating and platings

Continuing search for corrosion sources and potential sources

4.3.14 LUBRICATION CONTROL PLAN

The purpose of the lubrication control plan is to assure that:

The lubrication method and accessibility requirements are resolved by the design

The types of lubrication fittings are standardized

This information is collected for issuance of consolidated maintenance instructions

4.3.15 NOISE CONTROL PLAN

Airplane interior sound levels are an important consideration in achieving an acceptable airplane. Therefore, it is necessary to provide interior sound levels for the airplane that will demonstrate that the flight crew and passengers will not be subjected to excessive noise levels throughout the flight envelope. It is also important to define the structural noise environment resulting from the engine exhaust upon the wing, flaps, and body so that the structure can be designed to have adequate life.

4.3.16 ELECTRO-MAGNETIC COMPATIBILITY PLAN

The prime objective of the electro-magnetic compatibility (EMC) plan is to ensure that the airplane meets the requirements of customer specifications and current FCC and FAA regulations.

The secondary objective is to accomplish compatibility at minimum program cost and airplane weight.

4.3.17 PURCHASED EQUIPMENT PROCUREMENT CONTROL PLAN

The purpose of this plan is to assure that:

A consistent approach to equipment designation and release for procurement is used by all design groups

The proper equipment support is negotiated through joint Engineering and Materiel efforts as part of the purchase order

Flexibility is maintained to support program cost objectives by:

Avoiding firm selection of hardware until a cost position is established

Identification of potential alternate sources for identical or similar items

4.3.18 LIAISON PLAN

Engineering Liaison activities will focus on:

Assisting manufacturing in the implementation of engineering specification and drawing requirements

Keeping the design project organizations informed of operations activities affecting, or potentially affecting, engineering functions so that problems can be treated with a systematic, planned approach

4.3.19 INVENTIONS AND PATENTS PLAN

The purpose of this plan is to identify, protect, and exploit inventions and other proprietary rights emerging from design and development activities. Early identification to management of new configurations, designs or ideas that may be patentable or may infringe on existing patents is important for the following reasons:

If the idea is indeed a new one, patent proceedings should begin as soon as possible, before others become aware of the idea, so that the company will be free to use the invention on its own products without encumbrance.

Both the inventor and the company may profit monetarily when the patent is marketable outside the company. If the invention is developed while the inventor is working under Government contract funding, the Government has a royalty-free license to use the invention, but non-Government use could still generate royalty income to the inventor and the company.

The patent search will reveal any existing patents. If the designer anticipates using a design that may infringe on an existing patent, the company is in a better position to bargain for a reasonable royalty fee early before the feature becomes "locked in."

4.3.20 SUBCONTRACTOR/ASSOCIATE CONTRACTOR MANAGEMENT PLAN

When a subcontractor or associate contractor is involved it is necessary to develop a management plan to coordinate control and monitor the activities of that facility.

The management plan covers such items and/or activities as: design approval, design decision, release change control, geometry definition, design criteria (material allowables, standards, processes, design methods), weight control, liaison function, interface control, and cost control.

4.4 DRAWING/DATA CONTROL AND RELEASE PLAN

This plan is intended to provide for the most economical preparation and efficient use of engineering drawings and data. The procedures should include:

Preparation instructions

Numbering system (WBS-oriented)

Quantity forecasts

Release

Security

Change identification

4.5 TEST AND ANALYSIS PLAN

The purpose of this plan is to establish ground rules for authorization and control of testing, which is of four types, which are:

Developmental testing (includes wind tunnel and laboratory testing)

Ground testing (includes checkout and verification tests on the full-scale assembled airplane)

Flight testing

Functional testing

4.6 SERVICE SUPPORT PLAN

The purpose of this plan is to establish procedures depicting the company support to the customer. The plan should include:

Training

Technical services

Field service support

Manuals/manual maintenance

Spare parts

5.0 GENERAL-PURPOSE SUPPORT REQUIREMENTS

The design process is supported and guided by the data and direction set forth in this section. The product configuration (sec. 5.1) is controlled specifically by technical definitions (performance and function) and geometry definitions. Data required for the design (technical analysis), such as stress, loads, aerodynamics, weights and material technology, are described in section 5.2. Computer aids to the design process (conceptual design, configuration design and detail design) are shown in section 5.3.

The design intelligence section (sec. 5.4) lists the knowledge or awareness that enables the designer to invent the most efficient design for the state of the art at each point in time.

5.1 PRODUCT CONFIGURATION CONTROL

It is estimated that more than 2/3 of a design engineer's time is used in gathering data to perform the design task. This section describes the categories of the data required. The data is arranged in two categories, a technical description and a physical description of the vehicle. Section 5.1.1 Product Technical Definition, describes typical technical data required by the designer. These include topics such as function, purpose, cost, weight, materials, life, etc. Section 5.1.2, Geometry Definition, describes the physical requirements of the design and how they are defined.

5.1.1 PRODUCT TECHNICAL DEFINITION

A key portion of a total program plan is the product technical definition, because it will be used as a basis for design and for other parts of the program plan, including such items as management, resources, manufacturing, and pricing. Therefore, it is required that certain information be developed and documented prior to a go-ahead and that such information be updated and maintained throughout the production program. The documents must contain sufficient narrative, engineering graphs, drawings, and data to be comprehensible to users. The documents described in the following paragraphs list subjects that are to be considered in connection with each and will ensure that each subject is covered adequately. A typical product technical definition process is shown in figure 3.

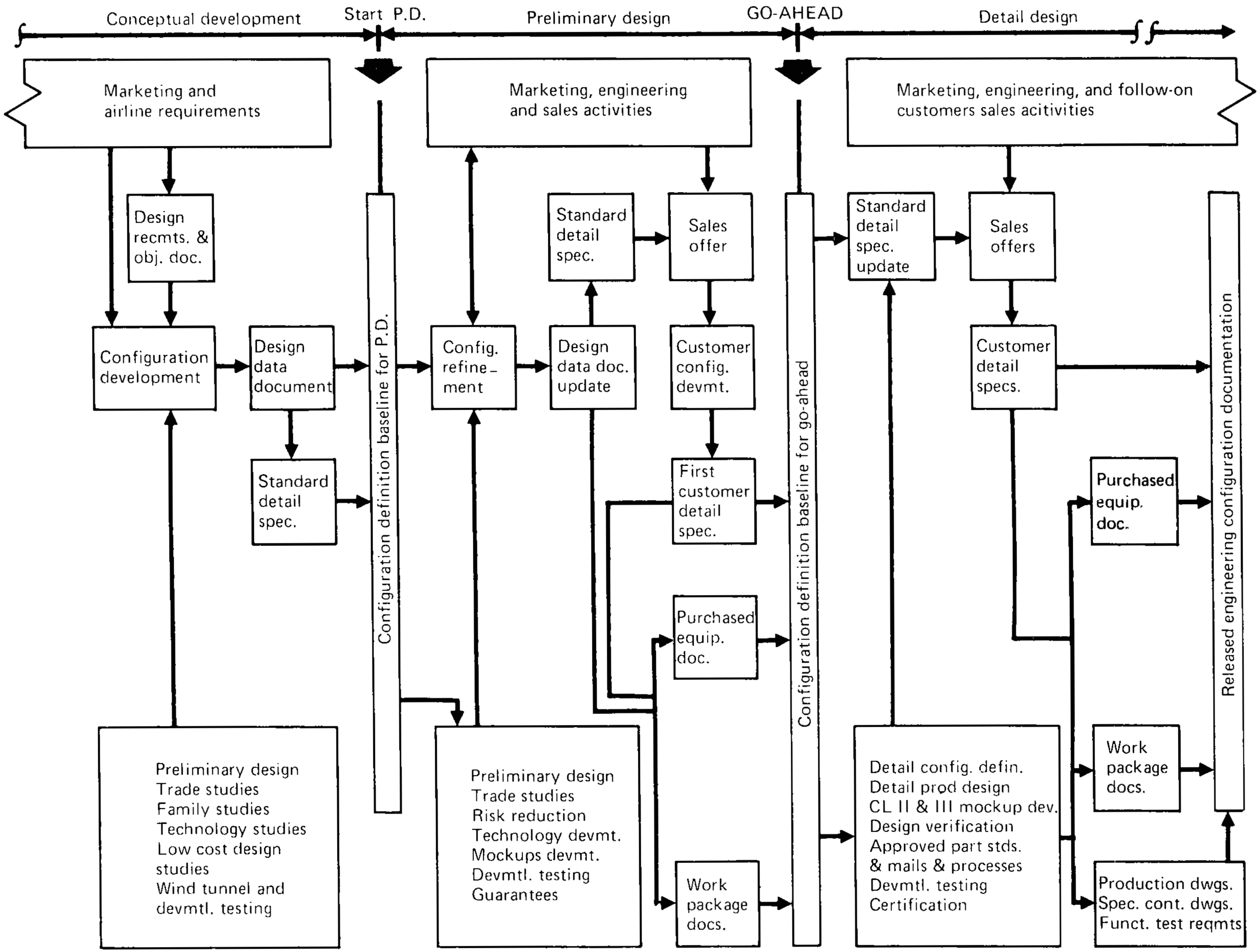


Figure 3.— Product Technical Definition Process

5.1.1.1 Design Requirements and Objectives Document

This document identifies the documented qualitative and quantitative requirements and objectives to be satisfied in the design of the product and its hardware subelements. The design requirements are imposed by the customer, by Governmental regulations, or by company engineering design criteria or standards which should not be substantially exceeded without proper approval. The design objectives represent items for which a greater than minimum acceptability is desired. The designer should strive to achieve this standard to the degree of technical feasibility without compromising achievement of the design requirements and product cost objectives. Design objectives cover all mission and operation requirements; design disciplines; design standards and criteria; and technology, product assurance, producibility, and performance requirements. The subjects to be covered in this document are:

General objectives

Performance

Structures and weights

Payload systems

Cost and economics

General subsystems

Operational requirements:

Airplane Safety	Reliability
Handling Characteristics	Utilization
System Environment	Noise
Maintainability	Airport compatibility

Growth and derivatives

Design Requirements

- General
- Aerodynamics
- Structural
- Systems

5.1.1.2 Configuration Definition Document

The configuration definition represents documentation of the baseline configuration(s) selected by comparative evaluation of alternative designs at the end of the conceptual development phase. It is updated throughout the subsequent design process as necessary to accurately reflect a summary definition of the product. It includes configuration descriptions of the baseline airplane, the system level design requirements and objectives, and the customer mission requirements defined for hardware elements typical of levels 2 or 3 of the work breakdown structure (e.g., overall airplane, airframe, airframe system, propulsion system, payload system). The specific level of detail contained in the "system level" product technical definition for any particular WBS hardware element will depend on the specific nature of the product and the program involved. However, it must be defined in sufficient detail to serve as an adequate foundation for all of the related program planning, cost estimates, risk analyses, data requirements, and resource planning required for authorization of a preliminary design phase program. The subjects to be covered in this document are:

General

Configuration technical definition

Weight and balance

Ground handling characteristics

Structures and materials

Flight deck accommodations

Propulsion, fuel, and accessory drive and starting systems

Fire detection and extinguishing systems

Hydraulic power system

Flight control system

Electrical subsystem

Electronics system

Environmental control system

Passenger and cargo compartment system

Ground support equipment

5.1.1.3 Technical Achievement Status Document

Technical performance measurements are desired to provide status as to how well the program is meeting the technical performance requirements established in the configuration definition document. Technical problems requiring management attention are identified. The subjects to be covered in this document are:

Range at full payload

Payload at design range

Maximum gross weight

Operating weight empty

Take-off distance (max. gross weight)

Take-off nose limits

Initial cruise altitude

Direct operating costs (design range)

Approach noise

Approach speed (max. landing weight)

Landing distance

Dispatch reliability

Fatigue life

Seating capacity

Cargo volume

Speed

Airplane dimensions

C.G. balance

Fuel capacity

Engine performance

Fuselage pressurization

5.1.1.4 Standard Model Specification Document

The standard model specification (commercial aircraft) defines a basic configuration for pricing and sales offers. It is the basis for development of each customer's detail specification. Production design activities include both those required to develop the standard configuration of the airplane and those needed to develop customer variations negotiated to comprise each customer's configuration. These activities overlap and affect each other as commitments are made to new customers for unique features at the same time as the first configuration is developed and certified. Subject matter in this document includes:

Airplane general description
General requirements
Characteristics
Structure
Power plant
Instrument and control panels
Surface control system
Hydraulic system
Electrical system
Radio and electronics
Furnishings
Cabin pressurization and air-conditioning
Ice elimination and defogging
Special equipment
Standard parts and interchangeability
Maintenance and inspection

5.1.1.5 Test and Test Data Document

The purpose of this document is to assure that all program testing to be conducted and all resources expended are in proper balance in terms of test requirements, schedule requirements, program risk evaluations, and allocated budgets. It is the control vehicle to assure compliance with product technical requirements. The subjects include but need not be limited to:

Program Summary

Pre-go-ahead testing
Research programs
Development testing

Qualification
Certification

Test requirements

Analysis
Customer
Certification
Boeing technology staff
Boeing design qualification

One-page test plans

Aerodynamic tests
Low-speed performance
High-speed performance
Buffet boundary; stall characteristics
Aerolastic effects
Longitudinal control; hinge moments
Lateral/directional stability
Lateral/directional control; hinge moments
Flutter
Pressure distribution and loads
Inlet development
Exhaust/thrust reverser development
Fuel vent and dump systems development
Engine performance

5.1.1.6 Mission Requirements Document

Mission requirements are the route that an airplane must fly equated to nautical miles and the rules that govern how the route shall be flown. These include rules for ground and air maneuvers, field length and altitudes, airport and cruise temperatures, fuel reserves, and operating allowances for route winds. Total mission requirements represent the aggregate of these requirements for the total route structure of an airline and the aggregate of all airlines and route structures considered in the market analysis and/or sales forecast. Document content includes:

Market

Factors influencing market potential

Traffic characteristics of flights between city pairs

Physical characteristics of airports

Competition factors

- Competition among manufacturers
- Competition among the various airlines
- Competition between air travel and surface travel
- Government regulations and restrictions - national/international

Strategies

- Major characteristics
- Timing of product
- Airlines economics
- Commonality concept

Technological consideration

- Present state of the art
- Anticipated advance in state of the art
- Present and anticipated Government requirements

Design envelope

- Range
- Payload
- Operating costs
- Other limitations
- Tolerances on parameters and effects of variation from goals on anticipated sales

5.1.2 GEOMETRIC DEFINITION

The geometric definition for IPAD is essentially a master mathematical definition developed for both the external surfaces and the interior components. It is the standard geometry definition system to satisfy needs of all functional groups from concept through engineering design and through the manufacturing of product. The basic requirements for the planning and development of such a common geometric system is given in the next paragraph.

5.1.2.1 Basic Requirements

The geometric system is a standard system that is commonly recognized and used and whose basic coordinate system can be transformed and readily related to an auxiliary coordinate system or vice versa.

The geometric system uses a single, right-hand Cartesian reference coordinate system established by the project design engineering. The axis is identified as X, Y, Z. The functional label and the positive direction of these axes are shown in figure 4.

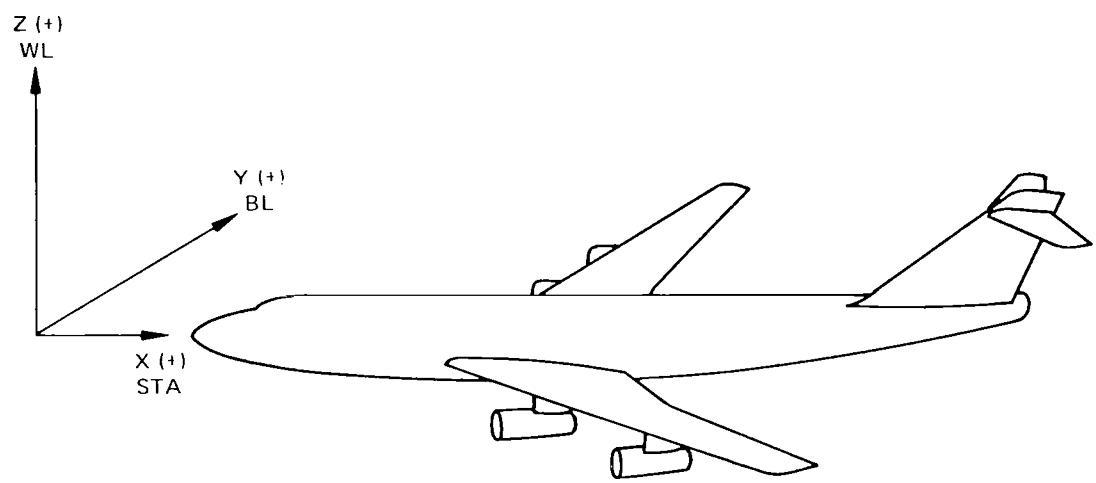


Figure 4.— Reference Coordinate System

The coordinate origin of the system basically uses the body coordinate system established by design engineering. The default values (arbitrary value providing for vehicle growth) of the system are:

Coordinate	Functional Label	Axis Direction	Reference	Default Value
X	Station	Longitudinal	Sta 0	200 in. fwd. of nose
Y	Buttock Line	Horizontal	BL 0	Airplane centerline
Z	Water Line	Vertical	WL 0	200 in. below (subsonic) 400 in. below (supersonic)

The geometric system uses a unique and plain English language and is operable in an interactive, conversational mode. It allows the geometric surfaces to be retrieved, modified, or extracted on display. The geometric system is able to describe all real external and internal airframe surfaces in two or more selected levels of accuracy chosen by the engineers to best suit their needs.

The geometric system is capable of interfacing the required engineering processes in an aircraft design system to determine the kinematic motion or elastic deformation of the defined geometries. The following are the examples:

Wing jig geometry to flight geometry

Flap stowed position to extended position

Landing gear retracted position to extended position

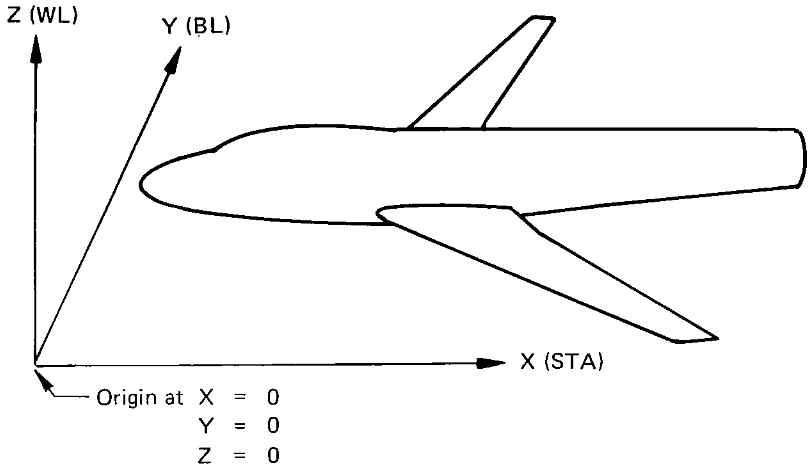
The input data uses a simple format, such as point, line, curve, angle degree, etc., to produce a unique mathematic definition.

The geometric definitions defined through this system are controlled and stored in the data base and can be accessed and processed through a release mechanism under an exclusively established data management system. The stored data can be released in a form that is required by manufacturing for their ready usage.

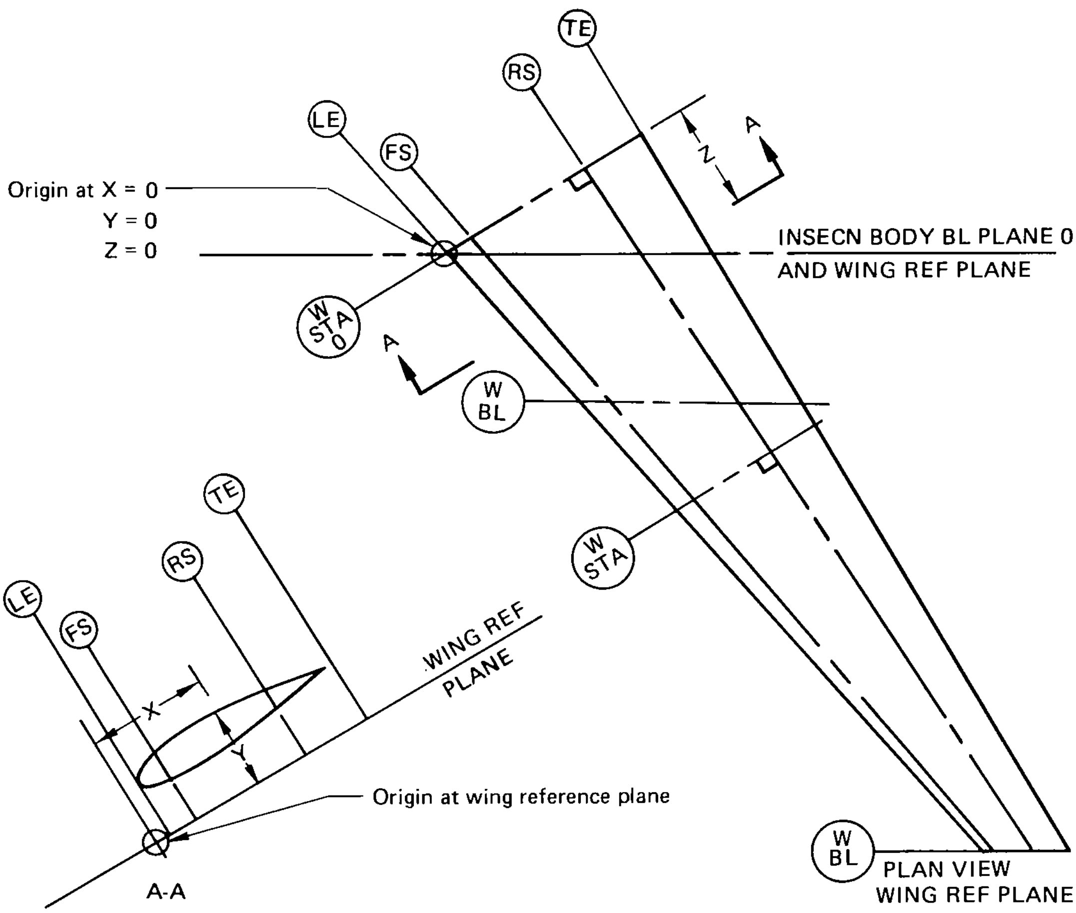
The coordinate system for each main component of the aircraft is arranged to best suit the design and manufacture of that area. The body coordinate system generally uses the established reference coordinate system.

The wing coordinate system is developed using the rear spar plane and wing chord plane intersection as a base, wing stations being normal to the rear spar. Wing station 0 is located at the intersection of the leading edge and body buttock plane 0. Body-wing coordinate transformation formulas are developed to facilitate transition between the two.

A coordinate system for the wing leading edge and trailing edge areas is selected for convenience and transformation formulas are used for coordination between these systems and the wing coordinate system. Empennage coordinates (fin and stabilizer) are arranged in the same way as wing coordinates. The coordinate systems for body and wing are shown in figure 5.



(a) Body Coordinate System



(b) Wing Coordinate System

Figure 5.— Component Reference Coordinate Systems

5.1.2.2 Conceptual Design Geometry Definition

The airplane geometry is defined in three-dimensional surfaces to generate three-view drawings; size body, wing, empennage, and engines; and locate wing, landing gear, and empennage. All of this must be accomplished to a detail level that is commensurable to the broader accuracy used at the conceptual design stage for the number of iterations involved and the economical operation of the computer.

An example of conceptual design geometry definition is shown in table 1.

Table 1.—General Geometry Definition

<table>
<tr><td rowspan="9">INPUT
DATA</td><td rowspan="4">BODY</td><td colspan="2">CENTERLINE DIAGRAM</td></tr>
<tr><td colspan="2">CROWN</td></tr>
<tr><td colspan="2">KEEL</td></tr>
<tr><td colspan="2">MAX. HALFBREADTH CONTOUR</td></tr>
<tr><td rowspan="5">WING</td><td colspan="2">PLANFORM</td></tr>
<tr><td rowspan="4">CROSS-
SECTION</td><td>MAX. THICKNESS</td></tr>
<tr><td>LOCATION,
MAX. THICKNESS</td></tr>
<tr><td>LEADING EDGE RADIUS</td></tr>
<tr><td>TRAIL. EDGE
CLOSURE ANGLE</td></tr>
<tr><td rowspan="4">INPUT
FORMS</td><td colspan="3">LINE – USING POINTS</td></tr>
<tr><td colspan="3">CURVE (E.G., CUBIC, QUINTIC) – USING POINTS</td></tr>
<tr><td colspan="3">POINT OF CENTER</td></tr>
<tr><td colspan="3">RADIUS</td></tr>
<tr><td rowspan="2">OUTPUT
DATA</td><td colspan="3">CENTERLINE DIAGRAM</td></tr>
<tr><td colspan="3">OUTSIDE MOLD LINE AND PLANFORM DATA</td></tr>
<tr><td rowspan="3">OUTPUT
FORMS</td><td colspan="3">MATHEMATICAL PRINTOUT – SURFACE DEFINITION</td></tr>
<tr><td colspan="3">ON-LINE/OFF-LINE MEDIUM ACCURACY
HARD COPY DRAWINGS</td></tr>
<tr><td colspan="3">OFF-LINE HIGH-ACCURACY HARD COPY
DRAWINGS</td></tr>
</table>

5.1.2.3 Preliminary Design Geometry Definition

During preliminary design the airplane geometry is refined further in several progressive steps until the mathematical geometry is completely defined in three dimensions and permits geometry extractions at any location with accuracy required for detail design and manufacturing processes that follow.

The wing shape is now completely defined as to planform, camber, twist, thickness, and airfoil shape. The wing components (structure: ribs and spars; control surfaces: flaps, aileron, spoilers, and leading edge devices) are fully determined. The body is defined from nose to tail including interfaces and fairings to windshield, wing, and empennage. The empennage and its components, propulsion system, inlets, cowlings, and struts are all completely defined geometrically.

An example of preliminary design geometry definition is shown in table 2.

Table 2.—Preliminary Design Geometry Definition

INPUT DATA	BODY	LONGITUDINAL CONTROL CURVES
		DEFINING MEMBERS
	WING	PLANFORM
		AIRFOIL
		CAMBER/THICKNESS
		TWIST
INPUT FORMS	LINE – USING POINTS	
	CURVE (E.G., CUBIC, QUINTIC) – USING POINTS	
	POINT OF CENTER	
	RADIUS	
OUTPUT DATA	FULLY DEFINED EXTERIOR SURFACE WITH TRANSFORMATION EQUATIONS TO RELATE TO AUXILIARY COORD. SYSTEMS	
	STRUCTURAL DEFINITION DRAWINGS, DEFINING SHAPE OF MAJOR STRUCTURAL COMPONENTS	
	REFINED CENTERLINE DIAGRAM	
	ENGINE NACELLE CONTROL POINTS	
OUTPUT FORMS	MATHEMATICAL PRINTOUT – SURFACE DEFINITION	
	ON-LINE/OFF-LINE MEDIUM-ACCURACY HARDCOPY DRAWINGS	
	OFF-LINE HIGH-ACCURACY HARDCOPY DRAWINGS	
	HARDCOPY/SCREEN DISPLAY – EXTRACTION OF PREDEFINED SURFACES	

5.1.2.4 Detail Design Geometry Definition

The final mathematical three-dimensional geometry definition is extracted and mathematically dissected to produce external and internal contour for each detail part, assembly, or installation.

An example of detail design geometry definition is shown in table 3.

Table 3.—Detail Design Geometry Definition

INPUT DATA	CONTROL CURVES
	DEFINING MEMBERS
INPUT FORMS	LINE
	CURVE (E.G., CONE, CUBIC, QUINTIC, ETC.)
	POINT OF CENTER
	RADIUS
OUTPUT DATA	LABELED SECTION – CUT DEFINITIONS
	PART GEOMETRY (DATA SETS) – INSTALLATION, ASSEMBLIES, AND DETAIL PARTS
	3-VIEW DEFINITION OF VEHICLE INTERIORS FOR SYSTEM DEVELOPMENT/INSTALLATION
OUTPUT FORMS	MATHEMATICAL PRINTOUT – SURFACE DEFINITION
	ON-LINE/OFF-LINE MED. - ACCURACY HARDCOPY DRAWINGS – SURFACE EXTRACTION PLANE
	SCREEN DISPLAY – EXTRACTION OF PREDEFINED SURFACES

5.2 TECHNICAL ANALYSIS

This section deals with the information and activities of the staffs in developing the principal information required for the design process.

Section 6.0 shows the design activity flow from the time design commences to the production and follow-up phases of the design process.

The technical staff information interfaces shown in figure 6 do not indicate the level of activity associated with the design timeframe but indicate the kinds of information received and produced by the technical staff discipline. The weights staff data shown is an exception and is presented in greater detail to illustrate the increased data support needs as design progresses.

The IPAD development schedule and budget do not permit all disciplines to have levels of presentation equivalent to that of the weights staff. In the case of systems, no detailed information is presented.

The disciplines addressed are weights, aerodynamics, flight control, propulsion, noise, and structures. Figure 6 is an overview of the data communication between the staff groups.

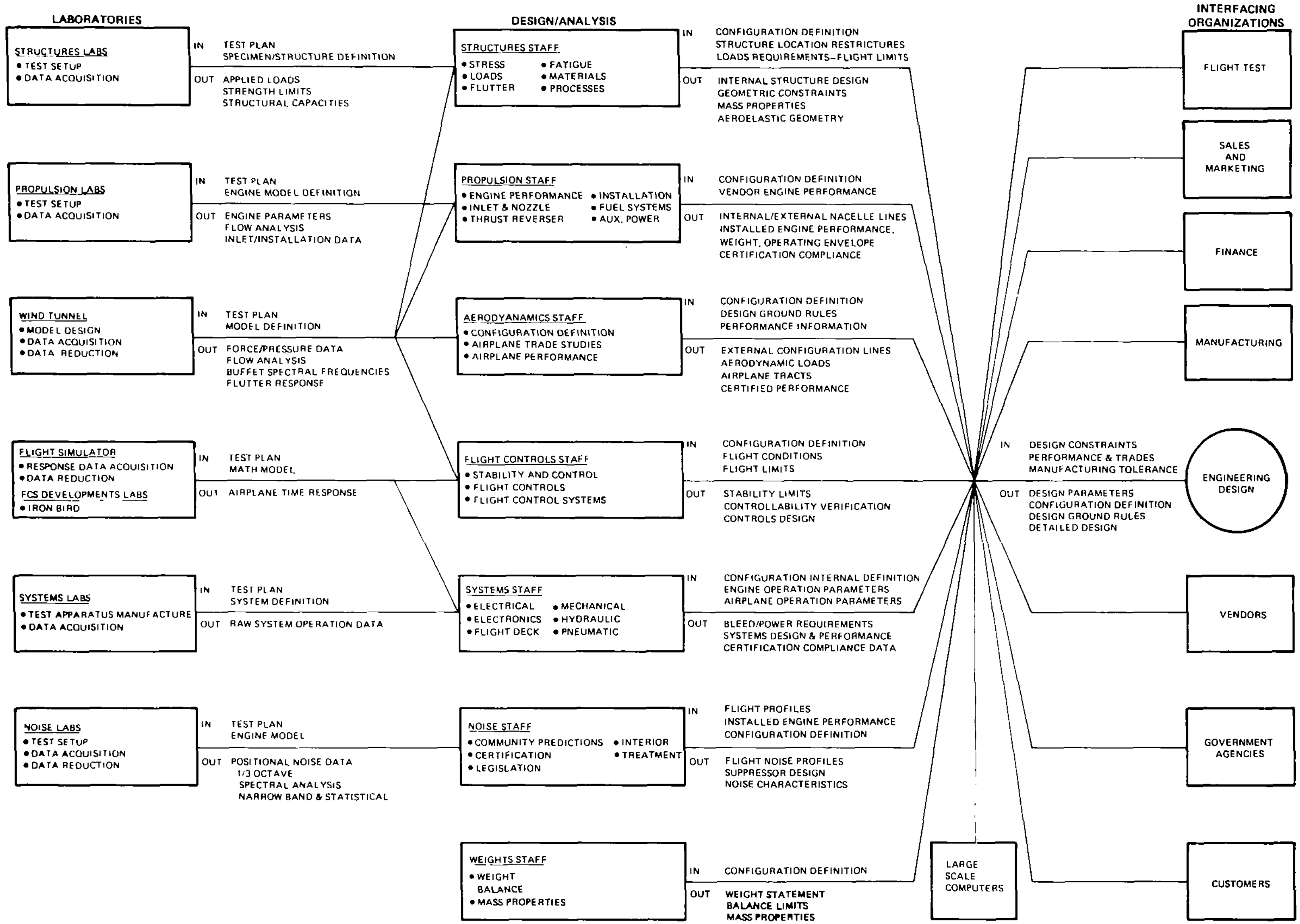
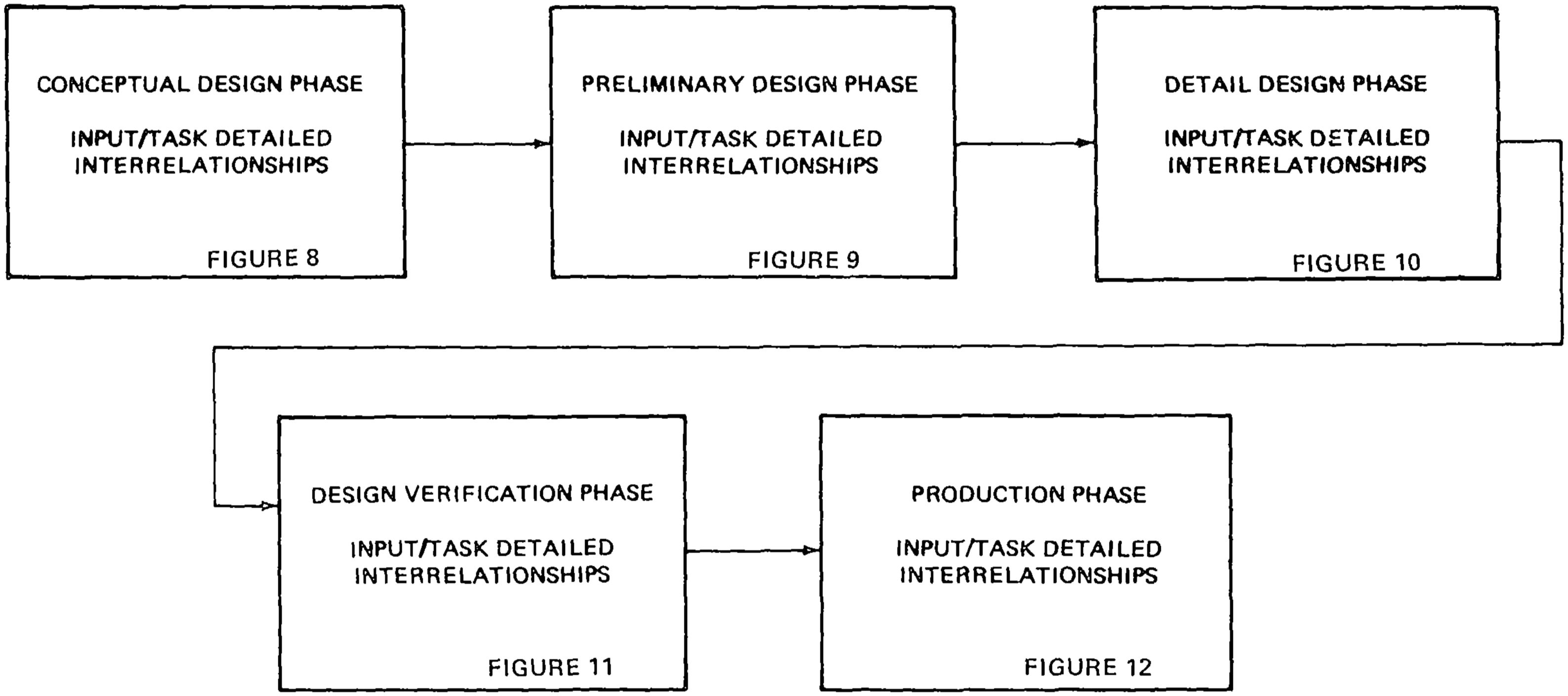


Figure 6.— Primary Technology Staff Communications



SEE ADDENDA A-1
FOR INDEPTH OVERVIEW

Figure 7.— Chart Relationship; Weight Technology - Staff Design Cycle Overview

5.2.1 WEIGHTS TECHNOLOGY

This section identifies the tasks performed by the weights technology staff during a typical airplane design cycle.

Figure 6 is a brief overview of the task phases involved. Addenda A-1 provides an in-depth overview of the complete design cycle, showing general activities in the design process phases from conceptual design through preliminary design, detail design, design verification, and production.

Design phases are pictured in figures 8 through 12, each phase depicted on its own overview chart with a description of the activities.

5.2.1.1 Conceptual Design

The conceptual design phase of the weight staff activities contains two distinct design areas or levels: design mission selection and configuration sizing. Both of these tasks are invoked in arriving at a design concept. Figure 7, weights technology conceptual design overview, illustrates the data flow. The chart shows the input data, its source, the weights staff process, and output and the recipient of the data. The following lists the weights staff output and processes:

Class I Weight and Balance Estimates--Estimate preliminary weight and balance from statistical and semistatistical equations using general parameteric inputs such as gross weight, number of engines, wing area, aspect ratio, fuselage wetted area, fuel capacity, number of passengers, etc. (Supporting computer program: ORGY)

Location and Loadability Studies--From Class I weight and balance estimates, determine the wing, gear, and engine locations; fuel and payload distribution; and tail size required for airplane stability and control through center of gravity operational limits. Establish and evaluate the fuel, passenger, and cargo loading requirements, procedures, schedules, and flexibility of study airplane configurations. (Supporting computer programs: ORGY, SPUD, TEW073)

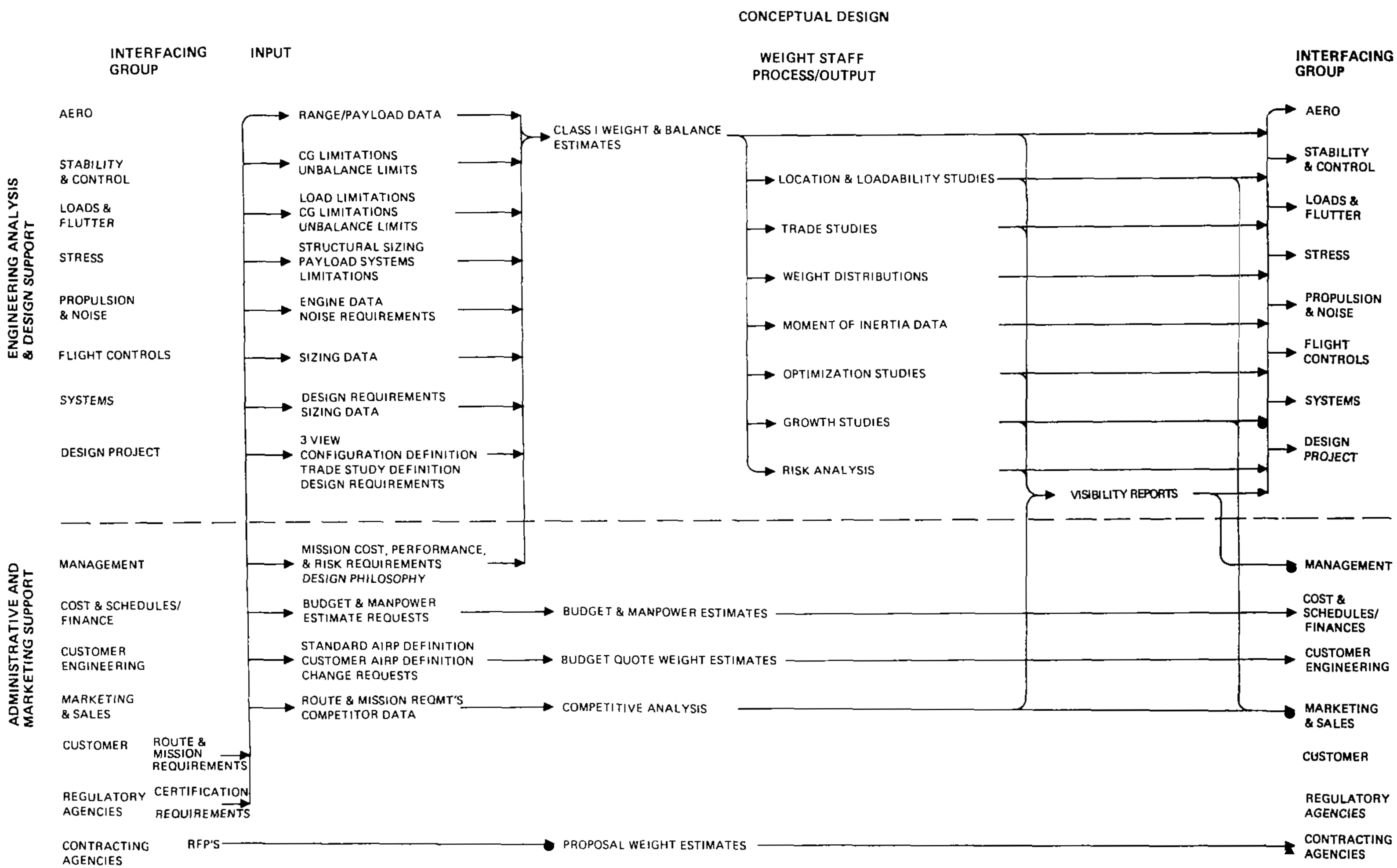


Figure 8.—Weight Technology—Concept Design Phase

Trade Studies--Evaluate the weight and balance effects of configuration level trade studies which define alternate design concepts satisfying the same design requirements. (Supporting computer program: ORGY)

Weight Distributions--Provide vehicle, payload, and fuel distributions for load analysis, flutter analysis, and stability and control analysis. (Supporting computer program; TEW053)

Moment of Inertia Data--Provide moment of inertia data of the airplane about its axes of rotation for sizing and locating control surfaces, and for flutter analysis. (Supporting computer programs: TEW053, SCOWL, ATLAS, TW28)

Optimization Studies--Evaluate the weight and balance effects of refinements to a given design concept which results in improved airplane weight, cost, or performance. (Supporting computer program: ORGY)

Growth Studies--Determine operational empty weight changes associated with configuration gross weight increases. (Supporting computer program: ORGY)

Risk Analyses--Prepare quantitative assessments of the probability of meeting airplane weight loads by analyzing the configuration definition, the potential weight impact of unresolved design/analysis problems, availability of planned new technology items, and probable effect of weight and cost reduction programs.

Visibility Reports--Prepare summary reports which present the results of weight analyses and studies for management decision and project and staff utilization. (Supporting computer programs: SWRS, WEST)

Budget and Manpower Estimates--Estimate weight staff budget and manpower requirements based on anticipated total program manpower and schedule.

Budget Quote Weight Estimates--Estimate weight and balance effect of customer-requested changes for budget quotes.

Competitive Analyses--Prepare weight estimates of competitor aircraft and comparisons of Boeing/Competitor aircraft for performance evaluation, marketing analysis, and sales support. (Supported by all programs)

Proposal Weight Estimates--Prepare weight estimates in support of new business bids in response to requests for proposals from contracting agencies. (Supported by all programs)

5.2.1.2 Preliminary Design

The preliminary design phase of the weights activities staff also contains two levels of design activity: design refinement and design verification. Both of these tasks make up the preliminaries design activity. Figure 9 illustrates the data flow. The chart shows the input data, its source, the stress staff process and output, and the recipient of the output data.

PRELIMINARY DESIGN

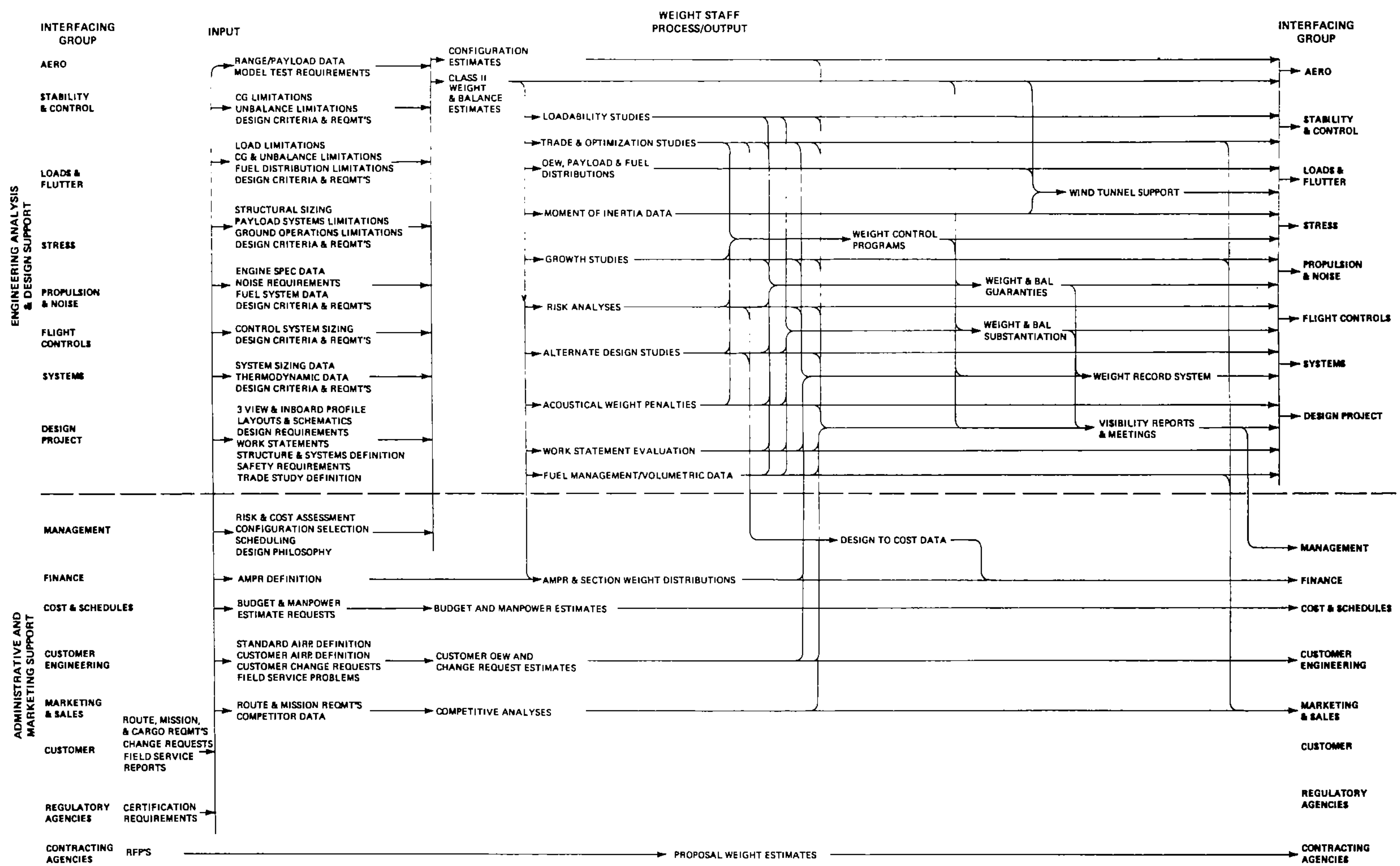


Figure 9.—Weight Technology—Preliminary Design Phase

The following lists the weights staff output and processes used during preliminary design:

Configuration Estimates--Continue Class I weight and balance estimates of alternate study configurations. (Supporting computer program: ORGY)

Class II Weight and Balance Estimates--Estimate airplane weight and balance from analytical equations using geometric, system sizing, and structural sizing preliminary design parameters. (Supporting computer programs: ORACLE, LEMBO, GEARS, PROFIX, AESOP)

Loadability Study--Establish and evaluate the fuel, passenger, and cargo loading requirements, procedures, schedules, and flexibility for the selected configuration. (Supporting computer programs: FUELPD, TEW053, TEW073, SPUD)

Trade and Optimization Studies--Evaluate the weight and balance effects of subsystem level trade studies which define alternate design concepts satisfying the same design requirements. Evaluate the weight and balance effects of refinements to a given design concept which results in improved airplane weight, cost, or performance. (Supporting computer programs: ORACLE, LEMBO, GEARS, PROFIX, AESOP)

OEW, Payload, and Fuel Distributions--Provide vehicle, payload, and fuel distributions for load analysis, flutter analysis, and stability and control analysis. (Supporting computer program: TEW053)

Wind Tunnel Support--Provide scaled mass property data and calculate and verify model section weights and balance for weight, C.G., and inertia simulation.

Moment of Inertia Data--Provide moment of inertia data of the airplane about its axis of rotation and sizing and locating control surfaces, and for flutter analysis. (Supporting computer programs: TEW053, SCOWL, ATLAS, TW28)

Weight Control Programs--Initiate the guidelines and procedures required to monitor and change the design to limit or reduce the weight growth which occurs with increasing design definition and problem resolution.

Growth Studies--Continue determination of operational empty weight changes associated with configuration gross weight increases. (Supporting computer program: ORGY)

Weight and Balance Guarantees--From current weight estimates, risk analyses, and weight reduction potential, establish the nominal specification and maximum guarantee weight and balance of the configuration for customer sales negotiations.

Risk Analyses--Continue quantitative assessments of the probability of meeting airplane weight goals by analyzing the configuration definition, potential weight impact of unresolved design/analysis problems, availability of planned new technology items, and probable effect of weight and cost reduction programs.

Weight and Balance Substantiation--Verify Class I weight and balance estimates as design details are established by calculating and documenting detailed weights from layouts, schematics, block diagrams, system descriptions, comparison to existing airplanes, etc.

Alternate Design Studies--Initiate and evaluate alternate solutions to the proposed design which result in improved weight and/or balance performance.

Weight Record System--Enter detailed data into the weight staff data base for weight documentation, tracking, and change history. (Supporting computer program: SWRS)

Acoustical Weight Penalties--Establish and evaluate both usual and special requirements for acoustical insulating material required for passenger comfort.

Visibility Reports and Meetings--Prepare summary reports and conduct review meetings to present OEW estimates, change histories, weight trends, and weight analyses for management decision and project and staff utilization. (Supporting computer program: SWRS)

Work Statement Evaluation--Evaluate work statement definitions to substantiate weight estimates of the initial design or changes to the design.

Fuel Management/Volumetric Data--Integrate fuel management limitations and define tank ends and fuel management procedures. Calculate fuel volumes for panel loading and establishment of fuel management procedures. (Supporting computer programs: FUELPD, TEW053, SCOWL)

Design to Cost Data--Provide weight analyses of design-to-cost trade data.

AMPR and Section Weight Distributions--Provide weight distributions by airplane manufacturer's planning report (AMPR) definition and by airplane section for cost estimating. (Supporting computer program: SRWS)

Budget and Manpower Estimates--Estimate weight staff budget and manpower requirements based on anticipated total program manpower and schedule.

Customer OEW and Change Request Estimates--Estimate weight and balance of specific customer configurations and customer requested changes.

Competitive Analyses--Prepare weight estimates of competitor aircraft and comparisons of company/competitor aircraft for performance evaluation, marketing analysis, and sales support. (Supported by all programs)

Proposal Weight Estimates--Prepare weight estimates in support of new business bids in response to requests for proposals from contracting agencies. (Supported by all programs)

5.2.1.3 Detail Design

The detail design phase of the weights staff activities is one of data refinement and growth production since the detail design is in process with (presumed) final data. Figure 10 illustrates the data flow. The chart shows the input data, its source, the weight staff processes and output, and the recipient of the data.

Figure 10 lists the weights staff output and processes during the detail design.

DETAIL DESIGN

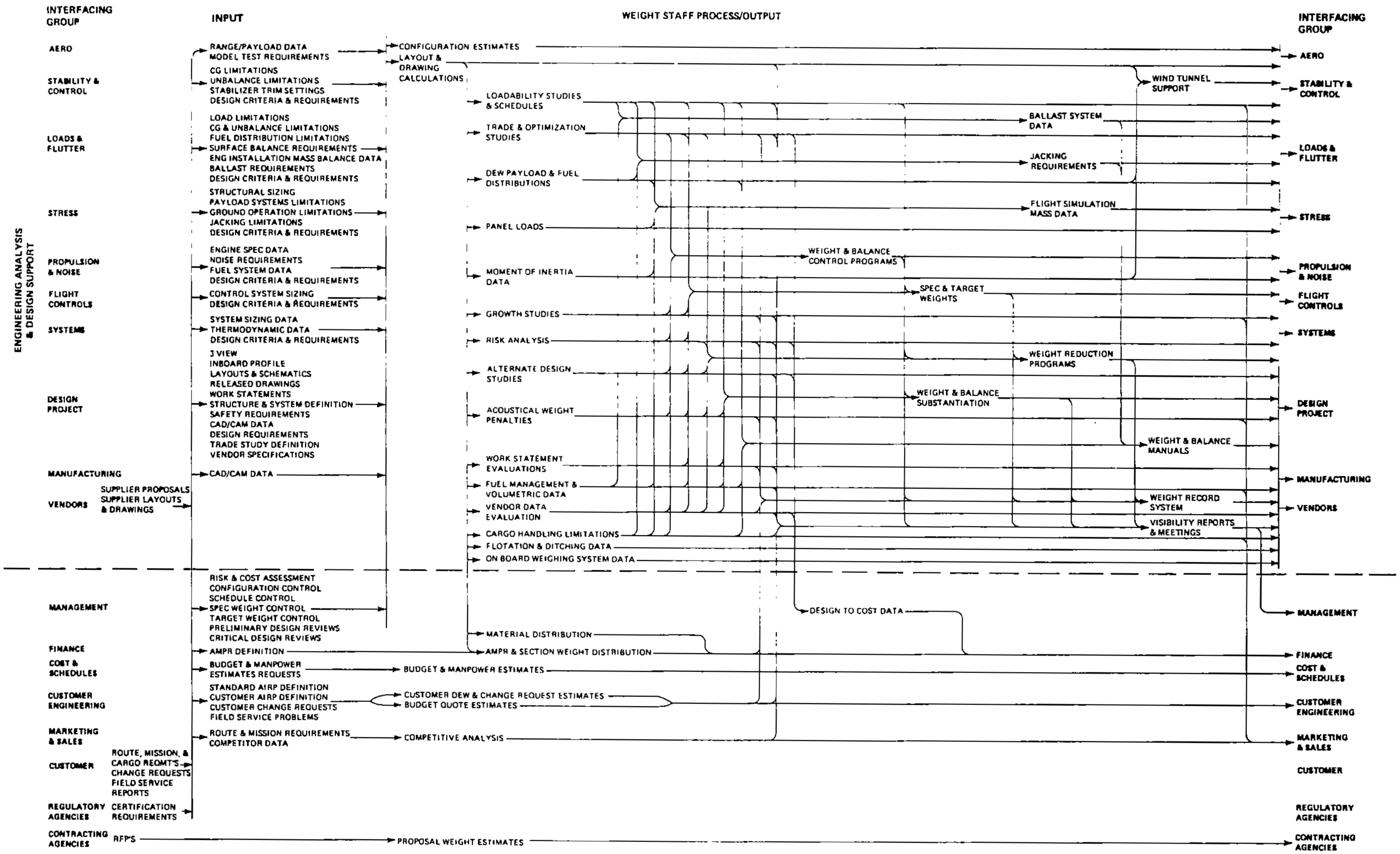


Figure 10.—Weight Technology—Detail Design Phase

Configuration Estimates--Continue Class I weight and balance estimates of alternate study configurations. (Supporting computer program: ORGY)

Layout and Drawing Weight and Balance Calculations--Determine airplane weight and balance by calculating structure and system detail parts weight and balance from layouts, schematics, block diagrams, and released drawings.

Wind Tunnel Support--Provide scaled mass property data and calculate and verify model section weights and balance for weight, c.g., and inertia simulation.

Loadability Studies and Schedules--Establish fuel, passenger, and cargo loading requirements and evaluate loading flexibility. Prepare loading schedules. (Supporting computer programs: FUELPD, TEW053, TEW073, SPUD)

Ballast System Data--Establish flight test airplane ballast requirements.

Trade and Optimization Studies--Evaluate the weight and balance effects of subsystem and component level trade studies which define alternate design concepts satisfying the same design requirements. Evaluate the weight and balance effects of refinements to a given design concept which results in improved airplane weight, cost, or performance. (Supporting computer programs: ORACLE, LEMBO, GEARS, PROFIX, AESOP)

Jacking Requirements--Analyze operational and jacking conditions to establish jacking requirements and limitations.

OEW, Payload, and Fuel Distributions--Provide vehicle, payload, and fuel distributions for load, flutter, and stability and control analyses. (Supporting computer program: TEW053)

Flight Simulation Mass Data--Provide airplane mass properties characteristics for flight simulator development. (Supporting computer programs: TW28, TEW053)

Panel Loads--Provide vehicle and payload weight distribution by panels for load and flutter analyses. (Supporting computer programs: MASS, TEW053, SCOWL, ATLAS)

Weight Control Programs--Monitor and evaluate the design and identify the changes required to limit or reduce the weight growth which occurs with increasing design definition and problem resolution.

Moment of Inertia Data--Provide moment of inertia data of the airplane about its axis of rotation for sizing and locating control surfaces, and for flutter analysis (Supporting computer programs: TEW053, SCOWL, ATLAS, TW28)

Specification and Target Weights--From current weight estimates, risk analyses, and weight reduction potential, establish the nominal spec and maximum guarantee weight and balance of the configuration for customer sales negotiations. Establish the design target weight required to ensure that the specification weight is achieved.

Growth Studies--Continue determination of operational empty weight changes associated with configuration gross weight increases. (Supporting computer program: ORGY)

Risk Analyses--Continue quantitative assessments of the probability of meeting airplane weight goals by analyzing the configuration definition, potential weight impact of unresolved design/analysis problems, availability of planned new technology items, and the probable effect of weight and cost reduction programs.

Weight Reduction Programs--Establish guidelines and procedures for special program-wide weight reduction programs. Develop weight reduction proposals and evaluate weight reduction proposals from other design and staff organizations.

Alternate Design Studies--Initiate and evaluate alternate solutions to the proposed design which result in improved weight and/or balance performance.

Weight and Balance Substantiations--Verify layout weight calculations as design details are finalized by calculating and documenting weights of released drawings.

Acoustical Weight Penalties--Establish and evaluate both usual and special requirements for acoustical insulating material required for passenger comfort.

Weight and Balance Manuals--Begin preparation of customer specific fuel, passenger and cargo loading requirements, data, and schedules for customer weight and balance manuals, per ATA Spec. 100. (Supporting computer program: TW47)

Work Statement Evaluations--Evaluate work statement definitions to substantiate weight estimates of the initial design or changes to the design.

Fuel Management/Volumetric Data--Integrate fuel management limitations and define tank ends and fuel management procedures. Calculate fuel volumes for panel loading and for establishment of fuel management procedures. (Supporting computer programs: FUELPD, TEW053, SCOWL)

Weight Record System--Enter detailed data into the weight staff data base for weight documentation, tracking, and change history. (Supporting computer program: SWRS)

Vendor Data Evaluations--Establish specification weights for vendor supplied parts. Evaluate and rate vendor proposal weight data. Monitor vendor weight performance and establish vendor weight control programs where required.

Visibility Reports and Meetings--Prepare summary reports and conduct review meetings to present OEW estimates, change histories, weight trends, and weight analyses for management decision and project and staff utilization. (Supporting computer program: SWRS)

Cargo Handling Limitations--Identify cargo handling limitations to ensure compliance with contract requirements.

Flotation and Ditching Data--Analyze flotation and ditching characteristics of the configuration (structural integrity, flotation attitude, flotation time, etc.) to show compliance with FAR 25. (Supporting computer program: TW63)

Onboard Weighing - System Data--Provide airplane weight and balance characteristics and analytical support for onboard weighing system design.

Design to Cost Data--Provide weight analyses of design-to-cost trade data.

Material Distribution--Provide distribution of airplane structural weight by type of material for cost estimating.

AMPR and Section Weight Distributions--Provide weight distributions by airplane manufacturer's planning report (AMPR) definition and by airplane section for cost estimating. (Supporting computer program: SRWS)

Budget and Manpower Estimates--Estimate weight staff budget and manpower requirements based on anticipated total program manpower and schedule.

Budget Quote Estimates--Calculate weight and balance effect of customer-requested changes for budget quotes.

Customer OEW and Change Request Estimates--Calculate weight and balance of specific customer configurations and customer-requested changes.

Competitive Analyses--Prepare weight estimates of competitor aircraft and comparisons of company/competitor aircraft for performance evaluation, marketing analysis, and sales support. (Supported by all programs)

Proposal Weight Estimates--Prepare weight estimates in support of new business bids in response to requests for proposals from contracting agencies. (Supported by all programs)

DESIGN VERIFICATION

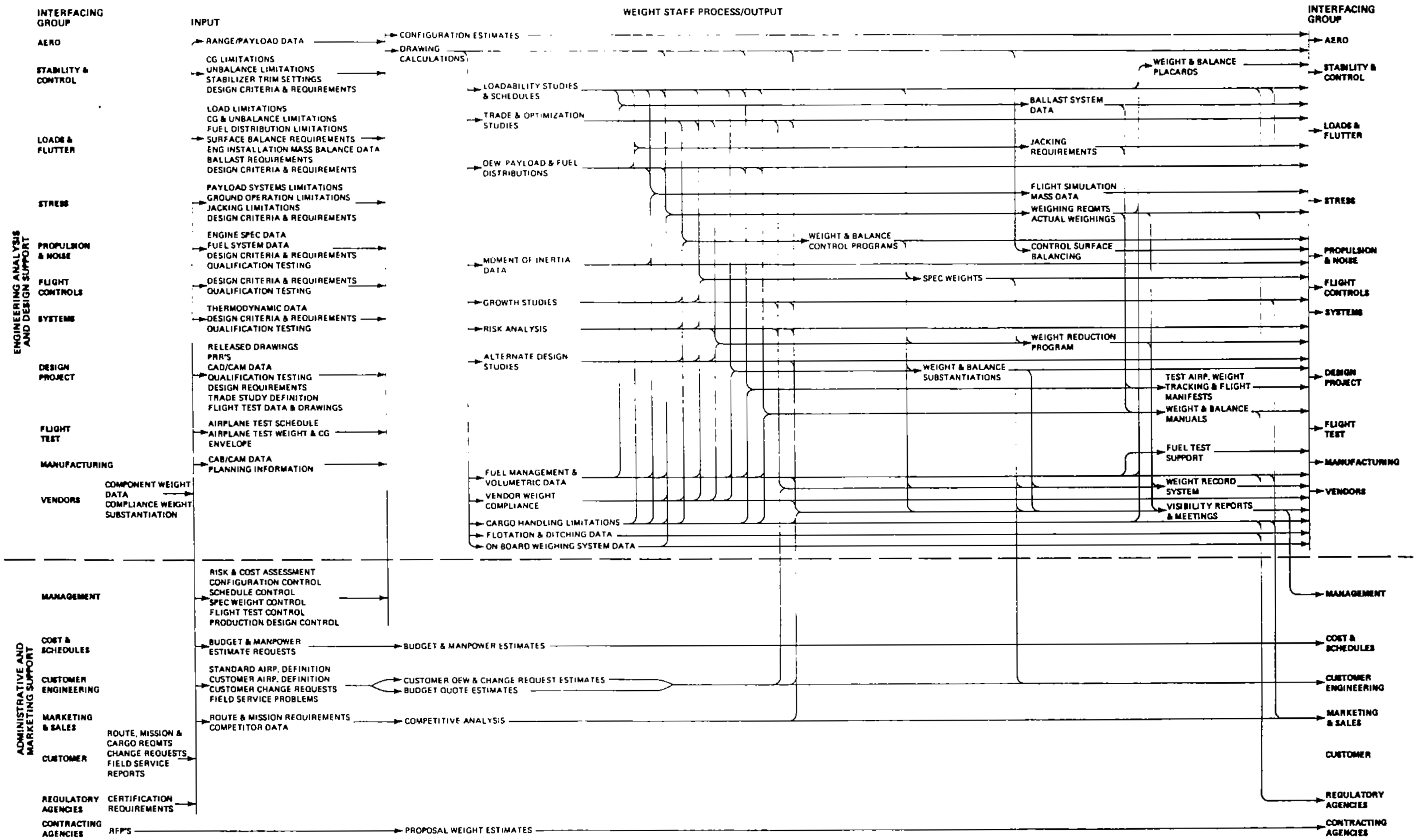


Figure 11.—Weight Technology—Design Verification Phase

5.2.1.4 Design Verification

The design verification phase of the weights staff activities begins as the detail design is released for production. Figure 11 illustrates the data, data sources, weights staff processes, output data, and data recipients.

The following lists the weights staff output and processes used at design verification:

Configuration Estimates--Continue Class I weight and balance estimates of alternate study configurations. (Supporting computer program: ORGY)

Drawing Weight and Balance Calculations--Determine airplane weight and balance by calculating structure and system detail parts weight-and-balance from released drawings.

Weight and Balance Placards--Analyze flight test airplane placard requirements and establish placard limits.

Loadability Studies and Schedules--Establish fuel, passenger, and cargo loading requirements of customer configurations and evaluate loading flexibility. Prepare loading schedules. (Supporting computer programs: FUELPD, TEW053, SPUD)

Ballast System Data--Establish flight test airplane ballast requirements and provide ballast system design support.

Trade and Optimization Studies--Continue evaluation of the weight and balance effects of subsystem and component level trade studies which define alternate design concepts satisfying the same design requirements and evaluation of the weight-and-balance effects of refinements to a given design concept which results in improved airplane weights, cost, or performance. (Supporting computer programs: ORACLE, LEMBO, FEARS, PROFIX, AESOP)

Jacking Requirements--Analyze operational and maintenance jacking conditions to establish jacking requirements and limitations.

OEW, Payload, and Fuel Distributions--Provide vehicle, payload, and fuel distributions for load, flutter, and stability and control analyses. (Supporting computer program: TEW053)

Flight Simulation Mass Data--Provide airplane mass properties characteristics for flight simulator development. (Supporting computer programs: TW28, TEW053)

Weighing Requirements and Actual Weighings--Establish procedures and requirements for actual weighings of vendor parts, part assemblies, and total airplanes. Weigh parts and assemblies and prepare shop work orders for weighings of large assemblies and total airplanes.

Weight Control Programs--Monitor and evaluate the design and identify the changes required to limit or reduce the weight growth which occurs with increasing design definition and problem resolution.

Control Surface Balancing--Establish and document the procedures, limits, and test methods for the static balancing of control surfaces for flutter control.

Moment of Inertia Data--Provide moment-of-inertia data of the airplane about its axes of rotation for verification of sizing, locating control surfaces, and flutter analysis. (Supporting computer programs: TEW053, SCOWL, ATLAS, TW28)

Specification Weights--From calculated and actual weights and customer change requests, establish the nominal specification and maximum guarantee weight and balance of specific customer configurations.

Growth Studies--Continue determination of operational empty weight changes associated with configuration gross weight increases. (Supporting computer program: ORGY)

Risk Analyses--Continue quantitative assessments of the probability of meeting airplane weight goals by analyzing the configuration definition, potential weight impact of unresolved design/analysis problems, availability of planned new technology items, and the probable effect of weight and cost reduction programs.

Weight Reduction Programs--Coordinate procedures for special program-wide weight reduction programs. Develop weight reduction proposals and evaluate weight reduction proposals from other design and staff organizations.

Alternate Design Studies--Initiate and evaluate alternate solutions to the proposed design which result in improved weight and/or balance performance.

Weight and Balance Substantiations--Continue verification of layout weight calculations as design details are finalized by calculating and documenting weights of released drawings.

Test Airplane Weight Tracking and Flight Manifests--Track the weight and balance of flight test airplanes. Analyze loading and ballast for specific test conditions and provide weight and balance manifest support.

Weight and Balance Manuals--Prepare customer specific fuel, passenger and cargo loading requirements, data, and schedules for customer weight and balance manuals, per ATA Spec. 100. (Supporting computer program: TW47).

Fuel Test Support--Establish procedures and provide support for the determination of airplane-unusable and trapped fuel.

Fuel Management/Volumetric Data--Verify fuel management limitations, procedures, and fuel volumes. (Supporting computer programs: FUELPD, TEW053, SCOWL)

Weight Record System--Enter detailed data into the weight staff data base for weight documentation, tracking and change history. (Supporting computer program: SWRS)

Vendor Weight Compliance--Monitor vendor weight performance and establish vendor weight control programs where required. Identify vendor parts to be verified by actual weighings.

Visibility Reports and Meetings--Prepare summary reports and conduct review meetings to present OEW estimates, change histories, and weight trends and analyses for management decision and project and staff utilization. (Supporting computer program: SWRS)

Cargo Handling Limitations--Verify cargo handling limitations to ensure compliance with contract requirements.

Flotation and Ditching Data--Continue analysis of flotation and ditching characteristics of the configuration (structural integrity, flotation attitude, flotation time, etc.) to show compliance with FAR25. (Supporting computer program: TW63)

Onboard Weighing - System Data--Provide airplane weight and balance characteristics and provide analytical support for onboard weighing system design.

Budget and Manpower Estimates--Estimate weight staff budget and manpower requirements based on anticipated total program manpower and schedule.

Customer OEW and Change Request Estimates--Calculate weight and balance of specific customer configurations and customer-requested changes.

Budget Quote Estimates--Calculate weight and balance effect of customer-requested changes for budget quotes.

Competitive Analyses--Prepare weight estimates of competitor aircraft and comparisons of company/competitor aircraft for performance evaluation, marketing analysis, and sales support. (Supported by all programs).

Proposal Weight Estimates--Prepare weight estimates in support of new business bids in response to requests for proposals from contracting agencies. (Supported by all programs)

5.2.1.5 Production

The production phase of the weights staff activities are shown in figure 12. The chart gives visibility to the input data, data source, weights staff output data, processes used, and the recipient of the data.

The following lists the output data and process used by weight technology during the production phase:

Configuration Estimates--Continue Class I weight and balance estimates of derivative configurations. (Supporting computer program: ORGY)

Weight and Balance Placards--Analyze airplane placard requirements and establish placard limits and nomenclature.

PRODUCTION

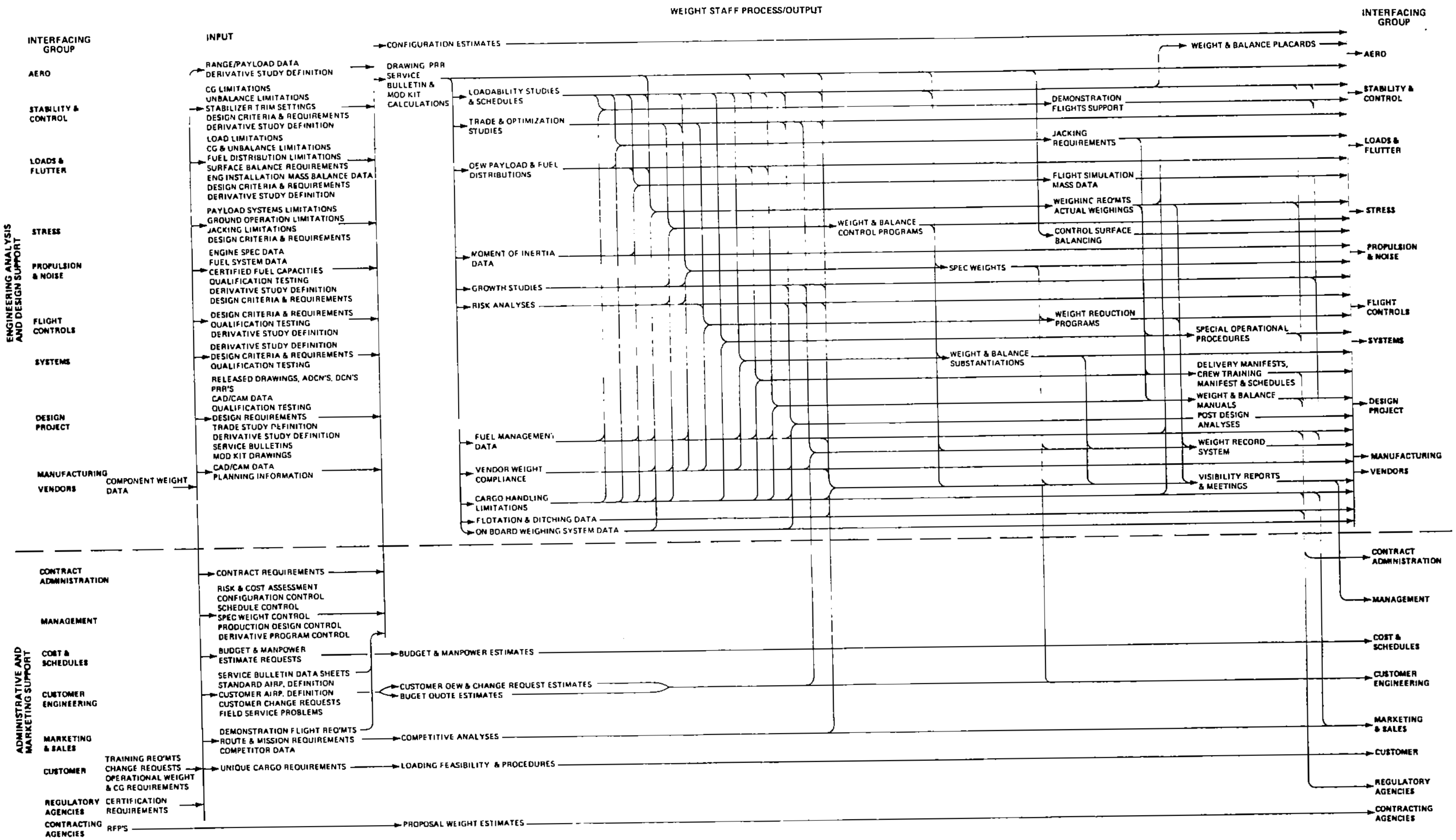


Figure 12.—Weight Technology—Production Phase

Drawing Weight and Balance Calculations--Calculate changes to the airplane's weight and balance from released drawings, PRR,s, service bulletins, and modification kits.

Loadability Studies and Schedules--Establish fuel, passenger, and cargo-loading requirements of customer and derivative configurations and evaluate loading flexibility. Prepare loading schedules. (Supporting computer programs: FUELPD, TEW053, TEW073, SPUD)

Demonstration Flights Support--Provide required support for special demonstration flights, including flight manifests, cargo flexibility analyses, data for customer presentations, etc.

Trade and Optimization Studies--Continue optimization of the weight and balance effects of subsystem and component level trade studies which define alternate design concepts satisfying the same design requirements and evaluation of the weight-and-balance effects of refinements to a given design concept which results in improved airplane weight, cost, or performance. (Supporting computer programs: ORACLE, LEMBO, GEARS, PROFIX, AESOP)

Jacking Requirements--Analyze operational and maintenance jacking conditions to establish jacking requirements, limitations, and procedures.

OEW, Payload, and Fuel Distributions--Continue analysis of vehicle, payload, and fuel distributions of customer and derivative configurations. (Supporting computer program: TEW053)

Flight Simulation Mass Data--Provide airplane mass properties characteristics for flight simulation. (Supporting computer programs: TW28, TEW053)

Weighing Requirements and Actual Weighings--Establish procedures and requirements for actual weighings of vendor parts, part assemblies, and total airplanes. Weigh parts and assemblies and prepare shop work orders for weighings of large assemblies and total airplanes.

Weight Control Programs--Monitor and evaluate the design and identify the changes required to limit or reduce the weight growth which occurs with production corrections and product improvements.

Control Surface Balancing--Establish and document the procedures, limits, and test methods for the static balancing of control surfaces for flutter control.

Moment of Inertia Data--Provide moment of inertia data of the airplane about its axes of rotation for verification of sizing, locating control surfaces, and flutter analysis. (Supporting computer programs: TEW053, SCOWL, ATLAS, TW28)

Specification Weights--From calculated and actual weights and customer change requests, establish the nominal specification and maximum guarantee weight and balance of specific customer and derivative configurations.

Growth Studies--Continue determination of operational empty weight changes associated with configuration gross weight increases. (Supporting computer program: ORGY)

Risk Analyses--Continue quantitative assessments of the probability of meeting derivative airplane weight goals by analyzing the configuration definition, potential weight impact of unresolved design/analysis problems availability of planned new technology items, and probable effect of weight and cost reduction programs.

Weight Reduction Programs--Coordinate procedures for special program-wide weight-reduction programs. Develop weight-reduction proposals and evaluate such proposals from other design and staff organizations.

Special Operational Procedures--Establish special operational procedures, as required, for unique customer cargo requirements, airplane recovery operations, etc.

Weight and Balance Substantiations--Continue verification of airplane weight by calculating and documenting weights of drawings, PRR's service bulletins, etc.

Delivery Manifests--Prepare weight and balance control and loading manual supplements, delivery manifests, and weight compliance reports (if applicable) for delivery of customer airplanes.

Crew Training Manifests and Schedules--Prepare example manifest and loading schedules for customer flight crew training.

Weight and Balance Manuals--Prepare customer weight and balance manuals containing customer-specified fuel, passenger, and cargo-loading requirements, data, and schedules, per ATA Spec. 100. (Supporting computer program: TW47)

Post Design Analyses--Analyze and document the weight performance of the design and identify areas of potential weight improvement.

Fuel Management Data--Verify fuel management limitations and procedures. Analyze derivative fuel management requirements. (Supporting computer programs: TEW053, SCOWL)

Weight Record System--Enter detailed data into the weight staff data base for weight documentation, tracking, and change history. (Supporting computer program: SWRS)

Vendor Weight Compliance--Monitor vendor weight performance. Identify vendor parts to be verified by actual weighings.

Visibility Reports and Meetings--Prepare summary reports and conduct review meetings to present OEW estimates, change histories, weight trends, and weight analyses for management decision and project and staff utilization. (Supporting computer program: SWRS)

5.2.2 AERODYNAMICS

Charts are presented to give visibility to the aerodynamics staff activities and responsibilities.

Figure 13 presents the aerodynamic staff data flow activities and figure 14 illustrates the areas of responsibility.

5.2.3 FLIGHT CONTROL

Flight control activity is presented as a flow of information. Figure 15 presents a picture of the internal data flow while figure 16 illustrates information flow within the staff.

5.2.4 PROPULSION

Propulsion technology staff communications and data flow are shown in figure 17.

5.2.5 NOISE

The activities, data flow, and interfaces involving the noise technology staff are shown in figure 18.

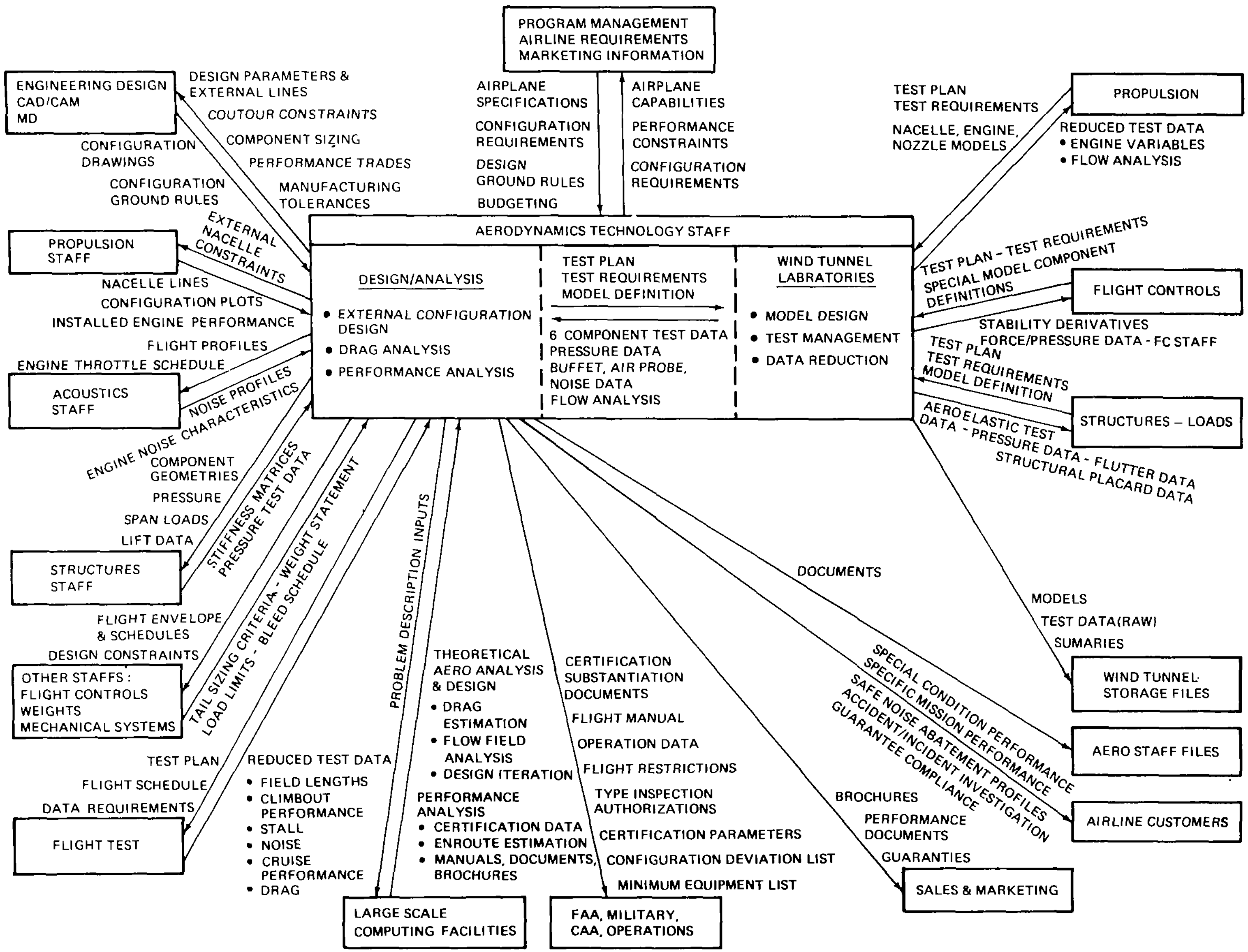


Figure 13.—Aerodynamics Technology Staff Activities

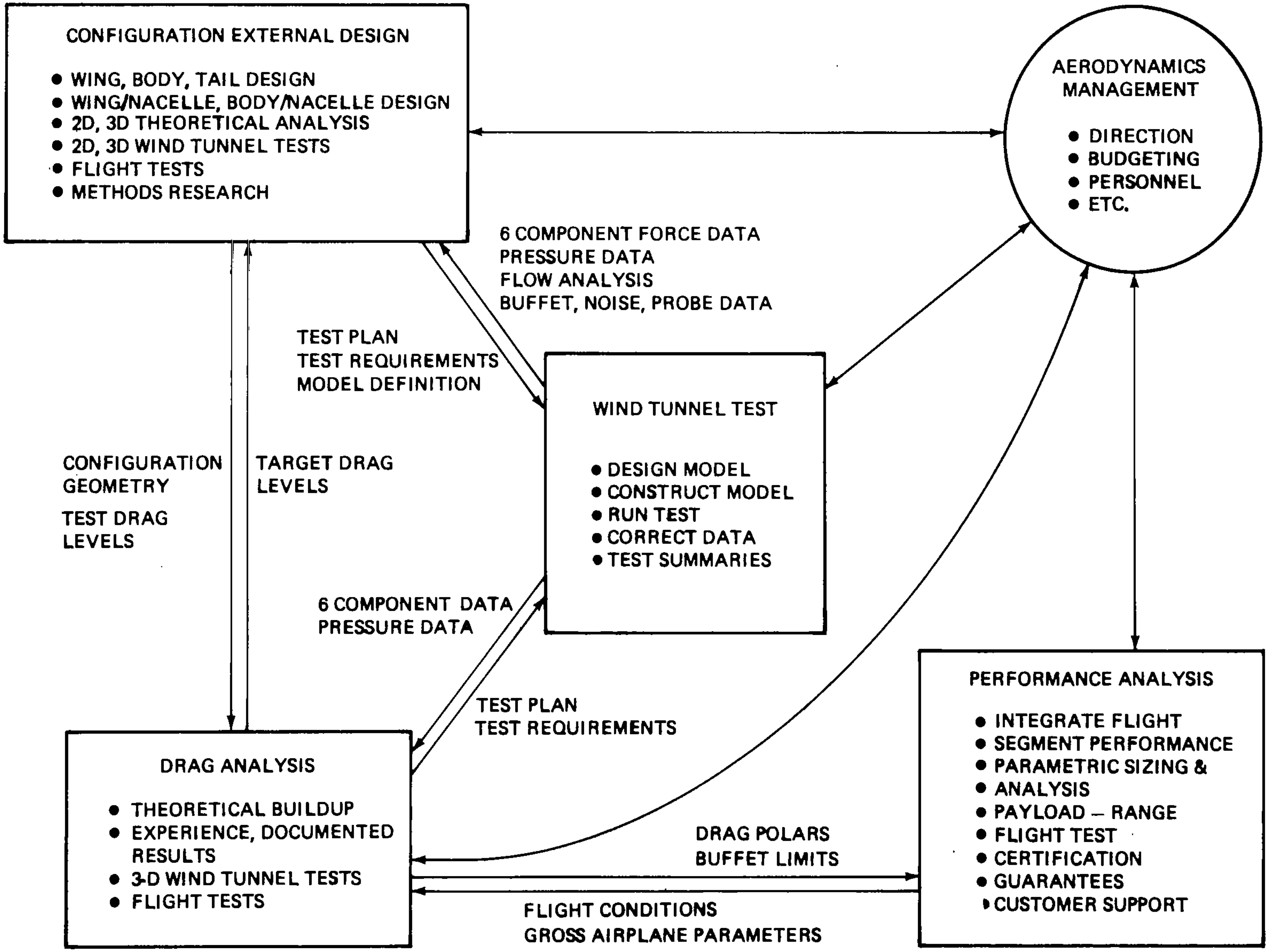


Figure 14.–Aerodynamics Technology Staff Responsibilities

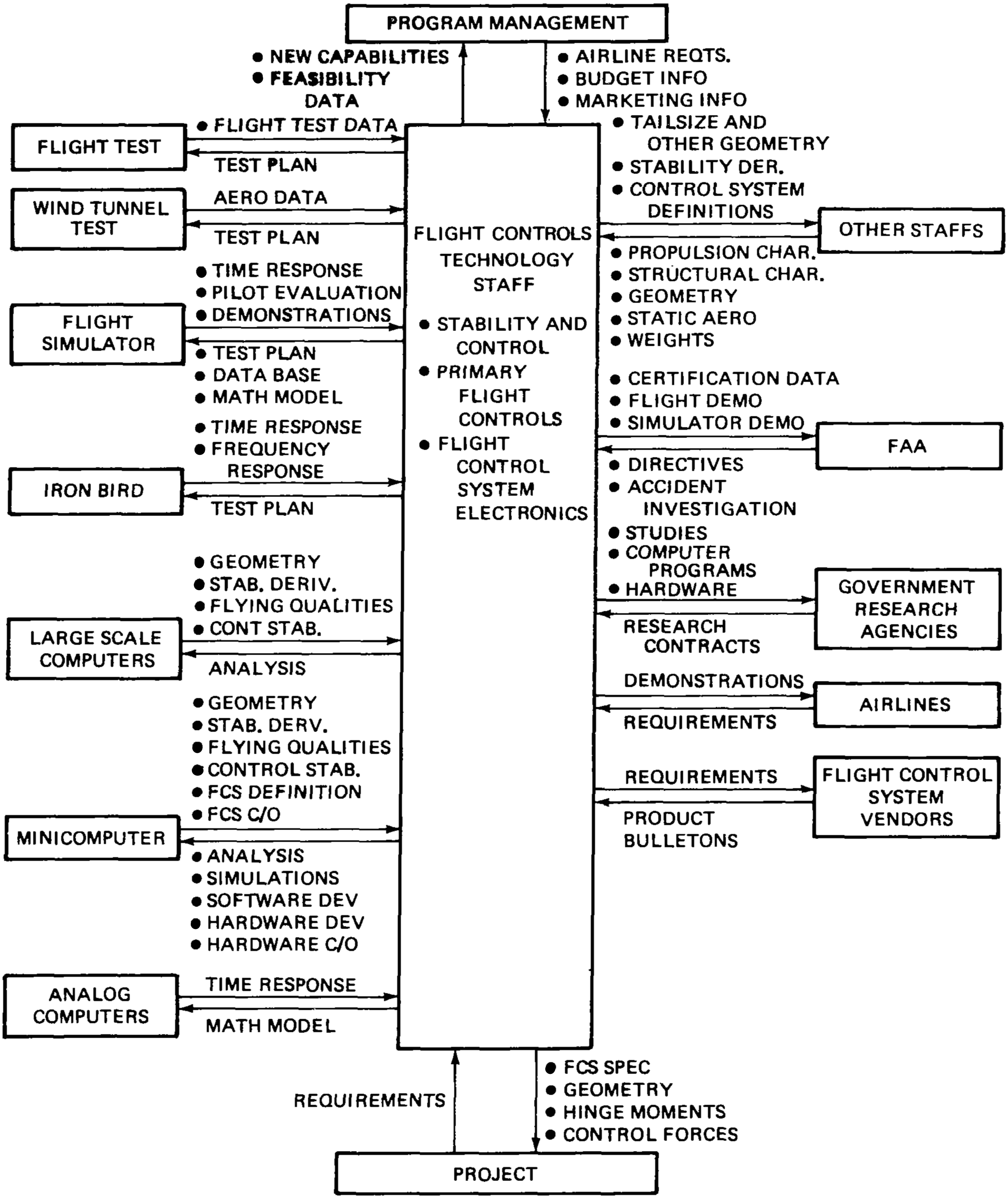


Figure 15.—Flight Controls Technology Staff Information Flow

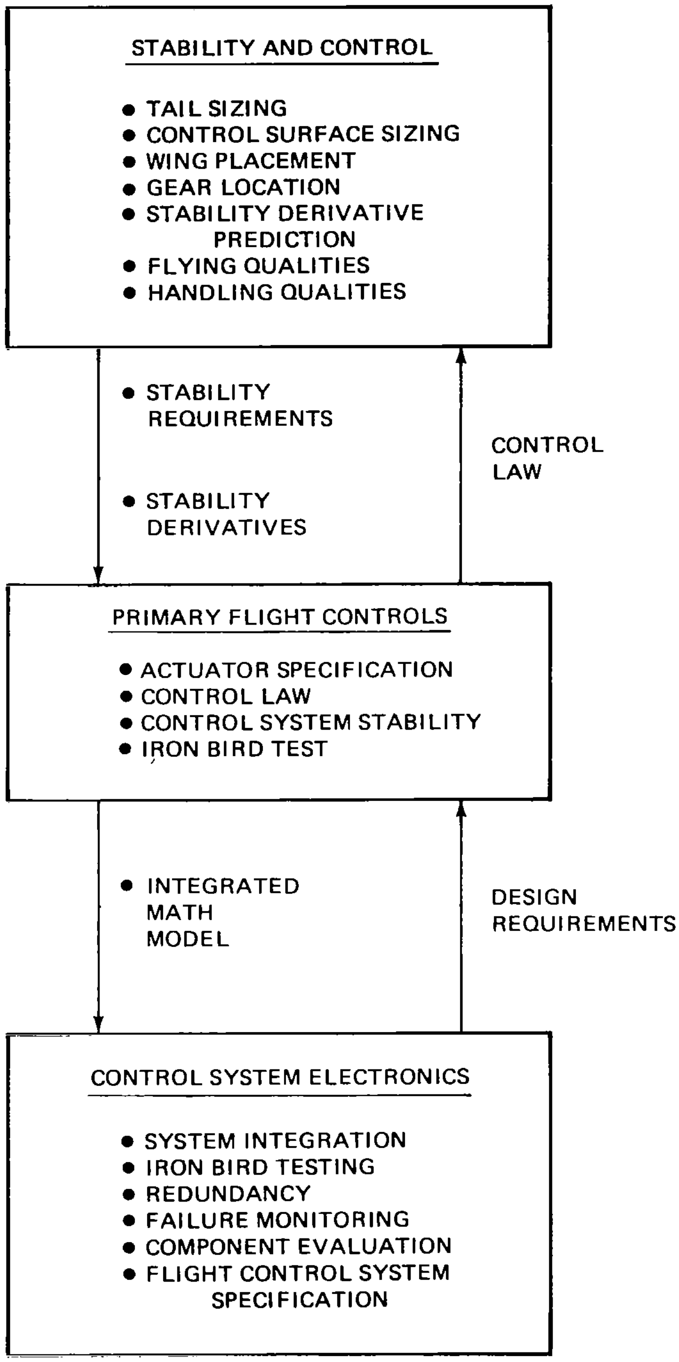


Figure 16.—Flight Controls Technology Staff Internal Information Flow

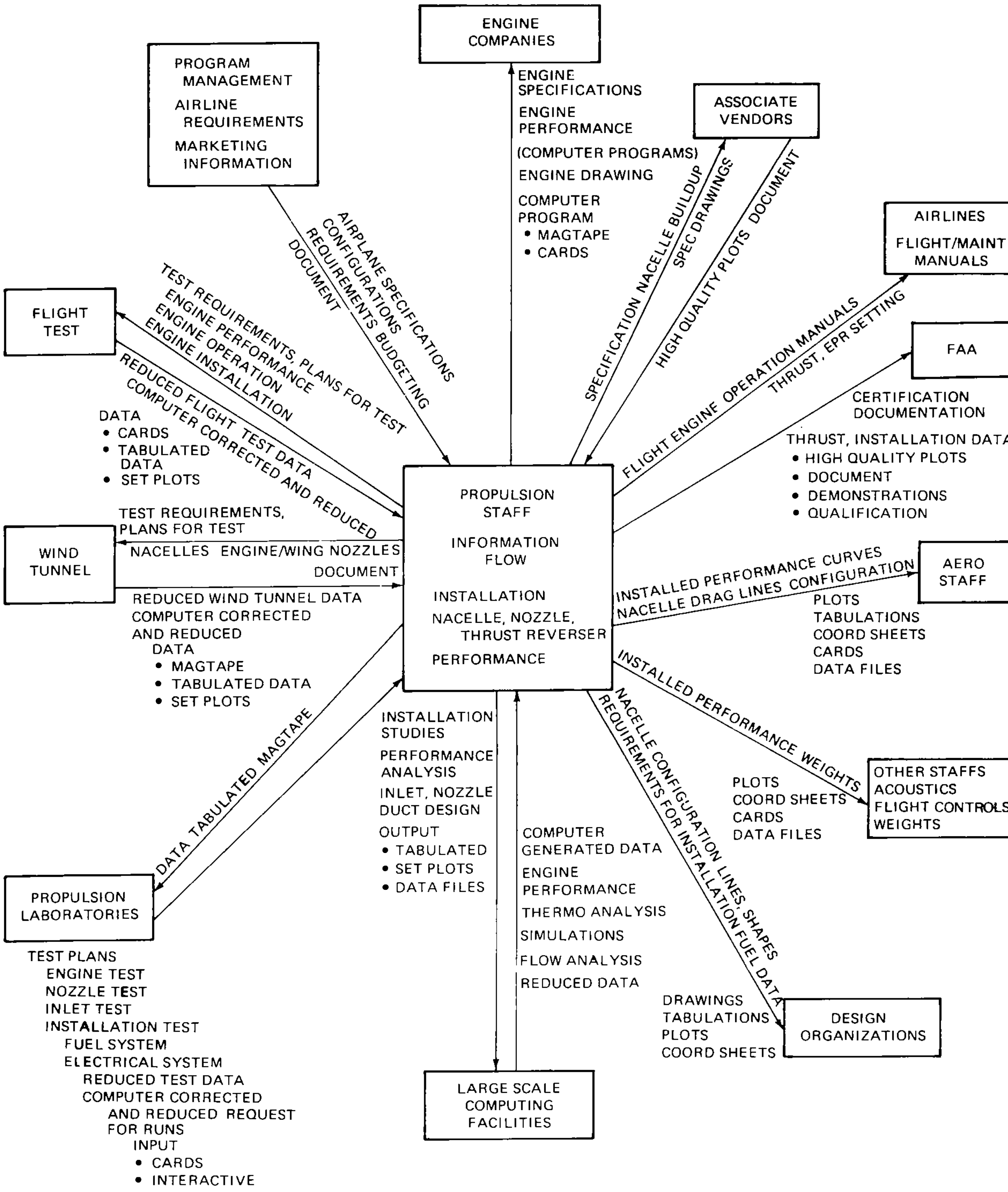


Figure 17. –Propulsion Technology Staff Communications

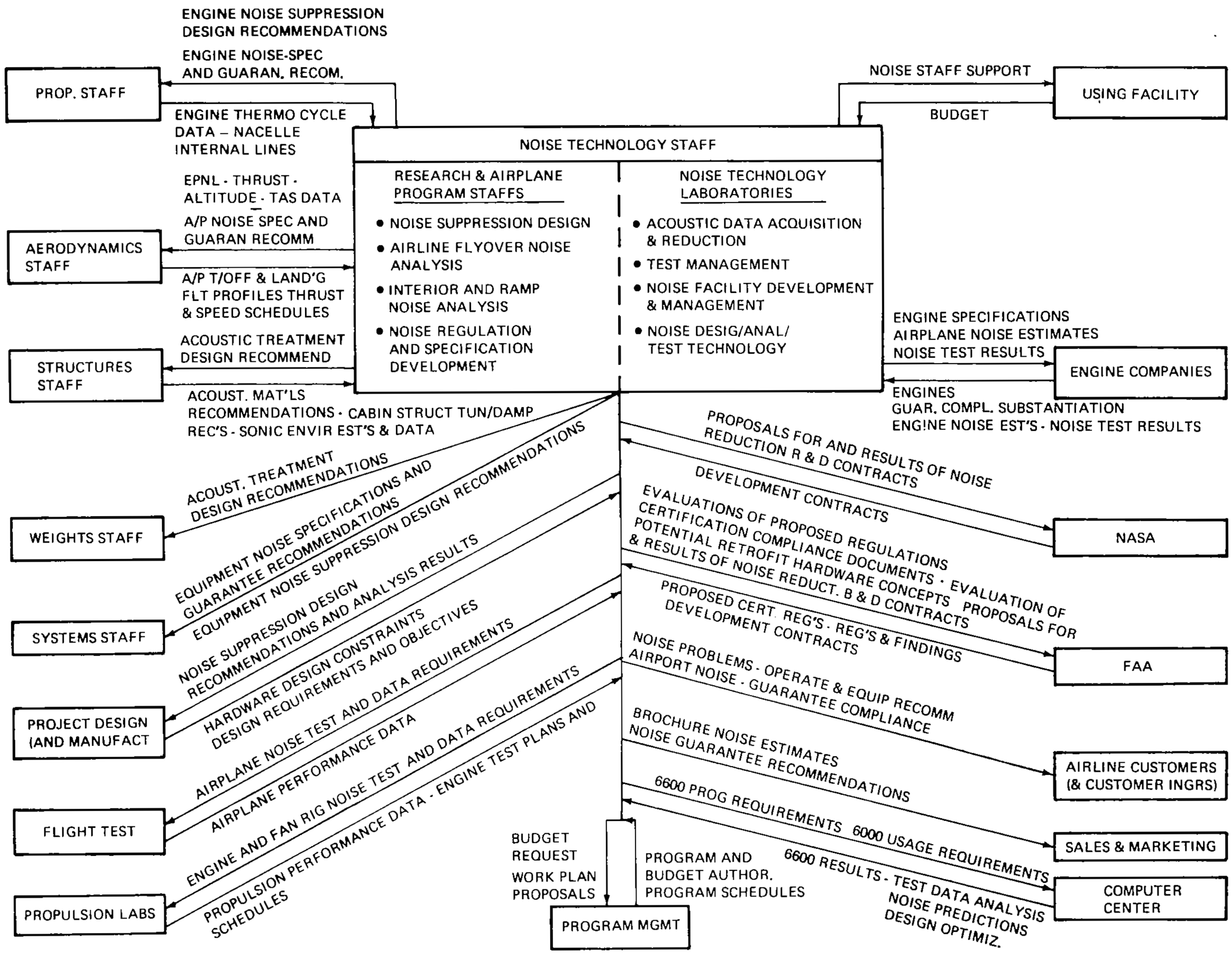


Figure 18.—Noise Technology Staff Communications

5.2.6 STRUCTURES - LOADS AND DYNAMICS

The activities of the structures technology staff are grouped in two related areas: 1) loads and dynamics staff and 2) stress and fatigue staff. The activities of these staffs are shown in overview (figure 19) and as a data flow (figure 20).

The following is a description of loads and dynamics activities as they progress through the design phases.

5.2.6.1 Task Definition - Conceptual Design

Define criteria--Design conditions, types of external loadings, and operational limits that influence structural sizing are defined.

Basic Flutter Assessment--Statistical trends are used as configuration guidelines considering wing loading, wing sweep, thickness ratio, material, mass distribution, and operating conditions.

Analytical Methods Defined--The staff determines whether analyses will use beam and/or finite element structural representations, subsonic and/or supersonic aerodynamic theories, and anticipates the required complexity of mathematical models.

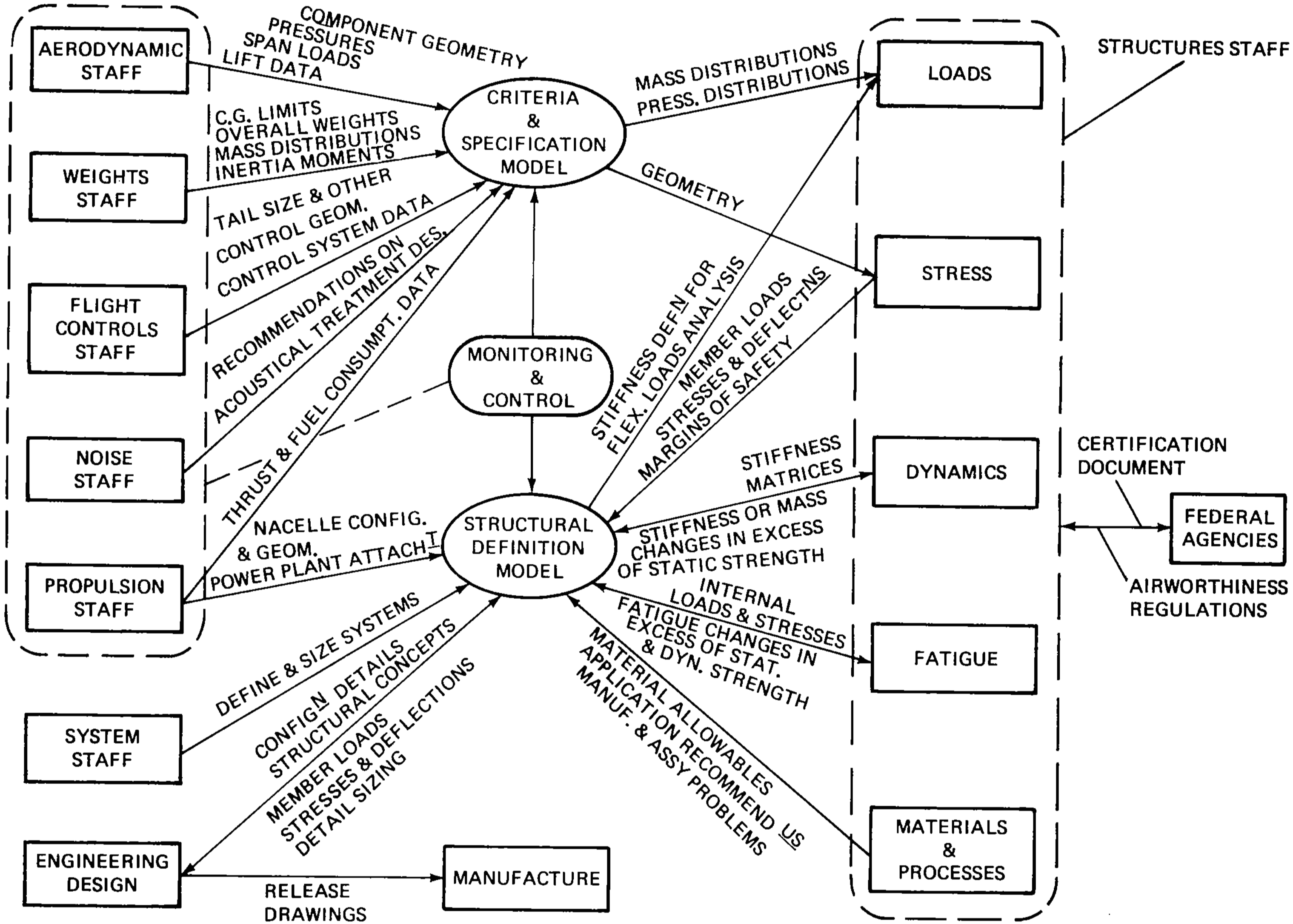


Figure 19.—Loads and Stress Technology Staff Overview

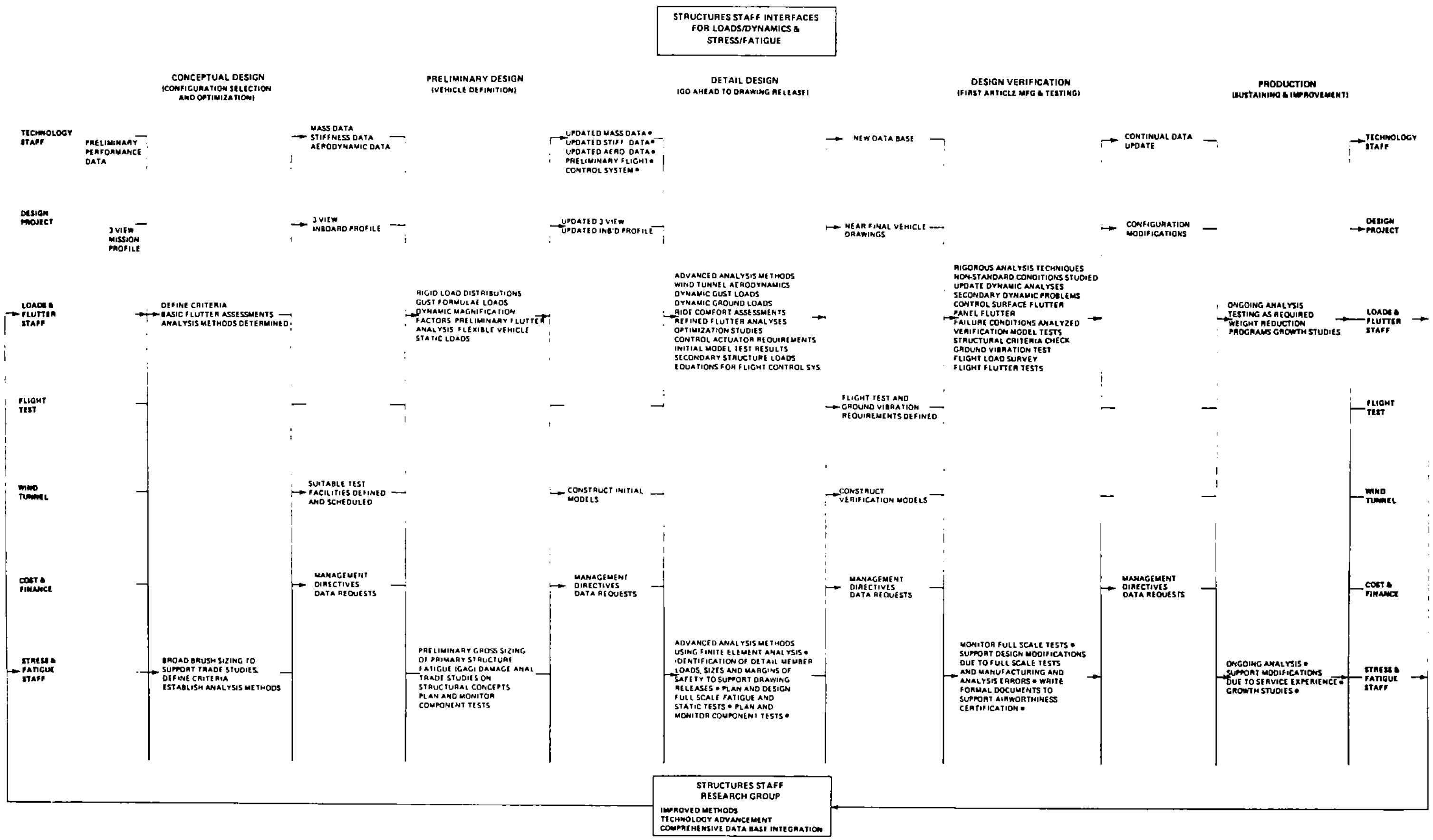


Figure 20.—Structures Technology Staff Interface and Data Flow

5.2.6.2 Task Definition - Preliminary Design

Rigid Loads Distribution--Initial calculations of load distributions on major airframe components are made for both specified design conditions and a fatigue mission profile.

Gust Formulae Loads--Initial gust loads will be determined by appropriate gust loads formulae modified by statistical dynamic factors.

Preliminary Flutter Analysis--Initial flutter analysis will use best available mass and stiffness distributions to compute vibration modes and frequencies for equation formulation. Changes in structural arrangement are suggested to meet flutter criteria.

Flexible Airframe Static Loads--Starting with the structural definition resulting from rigid load application, flexible loads are cycled until structural criteria are met by changes in geometry, structural arrangement, and weight and stiffness distributions.

5.2.6.3 Task Definition - Detail Design

Advanced Analytical Methods--As the configuration is refined, more advanced analytical tools are used. Aerodynamic force model data is used in a new cycle of gust formulae and flexible vehicle static loads.

Dynamic Gust Loads--Fully dynamic gust loads analyses are made, both vertical and lateral, for critical design conditions. Both discrete gust and statistical gust studies are considered. Gust analyses for fatigue sizing are included.

Dynamic Ground Loads--Fully dynamic loads encountered during landing impact and taxi over rough runways are determined. Landing gear non-linearties are included.

Ride Comfort Assessment--In conjunction with both the flight and ground induced dynamic loads, ride comfort is evaluated in terms of lateral and vertical accelerations at crew and passenger locations.

Refined Flutter Analyses--Additional flutter analyses of the refined configuration are made using updated data banks.

Flutter Optimization Studies--Most advantageous changes in configuration geometry mass and/or stiffness for flutter clearance are determined.

Control Actuator Requirements--Control stiffness requirements are provided to meet flutter criteria.

Initial Wind Tunnel Model Results--All applicable force, pressure, and flutter model data are incorporated in appropriate dynamic analyses.

Secondary Structure Loads--Loads are provided on secondary structure, relying heavily on data from a similar previous configuration.

Equations for Flight Control System--Flexible vehicle equations of motion are developed for use in flight control synthesis and analysis.

5.2.6.4 Task Definition - Design Verification

Rigorous Analysis Techniques--Utilize sophisticated tools to maximum advantage, making best use of available theoretical and experimental data.

Nonstandard Conditions--Make sure vehicle can withstand any inadvertent or deliberate nonstandard loadings and usages within the acceptable flight regime.

Update Dynamic Analyses--Repeat critical dynamic load and flutter analyses to provide a maximum level of confidence in theoretical predictions.

Secondary Dynamic Loads--Perform dynamic load studies on secondary structure subject to rapid loading conditions.

Control Surface Flutter--Include control surfaces in detailed flutter analyses.

Panel Flutter--Investigate panel flutter possibilities on exposed skin panels.

Failure Condition Analyses--Identify and analyze failure conditions to confirm that flutter requirements are met.

Verification Model Tests--Update wind tunnel model definitions to reflect any significant design changes.

Structural Design Criteria--Ensure that final configuration provides compliance with all loads and flutter criteria.

Ground Vibration Test--Verify the theoretically predicted vibration characteristics of the vehicle.

Flight Loads Survey--Make inflight measurements of gust and maneuver loads to verify analytical results.

Flight Flutter Testing--Ensure by full-scale testing that the aircraft is free from flutter throughout the design flight envelope.

5.2.6.5 Task Definition - Production

Ongoing Analysis--Continue theoretical studies in support of sustaining aircraft programs.

Follow-on Testing--Conduct wind tunnel and flight testing as required to investigate proposed vehicle modifications.

Weight Reduction Program--Support efforts to meet or improve performance guarantees.

Growth Studies--Provide accurate determination of growth potential for future derivative aircraft.

5.2.7 STRUCTURES - STRESS AND FATIGUE

The following is a description of stress and fatigue tasks as they progress through the design phases.

5.2.7.1 Task Definition - Conceptual Design

Broad Brush Sizing for Trade Studies--Analyze alternate design concepts satisfying the same design requirements and using the same level of elementary theory to obtain a quick evaluation of relative design merit.

Define Criteria--Interpret Federal or miliary airworthiness requirements relative to the design under consideration. Establish the company position and agreed practice in dealing with important and critical design discussion. Prepare a formal criteria document for in-house use.

Establish Analysis Methods--Arrange engineering/management agreement to establish the analysis quality and depth commensurate with type of design, manpower, and budget constraints.

5.2.7.2 Task - Preliminary Design

Preliminary Gross Sizing of Primary Structure--The primary structure is sized, using elementary engineering theory, at selected sections for static strength and fatigue. The fatigue analysis estimates ground-air-ground (GAG) cycle stresses and damage ratios. The wing box is sized and the flexural and torsional rigidity and shear center location are determined. The body monocoque is sized and the flexural rigidity about the vertical and horizontal axes determined along with the torsional rigidity and shear center location. At the wing-body intersection and other regions of discontinuity, elementary beam theory is modified by effectivity factors based on test experience or more sophisticated analyses performed on similar airplanes.

Trade Studies on Structural Concepts--Studies involving evaluation of different structural solutions to the same problem are studied. Selection is a trade of cost, weight, and risk factors.

Plan and Monitor Component Tests--Critical components with a high analysis risk factor are selected for static and fatigue testing. The stress and fatigue group is included in selecting, planning, and evaluating the results of these tests.

5.2.7.3 Task - Detail Design

Advanced Analysis - Finite Element--Using the sizing predicted by conventional methods, a mathematical model is built to describe the more highly redundant structural region such as the wing body intersection. Computer solution yields large amounts of data about selected points (nodes) and the idealized members connected to the nodes. The output consists of deflections, internal forces, and stresses for a large number of applied load cases.

Lengthy interpretation of the output is currently required to convert the discontinuous effects of the finite elements to continuous functions and interpret the idealization into real structure.

Large structural models are sometimes constructed by a mathematical joining of substructures. Current trends in finite element analysis toward programs for rapid input preparation and post-processing of output, together with resize capability, will permit its use as a preliminary design tool.

It is felt that in the IPAD environment, finite element methods will become prime structural analysis tools, not only for detail design but throughout the design process. Small structural design tasks will be quickly analyzed in an interactive mode.

Detail Member Loads/Sizes/Safety Margins--Detail member loads are calculated and released to engineering for design of parts and preparation of drawings.

Final drawings are checked and approved to indicate satisfactory strength and fatigue levels.

Full-Scale Fatigue and Static Tests--Load conditions are reviewed and a decision is made on the critical load conditions to be tested and the order of such testing to achieve maximum information before incurring failure. Conditions to be tested to limit, ultimate, and failure are decided. A method of loading is planned and calculation of applied loads to give equivalent effects on the structure to the inflight effects is made. Coordinate closely with test groups to ensure the test rig is functionally satisfactory and that the recording instruments and techniques will supply the needed information.

Plan and Monitor Component Tests--Continuation of component testing from preliminary design phase.

5.2.7.4 Task - Design Verification

Monitor Full-Scale Tests--Compare test results with predicted analysis values. Analyze discrepancies and determine the cause.

Support Design Modifications Due to Full-Scale Tests --Initiate work-around solutions or perform more refined analysis to verify acceptance manufacturing and analysis errors.

Airworthiness Certification--Summarize stress and fatigue analyses in formal document form to provide visual evidence of compliance with the appropriate airworthiness regulations.

5.3 COMPUTER-AIDED DESIGN

Computer-aided design is the use of computer hardware and its associated software to assist engineers in developing and evaluating designs and producing data and drawings.

When the word "design" is used here, it carries such meanings as:

To mentally invent, contrive, map out, or plan a project for a purpose

To proportion, form, or shape an object or action for a purpose

To draw, sketch, outline, or detail any of the above

The "design" then plans and/or controls the interaction between many subjects such as materials, people, money, energy, time, objects, and functions.

The computer with its programs and related functions is used to aid the designer in all levels of design, hence the designation "computer-aided design."

Computer-aided design is an engineering tool used from market research to product design that satisfies the market needs and is the data source for conventional and computer-aided manufacturing. (See document D6-IPAD-70011-D, Production Manufacturing Interface Document.) Within these areas there are requirements for general and specific programs, and for batch and interactive conversational capabilities.

General programs are general in scope and usage and their needs are based on previously experienced design requirements. Specific programs are to satisfy a particular requirement and are created as needed. Batch programs created on punched cards or by remote terminal are processed on a time delay (15 minutes to overnight). Interactive conversational programs are accessible via remote terminals, have predefined questions for solution of specific problems, and give immediate response to questions.

A computer-aided design work station operates under a computer management system which has the capability of initiating or executing conversational computer programs and creating or modifying geometry from an interactive graphics device. The management system controls data flow, program usage, and stored data. Hardcopy printouts are available at both high and low accuracy levels, as required.

The computer aids to design are described here as they apply to three design phases: conceptual, preliminary, and detail design. (Sustaining design is a part of detail design.)

5.3.1 CONCEPTUAL DESIGN

Computers are used for many of the activities in conceptual design phase. Here the effort is primarily directed towards configuring trade studies and parametric analysis. Typical tasks for a subsonic airplane are listed below in the order that they may probably occur in each refinement cycle in the conceptual phase of the design process.

SEQUENCE OF CAD TASKS - SUBSONIC AIRPLANE

a) Analyze market activities for design mission, market categories, economics, competitive data, critical route performance, market size, etc.

b) Provide relative cost values in constant-year dollars

c) Conduct airplane configuration trade studies

d) Calculate configuration parameters to describe airplanes for the market analysis using parametric calculations

e) Prepare an integrated geometry consisting of payload and control cabin arrangements, wing and empennage planforms, parametric loft definition, control surface arrangements, propulsion arrangements, structure arrangements, etc.

f) Perform optimization studies on engine cycle data and nacelle geometry to support performance calculations

g) Calculate "noise footprints" to support design iterations

h) Estimate drag and lift characteristics to support field and cruise performance calculations

i) Calculate a simplified flutter analysis

j) Estimate maneuver margins, stability, and control

k) Ascertain by computer analysis that the airplane configuration is statically balanced within acceptable c.g. range using statistical or estimated stability and control data

l) Predict loads from parametric data

m) Calculate a preliminary gross structural sizing for strength and fatigue

n) Size typical elements at selected sections using elementary beam theory, i.e., wing surfaces and spars, fuselage lobes and sidewalls, and empennage surfaces and spars

o) Use statistical calculations for airplane weights

p) Estimate overall system weights with general placement within a configuration for a realistic weight and balance survey

5.3.2 PRELIMINARY DESIGN

Computers are used in the preliminary design phase of engineering design involving analysis, data reduction, and interactive graphics. The computer tasks for a subsonic airplane design are listed below in the approximate order for one iteration or loop in the preliminary design phase. (Some of these are refinements of tasks performed in the conceptual design phase, section 5.3.1.)

a) Refine the parametric wing geometry and extract wing contours for checking wing suitability

b) Refine airplane geometry

c) f Analyze airplane configuration for control and dynamic stability

d) Update weights and balance when inputs are changed

e) Refine vehicle loads (wing, fuselage, empennage) for flight and ground conditions

f) Size control system actuators

g) Size landing gear

h) Analyze propulsion system design and performance

i) Analyze reliability

j) Develop hydraulic system requirements

k) Determine environmental control load and power requirements

l) Determine electrical power system requirement

m) Determine fuel system requirements

n) Size structure for strength, flexibility, and fatigue

o) Analyze wind tunnel tests

p) Summarize aerodynamic performance

q) Refine airplane geometry

r) Prepare geometry for layouts

5.3.3 DETAIL DESIGN

The end product of the detail design phase of the design process is a completely defined, approved design of a desired product that is presented to the users (manufacturing, inspection, customer, etc.) on a medium and in a form that is most efficient for the particular customer's uses.

The detail phase is the design period when most of the engineering manhours are expended and when the design engineer makes maximum use of the computer (analysis programs, interactive graphics, and geometry definition).

Since the detail design phase involves more engineering design hours and simultaneous design effort than any previous phases, it is important that the preceding preliminary design phase be complete in all areas before detail design begins. Any design redirection or data changes during detail design increases the manhours consumed and causes schedule slides.

The computer is involved in the refinement of the previous preliminary design tasks (sec. 5.3.2) plus detail design tasks and drawing/data preparation. Tables 4 through 6 represent computer tasks for the different design areas:

Table 4.--General Design Tasks

DESIGN ELEMENTS	DESIGN CONSIDERATIONS
Section Properties	Shear center for standard sections Shear center for arbitrary sections Torsion constant
Frames and Trusses	Pin-joined 2D trusses Pin-joined 3D trusses Rigidly joined 2D trusses Rigidly joined 3D trusses Small-scale finite element analysis
Shear Webs	Shear resistant Diagonal tension field
Beams and Columns	Non-constant section columns Beam columns (single and continuous span)
Weight and Volume Computations	Detail weight and centroid Assembly weight and centroid Tank volumes and centroid Trapped fuel and water volumes
Extrusion Selection	Availability
Mechanisms	Kinematic displays of flaps, landing gear, etc.
Pin Joints	Single-pin joint analysis
Web Cutouts	Ring doubler requirements Small and large door cutouts
Classification Coding: Detail Part Design	Classifying detail parts by shape, function, material, production methods to locate existing similar/identical/usable parts where economic are gained in the use of existing tools, tool planning, machine programming. Washers Clips (angles, tee's, zee's, etc.) Bushings (straight, stepped, shoulder, etc.) Springs (coil, spiral, leaf)

Table 5.--Specific Design Tools

DESIGN ELEMENTS	DESIGN CONSIDERATIONS
Controls and Hydraulics	CAMS--both feel and positional Cable length determination Cable break points and pulley tangent points Plane of pulleys with relation to cable runs Four-bar linkage in one plane Four-bar linkage in two planes
Flight Deck	Vision polars Pitot static TAT probes Panel base plates and light plates Lining contours
Electrical/Electronics	Circuit breaker panel position Equipment rack installations Wire bundle disconnect panels Antenna installations
Propulsion (Fuels)	Fuel tank definition Height/volume/c.g. Fuel system flows/pressure Dripstick calibration Fuel tank plots Wetted area, volume Jet pump design Fuel tank temperatures Fuel tank plotting Fuel probe design Attitude error analysis Vent system design
Propulsion (Power Plant and APU)	Plan forms Contours Ultimate and fatigue structural analysis Tube and duct layout Clearance studies Transformations
Environmental Control Systems	Duct layout Duct loads
Forgings and Castings Design	

Table 6.--Drafting Details and Assemblies

DESIGN ELEMENTS	DESIGN CONSIDERATIONS
Wing	Geometry, Skins, Stringers, Spars, Ribs, Flaps, Aileron, Body-wing joint
Body	Geometry, Skins, Stringers and longerons, Floor beams, Frames, Bulkheads
Empennage	Fin geometry Fin skin Fin spars Fin ribs Rudder Fin body joint Stabilizer geometry Stabilizer skin Stabilizer spars Stabilizer ribs Elevators
Nacelle Strut	Skin Ribs Bulkheads Engine/strut interface Strut/wing interface System interface
Propulsion Pod	Inlet cowling Fan cowling Engine cowling Thrust reverser
Systems	Wiring--schematics, diagrams, bundles and bundle installations Hydraulic--schematics, diagrams, tubing assemblies and tubing installations Pneumatic--schematics, diagrams, ducts and duct installation Environmental control--schematics, diagrams, system installation

5.3.4 UNIQUE COMPUTER DESIGN AIDS

The computer-aided design discussed in the previous paragraphs dealt primarily with scientific programs involving the design process itself. There are other areas where business systems and scientific programs have considerable impact on design and manufacturing procedures. Two of the primary areas are in drawing release and data management.

5.3.4.1 Drawing Release

The drawing release function provdies an administrative and clerical service to the engineering design organization and acts as the interface between the design organization and the downstream organizations using the engineering drawings and related data.

In support of the engineering design organization, the release function assigns and maintains appropriate records for drawing and part numbers, drawing sheet numbers, revision identifications, and control numbers for supportive engineering documentation. It receives the completed packages of engineering drawings and data from the design groups, processes the packages to complete the record-keeping function, and issues the drawings and related data to the reproduction unit for distribution to the using organization.

In support of user organizations, the release function provides engineering data required to accomplish the planning, ordering, producing (or purchasing), and accounting for all hardware components. It produces indexes of drawings to be supplied to customers representing the configuration of the product purchased.

Inherent in an automated drawing release system is the ability to monitor schedule performance (actual drawing release dates versus scheduled dates), and to generate timely reports to management identifying actual or impending schedule non-conformance which may have an adverse effect on the program. Additionally, it may be used to provide extracts, audits, and statistical data to satisfy either standard or special report requests. It contains a historical log which may be used to trace the changes of product configuration.

5.3.4.2 Data Management System

At the beginning of a program, a data management policy is established to control the design and implementation and maintenance of those computing systems which support engineering and manufacturing activities. This policy is implemented in the form of engineering or interorganization technical and administrative documents, manuals, directives and procedures used to direct and control the engineering design, management and administration functions.

5.4 DESIGN INTELLIGENCE

Design intelligence is the knowledge, background, techniques, methods, imagination, data, and etc., that the engineer needs to design a product. The design intelligence each engineer personally has is augmented by two categories of data: design directives and design standards. These data are used in all phases of design level in IPAD program.

5.4.1 DESIGN DIRECTIVES

Design directives comprise a category of information containing basic design theories, design disciplines, data, and procedures for engineering documentation (drawings, memos, etc.) and control. Design directives include documents such as procedures manuals, design guides for each system in a flight vehicle, stress manuals, etc.

5.4.1.1 Procedures Manual

The procedures manual describes the engineering drawing, its classifications, arrangement, sizes, and format. It contains instructions relating to drawing distribution, drafting materials, and elementary drafting techniques, and it standardizes drawing data changes. It also contains the procedures for the release and distribution of the following documents relating to drawing data released for manufacturing or drawing change:

An ADVANCE MATERIAL REQUIREMENT authorizes ordering raw material, parts, and equipment, especially those of non-standard or hard-to-obtain items, in advance to ensure their availability for meeting manufacturing schedules.

A PARTS REQUIREMENTS authorizes the manufacturing of parts and directs the disposition of drawings and drawing originals (vault, copy runs, files, etc.).

A DRAWING INVENTORY summarizes an engineering release package and is used by the planning and procurement departments as a checklist.

A CHANGE NOTICE describes the last change made to a drawing (design) that brought it to its current configuration and identifies the existing configuration of the drawing.

A CHANGE MEMO describes design changes in detail and schedules and controls compliance on selected aircraft.

5.4.1.2 Design Manual

The design manual has two main features: general design information and structural allowables.

General Design Information--This category consists of a compendium of requirements, techniques, methods, and data commonly and frequently used in various fields of engineering design. It contains the following information:

Design techniques, criteria, and methods (e.g., weld-joint classification and process, sheet metal forming criteria, fastener strengths, installation methods, and clearance and access requirements)

Basic design data (e.g., bearings and bushings classifications, load rating and allowables, properties of mechanical joints, and tolerances and machine allowables of forgings)

Selected parts, materials, and processes (e.g., forging and casting classifications and specifications; metal alloys specifications and stock sizes; and adhesive bonded panel specifications and classifications, sizes, and physical properties data)

Structural Allowables Document--The structural allowables document is a source of structural properties and allowables for all materials used in flight vehicles and equipment such as:

Basic mechanical properties (static and dynamic)

Fatigue properties

Mechanical joint allowables

Weld joint allowables

5.4.1.3 Durability Design Manual

The durability design manual has two main features: structural configurations and methods and allowables.

Structural Configurations--This section contains families of structural design configurations used as references or as the basis for structural design for a desired durability. The configurations are arranged into two categories: baseline configuration and approved configurations.

Baseline Configuration--This applies to a design for which service experience, test, or analysis has indicated a particular fatigue quotient and for which a viable design refinement exists.

Approved Configurations--This applies to is a proven design based on test or experience, that will be used as the basis for new design.

Methods and Allowables Manual--Successful fatigue design depends on the combined actions of management, design, weights, loads, stress, test, aerodynamics, configurations, manufacturing, and liaison. Long-life airplane structure, which is competitive in cost and performance, will be attained when all disciplines strive for efficient configurations related to structural durability.

Improved detail design practices and operating stress controls are required to meet fatigue design objectives. Fatigue design is initiated during the layout phase and carried to conclusion with the ultimate in strength design. A fatigue margin is determined for all structure, subject to ultimate strength analysis.

The methods and allowables manual provides information for the design and analysis configurations of an aircraft structural components to meet design objectives. It also provides guides for engineers to use to achieve desirable structural durability, (e.g., corrosion, sonic fatigue, drainage,) in association with ultimate strength design. The scope of this manual covers fatigue design methods and fatigue design allowables.

Fatigue Design Methods--This is a list of techniques used to meet fatigue design objectives. This fatigue design method is a rapid engineering tool. Significant features include:

A fatigue check and margin similar to the static strength check.

A technique to allow designing for fatigue in the layout phases.

Fatigue conditions presented as equivalent load conditions which replace exceedance type spectra. This feature improves basic understanding and eliminates the requirement for complex solution.

An inventory of fatigue rated design details based on test and service experience and methods for determining fatigue ratings of new designs.

Final fatigue check calculations reduced to a single major stress excursion (GAG cycle) expected each flight and a factor for the additional damage of the smaller excursions.

A simple form which quickly summarizes the fatigue check and relates detail design quality to operating stress.

Fatigue Design Allowables-- This manual contains information and methods for evaluating the fatigue properties of design configurations such as tension structures, shear joints, etc., that guide the engineer in achieving efficient fatigue design. Fatigue criteria, fail-safe design concepts, crack growth rates, etc., relating to structure durability are also contained in this manual.

5.4.1.4 Design Guides

A design guide is a series of documents providing recommendations, data, and constraints based on past experience for selected flight vehicles' design elements, (e.g., passenger floor panels, cargo door, windshield, automatic flight controls, electrical power systems, propulsion systems) which is broken down into a number of individual documents to cover each subsystem or subject. An example of a design guide applicable to propulsion subsystems is shown below.

DESIGN GUIDE—PROPULSION

General (fasteners, finishes, sealings, sheet metal, bushings)

Electrical (clamps, supports, connections)

Engine Build-Up (system pressures, detail design, flexible cables)

Engine Inlet and Cowls

Engine Shroud and Exhaust

Lists and Tables (tubing support, bending radius - tube, bending radius - hose)

Structural Criteria and Interface Loads

5.4.1.5 Stress Manual

The stress manual is a structures staff or structural designer's working manual containing information for stress analysis of structural components of flight vehicles or airborne equipment. The approved analysis methods, analysis applications, computer program applications, and materials and fasteners property data are included. The typical analysis methods are: tension, compression, shear bending, torsion, combined loading stress, fracture mechanics, thermal, accoustic, and vibration. The typical analysis applications are beams, frames, fittings and joints, sandwich panels, and composite structures.

5.4.2 STANDARD PARTS, MATERIAL SPECIFICATIONS, AND PROCESSES

This category of information contains reference data for standard parts, material specifications, and processes. Of the three, the standard parts and the material processes are the most commonly used manuals.

5.4.2.1 Standard Parts

This is a series of manuals containing information on sizes, shapes, types, material, identification numbers, code, and markings for the hardware and prefabricated assemblies commonly used in the aerospace industry. Both commercial and Government standards are included.

The management, maintenance and control of the information are included in the documents. The following are the examples of standard parts and management systems.

Extrusions, shapes, forms

Inserts, latches, valves

Bolts, nuts, rivets, miscellaneous fasteners

Packings, shims

Bearings, bushings

Electrical/electronic parts

Connectors, receptacles, plug, inserts, terminals

Switches, terminals, contacts, circuit breakers, relay

Wire, cables, wire bundles, conduit assemblies

Condensers, capacitors

5.4.2.2 Material Specifications

This standard document contains specifications, identification, and characteristics of materials used in the aerospace industry for design and evaluation. It includes both commercial and Government standards. The management system covering data compilation, format arrangement, and implementation to bring the data to state-of-the-art condition and documentation and control are included in the standards. The following are examples of the subject content of the manual with detail information including identification, material specification, etc., for each material.

METALLIC MATERIALS

Ferrous Metals

Iron and steel alloys
High-strength steel alloys
Corrosion-resistant steels

Nonferrous Metals

Aluminum alloys and castings
Titanium alloys and castings
Magnesium alloy and castings
Miscellaneous alloys

NONMETALLIC MATERIALS

Wood
Plastics
Composite
Elastomers and cork

5.4.2.3 Processes

Process specifications are statements of engineering requirements supplemental to engineering drawings or to other specifications to assure quality and the reliability of parts made to the engineering design. The manufacturing and quality control organizations use these specifications as a means to establish and check manufacturing processes to ensure that engineering requirements are met and part integrity is achieved.

The processes covered by this document include:

Rivet installation (solid and blind)

Welding processes (fusion welding; aluminum, steel, and titanium alloys; and resistant welding)

Bolts-and-nuts installation

Application of adhesive

Sealing (structural, fuel tank)

Plating

Painting

6.0 DESIGN NETWORKS

6.1 DESIGN ACTIVITY SEQUENCES

Section 6.0 deals with the design activities involved in the development of a product. Since it is a large field to view, the design process is divided into portions for easier description and comprehension. The divisions are made as each of the nine major activities occur.

6.1.1 DEVELOPMENT CYCLES

Figure 21 shows a sequence of the major activities of product development. The four continuous activities at the top of figure 21 form the industrial background from which the product development originates. The top line is the research and development to provide new design concepts and technology. The resources control of a company provides capability to support a new product in terms of manpower, facilities and finances. The marketing, finance,and preliminary design groups combine these resources with continuing conceptual studies of new products. Management authorizes a preliminary design effort when the marketing studies reveal a product with sufficient sales potential to warrent further study. This initiates the development cycle of a specific product. The process then enters several phases of design leading to firm offers for the sale of the product to potential customers. If sufficient sales response is generated by the potential product, management will authorize a go-ahead for detail design, manufacture, verification and support.

The development cycle for a typical subsonic transport aircraft requires several years from preliminary design go-ahead through airplane type certification, and the preliminary design phase requires approximately 25 to 30 percent of the total development cycle time. More complex products, such as a supersonic transport or a space shuttle, will require several more years and the preliminary design effort may require a larger percentage of the development cycle. The IPAD system must support time-related, highly flexible development processes and provide continuity of the data development required to support integrated design tasks.

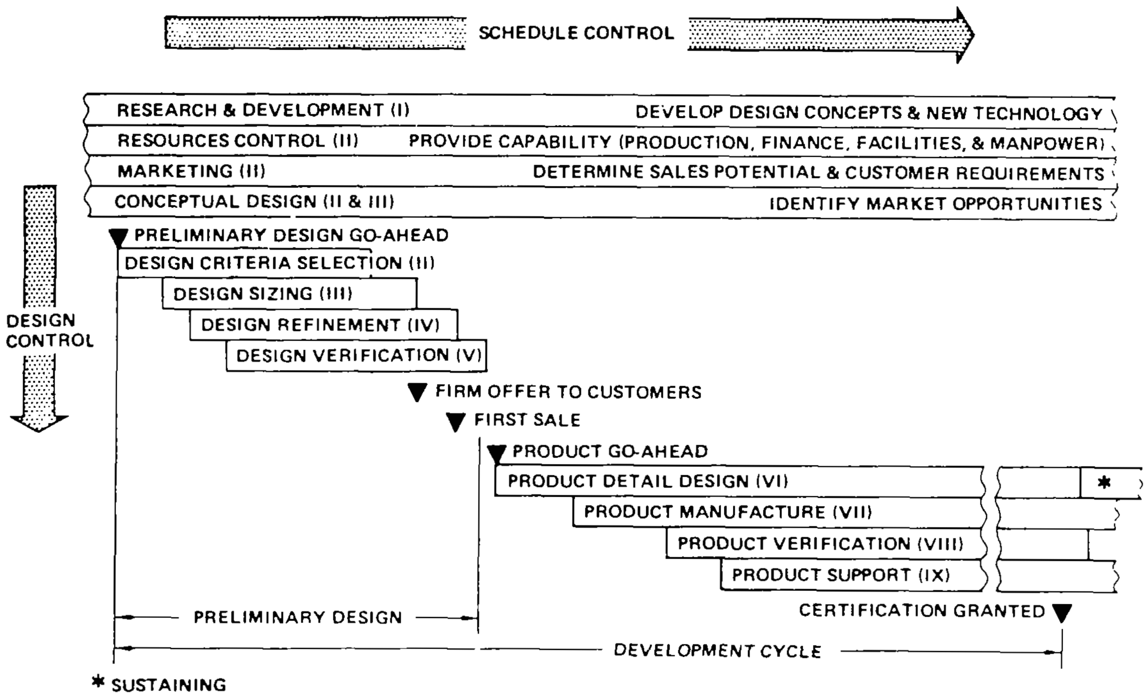


Figure 21. —Development Cycle

6.1.2 DESIGN ACTIVITY LEVELS

The purpose of design activity levels is to subdivide the environment within which IPAD will relate to a product and its design process. This division is considered to be product-independent and serves as a guide for the classes of man and machine involvement with a product. Figure 22 shows the nine activity levels divided into three sections.

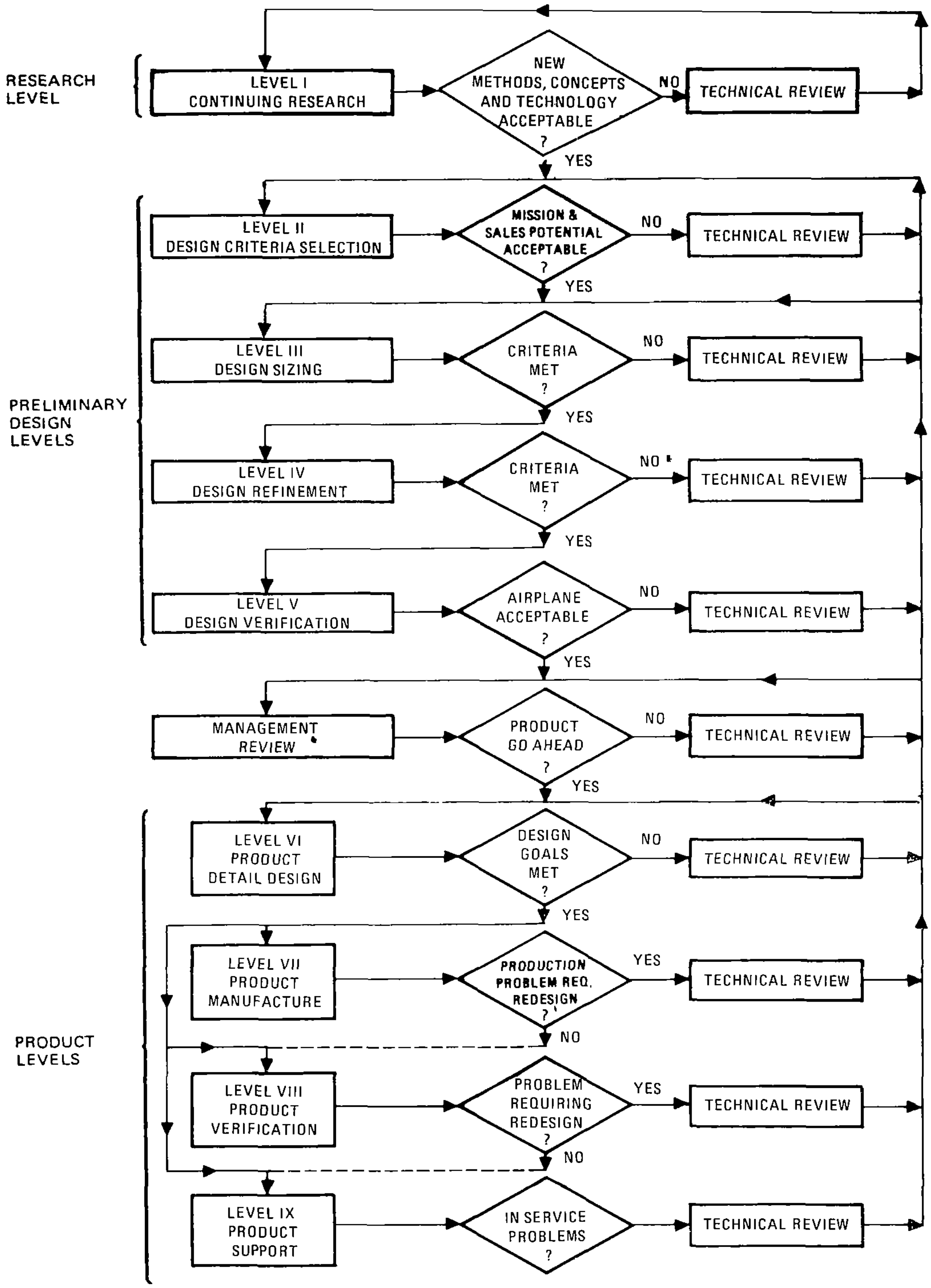


Figure 22.—Activity Levels

6.1.2.1 Research Level

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

6.1.2.2 Preliminary Design Levels

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

Because the following terms are referred to frequently in connection with preliminary design, they are defined here.

Computational Flow Time--The total elapsed working time from start to end of the computational process begins with the user collecting, revising, and updating data already in the library. The user then commits the job into execution. If the job is small, the user remains at the terminal; if it is large, he enters it into a batch execution mode. After execution is complete, the user makes a cursory examination to determine whether the results are essentially complete and correct. This marks the end of the computational flow time.

Execution Time--Actual execution of the host CPU, measured relative to third generation equipment for this document.

Design Cycle Time--The total elapsed working time from the beginning to the end of a single examination of a given design. The calculations made during this period will analyze, recycle, and suggest redesign for the input design. ("Design" is used here for a complete airplane in early level, a section (wing, body, etc.) in later levels, or for a part (rib, bulkhead, etc.) in still later levels.)

Converged Design Cycle Time--The total time from the beginning of the first design cycle until the end of a design cycle that has developed a design which meets the objectives and constraints. (See parenthetic discussion of "design" in preceding paragraph.)

Level II is the first of the preliminary design levels. It has the goal of determining the design criteria that will result in the product with the greatest sales potential. There will be some limited design and analysis calculations performed in support of the search for the best design criteria, but the computational flowtime for a level II solution would be small. Typically, a level II computational flow time would be about two days and require approximately 30 minutes execution time. In this level, computational flow time and design cycle time are synonymous. The representations of the pertinent technologies would be in greatly simplified forms.

Level III has the goal of sizing the design to the marketing criteria established in level II. It also will resize a design that has been found to be deficient in a higher level. Therefore, this level must use more rigorous analysis tools and a more complete design representation. This level may still be executed without user intervention, with a computational flow time on the order of two and one half weeks to one month, having execution times of approximately 1 to 20 hours. In this level, computational flow time and design cycle time are also synonymous.

Level IV has the goal of refining the design by applying more powerful analysis capabilities in previously represented technologies, and by introducing new technologies into the analysis. This is to reduce risk within a short time period by doing a thorough analysis of the major areas of the design. It is likely that the first several examinations of a design sized in level III will reveal deficiencies and thus require resizing. The computer executions in level IV will be done with user interaction, with design cycle times of one to two months, and with execution times of approximately 25 to 60 hours. This level will have a converged design cycle time of two to four months.

Level V has the goal of verifying the design so that a decision about product go-ahead can be made with minimum risk. This verification is achieved by the most rigorous analysis available in the various technologies and by performing selected tests to provide specific data to supplant generalized information obtained from the data base. The design cycle times for this level would be 1.5 to 3 months with execution times of approximately 40 to 200 hours. The converged design cycle time would be three to six months.

6.1.2.3 Management Review

Following level V, the design is reviewed and the commitment to production is considered. If the production go-ahead is granted, the activity proceeds to level VI. If the design is not suitable, management provides direction to return the design to level III for sizing a new design concept, or to level II to establish new or revised marketing criteria that will generate an entirely new group of designs.

6.1.2.4 Product Levels

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

Level VI, product detail design, is the level in which the detailed parts for the product will be designed. This will require much analysis activity, interactive parts design, and thorough testing of components and details unique to this product. The IPAD environment will enhance the detail design process by providing automated support of the data base, aiding in the interface between design and manufacturing, coordinating the various analysis results, and providing management information about the progress in the detail part design activities.

Level VII is assigned to product manufacture. The making of the product will be done from information conveyed from the IPAD system to manufacturing. Much of this interface is expected to be with the computer-aided manufacturing (CAM) systems. Manufacturing problems requiring design modifications will be related to level VI for redesign.

Level VIII performs product verification. As soon as components (and ultimately the completed product) are available from manufacturing, testing will commence in order to verify the product. The IPAD system will support the documentation of results through its data base capabilities and will convey information to level VI in cases where redesign is necessary.

Level IX provides product support once the product is in service. Problems arising from use in service will be referred to Level VI for solution. The data base facilities of IPAD will aide in collecting in-service part histories, which will be used to improve the data base used in the preliminary design levels.

Figure 22 shows the four levels in the product level group. However, the direction of the arrows on the flow paths are significant. They indicate that level VI provides design information to level VII, VIII and IX and these levels return information to level VI. Thus, levels VII, VIII, and IX do not communicate directly, but through level VI, because the information to be relayed will concern the detail design. As long as the product is in service, there will be a need for some sustaining activity in each of the four product levels. The data base established, maintained, and qualified by the IPAD system will be of great utility in supporting the product over a long time period.

The nine levels of activity relating the product to the IPAD environment are of a general nature, and it appears they can be applied to a wide range of products, such as trucks, ships, airplanes, etc. However, the more complex products will yield the information required to develop the IPAD system and select host hardware. Also, the design and manufacture of more complex products should have greater benefits from the IPAD environment. Two product classes have been chosen for examination in this description: subsonic commercial aircraft and supersonic commercial aircraft. In addition, a brief examination was made of a naval hydrofoil. These projects will be discussed in further detail in the following sections.

For the airplane studies, the technical design and analysis functions of levels II and III match the design (configuration) size to the mission and design requirements. These levels treat the configuration as a unit, and the propulsion analysis deals only with development of engine thrust requirements and cycle matching or matching the configuration to a specific engine. Both cases require a preselected propulsion design concept that includes number and location of the engines. Level IV refines the sized configuration by developing a more complete definition of structure and nonstructure items and by providing greater confidence through increased analysis. This level also treats the configuration as a unit; however, a parallel propulsion study is conducted to monitor the propulsion installation and performance requirements. This study determines the feasibility of meeting the propulsion requirements with an existing engine (or by a proposed new engine) and the validity of nacelle integration.

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

It is re-emphasized that the design networks presented in sections 6.2 and 6.3 are examples only; they are not strictly hands-off automated networks. However, the capability for near automated configuration sizing is an IPAD implementation goal. This requires development of default data for variables that do not routinely change and can be established for a class of problem. It is further emphasized that all default values must be identified on command and that the capability to alter them must be provided. Using suitable default values will provide the basis for near-automated configuration sizing at levels II and III and extend the configuration designer's capability to search for benefits from unconventional designs that might thereby provide insight for innovation. The design and analysis activities in levels IV, V, and VI require active support of specialists from all the involved disciplines.

There is a considerable degree of similarity between the network descriptions of projects 1 and 2. For the sake of completeness, each description is presented complete. The reader is advised that there will be much repetition between the two network narratives.

It will also be noticed that optimization is not mentioned in these network narratives but is applied with discretion to selected parts of the design network, as circumstances require for most effective use of various types of optimization. (See section 5.0 of reference 3.)

6.2 PROJECT 1 - SUBSONIC COMMERCIAL AIRCRAFT

6.2.1 PROJECT DEFINITION

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

6.2.2 DESIGN NETWORKS

The design activity level concept of figure 21 applies to this project. However, the titles of levels III, IV, and V are referred to as configuration sizing, configuration refinement, and configuration verification. The following table represents the time objectives for the preliminary design levels:

Level	Time per Design Cycle	Time for Converged Design Cycle
II	2 days	*
III	2 and 1/2 weeks	*
IV	1 month	2 months
V	1 and 1/2 months	3 months

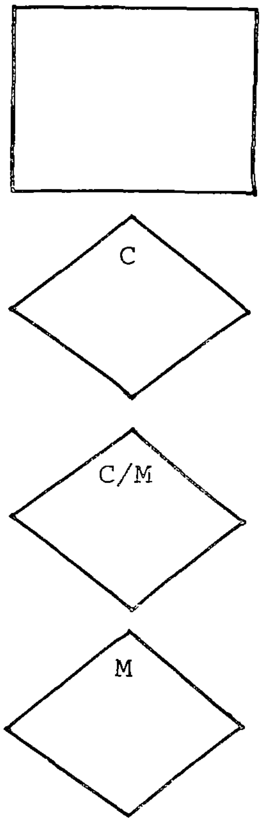
* One design cycle provides a converged design at levels II and III. A management decision is required to continue until a converged design is obtained at levels IV and V. This provides management control of the costs for computing and development testing (section 6.1.2).

6.2.2.1 Detailed Design Networks for Product Levels

Figures 23 through 42 present the detailed design networks for project 1. The following information is pertinent to the networks:

PROJECT 1 - SUBSONIC A/C (cont'd.)

Network blocks



Activity or event*

Computer decision

Computer or man decision

Man (or men) decision

* Any activity which has a "do" connection, (e.g., display, develop, revise, etc.) includes the "gather information" network described in section 6.5.

6.2.2.2 Weights Nomenclature

Type A - Statistical group weights

Type B - Analytical primary structure weights, statistical weights for rest of airplane except for known components

Type C - Analytical primary and secondary structural weights, statistical weights for rest of airplane except for known components

Type D - Analytical weights (primary structure, secondary structure and all other items) except for known components.

Type E - All weights are determined by individual part.

OEW - Operating empty weight. This designates the weight of the airplane including all weight except payload and usable fuel.

6.2.2.3 Equations of Motions

The equations of motion are a large group of technical program elements which have been identified as a procedure in a separate network. They were grouped as a procedure because they are repeated many times throughout the design networks. The equations-of-motion network is shown in figure 42.

6.2.2.4 Gather Information Network

Throughout the design process, at each event where there is a "do" requirement (design, define, display, etc.), the engineer must gather information required to "do" that task. The "gather information" network describes the sequence of events that are anticipated in the quest for a particular information. The "gather information" network is shown in section 6.5.

6.2.2.5 Narrative Descriptions

A narrative describing the design and analysis activities is presented in section 6.2.3. Each network narrative is identified by a reference network block number. Throughout the narrative, references are made to technical program elements; an example would be ARO-1 which is an aerodynamics technical program element for subsonic wing-body design and analysis. It is an existing computer program which has been identified as a candidate for IPAD. (See Feasibility Study, volume V, Document D6-60101-5.)

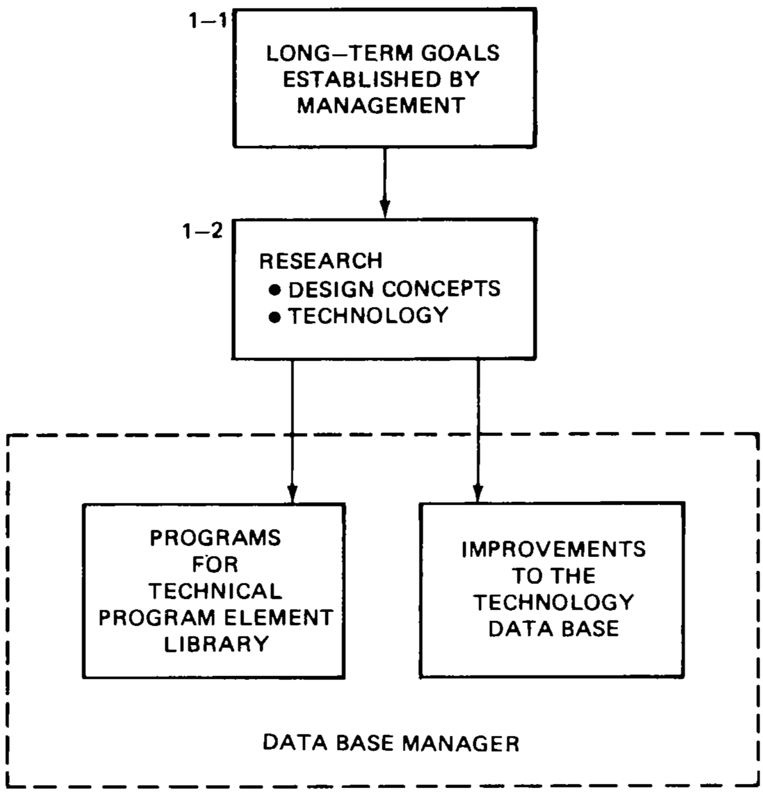


Figure 23.—Design Networks: Project 1 (Subsonic Commercial Transport)—Level I

LEVEL II – DESIGN MISSION SELECTION

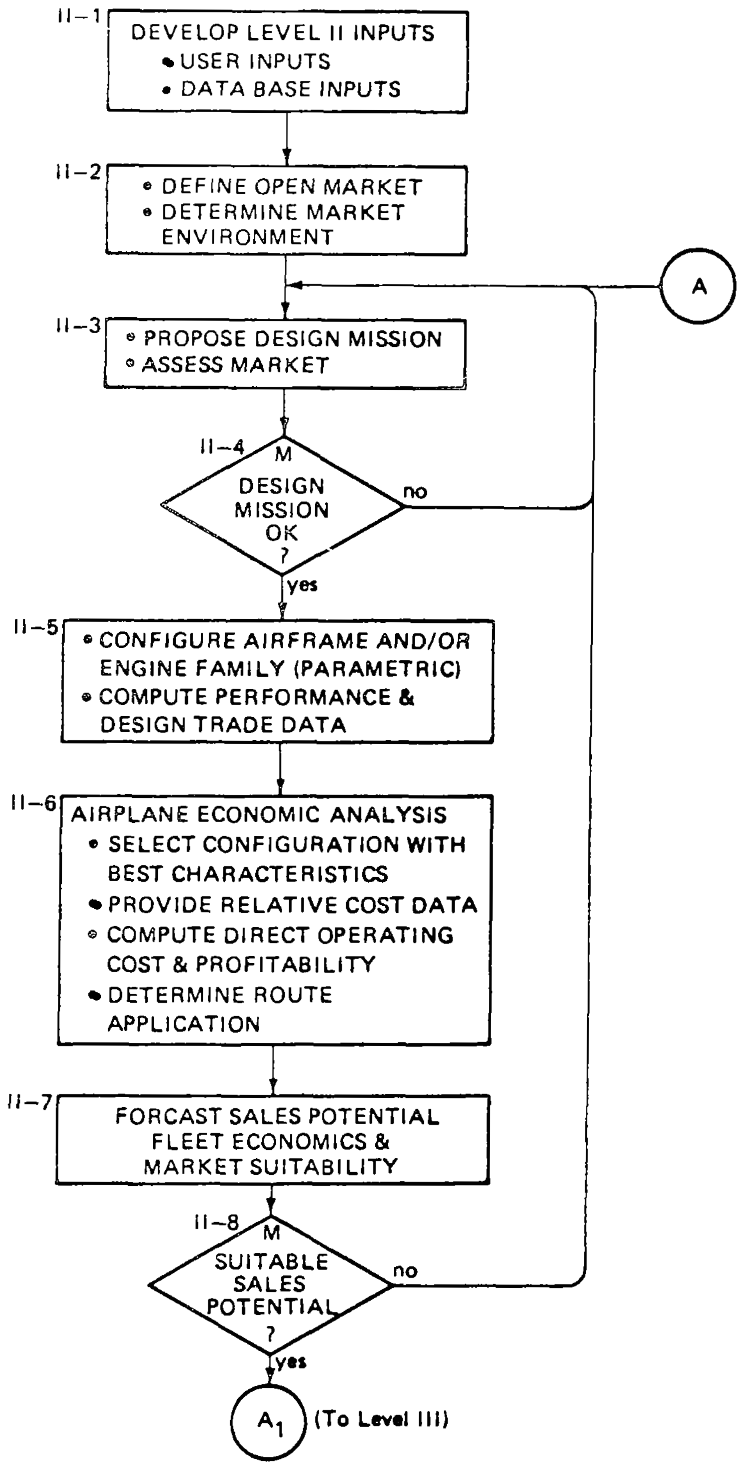


Figure 24.– Design Networks: Project 1, Level II

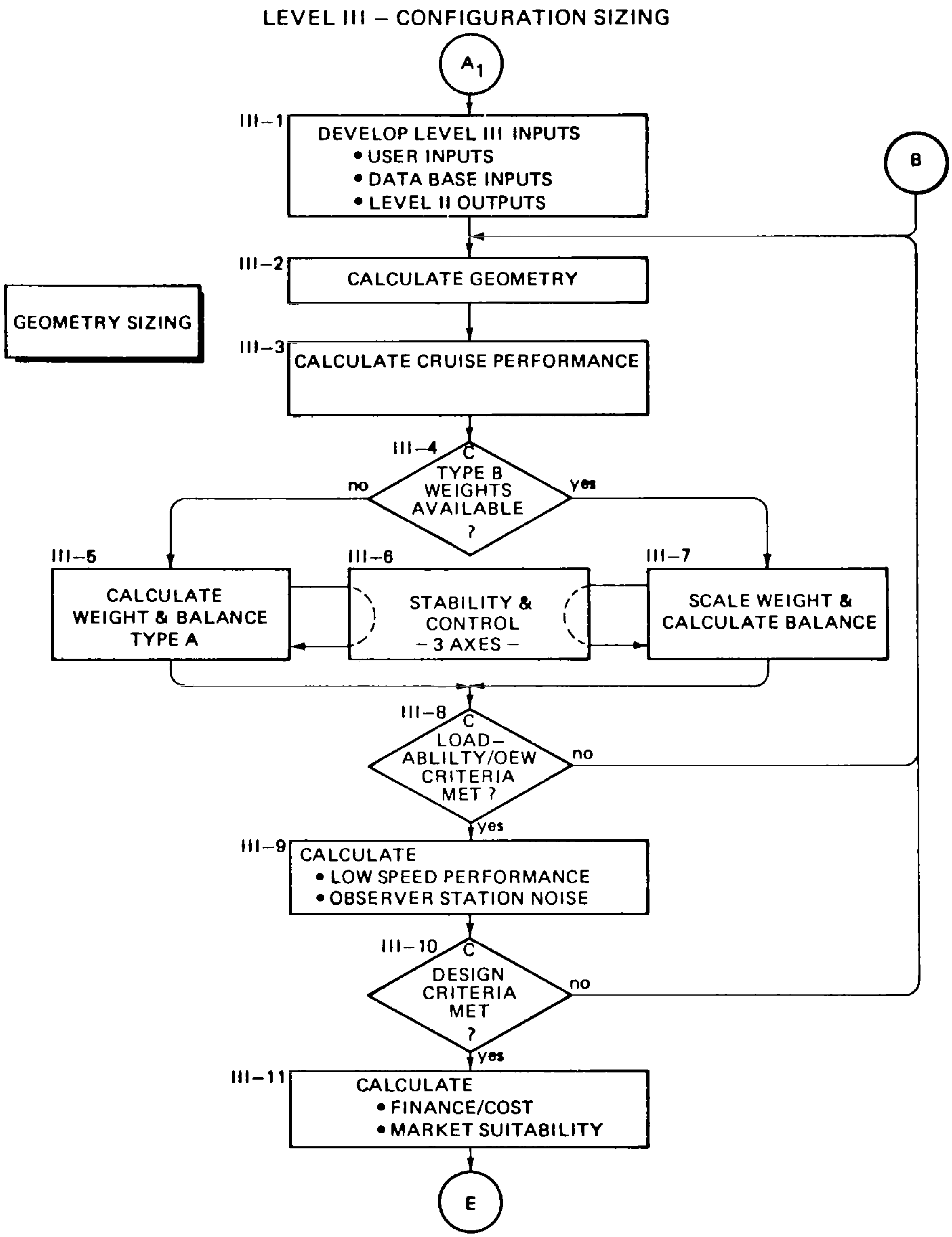


Figure 25.—Design Networks: Project 1, Level III

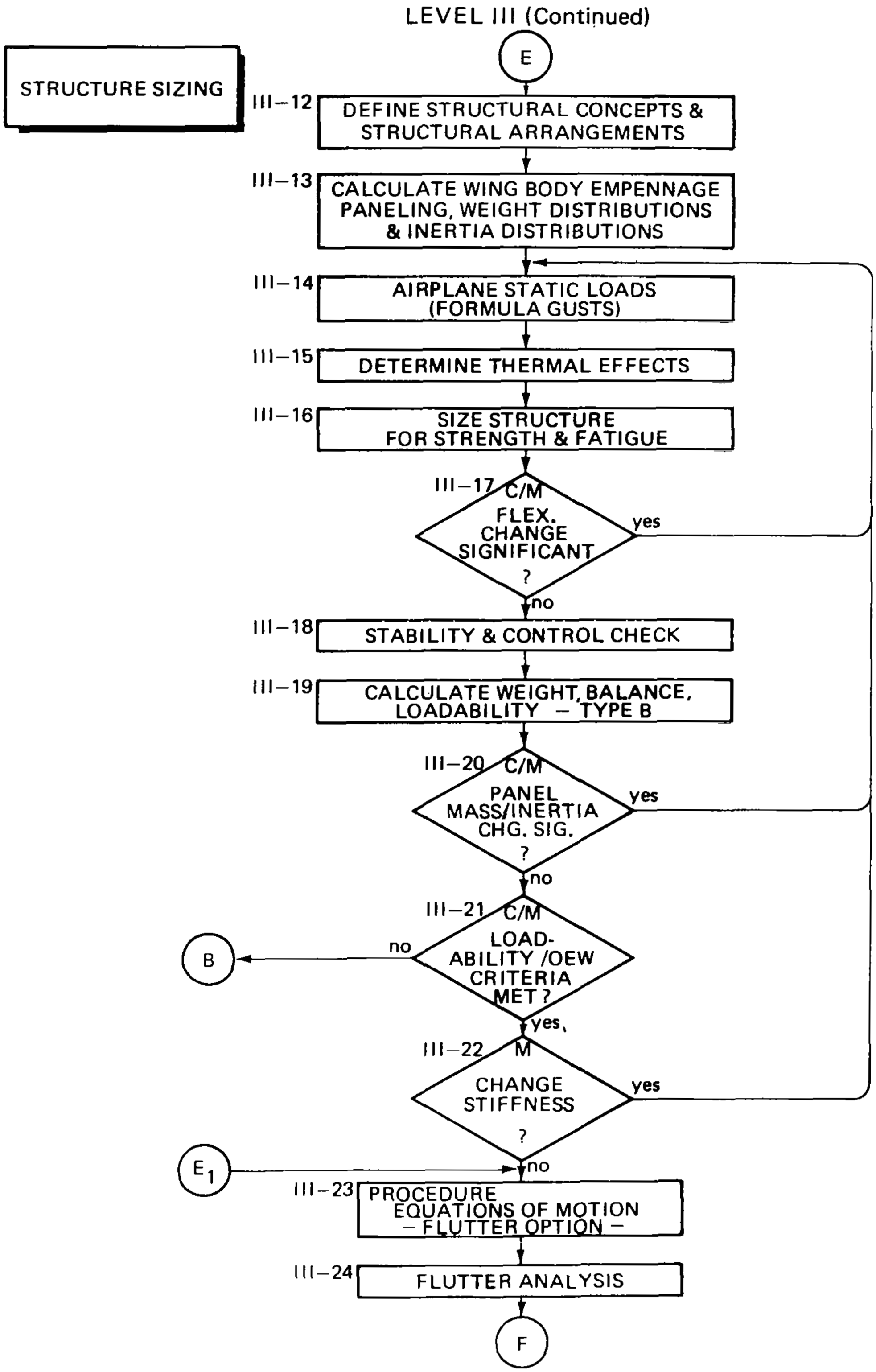


Figure 26.—Design Networks: Project 1, Level III (Continued)

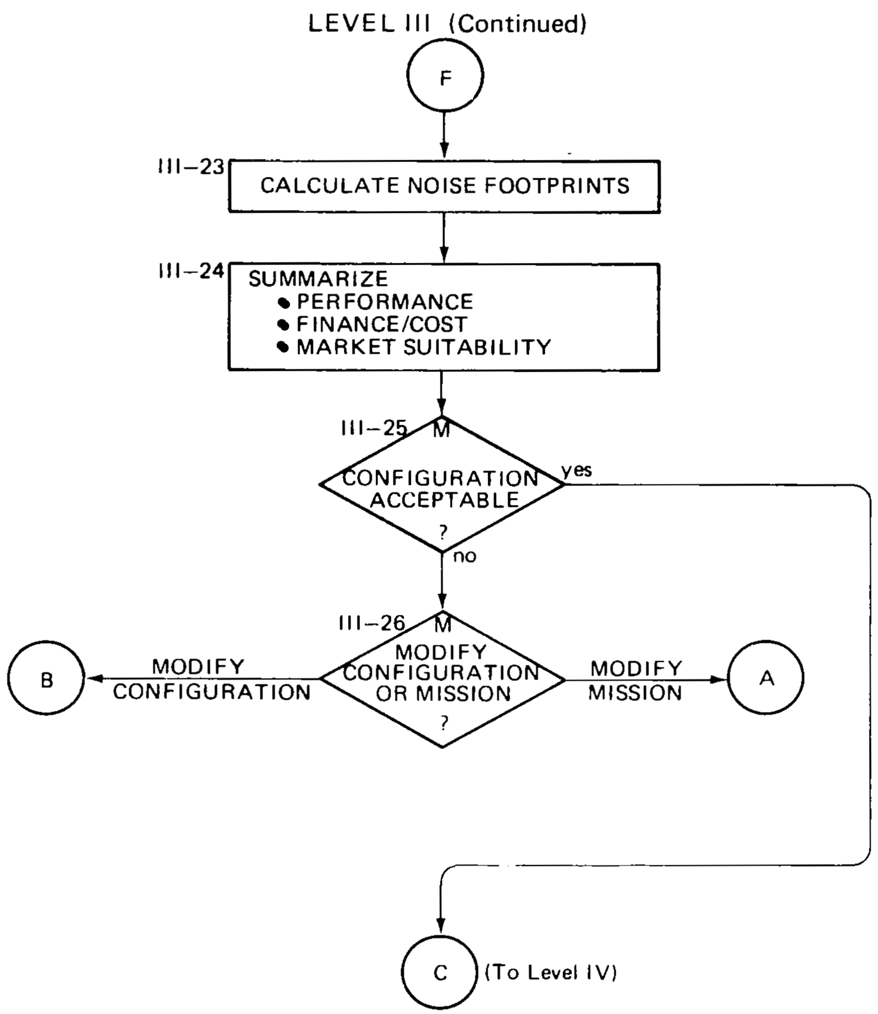


Figure 27. —Design Networks: Project 1, Level III (Continued)

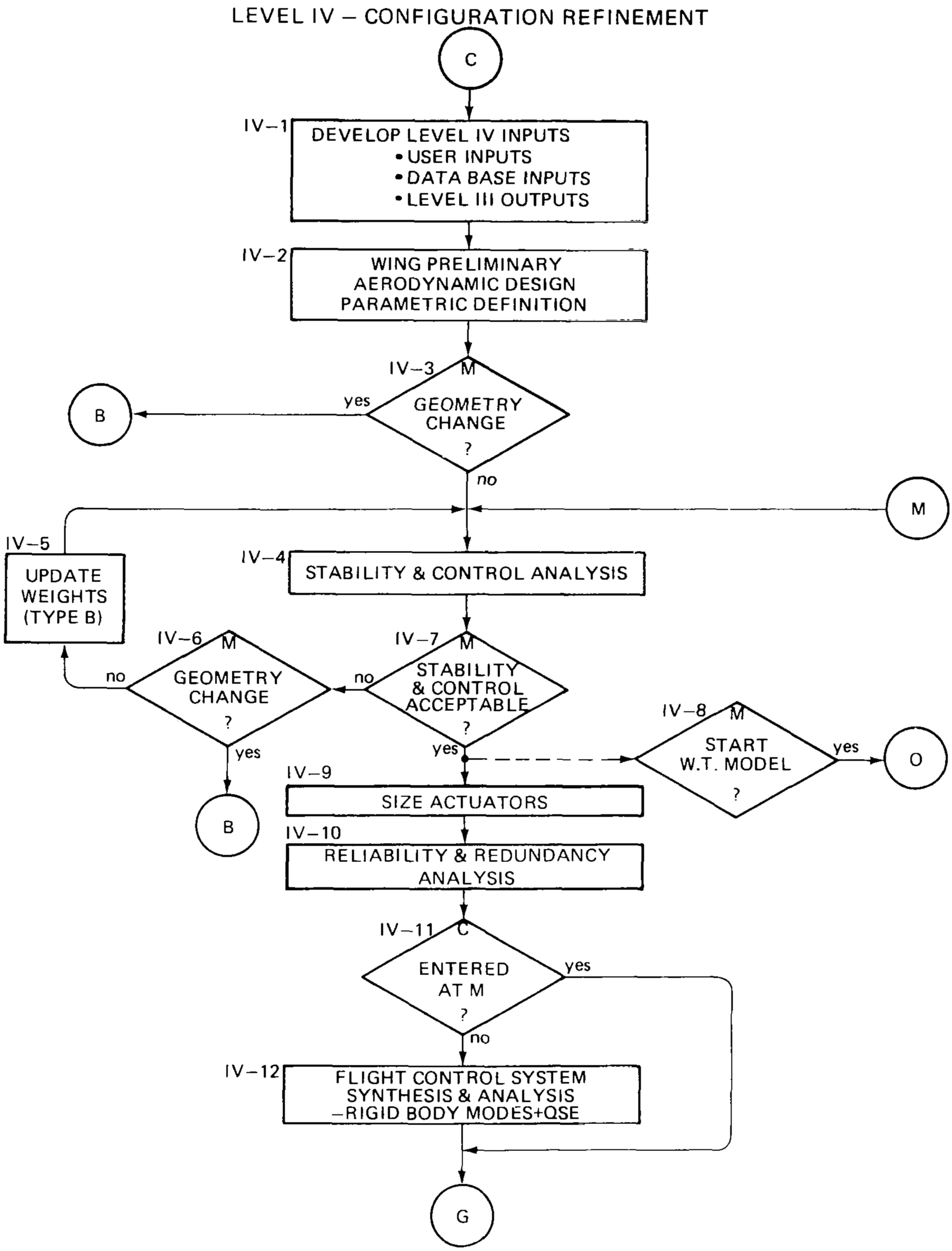


Figure 28.—Design Networks: Project 1, Level IV

LEVEL IV (Continued)

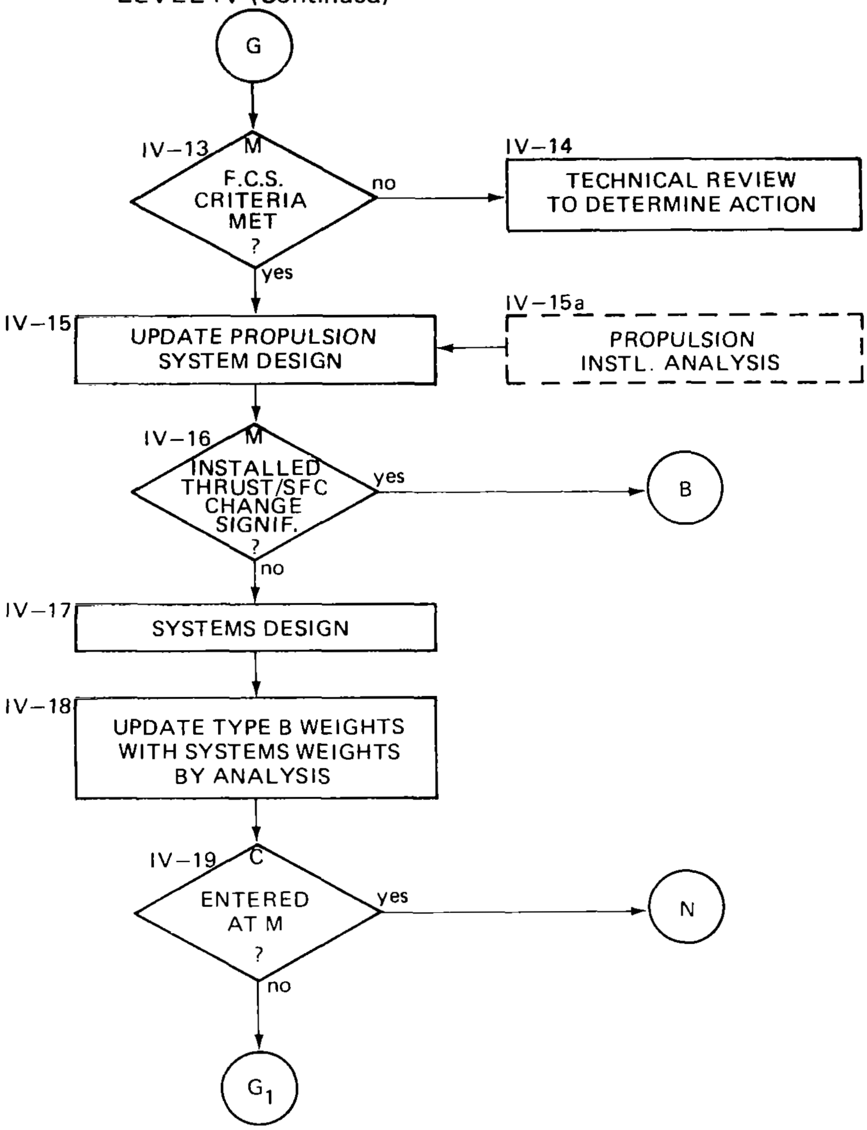


Figure 29.—Design Networks: Project 1, Level IV (Continued)

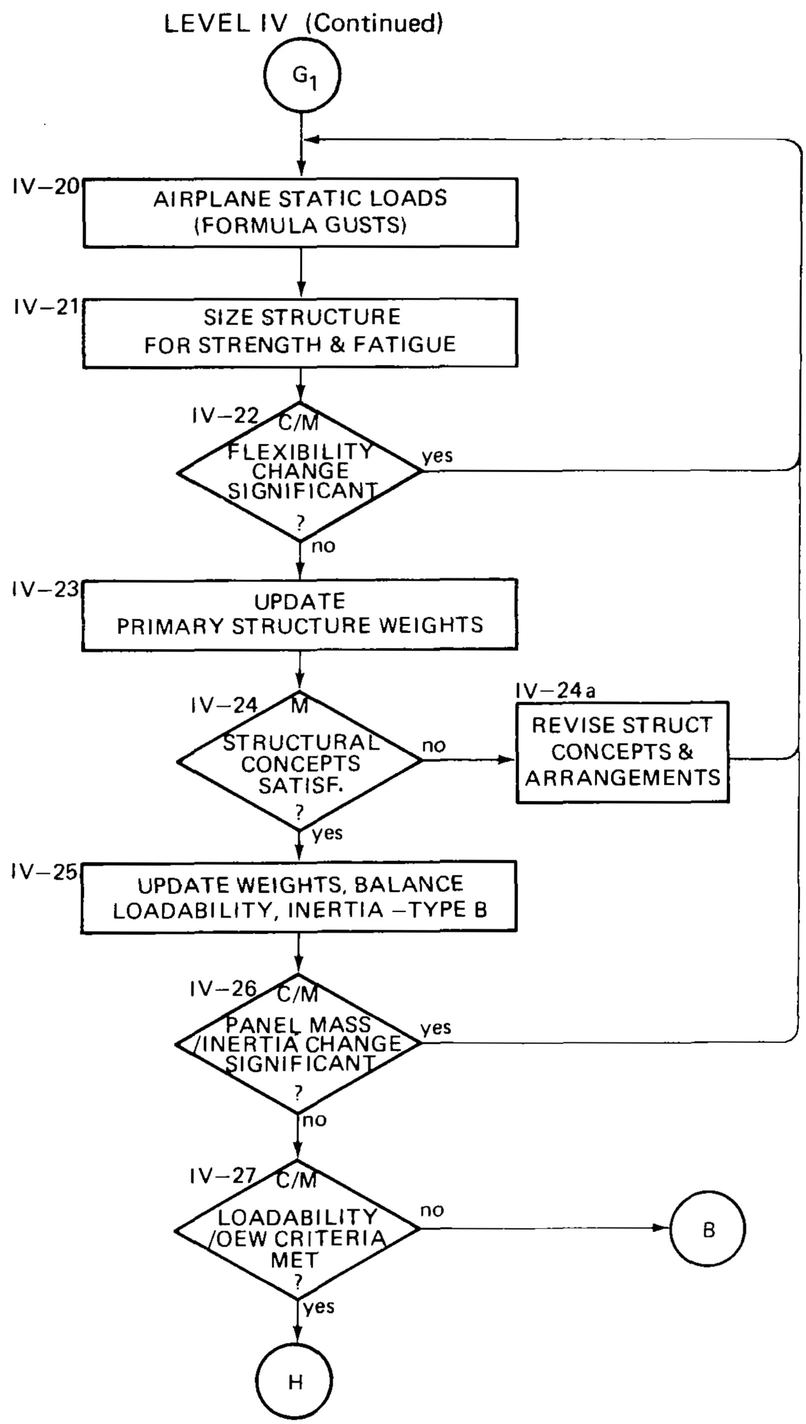


Figure 30.–Design Networks: Project 1, Level IV (Continued)

LEVEL IV (Continued)

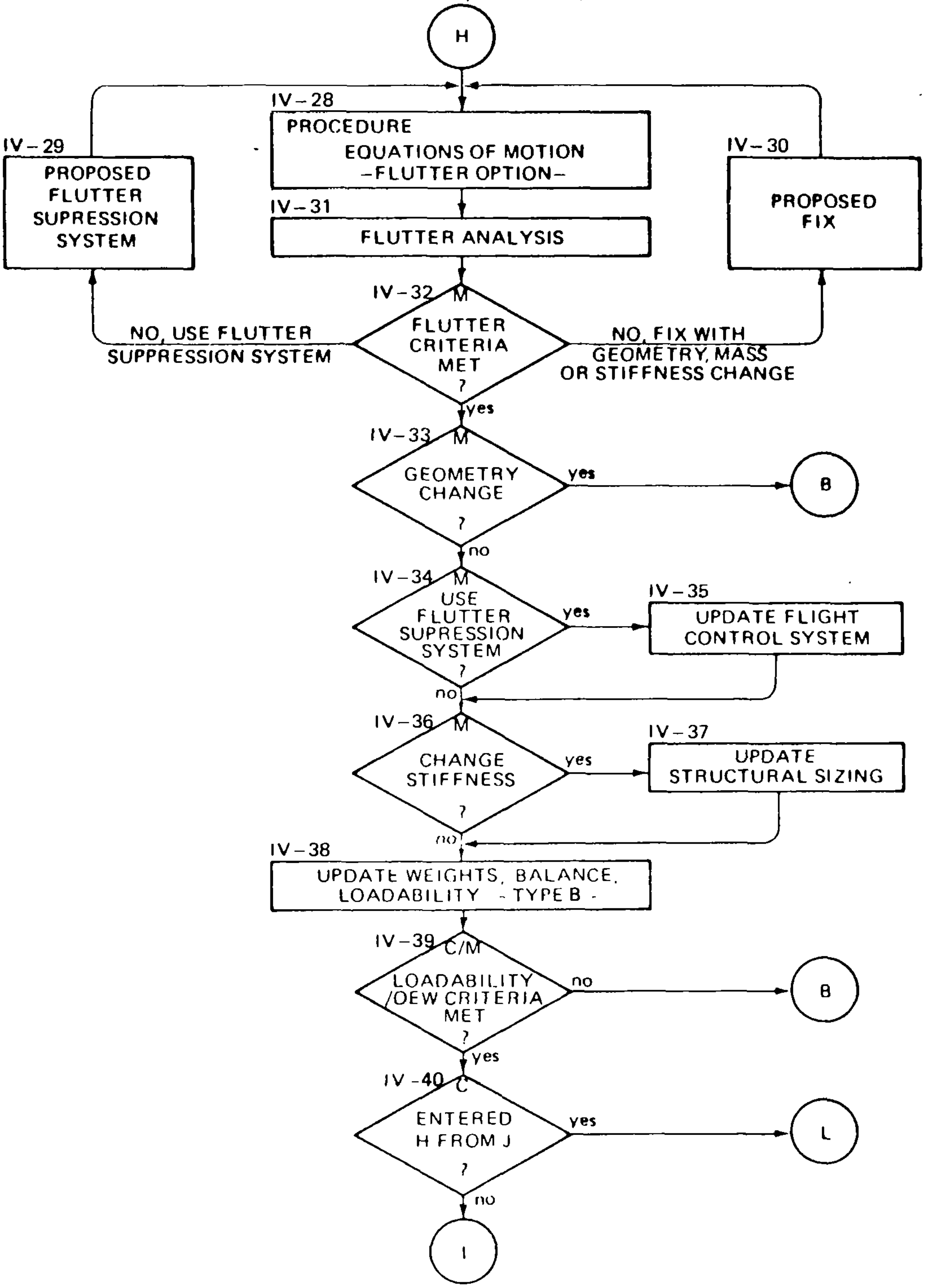


Figure 31.—Design Networks: Project 1, Level IV (Continued)

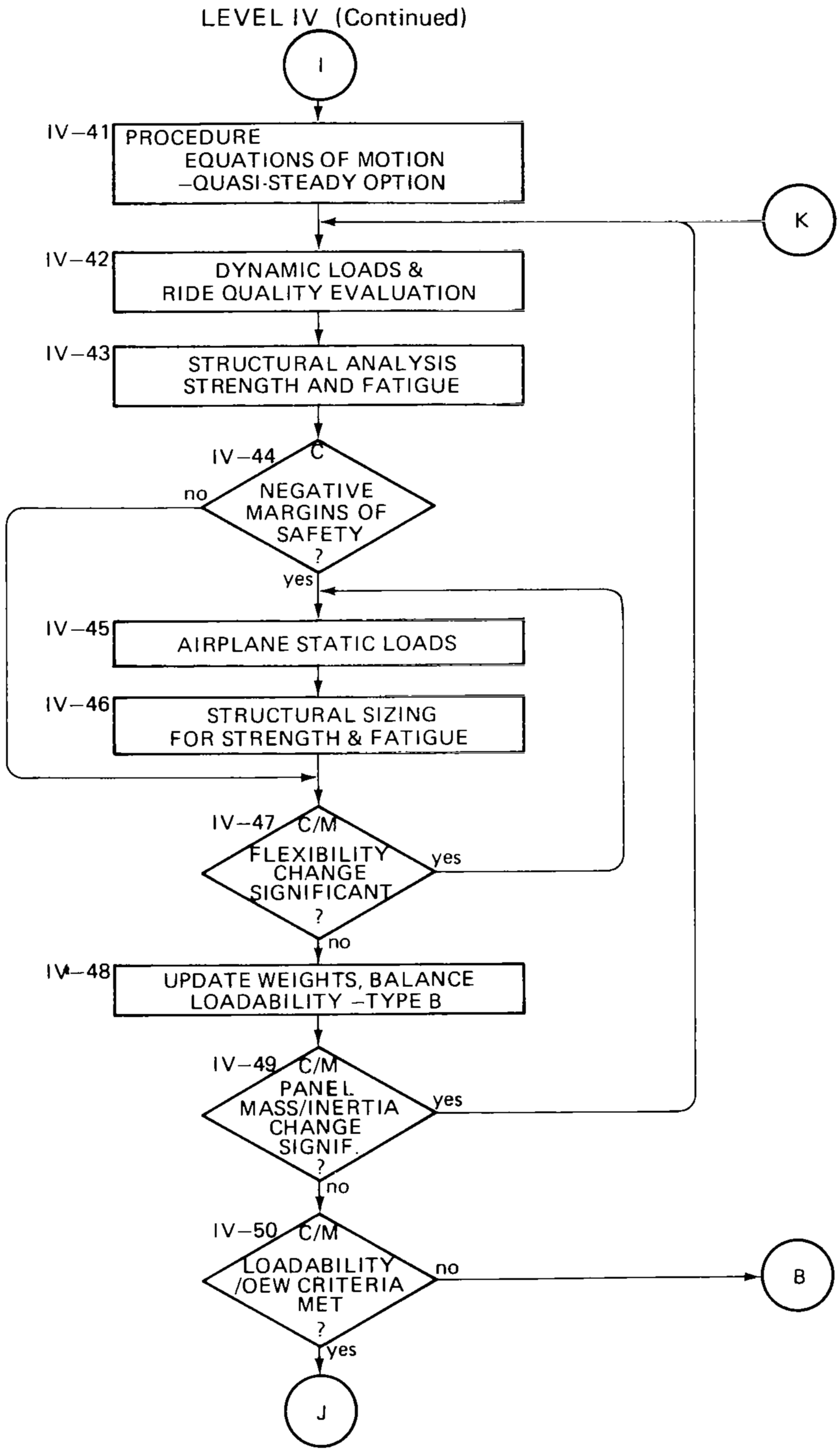


Figure 32.—Design Networks: Project 1, Level IV (Continued)

LEVEL IV (Continued)

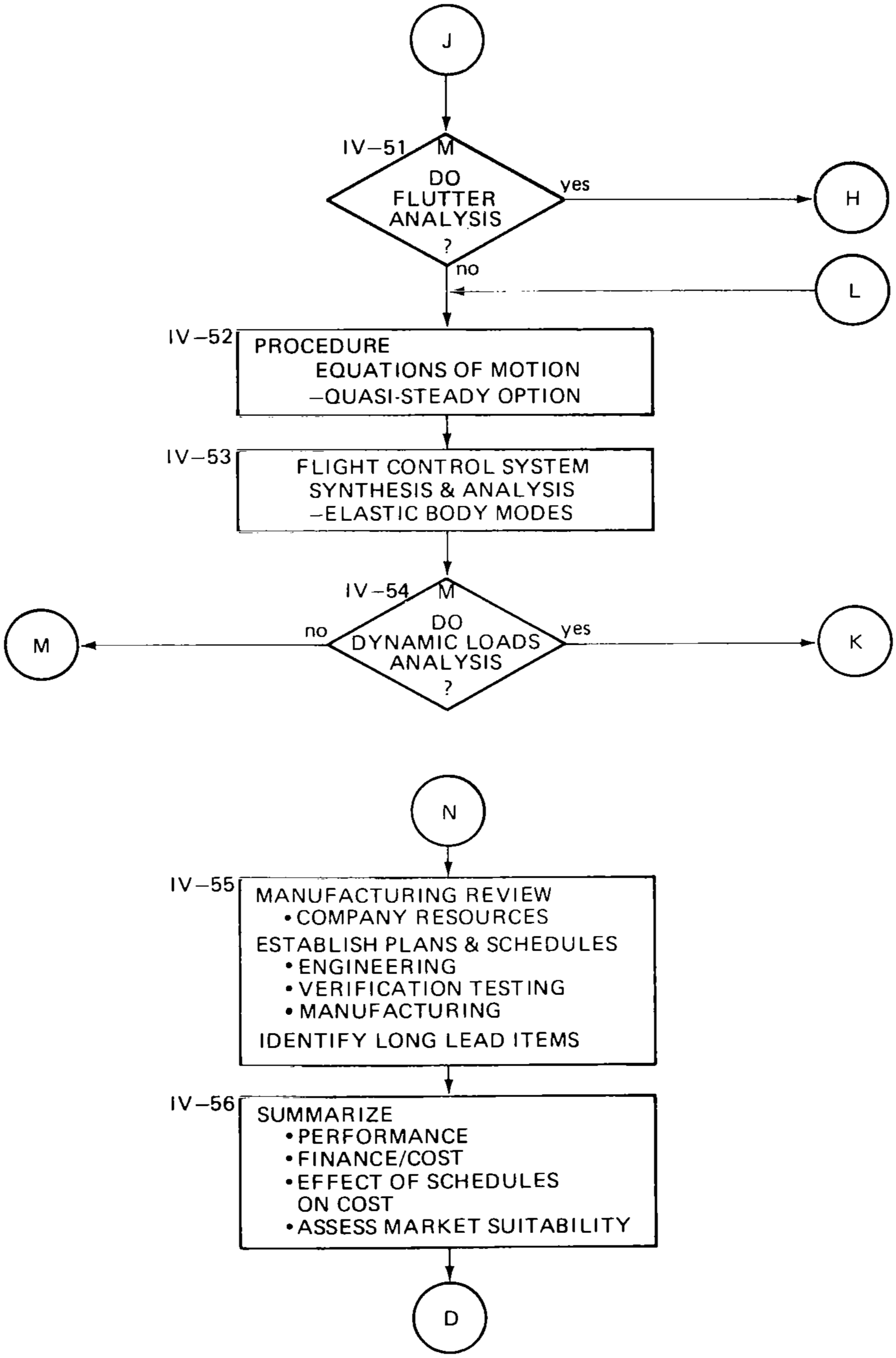


Figure 33.—Design Networks: Project 1, Level IV (Continued)

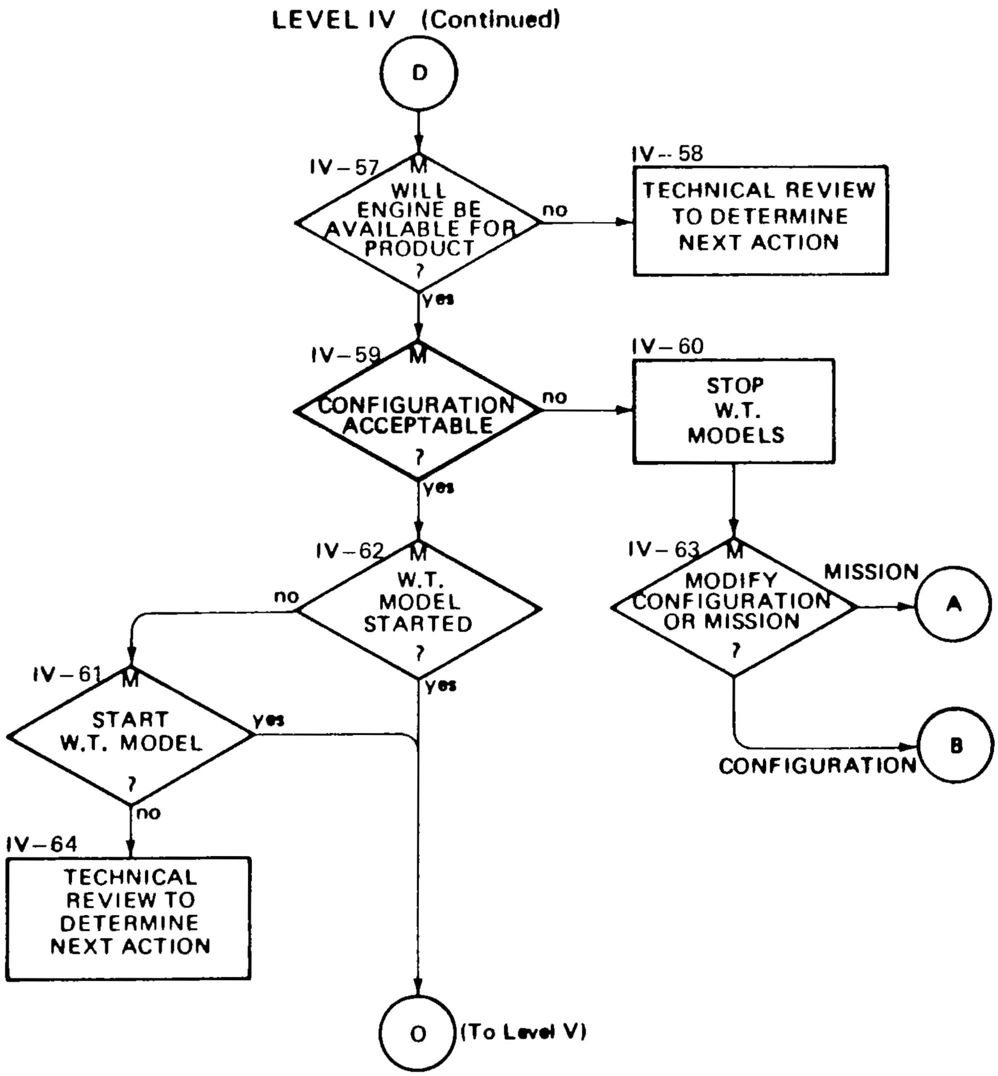


Figure 34.—Design Networks: Project 1, Level IV (Continued)

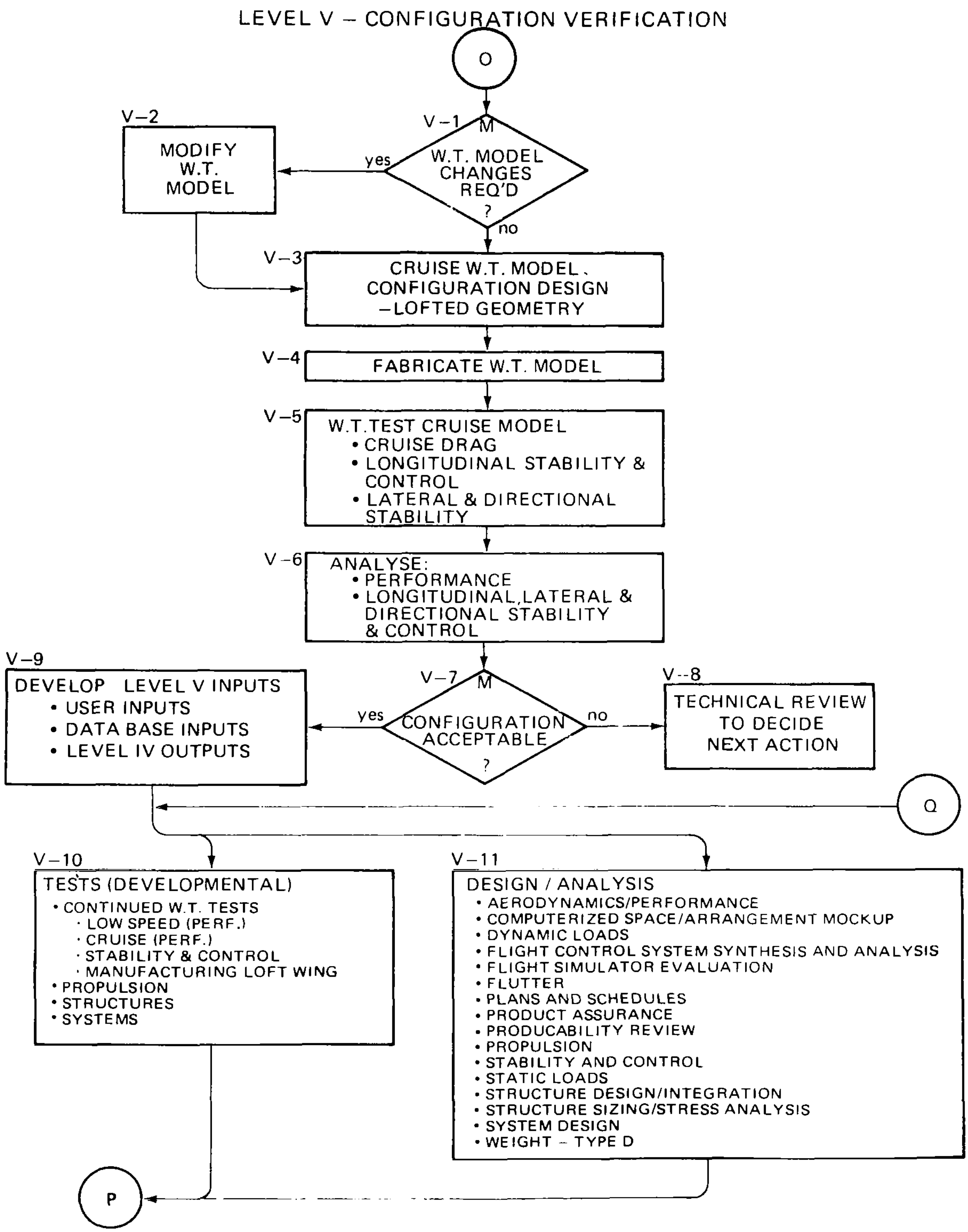


Figure 35.—Design Networks: Project 1, Level V

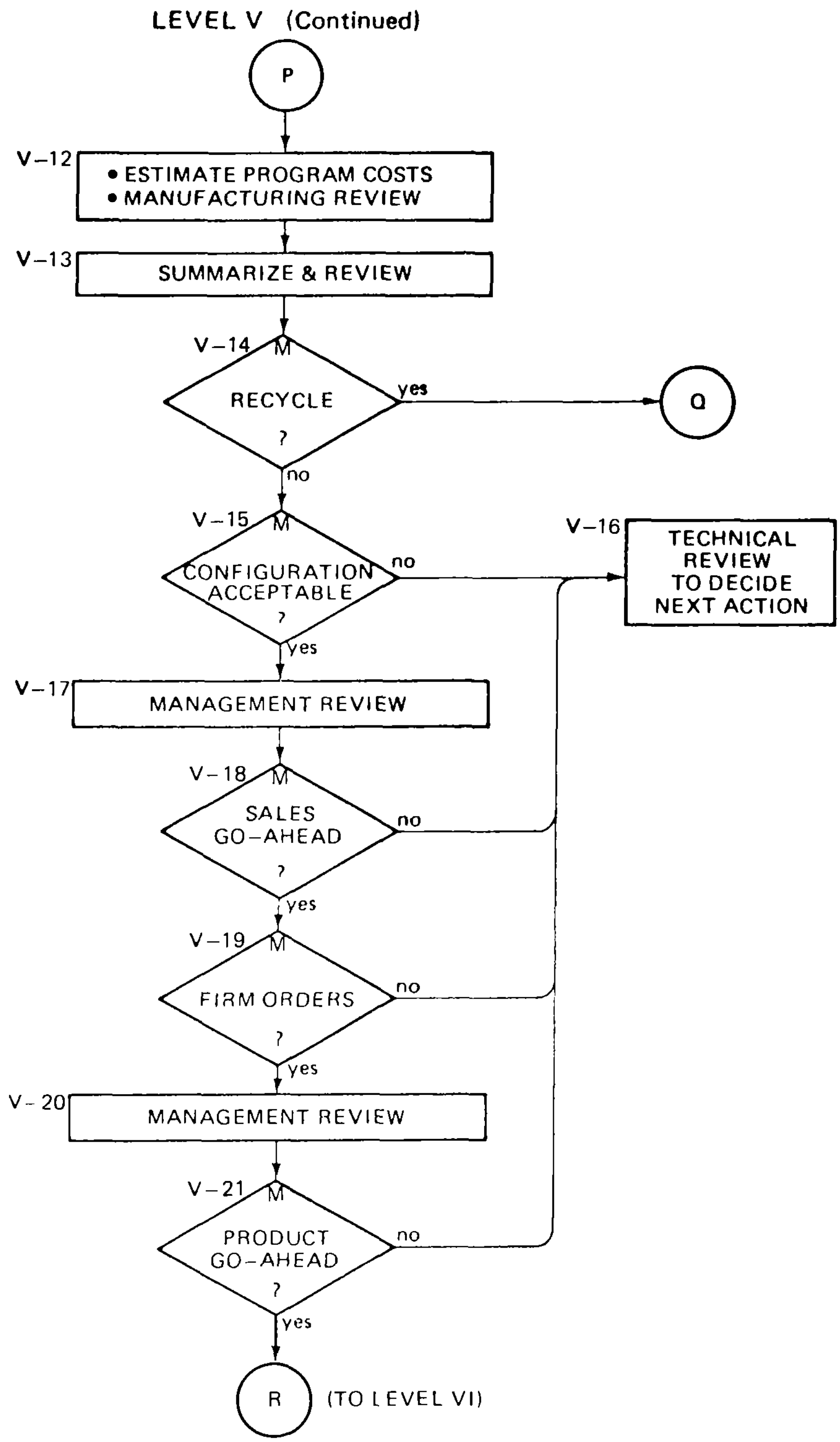


Figure 36.—Design Networks: Project 1, Level V (Continued)

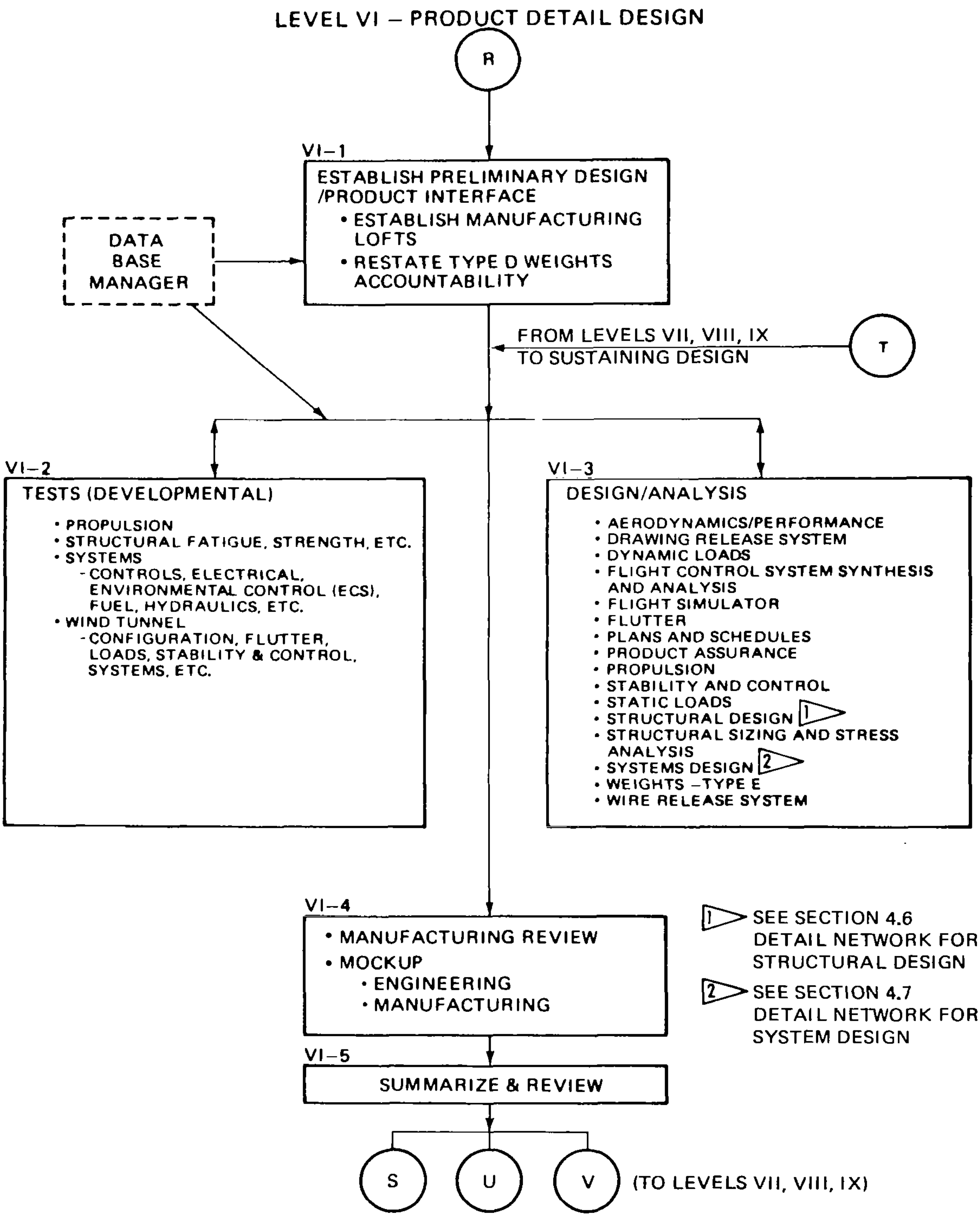


Figure 37.—Design Networks: Project 1, Level VI

LEVEL VII – PRODUCT MANUFACTURE

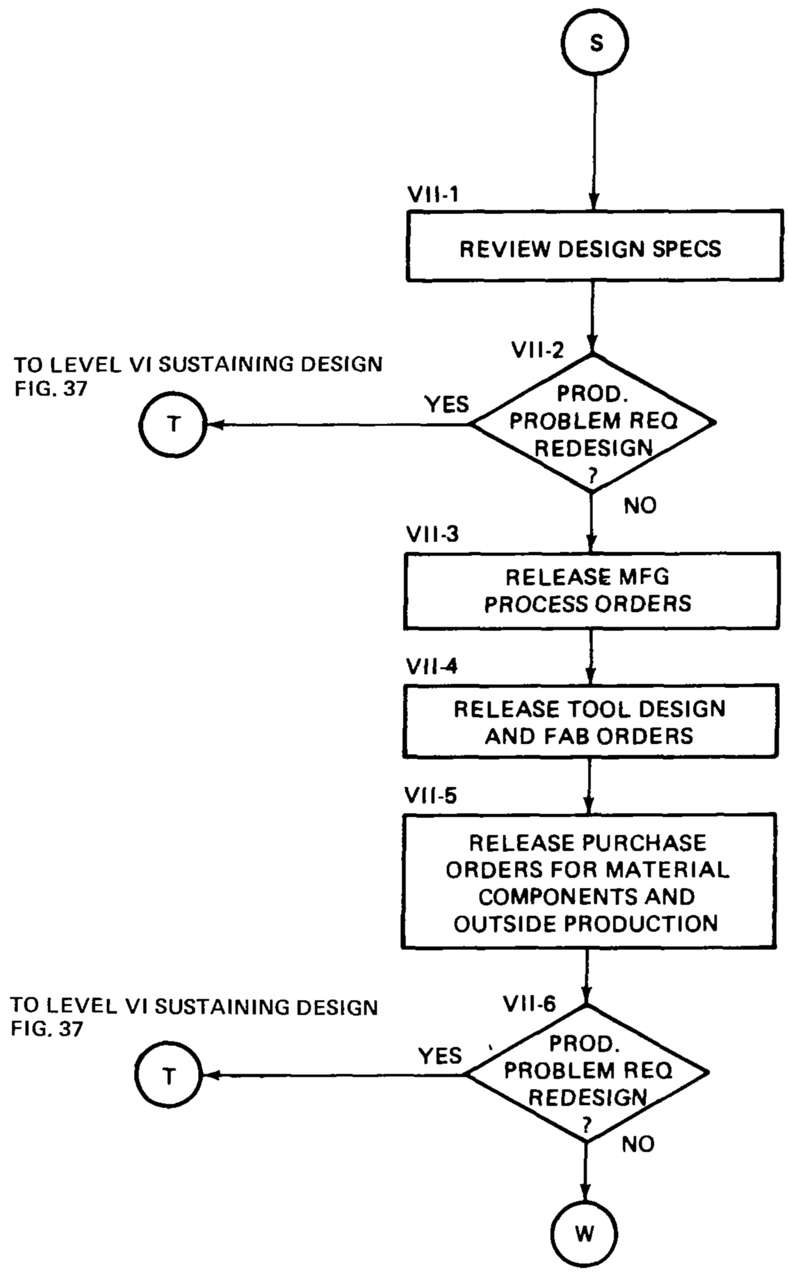


Figure 38.—Design Networks: Project 1, Level VII

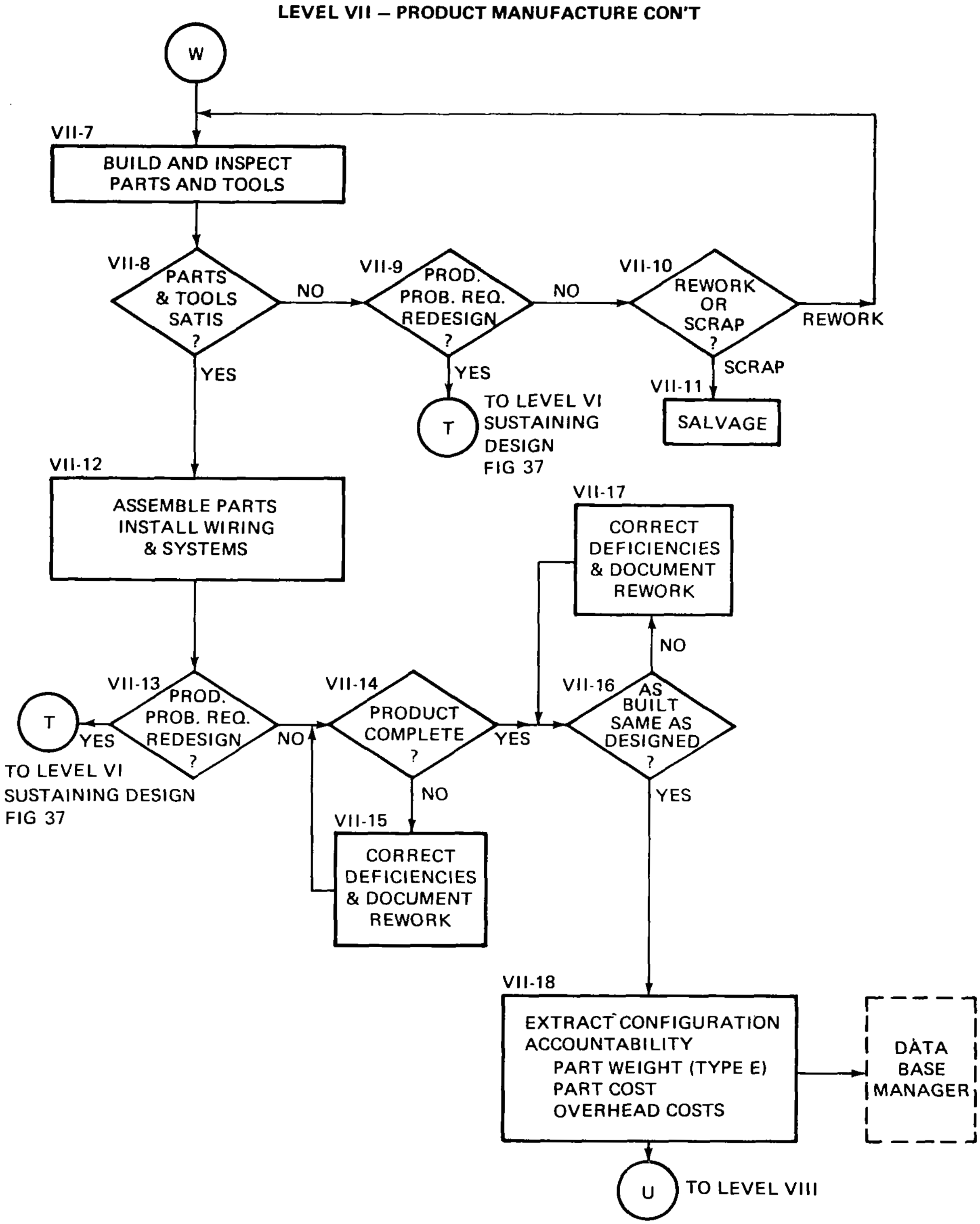


Figure 39.—Design Networks: Project 1, Level VII (Continued)

LEVEL VIII – PRODUCT VERIFICATION

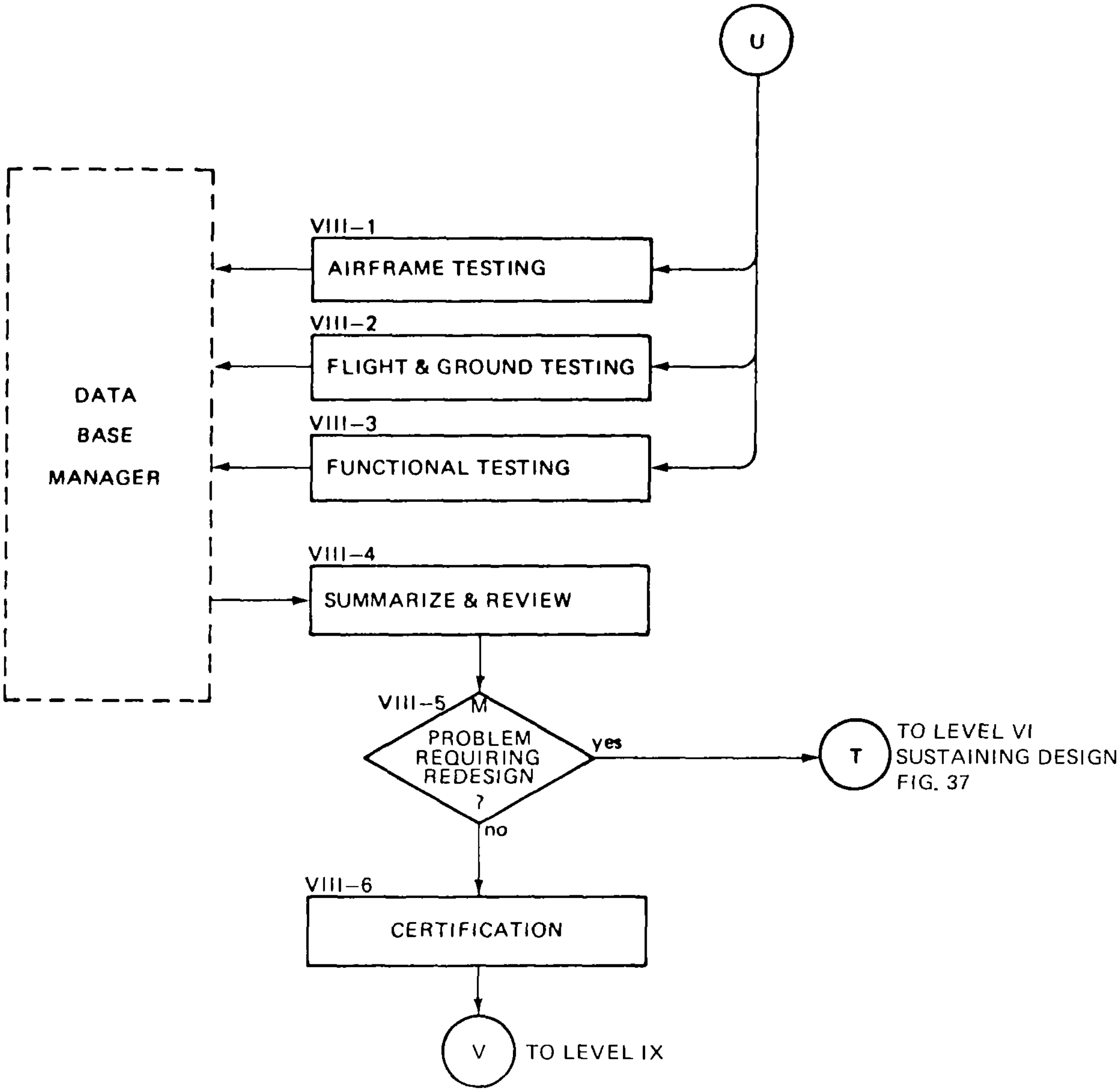


Figure 40.–Design Networks: Project 1, Level VIII

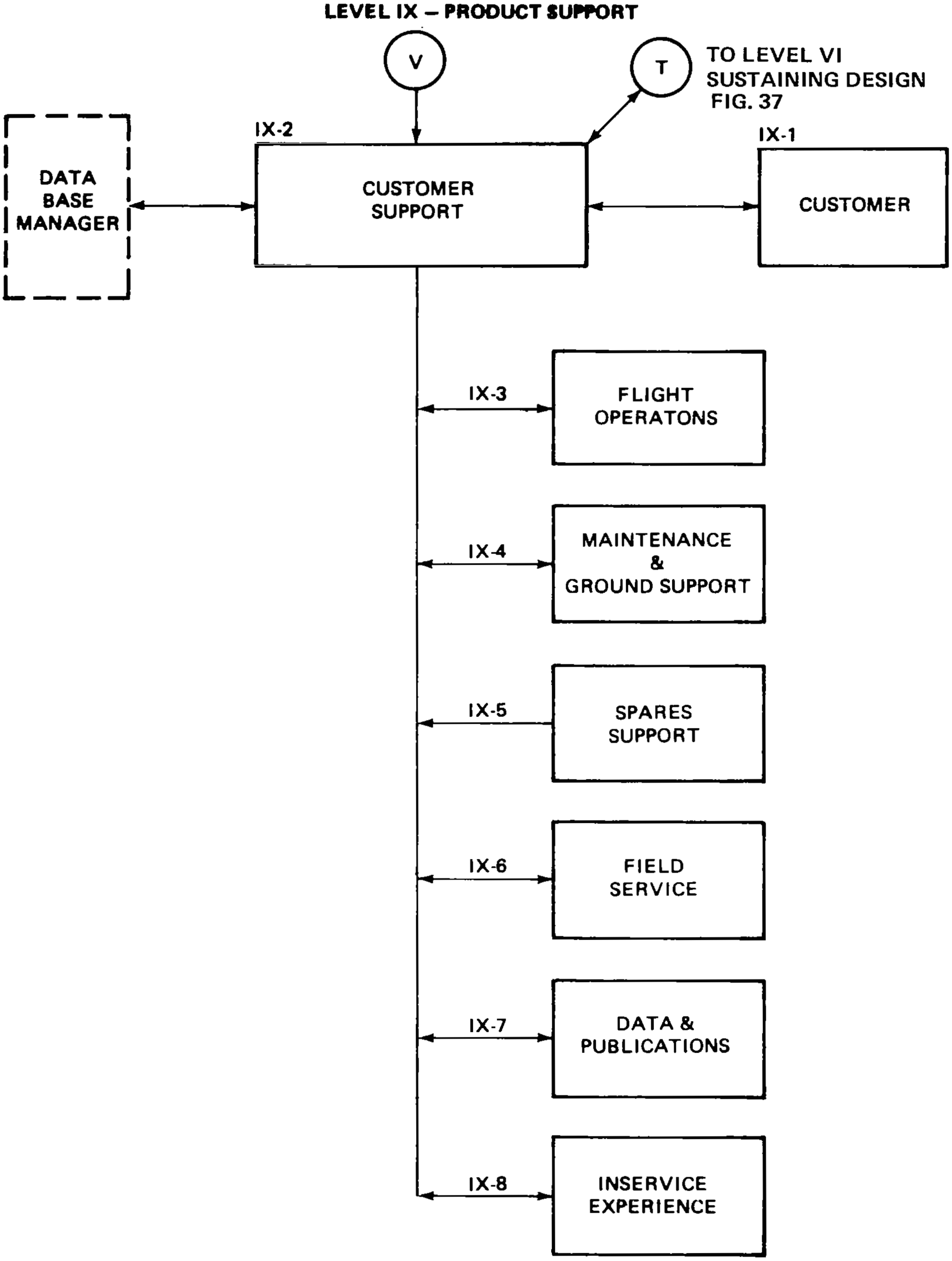


Figure 41.—Design Networks: Project 1, Level IX

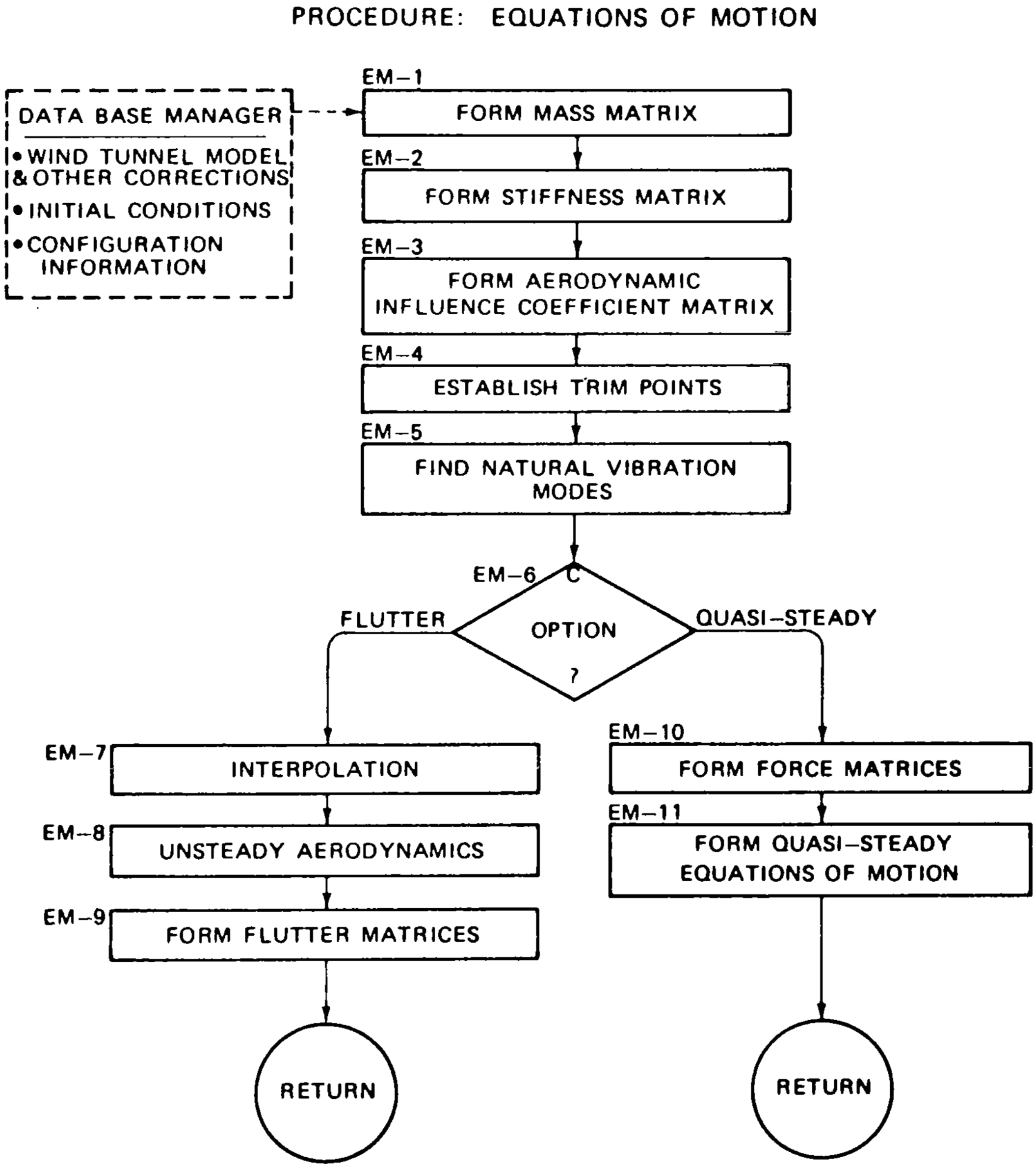


Figure 42.– Design Networks: Project 1, – Procedure – Equations of Motion

6.2.3 NETWORK ACTIVITIES DESCRIPTION

6.2.3.1 Level I: Continuing Research

The purpose of this level is to perform and monitor continuing research and assimilate results that will be important to the designer in the IPAD environment. (See fig. 23.)

Block I-1. Long-Term Goals Established by Management--Research in the technical areas of the IPAD environment will continue in the pursuit of long-term goals. These goals will be set by management and will not be required by specific IPAD activities. However, the analysis capabilities of IPAD levels II to VI may be used to indicate the more profitable areas in which research funds could be spent.

Block I-2. Research--This block represents the research being conducted to support the advancement of the state of the design and analysis arts. Design concepts refer to research conducted to develop detail application capability, such as distributed-load aircraft, V/STOL aircraft, laminar-flow control use of composite materials, manufacturing processes, jet noise suppression, variable bypass ratio engines, etc. Technology refers to the general development of information and processes within specific disciplines, such as aerodynamic characteristics of pressure distribution over airfoil shapes, potential flow analysis, or materials development characteristics. The users of the IPAD system will monitor these activities to enter new technical program elements into the library and improve the technology data bases.

6.2.3.2 Level II: Design Mission Selection

The goal of level II is to select the design mission and criteria for the subsequent design. Some very brief analysis and design logic will be required to support the selection of these criteria. (Conversely, finding markets and missions for configurations and design concepts also occurs here.)

Block II-1. Develop Level II Inputs--The data stream for this project begins with level II. The initial inputs will be derived from two sources. The user will provide specific inputs such as the problem constraints, performance requirements, and technology time period. The last item will point to groups of data in the data base required to support the various technologies. Level II is intended to be executed without interruption, therefore, all the inputs required for level II should be given at the beginning.

Block II-2. Define Open Market; Determine Market Environment--Goal: To identify the open market for a new airplane and determine market environment disciplines for the new airplane engineering design.

A mathematical model (MKT-1) calculates airline fleet requirements based on airline traffic forecasts and airplane inventory. An optimum new airplane is determined for this market. The airplane route system is also identified and its market environment disciplines are determined by processing the market factors such as competitive market shares, growth, wind temperature, airfields, etc. (MKT-2).

Block II-3. Propose Design Mission, Assess Market --Goal: To analyze market requirements and determine design mission requirements that need to be met for the market environment disciplines determined in block II-2.

The market potential of a new airplane is evaluated (MKT-3).

Block II-4. Design Mission OK?--Goal: To determine if the design mission meets the market environment disciplines.

This decision is manual, and human judgment may be exercised in interpreting the disciplines.

Review and recycle if desired.

Block II-5. Configure Airframe and/or Engine Family (Parametric); Compute Performance & Design Trade Data--Goal: To configure an airframe and/or engine family and compute the performance characteristics of the family. This will provide design trade data for the family.

The elements comprising this activity are to be executed with a minimum of input, as the intent is to provide data for the selection of the design mission rather than to determine the best configuration. The inputs will be composed primarily of range, payload, Mach number, technology base (time period), a grid of thrust loading (T/W) and wing loading (W/S), and an initial OEW (WTS-1). The (DCA-2) geometry module will turn each airplane in the grid into a parametric geometry. The performance will be calculated using a simplified process (PRF-1). Support for this calculation will be provided by the cruise drag module (ARO-7), the low-speed lift and drag module (ARO-8), the thrust modules (PRO-3, 4, 5, or 6), and a group weight-and-balance module (WTS-2).

The weight-and-balance module will contain the following analyses:

Statistical OEW prediction methods which produce a 30-item group weight statement

Statistical OEW balance-arm prediction methods which produce a 30-item horizontal center-of-gravity statement

Fuel volume and fuel management calculation

Passenger, cargo, and fuel loading calculations

Three-axes mass moment of inertia about the airplane c.g. calculation

Airplane balance and loadability calculations

The base statistical equations are of a form such that each group weight item is predicted as a function of a set of independent parameters.

The process of finding the correct size of the geometry and/or engine is iterative (figure 43). The iteration is performed for each geometry of the T/W-versus-W/S grid. The result will be a field ("thumbprint") of airplanes that will all do the mission. The trade information will allow valid selection of the best design mission, e.g., the mission with the best sales potential for the class of airplane under consideration.

The design trade data will also consist of comparative evaluations of operational and support costs for competing configurations. These trades will be done by REL-1, -4, -14 and -41 for alternate engine and system concepts and by REL-1 and -4 for support requirements and operational facilities at the airports in the intended routes.

Block II-6. Airplane Economic Analysis--Goal: To evaluate the operating economics of an airplane.

Airplane relative cost values are determined (FNC-2). Airplance economics are evaluated in terms of trip operating cost, ROI, break-even load factor, etc. (MKT-4). For a given airplane route system, the operating profitability of the airplane is evaluated (MKT-5). As an aide in design refinement, economic sensitivity and design trade evaluation can be an option in MKT-4.

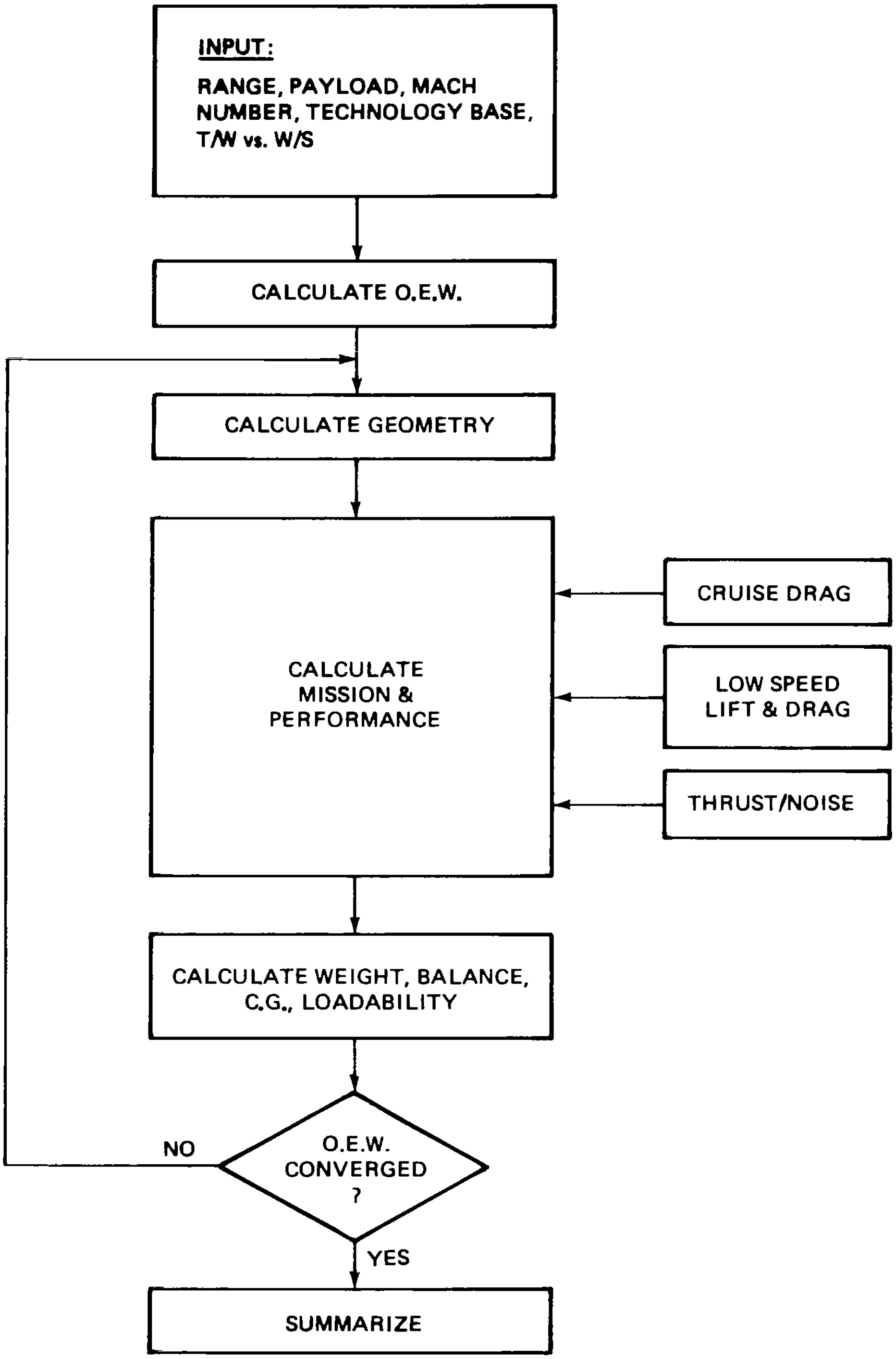


Figure 43.—Convergence Loop — Configuration Size and Performance

In addition, the total airplane performance will be assessed in terms of reliability and maintainability in regard to airplane availability, support costs (personnel and material), and airport operational considerations. This assessment will be done by the maintenance, operation, and support simulation models of REL-1 and -4.

Block II-7. Forecast Sales Potential--Goal: To forecast the sales potential of a new airplane.

Requirements of the new airplane are calculated by airline and year to determine total sales potential of the new airplane (MKT-6).

Block II-8. Suitable Sales Potential?--Goal: To determine whether the sales potential is sufficient for the related development cost.

A man decision is made based on a review of the sales potential for each candidate configuration under investigation.

6.2.3.3 Level III: Configuration Sizing

The goal of level III is to size candidate configurations to the design mission and criteria. The sizing logic should be constructed to be executed with minimal user intervention. (See figs. 25 through 27.)

The level III network has been divided into two parts, "geometry sizing" and "structure sizing." The geometry sizing part is an iterative process controlled by an equation-solving module (DCA-4), which drives the configuration design variables such as wing area, root chord, tip chord, etc., until a prescribed set of equality and inequality constraints (range, field length, etc.) are satisfied. Analyses for geometry sizing are based on statistical data, and no user intervention is envisioned when a configuration designer develops the input. The structure sizing part defines the primary structure, which is sized by analysis. This analysis includes static loads with statistical factors for dynamic loads, smeared material sized for strength and fatigue, weights, and an optional flutter analysis. The basis for the weight estimate of secondary structure and nonstructure items remains statistical. The iterative looping for structure sizing is man-controlled, and the configuration designer may consult with specialists in structure design, static loads, dynamic loads, stress, flutter, and weights.

Block III-1. Develop Level III Inputs--The development of inputs for level III will be similar to level II for the categories of user and data base information. However, in many cases a level III execution will begin from a level II solution. In these instances, the preparation of information required by level III from level II results is to be aone by automatic processes. These default calculations will be approved and corrected by the user prior to execution of level III.

It will be desirable, but not necessary, to execute level III without interruption, so the input information for the entire execution should be available at the beginning. The user may monitor the solution(especially in cases where optimization is being done) to interrupt, correct, then restart a solution.

Block III-2. Calculate Geometry--Goal: To define and control the airplane geometry, including planforms, arrangements, propulsion, and the location of major equipment items.

An airplane geometry consisting of the body, wing, empennage, power plants, and landing gear is integrated into a lofted general arrangement (DCA-1, DGL-1, and PRO-1 or PRO-2). The initial sizes are input and may represent an existing airplane, a modification of an existing airplane, or the designer's judgment for a new airplane. This module will accept input from subsequent analysis modules and will resize the wing, engines, empennage, and control surfaces and/or will relocate the wing and landing gear to meet the mission requirements and criteria for performance, weights, balance, loadability, stability, and control.

The body is characterized by the fineness ratio, planview, halfbreadth, camber line, crown line, keel line, and floor line. The design is related to the requirements for the control cabin, payload (passenger, baggage, and cargo), type of empennage, and propulsion arrangement. The payload requirements include criteria for comfort, seating arrangements, aisles, access to emergency exits, lavatories, galleys, cargo compartments, cargo containers, doors, clearances for loading and emergency evacuation, windows and structure.

The wing is characterized by parameters such as aspect ratio, taper ratio, sweep angle, thickness form, twist, and camber form. Flight and ground control surfaces are identified by type and percent of chord and span. Spars and the main gear support structure are located to provide space for control surfaces and actuators. Spar depths and wing fuel volumes are determined.

The empennage is characterized by the location and type of horizontal stabilizer (body-mounted or mounted on the vertical fin) and by parameters similar to the wing.

The power plants are characterized by an engine cycle (rubber engine) and a nacelle geometry or by input of a specific engine and nacelle. The engines may be located symmetrically on the wing and body or on the body centerline. The rubber engines are sized for takeoff or cruise thrust.

The landing gear arrangements are characterized by kind (bicycle or tricycle, body- or wing-mounted), type (dual or truck), and number of main gear (two, three, or four). The gear is located and sized to meet criteria for strength, flotation, ground handling, takeoff rotation, pitch, and roll.

The controls are characterized by primary flight (longitudinal, lateral, and directional), secondary flight (lift and drag) and ground (drag and directional). The primary flight control surfaces are sized and located to meet stability and control criteria. The secondary flight and ground control surfaces are sized and located to integrate with the flight control surfaces and landing gear structure and to meet requirements for field length performance.

Major items such as fuel tanks, electronics, environmental control units, and the auxiliary power control unit are located to reserve space and provide weight and balance information. (DCA-3, STM-1, -23, -24, -25).

Block III-3. Calculate Cruise Performance--Goal: The goal is to calculate the cruise part of a mission in order to determine fuel burned, block time, and flight profile.

The cruise part of the mission consists of the acceleration and climb to the cruise altitude and speed, the cruise, the descent for landing, and the diversion to an alternate, all done by PRF-2. Simplified equations of motion are integrated and give results that are accurate to within ±1% of the actual results. The cruise drag is provided by module ARO-7. Thrust and fuel consumption information is provided either by table lookup (PRO-5) or by thermodynamic cycle-matching (PRO-3 or PRO-4), together with the engine installation module (PRO-6). In general, the cycle-matching technique will be used, as it is more flexible and can provide practically any thermodynamic parameters pertaining to the engine.

The output of this event will be fuel burned, flight times and mission profile.

Block III-4. Type B Weights Available?--Goal: If the level III analysis has been executed to the point where type B weights have been calculated (block III-17 or in level IV), rather than re-executing a statistical type A weights analysis because of a slight change in the configuration, greater accuracy will be obtained by scaling the group weights as determined in the type B weights analysis. This would be done in block III-7.

Block III-5. Calculate Weight and Balance - Type A--Goal: To provide the necessary output, consistent with the amount of information known at this level, to determine whether the configuration under consideration is acceptable from the standpoints of weight, balance, and loadability.

The technical program element (WTS-2) providing this information contains the following analysis:

Statistical OEW weight prediction methods which produce a 30-item group weight statement (base buildup options)

Statistical OEW balance arm prediction methods which produce a 30-item horizontal center-of-gravity (c.g.) statement

Fuel volume and management calculations

Passenger, cargo, and fuel loading calculations

Three-axis mass moment of inertia about the airplane c.g. calculations

Airplane balance and loadability calculations (determined in conjunction with the stability and control block III-6)

The base buildup statistical equations are of a form such that each group weight item is predicted as a function of a set of independent parameters. This type of equation is not suited for scaling.

Block III-6. Stability and Control Analysis--Goal: The horizontal and vertical tail surfaces are sized and located on the airplane to satisfy a practical c.g. location and range. The main landing gear location and size is selected. Lateral control surfaces are sized and located on the wing.

An option allows aft-balanced configurations to be studied for expected performance benefits using a handling-qualities longitudinal SAS.

The stability, control, and balance module (S&C-1) uses Boeing experience in subsonic airplane design to formulate and design certain critical requirements for longitudinal stability, longitudinal control, directional stability, and directional control. Lateral controls are selected using Boeing experience on swept-wing airplanes.

An option provided by S&C-2 uses statistical data to provide an increment of maneuver margin which will be provided by a stability augmentation system (SAS). This option allows a wider discretion in c.g. location and range.

If the S&C requirements are not met, the geometry module will be required to resize the empennage and/or control surfaces. These changes are controlled by DCA-4 and are executed after the test in block III-8.

Block III-7. Scale Weight and Balance--Goal: To provide the necessary output, consistent with the amount of information known at this level, to determine if the configuration under consideration is acceptable from the standpoints of weight, balance, and loadability.

The technical program element providing this output contains the following analyses (WTS-2):

Statistical OEW weight prediction methods producing a 30-item group weight statement (scaling options)

Statistical OEW balance arm prediction methods producing a 30-item horizontal c.g. statement

Fuel volume and management calculations

Passenger, cargo, and fuel-loading calculations

Three-axis mass moment of inertial about the airplane c.g. calculations

Airplane balance and loadability calculations determined in conjunction with the stability and control analysis (block III-6)

The scaling statistical equations are of a form such that each group weight item is predicted as a function of a base weight and a set of parameters normalized to reflect changes in configuration.

Block III-8. Loadability/OEW Criteria Met?--Goal (1): To compare the OEW calculated by the weights analysis (block III-5 or block III-7) and the OEW sized by the cruise performance analysis (block III-3) and to determine whether the difference between the OEW's is within acceptable limits. If the difference is too great, the geometry module (block III-2) will be required to resize the configuration. The required changes are computer-controlled by DCA-4.

Goal (2): To compare the available forward and aft center-of-gravity limits as determined by the stability-and-control analysis (block III-6) and the required forward-and-after center-of-gravity balance and loadability limits as determined by the weights analysis (block III-5 or III-7). If the difference between the required and available center-of-gravity limits is too great, the geometry module (block III-2) will be required to resize the empennage. If the OEW c.g. position does not result in acceptable airplane balance, the geometry module (block III-2) will be required to adjust the position of such items as the wing and gear relative to the body. The required changes are computer-controlled by DCA-4.

Block III-9. Calculate Low-Speed Performance and Observer Station Noise--Goal: This activity will calculate the takeoff and landing performance of a configuration. Observer station noise will be provided.

The takeoff and landing performances are determined by separate technical program elements. However, both are supported by a low-speed lift-and-drag module (ARO-8) and by thrust and fuel flow modules that utilize either table lookups (PRO-5) or thermodynamic cycles (PRO-3 or PRO-4). The propulsion modules are interfaced by the engine installation module (PRO-6).

Takeoff and climb-out performances (PRF-3) are provided by integrating simplified equations of motion. The takeoff field length is determined for the balanced field situation, and the largest flap setting that will meet the FAA minimum climb gradient is used.

Landing performance (PRF-4) is also found by integrating the equations of motion. The procedure finds the minimum flap setting that will meet the FAR 25 climb-out requirements.

Observer station noise for takeoff, approach, and sideline is estimated using module PNZ-1.

Block III-10. Design Criteria Met?--The loop that iterates to size a configuration begins at block III-2 and ends at this block.

The iteration is necessary to find the values for the parameters controlling the configuration size that produces a geometry that meets the input requirements. The order of the activities in the loop of level III will cause the size to be established first to do the cruise part of the mission, then the takeoff and landing portions. The cycling will be computer-controlled by DCA-4.

Block III-11. Calculate Finance, Cost, Market Suitability--The configuration sizing of the first part of level III will produce performance information of greater reliability than was available from block II-5. Thus, the finance and marketing activities of blocks II-6 and II-7 can be repeated to obtain better insight into the product suitability. This requires the use of FNC-1, a preliminary design cost model, and MKT-4, -5, and -6 to evaluate the route system application on the market model of the configuration under consideration. Market suitability and the forecast of sales potential can be updated.

Block III-12. Define Structural Concepts Arrangement--Goal: Define the structural concepts and materials of the airframe primary structure. Synthesize the arrangement in detail adequate for preliminary gross sizing but consistent with appropriate design criteria.

Identify the nature of the primary structure for the major airframe components, wing, body, empennage, landing gear and nacelles. The materials and structural concepts chosen will influence allowable loads and deflections that are determined in subsequent network event blocks.

Integrate the major structural elements into the airframe geometry in a manner appropriate for the structural concepts, materials used, manufacturing capabilities, and other design criteria. Spars, ribs, bulkheads, cutouts, frames, stringers, keel beam, floor beams, longerons, and landing gear support structure are located and identified. The arrangement of these primary structural elements will provide for an efficient, durable, low-cost, and--most important--safe airframe. Many design criteria are involved in this synthesis. In addition to those already mentioned, structural continuity, fail safety, fatigue, redundance, fuel management, fuel tank sealing and access, manufacturing capabilities and practices, systems space envelopes, and certification requirements are some other less obvious but important considerations.

Geometric considerations will be based on input from block III-2 (calculate geometry) and the output will provide the necessary depth for finite element geometry used later in block V-

11. The output of this task will also be compatible with computerized drafting practices and requirements. This will provide for use of these methods and this data for layout and design studies at levels IV and V and further, a first basis for computer-drawn detail parts at level VI (DSA-1, -2, -3, -4, and DGL-9).

Block III-13. Calculate Wing, Body, and Empennage Paneling & Weight Distributions--Goal: To provide the necessary information for initial structural loads and stress analyses. The required information is of the following types:

a) Airplane planform and section geometry

b) Airplane aerodynamic and structural panel definitions

c) A preliminary estimate of the structural panel weights, center of gravities, and inertias.

When operating within the IPAD system, items b) and c) will be performed by this activity, while item a) will be done by block III-2.

The program element available for the wing analysis is WTS-3 and the program element available for the body/empennage analysis is WTS-4.

Block III-14. Airplane Static Loads--Goal: Calculation of load distributions on the major airframe components resulting from design conditions (static and gust formulae) and a fatigue mission profile.

Wing loads are calculated using a theoretical pressure distribution based on a modified Kuchemann lifting surface theory (SLO-1). This data may be modified to include effects not predicted by theory or previous wind tunnel information. Load distributions are based on the Weissinger L method (SLO-2), yielding spanwise distributions of shear, moment, and torsion along the load reference axis. These distributions include effects of airload, inertia, and thrust from wing-mounted engines.

Fuselage load distributions are calculated by summing a series of idealized inertia panels (SLO-3).

Empennage loads are calculated as a function of rigid airframe response to control or gust input and tail off aerodynamic characteristics (SLO-3).

Flight condition data will be input by a knowledgeable user.

Block III-15. Size Structure for Strength and Fatigue-- Goal: Preliminary gross sizing of the primary structure for static strength and fatigue (fail-safe design) to establish airplane structural weight and elastic response characteristics.

For the structure defined in block III-12 and the loads calculated in III-14, the primary structure is sized at selected sections for static strength and fatigue. The fatigue analysis estimates ground-air-ground (GAG) cycle stresses and GAG damage ratios. The wing upper panel, lower panel, front spar, and rear spar are sized (skin (or web) thickness and stiffening material) and the section flexural rigidity, torsional rigidity, and shear center location are calculated (STR-1). The body upper lobe, lower lobe, deck, and side-walls are sized; and the section flexural rigidity (about a vertical and a lateral axis), torsional rigidity and shear center location are calculated (STR-2). The empennage structure is sized in a manner analogous to the wing.

Material properties, structural component allowables, fatigue reliability factors, GAG cycle stresses, and GAG damage ratios for locations on major components are obtained from the data base.

Elementary beam theory, modified by effectiveness factors to account for sweep effect or structural discontinuity, is used instead of the more costly finite element analysis. Elementary beam theory is technically adequate for a major portion of the structure: where it is not, past experience is used to modify the theory by means of effectiveness factors.

Block III-16. Flexibility Change Significant?--Goal: A computer or man decision on the significance of the change in flexibility.

Loads are calculated for a given flexibility; the resulting strength designed structure is sized; and a new flexibility is calculated. If the change in flexibility is such that a significant loads change would result, the loads and sizing routines (blocks III-14 and III-15) are repeated.

If the change is not significant the resulting structure is weighed (block III-17).

Block III-17. Calculate Weight, Balance, and Loadability - Type B--Goal: To calculate type B weight, balance and loadability for the configuration which has been sized for strength and fatigue.

Accomplishing this activity involves technical program elements that accomplish the following:

Execution of the weights update control module (WTS-15) that would re-execute only those portions of the weights technical program elements whose input had changed

Calculation of wing primary structure mass elements based on smeared stress-sized material (WTS-5)

Calculation of body/empennage primary structure mass elements based on stress-sized material (WTS-6)

Calculation of wing secondary structure mass elements (WTS-7)

Calculation of body/empennage secondary structure mass elements (WTS-8)

Calculation of landing gear mass elements (WTS-9)

Calculation of nacelle and strut, propulsion, fixed equipment, and standard and operational mass elements (WTS-10)

Calculation of fuel mass elements (WTS-11)

Accumulation of mass elements within each structural panel and the calculation of weight, center of gravity, and inertia for each structural panel and for the wing, body, and empennage (WTS-12)

Generation of a weight statement patterned after the AN 9102-D format based on the previously calculated mass elements (WTS-13)

Calculation of total airplane mass properties for various points on the balance diagram and the determination of updated panel mass properties for recycling through the structural analyses of blocks III-14 and III-15 (WTS-14)

The type B weights are suited for scaling. Data communication is shown on figure 44 and will be similar in level IV.

Block III-18. Panel Mass/Inertia Change Significant?--Since the loads analyses are sensitive to panel mass properties, each time the weights analyses updates the panel's mass, center of gravity and inertia, the effect of these changes on the loads analyses should be examined. If the panel mass properties changes are significant, the loads and the structural analyses should be re-executed.

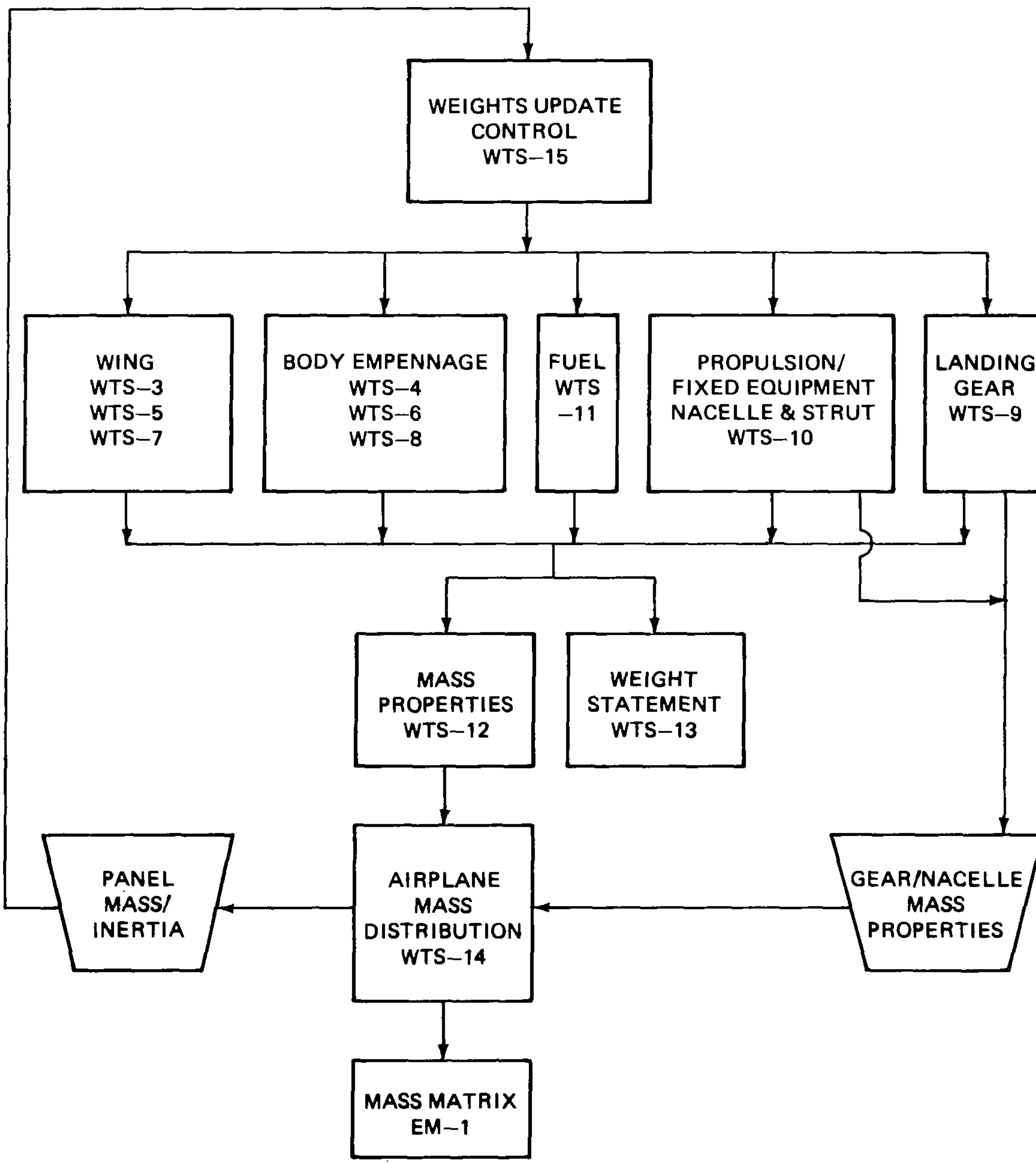


Figure 44.—Weights Analysis—Data Communication

Block III-19. Loadability/OEW Criteria Met?--Goal 1: To compare the OEW calculated by the weights analysis, (block III-17) and the OEW, as sized by the cruise performance analysis (block III-3) and to determine whether the difference between the OEW's is within acceptable limits. If the difference is too great, the geometry module (block III-2) will be required to resize the configuration. The required changes are man-controlled in the structure sizing part of level III.

Goal 2: To compare the available forward and aft center-of-gravity limits, as determined by the stability and control analysis (block III-6) and the required forward and aft center-of-gravity balance and loadability limits, as determined by the weights analysis (block III-17). If the difference between the required and available center-of-gravity limits is too great, the geometry module (block III-2) will be required to resize the empennage. If the OEW c.g. position does not result in acceptable airplane balance, the geometry module (block III-2) will be required to adjust the position of such items as the wing and gear relative to the body. The required changes are man-controlled in the structure sizing part of level III.

Block III-20. Do Flutter Analysis?--Goal: Man decision to execute or bypass the flutter analysis.

Block III-21. Equations of Motion, Flutter Option--Goal: Formulate the equations of motion for flutter analysis of the initial structural sized configuration.

Equations of motion for flutter analysis of a configuration with high-aspect-ratio wing will be formulated as a second-order system of ordinary differential equations with the generalized mass and stiffness matrices (block EM-5) and generalized-forces matrices calculated by lifting-line theory (SFL-12). Vibration modes calculated from block EM-5 will be used as generalized coordinates.

Block III-22. Flutter Analysis--Goal: Conduct flutter evaluation of the initial structure-sized configuration.

A simplified preliminary flutter analysis of the initial structural-sized configuration will be performed. The flutter equations will be solved by either the traditional v-g method (SFL-10), the classic British method (SFL-11), or an automated scheme (SFL-12). Flutter results will be hand-interpreted or monitored on an interactive display by a flutter analyst when using programs SFL-10, SFL-11. However, using the program SFL-12 flutter results are calculated automatically. Flutter sensitivities with respect to the placement of engines or external stores and to the fuel distributions will be presented. The purpose is to make an initial flutter check which will be used as a guide in rating competing configurations.

Block III-23. Calculate Noise Footprints--Goal: Provide noise footprints for the airport community.

On completion of the level III configuration sizing, noise footprints will be calculated by the noise prediction module (PNZ-1). The footprints will provide perceived noise level contours along the flight path for both takeoff and approach. These contours predict the maximum perceived noise levels on the ground.

Block III-24. Summarize Performance, Finance, Cost, and Market Suitability--At this point, the design sizing of level III will have been completed. It will be useful to collect the most recent technical information about the configuration and summarize the performance and cost. From there, the market suitability will be investigated. The performance summary will be done by PRF-5, finance and cost consideration by FNC-1, and the market suitability by MKT-4, -5, and -6.

The utilization, maintenance, and dispatch reliability will be assessed. Probable route structures, aircraft fleets, airport facilities, and operational and environmental factors are used by REL-1 and -4. Additional inputs to these are ground service equipment and airplane interactions as well as maintenance time data produced by REL-6 to -13 and -15 to -40. Also included is a determination of the capability to change an engine within a time interval compatible with the planned utilization. This is a manual review.

Block III-25. Configuration Acceptable--Goal: Man decision based on a review of the effects of the primary structure definition on the performance, noise levels, cost, and market suitability of the final airplane configuration analyzed in level III. Blocks III-23 and III-24 provide data for this review.

Block III-26. Modify Configuration or Mission--There are two options from a negative result in block III-25. The designer may elect to retain the design mission and criteria and return to the beginning of level III to resize, using different sizing rules, or the designer may return the design sequence to level II to evaluate the effects of an alternate design mission.

6.2.3.4 Level IV: Configuration Refinement

The goal of level IV is to refine a configuration by applying more advanced analysis methods to the design. Competing configurations may be evaluated based on level II and level III data, provided that sufficient configuration similarity exists to ensure that consistent analysis techniques have been used. Therefore, only the best configuration of each type will be selected for configuration refinement in level IV. (See figs. 28 through 34.)

Block IV-1. Develop Level IV Inputs--The design and analysis activities of level III have enriched the data base about the configuration. These new data, as well as criteria and constraints from level II, will be put into forms suitable for the level IV analysis methods. This action will be supported primarily by the data base manager. Additionally, user inputs and information from the data base not previously required will be established. This activity is shown symbolically at the head of level IV, but due to the interactive nature of level IV, the data preparation activity may be done selectively throughout level IV.

Block IV-2. Wing Preliminary Aerodynamic Design, Parametric Definition--Goal: To determine whether the parametric distributions of wing thickness camber, twist, and shear can be successfully developed into a valid wing for subsequent wind tunnel testing.

The geometry design of level III done by modules DCA-1, DGL-1, and PRO-1 in block III-2 will specify parametrically a wing thickness, camber, twist, and shear distribution. The activity in this block is to determine whether the wing so generated is sufficiently close to an aerodynamically suitable definition. If not, the degree of modification required will be investigated to see if the results of level III are invalidated.

The investigation of the parametric wing uses the geometry module (DGL-1) to turn the parameters into wing contours. The design/analysis is driven by module ARO-2, which uses module ARO-1 to provide wing and body pressures. The design/analysis proceeds only far enough to determine the suitability of the wing. The wind tunnel model design will be completed later.

Block IV-3. Geometry Change?--Goal: To decide whether to modify the Level III wing definition.

The design/analysis of block IV-2 will determine whether the wing from level III can be developed with only minor modifications into a wing likely to produce the desired performance in a wind tunnel test. If the upper isobar pattern and span load design objectives can be met with minor camber or twist changes, the wing will be acceptable and the network flow will procede to block IV-4. If, however, major camber and twist or thickness modifications are suggested, the design process must return to the start of level III to incorporate these modifications into the design.

Block IV-4. Stability and Control Analysis--Goal: The preliminary design sizing of the airplane conducted in level III is analysed in detail to decide what changes are required (if any) to the tail and control surfaces to meet specific design requirements and provide good flying qualities. Analysis of the configuration provides data whereby a computerized pilot model, in conjunction with a handling qualities estimator, will output pilot rating numbers for specific disturbances or maneuvers. In addition to the simulation, certain checks are made to establish that airplane control capability is adequate to meet specific requirements--particularly critical for low-speed performance such as landing flare, minimum control speed, and roll response.

Analysis of the airplane control and dynamic stability characteristics is achieved using technical program elements (S&C-3, -4, -5, -12, -13, -14, and -17) to calculate aerodynamic parameters. These programs analyze the airplane configuration using estimated aerodynamic data or wind tunnel data, if available, and provide the longitudinal lateral and directional static and dynamic derivatives, including control surface effects, necessary for dynamic analysis and simulation. Standard textbook and data sheet methods are used to compute aerodynamic derivatives which are factored, where appropriate, by aeroelastic correction factors obtained initially from level III analysis (blocks III-14, and III-15) and finally (when additional passes through level IV occur), from level IV analysis (blocks IV-45, and IV-46).

An assessment of the airplane dynamic stability and control characteristics is achieved by S&C-6, which uses small disturbance theory to provide response characteristics, frequencies, periods, times to damp, etc.

A computerized pilot model in conjunction with a handling qualities evaluator (S&C-18) is used in addition to the dynamic characteristics program (S&C-6) to provide information on the airplane flying qualities by outputting pilot rating numbers (based on the Cooper scale) for specific disturbances and maneuvers.

Additional technical program elements (S&C-7, S&C-8, S&C-9, S&C-10, S&C-11) perform specific control effectiveness checks to meet requirements:

CHECK	REQUIREMENT
Takeoff rotation	
Landing flare	
Minimum control speed, ground	Adequate control to meet low-speed performance
Minimum control speed, air	
Roll response criteria--all speeds	

<u>Block IV-5. Update Weights (Type B)</u>--Goal: To update the weights based on minor changes to the configuration in order to achieve acceptable stability and control. These changes are of a minor nature in that they do not result in a geometry change that would affect the entire design; instead they would primarily affect the weight. An example might be to change from a single-hinged to a double-hinged rudder.

To account for these changes, the following weights technical program elements would be used:

For purposes of increasing the accuracy and decreasing the computational time required to perform the weights analysis, it would be desirable to develop a weights technical program element (WTS-15) which would re-execute only those portions of the weights programs whose input had changed

Update of the wing secondary structure mass elements (WTS-7)

Update of the body/empennage secondary structure mass elements (WTS-8)

Update of the fixed equipment mass elements (WTS-10)

Generation of a weight statement patterned after the AN9102-D format based on the previously calculated mass elements (WTS-13)

<u>Block IV-6. Geometry Change?</u>--Goal: Determine whether changes in tail surfaces or flight control surfaces are required.

This decision is manual; therefore, human judgment will be required. If the stability and control characteristics (IV-7) show a stability deficiency or a control effectiveness well below the requirement, a geometry change decision is clearly indicated, and a return is made to level III. However, control surface effectiveness increases causing only small changes to the configuration can be accommodated with an update in weights (block IV-5) and recycle through the stability and control analysis (block IV-4).

Block IV-7. Stability and Control Acceptable?--Goal: Determine if the stability and control requirements have been satisfied.

This is a manual decision. Human judgment will be exercised in the interpretation of the criteria and to determine whether there is need to recycle the event.

Block IV-8. Start Wind Tunnel Model?--Goal: Decision to be made about starting the design of a cruise-shape wind tunnel model for testing in level V.

This is a man decision influenced by confidence gained in the aerodynamic, stability, and control design analyses performed in blocks IV-2 and IV-4. Wind tunnel model construction requires up to three months design lead time; hence, an intelligent decision can shorten the time required to develop a configuration design in level V. This decision is considered each time this point in the network is passed.

Block IV-9. Size Actuators--Goal: The preliminary sizing of all control system actuators to improve the airplane weight estimates and assist in hydraulic power requirements and system definition, flutter considerations, and physical space requirements definition. The design functions of reliability and redundancy analyses, flight control system synthesis and analysis, and actuator sizing occur in preliminary detail in level IV so that system definition and subsequent airplane refinements will not cause transients in level V. The absence of wind tunnel hinge moment data and aeroelastic correction data is the reason the actuator sizing is preliminary.

Rigid control surface hinge moment coefficients for all flight control surfaces are established by preliminary analyses using theoretical estimates or historical data. Technical program elements (S&C-15, 16) using estimated aeroelastic corrections based on historical data for subsonic transport airplanes compute the actuator requirements. In addition, the actuator sizing depends on the (FCS-17) program used for defining redundancy and reliability. Control surface actuator rate requirements are specified from past experience gained on similar aircraft.

Block IV-10. Reliability and Redundancy Analysis--Goal (1): To establish the reliability and redundancy of the aircraft and its systems.

The flight control system is examined by FCS-17. Previously assumed levels of redundancy are compared with selected criteria to assure that selected control systems and supporting systems are adequate.

Goal (2): To establish safety requirements and allocations.

Ground and flight safety must be considered in design and evaluation. Inflight safety is a function of the man/machine performing in the overall operational environment. Requirements and allocations for inflight safety are developed from historical data and the projected design mission profile.

Ground safety is affected by the aerospace vehicle itself and its operation and interface with ground operations equipment, personnel, and facilities. Safety allocations and requirements evolve from consideration of these factors and historical safety problems in relation to the projected ground operations.

Development of safety design requirements and allocations is a manual function.

Goal (3): To establish reliability and maintainability requirements and allocations.

Both inflight and dispatch reliability must be considered in design evaluation. Inflight reliability is mainly a function of inherent reliability of the airplane equipment. Requirements and allocations for inflight reliability are developed from historical data and the projected design mission profile.

Dispatch reliability is affected by available ground time, capability to defer and perform maintenance required to dispatch in the time available, and the inherent reliability of the aerospace system equipment. Both reliability and maintainability requirements and allocations evolve from consideration of these factors and history in relation to the projected design mission profile.

Development of reliability and maintainability design requirements and allocations is a manual function, supported by REL-6 to -13, REL-15 to -40, and REL-42.

Goal (4): To evaluate failure mode effects and determine needed corrective action. This analysis focuses on reliability, maintainability, and safety problems and serves as a starting point for quantitative system reliability and safety analyses.

The effect of failure of all identified functions and components is determined within the system for each failure mode. Means of recognizing the failure and compensatory provisions and procedures are identified. Order of probability of occurrence of the event is assessed.

Performance of the failure mode effect analysis is manual. Output is a tabulation by function or component of factors associated with its failure modes.

Goal (5): To identify fault hazards associated with operation of the system and their safeguards.

A fault hazard analysis is a tabulation of all hazards identified with operation of the system through each phase of operation. Function, component, operator failures, and combinations of failures causing the hazard are identified. Order of probability for each combination is assessed. Compensatory provisions and/or procedures are identified.

Performance of the fault hazard analysis is manual. Output is a tabulation by hazard of factors associated with its occurrence. The analysis is supported by REL-6 to -13, REL-15 to -40, and REL-42.

Goal (6): To assess relative merits of the flight control system design trade studies and assess the overall system from the standpoint of safety and reliability.

Flight safety and redundancy of flight control systems in all flight phases and design conditions are studied. Fault tree (REL-5) analysis is used for overall airplane flight safety assessment of the control system.

Redundancy studies within the flight control subsystems are performed with the COBRA (REL-3), the ARMM (REL-2), and CTS(REL-14 and 41) programs.

<u>Block IV-11. Entered at M?</u>--This is a computer decision. In a pass-through of level IV, the flight control system is analyzed with rigid body modes plus quasi-static aeroelastic corrections in IV-12 and with elastic body modes in IV-53. The analysis mode in IV-53 decides that further passes through IV-12 are unnecessary.

<u>Block IV-12. Flight Control System Synthesis and Analysis</u>--Goal: Flight control system gains and compensation filters are selected. The flight control system design is necessary to provide required

airplane handling qualities. Components of the flight control system are sized for weight considerations.

Optimal control theory (FCS-3, FCS-6, and FCS-7) is used to automate the parameter sizing process for each flight condition. The generalized inverse technique (FCS-4 or FCS-5) is used to force parameter compromises necessary for satisfying the flight control system over the entire flight envelope. The resulting control system is analyzed for stability margins by use of classical linear controls analysis techniques (root locus, Bode, etc., FCS-1 or FCS-2). The preceding programs (FCS-1 and FCS-2) perform dynamic response checks to evaluate the compliance with airplane handling qualities criteria.

Another computer program development (FCS-12) is required to size flight control system hardware for a weights assessment.

The equations of motion for this level consist of rigid body modes with static aeroelastic corrections (FCS-11) instead of the more costly elastic mode representation. The gains and compensation would be tempered to anticipate elastic mode problems.

The entire flight control system synthesis process is automatic at this design level. However, a knowledgeable operator is required to intervene if problems develop during on-line operation.

Block IV-13. FCS Criteria Met?--Goal: Determine whether the flight control system criteria have been satisfied.

This decision is manual, and human judgment may be exercised in the interpretation of the criteria. If definite control system difficulties are present, the design process is stopped and a review is held.

Block IV-14. Technical Review to Determine Action--Goal: Determine required action such as further control system refinements, and modification of criteria, airplane, or flight envelope.

These decisions will generally be a committee function outside of the IPAD system.

Block IV-15. Update Propulsion System Design--Goal: Update all propulsion system data to show the effects of the propulsion installation analysis (block IV-15a).

All propulsion and noise data will be updated to concur with the current propulsion system configuration in accordance with block IV-15a.

Block IV-15a. Propulsion Installation Analysis--Goal: Analyze and refine the installed propulsion system in a parallel effort to the IPAD mainstream.

All propulsion and noise disciplines will be involved in the analysis and refinement of the installed propulsion system. This effort will involve such areas as inlets, nozzles and thrust reversers, acoustic treatment, airbleed and horsepower extraction requirements, accessory equipment, and the bare engine components (compressor, turbine, etc.). The effort may require the use of propulsion and noise modules (PRO-1, -2, -3, -4, -5, and -6 and PNZ-1).

Block IV-16. Installed Thrust/SFC Change Significant?--Goal (1): To evaluate the change in the installed thrust or specific fuel consumption.

The performance and sizing calculations of level III assumed an installation penalty to thrust and SFC based on historical or empirical values. While the level III and level IV analyses were conducted, outside activity has been conducted to establish by analysis and tests more accurate values for the installed thrust and SFC. If these values differ significantly from those assumed in the sizing activities, the design must be returned to level III to be resized.

Block IV-17. Systems Design--Goal (1): To define system concepts and sizing criteria in sufficient detail to ensure that design requirements are identified and provide sizing information for weight and balance estimating.

Flight Control System--Schematic diagrams are developed for each control system using data developed by FCS-12, -15, and -17 and STM-2, -3, and -4. Critical mechanical elements, such as control mixers and feedback concepts, are identified and design criteria are established. Actuator sizing and redundancy criteria are developed by network blocks IV-9 and IV-10 and the actuators are sized by FCS-15.

Landing Gear--Schematic diagrams are developed for the brake system and the steering system. Sizing criteria for the brakes, wheels, tires, and steering are developed (STM-14, -15, and -18).

Hydraulics--A schematic diagram is developed for the hydraulic system. Load analysis inputs are used to determine fluid flow requirements, establish distribution paths, and size pumps. Load-balancing and component-sizing trades are conducted (STM-2, -3, and -4). Critical hydraulic system items are identified and design criteria established.

Auxiliary Power Unit (APU)--A load schedule is determined for shaft power and air flow (STM-8). Critical considerations, such as capability for inflight starting, are identified and design criteria established.

Environmental Control System (ECS)--Schematic diagrams are developed for the ECS system and the pneumatic control and distribution system. Propulsion and APU interfaces are established. Load analysis inputs are used to determine requirements for heating and cooling cycles (STM-10, -11 and -12). Critical considerations such as temperature pulldown capability on a hot day are identified and design criteria established.

Electrical Power System--A schematic diagram is developed for the electrical power system. Load analysis inputs are used to determine power generation requirements (STM-20). System arrangement trade studies provide initial optimization of equipment relationships (STM-21). Critical considerations such as loads requiring source redundancy are evaluated and design criteria established.

Avionics--Mission profile data are used to determine requirements for avionic subsystems: navigation, flight instruments, communication, weather radar, utilities, and advisory equipment. Electrical and cooling loads are determined (STM-13). Critical considerations, such as category IIIa landing capability and requirements for antenna locations, are evaluated and design criteria established.

Fuel System--Schematic diagrams are developed for the following fuel subsystems: refuel, fuel vent and surge, and engine fuel feed. Flow rates, refuel time, etc., are used to establish line sizes (STM-26, -27, -28, -29, and -30). Critical considerations such as pressure constraints, valve failure cases, wing deflections, and quantity gauging requirements are identified and design criteria established.

Goal (2): Comparative evaluation of design trade study configurations and assessment of configurations against the reliability, maintainability, and safety requirements and allocations.

Fault tree simulation (REL-5), computerized Boolean reliability analysis (REL-3), automatic reliability mathematical modeling (REL-2), and CTS (REL-14 and -41) are used for studies at this level. Program selection depends on problem and system complexity and comparative factors selected for evaluation.

Block IV-18. Update Weights - Type B (Nonstructural)--Goal: To calculate updated mass properties for the nonstructural items that may have changed since analysis by block III-17. The primary changes will be to the propulsion groups (block IV-15) and the systems groups (block IV-17).

To accomplish this activity the following technical program elements are involved:

To increase the accuracy and decrease the computational time required to perform the weights analysis, develop a weights technical program element (WTS-15) which would re-execute only those portions of the weights programs whose input had changed

Update landing gear mass elements (WTS-9)

Update nacelle and strut, propulsion, fixed equipment, and standard and operational mass elements (WTS-10)

Update fuel mass elements (WTS-11)

Accumulate mass elements within each structural panel and calculate weight, c.g., and inertia for each structural panel and for the wing, body, and empennage (WTS-12)

Generate a weight statement patterned after the AN9102-D format based on the previously calculated mass elements (WTS-13)

Calculate total airplane mass properties for the various points on the balance diagram and determine of updated panel mass properties for structural analysis blocks IV-20 and IV-21 (WTS-14)

Block IV-19. Entered at M?--This is a computer decision. At this position in the design cycle repetition of blocks IV-20 through IV-53 is not necessary, because this is the last cycle for the particular design case under investigation.

Block IV-20. Airplane Static Loads--Goal: Calculation of load distributions on the major airframe components resulting from design conditions (static and gust formulae) and a fatigue mission profile.

Wing loads are calculated using a theoretical pressure distribution based on a modified Kuchemann lifting surface theory (SLO-1). This data may be modified to include effects not predicted by theory or previous wind tunnel information. Load distributions are based on the Weissinger L method (SLO-2), yielding spanwise distributions of shear, moment, and torsion along the load reference axis. These distributions include effects of airload, inertia, and thrust from wing- mounted engines.

Fuselage load distributions are calculated by summing a series of idealized inertia panels (SLO-3). Empennage loads are calculated as a function of rigid airframe response to control or gust input and tail off aerodynamic chracteristics (SLO-3). Flight condition data will be input by a knowledgeable user.

Any requirements for loads on secondary structure will be met by hand calculations based on data from a similar past configuration.

Block IV-21. Size Structure for Strength and Fatigue--Goal: Preliminary detailed sizing of the primary structure for static strength and fatigue (fail-safe design) to improve estimates of airplane structural weight and elastic response characteristics.

For the structural arrangement and structural concepts defined in III-12, the sizing established in III-15, and the loads calculated in IV-20, the primary structure is sized at the selected sections for static strength and fatigue. The wing upper panel and lower panel skin-stringer segments and the front and rear spar web thicknesses (and stiffening material) are sized for the most critical conditions (static strength or fatigue). Additionally, the section flexural rigidity, torsional rigidity, and shear center location are calculated (STR-3 and STR-5). The fuselage semimonocoque skin-stringer segments are sized in user-defined subsets (e.g., upper lobe, lower lobe, deck, sidewalls, etc.). Section flexural rigidities (about a vertical and lateral axis), torsional rigidity, and shear center location are calculated (STR-4 and STR-5). The empennage structure is sized in a manner analogous to the wing.

Material properties, structural component allowables, fatigue reliability factors, and detail fatigue ratings for major component structure are obtained from the data base.

Elementary beam theory, modified by effectiveness factors to account for sweep effects or structural discontinuities, is used instead of the more costly finite-element analysis. Elementary beam theory is technically adequate for a major portion of the structure. For those regions where elementary beam theory is not technically adequate, past experience is used to modify the theory via the effectiveness factors.

Block IV-22. Flexibility Change Significant?--Goal: A computer or man decision on the significance of the change in flexibility.

Loads are calculated for a given flexibility; the resulting strength designed structure is sized; and a new flexibility is calculated. If the change in flexibility is such that a significant loads change would result, loads and sizing blocks IV-20 and IV-21 are repeated. If the change is not significant, the resulting structure is weighed (block IV-23).

Block IV-23. Update Primary Structure Weights--Goal: To update the primary structure weight based on the refined skin/stringer material sizes supplied by the stress analysis in block IV-21 and present the results in the form of a weight statement in order that the structural concepts can be evaluated.

Accomplishment of this activity involves technical program elements that:

Execute the weights update control module (WTS-15) that would re-execute only those portions of the weights technical program elements whose input had changed.

Update wing primary structure mass elements based on stress-sized skin/stringer material (WTS-16).

Update body/empennage primary structure mass elements based on stress-sized skin/stringer material (WTS-17).

Update wing secondary structure mass elements (WTS-18, WTS-7).

Update body/empennage secondary structure mass elements (WTS-19 or WTS-8).

Generate a weight statement patterned after the AN 9102-D format based on the previously updated mass elements (WTS-13).

Block IV-24. Structural Concepts Satisfactory?--Goal: Provide for investigation of alternate structural concepts and arrangements.

Review the structural concepts and arrangements identified in block III-12 and sized in block IV-21 for possible areas of improved efficiency. Should the design be judged adequate, work would commence at block IV-25. Should an improved design be required, it would be identified in block IV-24a.

This decision is manual and heavily influenced by judgment relative to producibility and risk.

Block IV-24a. Redefine Structural Concepts and Arrangements--Goal: Optimization of structural concepts and arrangements.

Alternate structural concepts and arrangements would be investigated for those areas identified as candidates for improved structural efficiency in block IV-24. Sizing for strength and fatigue (block IV-21) of the original concepts and arrangements (block III-12) has provided a baseline for trade studies of possible alternate designs.

Input data from DSA-1, -2, -3, and -4 would be modified using the interactive design tool of DSA-5. All of the considerations of block III-12 will be involved in a process heavily influenced by manual judgment in the interactive process. STR-3, -4, and -5 would provide structural sizing data upon which this judgment would be based. The modified concepts and arrangements would then be resized in block IV-21 to provide a new baseline airframe structure (DSA-1, -2, -3, -4, and -5, and DGL-7 and -9).

Block IV-25. Update Weight, Balance, Loadability, and Inertia (Type B)--Goal: To calculate type B weight, balance, and loadability for the configuration which has been sized for strength and fatigue. The primary structure weights are based on stress-sized skin/stringer material.

Most of the technical program elements required to support this activity were executed in blocks IV-18 and IV-23. The additional technical program elements required would be:

Execution of weights update control (WTS-15)

Update of fuel mass elements (WTS-11)

Accumulation of mass elements within each structural panel and calculation of weight, center of gravity, and inertia for each structural panel and for the wing, body, and empennage (WTS-12)

Generation of a weight statement patterned after the AN9102-D format based on the previously updated mass elements (WTS-13)

Update of total airplane mass properties for various points on the balance diagram and update of panel mass properties for recycling through the structural analyses blocks IV-20 and IV-21 (WTS-14)

Block IV-26. Panel Mass/Inertia Change Significant?--Goal: Since the loads analyses are sensitive to panel mass properties, each time the weights analyses updates the panel's mass, center of gravity, and inertia, the effect of these changes on the loads analyses should be examined. If the panel mass properties changes are significant, the loads and the structural analyses should be re-executed.

Block IV-27. Loadability/OEW Criteria Met?--Goal 1: To compare the OEW which is calculated by the weights analysis (block IV-25) and the required OEW as sized by the cruise performance analysis (block III-3) and to determine whether the difference between the OEW's are within acceptable limits. If the difference is too great, the geometry module (block III-2) will be required to resize the configuration. The required changes are man-controlled in level IV.

Goal 2: To compare the available forward and aft center-of-gravity limits, as determined by the stability and control analysis (block IV-4), and the required forward and aft center-of-gravity balance and loadability limits, as determined by the weights analysis (block IV-25). If the difference between the required and available c.g. limits is too great, the geometry module (block III-2) will be required to resize the empennage. If the OEW c.g. position does not result in acceptable airplane balance, the geometry module (block III-2) will be required to adjust the position of such items as the wing and gear relative to the body. The required changes are man-controlled in level IV.

Block IV-28. Equation of Motion - Flutter Option--Goal: Formulate equations of motion for flutter analysis of refined configurations.

Activity here is basically the same as design network block IV-21. Added will be the modal interpolation and lifting surface theory oscillatory aerodynamics calculations.

Block IV-29. Proposed Flutter Suppression System--Goal: A flutter suppression control system is synthesized for the purpose of increasing the flutter speed.

The procedure for selecting gains and filters is similar to the procedure described in block IV-12. Thus, the optimal control theory programs (FCS-3, FCS-6, and FCS-7) and the generalized inverse technique (FCS-4 or FCS-5) will be used as an aid to parameter sizing. However, the criteria and the emphasis of elastic modes make this block differ from block IV-12. The strategy is to increase the flutter speed as much as possible without introducing stability problems. Sensor location and control surface size and location are critical considerations. Due to these complexities, manual intervention is required in the synthesis process. In particular, classical controls methods of FCS-1 or FCS-2 will be used for the majority of the synthesis effort. Note that FCS-1 requires a development of Nyquist and Bode techniques for accommodating the frequency dependent (complex coefficient) flutter matrices.

The equations of motion formed for the flutter analysis (block IV-28) can also be used for the flutter suppression system work. However, equations of motion based upon quasi-steady aerodynamics combined with the Wagner function may also be used. This latter set will be used for cost considerations.

Block IV-30. Proposed Fix--Goal: Determine changes on configuration geometry, mass, or stiffness for flutter clearance.

The critical flutter conditions identified in design network (block IV-31) will be analyzed to appraise flutter mechanism using an energy display approach (SFL-13). Parametric flutter trend studies on stiffness changes, mass balance, and geometry change using lifting-line unsteady aerodynamics (SFL-12) will be used to determine how the flutter deficiencies should be removed. These trend studies are performed through the design network (blocks IV-28, IV-31, IV-32, and IV-30). This loop is terminated when the desired flutter clearances are achieved. Lifting surface aerodynamics (presented in the description of block EM-8) will be used to confirm the results of changes in stiffness, mass, or geometry.

Block IV-31. Flutter Analysis--Goal: Evaluate flutter boundaries of the refined configurations.

Flutter boundaries of the refined configurations will be determined over the flight envelope by the same solution methods used in design network block III-22.

Block IV-32. Flutter Criteria Met?--Goal: Determine whether the flutter criteria have been satisfied.

This decision is manual. If flutter deficiency exists, improvements will be made by: 1) geometry, mass, or stiffness change or 2) active flutter suppression system. A decision will be made to determine whether 1) or 2) or both should be used to satisfy flutter requirements.

Block IV-33. Geometry Change?--Goal: Determine whether a configuration change is required for flutter clearance.

This decision is manual. Geometry changes in terms of modifications to existing main lifting surfaces or control surfaces, or addition of new control surfaces may be the results of the design network blocks IV-29 and IV-30. If the geometry change is required to clear flutter, the design flow will go back to the start of level III.

Block IV-34. Use Flutter Suppression System--Goal: Decide whether to use an active flutter suppression system.

The flutter suppression system synthesis is described in block IV-29. The decision is manual and involves considerations of benefits, risk, cost, complexity, and weight.

Block IV-35. Update FCS--Goal: Re-size the flight control components for weight considerations.

The additional components required for the flutter suppression system will be estimated. A computer program development is required (FCS-12).

Block IV-36. Change Stiffness?--Goal: Determine whether structural stiffness change should be made for flutter clearance.

This decision is manual. If the stiffness increase (identified in the design network block IV-30) over the strength and fatigue sizing is to be made to clear flutter, the required stiffness will be provided for design network block IV-37. If the answer to the question is no, design network block IV-38 will be executed and any mass change required for flutter clearance will be input.

Block IV-37. Update Structural Sizing. Goal: To identify flutter-prescribed resizing for updating the primary structure weight and establish minimum size constraints for all further strength and fatigue design activities.

If a stiffness (sizing) increase over the strength and fatigue sizing is required to meet the flutter criteria, the sizing required is identified and updated. For all skin and web gage increases, the stiffening material will be compared to the minimum allowable stiffening material and increased if required. Flutter-prescribed sizing will be considered to be minimum size constraints in all further strength and fatigue sizing activities (STR-3, -4).

Block IV-38. Update Weights, Balance, and Loadability - Type B--Goal: To calculate type B weight, balance, and loadability for the configuration which has been sized for strength, fatigue, and flutter. This involves technical program elements that:

Execute weights update control (WTS-15); re-execute only those portions of the weights technical program elements whose input had changed.

Update wing primary structure mass elements based on stress-sized skin/stringer material (WTS-16).

Update body/empennage primary structure mass elements based on stress-sized skin/stringer material (WTS-17).

Update wing secondary structure mass elements (WTS-18, WTS-7).

Update body/empennage secondary structure mass elements (WTS-19 or WTS-8).

Update fuel mass elements (WTS-11).

Accumulate mass elements within each structural panel and calculate weight, c.g., and inertia for each structural panel and for the wing, body, and empennage (WTS-12).

Generate a weight statement patterned after the AN9102-D format based on the previously updated mass elements (WTS-13).

Calculate total airplane mass properties for various points on the balance diagram and the determination of updated panel mass properties for recycling through the structural analyses (WTS-14).

There will be no updating of the flight control system weights until the effects of the flight control system changes can be reflected in the other airplane systems analyses (block IV-17). Therefore, the flight control system weights will be updated in block IV-18.

Block IV-39. Loadability/OEW Criteria Met?—Goal (1): To compare the OEW which is calculated by the weights analysis (block IV-38) and the required OEW as sized by the mission analysis (block III-3) and determine whether the difference between the OEW's is within acceptable limits. If the difference is too great, the geometry module (block III-2) will be required to resize the configuration. The required changes are man-controlled in level IV.

Goal (2): To compare the available forward and aft center-of-gravity limits as determined by the stability and control analysis (block IV-2) and the required forward and aft center-of-gravity balance and loadability limits as determined by the weights analysis (block IV-38). If the difference between the required and available center of gravity limits is too great, the geometry module (block III-2) will be required to resize the empennage. If the OEW CG position does not result in acceptable airplane balance, the geometry module (Block III-2) will be required to adjust the position of such items as the wing and gear relative to the body. The required changes are man-controlled in level IV.

Block IV-40. Entered H From J?--This is a computer decision. The decision in block IV-51 to perform flutter analysis requires a recycle through equations of motion (block IV-28) and subsequent events (blocks IV-31 through IV-39) but no recycle of events (blocks IV-41 through IV-51) that are primarily updated analyses.

Block IV-41. Equations of Motion--Goal: To establish the equations of motion prior to investigating the dynamic loads and ride quality.

The unaugmented quasi-steady equations of motion generated in Block EM-11 are a set of theoretical equations with experimental corrections incorporated into them to more realistically represent the actual airplane. This block will incorporate the SAS system into the equations of motion using technical program element SDL-2. The flight conditions for which the equations of motion are to be generated will be manually selected to be adequate for the dynamic loads block IV-42.

Block IV-42. Dynamic Loads and Ride Quality Evaluation--Goal: The purpose of this element is to provide design loads to size the structure of the airplane. However, the many facets in providing these loads require the skill of experienced engineers.

To provide design flight gust loads, it is necessary to pick points on the flight envelope in terms of altitude, speed, payload, and fuel loading which may produce the maximum dynamic loads on any selected location of the aircraft. The first step is to check the stability (SDL-3) of the equations of motion (block IV-41). Then, the equations of motion and load equations generated from data of block EM-10 must be analyzed by a discrete gust analysis (SDL-6), a statistical PSD gust analysis (SDL-4) using the design envelope approach, and a statistical gust analysis for a typical mission profile using programs SDL-4 and SDL-5. Fatigue sizing of the aircraft also requires a mission profile gust analysis that generally has a lighter payload than in the design envelope analysis. The mission profile is an average payload and fuel distribution that would be experienced during an average mission for which the airplane is designed. The design envelope and discrete gust approach uses extreme loadings that are possible to obtain the highest loads on the airplane. The gust profile considered must include both a vertical and a lateral gust, each of which is considered independent of the other.

The ride qualities should be evaluated at this time in terms of lateral and vertical accelerations along the body. Until an absolute criterion is developed, the ride qualities would have to be compared quantitatively with existing aircraft.

The design ground loads would be caluclated with a dynamic math model simulating both a landing impact and a taxi analysis (SDL-7) on various measured runways around the world. The ride qualities during taxi would also be evaluated at this time.

Block IV-43. Structural Analysis for Strength and Fatigue--Goal: To determine the margins of safety (strength and fatigue) of the previously sized detail structural elements for the dynamic load conditions of block IV-42.

For the detailed structural sizing established in block IV-21 and as updated by block IV-37 for flutter, stress analyses are performed for the dynamic load conditions of IV-42. The capability to perform analysis only (without resizing) to obtain margins of safety is inherent in STR-3, STR-4, and STR-5.

Analysis rather than design is used to obtain the computational cost savings available when no negative margins of safety exist for the dynamic load conditions and the flexibility changes, if any, since the last static loads calculations are too small to produce a significant change in the static loads. It should be noted that the cost of an analysis is estimated as one-third or less that of a design sizing. Further, there should be very few dynamic load conditions compared to the number of static load conditions.

Block IV-44. Negative Margins of Safety?--Goal: Computer decision to determine it the dynamic load conditions are critical for any of the previously sized detail structural elements.

Block IV-45. Airplane Static Loads--Goal: Calculation of load distributions on the major airframe components resulting from design conditions (static and gust formulae) and a fatigue mission profile.

Wing loads are calculated using a theoretical pressure distribution based on a modified Kuchemann lifting surface theory (SLO-1). This data may be modified by an engineer to include effects not predicted by theory or previous wind tunnel information. Load distributions are based on the Weissinger L method (SLO-2), yielding spanwise distributions of shear, moment, and torsion along the load reference axis. These distributions include effects of airload, inertia, and thrust from wing-mounted engines.

Fuselage load distributions are calculated by summing a series of idealized inertia panels (SLO-3). Empennage loads are calculated as a function of rigid airframe response to control or gust input and tail-off aerodynamic chracteristics (SLO-3). Flight condition data will be input by a knowledgeable user.

Any requirements for loads on secondary structure will be met by hand calculations based on data from a similar past configuration.

Block IV-46. Structural Sizing for Strength and Fatigue--Goal: To modify the preliminary detailed sizing of the primary structure for strength and fatigue (fail-safe design) for critical dynamic load conditions and/or revised static loads resulting from structural flexibility changes.

Using the structural definition (geometry and sizing) established in block IV-21 with the sizing as updated by block IV-37, the primary structure is resized for strength and fatigue for fail-safe design (STR-3, STR-4, STR-5). Static load condition data are obtained from block IV-45, while the dynamic load condition data are obtained from block IV-42. Sizing activities parallel those of block IV-21.

Block IV-47. Flexibility Change Significant?--Goal: A computer or man decision on the significance of the change in flexibility.

Loads are calculated for a given flexibility; the resulting strength-designed structure is sized; and a new flexibility is calculated. If the change in flexibility is such that a significant loads change would result the loads/sizing routines (blocks IV-45 and IV-46) are repeated.

If the change is not significant the resulting structure is weighed (block IV-48).

Block IV-48. Update Weights, Balance, and Loadability - Type B-- Goal: To calculate type B weight, balance, and loadability for the configuration which has been sized for strength, fatigue, flutter, and dynamic loads.

To accomplish this involves technical program elements that will:

Execute weights update control (WTS-15) that would re-execute only those portions of the weights technical program elements whose input had changed.

Update wing primary structure mass elements based on stress sized skin/stringer material (WTS-16).

Update body/empennage primary structure mass elements based on stress sized skin/stringer material (WTS-17).

Update wing secondary structure mass elements (WTS-18, WTS-7).

Update body/empennage secondary structure mass elements (WTS-19 or WTS-8).

Update fuel mass elements (WTS-11).

Accumulate mass elements within each structural panel and calculate weight, c.g., and inertia for each structural panel and for the wing, body, and empennage (WTS-12).

Generate a weight statement patterned after the AN9102-D format based on the previously updated mass elements (WTS-13).

Calculate total airplane mass properties for various points on the balance diagram and determine updated panel mass properties for recycling through the structural analyses (WTS-14).

There will be no updating of the flight control system weights until the effects of the flight control system changes can be reflected in the other airplane systems analyses (block IV-17). Therefore, the flight control system weights will be updated in block IV-18.

Block IV-49. Panel Mass/Intertia Change Significant?--Since the loads analyses are sensitive to panel mass properties, each time the weights analyses update the panel's mass, center of gravity, and/or inertia, the effect of these changes on the loads analyses should be examined. If the panel mass property changes are significant, the loads and the structural analyses should be examined.

Block IV-50. Loadability/OEW Criteria Met?--Goal (1): To compare the OEW calculated by the weights analysis block IV-48 and the required OEW as sized by the cruise performance analysis (block III-3) and determine whether the difference between the OEW's is within acceptable limits. If the difference is too great, the geometry module (block III-2) will be required to resize the configuration. The required changes are man-controlled in level IV.

Goal (2): To compare the available forward and aft center-of-gravity limits, as determined by the stability and control analysis (block IV-4), and the required forward and aft center-of-gravity balance and loadability limits, as determined by the weights analysis (block IV-48). If the difference between the required and available center of gravity limits is too great, the geometry module (block III-2) will be required to resize the empennage. If the OEW c.g. position does not result in acceptable airplane balance, the geometry module (block III-2) will be required to adjust the position of such items as the wing and gear relative to the body. The required changes are man-controlled in level IV.

Block IV-51. Do Flutter Analysis?--Goal: Determine whether further flutter analysis is required.

Manual decision is made to determine whether further flutter analysis should be performed to ensure the proper flutter-free performance of the newly derived configuration with strength design in which dynamic loads and ride quality effects are included.

If the answer to the question is yes, the design flow will go back to design network (block IV-28.) Otherwise, the configuration will be ready for flight control system synthesis and analysis through design network (blocks IV-52 and IV-53).

Block IV-52. Equations of Motion - Quasi-Steady Option--Goal: Develop the equations of motion to be used for flight control system work.

The equations of motion consist of the rigid body modes and about 10 elastic modes. Two basic sets of data are produced, namely the longitudinal axis equations and the lateral-directional axes equations. Approximately 10 operating points are required to cover the flight envelope. Quasi-steady aerodynamics are sufficient for the flight controls problem. Estimates of control surface and actuator dynamics will be adequate at this stage in the design process.

Block IV-53. Flight Control System Synthesis and Analysis--Elastic Body Modes--Goal: Re-examine the flight control system using elastic body modes and modify the control system as needed.

The previous handling qualities control system work (block IV-12) is performed using simplified rigid-body equations of motion. Although elastic modes were not used in block IV-12, the static aeroelastic effects were simulated and the gains and compensation networks were tempered to anticipate higher frequency dynamics. It is anticipated that flight control system modifications will be minor. If the flight control system criteria are not satisfied due to presence of elastic modes, the situation will be examined after the end of the level IV computational activity. The decision will then be whether to press for more control system refinements or modify the airplane or flight envelope.

Block IV-42 evaluated the ride quality of the airplane. If ride improvement is required, a ride quality stability augmentation system (RQSAS) will be developed at this point.

Computational activity will be similar to block IV-12, and FCS-1 through FCS-7 may be required. As is the case with the flutter suppression system synthesis (block IV-29), the elastic modes will require more manual intervention and more emphasis of classical controls techniques (FCS-1 or FCS-2). The flight control system hardware will be resized by use of FCS-12.

Block IV-54. Do Dynamic Loads Analysis?--Goal: Man decision to determine whether any significant changes in weight, flexibility, and flight control system synthesis have been made to the system from blocks IV-43 to IV-53 that would affect dynamic loads.

Block IV-55. (1) Manufacturing Review--Goal: To provide operations with design concepts to the extent that company resources can be reviewed and the preliminary manufacturing plan prepared.

Operations must initiate program planning in conjunction with the product technical definition. Based on itemized work statements, the initial make-or-buy and manufacturing plans are developed. Concurrently, available in-house resources are reviewed for compatibility in time and suitability.

(2) Establish Plans and Schedules--Goal: To provide operations, marketing, and finance with initial plans and scheduling information.

Initial planning will include estimates of the engineering release schedule, configuration verification test plan, and manufacturing schedule.

(3) Identify Long Lead Items--Critical long lead items (e.g., engines, forgings, etc.) will be identified and procurement criteria established.

Block IV-56. Summarize Performance--The design refinement of level IV has been completed. The performance will be summarized by use of PRF-5, finance and cost considerations by FNC-1, and the market suitability predicted by MKT-4, -5, and -6. The effect of schedules on cost will also be assessed by FNC-2, -3, and -4.

The marketing analyses will be supported by an evaluation of the total system in the operational environment within the level of definition available.

Simulation models REL-1 and REL-4 will evaluate interactions, major influences, controlling parameters, special features, and characteristics affecting utilization dispatch reliability, maintenance, and logistics facilities. Cost variables such as fleet size, route structure, scheduled flight time, and ground time are used to assess each change in configuration or design and to evaluate strengths and weaknesses of each airplane in operational environments.

Block IV-57. Will Engine be Available for Product?--Goal: Determine whether the engine availability schedule is compatible with the airframe manufacturing and delivery schedule.

This decision will be manual and will determine whether the airframe manufacturing and delivery schedule allows sufficient lead time for the engine development.

Block IV-58. Technical Review to Determine Next Action--Goal: Determine next action if the engine availability test (IV-57) is negative.

This management-level review will be to decide on further action should the current airframe schedule allow insufficient lead time for engine development.

Block IV-59. Configuration Acceptable?--Goal: This is a man decision based on a review of all tasks undertaken in level IV. To be acceptable means that no reason is found to prevent the design from proceeding to level V.

Block IV-60. Stop Wind Tunnel Model--Goal: In the event the configuration review in block IV-59 is found to be unacceptable, the design of the cruise shape wind tunnel model, commenced in block IV-8, should be terminated.

Block IV-61. Start Wind Tunnel Model?--Goal: This event is a man decision to start the design of the cruise-shape wind tunnel model if not already in work. The decision is influenced by a management review to commit the configuration design cycle into level V.

Block IV-62. Wind Tunnel Model Started?--Goal: This event is a man decision to determine whether the design of the wind tunnel cruise-shape model identified in block IV-8 has commenced.

Block IV-63. Modify Configuration or Mission--There are two options from a negative result in block IV-59. The designer may elect to retain the design mission and criteria and return to the beginning of level III to resize, using different sizing rules, or the designer may return the design sequence to level II to evaluate the effects of an alternate design mission.

Block IV-64. Technical Review to Determine Next Action--Goal: This event is a review of the total airplane design by a technical review committee to assist the management decision on the next course of action.

6.2.3.5 Level V: Configuration Verification

The goal of level V is to verify candidate configurations so that selection among them and the commitment of product go-ahead can be made with the minimum risk practicable. These verifications will be achieved by tests and analyses. Tests will include wind tunnel models, selected system and structural concepts, and propulsion systems. The design and analysis will be done as rigorously as possible, with preliminary detail part design wherever needed to develop confidence in the overall design. (See figs. 35 and 36.)

Block V-1. Modify Wind Tunnel Model?--Man decision as to whether changes in the design of the wind tunnel cruise-shape model are required.

Block V-2. Modify Wind Tunnel Model--Goal: Modification of design and construction of the wind tunnel cruise-shape model.

In order to achieve early wind tunnel test dates, the model drawings and definitions for level V testing are released early in level IV. Some modification of these early model lines will usually result from further analysis in level IV. This activity represents the updating of the wind tunnel model definitions to represent all of the level IV results.

Block V-3. Cruise Wind Tunnel Model Configuration Design With Lofted Geometry--Goal: To design the various configurations to be tested for cruise drag and longitudinal stability and control characteristics.

The model will be designed at a subcritical Mach number using potential flow analysis with corrections based on experience (ARO-1, -2, -3). Model components which will be actively designed are wing, body, empennage, nacelles, and pylons. Options in addition to the nominal shape will be designed for alternate configurations. All of the geometry will be represented as a computerized loft using geometry control system GCS (DGL-2, -3), which provides data for the components to be fabricated by the numerical control processes.

Block V-4. Fabricate Wind Tunnel Model--Goal: To construct the cruise shape wind tunnel model designed in Block V-3.

The fabrication of these models will utilize numerical control processes to machine the wing, forward and aft body, empennage, nacelles and pylons. The control tapes for these machines will be produced from contour information contained in the IPAD data bank (DGL-2, -3).

Block V-5. Wind Tunnel Test--Goal: This test will provide a measure of the cruise drag and longitudinal stability characteristics of the airplane.

If the drag estimates (and particularly wing design) made in level IV are confirmed, acceptance of the aerodynamic performance will be verified.

The second part of the test provides basic longitudinal stability and control information and lateral-directional stability data for the cruise configuration. There are no lateral or directional controls on the model at this stage. The data will be used to confirm or to show the need for changes in the airplane configuration.

This task will be performed using normal wind tunnel procedures. Wind tunnel data reduction programs will convert the data into acceptable form for inclusion in the IPAD data bank.

Block V-6. Analyze--Goal: To analyze cruise drag and longitudinal stability and control data.

Cruise performance calculated from data of wind tunnel test block V-5 is compared with estimated performance used in level IV analysis (block IV-56). Changes in configuration design will be identified from this comparison. The airplane performance will be calculated using measured drag data (PRF-2, -3, -4).

Cruise configuration longitudinal stability and control characteristics and lateral-directional stability characteristics will be compared with estimates made early in level IV. Changes in configuration design will be identified to meet handling qualities criteria.

The stability and control analyses in this level will identify the design constraints and problems foreseen for the configuration and make changes where necessary before the major design and analysis tasks of block V-11 are commenced.

S&C-3, -4, -6, -12, -14, -17 technical program elements calculate the basic aerodynamic characteristics using cruise configuration wind tunnel data from block V-5 replacing the aerodynamic estimates used previously with these programs. Aeroelastic correction factors used originate from blocks IV-45 and IV-46.

Handling qualities estimation for the cruise configuration will use S&C-18 with a computerized pilot model and S&C-19 which is a true piloted simulation. The piloted simulation will include the flight control system synthesized in block IV-12 and control surface actuation characteristics defined in block IV-9. Design conditions for this task are greatly expanded from those investigated in level IV and will cover, in addition to normal flight conditions over the entire flight envelope, those failure conditions that could have major impact on the design.

Block V-7. Configuration Acceptable--Goal: Determine acceptability of cruise performance, longitudinal stability and control, and lateral and directional stability.

This decision is manual and human judgment will be exercised to evaluate the acceptability of the configuration.

Block V-8. Technical Review to Determine Next Action--Goal: Determine degree of unacceptability of configuration from block V-7 and establish whether configuration changes can be made to produce an acceptable condition.

The decision of a technical committee is required. Data from analyses of block V-6 will be reviewed.

Block V-9. Develop Level V Inputs--The analysis and design methods to be used in level V will be the most powerful available in each technical discipline. These will be executed as separate jobs, but will coordinate and transfer data between jobs through the data base management facilities of the IPAD system. Thus block V-9 develop inputs occurs many times throughout level V. It is shown here to indicate that each execution will collect user inputs, technology data base inputs, additions to the data base resulting from test data, and outputs from level IV and use all of these as sources for information for subsequent analysis, design, and testing.

Block V-10. Tests (Development)--Goal: To aid the configuration verification through testing.

The following tests represent a sample and are reported to show the character of the level V development tests. In general, these tests are conducted as required to verify with confidence the airplane performance, and the concepts of the structure and systems.

Continued Wind Tunnel (WT) Tests

Low-Speed WT Model--Goal: Measurement of drag and lift characteristics for the low-speed configuration performance identified in level III.

S&C Longitudinal and Directional Low-Speed WT Test--Goal: Measurements of stability and control characteristics to compare with the low- speed stability and control estimates made for the airplane in lLevel IV. High angle of attack data will be taken to show satisfactory stall recovery. Engine failures will be simulated.

Additional Cruise Configuration WT Tests--Goal: Addition of lateral and directional control surfaces to the cruise configuration wind tunnel model will enable correlation of cruise lateral and directional control characteristics to be made with the estimates in level IV.

WT Test - "Manufacturing Loft" Wing--Goal: To test the aerodynamic difference between the wing defined by aerodynamics and the wing considered manufacturable.

Manufacturing considerations invariably require some modification to the wing lofted by aerodynamics. If these changes are extensive, the performance degradation should be established by wind tunnel test.

Loads Wind Tunnel Pressure Models--Goal: To measure pressure data for the loads analysis. Two pressure models are required as a minimum, namely, high-speed and low-speed. On the high-speed model, pressures would typically be measured on the wing, body, horizontal tail, vertical fin, and nacelle. Runs would be made throughout the Mach number range and alpha range (negative stall to positive stall) with beta sweeps at selected conditions. Configurations would include clean and spoiler (speed brake), roll control, and elevator and rudder deflections (singly and in combination).

On the low-speed model, additional pressure would be required (e.g., high-lift devices, gear doors, gear cavities, and leading and trailing edge cavities). Configurations resulting from various flap and control surface deflections would again be tested over the full alpha range.

Strain gage measurements taken during total airplane force tests to obtain loads on smaller components, nacelles, struts, ailerons, stabilizer, etc., could be used prior to the availability of pressure data and as a check of integrated pressure data.

Propulsion Tests--Goal: Perform required tests to verify the propulsion system configuration.

Engine rig, wind tunnel, flight, and other tests are performed to verify the design of the various components of the propulsion system (inlet, nozzles, thrust reversers, acoustic treatment, etc.). Questions which must be answered include performance of the propulsion system at altitude (may require flight testing of new engines), flight cycle fatigue, inlet distortion, oil flow indication, anti-icing, water injection, sand ingestion, low- and high-temperature starting, etc.

<u>Structural Development Tests</u>--Goal: The goal of the structural development tests is to verify theoretical requirements and establish baselines for empirical evaluations for structural components. These tests would be product-oriented and would not include research and development tests. All testing required to ensure complete technical confidence in the configuration must be accomplished at this level.

Theoretical requirements include testing (e.g., wing panels) for comparison between predicted allowables and fracture stresses, etc. The main purpose of this type of testing is to correlate predictions and test data for every conceivable allowable stress (stability, fatigue, fail-safe allowables, etc.) in order to prepare for the full-scale test assemblies to follow.

Empirical evaluation consists of testing to establish design guidelines for situations where theoretical approaches fail or become unreliable. Its purpose is to establish minimum gages, edge margins, baselines for fatigue analysis, required area ratios for fail-safe design, etc. It covers problem areas such as:

Bird impact on windshield

Detail fatigue ratings for design details not previously used or tested

Strength of fittings

Hail impact

Crack propagation

Sonic fatigue

Lightning strike

Systems Tests--Goal: To conduct developmental tests required to verify that the definition of each system is within the current design and production capability.

This testing is general and must be responsive to areas of concern which are identified during the design/analysis function of both levels IV and V. For example: The flight control system would require testing if a decision were made to transmit control commands completely by an electrical and electronic "fly-by-wire" process.

Block V-11. Design/Analysis--Goal: To do the design and analysis activities required to support the configuration verification process and begin the design of long-lead-time items.

In level V, this activity is too broad in scope to be meaningfully put into a design network. Instead, selected technical disciplines have summarized the scope of activities they intend to do in this level. The level IV network activities may be repeated but limited to a portion of the airplane in greater detail.

The design of long-lead-time items will begin in level V and be continued into level VI. Examples include engine and nacelle integration, critical forgings (main landing gear shock strut, flap track beams), and control system mixers and electronics.

Aerodynamics/Performance--All of the analysis capabilities of aerodynamics will be used at this level. ARO-1 and -2 will be used to design wings for wind tunnel testing. ARO-3 will provide exact potential flow results for detailed wing design, empennage design, component integration, (e.g., wing-body fairings, nacelle pylon-wing geometries, etc., to support both wind tunnel model design and prototype design. ARO-4, -5, -6 will support those calculations that require AIC matrices.

Performance calculations will be required to support configuration modifications. PRF-2, -3, -4 and -5 will use test data and estimates to make these calculations.

Computerized Space/Arrangement Mockup--Goal: To reserve locations for items of fixed equipment which have been identified during the preliminary design and evaluate the adequacy of raceways for routing system services.

The airplane interior volume is divided into a matrix. Space envelopes are defined which represent the major compartments such as flight crew, passengers, cargo, electronics bay, control surfaces, propulsion, fuel tanks, landing gear, and auxiliary power unit. Also, smaller space envelopes are defined which represent fixed equipment such as actuators, pumps, filters, heat exchangers, and oxygen cylinders. Raceways are defined which provide for routing control cables, wiring, ducting, and tubing. (See DCA-3).

Dynamic Loads--All of the dynamic loads analyses performed in level IV will be repeated in level V using the same theories and programs but with refined input data as it becomes available.

Input data is refined by employing wind tunnel data, flight test data, and ground vibration test data corrections to the theoretical data. The quality of the analysis is improved by increasing the number of elastic modes and employing residual stiffness in the analysis in conjunction with the refined data.

In addition, many smaller design problems will be solved as the need arises. These problems are difficult to predict in advance but will be of the type such as changing nacelle flexibility to lower wing-nacelle attachment loads.

Flight Control System Synthesis and Analysis--Goal: Refine and expand definition of flight control system; perform response calculations to ascertain compliance with the criteria; complete definition of flight control system mechanization and redundancy concepts; analyze failure modes and effects; perform control surface actuator stability analysis; evaluate candidate hardware.

The flight control system will be updated to reflect data changes. The control system developed for block IV-12 must provide acceptable airplane handling qualitites. Analysis of the ride improvement and flutter suppression control systems which may have been identified in blocks IV-42 and IV-29, respectively, will be continued. The autopilot and autoland design concepts will be finalized. Computer programs FCS-1 through FCS-7 will be used in much the same way as in block IV-12. However, classical control techniques (FCS-1 or FCS-2) will be emphasized more heavily to permit a finer tuning of the gains and filters. Mechanization, redundancy, and failure studies will require nonlinear solutions afforded by FCS-8, FCS-9, or FCS-10. Nonlinearities may also be studied by use of the simulation described in S&C-19.

Equations of motion used for this event will consist of both the rigid body set (FCS-11) and the elastic mode set. (See figure 42.)

Flight Simulator Evaluation--Goal: Provide a simulation of the airplane in flight.

The simulation will model the six-degrees-of-freedom nonlinear dynamics, pertinent vibration modes, flight control system, hydraulic system, propulsion system, pilot's control, and pilot's displays. For piloted operation, the simulation will be operated at real time. The cab will be fixed-based (as opposed to moving-base) for this design level.

Nonlinear time responses will be produced for control inputs, gusts, and failures. A particularly important result of the simulator study is the pilot rating of the airplane's handling qualitites. However, due to the inclusion of many technical disciplines in the simulation, the simulator acts as an analytical systems integration tool.

The flight simulator for this level will be an off-line device such as the EAI-8400. Software for providing the simulation is in existence; however, the computer programs are generally tailored for a particular airplane.

Flutter--Goal: Perform flutter analysis on the configurations updated by static wind tunnel model tests.

Wind tunnel testing of the cruise configuration and low-speed configuration models may result in changes on wing airloads, tail size, and empennage control surface size. Flutter analysis using the same procedure and computer programs (SFL-1 through SFL-13) in level IV will be carried out on these updated configurations to ascertain compliance with the flutter requirements. Important structural detail information on main structure cut-outs, stiffness of major structure junctions, mounting stiffness of localized masses, and control surface stiffness and the corresponding updated mass distribution will be available as input to the flutter analysis. Measured sectional lift curve slopes and aerodynamic center locations from the static wind tunnel model test data will be incorporated in unsteady airloads predictions. Control surface flutter analyses are performed. Failure conditions will be identified and analyzed to ensure compliance with the flutter criteria.

Plans and Schedules--Goal: To provide operations, marketing and finance with plans and scheduling information.

Update the block IV-55 estimates of the engineering release schedule, the configuration verification test plan, and the manufacturing schedule. Continue identification of critical long lead items such as engines, forgings, etc., and procurement criteria. Make initial estimate of the level VI product development test plans, engineering manpower plan, and integrated engineering schedule for time dependent relationships between technical tasks. In addition, the level VII product verification test plan is initiated.

Product Assurance:

a) System Failure Mode Effect Analysis--Goal: The objective of the failure mode effect analysis is to reveal design inadequacies and to identify where corrective action is needed. This analysis focuses attention on potential reliability, maintainability and safety problems and serves as a starting point for quantitive system reliability and safety analyses.

   The analysis determines the effect of failure of identified functions and components within the system for each failure mode. Means of recognizing the failure and compensatory provisions and procedures are identified. Order of probability of occurrence of the event is assessed. Output of the analysis is a tabulation by function or component of factors associated with its failure modes.

b) System Fault Hazard Analysis--Goal: The objective of the fault hazard analysis is to identify all hazards associated with operation of the system and their safeguards.

   A fault hazard analysis is a tabulation of the hazards identified with operations of the system through each phase of operation. Function, component, or operator failures causing the hazard are identified. Order of probability for each combination of hazard producing events is assessed. Compensatory provisions and procedures are identified.

c) System Design Reliability/Safety Analyses--Goal: Assessment of system design configuration against the reliability and safety requirements and allocations.

   Fault tree simulation (REL-5), computerized Boolean reliability analysis (REL-3), automatic reliability mathematical modeling (REL-2), and CTS (REL-14 and 41) are used for studies at this level. Program selection is dependent on problem and system complexity and comparative factors selected for evaluation.

d) Flight Control System Reliability/Safety Analysis--Goal: To assess the overall system from the standpoint of reliability and safety.

Flight safety and reliability in all flight phases and design conditions are studied. Fault tree (REL-5) analysis is used for overall airplane flight safety assessment of the control system.

Reliability studies within the flight control subsystems are performed with the COBRA (REL-3), the ARMM (REL-2), and CTS (REL-14 and 41) programs.

e) Major Component Specification Control Drawing Reliability, Maintainability, Safety Requirements--Goal: To assure reliability, maintainability, and safety requirements for functions and components are realized in the actual hardware.

Reliability, maintainability, and safety requirements and allocations, established in level IV and used in all assessment analyses, are defined in the specification control drawings for all hardware. Contribution to overall system unreliability of major items is assessed as these component detail designs are developed. Manual calculations, CTS (REL-14 and 41) and COBRA (REL-3) are primarily used for these component assessments.

f) System Design Maintainability Analyses--Goal: Assessment of system design configuration against the maintainability requirements and allocations.

This assessment is manual. It supports the reliability and safety analyses of block V-11. Accessibility will be studied and optimized through use of the computerized space arrangement mockup.

g) Airplane System Reliability and Maintainability Evaluation--Goal: An evaluation of the total system in the operational environment to the level of definition available.

Simulation model (REL-1 or REL-4) will evaluate interactions, major influences, controlling parameters, special features and characteristics affecting utilization, dispatch reliability, maintenance, and logistics facilities and costs.

Variables such as fleet size, route structure, schedules, flight time, and ground time are altered to assess each change in design and evaluate strengths and weaknesses of each airplane in operational environments.

h) Engine Change Capability--Goal: To determine capability of engine change within a time interval compatible with planned utilization.

All engine installations are assessed with regard to access for both handling equipment and personnel. Disposition of cowling, associated and intervening airplane structure, engine buildup (EBU) requirements, and compatibility with existing GSE are considered.

Producibility Review--Goal: To assure that the design decisions are commensurate with cost effective fabrication and assembly practices.

Producibility is a prime consideration during the design solution phase. Affirmation by operations personnel is essential before drawings are released. This activity is initiated as soon as the design solution is selected.

The computer-aided design support group verifies that the aerodynamic wing which is defined in the geometry control system (DGL-2) can be redefined in the master dimensions system (DGL-4) within the specified tolerance. (In an IPAD environment a common geometry system is used throughout all design levels.)

Propulsion--Goal: Perform detailed design and analysis of the propulsion system.

A detailed design and analysis will be performed on all major components of the propulsion system to verify the propulsion system configuration. The network block IV-15a activities are continued and will include further definition of the nacelle mounting structure, systems interface, inlet and nozzle integration with acoustic materials and thrust reverser, mechanical function integration, etc.

Stability and Control--Goal: To update the stability and control low-speed analysis and cruise configuration lateral and directional control effectiveness.

The items examined include low-speed stability and control characteristics based on wind tunnel data that meet criteria and the estimates made for the airplane in level IV, satisfactory control characteristics at high angles of attack, and lateral and directional control effectiveness for the cruise configuration that meet the estimates made in level IV. Also, the cruise configuration longitudinal stability and control, the control of engine failures, and flight simulation of critical conditions are reviewed.

Stability and control analyses following the low-speed wind tunnel tests and cruise configuration wind tunnel tests undertaken in block V-10 are similar to block V-6 which analyzed cruise configuration conditions only. A basic aerodynamic understanding of the configuration exists supported by wind tunnel data for blocks V-5 and V-10. Aeroelastic data from blocks IV-45 and IV-46 are used, with the rigid aerodynamics data, to permit a range of conditions over the entire flight envelope to be studied on the flight simulator for constraints and problem areas such as engine failure. These must be identified and incorporated in the design before project go-ahead in level VI is commenced. S&C-3, -4, -6, -12, -14, and -17 technical program elements enable the basic aerodynamic characteristics to be calculated. Handling qualities estimation will use S&C-19, which is a true piloted simulation. The piloted simulation will consider the current flight control system. Pilot's flight displays and controllers will be representative of those planned for the airplane. The simulator tests will also review the applicability of design criteria related to flying qualities and develop improvements where required.

Static Loads--Generation of static loads in level V uses the same theories as in the lower levels. However, the quality of the input is refined (e.g., theoretical aerodynamics is replaced by wind tunnel data, then by flight test data). The coverage of the airframe is extended to the entire structure rather than merely the primary structure. Loads produced are such that detailed design may be completed, and the requirements of the appropriate certification authority (e.g., FAA, CAB) are met, together with any special company requirements.

Loads on secondary structure (high-lift devices, control surfaces, fairings, doors) are calculated by hand (the methods are not presently amenable to computerization) using data from a similar past configuration, past experience, or wind tunnel data for the actual configuration. The format of the loads may be anything from a simple hinge moment to a full-pressure contour map.

In addition, many studies are performed, such as definition of fuel transfer weights and penalties resulting from nonstandard flight configurations (e.g., spare engine carriage).

The network shown in figure 45 represents typical data paths through a subsonic static loads analysis (e.g., figure 29, block IV-26). It should not be assumed that a module shown is executed only once per pass, is executed on every pass, or is subject to a fixed order of execution.

A majority of the load paths can be broken into three steps; 1) reduction of wind tunnel data, 2) calculation of the load distribution and 3) selection of critical conditions. The modules currently used to perform these tasks are described in SLO-5 through -41. It should not be implied that modules will be structured in this manner at the time of IPAD implementation.

Condition data is always input by a knowledgeable user. The number of variables make automatic selection impracticable at this time.

Structural Design--Goal: Provide optimum feasible design solutions for all major structural components (wing, body, empennage, nacelles and landing gear) and integrate these components will all other airplane systems.

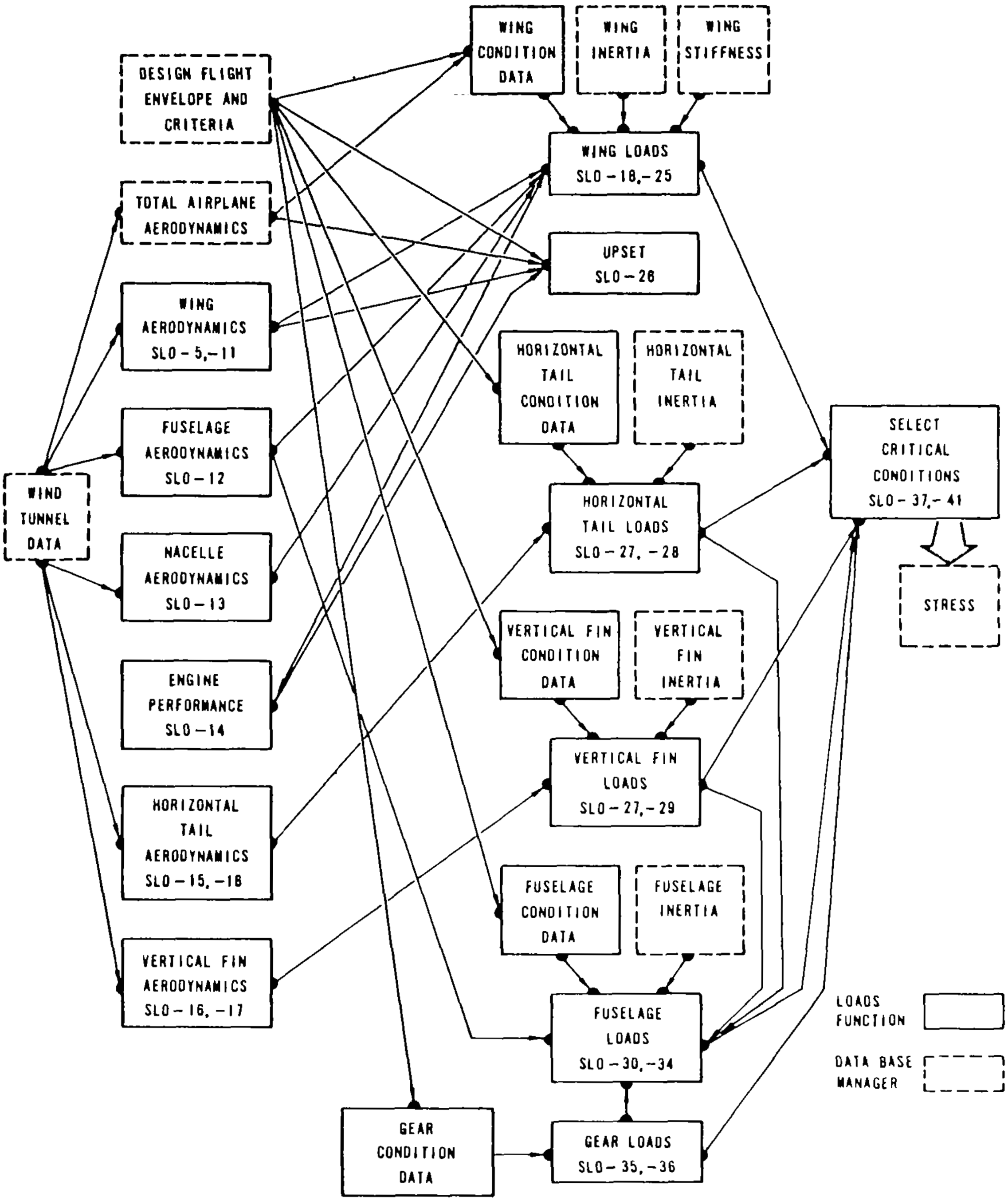


Figure 45.–Static Loads Analysis–Data Communication (Subsonic Configuration)

The design of each component and the major structural joints which attach it to the rest of the airframe will be defined in detail sufficient to preclude the possibility of serious deficiencies later in the program. The depth of detail studied will be commensurate with the complexity of the proposed solutions and will compensate, along with appropriate structural development tests (block V-10), for any lack of service experience with innovative designs. Studies will include any minor trades required to optimize the structure.

A typical specimen of each structural element having multiple usage will be designed as well as each individual unique element. Section breaks, joints and splices, fasteners, tolerances, finishes, material gauges and trim, attachments, and protective coatings will all be investigated in detail. Manufacturing methods for fabrication, assembly, and installation of each structural element and airplane component will be considered in terms of producibility, cost, weight, and durability. Provisions for equipment and systems will be incorporated into the primary structure to minimize the effects of space requirements and support hardware. All load conditions and design criteria, as well as safety and certification requirements, will be accommodated in the design at this level.

The structural design detail network and narrative at this design level (V) are similar to and are rendered to the same degree of detail as that shown in section 6.6 for detail design level VI through design evaluation stages.

Special structural design considerations are:

Body: Control cab windows, access doors and cutouts, pressure shell integrity and fail-safety, structural continuity, and compatibility with the wing and empennage

Wing: Structural continuity and fail-safety, fuel containment, control surface installation and systems equipment, and integration with the body and landing gear

Empennage: Structural continuity and fail-safety, control surface installation, and systems equipment and integration with the body

Nacelles: Structural integrity, service access segments, and integration with the engine and propulsion system

Wing-Body Joint: The complexity of this joint, with its requirements for continuity of load paths and compatibility of deflection and strain, necessitates analytical modeling. Great care and attention to detail in this area at level V is mandatory. Other considerations of major importance are fabrication, assembly, and production sequencing of the airframe. Fuel containment has significant influence on these decisions.

System Structures Interface: The systems-structure interface would be defined in a computer mockup. This would not replace the full-scale mockups required in level VI but would permit all systems runs and equipment envelopes to be readily defined early in the design process so that structural designers can provide access and support as required with a minimum of confusion. This mockup would be generated early, in blocks III-2 and III-12, and would permit input refined in block IV-17 and on through blocks V-11 and VI-3 to be retained in the data bank throughout the program.

The tasks required for this level are only briefly discussed above. Most of the structural design effort should be accomplished at this stage. The primary tool will be the interactive design program (DSA-5), which will be used in conjunction with the appropriate design analysis program and the graphics program ADEL (DGL-7). Examples of design analysis programs for major structural elements are the body frame design program (DSA-6) and the floor beam design program (DSA-7).

Data input will be from DGL-2 and -3 (GCS lofting) DSA-1, -2, -3, and -4, (structural arrangement definitions), and STR-3, -4 and -5 (structural sizing for strength, fatigue, and fail-safety).

Detail sizes of the structural element (beam chords, shear webs, etc.) would be optimized during an initial run of the design analysis program. The design engineer would modify the detail sizes to suit localized constraints and design factors for a typical element. Comments concerning these modifications to the optimized design would be stored in the data bank by the designer. These comments would be used by the staff personnel to understand the final design and by designers to incorporate design innovations in new aircraft models. A final run of the design program would optimize the design of the structural element using data bank criteria and these last design constraints made by the engineers.

The output of this task will be a complete definition of all structural elements and components necessary for the project design to begin level VI. All data and backup information will be stored in the data bank for interactive design purposes.

Structural Sizing and Stress Analysis--Goal: To provide support for the level V structural design (DSA-5, -6, -7, etc.) It includes detail stress analysis and sizing of all representative structural details, and covers integration of major structural components (e.g., solution of the wing-body joint).

The sizing and analysis in this level will provide the first basis for detail designs such as joints, fittings, stringer configurations, body frames, bulkheads, spars, control surfaces, ribs, attachments for landing gears, nacelles, control surfaces, etc. The analysis will cover static strength, fatigue, fracture mechanics, and fail safe. Also, local optimization will take place. The optimization will be directed toward items such as stringer configuration and spacing, rib spacing, frame spacing, and joint configurations and principles (STR-1 to -5). The impact of new gages and flexibilities will be established by load recycling.

The analysis will also include areas influenced by component integration such as the wing body joint, where the influence on load distribution due to component interaction will be established using finite element analysis. (See STR-7 to -13.)

System Design--Goal: To continue definition of systems until all design requirements have been identified and all equipment items are identified as existing or capable of development.

All systems design activities are similar in level V. These are described below.

Detail installation layouts for equipment items are drawn using computer-aided drafting practices (DGL-7, -8 and -9). The interface with structure for mounting provisions is entered in the structure data base, and a space definition of the component is entered in the computer mockup (DCA-3).

System schematic diagrams developed in block IV-17 are updated.

Initial schematic diagrams of the electrical circuits for each system are developed, and planning for integration with the wire release system (STM-21) is initiated.

Selection of existing "off-the-shelf" equipment is completed, and preliminary procurement specifications for new equipment items are initiated.

The testing required to verify system performance is initiated.

Maintenance plans for each system are initiated and reliability goals are established.

Other system activities will occur at level V. For example, a steering and ground-handling simulation (STM-19) will be conducted to develop additional design criteria for the landing gear. Hydraulic system dynamic, sizing, and thermal analyses are conducted (STM-5, -6, -7). Brake sizing and landing gear flotation analyses will be updated (STM-16, -17). Trade studies such as alternate APU locations (STM-9) will be conducted.

The system design detail network and narrative at this design level (V) is similar to that shown in section 6.7 for systems design level III.

Weights (Type D)--Goal: To calculate type D weight, balance, and loadability for a configuration which has been sized for strength, fatigue, flutter, and dynamic loads.

To accomplish this involves technical program elements that:

Execute weights update control (WTS-15) that would re-execute only those portions of the weights technical program elements whose input had changed.

Update wing, body, and empannage mass elements based on stress-sized skin/stringer material refined by local applications of finite element structural analysis (WTS-21).

Update wing secondary structure mass elements (WTS-18).

Update body/empennage secondary structure mass elements (WTS-19).

Update landing gear mass elements (WTS-9).

Update nacelle and strut, propulsion, fixed equipment, and standard and operational mass elements which will require development of a new technical program element (WTS-23) to accommodate a greater level of detail, especially in the systems areas, than is available by using technical program element WTS-10.

Update fuel mass elements (WTS-11).

Accumulate mass elements within each structural panel and calculate weight, center of gravity, and inertia for each structural panel and for the wing, body, and empennage (WTS-12).

Generate a weight statement patterned after the AN9102-D format based on the previously updated mass elements (WTS-13).

Calculate total airplane mass properties for various points on the balance diagram and determine updated panel mass properties for recycling through the structural analyses (WTS-14).

Block V-12. Estimate Program Costs--Goal: To provide program management with initial program cost estimates.

Initial program cost estimates will include several production quantities. Estimates of hours and dollars are provided and detail cost elements are summarized by sections and components of the airplane (FNC-2). An assessment is made of the production cost over a period accounting for changes in the manufacturing schedule for introduction of new customer configurations. The impact of derivatives from the base model is assessed (FNC-3). Return on investment and cash flow by year is estimated (FNC-4).

Block V-12. Manufacturing Review--Goal: To provide Operations with advanced design data to complete the company resources review and to prepare the manufacturing plan.

Operations must continue the program planning activities started in block IV-55. Based on itemized work statements, the make-or-buy and manufacturing plans are developed. The estimate of available in-house resources is finalized.

Block V-13. Summarize and Review--Goal: Summary of all design and analysis tasks, test results, etc.

This activity comprises a review of the design with associated program costs and marketing, product assurance, and manufacturing requirements (block V-12); action to determine whether design and analysis tasks in block V-11 are coordinated with the same technology level; and a decision concerning the need for further tests in block V-10.

Block V-14. Recycle?--Goal: Man decision whether to recycle the tasks of blocks V-10 through V-12 (tests, design/analysis, program costs) resulting from the summary and review undertaken in block V-13.

Block V-15. Configuration Acceptable--Goal: Man decision to review integrity of the technical design concerning a management recommendation for product go-ahead.

This is a critical event; any configuration change after design level V is disastrous to budget and schedule. Design level VI manpower effort, which follows, is increased six to ten times over that in level V. Time and manpower expended on a discarded configuration at level VI multiply the losses experienced in a discarded confiuration in level V.

Block V-16. Technical Review--Goal: Review by technical committee on the action to be taken following unacceptable results for configuration (block V-15), sales (block V-18), firm orders (block V-19) and product go-ahead (block V-21).

Block V-17. Management Review--A technical review is presented to management, based on engineering report in blocks V-13 and V-15.

The program management office (PMO) and manufacturing participate in the management review and receive design information supporting preliminary decisions. PMO must have assurance that the design intent meets the customer requirements. Manufacturing begins selection of subcontractors for long-lead "buy" items.

Block V-18. Sales Go-Ahead--This is a major program milestone. Management authorization is granted to proceed with a sales effort.

Block V-19. Firm Orders--This is a major program milestone and supports a decision to recommend a product go-ahead to management.

Block V-20. Management Review--Goal: Review by management of all sales activities, including market analysis, airline interest, firm orders, and program costs.

Block V-21. Product Go-Ahead--This is a major program milestone. Management authorizes go-ahead with product design, manufacture, verification, and support.

6.2.3.6 Level VI: Product Detail Design

The end item of level VI effort is a detailed description of the product to be built. The description includes drawings, specifications, processes, and quantities.

Level VI will begin when the decision has been made to commit the design to project status and while the risk of detail configuration change is very small. This level will dominate the group of IPAD levels denoted as the product levels (detail design, manufacture, verification, and support while in service). The activities of level VI will require careful management control. The design, analysis, and testing will be discussed by certain areas.

There is a general procedure that an engineer uses in the design process for each item. To illustrate this premise, two design items (a structures and a system design) were selected and detail design networks prepared of the step-by-step process for their detail design. Although the depth of the structural design network is greater than the fuel system network, the same procedure is required in each and the premise is true. (See section 6.6 for detail network for a structure design and section 6.7 for detail network for a system design.)

The general network for product detail design network description of figure 37 and figure 60 follows.

<u>Block VI-1. Establish Preliminary Design/Product Interface</u>--Goal: To provide program management, the engineering design project, engineering technology staffs, finance, marketing, and manufacturing operations with a consistent data base definition of the preliminary design configuration.

Many preliminary design-to-product interface activities occur. The plans and schedules required for program management (program, engineering cost and schedules, design development and verification test, and customer support plans) are finalized.

The data base detail configuration definitions are improved. For example, the configuration definition is finalized to include a complete manufacturing-oriented master dimension definition of the lofts (DGL-4). The weights accountability (type D weights) is revised as required for engineering, finance, and manufacturing (WTS-22). Weights accountability has been structured to provide:

A meaningful definition of the product in terms of weight data and descriptions

A meaningful weight history for evaluation of the final product design

The flexibility to handle a variety of design projects

A system that can interface with the previously executed weights analysis programs

A system which is efficient in terms of data and input, editing, and verification; internal data storage and manipulation; and output data report generation

Block VI-2. Tests (Development)--Goal: To perform the tests necessary to do the detail design of the product. This does not include final verification testing.

The following tests are a continuation of the testing conducted for block V-10 and are only a sample of the required testing.

Propulsion--Goal: Perform necessary tests to support detailed design of the propulsion system.

Tests performed will provide data to support detailed design of the propulsion system and will include tests such as inlet distortion, noise suppression, etc.

Structural Tests--Goal: This testing is directed toward subassemblies; its prime purpose is to correlate between analytical and factual stress distributions. It concerns itself mainly with structural details, such as wing body joints, cutouts (body doors, wing access holes) areas of load redistribution (landing gear beam attachments, control surface attachments, nacelle attachments, wing attachments, empennage attachments, bulkheads, etc.).

It constitutes a verification of the structural details for which past experience is insufficient and provides data for updating the structural sizing.

Systems Tests--Goal: To conduct development tests required to verify that performance of each system is as predicted or is an acceptable deviation.

The following are two examples of flight control system testing.

a) Control System Development Fixture (Iron Bird)--Goal: Design and fabricate the test hardware and perform the control system tests.

The control system development fixture consists of flight quality control system hardware attached to a boilerplate simulation of the airplane. Geometry and local structural stiffness are simulated. The fixture permits a complete functional checkout of the control system. Also, control surface and actuator response tests may be performed. Control system analysis programs (FCS-1 or FCS-2) and digital simulations (FCS-8, FCS-9, FCS-10, or S&C-19) will be required to interpret the test results and assist with the conduct of the tests.

b) Control System Response Tests--Goal: Measure control surface and sensor responses.

The flight control system design is dependent upon the transfer functions of the flight control components integrated into the airplane. These tests will be performed upon a flight article, probably the same airplane used for the ground vibration testing. The test procedure will be to run frequency responses of the control surfaces. Measurements will be taken of the control surface motion, flight control sensor outputs, feedback signal to the control surfaces, and various test pickups mounted on the airplane structure. A variation of this test will be to increase the feedback gain until an oscillatory condition is realized. In either case, a mathematical model of the airplane in the test configuration will be required. The mathematical model will be adjusted and corrected to force agreement with the test results. These adjustments and corrections will then be extended to the mathematical models of the airplane in the flight configurations.

Wind Tunnel Tests--Goal: To provide configuration testing to improve aerodynamic description of the airplane; improve areas of low lift, high drag, interference, etc.; support the aerodynamic cleanup program; and accomplish final testing to supply aerodynamic data to support performance guarantees.

Other goals are stability and control tests to solve problems and uncertainties arising from analysis of level V wind tunnel tests, control surface hinge moment testing to establish flight control actuator sizes with more accuracy, extensive control surface effectiveness testing, (including interference effects) for detailed control system design, detailed pressure model testing for loads evaluation, and wind tunnel flutter model testing to confirm and complement analytical flutter predictions of levels V and VI and to verify the control system stability margins if a flutter suppression system is employed.

Analytical flutter predictions made in levels V and VI are verified and complemented with extensive wind tunnel testing to provide substantiating information, particularly in the areas where structural and aerodynamic uncertainties exist. Dynamically scaled flutter models of the airplane and its components are tested in low-speed and transonic wind tunnels.

In low-speed tests, flutter characteristics and critical flutter speeds of primary surfaces of the airplane and sensitivity of flutter to various design parameters will be determined. In transonic tests, Mach effects (especially the high subsonic region) on overall airplane flutter and buzz characteristics of control surfaces will be determined. If a flutter suppression system is required, the flutter model test will verify control system stability margins. The test will compare experimental gain margin, phase margin, and gain peaking with theoretical results. The control systems analysis program of FCS-1 will be used to predict stability margins of the model. Finally, system tailoring tests will be performed on APU and air-conditioning inlets, pitot static provisions, etc.

<u>Block VI-3. Design/Analysis</u>--Goal: To perform the design and analysis tasks necessary for the detailed design of all the parts.

The activities of the different technical disciplines will be summarized. In addition to the items discussed below, interactive graphics will be extensively used for detailed parts design. The lofting technical program elements will be coupled with the various design and analysis technical program elements to support this design.

Aerodynamics/Performance--All of the design and analysis elements available within aerodynamics will be used at this level. ARO-1 to -6 and -17 will be used for detailed wing, body, empennage, nacelle, and pylon design and analysis for both wind tunnel models and production configurations.

Drawing Release System--Goal: To control the listing and release of parts information to manufacturing.

Drawing release provides an administrative and clerical service to engineering design, and acts as the interface between the design organization and downstream organizations using engineering drawings and related data.

In support of the engineering design organization, the release function assigns and maintains appropriate records for drawing and part numbers, drawing sheet numbers, revision identifications, and control numbers for supportive engineering documenation. It receives completed packages of engineering drawings and data from design groups, processes packages to complete record keeping, and issues drawings and related data to the reproduction unit for distribution to the using organizations.

In support of user organizations, the release function provides engineering data required to accomplish planning, ordering, producing, purchasing, and accounting for all hardware components. It produces indexes of drawings to be supplied to customers, representing configuration of the product purchased.

Inherent in an automated drawing release system is the ability to monitor schedule performance (actual drawing release dates versus scheduled dates), and to generate timely reports to management identifying actual or impending schedule nonconformance which may adversely affect the program. Additionally, it may be used to provide extracts, audits and statistical data to satisfy either standard or special report requests. It contains a historical log which may be used to trace the changes of product configuration.

Dynamic Loads--All of the dynamic loads analyses performed in levels IV and V will be repeated in levels VI using the same theories and programs but with refined input data as it becomes available.

Input data is refined by employing wind tunnel data, flight test data, and ground vibration test data corrections to the theoretical data. The quality of the analysis is improved by increasing the number of elastic modes and employing residual stiffness in the analysis in conjunction with the refined data.

In addition, many smaller design problems will be solved as the need arises. These problems are difficult to predict in advance but will be on the order of changing nacelle flexibility to lower wing-nacelle attachment loads.

Flight Control System Synthesis and Analysis--Goal: To complete definition of the flight control system.

The work of level V will be continued; however, the detail will be sufficient for final drawing release. The computational activity will be similar to block V-11, and the computer programs of FCS-1 through FCS-11 and S&C-19 will be used. Specializations of the foregoing list of programs may be required. These changes may be temporary (one time) or may result in the definition of a new computer program which is valid for only one airplane. Also, additional computer programs are required to solve specific problems that pertain to a particular airplane project.

Flight Simulator--Goal: Provide a simulation of the airplane in flight.

The fixed base simulation will be similar to the work performed in block V-11; however, as time progresses, more detail is introduced.

The effects motion produces upon the pilot will be measured by use of a moving base simulator in a different facility than the fixed-base simulation. Discrete gusts, wind shears, random turbulence, failures, and pilot input provide the excitation to drive the cab. The primary result of the simulator study is the pilot rating changes produced by motion.

Flutter--Goal: Perform flutter analysis to support detail design.

The flutter work of level V will be continued to the detail required for final design. The computational activity and computer programs used will be the same as level V. Additional computer programs may be required to solve specific problems which are pertinent to the particular airplane project. If uncertainties of theoretical predictions exist, they will be resolved experimentally.

Plans and Schedules--Goal: To provide program management, operations, marketing, and finance with plans and scheduling information.

The block V-11 estimates of the engineering release schedule and manpower plan, the product development/verification test plans, and the manufacturing schedule are updated. Identification of critical schedule items (e.g., forgings, mockups, etc.) is continued.

An integrated engineering schedule is initiated to identify and define the schedule relationships between the technical tasks to be performed by the various design project groups and the technology staff groups during the final design process in level

VI. The purpose is to ensure schedule integration between tasks which are highly interdependent in terms of technical data availability and timely performance of design and technical tasks relative to data. The integrated engineering schedule(s) sets forth the major milestones representing the following schedule dependencies:

Design project group schedule requirements for key interface design data from another design project group upon which their effort is dependent

Design project group schedule requirements for key technical data from a technology staff discipline group upon which their design effort is dependent

Technology staff discipline group schedule requirements for key design data from a design project group upon which their technical tasks are dependent

Technology staff discipline group schedule requirements for key technical data from another technology staff discipline group upon which their technical tasks are dependent

Product Assurance:

a) Airplane System Detail Design Reliability Safety Analyses--Goal: To incorporate additional design detail into the level V reliability and safety analyses and revise and update level V system simulation models with new data from level VI design effort. Fault tree simulations (REL-5), ARMM (REL-2), COBRA (REL-3), and CTS (REL-14 and -41) models will be updated as required to assess impact of level VI additional design detail. Re-allocations as required will be identified.

b) System Design Maintainability Analyses--Goal: Assessment of system design configuration against the maintainability requirements and allocations. This assessment is manual. It supports the reliability and safety analyses of VI-3. Accessibility will be studied and optimized through use of the computerized space arrangement mockup.

c) Component Specification Control Drawing Reliability, Maintainability, Safety Requirements--Goal: To assure that reliability, maintainability, and safety requirements for functions and components are realized in the actual hardware.

Reliability, maintainability, and safety requirements and allocations, established in level IV and used in all assessment analyses, are defined in the specification control drawings for all hardware. Contribution to overall system unreliability of components is assessed as these component detail designs are developed. Manual calculations, CTS (REL-14 and -41), and COBRA (REL-3) are primarily used for these component assessments.

d) Airplane System Reliability and Maintainability Evaluation--Goal: An evaluation of the total system in the operational environment.

Simulation model (REL-1 or REL-4) will evaluate interactions, major influences, controlling parameters, special features, and characteristics affecting utilization, dispatch reliability, maintenance, and logistics facilities and costs.

Variables such as fleet size, route structure, schedules, flight time, and ground time are altered to assess each change in design and evaluate strengths and weaknesses of each airplane in the operational environment.

Propulsion--Goal: To complete final design and development of the propulsion system.

The level V activities are continued to complete design and integration of the nacelles and mounting structures. The techniques and activities described in the following sections of "structural design" and "systems design" are applicable to the propulsion system.

Stability and Control--Goal: To complete all airplane stability and control analysis; control interference effects, thrust reverser effects, and unusual configuration effects; analyze all wind tunnel testing; size actuators from control surface wind tunnel tests in block VI-2; do detailed control surface effectiveness analyses to assist control system design; and perform flight simulation of all design conditions including failures, turbulence, and gust effects.

This level is the product detail design phase where analyses are aimed at achieving a total practical airplane control system and SAS design in conjunction with complete understanding of the basic flying qualitites of the configuration. Wind tunnel tests in block VI-2 will not only update previous wind tunnel data of level V but will provide an extensive range of aerodynamic data for all possible control surface applications, high-lift application, speed brakes, landing gear, thrust reversers, etc. Aerodynamic characteristics will be calculated from wind tunnel data in program elements (S&C-3, -4, -6, -12, -14, -17).

Aeroelastic corrections will originate from structural load analyses undertaken in block V-11. Control surface actuators will be resized using rigid hinge moment data from wind tunnel tests block VI-2 and with aeroelastic corrections obtained from structural load analyses in block V-11. Actuator rate requirements will be specified from the flight simulator tests undertaken in block V-11, and further simulator testing in this level VI. Piloted simulation will be extensive and will incorporate the current flight control system. Pilot displays and controls will be representative of the airplane. An assessment of flight control system effects, gearings, rates, etc., on handling qualities will be made in conjunction with assessment of failure modes (mechanical, hydraulic, engine thrust). Models to simulate discrete gusts and turbulence will be incorporated in the flight simulation.

Static Loads--Generation of static loads in level VI uses the same theories as in the lower levels. However, the quality of the input is refined (e.g., theoretical aerodynamics is replaced by wind tunnel data and flight test data). The coverage of the airframe is extended to the entire structure rather than only the primary structure. Loads produced are such that detailed design may be completed and the requirements of the appropriate certification authority (e.g., FAA) are met, together with any special company requirements.

Loads on secondary structure (high-lift devices, control surfaces, fairings, doors, etc.) are calculated using data from a similar past configuration, past experience, or wind tunnel data for the actual configuration. The format of the loads may be anything from a simple hinge moment to a full pressure contour map.

In addition, many studies are performed within the loads organization (e.g., definition of fuel transfer weights, definition of penalties resulting from nonstandard flight configurations such as spare engine carriage), the output of which may not be passed to other technologies.

The network shown in figure 45 represents typical data paths through a subsonic static loads analysis. It should not be assumed that a module shown is executed only once per pass, is executed on every pass, or is subject to a fixed order of execution.

A majority of the load paths can be broken into three steps: 1) reduction of wind tunnel data, 2) calculation of the load distribution, and 3) selection of critical conditions to be passed to the stress organization. The modules currently used to perform these tasks are described in SLO-5 through -41. It should not be implied that modules will be structured in this manner at the time of IPAD implementation.

Condition data is always input by a knowledgeable user. The number of variables make automatic selection impracticable at this time.

Structural Design--Goal: Expand and refine the structural design as defined in block V-11 into a completely detailed engineering package. This package would consist primarily of data filed in the computer data bank, but could also include any desired hardcopy such as engineering drawings, documents, specifications, or reports.

It is intended that no new structure design definition be accomplished at block VI-3, but only expansion and refinement of solutions and concepts of block V-11. It is here that the real capabilities of the computer can be utilized to provide efficiency in the design process. The design definition of a single body frame, floor beam, or wing rib from block V-11 can be repeated almost instantly 2, 4, or even 50 times. It can be readily modified to accommodate any number of optional, alternate, or special cases of similar concept. These special cases would include exceptional geometric or spatial limitations on the structure, unusual manufacturing or assembly conditions, or differing sealing or system-to-structure interface requirements. Only the incremental change in the design would require study while the data base would retain--instantly available--the remaining part of the design. Such a concept would be especially valuable for an area-ruled body. Every frame would be similar in concept but of different diameter with varying stringer pitch. In like manner, all floor beams would be of different length. The problem of retaining and utilizing such information is particularly well suited to the computer.

The systems-to-structure interface would be refined in the computer mockup identified in block V-11, but a full-scale class III mockup would also be necessary and will be defined in block VI-4.

Great efficiencies would be derived from both the speed and accuracy of data transfer between the men and machines in the interactive design process. In addition, with fewer people involved, the management can be more concerned with technical considerations and less with manpower. Hopefully, the peak on the engineering manpower mountain presently necessary in product detail design can be reduced because of a more thorough preparation in block V-11 and the improved design efficiency of the interactive tool (DSA-5) and the design analysis programs (DSA-6) and on.

All of the design connsiderations, criteria, and constraints of blocks III-12, IV-24a, and V-11 will continue to influence the design process at this level. Great attention to fine detail will be mandatory to complete the design package. All fabrication and installation requirements for every part and assembly must be determined during level VI. These requirements include hardware material, heat treatment, geometry, fit-up tolerance with adjacent parts, fastener spacing and location, surface finish, and protective coating requirements. (See section 6.6, Detail Network, for structural design.)

One potential benefit of the use of IPAD will be identification and control of parts. This control and identification would begin with part numbering and automated parts release at level VI. Manufacturing and material visibility of these parts begins at this point. Raw material orders, NC programming, and large tool planning would all use the data base inputs made at this level. A most important aspect is that the data would at this point be in a form accessible and acceptable to operations without requiring conversion for automated fabrication techniques.

Structural Sizing and Stress Analysis--Goal: The objective of this task is to perform stress analysis and sizing of individual components (i.e., identify and size each individual body frame and all other detail parts)--in other words, increase the refinement from representative to individual designs (DSA-5, -6, -7, etc.). This sizing and analysis covers all design details, so parts are analyzed and sized individually. The structural idealization is refined and the internal load distribution is calculated for the detailed area and stiffness properties obtained from the individual sizing.

Test results from level V as well as VI are used to correct theoretical results. The corrections should be applied to both internal and external loads, such as airloads on control surfaces.

The sizing of the components and subasssemblies is based on the same considerations as in level V; however, the qualitative result is more accurate weights and distributions as the internal loads are based on more accurate internal loads distributions, which, furthermore, are updated with respect to level V test results.

Parallel activities will include finite element idealization of local areas, such as wing-body joint, access doors in lower wing skins, door cutouts in the fuselage skin, etc., (STR-7 to -13). These results will be used for comparison with test results and after correlation, serve as a basis for the sizing of the respective components and subassemblies.

System Design--Goal: To complete final design and development of all systems. (See section 6.7, Detail Design Network Systems.)

Level V activities are continued and the following additional activities completed.

a) Identify all hardware required and release preliminary information to the mockup. Finalize and release design of detailed parts and installation information.

b) Finalize and release procurement specifications for new equipment items.

c) Finalize and release maintenance information including:

   (1) A system schematic diagram with system maintenance requirements noted. The system "new condition" operational limits are identified for the manufacturer's functional test requirements. In addition, the system "in-service" minimum acceptable operational limits are established for the operator's functional test requirements to allow for normal deterioration.

   (2) A component maintenance data sheet for all components of maintenance significance. This data sheet contains information on accessibility, servicing, test and inspection, and removal and replacement. The following information is established for each component:

      (a) Test Provisions: self-test or test-in-place. The operable condition of a component is continually indicated or may be indicated if a button is pressed.

      (b) The component removal basis in one of three categories: (1) Time-controlled components with predictable wear-out rates which will be removed and replaced in accordance with the scheduled time between overhauls (TBO). (2) Condition-controlled components which can continue to operate until inspection and tests (made without removal or tear-down) indicate the part is no longer airworthy. This category is generally related to parts which fail or wear out gradually. (3) Failure-controlled components which can continue in service until failure. This category is generally related to parts which fail abruptly and whose failure does not impose any hazard.

(3) Procurement specifications: Each procurement specification contains a maintainability requirement to meet the intent of (2)(b)(1) and (2)(b)(2), above, and a test to prove satisfactory operation at a specified deteriorated performance level.

d) Finalize and release schematic diagrams of the electrical circuits and develop integration with the wire release system (STM-22).

Weights (Type E)--Goal: To provide the staff, project, finance, and manufacturing organizations with the current status of the configuration's definition in terms of weight and weight-related items in a form that is meaningful to each recipient.

The weight data are based on calculations from released engineering drawing by part and actual part weights. A first attempt to provide this capability is contained in technical program element WTS-22.

Wire Release System--This is a typical packaged part design process with the goal to define, integrate,and control all wiring in the airplane.

The wire release system is a composite of approximately 80 programs. Its primary data base consists of a wire masterfile, an equipment masterfile, and a file containing production information (primarily from planning and mockup inputs). Several smaller files provide specialized information to be merged with the primary data on various output reports (STM-22).

The major output reports are used in the following ways.

REPORT TYPE	USE
Engineering Reports	Input of wire and equipment to data files
	Verification of agreement between data files and wiring diagrams
	Reference information for

	configuration of any airplane
Mockup Reports	Input of wire lengths and subassembly groupings
	Reference information from which formboards and production illustration drawings are produced
Planning Reports	Input assembly sequencing information
	Issue production orders for every bundle required
Material Reports	Purchase wire, connectors, etc.
Manufacturing Reports	Cut and mark wire
	Preassemble connectors
	Assemble bundles
	Test bundles
	Connect bundles together after installation in airframe.
Customer Airlines Reports	Maintenance
	Identification of spare wires
	Identification of bundles and equipment for ordering spares
	Input of information on post-delivery modifications

Program descriptions include:

Manufacturing Plan (includes bundle equipment list)--This program provides a report containing production information, quantity, parts used, installation location, and sequence of assembly. Some engineering input is required, but most of this data originates with mockup or planning.

Wire List--This program lists each wire in every bundle. It shows information as wire number, termination (both ends), size, length, color, type, and assembly sequence; and it references the wiring diagram that shows the wire.

Equipment List--This program shows part number, description, next assembly, reference wiring diagram, etc., for each equipment item number used.

The three programs above are the heart of the wire release system. Their master-files record the detail configuration for every airplane of a model series and are updated with any frequency desired (usually three times per week). The other files in the data base contain information of general applicability rather than specific data for individual airplanes. All other reports in the wire release system are "derived" reports, that is, derived from the data supplied by the three major programs and the several smaller data files or tables with no additional input of information.

Shop aid reports include:

Assembly Connection List--a report showing how long to cut each wire, wire type and size, how to mark it, and how to connect it. A separate list is issued for each group of wires within a bundle.

Plug Maps--physical layouts of connector insert arrangements with the wire number for each pin printed immediately below the pin number.

Formboard List--similar to the assembly connection list except sorted by equipment item number rather than wire number (to enable the worker to finish one item before starting another.)

Manufacturing Plan--basically the same as used by engineering except that part numbers for all equipment items are added by the computer from the equipment file.

Other manufacturing reports include:

Part Requisition Cards--used to issue parts and serve as materiel records.

Bundle Assembly Tags--control the routing of bundles in the proper sequence through the production line.

Datex Cards--supplement the assembly connection list for wires that can be machine-cut and -coded.

Wire Identification Tapes--provide wrap-around identification tags for those wires which cannot be machine-coded.

Automatic Wire Tester Cards--used for automated testing of completed wire bundles.

Bundle Sequence List--complete list of bundles required for an airplane, sorted in production sequence.

Hook-up Charts--hook-up information required at the time bundles are installed in the airframe.

Other nonmanufacturing reports include:

Diagram Check List--extract of the wire file, sorted by wiring diagram, used to check compatibility between data base and wiring diagrams.

Equipment Check List--analogous to diagram check list but extracted from equipment file.

Wire Compare List--shows only the differences between any two airplanes of the same model.

Part Number Summary--extract of the equipment file sorted by part number.

Bundle Assembly Index--identifies bundles with the airplanes on which they are to be installed.

Diagram Equipment List--part of the diagram manual report (DMR); an equipment list for one customer only, sent to the airline for maintenance information as part of wiring diagram manual. Diagram manual reports are available to customer airlines on hard copy, punched cards, magnetic tape, or microfilm, at the customer's option.

Diagram Wire List (Part of DMR)--full wire listing for all bundles for one customer block.

Hook-up Charts, Ground List, Splice List, Terminal List--part of the DMR and giving hook-up information for various equipment items.

Wire Quantity Report--gives materiel information on how much wire of each type and size is required per airplane. Total wire weight per airplane can also be obtained from this program.

<u>Block VI-4. Manufacturing Review</u>--Goal: To monitor schedule sensitive item releases from engineering to ensure that manufacturing activities can be responsive.

Operations refines manufacturing plans and makes inputs to manufacturing computer systems for part card coding, detail and subassembly orders, and major assembly and installation paper. Engineering changes are scheduled and unit sequencing accomplished.

Engineering releases are monitored in accordance with the document industrial engineering (DIE) and manufacturing schedules adjusted for late releases. Manufacturing assemblies and detail deviations are identified for facility of production. These become inputs to the manufacturing systems but do not exist in the end product.

There is continuous interaction between engineering and operations as the part drawings are released. Engineering must respond quickly to design change requests that are based on improved cost and schedule assumptions. Many requests are initiated on the basis of problems encountered on the class III manufacturing mockup network (block VI-4). Where possible, changes are incorporated in the initial releases.

Block VI-4. Mockup--Goal: To provide the mockup planning department with information to develop the required engineering and manufacturing mockups and to produce production illustration drawings.

Engineering Mockup--Preliminary information and drawings are used to construct the engineering mockups. Class I mockups provide approximate information of the airplane structure and are used to evaluate full-scale integrated space and arrangement concepts of the airplane. Class II mockups provide more detail of the airplane structure and are used to evaluate full-scale structure and component installation concepts. These mockups include moving parts, where required, and provide final checkout information for the integrated engineering evaluation.

Manufacturing Mockup--Final engineering drawings are used to construct the class III manufacturing mockup. This mockup represents the exact production airplane structure made from final engineering information and is used for engineering and manufacturing evaluation of the integrated airplane structure and systems. The class III mockup is used to develop tubing, wiring, thermal and acoustic lining, and other parts that do not require detail information from engineering.

Manufacturing prepares production illustrations (PI drawings) which are cosigned by engineering. These are perspective views of wiring, system component, and tubing installations in the manufacturing class III mockup. These drawings provide installation information to manufacturing. Computer-aided design support can provide views of the structure to which the details are added manually. These are updated as the result of design changes.

Block VI-5. Summarize and Review--Goal: To summarize and review the detailed part design process by use of the management information system (MIS-1, -2 and -3).

The output of level VI effort is a detailed description of the product to be built. The description includes drawings, specifications, processes, and quantities.

6.2.3.7 Level VII: Product Manufacture

The goal of level VII is to build the product. This level appears by definition at the end of level VI. The IPAD system will interface with manufacturing, to the extent required to cause the product, as designed, to be built.

Document D6-IPAD-70011-D, Product Manufacture Interactions with the Design Process, is an in-depth description of the manufacturing and engineering interactions during conception, design, and fabrication of a product. The following narrative describes the brief activities. (Network shown in figures 38, 39, 61, and 62.)

Block VII-1. Review Design Specifications--The manufacturing task is twofold: it provides a manufacturing process that will build the product, and it uses that process to build the product so that the "as-built" configuration matches the "as-designed" configuration. It also endeavors to ensure that production is cost-effective.

Manufacturing reviews the design specifications at the time of release to ensure that incompatibilities are resolved and sensitive items released in accordance with the master schedule.

Block VII-2. Problem Requiring Redesign?--As a result of the review in VII-1, should production problems appear that may be solved by redesign of the product, the problem and suggestions are referred to product detail design level VI (fig. 37) for consideration. Any resulting design change is treated as sustaining design. (See section 6.6 and 6.7 for a detail network that includes a pattern for this type of problem solving.) After detail design has taken action, any resultant redesign is reviewed again as described in block VII-1. However, if no problem arises that dictates redesign, the activity continues to block VII-3. Blocks VIII-3, VIII-4, and VIII-5 are simultaneous activities.

Block VII-3. Release Manufacturing Process Orders--Manufacturing reviews prereleased process plans to verify that no changes are required to accommodate the released design specifications. New process plans are released for the parts not already in the planning system.

Block VII-4. Release Tool Design and Fabrication Orders--Tool design requests are released for contract tools, and tool fabrication orders are released for both design and nondesign tools. Major tooling already in work is reviewed for compatibility with releases.

Block VII-5. Release Purchase Orders--At this point in manufacturing activities, a make-or-buy decision is made. Procurement releases purchase orders for material and "off-the-shelf" items and outside production orders for "buy" components.

Block VII-6. Production Problem Requiring Redesign?--As manufacturing process orders are written and tools designed, design problems may surface that were previously overlooked. Design changes are requested to facilitate manufacture and tooling planning. If redesign is requested, the problem and recommendations are referred to product detail design level VI (fig. 37) for consideration. Any design revisions or sustaining design will reappear at manufacturing block VII-1 in the activity network. Having solved the problem, or in the event no problem was encountered, the activity proceeds to block VII-7.

Block VII-7. Build and Inspect Parts and Tools--Tooling is fabricated and inspected according to the tool design order, and tool tryouts are performed during the first lot manufacture. Detail parts are produced and inspected to the design specifications.

Block VII-8. Parts and Tools Satisfactory?--Parts and tools that pass inspection are sent to stores until they are used. Those that are rejected are further analyzed in block VII-9.

Block VII-9. Problem Requiring Redesign?--A study is made and the cause for rejection is determined. If redesign is a candidate for solution the problem is coordinated with detail design level VI for action (sustaining design). If the problem lies within the scope of tools or production methods, then a decision must be made to scrap or rework parts and/or tools.

Block VII-10. Rework or Scrap?--Quality control will determine whether a rejected part or tool can be reworked to meet design specifications. Engineering liaison is consulted at this time in determining whether costly rejected parts could be repaired, used "as is", or rejected Should the decision be to rework, the part/tool is referred to block VII-7 and continues from there.

Product detail design (level VI) provides engineering liaison to manufacturing for rapid engineering response to manufacturing design change requests that are the result of fabrication difficulties.

There are design discrepancies that affect producibility and are not apparent until the actual fabrication, assembly, or installation is attempted in the factory. When problems arise, engineering must respond quickly to the manufacturing request for a design change in order that the matter be resolved with minimum delay in the product process. The liaison activity provides the response and feeds the information to the parent organization to ensure that the affected design media are corrected.

Block VII-11. Salvage--If the part or tool cannot be reworked, it is scrapped and the materials are salvaged.

Block VII-12. Assemble Parts and Install Wiring and System--In block VII-8 if the tools and parts made on them were "as-designed," the detail parts are put together as subassemblies and major assemblies. Wiring and systems are installed according to the process plans and inspected to the design specifications. Final assembly and installations take form as major assemblies are joined.

The manufacturing process utilizes extensive computer systems to produce shop paper, collect cost data, report exceptions, and record configuration. Numerical control fabrication depends on a large general-purpose computer and the status of tools is reported by means of a computer program. For example, the design, planning and fabrication of wire bundles are controlled by a computer system (Wire Release System STM-22). The complexity of the process is controlled by a series of checks and rechecks, both manual and automated, with decision-making data available to management as a byproduct. The final check by quality control is a match of the "as-built" data base against the "as-designed" data base.

To further amplify this example, the Wire Release System provides manufacturing with reports designed to assist production as follows (STM-22):

Fabricating bundles	Cutting and marking wire, installing connectors, grouping and tying wire into bundles
Testing bundles	Using card-controlled automatic

	test equipment
Installing bundles	Making connections between bundles after installation in the airframe

The only information required for the above steps not supplied by the wire release system is contained in standardized assembly procedures, formboard drawings (subassembly level), and production illustration drawings (final assembly level).

Block VII-13. Production Problems Require Redesign?--Production problems may arise at any point and are reviewed by design liaison in the assembly areas. Fixes may be made immediately or design changes may be initiated to correct the problem and handled by detail design (level VI) as sustaining design.

Block VII-14. Product Complete?--Quality control audits the "as-designed" to the "as built" documentation to determine that the product is complete. Exceptions are reported.

Block VII-15. Correct Deficiencies--Shortages are corrected and the rework is documented.

Block VII-16. "As Built" Same as "As Designed"?--The same QC audit determines whether any deficiencies exist. Systems and wiring are tested for continuity and performance. Deficiencies are reported.

Block VII-17. Correct Deficiencies and Document--Deficiencies are corrected and the documenation is updated.

Block VII-18. Extract Configuration Accountability--Goal: Provide configuration accountability and cost data by airplane unit.

Throughout the manufacturing process, production events are occurring which deviate from the manufacturing plan. These include shortages, out-of-sequence rework, remove-and-replace operations, retrofit kit installations, etc. The interaction of the fabrication process with quality assurance assures that records are maintained to provide configuration accountability for each airplane unit. The data base is updated on a daily basis. Other parameters maintained in the data base are part and labor costs, part weights, and overhead costs. Various reports, both scheduled and requested, are compiled using elements from the data base and the management information system (MIS-2 and -3). For example, Wire Release System (STM-22) provides reports containing the amount of wire in an airplane by type and gage, weight, and a listing of all electrical and electronic equipment items.

The Standardized Weight Record System (WTS-22) provides weight and balance data and weight-related data such as cost/weight and weight change resulting from configuration changes.

Product manufacture, having completed its tasks of providing tools and building the product in a cost-effective manner, now turns the product over to product verification.

6.2.3.8 Level VIII: Product Verification

The goal of level VIII is to verify the safety and performance of the product. This will be achieved by tests most likely to be outside the IPAD man/machine environment, but the results will be recorded by the IPAD data base management system. (See figures 40 and 63.)

Block VIII-1. Airframe Testing--Goal: To ascertain the static strength and fatigue life of the airframe and verify that certification standards and requirements have been met.

This testing is destructive full-scale testing of primary structure and the verification relates to ultimate loads and predicted fatigue life. There is, however, a secondary objective, mainly of a data-collection character. The tests will be designed in such a manner that strain and deflection measurements can be used for inferences regarding plasticity effects and influences on internal load distribution, shear lag, and stiffness characteristics (local as well as gross). The results will be used for updating internal loads distributions and establishing airplane growth potential and/or improvements. Finally, these results will be incorporated in the data base for future reference and predictions. These tests will be supported by reliability and safety assessments (REL-6, -8, -9, -13).

Block VIII-2. Flight and Ground Testing--Goal: To conduct tests with a flight-capable airplane to verify flight and ground performance and safety. These are discussed for several technologies.

Aerodynamics--Goal: To certify the performance guarantees and regulations.

Proof of guarantees and Federal safety requirements demands extensive flight tests. Aerodynamics will, in the main, be concerned with measuring flight quantities that relate to performance. Low-speed lift capability is determined. Cruise fuel consumption, which, in turn, implies drag levels, is measured. Buffet and stall conditions are mapped.

The data taken during these flights will be reduced and placed in the IPAD data bank. This will facilitate the writing of manuals and documents supporting the measured performance.

Ground Vibration Testing--Goal: Verify the theoretically predicted vibratory characteristics of the airplane. Provide information on structural properties of the real airplane, which may serve as basis for improved final aeroelastic calculations before the first flight.

The manufactured airplane will go through an extensive ground vibration test to obtain the natural mode shapes and frequencies for comparison with the flutter model and theoretical modal data used in determining the flutter characteristics. The dynamic characteristics of the control system will also be determined by test. The generalized masses, natural frequencies, and damping characteristics associated with the natural modes of the airplane should be determined for use in verifying analytical flutter prediction.

Flight Control System--Goal: To demonstrate flight control system characteristics.

Flight tests are performed to verify the flight control system design. Note that the ground roll portion of tests to demonstrate an autoland system will be performed at this time. The tests are primarily transient response, and the simulations of FCS-8, FCS-9, FCS-10, and S&C-19 may be used to correlate experimental with theoretical results. Frequency response testing may also be used. Hence, the computer programs FCS-1 and FCS-2 will be activated. Flight test data reduction is a highly specialized field; therefore, the data reduction computer programs will probably operate in a stand-alone mode. After test data has been converted to a useful form by the data reduction programs, selected portions of the results will be transmitted to the IPAD data bank.

Flight Flutter Testing--Goal: To ensure that the airplane is free from flutter throughout the design flight envelope.

Full-scale flight flutter tests are conducted to ensure that the operational airplane will be safe from flutter and to determine the subcritical response characteristics of the airplane. In these tests, dynamic excitation is applied while the airplane is flown at constant speed and altitude while the resonance modes are excited. The recorded responses are analyzed to give resonance frequencies and decay data before the test is repeated at higher speeds. Test speed is increased for a range of altitudes until the whole design flight regime is shown to be safe or until an incipient flutter condition is discovered.

If a flutter suppression system is required, the flight flutter tests will verify the control system stability margins. The procedure is similar to the procedure followed in the wind tunnel flutter model tests (design network Block VI-2).

Propulsion--Goal: To establish the performance of the propulsion system.

The noise characteristics will be measured and the installed engine characteristics determined. Engine operating limits will be described and fuel usage measured. The effectiveness of the thrust reversers will be demonstrated.

Reliability Assessment--Goal: To assure adequacy of the flight and ground testing from the standpoint of reliability and safety.

The flight and ground test plan is reviewed prior to testing, review, and analysis of test data. This assessment is manual for pre-test review. Test data reductions will be by REL-6, -8, -9, -13.

Stability and Control--Goal: Extensive flight testing is required to certify that the flying qualities of the airplane comply with or exceed the requirements of such authorities as Federal Aviation Administration andBritish Air Registration Board. These requirements are for desirable airplane handling qualities during normal and possible failure conditions.

Stability and control are concerned with measuring flight behavior and correlation with estimated characteristics and registration requirements. Also of importance in these tests are those characteristics affecting the performance of the airplane and its ability to meet guarantees, (e.g., takeoff rotation speed and rotation rate, landing flare capability, and minimum control speeds.) Typical flight characteristics that will be measured are roll response, stick forces, trim requirements, asymmetric thrust effects, dynamic responses due to control inputs, crosswind takeoff and landing capabilities, system failures, etc. Data from these flight tests will be analyzed and stored in the IPAD data bank. A flying qualities document will be continually updated to reflect the actual flight characteristics measured in flight test, and flight simulator documents used for design as well as flight training and demonstration will be updated similarly.

<u>Block VIII-3. Functional Testing</u>--Goal (1): To prove acceptable operation of components and systems.

System components are bench-tested for compliance with prescribed operational requirements prior to installation on the airplane. Airplane systems are tested on the airplane for compliance with prescribed operation requirements.

The functional tests are performed following procedures established by engineering; for example, the wire release system provides IBM card decks for use in functional testing of Boeing-built electronic modules (Hughes FACT) and vendor-supplied modules are tested by a Hawker-Siddley TRACE. Data for this does not come from the wire release system.

Goal (2): To assure adequacy of functional testing from the standpoint of reliability and safety.

Functional test plans are reviewed prior to testing, review, and analysis of test data. This assessment is manual for pretest review. Test data reductions will be by REL-6, -8, -9, -13.

Block VIII-4. Summarize and Review--Goal: To provide engineering, finance, manufacturing, program management, and the customer (according to contractual obligations) with a current status of the product definition. These summaries and reviews give visibility as to production performance, schedules, costs, problems (and anticipated problems), effects of activities of interfacing departments, etc.

Block VIII-5. Problem Requiring Redesign?--Goal: To monitor the verification processes and determine which parts need redesign. These part designs will be returned to level VI (fig. 37) for review and redesign (sustaining design). The data base management system will retain the information describing the nature of the difficulty.

Block VIII-6. Certification--Certification is a major milestone. Once all the required airframe, flight, ground and functional tests have been satisfied and certification has been obtained, the product can enter the in-service phase.

6.2.3.9 Level IX: Product Support

This level has a great influence on the development and design of a product. Not only does it give feedback as to how well the product performs and where improvement can be made but it also promotes repeat use of the product by giving the customer the "most for his money." The business systems capability of the computer is used here. (See figs. 41 and 64.)

Block IX-1. Customer--The customer is one of the two most important ingredients in a business, the other being the product. A positive dialog is necessary between customer and supplier to achieve and maintain customer satisfaction with the product. The customer needs to know the capabilities of the product and the maintenance required, and the producer must supply that information.

Block IX-2. Customer Support--Customer support is the contact between the company and the customer; all questions, suggestions, instructions, etc., pass through this section.

Customer problems are referred to detail design level VI (fig. 37 and 60) for a solution (sustaining design) if they are beyond the scope of the published manuals.

The customer support section divides its activities in six major areas in which it maintains dialog with the customer, with engineering detail design and the data base manager. These areas are:

Product operation
Total maintenance and ground operations support
Spares support
Field service
Data and publications
In-service experience

Block IX-3. Flight Operations Support--There are four facets to operations support: integrated training phases, training programs, technical assistance, and flight publications.

Integrated Training Phases--A team approach is used for smooth and efficient performance of all flight operations services. The team is composed of thoroughly trained instructors, flight engineers, flight operations engineers, and a technical graphics and editorial staff, all working to provide total customer support.

"Total" customer support also depends upon interrelated training, technial assistance, and publications. The total concept is tailored to each customer's requirements to ensure safe and efficient airline operation.

a) The school courses include a broad description of the airplane and its equipment, with emphasis on systems operation. All course material is specially designed for the purchased airplane.

b) Team practice in a cockpit procedures trainer follows the ground school or instrument trainer course,and includes crew briefing sessions, practice of procedures by flight phase, and experience in responding to simulated abnormal and emergency situations. Actual cockpit conditions and systems operation can be usefully reconstructed in a cockpit trainer.

c) The instrument trainer course provides required instrument flight training and allows early evaluation of low-time pilots. In combination with simulator training, the instrument trainer can be used by an instructor or student to reinforce the flight director system and provide practice radio navigation. The instrument trainer course enables airline pilots with no previous flight director experience to become familiar with the system.

d) Simulator training teaches the crew to operate in a dynamic environment and to develop skills in normal, abnormal, and emergency procedures within a realistic time.

e) Flight training with the specific model purchased develops proficiency in each phase of actual flight. This training has substantially improved the quality, safety, and economics of flight crew operation.

Training Programs--An analytical approach to flight crew training is used, stressing a basic understanding of the aircraft systems rather than detailed knowledge. This approach has improved the results of all training programs. The key elements in this approach are:

The specific behavioral objective, which describes what the flight crew needs to know about the system

The learning task analysis, which records what a student already knows so that time and effort can be conserved in his training

The storyboard, which gives the most effective sequencing and grouping of program elements

Technical Assistance--Technical assistance is available to integrate the airplanes into existing fleets. A team including a pilot, a flight engineer, and a flight operations engineer can be assigned to work with each airline to ensure airplane operation with maximum effectiveness. Well before the delivery date of the airplane, the technical team visits the airline facility to develop a firsthand understanding of individual requirements and to assist in program planning. The flight team can handle such complex problems as the techniqus and procedures for maximum-range operation of rapid turnaround and dispatching. The same technical team helps the airline personnel during training and the initial operation of the aircraft.

Flight Publications--Flight publications are designed for on-the-job use and are related closely to the activity they support. Operation publications are carefully prepared by a team of experienced pilots, flight engineers, ground school instructors and technical writers. The procedures are defined by the specified behavioral objectives, and the storyboard technique arranges the information in a logical sequence. Basic revisions are covered under this program. Follow-on revision services and the incorporation of customer-originated material can be negotiated.

Flight publications include:

Airplane flight manual
Operations manual
Dispatch deviation procedures guide
Flight instructors principles and techniques of instruction
Flight patterns
Malfunction reporting system
Ground training manual
Quick reference handbook
Flight crew training manual
Pilot training manual
Flight engineer's training manual
Flight attendant's manual
Instructor flight engineer's guide
Flight crew instructor's guide
Instructor pilot guide
Crash, fire, and rescue information for jet aircraft

Block IX-4. Maintenance and Ground Operations Support--The customer support technical requirements organization is responsible for providing total maintenance and ground operations support to jet operators. This integrated support program includes: premodel introduction, maintenance facility, and equipment planning, with on-site inspections as negotiated; engineering and provisioning of maintenance facility and equipment data and documenation for specific maintenance programs; maintenance training courses designed to the customer's model configuration, with student training aids and documentation; and the full spectrum of ATA-100 maintenance technical publications. Additional specialized support publications enhance the customer's total maintenance program.

Maintenance and Ground Operations Systems--The maintenance and ground operations systems (MGOS) unit will assist a customer to plan and prepare for introduction of an airplane model that is new to his fleet. MGOS will provide both data support in planning a maintenance program that will establish a customer's airplane maintenance requirements and schedules. Also provided are data and support to determine the equipment and facilities needed for ramp operations and line, hangar, and shop maintenance. To assist a new customer with planning, an exchange of visits will be proposed and, if necessary, a scheduled development program will be designed. After introduction, sustaining technical assistance and data are provided to ensure consistent, effective customer support.

Planning Data for Maintenance Programs--The maintenance program data provided to each customer includes the maintenance planning data document and maintenance task cards. Airline maintenance inspection interval reports are sent bimonthly to the airlines.

a) The maintenance planning data (MPD) document contains the maintenance requirements of the basic airplane model, including the recommended inspection and overhaul intervals for the airplane's structure, systems, and components. The MPD also compiles direct maintenance manhours and material costs for scheduld checks on the airframe, components, and engines, shop repair, and routine/nonroutine maintenance in all areas. The information contained in the MPD document is based on actual airline operational experience.

b) The maintenance task cards for the basic airplane model describe each scheduled maintenance and structural inspection task and include references to the pertinent maintenance manual section or chapter. The task cards also show location of the structure, system, or component to be inspected (zone, area, and access door, where applicable), and indicate the time and manhours required for the inspection.

c) The airline maintenance inspection intervals report lists all customers by airplane type and the current inspection and overhaul intervals being applied by each customer to his fleet of airplanes. This report is supplied bimonthly to all customers.

Facility and Equipment Planning Data--Facility and equipment planning data are available to all commercial airplane customers.

Ramp equipment planning information is available from the facility and equipment planning document. This document enables an airline to determine the suitability of existing equipment and to identify additional requirements. Typical ramp equipment arrangements, and servicing and loading methods are also identified.

Maintenance facilities and equipment planning data sources include the facility and equipment planning document, special tool drawings, illustrated tool and equipment list document, systems test equipment document, engine handling document, airplane recovery document, and basic component repair data documents.

Customer Maintenance and Ground Operations Planning Support--Technical support is available on request for planning maintenance and ground operations programs, and equipment and facility requirements. Such support includes:

Assistance in evaluating recommended equipment requirements versus customer resouces, airplane fleet mix, and operating parameters

Assistance in determining facility requirements to support new airplane maintenance, ground operations, and component repair/overhaul

Lists of recommended ramp and maintenance equipment tailored to the existing fleet, route structure, and equipment inventory

A maintenance operations analysis using a computerized simulated maintenance planning model

Assistance in formulating a customized airplane maintenance plan and in establishing manpower levels and skills

Assistance in obtaining regulatory agency approval of the proposed maintenance program

Evaluation of airline operation to identify areas for improvement of ground operations and maintenance

Maintenance Training School--The maintenance training school primarily serves the airlines and governmental regulatory agencies. The main objective of the training program is to provide airplane systems training to help customer airlines achieve efficiency in the maintenance of their airplanes. A training planning conference with the airline defines the specific training program required, and the program is enhanced by a comprehensive curriculum, a qualified staff, the latest training techniques, and a modern training facility.

The training curricula, except for a few specialized courses for general familiarization, are designed to present detailed information on airplane systems. Courses concentrate on description, operation, location and interfaces, with servicing, troubleshooting and maintenance practices emphasized for each system. The courses are designed for the specific customer configuration with content, structure, and materials being revised frequently to incorporate improved training aids, techniques, and media.

Maintenance Publications--The maintenance publications organization prepares and publishes the technical manuals required for the maintenance of all commerical aircraft. These manuals are prepared in accordance with the Air Transport Association of America Specification No. 100, "Specification for Manufacturer's Technical Data" (ATA-100). Included are the following manuals:

Maintenance
Overhaul/component maintenance
Wiring diagram
Structural repair
Nondestructive test
Illustrated tool and equipment list
Corrosion prevention

These technical publications are a major part of the total publications plan, which is defined in detail in each purchase agreement negotiated by the company and its commercial airplane customers. Supplementary manuals for specific aircraft models are also available.

Maintenance Publications Services--The company provides technical data commensurate with efficient, safe, and profitable airline operation. To ensure continuation of this policy, the company will negotiate additional customer support services to enhance airline operations. These services include:

Incorporation of customer-originated procedures and data changes into maintenance and wiring diagram manuals

Manual consolidation programs

Update of existing manuals to current configuration

Block IX-5. Spares Support--The spares program ensures that all operators of the aircraft, large or small, receive the best support. The program is based on many years of experience in support of aircraft programs and focuses on these essential areas:

Spares Inventory--An efficient spare parts program is essential for profitable airline operation. The company must support all of its products and maintain a large inventory of spare parts at strategic locations for ready dispatch. An on-line business system is an aid in this task. Airline provisioning involves aircraft predelivery spares inventory investment forecast and customized, cost-effective provisioning after delivery.

Supplier Support--A supplier support program monitors repairable equipment suppliers to ensure adequate and timely product support.

Parts Catalog--The illustrated parts catalog (IPC), prepared in accordance with ATA-1001, is customized for each airline and is provided in either printed or microfilm form. The IPC is used for both spares provisioning and airline maintenance and will be revised quarterly until the delivered configuration of all aircraft is included. All of the data in the IPC are stored in computer files and are combined to produce a number of products to support provisioning. Some of these products are:

Provisioning data (IPD) cards
ATA-200 initial provisioning data
Peculiar and common part number data
Local fabrication part number listings
Vendor part number listings
Vendor part number/Boeing specification number
Cross-reference data

Spares Ordering--The on-line program for spares ordering encompasses purchase order processing; inventory planning; and control, invoicing, and shipping documenation. It can respond immediately to airline requirements. It has the capability for direct telecommunication linkup between the company and customers for direct order placement and to obtain order status, stock availbility, reorder lead time, and price. The communications networks can transmit messages worldwide in a matter of seconds through computerized switching centers and terminals such as IBM 1050 and 2741. These networks may be used to enter orders and inquiries directly into the program for processing. The on-line spares ordering program provides the following benefits to the customers:

Reduced order placement and processing flowtime

Faster invoicing and purchase order acknowledgement

Immediate response on purchase order status, prices, stock availability, and reorder lead time

Savings in paper processing, distribution, and clerical effort

Block IX-6. Field Service--The field service organization's primary objective is to provide total field support to customers. Field representatives are authorized to help airline personnel solve problems related to all facets of airline operation e.g., engineering and maintenance, spares, technical manuals, service bulletins, ground support equipment, and company supplier and subcontractor support. The principal services provided are:

Recommendations for resolving problems encountered in operating or maintaining the product

Liaison between the customer and the company to communicate and interpret specific operations and maintenance problems as they arise

Counsel and training to help airline personnel understand and interpret drawings, design documents, and service manuals

Dissemination of information about problems being experienced by other airlines operating the same equipment

Maintaining an awareness of the operator's dispatch reliability so that, when necessary, ways of improving performance can be recommended

On-site maintenance support is available to help customers introduce a new airplane or model. To accomplish this, specialized, experienced flightline technicians are available to:

Assist in obtaining and interpreting maintenance publications and communicating problems directly to the company

Conduct on-the-job training programs for customer personnel for operation and maintenance of such airplane systems as landing gear, cabin interphone, and passenger payload systems

Meet arrivals and departures of customer aircraft, review maintenance problems, assist in proper diagnosis, and recommend corrections

Customer support engineering is an organization of experienced engineers whose talents are specifically oriented toward the practical solution of problms encountered by in-service aircraft. Engineering skills from design project and technical staff groups are immediately available when required to assist the customer support engineers.

Major airplane structural damage often occurs under circumstances which make damage assessment and repair by the customer difficult. Competent damage survey and repair teams have perfected airplane repair procedures, and repair assistance is available to customers 24 hours a day, every day, by contacting the nearest customer support representative.

Service bulletins are published as they are required to update maintenance manuals, alert the operators to potential problem areas, and describe the installation of kits or modifications. In addition to detailed instructions, these features are also included:

Manpower breakdown

Visual aids

Background information benefits and consequences

Economic feasibility--modification costs versus maintenance cost

Block IX-7. Data and Publication--Airplane customers, in addition to service bulletins, are provided with all ATA-required specification data. Additional data considered beneficial to the customer are provided by contract. Customers are also given publications for information, some of which are:

Engineering drawings and data sets
Tool drawings
Weight and balance manual
Weight and balance supplement
Actual weight report
Functional test documents (systems and components)
Standard manuals
Maintenance and operations document
Instruction handbook
Training support materials

Block IX-8. In-Service Experiences--This level is concerned with collecting information required to support the product once it is in service. Its performance and other in-service information will be continually monitored by entering data in the data base and using the capabilities of the IPAD data base management system.

In-service parts histories will be monitored to detect problems and enrich the statistical data base for the preliminary design levels. For example, the wire release system (STM-22) technical program element will maintain wiring and equipment data for each airplane throughout its service life, including any modifications made after delivery. In addition, after an airplane has entered commercial service, maintenance activity such as part replacement, (scheduled and unscheduled), retrofit kit installation, and system failures are important to improve on current and future programs. These parameters are used to update the data base by airplane units. Customer engineering can request extracts of this type of information.

Also, the reliability data base is updated for the benefit of the following technical program elements: REL-6, -9, -11, -12, -15, -16, -17, -28, -29, -30, and -31.

In-service payload factors by route enter the marketing data base for marketing estimates of current and projected new products. In-service airplane performance change information is made available to the data bases of the affected technical disciplines where serious degradations will modify future designs. In-service systems performance of various systems will be recorded as the airplane is operated.

6.2.3.10 Procedure: Equations of Motion

The equations of motions are represented by the solution of a set of technical program elements that appear frequently throughout the preliminary design levels. The tasks that appear in this procedure are given below. (See fig. 42.)

Block EM-1. Form Mass Matrix--Goal: To form standardized mass matrices which will contain, for each predefined panel, the weight, c.g., and moments and products of inertia about the c.g. This data will be modified subsequently by the analysis in block EM-5 to transfer the mass data from the panel c.g. to a reference axis used by the dynamic loads, flutter, and flight controls analyses.

In order to facilitate analysis of various flight conditions, separate mass matrices should be developed for:

Wing (flaps up and down)
Body
Horizontal tail
Vertical tail
(each) nacelle and strut
Landing gear (up and down)
Payload
Fuel

The mass matrix will be developed by WTS-20.

Block EM-2. Form Stiffness Matrix--Goal: To form a stiffness matrix for specified kinematic freedoms.

PROJECT 1 - SUBSONIC A/C (cont'd.)

The airplane major component section elastic constants (flexural rigidities, torsional rigidity and shear center location) are assembled into an elastic beam representation of the airplane. From this representation, a reduced stiffness matrix may be generated for any set of specified kinematic freedoms (STR-6).

Block EM-3. Form Aerodynamic Influence Coefficient Matrix--Goal: To establish an aerodynamic influence coefficient matrix for use in the solution of the equations of motion.

The formation of the AIC matrix is controlled by ARO-4, which monitors the solution of a well-paneled (in the aerodynamic sense) AIC matrix, then shrinks it into a more managable size for subsequent loads analysis. The loads for the matrix are actually formed by ARO-5, which in turn relies on ARO-6 for the interference of the body on the wing. Wings, empennages, bodies, and nacelles are modelled. The solution is valid from Mach = 0 through Mach = 5, with a continuous solution through Mach = 1. The load distribution is still usable in the transonic regime, although accurate surface pressures are not provided where mixed flow exists.

Block EM-4. Establish Trim Points--Goal: Compute angle of attack, sideslip, and control surface settings required for trim.

Trim points are usually computed for level flight. However, a steady climb, vertical acceleration, steady turn, and sideslip are also valid initial conditions. The trim points are computed (S&C-16) by iterating upon the mass matrix (block EM-1), the stiffness matrix (block EM-2), and the aerodynamic influence coefficient matrix (block EM-3). These calculations are time-consuming due to the large matrix size. Hence, an alternate approach will be to build tables of trim points for several Mach number, altitude, and weight conditions. Subsequent trim point calculations will require only reference to a table.

Block EM-5. Natural Vibration Modes--Goal: Modal analysis is used throughout the industry when doing a flutter, dynamic loads, or elastic flight control system analysis.

The initial step in any of these analyses is to obtain the natural vibration modes of the airplane. The natural vibration modes program (SDL-1) is used to calculate both symmetric and antisymmetric free-free mode shapes. An option is included to be able to also calculate cantilever modes. The free-free mode shapes are calculated directly using a mass matrix and a free-free stiffness matrix from blocks EM-1 and EM-2, respectively. Included in the output with the mode shapes are modal frequencies, generalized inertia matrix, and generalized stiffness matrix.

The entire mode shape calculation would be automatic at design level IV.

Block EM-6. Option?--Goal: Determine option to be selected for generating equations of motion.

This decision is computerized. Two decisions are allowed, namely flutter or quasi-steady. If flutter option is selected, blocks EM-7, EM-8, and EM-9 will be executed. Otherwise, EM-10 and EM-11 will be executed.

Block EM-7. Interpolation --Goal: Provide modal values at aerodynamic control points.

The modal values of normal deflection and streamwise slopes at aerodynamic control points will be interpolated from the vibration modes along the lifting surface elastic axis (calculated in block EM-5). The interpolation is done by using a chain-of-cubics fitting scheme (SFL-1). These interpolated modal values will be required for executing the lifting surface oscillatory aerodynamic programs described in block EM-8.

Block EM-8. Unsteady Aerodynamics--Goal: Provide generalized force matrices for flutter analysis.

Generalized-force matrices are calculated by executing unsteady airloads program.

For a rapid flutter analysis, generalized-force matrices are generated using lifting line theory (SFL-2). State-of-the-art lifting surface unsteady aerodynamics are used for flutter analysis of refined configurations. Programs identified as SFL-3, SFL-4, SFL-5, SFL-6, SFL-7, SFL-8 will provide the capability to predict oscillatory airloads on single-planar lifting surfaces, single rigid cowl, main surface with leading edge and trailing edge control surface(s) and tab, wing-body, wing-tail, wing-cowl, T-tail, V-tail, and other general configurations.

Generalized-force matrices may be interpolated with respect to reduced frequency at a certain Mach number using SFL-9.

Block EM-9. Form Flutter Matrices--Goal: Formulate the equations of motion for flutter analysis.

Flutter matrices consist of generalized mass-and-stiffness matrices (block EM-5) and generalized-force matrices (block EM-8). These are formulated (along with speed, altitude, and Mach number) as coefficient matrices of a system of second-order ordinary differential equations (SFL-10, -11, and -12). Additional equations may be required to account for the presence of actuators (FCS-13) and control system feedbacks.

Block EM-10. Force Matrices--Goal: Generalized-force matrices are required to calculate both quasi-steady equations of motion (EM-11) and load equations except accelerations in the dynamic loads event (block IV-42).

The generalized-force matrix program (SDL-2) will use the aerodynamic influence coefficient matrix (EM-3), rigid body modes, natural vibration modes (EM-5), mass matrix (EM-1), and wind tunnel model corrections from the IPAD data base to generate panel aerodynamic and inertia forces on the airplane.

A knowledgeable engineer will be required to intervene if problems develop during on-line operation.

Block EM-11. Quasi-Steady Equations of Motion--Goal: The quasi-steady equations of motion are required in the solution of the elastic dynamic airplane for flight controls system analysis and dynamic loads analysis.

The unaugmented equations of motion program (SDL-2) uses input data from the force matrices (EM-10) and natural vibration modes (EM-5). The approach used in generating the equations of motion is the energy approach, or more specifically, the "Lagrange method." The program would be semiautomatic and would require an engineer to guide it during off-line operation.

6.3 PROJECT 2 - SUPERSONIC COMMERCIAL AIRCRAFT

6.3.1 PROJECT DEFINITION

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

6.3.2 DESIGN NETWORKS

As in project 1, the general product level concept of figure 20 applies to this project. However, the titles of levels III, IV, and V are referred to as configuration sizing, configuration refinement, and configuration verification. The following are time objectives for the preliminary design levels.

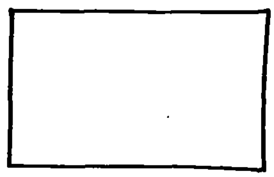
Level	Time Per Design Cycle	Time for Converged Design Cycle
II	2 days	*
III	1 month	*
IV	2 months	4 months
V	3 months	6 months

* One design cycle provides a converged design at levels II and III. A management decision is required to continue until a converged design is obtained at levels IV and V. This provides management control of the costs for computing and development testing (section 6.1.2).

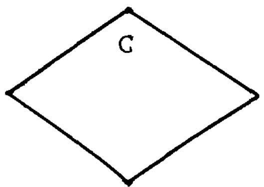
6.3.2.1 Design Networks for Product Levels

Figures 46 through 65 present the detailed design networks for project 2. The following information is pertinent to the networks:

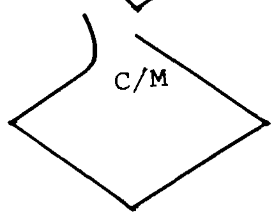
Network Blocks



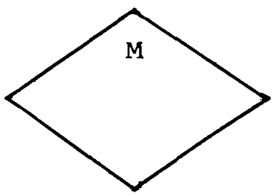
Activity or event*



Computer decision



Computer or man decision



Man decision

*Any activity which has a "do" connotation, (e.g., display, develop, revise, etc.) includes the "gather information" network described in section 6.5.

6.3.2.2 Weights Nomenclature

Type A - Statistical group weights

SUPERSONIC A/C (cont'd.)

Type B - Analytical primary structure weights, statistical weights for rest of airplane except for known components

Type C - Analytical primary and secondary structural weights, statistical weights for rest of airplane except for known components

Type D - Analytical weights (primary structure, secondary structure and all other items) except for known components

Type E - All weights determined by individual part

OEW - Operating empty weight. This designates the weight of the airplane including all weight except payload and usable fuel.

6.3.2.3 Equations of Motion

The equations of motion are a large group of technical program elements which have been identified as a procedure in a separate network. They were grouped as a procedure because they are repeated many times throughout the design networks, the equations-of-motion network is shown in figure 65.

6.3.2.4 Gather Information Network

Throughout the design process, at each event where there is a "do" requirement (develop, define, display, etc.), the engineer must gather information required to "do" that task. The "gather information" network describes the sequence of events that are anticipated in the quest for a particular information. The "gather information" network is shown in section 6.5.

6.3.2.5 Narrative Descriptions

A narrative describing the design and analysis activities is presented in section 6.3.3 . Each network narrative is identified by a reference network block number. Some parts of this narrative are the same as that of project 1; they have been included here for those who might choose to read only the project 2 description. Throughout the narrative, references are made to technical program elements; an example would be ARO-9, which is an aerodynamics technical program element for wave drag and supersonic area rule. It is an existing computer program that has been identified as a candidate for IPAD. (See Document D6-60181-5, Feasibility Study, Volume V.)

LEVEL I—CONTINUING RESEARCH

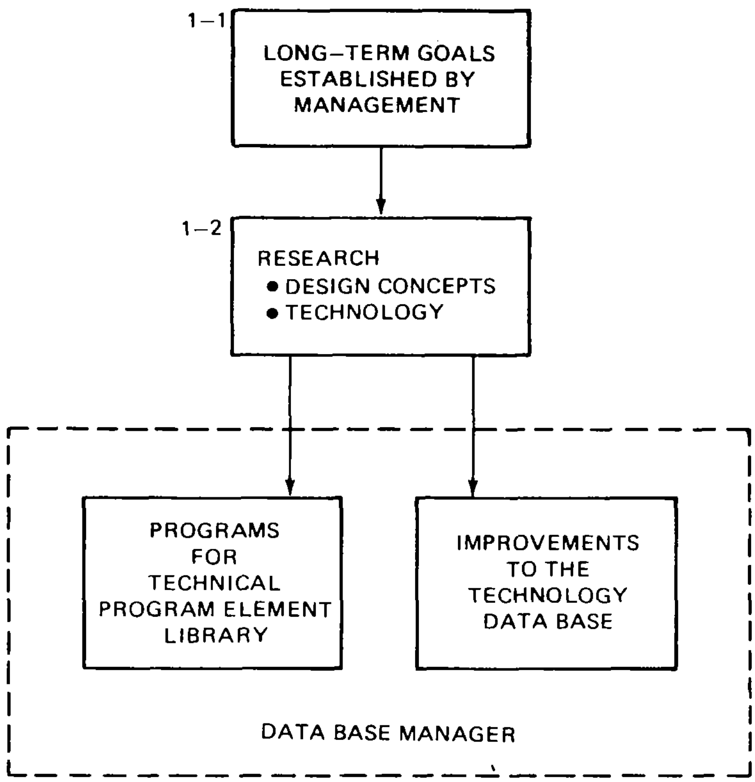


Figure 46.–Design Networks: Project 2 (Supersonic Commercial Transport), Level I

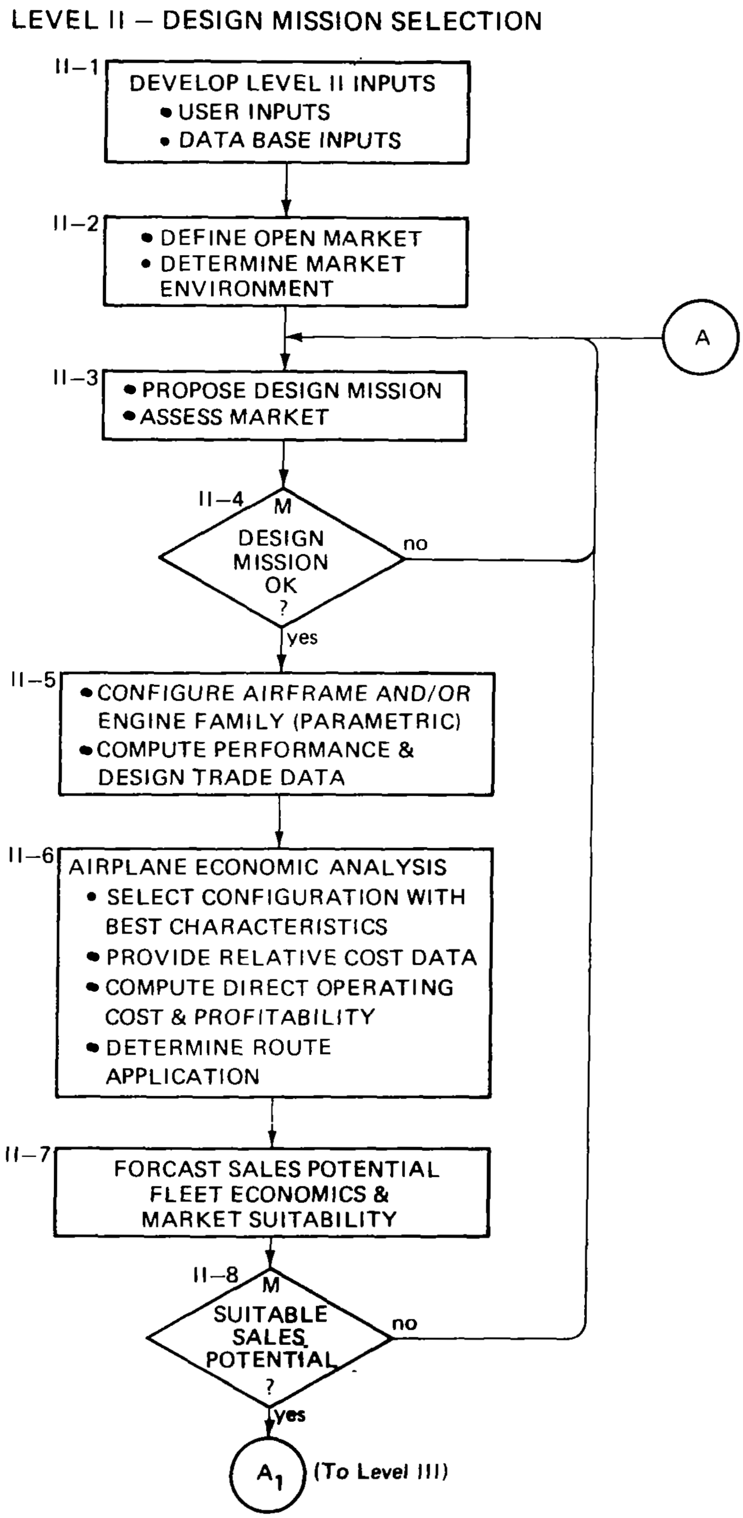


Figure 47.—Design Networks: Project 2, Level II

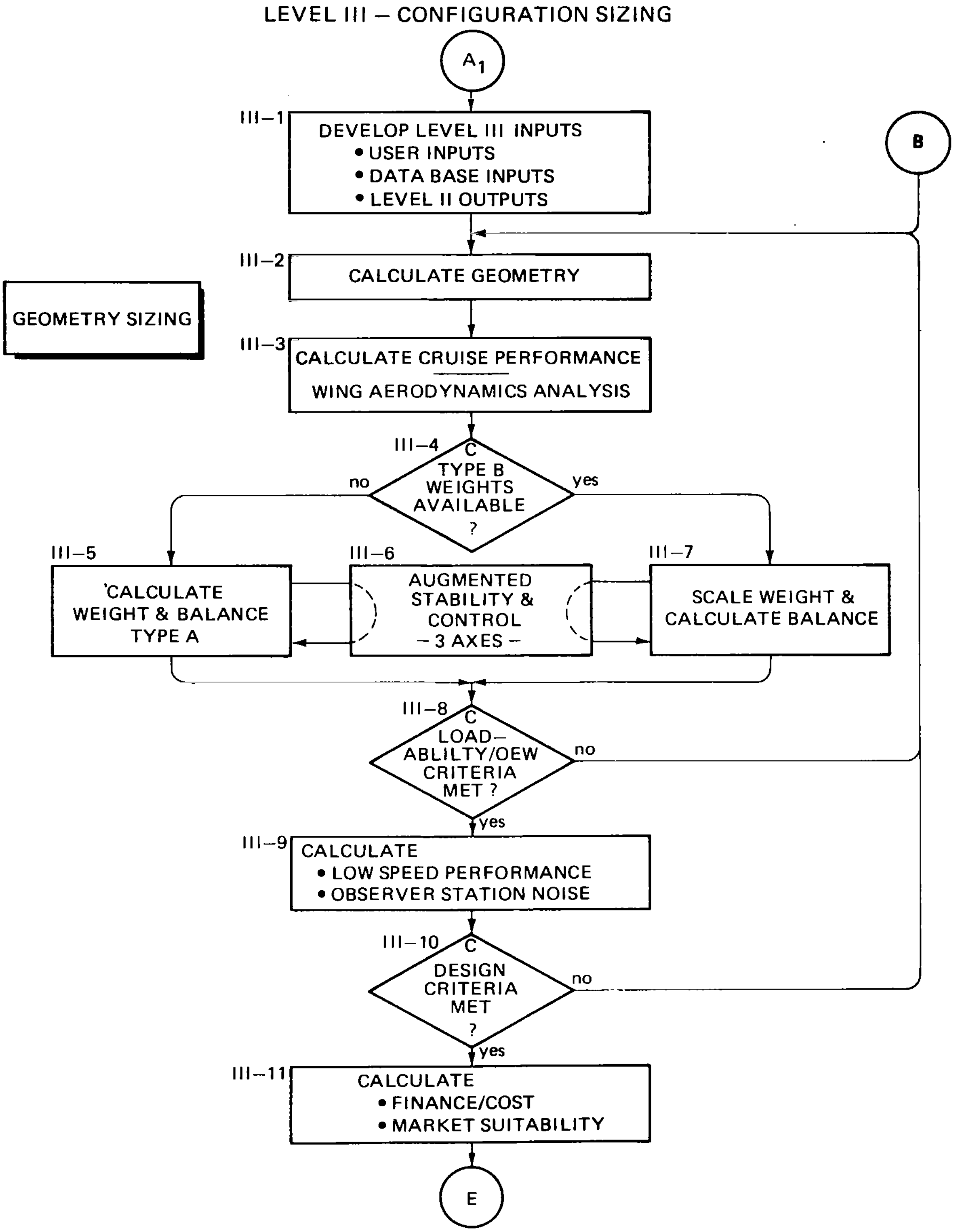


Figure 48.–Design Networks: Project 2, Level III

LEVEL III (Continued)

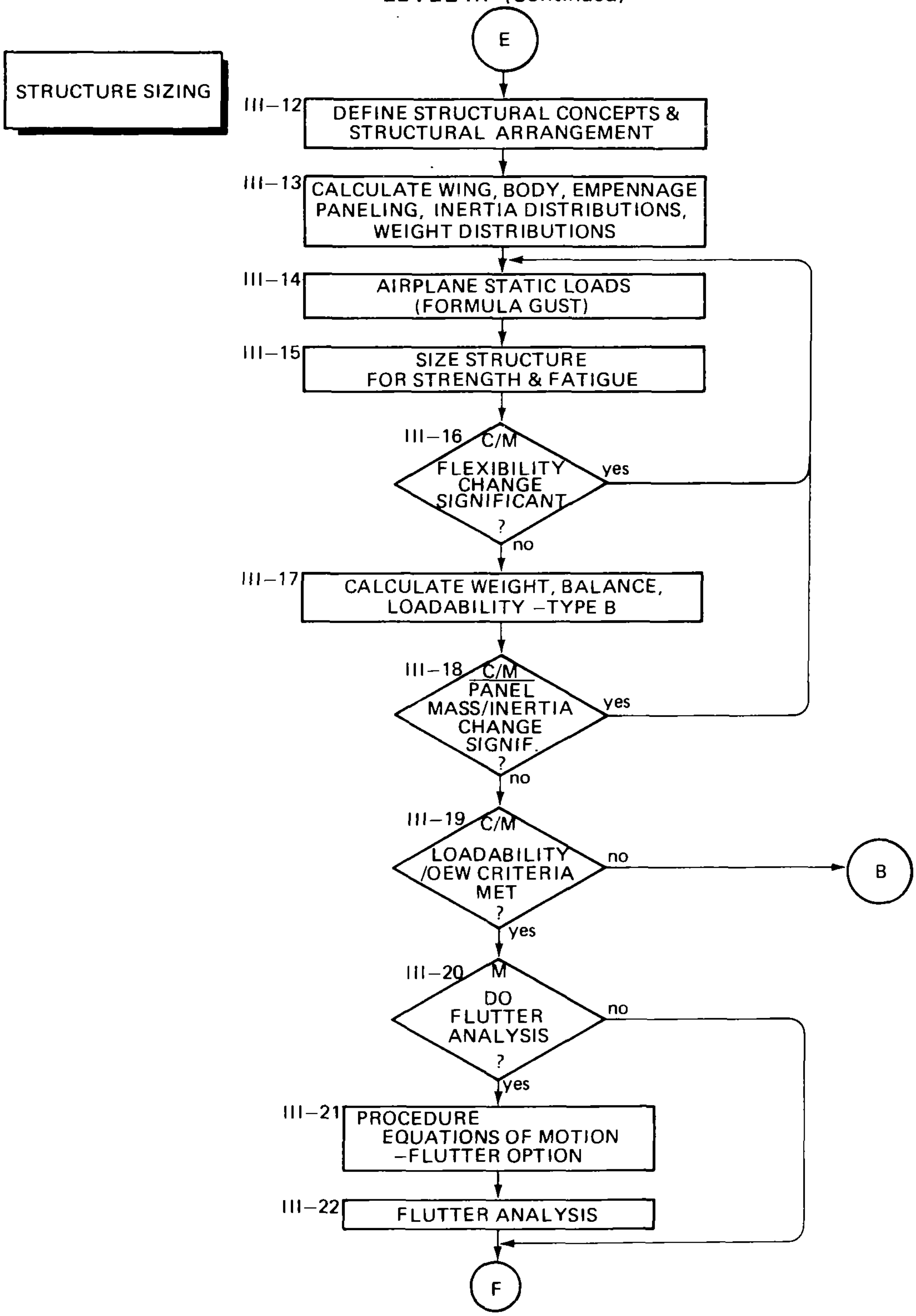


Figure 49.—Design Networks: Project 2, Level III (Continued)

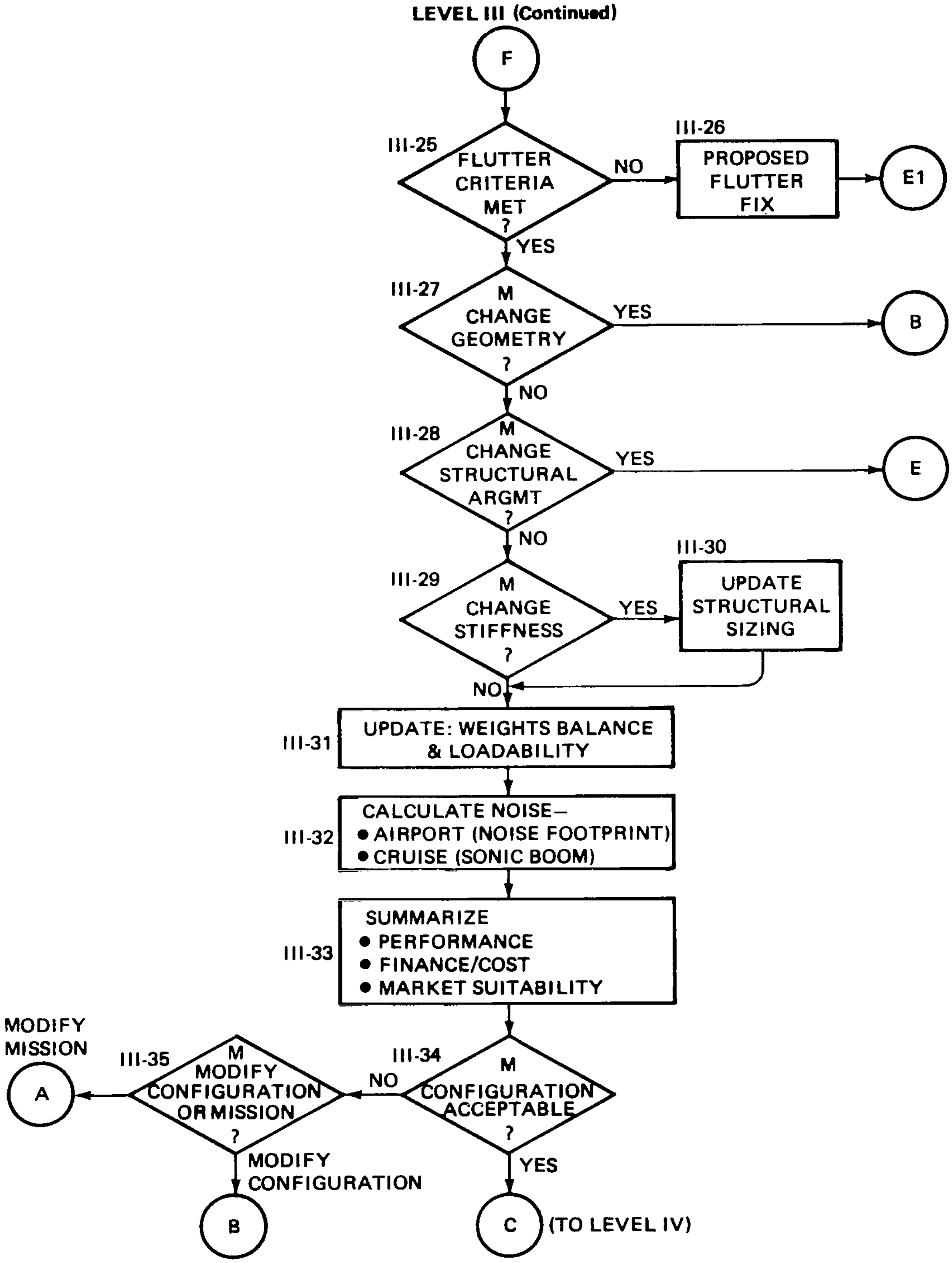


Figure 50.—Design Networks: Project 2, Level III (Continued)

LEVEL IV – CONFIGURATION REFINEMENT

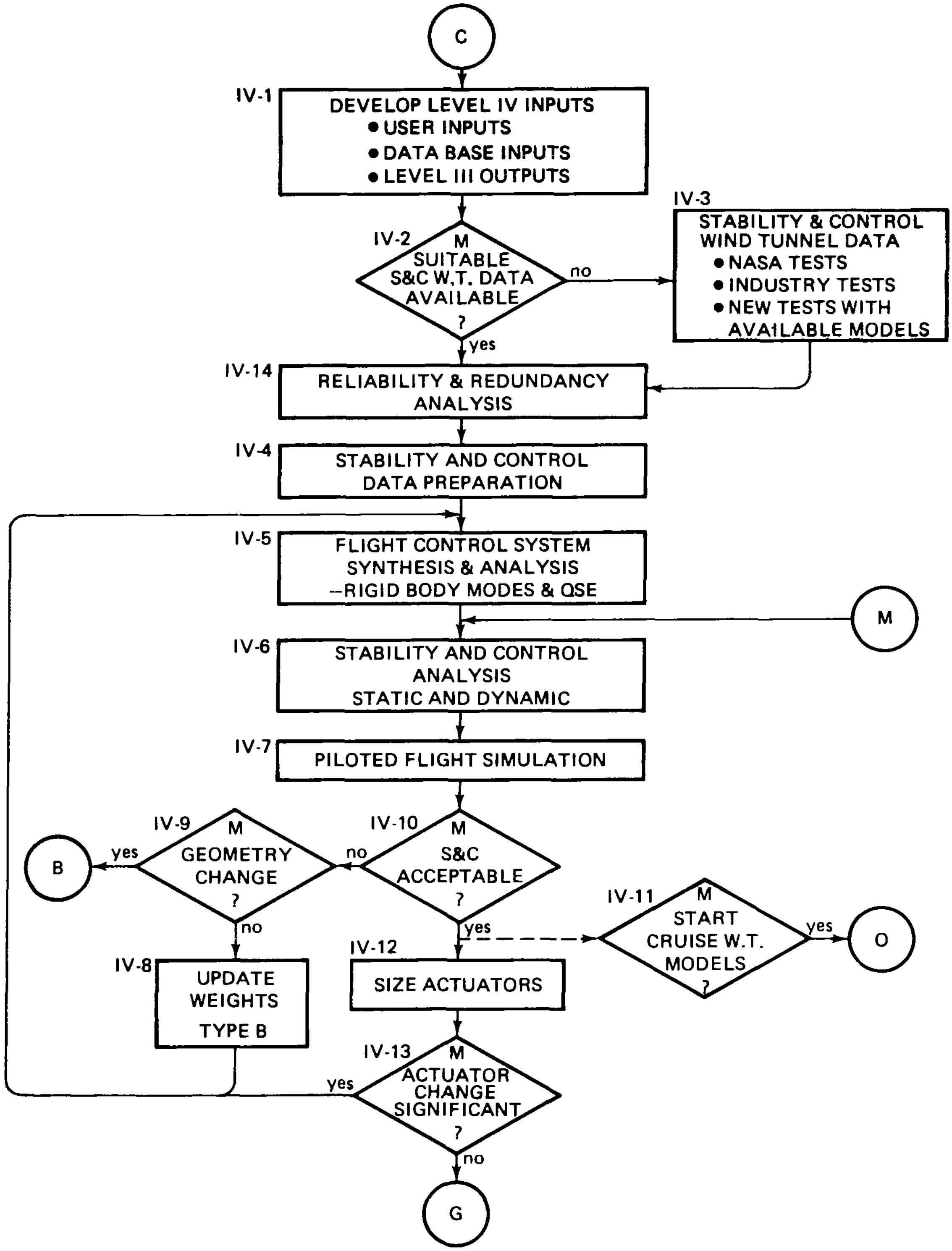


Figure 51.—Design Networks: Project 2, Level IV

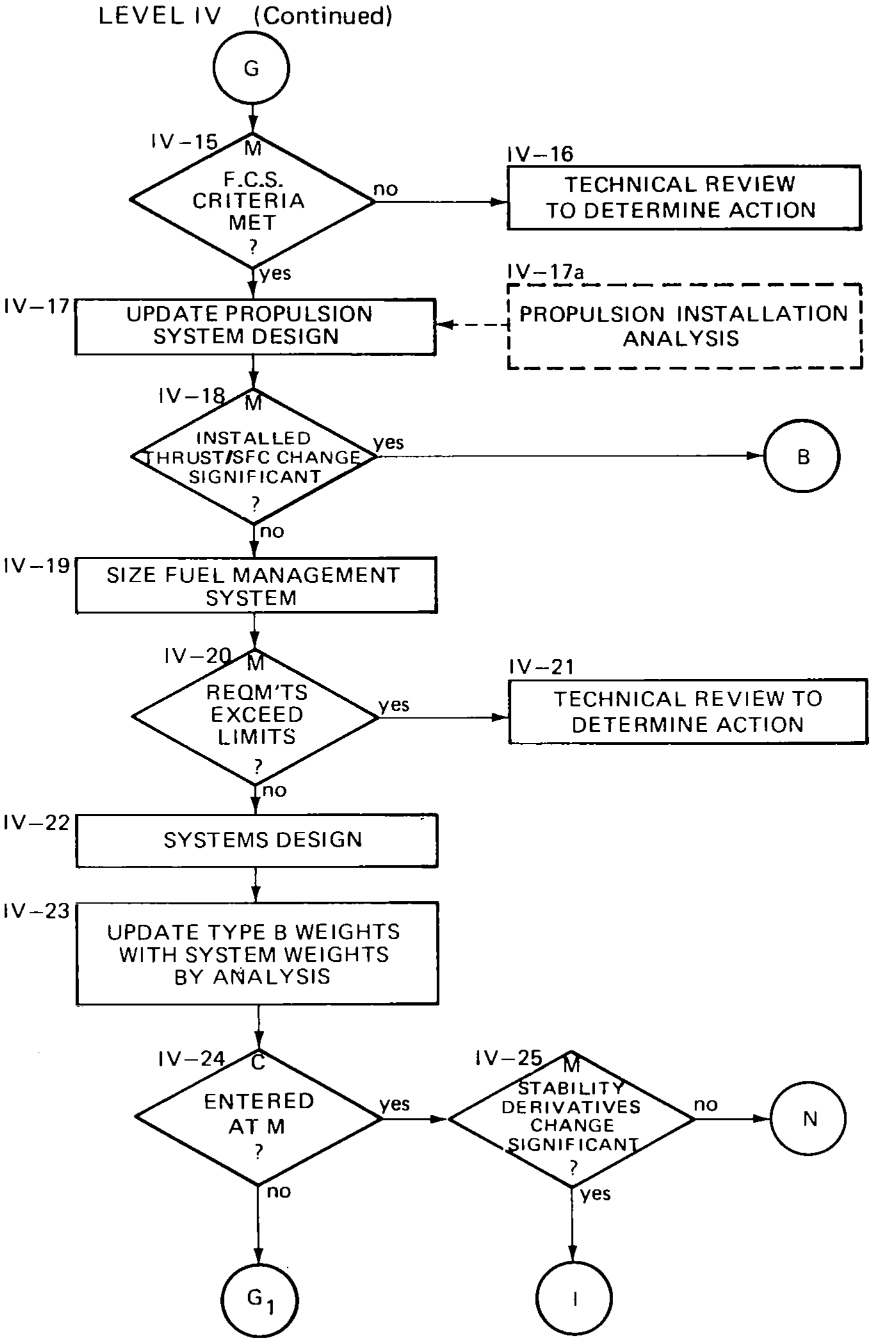


Figure 52.–Design Networks: Project 2, Level IV (Continued)

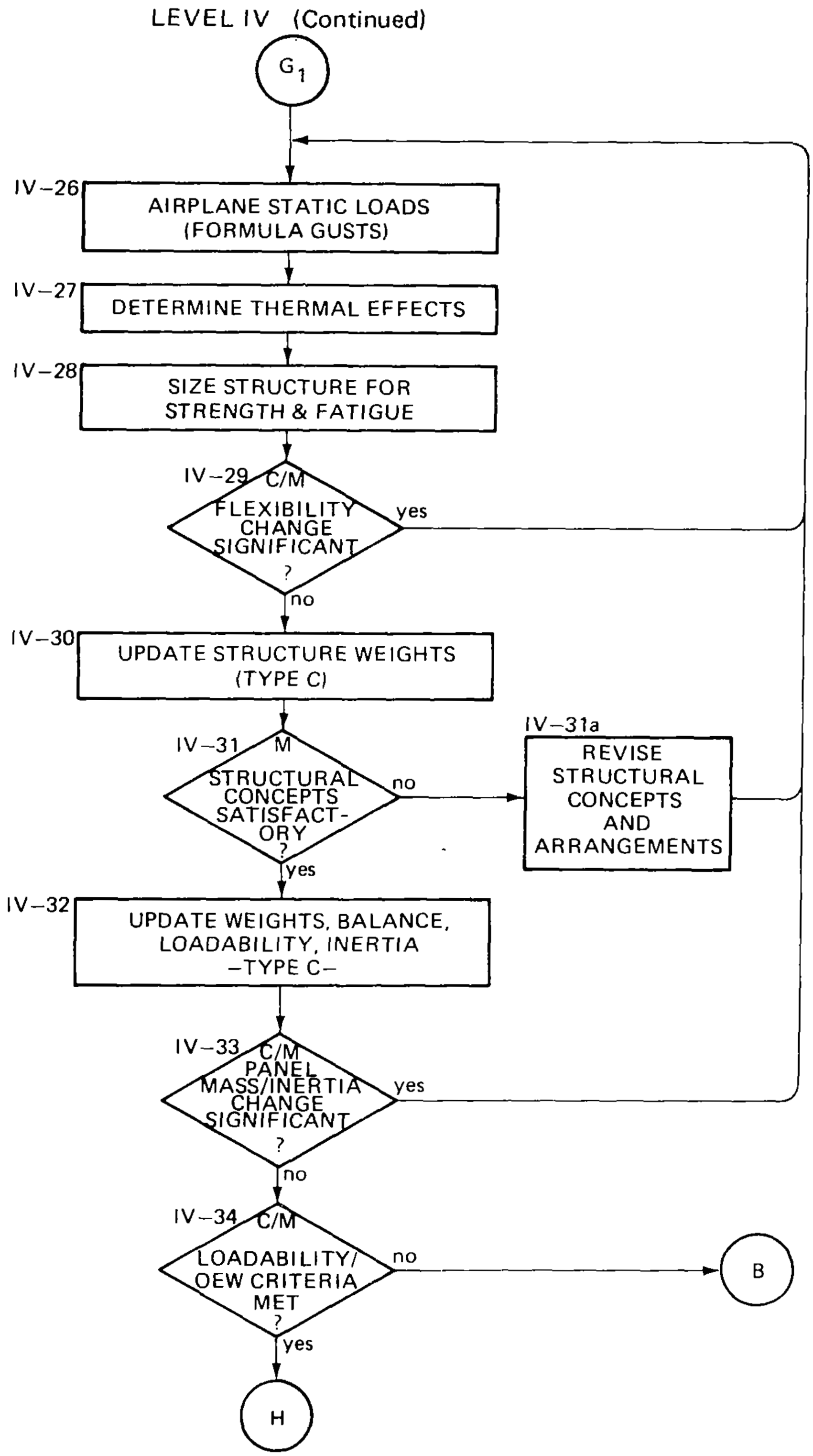


Figure 53.–Design Networks: Project 2, Level IV (Continued)

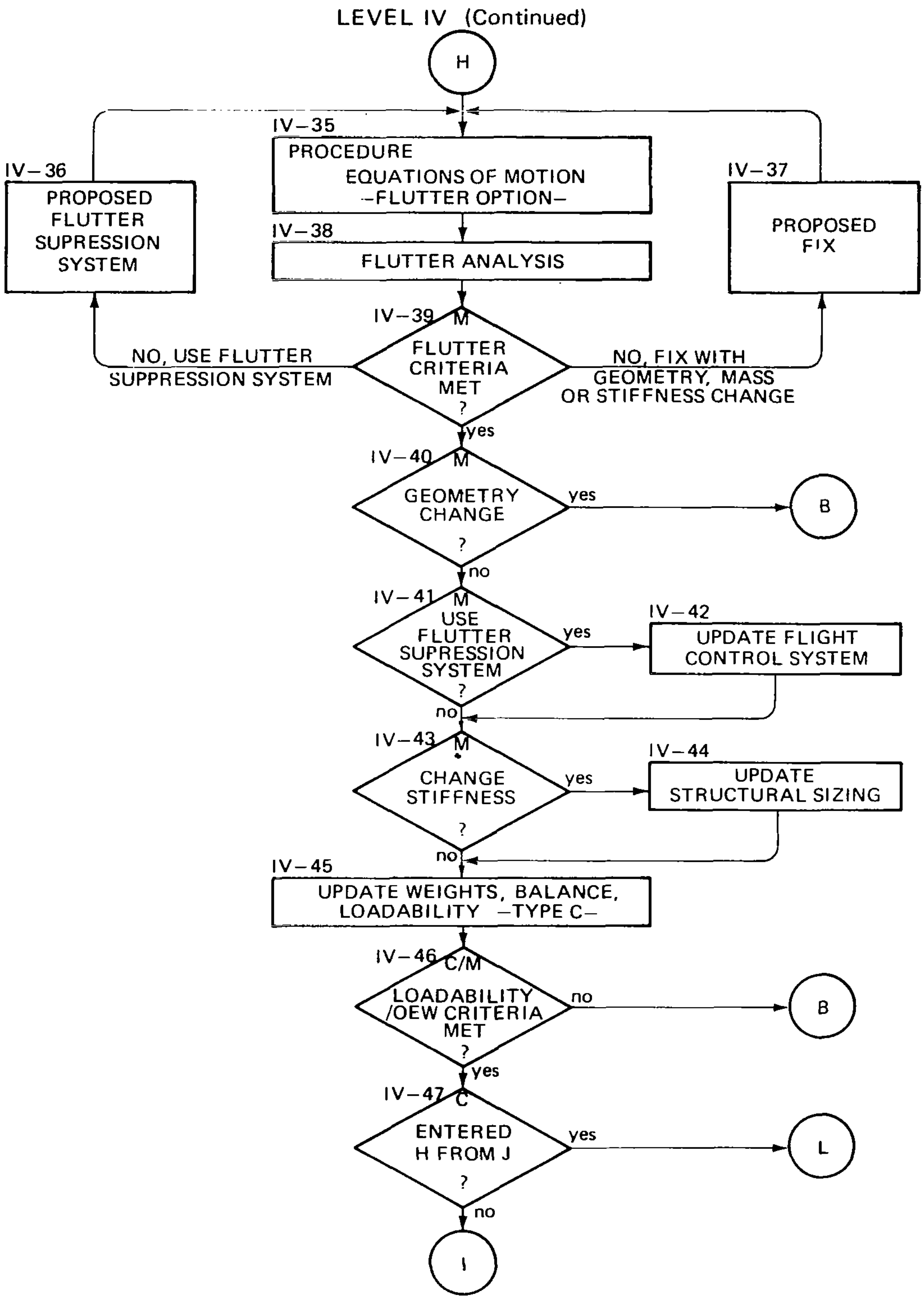


Figure 54.—Design Networks: Project 2, Level IV (Continued)

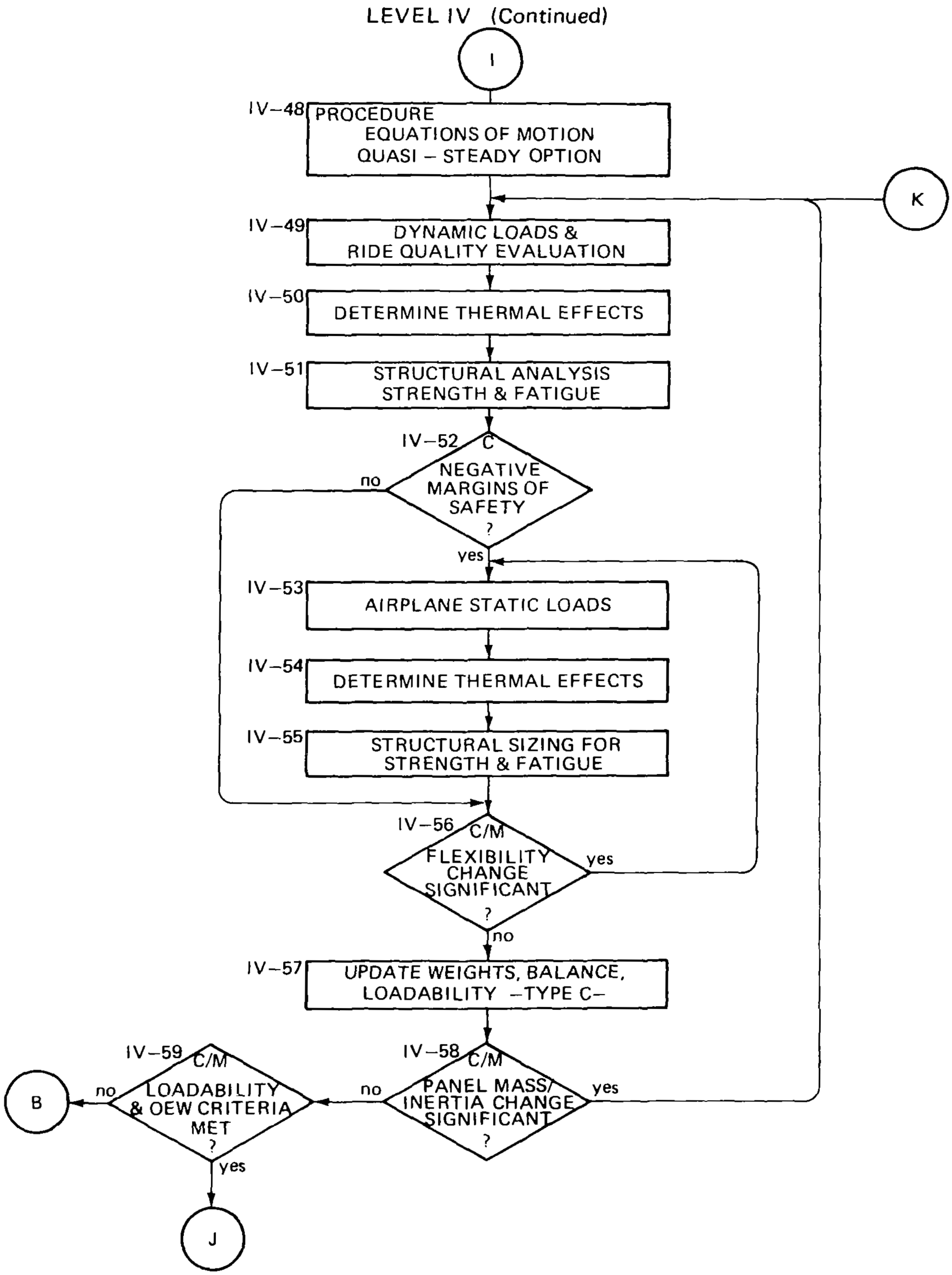


Figure 55.—Design Networks: Project 2, Level IV (Continued)

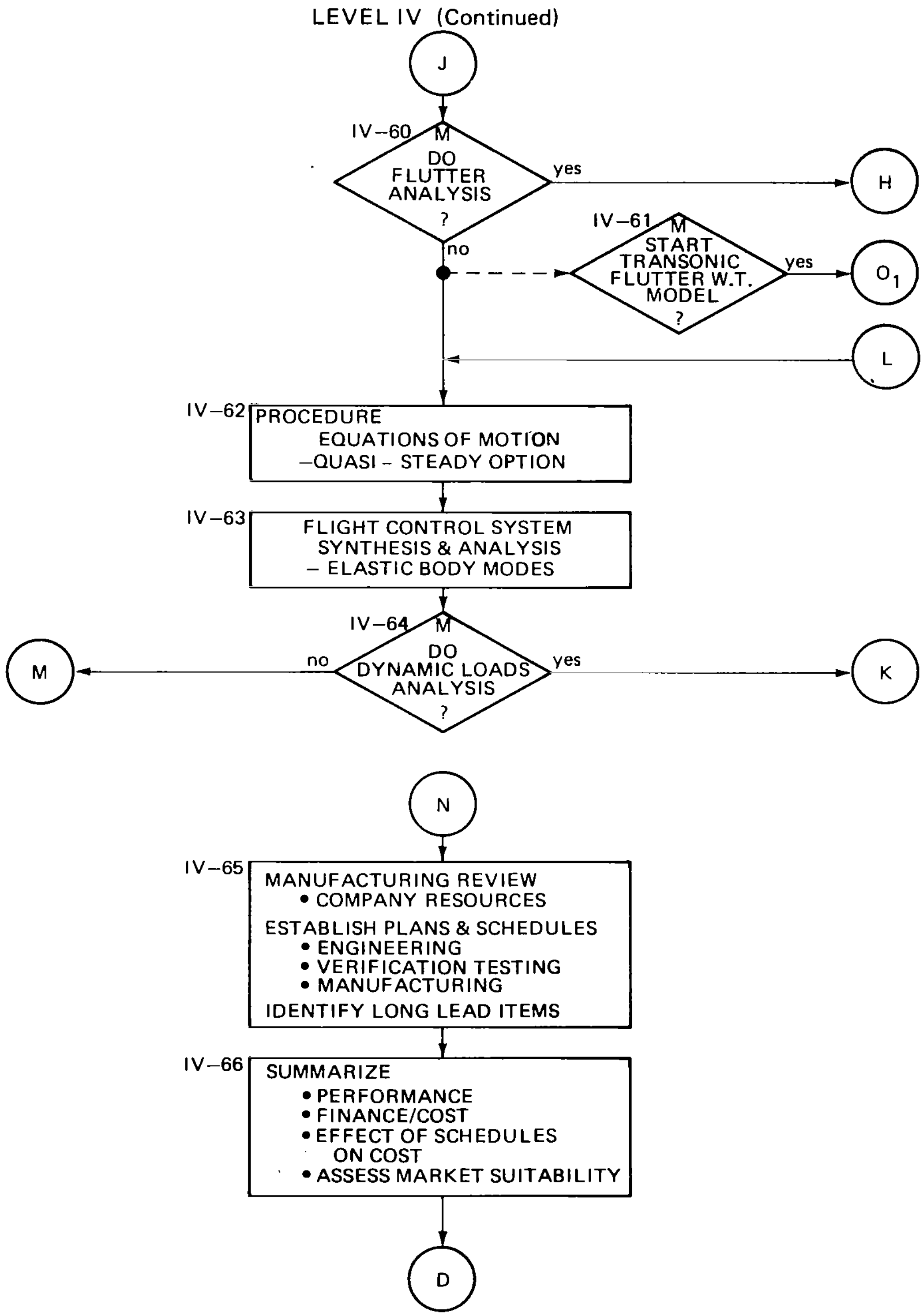


Figure 56.—Design Networks: Project 2, Level IV (Continued)

LEVEL IV (Continued)

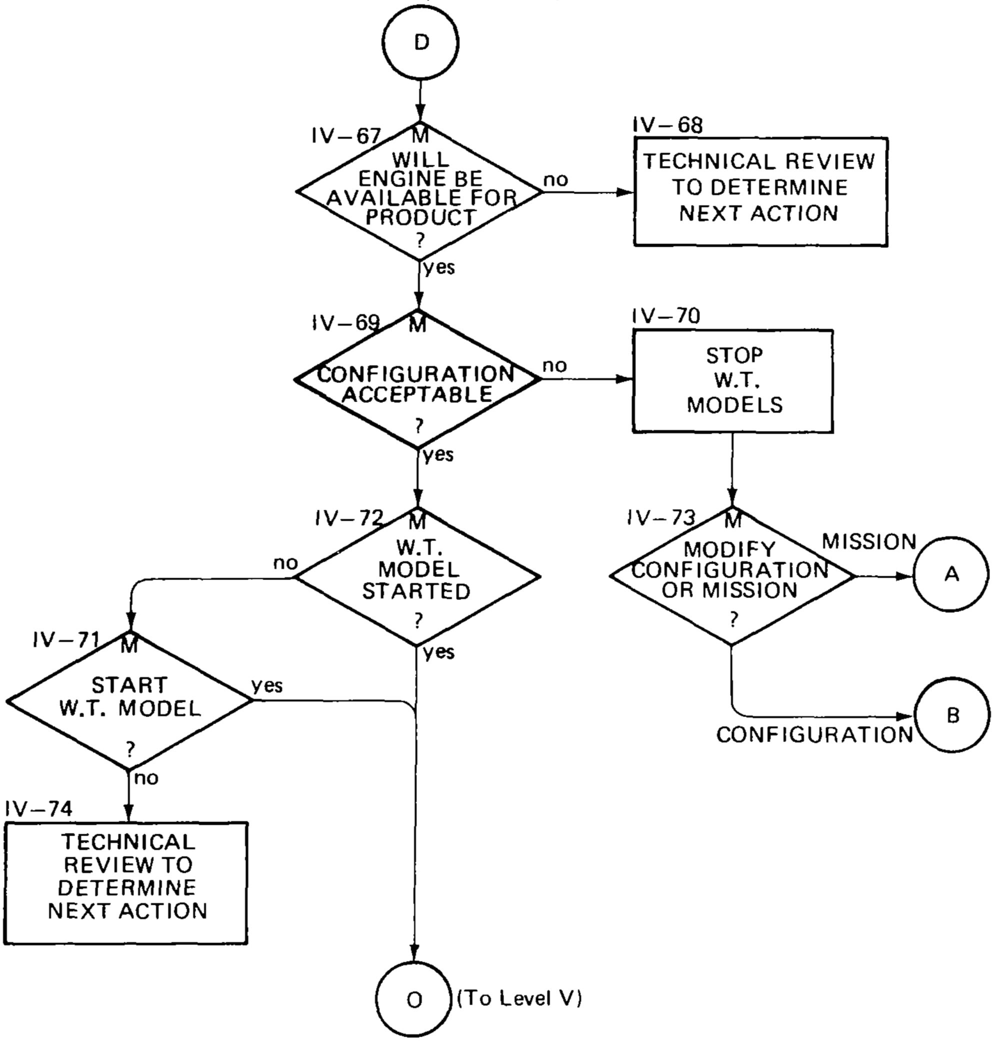


Figure 57.—Design Networks: Project 2, Level IV (Continued)

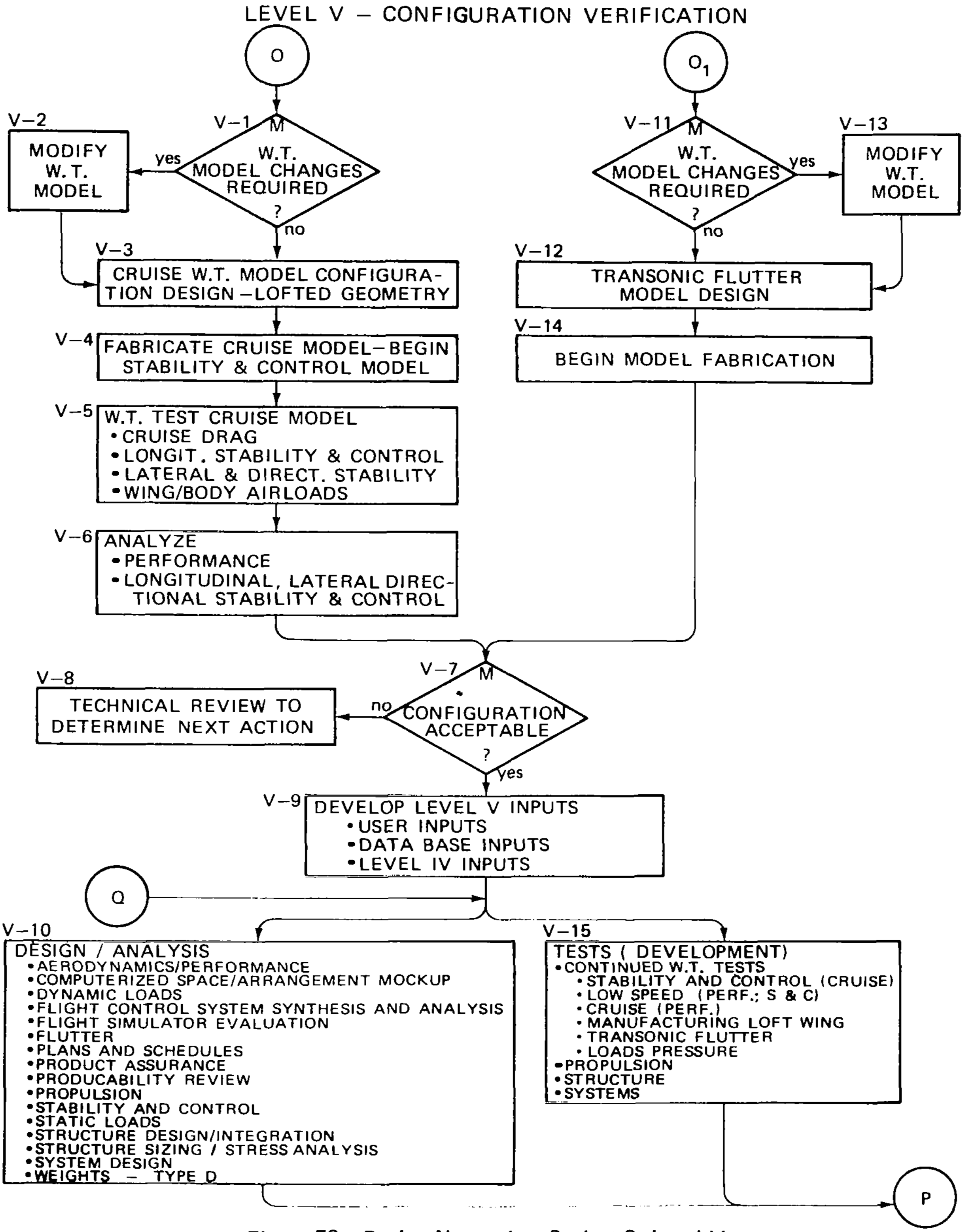


Figure 58.—Design Networks: Project 2, Level V

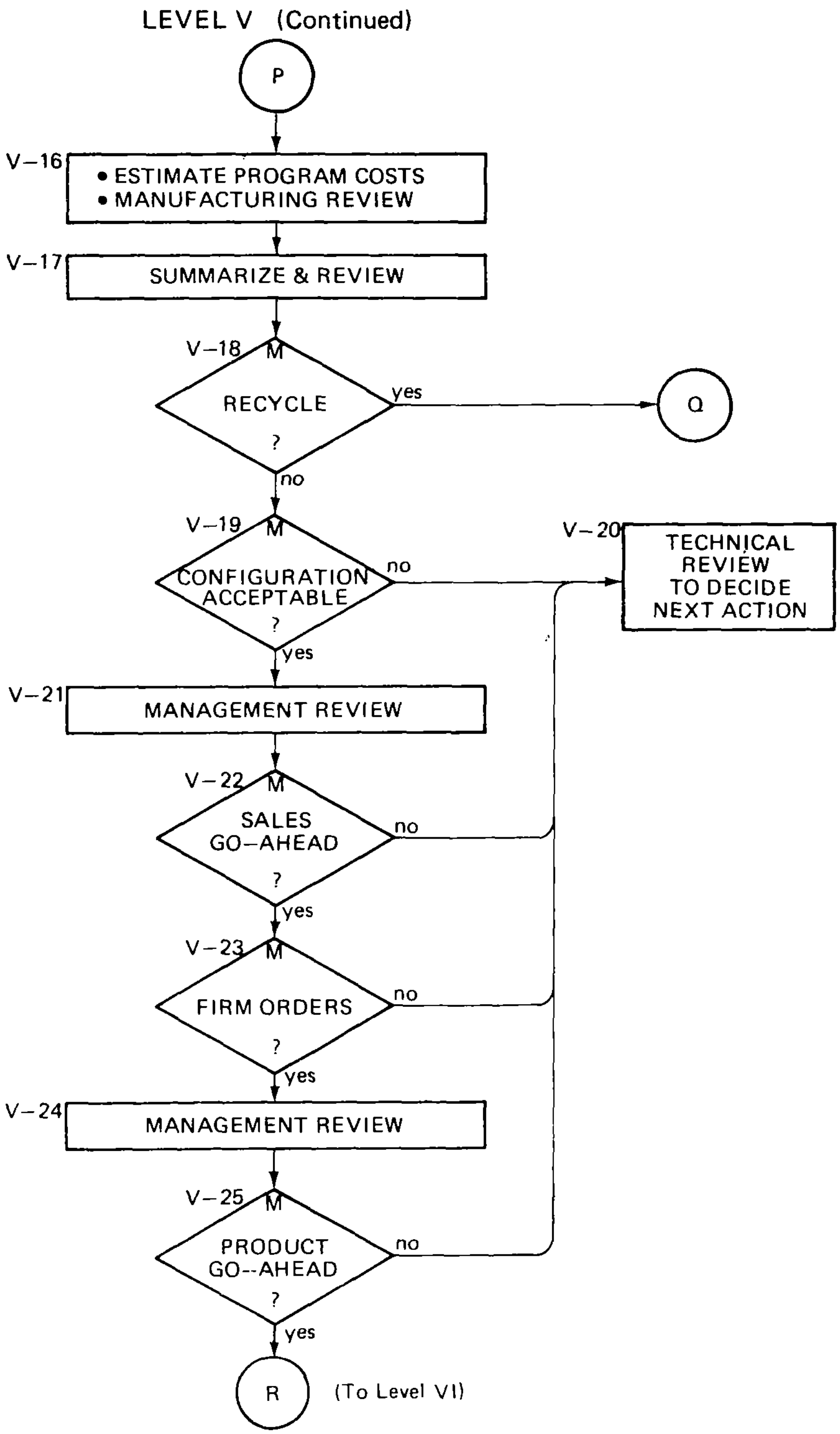


Figure 59.–Design Networks: Project 2, Level V (Continued)

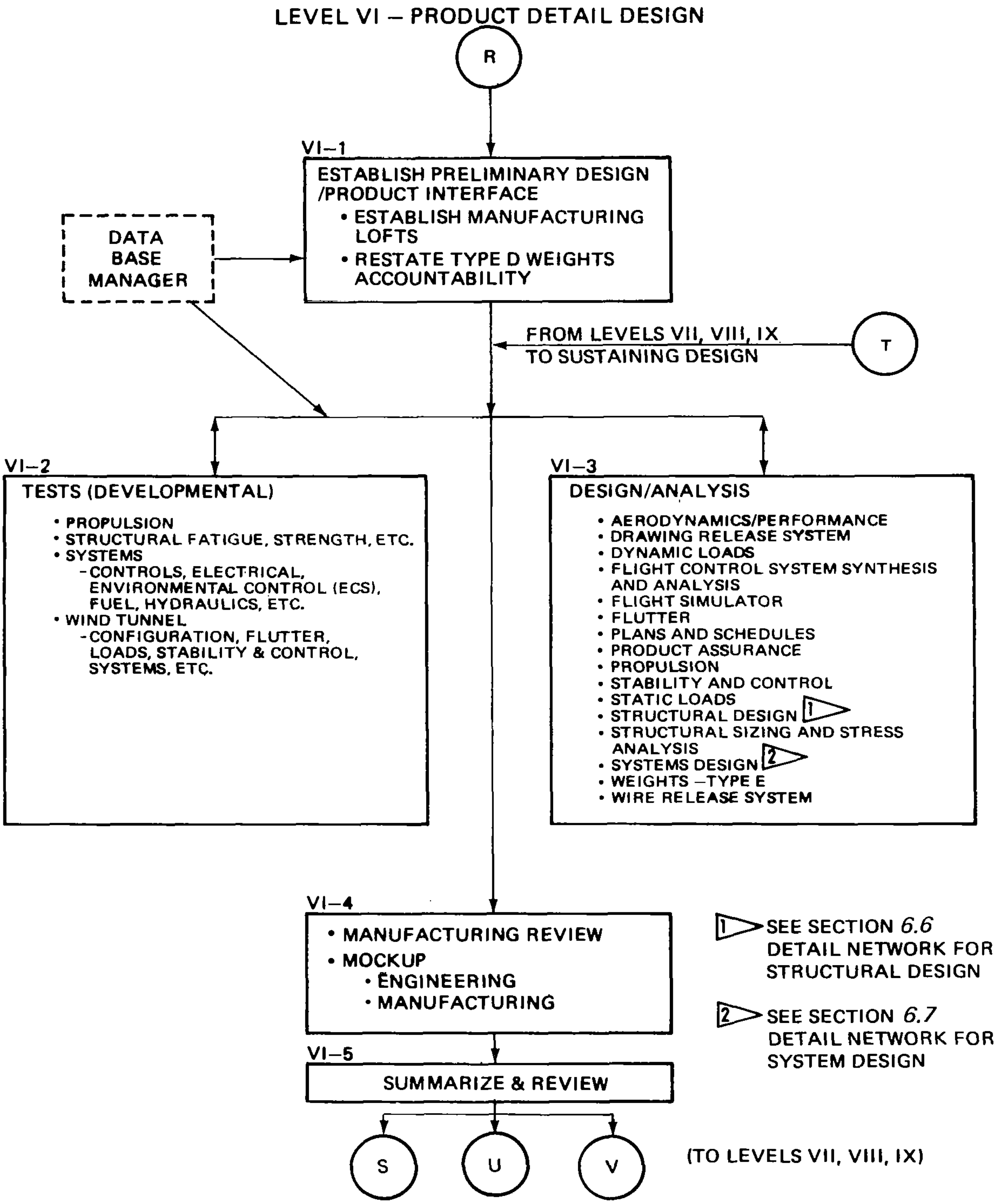


Figure 60.–Design Networks: Project 2, Level VI

LEVEL VII – PRODUCT MANUFACTURE

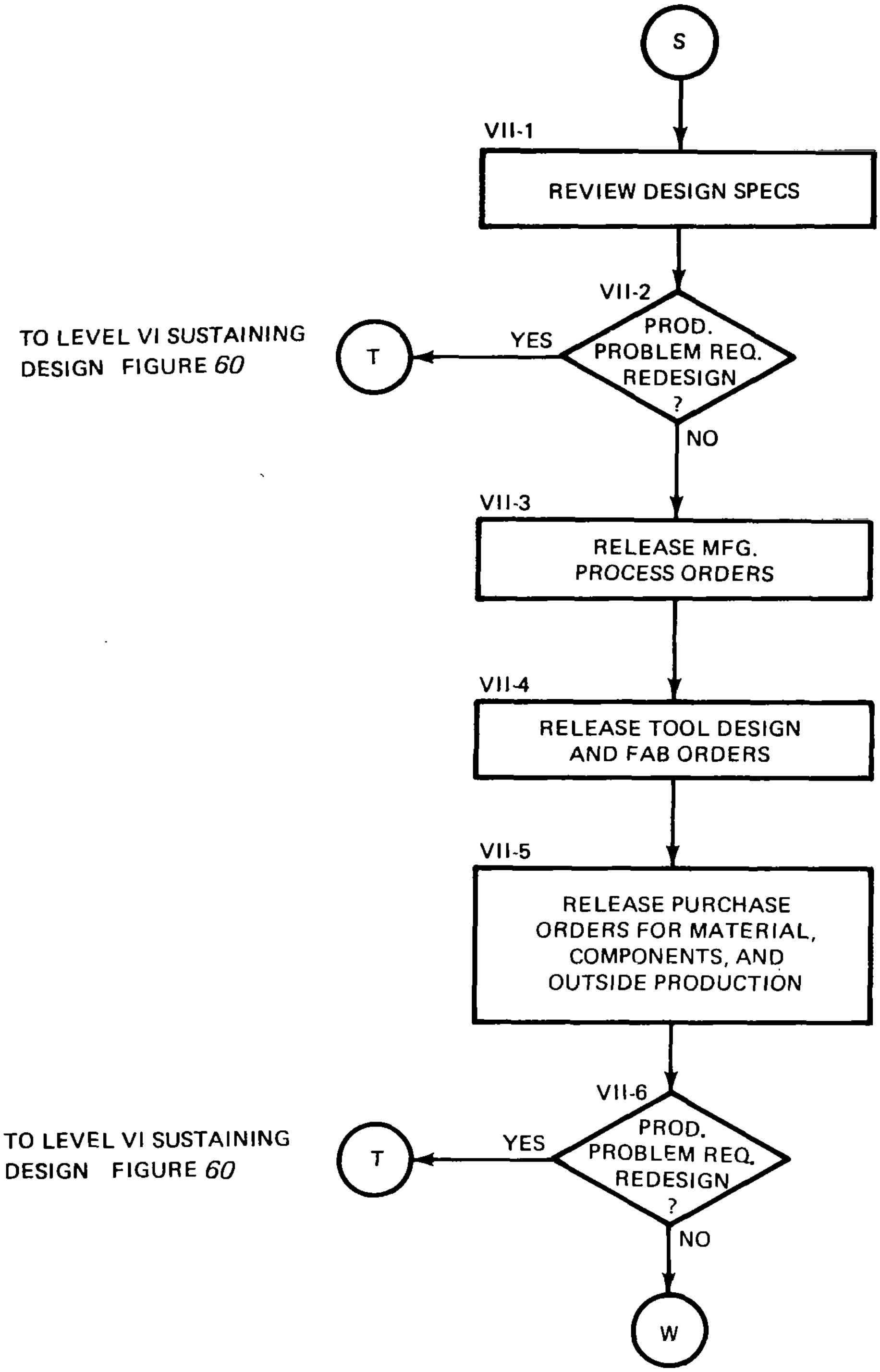


Figure 61.—Design Networks: Project 2, Level VII

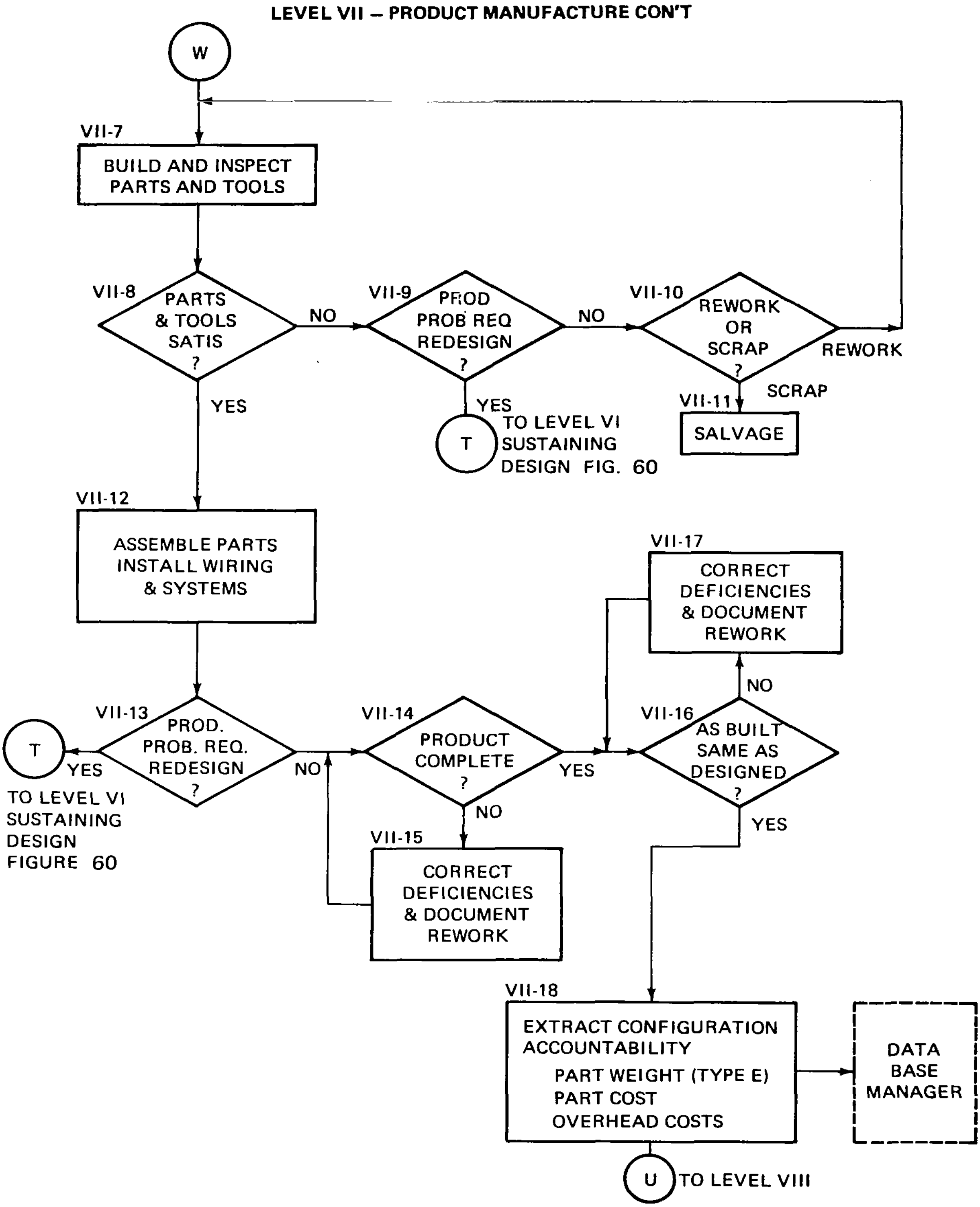


Figure 62.–Design Networks: Project 2, Level VII (Continued)

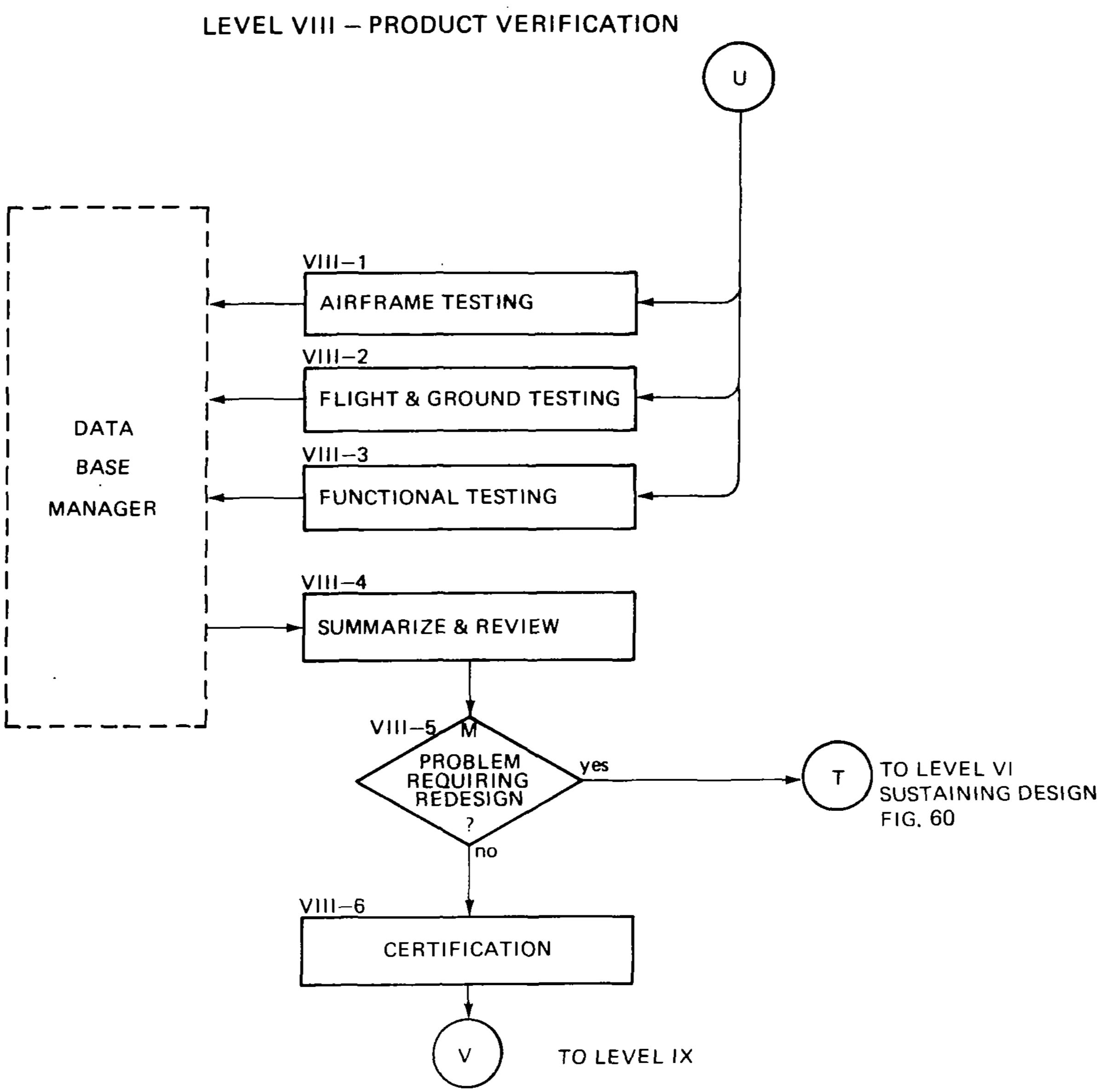


Figure 63.–Design Networks: Project 2, Level VIII

LEVEL IX – PRODUCT SUPPORT

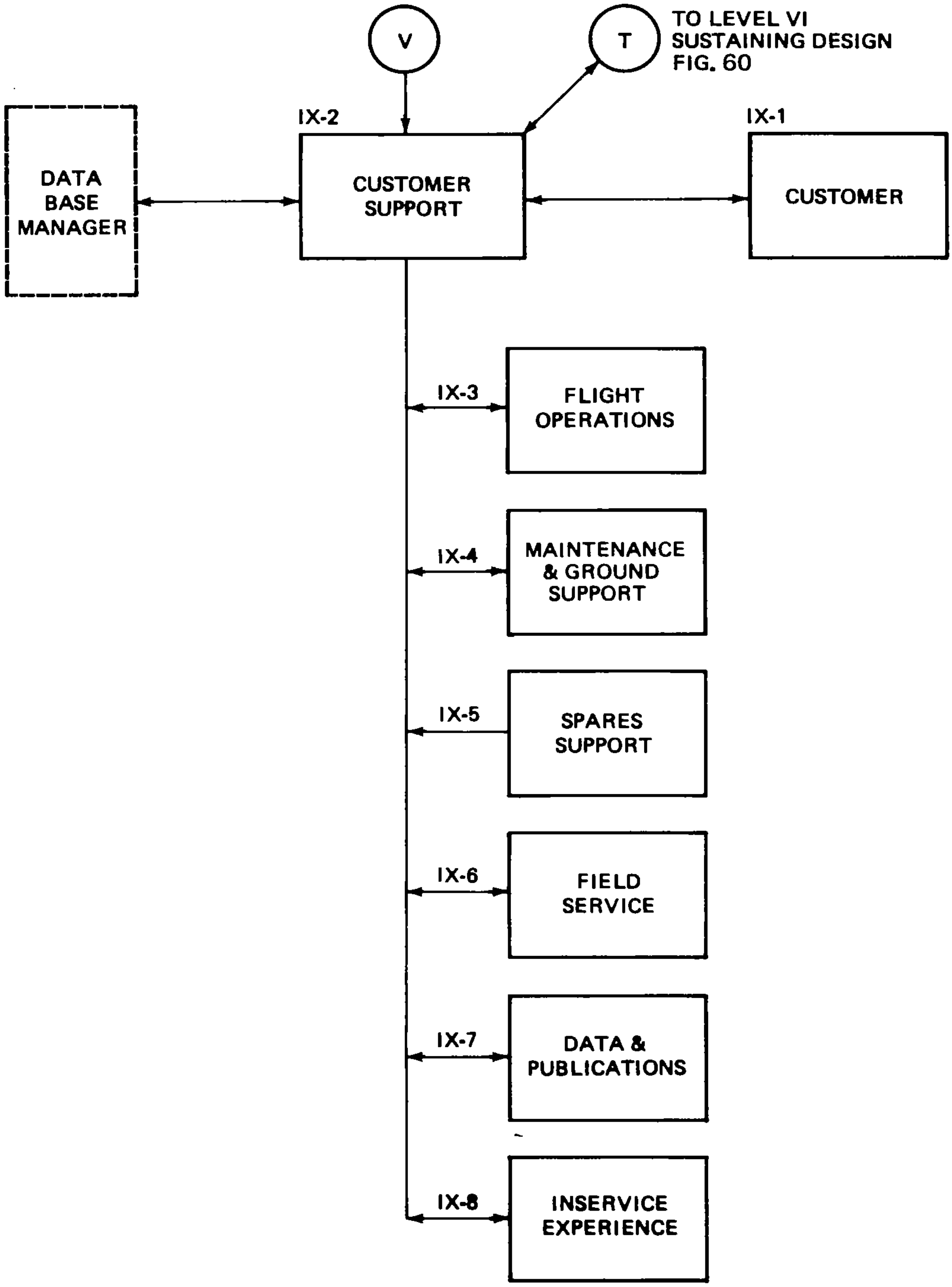


Figure 64.—Design Networks: Project 2, Level IX

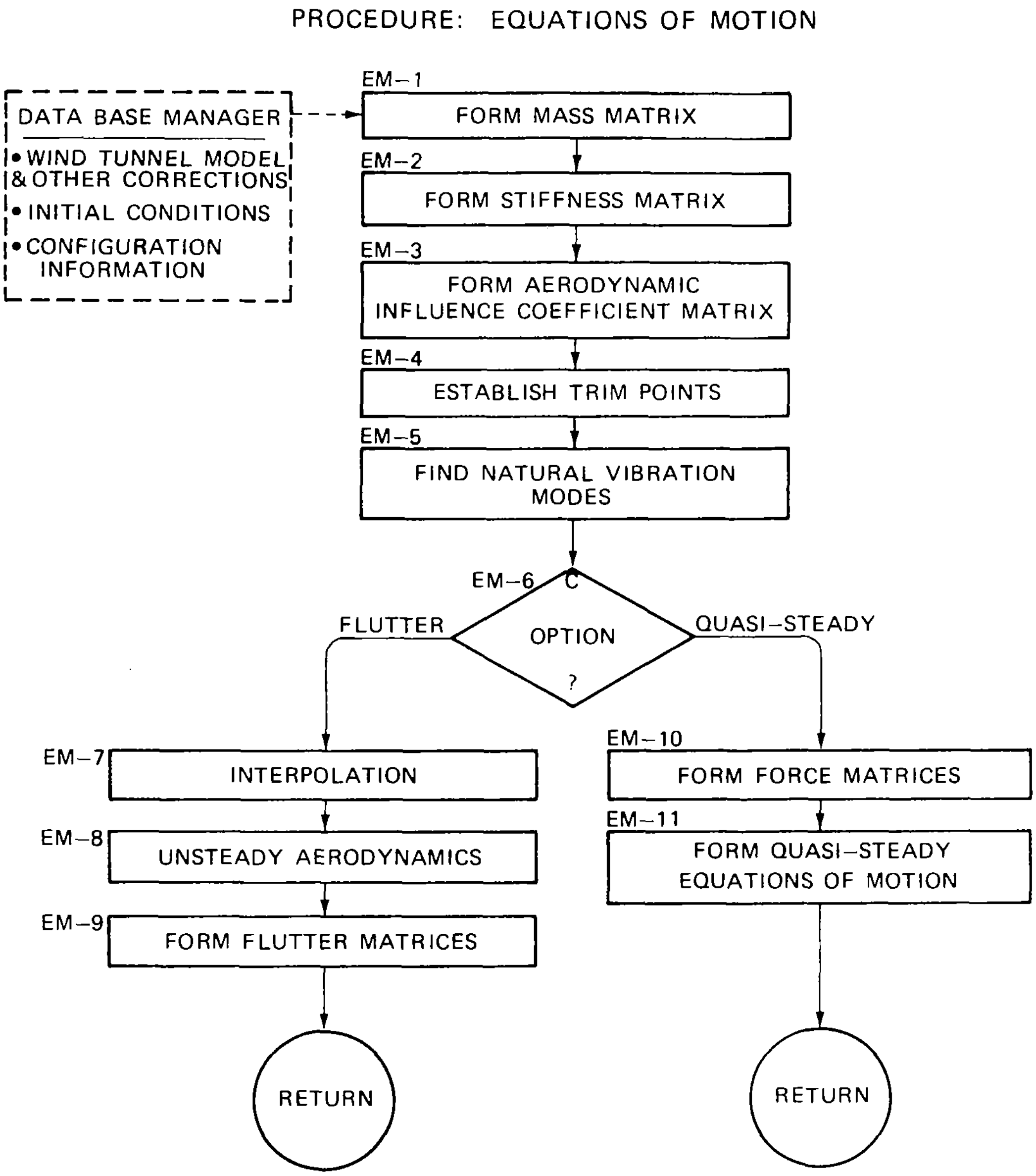


Figure 65.—Design Networks: Project 2, Procedure — Equations of Motion

6.3.3 Network Activities Description

6.3.3.1 Level I: Continuing Research

The purpose of this level is to monitor continuing research and to assimilate those results that will be important to the designer in the IPAD environment. (See fig. 46).

Block I-1. Long Term Goals Established By Management--Research in the technical areas of the IPAD environment will continue in the pursuit of long-term goals. These goals will be set by management and will not be required by specific IPAD activities. However, the analysis capabilities of IPAD levels II to VI may be used to indicate the more profitable areas in which research funds could be spent.

Block I-2. Research--This block represents the research being conducted to support the advancement of the state of the design and analysis arts. Design concepts refer to research conducted to develop detail application capability, such as use of composite materials, manufacturing processes, jet noise suppression, variable bypass ratio engines, etc. Technology refers to the general development of information and processes within specific disciplines, such as aerodynamic characteristics of pressure distribution over airfoil shapes, potential flow analysis or materials development characteristics. The users of the IPAD system will monitor these activities to enter new technical program elements into the library and improve the technology data bases.

6.3.3.2 Level II: Design Mission Selection

The goal of level II is to select the design mission and criteria for the subsequent design. Some very brief analysis and design logic will be required to support the selection of these criteria. (See fig. 47.)

Block II-1. Develop Level II Inputs--The data stream for this project begins with level II. The initial inputs will be derived from two sources. The user will provide specific inputs such as the problem constraints, performance requirements, and technology time period. The last item will point to groups of data in the data base required to support the various technologies. Level II is intended to be executed without interruption; therefore, all the inputs required for level II should be given at the beginning.

Block II-2. Define Open Market; Determine Market Environment--Goal: To identify the open market for a new airplane and determine market environment disciplines for the new airplane engineering design.

A mathematical model (MKT-1) calculates airline fleet requirements based on airline traffic forecasts and airplane inventory. An optimum new airplane is determined for this market. The airplane route system is also identified and its market environment disciplines are determined by processing the market factors such as competitive market shares, growth, wind temperature, airfields, etc., (MKT-2).

Block II-3. Propose Design Mission; Assess Market--Goal: To analyze market requirements and determine design mission requirements that need to be met for the market environment disciplines determined in block II-2.

The market potential of a new airplane is evaluated (MKT-3).

Block II-4. Design Mission OK?--Goal: To determine if the design mission meets the market environment disciplines.

This decision is manual and human judgment may be exercised in interpreting the disciplines.

Review and recycle if desired.

Block II-5. Configure Airframe and/or Engine Family (Parametric), Compute Performance & Design Trade Data--Goal: To configure an airframe and/or engine family and compute the performance characteristics of the family. This will provide design trade data for the family. (See fig. 66.)

The elements comprising this activity are to be executed with a minimum of input, as the intent is to provide data for the selection of the design mission rather than to determine the best configuration. The inputs will be composed primarily of range, payload, Mach number, technology base (time period), a grid of thrust loading (T/W) and wing loading (W/S), and an initial OEW (WTS-1). The DCA-2 geometry module will turn each airplane in the grid into a parametric geometry. The performance will be calculated using a simplified process (PRF-1). Low-speed lift and drag will come from ARO-8; thrust and fuel consumption from modules PRO-3, -4, -5 and -6, and a group weight-and-balance statement from module WTS-2. The subsonic drag will be provided by ARO-7. The supersonic drag will be done by component, with ARO-9 finding the wave drag and pressure drag due to lift, ARO-12 giving the skin friction drag, and ARO-17 finding the vortex drag-due-to-lift.

SUPERSONIC A/C (cont'd.)

The weight-and-balance module will contain the following analyses:

Statistical OEW prediction methods which produce a 30-item group weight statement

Statistical OEW balance arm prediction methods which produce a 30-item horizontal center of gravity statement

Fuel volume and fuel management calculation

Passenger, cargo and fuel loading calculations

Three-axis mass moment of inertia about the airplane c.g. calculation

Airplane balance and loadability calculations

The base statistical equations are of a form such that each group weight item is predicted as a function of a set of independent parameters.

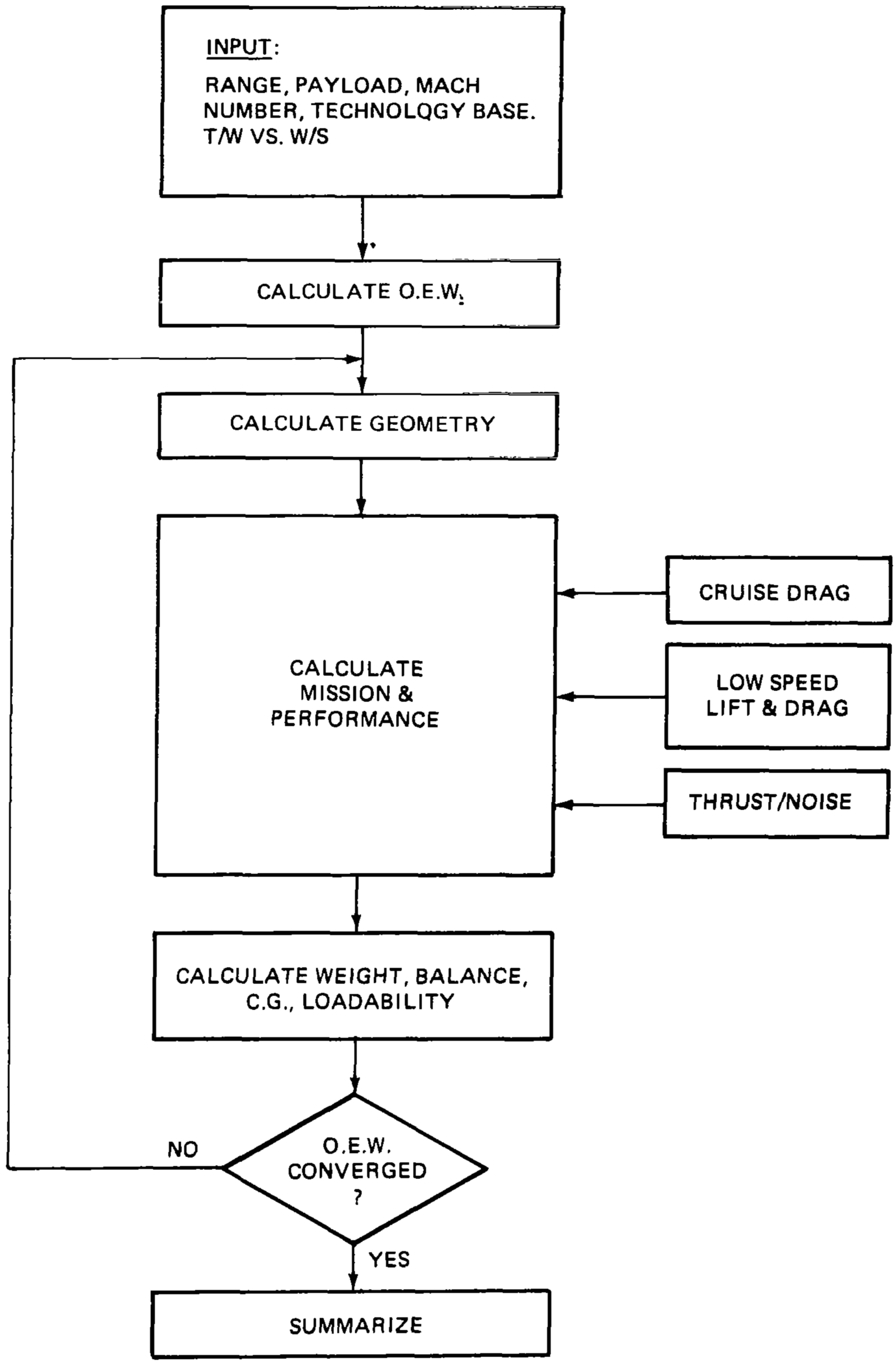


Figure 66.—Convergence Loop for Configuration Size and Performance

SUPERSONIC A/C (cont'd.)

The process of finding the correct size of the geometry and/or engine is iterative. (See figure 66.) The iteration is performed for each geometry of the T/W-versus-W/S grid. The result will be a field (a "thumbprint") of airplanes that will all do the mission. The trade information will allow valid selection of the best design mission, e.g., the mission with the best sales potential for the class of airplane under consideration.

The design trade data will also consist of comparative evaluations of operational and support costs for competing configurations. These trades will be done by REL-1, -4, -14 and -41 for alternate engine and system concepts and by REL-1 and -4 for support requirements and operational facilities at the airports in the intended routes.

Block II-6. Airplane Economics Analysis--Goal: To evaluate the operating economics of an airplane.

Airplane relative cost values are determined (FNC-1). Airplane economics are evaluated in terms of trip operating cost, ROI, break-even load factor, etc. (MKT-4). For a given airplane route system, the operating profitability of the airplane is evaluated (MKT-5). As an aide in design refinement economic sensitivity and design trade evaluation can be an option in MKT-4.

In addition, the total airplane performance will be assessed in terms of reliability and maintainability in regards to airplane availability, support costs (personnel and material), and airport operational considerations. This assessment will be done by the maintenance, operation and support simulation models of REL-1 and -4.

Block II-7. Forecast Sales Potential--Goal: To forecast the sales potential of a new airplane.

Requirements of the new airplane are calculated by airline and year to determine total sales potential of the new airplane (MKT-6).

Block II-8. Suitable Sales Potential?--Goal: To determine whether the sales potential is enough for the related development cost.

A man decision is made, based on a review of the sales potential for each candidate configuration under investigation.

4.3.3.3 Level III: Configuration Sizing

The goal of level III is to size candidate configurations to the design mission and criteria. The sizing logic should be constructed to be executed with minimal user intervention.

The level III network has been divided into two parts, "geometry sizing" and "structure sizing." The geometry sizing part is an iterative process controlled by an equation solving module (DCA-4) which drives the configuration design variables (e.g., wing area, root chord, tip chord, etc.) until a prescribed set of equality and inequality constraints such as range, field length, etc., are satisfied. The analysis to support geometry sizing is based on statistical data and no user intervention is envisioned when a configuration designer develops the input. The structure sizing part provides definition of the primary structure which is sized by analysis. This analysis includes static loads with statistical factors for dynamic loads, smeared material which is stress sized for strength and fatigue, weights and a flutter analysis. The basis for the weight estimate of secondary structure and nonstructure items remains statistical. The iterative looping for structure sizing is man controlled and the configuration designer may consult with specialists from the following disciplines: structure design, static loads, dynamic loads, stress, flutter and weights. (See figs. 48 through 50.)

Block III-1. Develop Level III Inputs--The development of inputs for level III will be similar to level II for the categories of user and data base information. However, in many cases a level III execution will begin from a level II solution. In these instances, the preparation of information required by level III from level II results is to be done by automatic processes. These default calculations will be approved and corrected by the user prior to execution of level III.

It will be desirable, but not necessary, to execute level III without interruption, so the input information for the entire execution should be available at the beginning. The user may monitor the solution (especially in cases where optimization is being done) to interrupt, correct, then restart a solution. However, the flutter solution decisions require man interaction.

Block III-2. Calculate Geometry--Goal: To define and control the airplane geometry, including planforms, arrangements, propulsion, and the location of major equipment items.

An airplane geometry consisting of the body, wing, empennage, canard, power plants, and landing gear is integrated into a lofted general arrangement (DCA-1, DGL-1 and PRO-2). The initial sizes are input and may represent an existing airplane, a modification of an existing airplane or the designer's judgment for a new airplane. This module will accept input from subsequent analysis modules and will resize the wing, engines, empennage, canard and control surfaces and/or will relocate the wing and landing gear to meet the mission requirements and criteria for performance, weights, balance, loadability, stability, and control.

An SST geometry is difficult to characterize and many variations have been investigated. In general, the configuration may be classified as tailed or tailless and by type of wing planform, i.e., delta or arrow. A tail or canard or combinations of both may be incorporated for stability and control considerations. The wing and canard may have fixed or variable geometry. A tailless version of the arrow wing may incorporate a retractable canard and vertical fins near the wing tips and at the body centerline. A wave-rider concept may require folding wing tips. Initial considerations include criteria for area distribution, effective camber surfaces, and center of pressure control or fuel tank arrangements to facilitate fuel management for center-of-gravity control over the operational speed envelope.

The body is characterized by the fineness ratio, planview, halfbreadth, camber line, crown line, keel line, floor line, and area distribution. The design is related to the requirements for the area distribution, control cabin, payload (passenger, baggage, and cargo), type of configuration, and propulsion arrangement. The payload requirements include criteria for comfort, seating arrangements, aisles, access to emergency exits, lavatories, galleys, cargo compartments, cargo containers, doors, clearances for loading and emergency evacuation, windows, and structure.

The wing is characterized by the type of planform and by parameters such as aspect ratio, taper ratio, sweep angle, thickness form, twist, and camber form. Flight and ground control surfaces are identified by type and by percent of chord and span. Spars and the main gear support structure are located to provide space for control surfaces and actuators. Spar depths and wing fuel volumes are determined. The wing may have fixed or variable geometry.

The empennage is characterized by the location and type of stabilizers and by parameters similar to the wing.

The canard is characterized by type (fixed, free-floating or controllable) and parameters similar to the wing. The canard may have fixed or retractable geometry.

The power plants are characterized by an engine cycle (rubber engine) and a nacelle geometry or by input of a specific engine and nacelle. The engines may be located on the wing and body or on the body centerline. The rubber engines are sized for takeoff, transonic acceleration or cruise thrust.

SUPERSONIC A/C (cont'd.)

The landing gear arrangements are characterized by kind (bicycle or tricycle), type (duel or truck), and number of main gear (two, three or four). The gear is located and sized to meet criteria for strength, flotation, ground handling, takeoff rotation, pitch, and roll.

The controls are characterized by primary flight (longitudinal, lateral, and directional), secondary flight (lift and drag), and ground (drag and directional). The primary flight control surfaces are sized and located to meet stability and control criteria. The secondary flight and ground control surfaces are sized and located to integrate with the flight control surfaces and landing gear structure and to meet requirements for field length performance.

Major items such as fuel tanks, electronics, and environmental control units are located to reserve space and provide weight and balance information (DCA-3, STM-1, -23, -24, and -25).

Block III-3. Calculate Cruise Performance, Wing Aerodynamics Analysis--Goal: The climb and acceleration, cruise, descent, and deceleration portions of the mission are calculated to provide fuel burned, block time, and flight profile.

The mission will be calculated by PRF-2. Simplified equations of motion are integrated and give results that are accurate to within 1% of real results. The cruise drag is provided by several modules. The subsonic drag is provided by module ARO-7. For the supersonic drag, modules ARO-9 and ARO-11 find the wave drag, module ARO-12 gives the skin friction drag, and either ARO-5 or ARO-10 provides drag-due-to-lift and wing-nacelle interference drag, and module ARO-6 determines the aeroelastic effect on drag. Thrust and fuel consumption data is provided either by table lookup (PRO-5) or by thermodynamic cycle-matching (PRO-3 or PRO-4), together with the engine installation module (PRO-6). In general, the cycle-matching technique will be used, as it is more flexible and can provide practically any thermodynamic parameters pertaining to the engine.

The process for finding the supersonic cruise drag will disclose the theoretical pressure distribution on the wing and body, if ARO-5 is used to find the drag-due-to-lift. Examination of the wing pressures and the body effect on the pressures will indicate the acceptability of the wing from the aerodynamic point of view. This does not imply an aerodynamic design to the degree desired for wind tunnel testing, but only that the thickness form does not contain regions that would later preclude a successful wing design.

Block III-4. Type B Weights Available?--Goal: If the level III analysis has been executed to the point where type B weights have been calculated (block III-19) or in level IV, rather than re-executing a statistical type A weights analysis because of a slight change in the configuration, greater accuracy will be obtained by scaling the group weights as determined in the type B weights analysis. This would be done in block III-7.

Block III-5. Calculate Weight and Balance - Type A--Goal: To provide the necessary output, consistent with amount of information known at this level, to determine whether the configuration under consideration is acceptable from the standpoints of weight, balance, and loadability.

The technical program element providing this information should contain the following analysis:

Statistical OEW weight prediction methods which produce a 30-item group weight statement (base buildup option)

Statistical OEW balance arm prediction methods which produce a 30-item horizontal c.g. statement

Fuel volume and management calculations

Passenger, cargo, and fuel loading calculations

Three-axis mass moment of inertia about the airplane c.g. calculations

Airplane balance and loadability calculations (determined in conjunction with the stability and control block III-6)

The base buildup statistical equations are of a form such that each group weight item is predicted as a function of a set of independent parameters. This type of equation is not suited for scaling.

Technical program element WTS-2 contains this analysis for subsonic transport designs. The difference in the analysis between subsonic and supersonic designs is primarily in items 1 and 2. For first implementation, it might be possible to substitute technical program element WTS-24 for the statistical weight methods in technical program element WTS-2.

Block III-6. Augmented Stability and Control--Goal: The horizontal and vertical tail surfaces are sized and located on the airplane in conjunction with a practical c.g. location and range. A flight control system will provide increments in maneuver margin that will be required for handling qualities with aft c.g.'s located for optimum trim drag. Lateral control surfaces are sized and located on the wing. The main landing gear location and size are selected.

Technical program element S&C-20 uses both theoretical and historical data to enable preliminary vertical and horizontal tail sizing to be made within a c.g. range chosen for minimum trim drag at cruise. The horizontal tail is sized to provide both control and stability in conjunction with a flight control system and SAS that will be synthesized by a combination of factored historical data and simplified calculations (FCS-14). Control and stability functions, which are affected through the all-moving horizontal tail, meet airplane pitch control criteria and the requirements of the SAS. The vertical tail is sized for directional stability criteria and directional control requirements using a conventional rudder surface. Directional stability is augmented by a lateral SAS using inputs based on Boeing SST experience.

Lateral controls selected by the program to meet simplified roll response criteria are preliminary but adequate to enable a provisional wing control surface and flap layout to be established.

The main landing gear location and size is selected following the selection of the aft cg limit.

If the stability and control requirements are not met, the geometry module will be required to resize the stabilizers and/or control surfaces. These changes are controlled by DCA-4 and are executed after the test in block III-8.

<u>Block III-7. Scale Weight and Balance</u>--Goal: To provide the necessary output, consistent with the amount of information known at this level, to determine if the configuration under consideration is acceptable from the standpoints of weight, balance and loadability.

The technical program element providing this output should contain the following analyses:

Statistical OEW weight prediction methods producing a 30-item group weight statement (scaling options)

Statistical OEW balance arm prediction methods which produce a 30-item horizontal c.g. statement

Fuel volume and management calculations

Passenger, cargo, and fuel-loading calculations

Three-axis mass moment of inertial about the airplane c.g. calculations

Airplane balance and loadability calculations determined in conjunction with the stability and control (block III-6)

The scaling statistical equations are of a form such that each group weight item is predicted as a function of a base weight and a set of parameters normalized to reflect changes in configuration. In this instance, base weights will be those determined by block III-19.

Technical program element WTS-2 contains this analysis for subsonic transport designs. The difference in the analysis between subsonic and supersonic designs is primarily in items 1 and 2. For first implementation, it might be possible to substitute technical program element WTS-24 for the statistical weights methods in technical program element WTS-2.

Block III-8. Loadability/OEW Criteria Met?--Goal (1): To compare the OEW calculated by the weights analysis (blocks III-5 or III-7) and the OEW as sized by the cruise performance analysis (block III-3) and to determine whether the difference between the OEW's is within acceptable limits. If the difference is too great, the geometry module (block III-2) will be required to resize the configuration. The required changes are computer-controlled by DCA-4.

Goal (2): To compare the available forward and aft center-of-gravity limits as determined by the stability-and-control analysis (block III-6) and the required forward-and-after center-of-gravity balance and loadability limits as determined by the weights analysis (blocks III-5 or III-7). If the difference between the required and available center of gravity limits is too great, the geometry module (block III-2) will be required to resize the empennage. If the OEW cg position does not result in acceptable airplane balance, the geometry module (block III-2) will be required to adjust the position of such items as the wing and gear relative to the body. The required changes are computer-controlled by DCA-4.

Block III-9. Calculate Low-Speed Performance and Observer Station Noise--Goal: This activity will calculate the takeoff and landing performance of a configuration. Observer station noise will be provided.

The takeoff and landing performances are determined by separate technical program elements. However, both are supported by a low-speed lift-and-drag module (ARO-8) and by thrust and fuel flow modules that utilize either table lookups (PRO-5) or thermodynamic cycles (PRO-3 or PRO-4). The propulsion modules are interfaced by the engine installation module (PRO-6).

Takeoff and climb-out performances (PRF-3) are provided by integrating simplified equations of motion. The takeoff field length is determined for the balanced field situation, and the largest flap setting that will meet the FAA minimum climb gradient is used.

Landing performance (PRF-4) is also found by integrating the equations of motion. The procedure finds the minimum flap setting that will meet the FAR 25 climb-out requirements.

Observer station noise for takeoff, approach, and sideline is estimated using module PNZ-1.

<u>Block III-10. Design Criteria Met?</u>--The loop that iterates to size a configuration begins at block III-2 and ends at this block. The iteration is necessary to find the values for the parameters controlling the configuration size that produces a geometry that meets the input requirements. The order of the activities in the loop of level III will cause the size to be established first to do the cruise part of the mission, then the takeoff and landing portions. The cycling will be computer-controlled by DCA-4.

<u>Block III-11. Calculate Finance, Cost, Market Suitability</u>--The configuration sizing of the first part of level III will produce performance information of greater reliability than was available from block II-5. Thus, the finance and marketing activities of blocks II-6 and II-7 can be repeated to obtain better insight into the product suitability. This requires the use of FNC-1, a preliminary design cost model, and MKT-4, -5, and -6 to evaluate the route system application on the market model of the configuration under consideration. Market suitability and the forecast of sales potential can be updated.

<u>Block III-12. Define Structural Concepts and Structural Arrangement</u>--Goal: Define the structural concepts and materials of the airframe primary structure. Synthesize the arrangement in detail adequate for preliminary gross sizing but consistent with appropriate design criteria.

Identify the nature of the primary structure for the major airframe components, wing, body, empennage, landing gear, and nacelles. The materials and structural concepts chosen will influence allowable loads and deflections that are determined in subsequent network event blocks.

Integrate the major structural elements into the airframe geometry in a manner appropriate for the structural concepts, materials used, manufacturing capabilities, and other design criteria. Spars, ribs, bulkhead, cutouts, frames, stringers, keel beam, floor beams, longerons, and landing gear support structure are located and identified. The arrangement of these primary structural elements will provide for an efficient, durable, low-cost, and--most important--safe airframe. Many design criteria are involved in this synthesis. In addition to those already mentioned, structural continuity, fail safety, fatigue, redundance, fuel management, fuel tank sealing and access, manufacturing capabilities and practices, systems space envelopes and certification requirements are some other less obvious but important considerations.

Geometric considerations will be based on input block III-2 (calculate geometry) and the output will provide the necessary depth for finite element geometry used later in block V-11. The output of this task will also be compatible with computerized drafting practices and requirements. This will provide for use of these methods and this data for layout and design studies at levels IV and V and further, a first basis for computer-drawn detail parts at level VI (DSA-1, -2, -3, -4 and DGL-9).

Block III-13. Calculate Wing, Body, and Empennage Paneling & Weight Distributions--Goal: To provide the necessary information for initial structural loads and stress analyses. The required information are of the following types:

a) Airplane planform and section geometry,

b) Airplane aerodynamic and structural panel definitions,

c) A preliminary estimate of the structural panel weights, center of gravities, and inertias.

When operating within the IPAD system, items b) and c) will be performed by technical program element WTS-25, while item a) will be done by block III-2.

Block III-14. Airplane Static Loads--Goal: Calculation of load distributions on the major airframe components resulting from design conditions (static and gust formulae) and a fatigue mission profile.

Static loads for a supersonic configuration would be generated using a panel representation of the airplane. The method used is based on Woodward's lifting surface method (ARO-5). Matrix methods are used to solve simultaneous linear equations for loads, deflections, accelerations, and stability derivatives. The current program (SLO-4) computes unit and balanced load solutions for symmetric maneuvers of a rigid or flexible airplane.

Integrated panel loads along a user-defined axis give shear, moment, and torsion.

This program forms the loads module with the ATLAS system (STR-6).

Flight condition data would be input by a knowledgeable user.

<u>Block III-15. Determine Thermal Effects</u>--Goal: To predict the effect of thermal heating on the aircraft's primary structure.

This estimation will be done by STR-16 for two missions, namely, the intended design mission and the design mission with an emergency descent. The result of the estimation will be the temperature history of the aircraft's primary structure.

<u>Block III-16. Size Structure for Strength and Fatigue</u>--Goal: Preliminary sizing of the primary structure for static strength and fatigue (fail-safe design) to establish airplane structural weight and elastic response characteristics.

For the structure defined in III-12, the loads calculated in III-14, and the thermal effects from III-15, the primary structure is sized for static strength and fatigue. The fatigue analysis/sizing estimates ground-air-ground (GAG) cycle stresses and GAG damage ratios (STR-5). For the strength sizing, finite element technology (e.g., STR-6) will be applied. Since flowtime is extremely important, the finite element model will be highly lumped. It is anticipated that the model would have 300-500 nodes with 750-1250 elements. Where applicable, elementary beam theory (STR-3, -4) could be applied for detailed sizing consistent with the finite-element model detail. The resulting sized-beam could be represented in the model as an equivalent beam or as a distributed section using offset technology or generalized constraints. Using generalized constraints would increase the number of nodes significantly but would not necessarily increase the number of active freedoms (unknowns). The finite element model would serve as the basis for the stiffness (flexibility) matrices which represent the structural elastic response characteristics.

Material properties, structural component allowables, fatigue reliability factors, GAG cycle stresses and GAG damage ratios for locations on major components are obtained from the data base.

<u>Block III-17. Flexibility Change Significant?</u>--Goal: A computer or man decision on the significance of the change in flexibility.

Loads are calculated for a given flexibility; the resulting strength-designed structure is sized and a new flexibility is calculated. If the change in flexibility is such that a significant loads change would result, the loads and sizing routines (blocks III-14 and III-16) are repeated.

If the change is not significant the resulting structure is weighed (block III-19).

Block III-18. Stability & Control Check--Goal: Tail sizing and balance task in block III-6 is checked using computed structural stiffnesses resulting from blocks III-14, -15, and -16.

S&C-20 program is rerun with computed stiffnesses replacing the statistical values. Structural flexibility has a major influence on SST tail and control sizing.

Block III-19. Calculate Weight, Balance, and Loadability - Type B--Goal: To calculate type B weight, balance, and loadability for the configuration which has been sized for strength and fatigue.

Accomplishing this activity involves technical program elements that:

Execute the weights update control module (WTS-15), which would re-execute only those portions of the weights technical program elements whose input had changed

Calculate wing primary structure mass elements based on finite-element analysis (WTS-21),

Calculate body/empennage primary structure mass elements based on finite element analysis (WTS-21)

Calculate wing secondary structure mass elements (WTS-7)

Calculate body/empennage secondary structure mass elements (WTS-8)

Calculate landing gear mass elements (WTS-)

Calculate nacelle and strut, propulsion, fixed equipment, and standard and operational mass elements (WTS-10)

Calculate fuel mass elements (WTS-11)

Accumulate mass elements within each structural panel and calculate weight, center of gravity, and inertia for each structural panel and for the wing, body, and empennage (WTS-12)

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Generate a weight statement patterned after the AN 9102-D format based on the previously calculated mass elements (WTS-13)

Calculate total airplane mass properties for various points on the balance diagram and determine updated panel mass properties for recycling through structural analyses of blocks III-14 and III-15 (WTS-14)

Determine fuel management requirements (WTS-26)

The type B weights are suited for scaling. Data communication is similar to that discussed in block III-32.

Block III-20. Panel Mass/Inertia Change Significant?--Since the loads analyses are sensitive to panel mass properties, each time the weights analyses update the panel's mass, center-of-gravity and inertia, the effect of these changes on the loads analyses should be examined. If the mass property changes are significant, the loads and the structural analyses should be re-executed.

Block III-21. Loadability/OEW Criteria Met?--Goal 1: To compare the available OEW calculated by the weights analysis (block III-19) and the OEW as sized by the cruise performance analysis (block III-3) and to determine whether the difference between the OEW's is within acceptable limits. If the difference is too great, the geometry module (block III-2) will be required to resize the configuration. The required changes are man-controlled in the structure sizing part of level III.

Goal 2: To compare the available forward and aft center-of-gravity limits, as determined by the stability and control analysis (block III-18) and the required forward and aft center-of-gravity balance and loadability limits, as determined by the weights analysis (block III-19). If the difference between the required and available center-of-gravity limits is too great, the geometry module (block III-2) will be required to resize the empennage. If the OEW c.g. position does not result in acceptable airplane balance, the geometry module (block III-2) will be required to adjust the position of such items as the wing and gear relative to the body. The required changes are man-controlled in the structure sizing part of level III.

Block III-22. Change Stiffness?--Goal: Man intervention in the analysis process to determine the effects of an arbitrary change in aft body stiffness (e.g., a horizontal tail configuration.)

An increase in aft body stiffness is made to the structural matrix. The recycle through blocks III-14 to III-21 will show the trade for the improved airplane longitudinal control and stability characteristics compared with the change in weight and balance.

Block III-23. Equations of Motion--Flutter Option--Goal: Formulate the equations of motion for flutter analysis of the initial structural sized configurations.

Equations of motion for flutter analysis of the initial structural sized configurations will be formulated (from Lagrange's equation) as a second-order system of ordinary differential equations with the generalized mass and stiffness matrices (block EM-5) and generalized-forces matrices (block EM-8) as coefficient matrices.

Each configuration will be divided into small regions of substructures. The system stiffness and mass matrices will be derived from those of substructures using a scale-merge-reduce operation (block SFL-21). Substructure stiffness and mass matrices will be calculated using finite element methods. Three-dimensional lifting surface theory will be used to calculate generalized-force matrices for both subsonic and supersonic flows. Vibration modes calculated from block EM-5 will be used as generalized coordinates. Programs to be used are presented in the descriptions of blocks EM-7, EM-8, and EM-9.

Block III-24. Flutter Analysis--Goal: Conduct flutter evaluation of the initial structure sized configuration.

A simplified preliminary flutter analysis of the initial structural-sized configuration will be performed. The flutter equations will be solved by either the traditional v-g method (SFL-10), the classic British method (SFL-11), or an automated scheme (SFL-12). Flutter results will be hand-interpreted or monitored on an interactive display by a flutter analyst when using programs SFL-10 or SFL-11. However, using the program SFL-12, flutter results are calculated automatically. Flutter sensitivities with respect to the placement of engines and external stores and to the fuel distributions will be presented.

Block III-25. Flutter Criteria Met?--Goal: Determine whether the flutter criteria have been satisfied.

This decision is manual. If flutter deficiency exists, improvements will be made by changing geometry, structural arrangement, stiffness, or mass.

Block III-26. Proposed Fix--Goal: To determine changes of configuration geometry, mass, stiffness and structural arrangement for flutter clearance.

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The critical flutter conditions identified in block III-24 will be analyzed to appraise flutter mechanism using an energy display approach (SFL-13). Parametric flutter trend studies on stiffness changes and mass changes for each geometry change (if any) coupled with any structural arrangement change will be conducted to determine how the flutter deficiencies should be removed. When a portion of the structure is to be changed, the mass and stiffness matrices of only those substructures affected by the change are recalculated and remerged with the unchanged substructures (SFL-21). These trend studies are performed through blocks III-23, -24, -25, and -26. This loop is terminated when the desired flutter clearances are achieved.

Block III-27. Geometry Change?--Goal: Determine whether a configuration geometry change is required for flutter clearance.

This decision is manual. Geometry changes in terms of modifications to existing main lifting surfaces are to be considered. If geometry changes are required to clear flutter, the design flow will go back to the start of level III.

Block III-28. Change Structural Arrangement?--Goal: Determine whether a structural arrangement change is required for flutter clearance.

This decision is manual. Structural arrangement changes will be considered here as a preliminary study of the effect of the structural design concept on flutter.

Block III-29. Change Stiffness?--Goal: Determine whether structural stiffness change should be made for flutter clearance.

This decision is manual. If the stiffness increase (identified in block III-26) over the strength and fatigue sizing is to be made to clear flutter, the required stiffness will be provided for block III-30. If the answer to the question is no, block III-31 will be executed and any mass change for flutter clearance will be input.

Block III-30. Update Structural Sizing --Goal: To identify flutter-prescribed resizing for updating the primary structure weight and establish minimum size constraints for all further strength and fatigue design activities.

If a stiffness (sizing) increase over the strength and fatigue sizing is required to meet the flutter criteria, the sizing required is identified and updated. For all skin and web gage increases, the stiffening material is increased if required. Flutter-prescribed sizing will be considered to be minimum size constraints in all further strength and fatigue sizing activities.

Block III-31. Update Weights, Balance, and Loadability--Goal: To calculate type B weight, balance, and loadability for the configuration which has been sized for strength, fatigue, and flutter. This involves technical program elements that:

Execute weights update control (WTS-15) that would re-execute only those portions of the weights technical program elements whose input had changed

Update wing primary structure mass elements based on stress-sized skin/stringer material (WTS-21)

Update body/empennage primary structure mass elements based on stress-sized skin/stringer material (WTS-21)

Update wing secondary structure mass elements (WTS-7)

Update body/empennage secondary structure mass elements (WTS-8)

Update fuel mass elements (WTS-11)

Accumulate mass elements within each structural panel and the calculate weight, center of gravity, and inertia for each structural panel and for the wing, body, and empennage (WTS-12)

Generate a weight statement patterned after the AN 9102-D format based on the previously updated mass elements (WTS-13)

Calculate total airplane mass properties for various points on the balance diagram and determine updated panel mass properties for recycling through the structural analyses (WTS-14)

Block III-32. Calculate Noise--Goal: This activity will provide noise footprints in the vicinity of the airport and the sonic boom overpressure during cruise.

Noise footprints will be calculated by the noise prediction module (PNZ-1). The footprints will provide perceived noise level contours along the flight path for both takeoff and approach. These contours predict the maximum perceived noise levels on the ground.

The sonic boom overpressures will be calculated at required points along the flight path. These overpressures may require modification to the flight profile. The process of calculating the overpressure is presented in figure 67. The first activity is to input the intended atmospheric model into module ARO-14. This will determine the propagation characteristics of sonic booms in the model atmosphere and will provide tables of scaling factors and aging constants for module ARO-13. This branch need be executed only when a new atmosphere model is to be used.

The sonic boom calculation is determined by volume and lift effects. Module ARO-9 determines the volume inputs and module ARO-10 determines the lift inputs to module ARO-13, which will produce pressure signatures and boom width information.

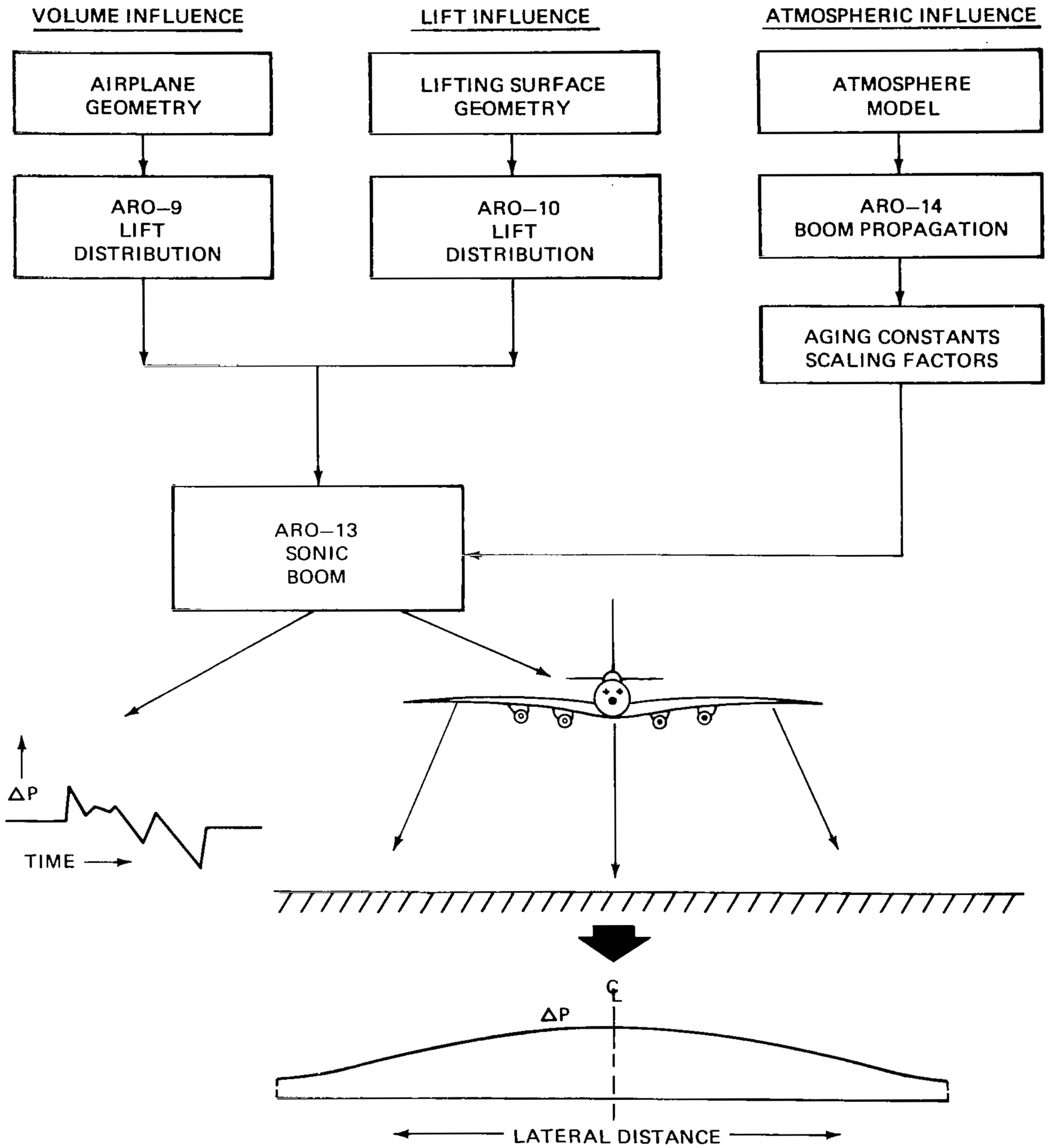


Figure 67.—Calculation of Sonic Boom

Block III-33. Summarize Performance, Finance, Cost, and Market Suitability--At this point, the design sizing of level III will have been completed. It will be useful to collect the most recent technical information about the configuration and summarize the performance and cost. From there, the market suitability will be investigated. The performance summary will be done by PRF-5, finance and cost consideration by FNC-1, and the market suitability by MKT-4, -5, and -6.

Utilization, maintenance, and dispatch reliability will be assessed. Probable route structures, aircraft fleets, airport facilities, and operational and environmental factors are used by REL-1 and -4. Additional inputs to these are ground service equipment and airplane interactions as well as maintenance time data produced by REL-6 to -13 and -15 to -40. Also included is a determination of the capability to change an engine within a time interval compatible with the planned utilization. This is a manual review.

Block III-34. Configuration Acceptable--Goal: Man decision based on a review of the effects of the primary structure definition on the performance, noise levels, cost, and market suitability of the final airplane configuration analyzed in level III. Blocks III-32 and III-33 provide data for this review.

Block III-35. Modify Configuration or Mission--There are two options from a negative result in block III-34. The designer may elect to retain the design mission and criteria and return to the beginning of level III to resize, using different sizing rules, or the designer may return the design sequence to level II to evaluate the effects of an alternate design mission.

6.3.3.4 Level IV: Configuration Refinement

The goal of level IV is to refine a configuration by applying more advanced analysis methods to the design. Competing configurations may be evaluated based on level II and level III data provided that sufficient configuration similarity exists to insure that consistent analysis techniques have been used. Therefore, only the best configuration of each type will be selected for configuration refinement in level IV. (See figures 51 through 57 for level IV detail networks.)

Block IV-1. Develop Level IV Inputs--The design and analysis activities of level III have enriched the data base about the configuration. These new data, as well as criteria and constraints from level II, will be put into forms suitable for the level IV analysis methods. This action will be supported primarily by the data base manager. Additionally, user inputs and information from the data base not previously required will be established. This activity is shown symbolically at the head of level IV, but due to the interactive nature of level IV, the data preparation activity may be done selectively throughout level IV.

Block IV-2. Suitable S&C Wind Tunnel Data Available--Goal: Determine availability of stability and control aerodynamic data adequate to build a data base for analyses. In particular determine availability of high angle of attack wind tunnel data essential for accurate tail sizing.

This is initially a man decision to search available data files. In time this decision can be made by the computer when a comprehensive SST data library exists. The importance of high angle of attack data for horizontal tail sizing is based on Boeing experience in SST design.

Block IV-3. Stability and Control Wind Tunnel Data--Goal: Wind tunnel data on a configuration similar to the design under study is required to enable an assessment to be made of subsonic speed pitch requirements and the sizing of the longitudinal control surfaces. High angle of attack wind tunnel data at subsonic speeds are particularly necessary, based on Boeing experience, since theoretical predictions are not accurate at the present time.

Obvious sources of data will be sought from NASA and industry wind tunnel tests. Actual wind tunnel testing may be undertaken using existing wind tunnel models similar to the design configuration.

Block IV-4. Stability and Control Data Preparation--Goal: Analysis of the configuration sized in level III and modified by wind tunnel data in block IV-2 and IV-3 to provide a data bank of preliminary stability and control static and dynamic aerodynamics. Data will be available for future flight control system and stability and control analyses.

Data preparation is performed in two separate technical program elements, each consisting of two functional parts. S&C-21 calculates basic longitudinal static aerodynamic stability derivatives and control effects using aerodynamic estimates, automated where practical, with aeroelastic corrections from level III analyses (blocks III-14, -16, and -26). Program S&C-22 uses the data of S&C-21 and estimates the longitudinal dynamic derivatives. The total output of S&C-21 and -22 is now available (along with mass and inertia characteristics) to have dynamic and control analyses performed. The lateral and directional axes are studied separately from the longitudinal axis; S&C-23 computes the static derivatives, S&C-24 the dynamic derivatives. The total output of both programs is now available (along with mass and inertia characteristics) to have dynamic and control analyses performed. All program elements have optional inputs:

a) Aerodynamic estimating subroutine can be bypassed by inputting actual wind tunnel data.

b) Aeroelastic data can be changed or modified at any stage from initial estimates to current configuration calculated values.

Block IV-5. Flight Control System Synthesis & Analysis, Rigid Body Modes and QSE--Goal: Flight control system gains and compensation filters are selected. The flight control system design is necessary to provide required airplane handling qualities. Components of the flight control system are sized for weight considerations.

The flight control system work for an SST is similar to but more critical than the corresponding work on a subsonic transport. Flexibility and dynamic pressures are more significant for an SST than for a subsonic. The greater range of the flight envelope (subsonic, transonic, and supersonic) requires an involved gain scheduler. An SST generally relies more heavily upon a stability augmentation system than would a subsonic transport. However, the same computational methods may be used for either project.

Optimal control theory (FCS-3, FCS-6, and FCS-7) is used to automate the parameter sizing process for each flight condition. The generalized inverse technique (FCS-4 or FCS-5) is used to force parameter compromises necessary for satisfying the flight control system over the entire flight envelope. The resulting control system is analyzed for stability margins by use of classical linear controls analysis techniques (root locus, Baud, etc., FCS-1 or FCS-2). The preceding programs (FCS-1 and FCS-2) perform dynamic response checks to evaluate the compliance with airplane handling qualities criteria. Revisions to the flight control system design may be mandated by the stability and control analysis block IV-6 and the piloted simulator study of block IV-7.

Another computer program development (FCS-12) is required to size flight control system hardware for a weights assessment.

The equations of motion for this level consist of rigid body modes with static aeroelastic corrections (FCS-11) instead of the more costly elastic mode representation. The gains and compensation would be tempered to anticipate elastic mode problems.

The entire flight control system synthesis process is automatic at this design level. However, a knowledgeable user is required to intervene if problems develop during on-line operation.

Block IV-6. Stability & Control Analysis; Static and Dynamic--Goal: Airplane analyses made to establish resizing of control surfaces and stabilizing surfaces for satisfactory handling qualities. Stability and control aerodynamic data from block IV-4 is used in conjunction with the current flight control system analyzed in block IV-5. A digital analysis measures the airplane dynamic response and control response characteristics. Flight simulation is undertaken in IV-7 to establish pilot's ratings and correlation with handling qualities criteria. Single analyses check airplane control surface capability for specific requirements such as low speed pitch control, directional control for engine failure and lateral control for roll response.

The technical program element (FCS-1) is used for the airplane response characteristics and control effects. Man intervention is required to analyze these results with the view of adjusting the airplane geometry to provide improved handling qualities.

Technical program elements S&C-7, -8, -9, -10 and -11 perform specific tasks to assess control surface capability for the following requirements:

TASK	REQUIREMENT
Takeoff rotation	pitch control for low-speed performance
Landing flare	
Minimum control speed, ground	directional control for low-speed performance
Minimum control speed, air	
Roll response criteria	lateral control

Block IV-7. Piloted Flight Simulation--Goal: Simulation of the airplane flying qualities to establish feasibility of control surface and empennage sizing of level III and checked by the dynamic analyses of block IV-6.

The computerized pilot evaluation is contained in the technical program element S&C-18. The actual piloted simulation is described by S&C-19. These programs will use the basic airplane characteristics from block IV-4 and the flight control system synthesized in block IV-5. The response of the airplane due to control inputs, gusts, and failures will be measured and rated by the simulation against established criteria.

Block IV-8. Update Weights (Type B)--Goal: To update the weights based on minor changes to the configuration in order to achieve acceptable stability and control. These changes are of a minor nature in that they do not result in a geometry change that would affect the entire design; instead they would primarily affect the weight. An example might be to change from a single-hinged rudder to a double-hinged rudder.

To account for these changes, the following weights technical program elements would be used:

For purposes of increasing the accuracy and decreasing the computational time required to perform the weights analysis, it would be desirable to develop a weights technical program element (WTS-15) which would re-execute only those portions of the weights programs whose input had changed.

Update of the wing secondary structure mass elements (WTS-7)

Update of the body/empennage secondary structure mass elements (WTS-8)

Update of the fixed equipment mass elements (WTS-10)

Generation of a weight statement patterned after the AN 9102-D format based on the previously calculated mass elements (WTS-13)

Block IV-9. Geometry Change?--Goal: Determine whether a change in flight control surface or tail stabilizing surface size, location, or deflection is required.

This decision is manual; therefore, human judgment will be required. Trades of improved stability or control to meet handling qualities criteria in block IV-10 will decide if large or small geometry changes are necessary.

Block IV-10. S&C Acceptable--Goal: Determine whether the stability and control handling qualities of block IV-6 and IV-7 are adequate and establish configuration changes to make trades if required.

This decision is manual and human judgment will be exercised in the interpretation of handling qualities criteria. Configuration trades established in block IV-7 will help make this decision.

Block IV-11. Start Wind Tunnel Model?--Goal: Decision to be made about starting the design of a cruise shape wind tunnel model for testing in Level V.

This is a man decision influenced by confidence gained in the aerodynamic and stability and control design analyses performed in blocks III-3, III-33, and IV-6. Wind tunnel model construction requires up to three months design lead time; hence, an intelligent decision can shorten the time to develop a configuration design in level V. This decision is considered each time this point in the network is passed.

Block IV-12. Size Actuators--Goal: Airplane weight estimates made in level III include statistical weights for the flight control actuation system. Actuators and hydraulic power requirements are sized individually in level IV on a preliminary basis using theoretical aerodynamic hinge moments to improve the airplane weight estimation and provide information for hydraulic power requirements, reliability and redundancy analysis, flight control system synthesis and analysis, flutter, and physical space requirements.

Rigid control surface hinge moment coefficients for all control surfaces are estimated either from theory or from past experimental data and corrected by estimated aeroelastic effects. Technical program elements S&C-15 and -16 perform the computations. FCS-17 provides hydraulic system requirements for redundancy and reliability.

Block IV-13. Actuator Change Significant--Goal: Update the description of the flight control actuation used in the flight control system synthesis and analysis in block IV-5 and piloted flight simulation in block IV-7.

This change is manual and human judgment will be exercised in deciding the need to update the stability and control and flight control system analyses.

Block IV-14. Reliability and Redundancy Analysis--
Goal (1): To establish the reliability and redundancy of the aircraft and its systems.

The flight control system is examined by FCS-17. Previously assumed levels of redundancy are compared with selected criteria to assure that selected control systems and supporting systems are adequate.

Goal (2): To establish safety requirements and allocations.

Ground and flight safety must be considered in design and evaluation. Inflight safety is a function of the man/machine performing in the overall operational environment. Requirements and allocations for inflight safety are developed from historical data and the projected design mission profile.

Ground safety is affected by the aerospace vehicle itself and its operation and interface with ground operations equipment, personnel, and facilities. Safety allocations and requirements evolve from consideration of these factors and from historical safety problems in relation to the projected ground operations.

Development of safety design requirements and allocations is a manual function.

Goal (3): To establish reliability and maintainability requirements and allocations.

Both inflight and dispatch reliability must be considered in design evaluation. Inflight reliability is mainly a function of inherent reliability of the airplane equipment. Requirements and allocations for inflight reliability are developed from historical data and the projected design mission profile.

Dispatch reliability is affected by available ground time, capability to defer and perform maintenance required to dispatch in the time available, and the inherent reliability of the aerospace system equipment. Both reliability and maintainability requirements and allocations evolve from consideration of these factors and history in relation to the projected design mission profile.

Development of reliability and maintainability design requirements and allocations is a manual function, supported by REL-6 to -13, REL-15 to -40, and REL-42.

Goal (4): To evaluate failure mode effects and determine needed corrective action. This analysis focuses on reliability, maintainability, and safety problems and serves as a starting point for quantitative system reliability and safety analyses.

The effect of failure of all identified functions and components is determined within the system for each failure mode. Means of recognizing the failure and compensatory provisions and procedures are identified. Order of probability of occurrence of the event is assessed.

Performance of the failure mode effect analysis is manual. Output is a tabulation by function or component of factors associated with its failure modes.

Goal (5): To identify fault hazards associated with operation of the system and their safeguards.

A fault hazard analysis is a tabulation of all hazards identified with operation of the system through each phase of operation. Function, component, operator failures, and combinations of failures causing the hazard are identified. Order of probability for each combination is assessed. Compensatory provisions and procedures are identified.

Performance of the fault hazard analysis is manual. Output is a tabulation by hazard of factors associated with its occurrence. The analysis is supported by REL-6 to -13, REL-15, to -40, and REL-42.

Goal (6): To assess relative merits of the flight control system design trade studies and to assess the overall system from the standpoint of safety and reliability.

Flight safety and redundancy studies of the flight control system in all flight phases and design conditions are studied. Fault tree (REL-5) analysis is used for overall airplane flight safety assessment of the control system.

Redundancy studies within the flight control subsystems are performed with the COBRA (REL-3), the ARMM (REL-2) and CTS(REL-14 and -41) programs.

Block IV-15. FCS Criteria Met?--Goal: Determine whether the flight control system criteria have been satisfied.

This decision is manual, and human judgment may be exercised in the interpretation of the criteria. If definite control system difficulties are present in the design, the IPAD process is stopped and a review is held.

Block IV-16. Technical Review to Determine Action--Goal: Determine required action: further control system refinements, modification of criteria, modification of airplane, or modification of flight envelope.

These decisions will generally be a committee function outside of the IPAD system.

Block IV-17. Update Propulsion System Design--Goal: Update all propulsion system data to show the effects of the propulsion installation analysis (block IV-17a).

All propulsion and noise data will be updated to concur with the current propulsion system configuration per block IV-17a.

SUPERSONIC A/C (cont'd.)

Block IV-17a. Propulsion Installation Analysis--Goal: Analyze and refine the installed propulsion system in a parallel effort to the IPAD mainstream.

All propulsion and noise disciplines will be involved in the analysis and refinement of the installed propulsion system. This effort will involve such areas as inlets, nozzles, and thrust reversers; acoustic treatment; airbleed and horsepower extraction requirements; and accessory equipment; as well as the bare engine components (compressor, turbine, etc.). The effort may require the use of propulsion and noise modules PRO-1, -2, -3, -4, -5, and -6 and PNZ-1.

Block IV-18. Installed Thrust/SFC Change Significant? --Goal: To evaluate the change in the installed thrust or specific fuel consumption.

The performance and sizing calculations of level III assumed an installation penalty to thrust and SFC based on historical or empirical values. While the level III and level IV analyses were conducted, outside activity has been carried out to establish by analysis and tests more accurate values for the installed thrust and SFC. If these values are significantly different than the ones assumed in the sizing activities, the design must be returned to level III to be resized.

Block IV-19. Size Fuel Management System--Goal: To calculate the fuel transfer rate required by the fuel management system to manage the travel of the airplane center of gravity.

Before the fuel management system can be sized, module PRF-2 will calculate the deceleration of the airplane due to critical engine failure. The appropriate drag modules (ARO-5, -6, -7, and -9 to -12), thrust modules (PRO-3 to -6), and weight and balance modules (WTS-7 to -15, and -26) will support this calculation. From this, the required fuel transfer rate to correspond with the aerodynamic center of pressure movement can be determined. The fuel management system will be checked against this fuel transfer rate and resized if necessary.

Block IV-20. Requirements Exceed Limits?--Goal: To determine whether the fuel transfer system is within acceptable limits.

The fuel system to maintain critical travel of the center of gravity has been sized by block IV-19. If the pump sizes, power requirements, and fuel line diameters are acceptable, the design process will proceed.

Block IV-21. Technical Review to Determine Action--Goal: To determine how to reconfigure a geometry with an excessive critical engine-out longitudinal center-of-gravity travel.

If the fuel system transfer rate to match the center-of-gravity travel is excessive, this constitutes a very serious configuration deficiency. A technical review is held to assess the situation and recommend the configuration revision most likely to solve the problem. Part of that recommendation will be instructions as to the next part of the design sequence to be executed.

Block IV-22. Systems Design--Goal (1): To define system concepts and sizing criteria in sufficient detail to insure that design requirements are identified and to provide sizing information for weight and balance estimating.

Flight Control System--Schematic diagrams are developed for each control system using data developed by FCS-12, -15, and -17 and STM-2, -3, and -4. Critical mechanical elements such as control mixers and feedback concepts are identified and design criteria are established. Actuator sizing and redundancy criteria are developed by network blocks IV-12 and IV-14, and the actuators are sized by FCS-15.

Landing Gear--Schematic diagrams are developed for the brake system and the steering system. Sizing criteria for the brakes, wheels, tires, and steering are developed (STM-14, -15, and -18).

Hydraulics--A schematic diagram is developed for the hydraulic system. Load analysis inputs are used to determine fluid flow requirements, establish distribution paths, and size pumps. Load balancing and component sizing trades are conducted (STM-2, -3, and -4). Critical hydraulic system items are identified and design criteria established.

Auxiliary Power Unit (APU)--A load schedule is determined for shaft power and air flow (STM-8). Critical considerations such as capability for inflight starting are identified and design criteria are established.

Environmental Control System (ECS)--Schematic diagrams are developed for the ECS system and the pneumatic control and distribution system. Propulsion and APU interfaces are established. Load analysis inputs are used to determine requirements for heating and cooling cycles (STM-10, -11, and -12). Critical considerations such as temperature pulldown capability on a hot day are identified and design criteria established.

Electrical Power System--A schematic diagram is developed for the electrical power system. Load analysis inputs are used to determine power generation requirements (STM-20). System arrangement trade studies provide initial optimization of equipment relationships (STM-21). Critical considerations such as loads which require source redundancy are evaluated and design criteria established.

Avionics--Mission profile data is used to determine requirements for avionic subsystems: navigation, flight instruments, communication, weather radar, utility, and advisory equipment. Electrical and cooling loads are determined (STM-13). Critical considerations such as category IIIa landing capability and requirements for antenna locations are evaluated and design criteria established.

Fuel System--Schematic diagrams are developed for the following fuel subsystems: refuel, fuel vent and surge, and engine fuel feed. Flow rates, refuel time, etc., are used to establish line sizes (STM-26, -27, -28, -29, and -30). Critical considerations such as pressure constraints, valve failure cases, wing deflections, and quantity gauging requirements are identified and design criteria established.

Goal (2): Comparative evaluation of design trade study configurations and assessment of configurations against the reliability, maintainability and safety requirements and allocations.

Fault tree simulation (REL-5), computerized Boolean reliability analysis (REL-3), automatic reliability mathematical modeling (REL-2), and CTS (REL-14 and -41) are used for studies at this level. Program selection is dependent on problem and system complexity and comparative factors selected for evaluation.

Block IV-23. Update Weights - Type B (Nonstructural)--Goal: To calculate updated mass properties for the nonstructural items which have changed since the analysis which was made by block III-19. The primary changes will be to the propulsion groups (block IV-17) and the systems groups (block IV-22).

To accomplish this activity the following technical program elements are involved:

For purposes of increasing the accuracy and decreasing the computational time required to perform the weights analysis, it would be desirable to develop a weights technical program element (WTS-15) which would re-execute only those portions of the weights programs whose input had changed.

SUPERSONIC A/C (cont'd.)

Update of landing gear mass elements (WTS-9)

Update of nacelle and strut, propulsion, fixed equipment, and standard and operational mass elements (WTS-10)

Update of fuel mass elements (WTS-11)

Accumulation of mass elements within each structural panel and the calculation of weight, center of gravity, and inertia for each structural panel and for the wing, body, and empennage (WTS-12)

Generation of a weight statement patterned after the AN 9102-D format based on the previously calculated mass elements (WTS-13)

Calculation of total airplane mass properties for the various points on the balance diagram and the determination of updated panel mass properties for the structural analysis in blocks IV-20 and IV-21 (WTS-14)

Block IV-24. Entered at M?--This is a computer decision. At this position in the design cycle, repetition of blocks IV-26 through IV-63 is not required.

Block IV-25. Stability Derivatives Change Significant?--Goal: Decision to repeat the analysis for equations of motion, dynamic loads, structural analysis, static loads, weights update, flutter analysis, and flight control system in blocks IV-48 through IV-64.

This is a man decision based on the change in the stability and control derivatives, evaluated in the data preparation block IV-4, due to improved aeroelastic corrections obtained during the first pass through level IV. A significant change in these flexible airplane derivatives will necessitate a recycle of the tasks identified above.

Block IV-26. Airplane Static Loads--Goal: Calculation of load distribution on the major airframe components resulting from design conditions (static and gust formulae) and a fatigue mission profile.

Static loads for a supersonic configuration would be generated using a panel representation of the airplane. The method used is based on Woodward's lifting surface method. Matrix methods are used to solve simultaneous linear equations for loads, deflections, accelerations, and stability derivatives. The current program (SLO-4) computes unit and balanced load solutions for symmetric maneuvers of a rigid or flexible airplane.

SUPERSONIC A/C (cont'd.)

Integrated panel loads along a user defined axis give shear, moment, and torsion.

This program forms the loads module within the ATLAS system (STR-6).

Flight condition data would be input by a knowledgeable user.

Any requirements for loads on secondary structure would be met by hand calculations based on data from a similar past configuration.

Block IV-27. Determine Thermal Effects--Goal: To predict the effect of thermal heating on the aircraft's primary structure.

This estimation will be done by STR-15 for two missions, namely the intended design mission and the design mission with an emergency descent. The result of the estimation will be the temperature history of the aircraft's primary structure.

Block IV-28. Size Structure for Strength and Fatigue--Goal: Preliminary detailed sizing of the primary structure for strength and fatigue (fail-safe design) to improve estimates of airframe structural weights and elastic response characteristics.

For the structural arrangement and structural concepts defined in blocks III-12 or III-26, the sizing established in block III-16, the loads calculated in IV-26, and the thermal effects from IV-27, the primary structure is sized for strength and fatigue. The strength sizing will be based on finite element technology (e.g., STR-6). Approximately twice the detail of the block III-16 sizing is envisaged for block IV-28. Thus, the model would have 600-1000 nodes with 1500-2500 elements. Where applicable, elementary beam theory (STR-3, -4) would be applied for detailed sizing consistent with the finite element model detail. The resultant sizing could be represented in the model as an equivalent beam or as a distributed section using offset technology or generalized constraints. Using generalized constraints would increase the number of nodes significantly but would not necessarily increase the number of active freedoms (unknowns). The finite element model is also the basis for the fatigue sizing (STR-5).

Material properties, structural component allowables, fatigue reliability factors, and detail fatigue ratings for major component structures are obtained from the data base.

Block IV-29. Flexibility Change Significant?--Goal: A computer or man decision on the significance of the change in flexibility.

SUPERSONIC A/C (cont'd.)

Loads are calculated for a given flexibility, the resulting strength-designed structure is sized, and a new flexibility calculated. If the change in flexibility is such that a significant loads change would result, the loads and sizing (blocks IV-26 and IV-28) are repeated.

If the change is not significant, the resulting structure is weighed (block IV-30).

Block IV-30. Update Primary Structure Weights--Goal: To update the primary structure weight based on the refined skin/stringer material sizes supplied by the stress analysis in block IV-28 and present the results in the form of a weight statement in order that the structural concepts can be evaluated.

To accomplish this activity involves technical program elements that:

Execute the weights update control (WTS-15) that would re-execute only those portions of the weights technical program elements whose input had changed

Update wing primary structure mass elements based on stress-sized skin/stringer material (WTS-21)

Update body/empennage primary structure mass elements based on stress-sized skin/stringer material (WTS-21)

Update wing secondary structure mass elements (WTS-18)

Update body/empennage secondary structure mass elements (WTS-19)

Generate a weight statement patterned after the AN 9102-D format based on the previously updated mass elements (WTS-13)

Block IV-31. Structural Concepts Satisfactory?--Goal: Provide for investigation of alternate structural concepts and arrangements.

Review the structural concepts and arrangements identified in block III-12 and sized in block IV-28 for possible areas of improved efficiency. Should the design be judged adequate, work would commence at block IV-32. Should an improved design be required, it would be identified in block IV-31a.

This decision is manual and heavily influenced by judgment relative to producibility and risk.

Block IV-31a. Redefine Structural Concept and

Arrangements--Goal: To optimize structural concepts and arrangements.

Alternate structural concepts and arrangements would be investigated for those areas identified as candidates for improved structural efficiency in block IV-31. Sizing for strength and fatigue (block IV-28) of the original concepts and arrangements (block III-12) has provided a baseline for trade studies of possible alternate designs.

Input data from DSA-1, -2, -3, and -4 would be modified using the interactive design tool of DSA-5. All of the considerations of block III-12 will be involved in a process heavily influenced by manual judgment in the interactive process. STR-3, -4 and -5 would provide structural sizing data upon which this judgment would be based. The modified concepts and arrangements would then be resized in block IV-28 to provide a new baseline airframe structure (DSA-1, -2, -3, -4, and -5, and DGL-7 and -9).

Block IV-32. Update Weight, Balance and Loadability (Type C)--Goal: To calculate type C weight, balance, and loadability for the configuration which has been sized for strength and fatigue. The primary structure weights are based on stress-sized skin/stringer material.

Most of the technical program elements required to support this activity were executed in blocks IV-23 and IV-30. The additional technical program elements required would be:

Execution of weights update control (WTS-15)

Update of fuel mass elements (WTS-11)

Accumulation of mass elements within each structural panel and the calculation of weight, center of gravity, and inertia for each structural panel and for the wing, body, and empennage (WTS-12)

Generation of a weight statement patterned after the AN 9102-D format based on the previously updated mass elements (WTS-13)

Update of total airplane mass properties for various points on the balance diagram and update of panel mass properties for recycling through the structural analyses (WTS-14)

Block IV-33. Panel Mass/Inertia Change Significant?--Goal: Since the loads analyses are sensitive to panel mass properties, each time the weights analyses updates the panel's mass, center of gravity, and inertia, the effect of these changes on the loads analyses should be examined. If the panel mass properties changes are significant, the loads and the structural analyses should be re-executed.

Block IV-34. Loadability/OEW Criteria Met?--Goal (1): To compare the OEW which is calculated by the weights analysis (block IV-31) and the required OEW as sized by the cruise performance analysis (block III-3) and to determine whether the difference between the OEW's is within acceptable limits. If the difference is too great, the geometry module (block III-2) will be required to resize the configuration. The required changes are man-controlled in level IV.

Goal (2): To compare the available forward and aft center-of-gravity limits as determined by the stability and control analysis (block IV-6) and the required forward and aft center-of-gravity balance and loadability limits as determined by the weights analysis (block IV-32). If the difference between the required and available center-of-gravity limits is too great, the geometry module (block III-2) will be required to resize the empennage. If the OEW cg position does not result in acceptable airplane balance, the geometry module (block III-2) will be required to adjust the position of such items as the wing and gear relative to the body. The required changes are man controlled in level IV.

Block IV-35. Equation of Motion - Flutter Option--Goal: Formulate equations of motion for flutter analysis of refined configurations.

Activity here is basically the same as design network block III-23. However, more refined stiffness, mass and vibration information will be available as input.

Block IV-36. Proposed Flutter Suppression System--Goal: A flutter suppression control system is synthesized for the purpose of increasing the flutter speed.

The procedure for selecting gains and filters is similar to the procedure described in block IV-5. Thus, the optimal control theory programs (FCS-3, -6, and -7) and the generalized inverse technique (FCS-4 or FCS-5) will be used as an aid to parameter sizing. However, the criteria and the emphasis of elastic modes make this block differ from block IV-5. The strategy is to increase the flutter speed as much as possible without introducing stability problems. Sensor location and control surface size and location are critical considerations. Due to these complexities, manual intervention is required in the synthesis process. In particular, classical controls methods of FCS-1 or FCS-2 will be used for the majority of the synthesis effort. Note that FCS-1 requires a development of Nyquist and Bode techniques for accommodating the frequency-dependent (complex coefficient) flutter matrices.

The equations of motion formed for the flutter analysis (block IV-35) can also be used for the flutter suppression system work. However, equations of motion based upon quasi-steady aerodynamics combined with the Wagner function may also be used. This latter set will be used for cost considerations.

Block IV-37. Proposed Fix--Goal: Determine changes on configuration geometry, mass, or stiffness for flutter clearance.

The critical flutter conditions identified in design network block IV-38 will be analyzed to appraise flutter mechanism using an energy display approach (SFL-13). Parametric flutter trend studies on stiffness changes, and mass changes for each geometry change (if any) will be conducted to determine how the flutter deficiencies should be removed. When a portion of the structure is to be changed, the mass and stiffness matrices of only those substructures affected by the change are recalculated and merged with the unchanged substructures (SFL-21). These trend studies are performed through the design network (blocks IV-35, -38, -39, and -37). This loop is terminated when the desired flutter clearances are achieved.

Block IV-38. Flutter Analysis--Goal: Evaluate flutter boundaries of the refined configurations.

Flutter boundaries of the refined configurations will be determined over the flight envelope by the same solution methods used in design network block III-24.

Block IV-39. Flutter Criteria Met?--Goal: Determine whether the flutter criteria have been satisfied.

This decision is manual. If flutter deficiency exists, improvements will be made by 1) geometry, mass, or stiffness change or 2) by active flutter suppression system. A decision will be made whether 1) or 2) or both should be used to satisfy flutter requirements.

Block IV-40. Geometry Change?--Goal: Determine if a configuration change is required for flutter clearance.

This decision is manual. Geometry changes in terms of modifications to existing main lifting surfaces, control surfaces, or addition of new control surfaces may be the results of the design network (blocks IV-36 and -37). If the geometry change is required to clear flutter, the design flow will return to the start of level III.

Block IV-41. Use Flutter Suppression System?--Goal: Decide whether or not to use an active flutter suppression system.

The flutter suppression system synthesis is described in block IV-36. The decision is manual and involves considerations of benefits, risk, cost, complexity, and weight.

Block IV-42. Update FCS--Goal: Resize the flight control components for weight considerations.

The additional components required for the flutter suppression system will be estimated. A computer program development is required (FCS-12).

Block IV-43. Change Stiffness?--Goal: Determine whether structural stiffness change should be made for flutter clearance.

This decision is manual. If the stiffness increase (identified in the design network block IV-37) over the strength and fatigue sizing is to be made to clear flutter, the required stiffness will be provided for design network block IV-44. If the answer to the question is no, design network block IV-45 will be executed and any mass change required for flutter clearance will be input, only when it was identified in block IV-37.

Block IV-44. Update Structural Sizing--Goal: To identify flutter-prescribed resizing for updating the primary structure weight and to establish minimum size constraints for all further strength and fatigue design activities.

If a stiffness (sizing) increase over the strength and fatigue sizing is required to meet the flutter criteria, the sizing required is identified and updated. For all skin and web gage increases, the stiffening material will be compared to the minimum allowable stiffening material and increased if required. Flutter-prescribed sizing will be considered to be minimum size constraints in all further strength and fatigue sizing activities.

Block IV-45. Update Weights, Balance, and Loadability (Type C)--Goal: To calculate type C weight, balance, and loadability for the configuration which has been sized for strength, fatigue and flutter. To accomplish this involves technical program elements that:

Execute weights update control (WTS-15) that would re-execute only those portions of the weights technical program elements whose input had changed

SUPERSONIC A/C (cont'd.)

Update wing primary structure mass elements based on stress-sized skin/stringer material (WTS-21)

Update body/empennage primary structure mass elements based on stress-sized skin/stringer material (WTS-21)

Update wing secondary structure mass elements (WTS-18)

Update body/empennage secondary structure mass elements (WTS-19)

Update fuel mass elements (WTS-11)

Accumulate mass elements within each structural panel and the calculation of weight, center of gravity, and inertia for each structural panel and for the wing, body, and empennage (WTS-12)

Generate a weight statement patterned after the AN 9102-D format based on the previously updated mass elements (WTS-13)

Calculate total airplane mass properties for various points on the balance diagram and determine updated panel mass properties for recycling through the structural analyses (WTS-14)

There will be no updating of the flight control system weights until the effects of the flight control system changes can be reflected in the other airplane systems analyses (block IV-22). Therefore the flight control system weights will be updated in block IV-23.

Block IV-46. Loadability/OEW Criteria Met?—Goal (1): To compare the OEW which is calculated by the weights analysis (block IV-45) and the required OEW as sized by the mission analysis (block III-3) and determine whether the difference between the OEW's is within acceptable limits. If the difference is too great, the geometry module (block III-2) will be required to resize the configuration. The required changes are man-controlled in level IV.

Goal (2): To compare the available forward and aft center-of-gravity limits, as determined by the stability and control analysis (block IV-6) and the required forward and aft center-of-gravity balance and loadability limits as determined by the weights analysis (block IV-45). If the difference between the required and available center-of-gravity limits is too great, the geometry module (block III-2) will be required to resize the empennage. If the OEW cg position does not result in acceptable airplane balance, the geometry module (block III-2) will be required to adjust the position of such items as the wing and gear relative to the body. The required changes are man-controlled in level IV.

<u>Block IV-47. Entered H From J?</u>--This is a computer decision. The decision in block IV-60 to do flutter analysis requires a recycle through equations of motion (block IV-35) and subsequent events (blocks IV-38 through -46) but no recycle of events (blocks IV-48 through -60) which are primarily updated analyses.

<u>Block IV-48. Equations of Motion</u>--Goal: To establish the equations of motion prior to investigating the dynamic loads and ride quality.

The unaugmented quasi-steady equations of motion generated in block EM-11 are a set of theoretical equations with experimental corrections incorporated into them to more realistically represent the actual airplane. This block will incorporate the SAS system into the equations of motion using technical program element SDL-2. The flight conditions for which the equations of motion are to be generated will be manually selected to be adequate for the dynamic loads block IV-49.

<u>Block IV-49. Dynamic Loads and Ride Quality Evaluation</u>--Goal: The purpose of this element is to provide design loads to size the structure of the airplane. However, the many facets in providing these loads requires the skill of experienced dynamists.

To provide design flight gust loads, it is necessary to pick points on the flight envelope in terms of altitude, speed, payload, and fuel loading which may produce the maximum dynamic loads on any selected location of the aircraft. The first step is to check the stability (SDL-3) of the equations of motion (block IV-48). Then, the equations of motion and load equations generated from data of block EM-10 must be analyzed by a discrete gust analysis (SDL-6), a statistical PSD gust analysis (SDL-4) using the design envelope approach, and a statistical gust analysis for a typical mission profile using programs SDL-4 and SDL-5. Fatigue sizing of the aircraft also requires a mission profile gust analysis that generally has a lighter payload than in the design envelope analysis. The mission profile is the average payload and fuel distribution that would be experienced during an average mission that the airplane is designed for. The design envelope and discrete gust approach use the most extreme loadings possible to obtain the highest loads on the airplane. The gust profile considered must be both vertical and lateral gusts considered independent of each other.

The ride qualities should be evaluated at this time in terms of lateral and vertical accelerations along the body. Until an absolute criterion is developed, the ride qualities would have to be compared quantitatively with existing aircraft.

The design ground loads would be caluclated with a dynamic math model simulating both a landing impact and a taxi analysis (SDL-7) on various measured runways around the world. The ride qualities during taxi would also be evaluated at this time.

Block IV-50. Determine Thermal Effects--Goal: To predict the effect of thermal heating on the aircraft's primary structure.

This estimation will be done by STR-18 for two missions, namely the intended design mission and the design mission with an emergency descent. The result of the estimation will be the temperature history of the aircraft's primary structure.

Block IV-51. Structural Analysis for Strength and Fatigue--Goal: To determine the margins-of-safety (strength and fatigue) of the previously sized detail structural elements for the dynamic load conditions of block IV-49.

For the primary structural sizing established in block IV-28 and as updated by block IV-44 for flutter, stress analyses are performed for the dynamic load conditions of IV-49. The capability to perform analysis only (without resizing) to obtain margins-of-safety is inherent in STR-3, -4, -5, -6, etc. Therefore, analysis, rather than design, is used to obtain the computational cost savings available when no negative margins-of-safety exist for the dynamic load conditions and when the flexibility and weight changes, if any, since the last static loads calculation (block IV-28) are too small to produce a significant change in the static loads. It should be noted that the cost of an analysis is estimated as one-third (or less) that of a design sizing. Further, there should be very few dynamic load conditions compared to the number of static load conditions.

Block IV-52. Negative Margins-of-Safety?--Goal: Computer decision to determine whether the dynamic load conditions are critical for any of the previously sized detail structural elements.

Block IV-53. Airplane Static Loads--Goal: Calculation of load distributions on the major airframe components resulting from design conditions (static and gust formulae) and a fatigue mission profile.

Static loads for a supersonic configuration would be generated using a panel representation of the airplane. The method used is based on Woodward's lifting surface method. Matrix methods are used to solve simultaneous linear equations for loads, deflections, accelerations, and stability derivatives. The current program (SLO-4) computes unit and balanced load solutions for symmetric maneuvers of a rigid or flexible airplane. Integrated panel loads along a user-defined axis give shear, moment, and torsion.

This program forms the loads module within the ATLAS system (STR-6).

Flight condition data would be input by a knowledgeable user.

Any requirements for loads on secondary structure would be met by hand calculations based on data from a similar past configuration.

Block IV-54. Determine Thermal Effects--Goal: To predict the effect of thermal heating on the aircraft's primary structure.

This estimation will be done by STR-15 for two missions, the intended design mission and the design mission with an emergency descent. The result of the estimation will be the temperature history of the aircraft's primary structure.

Block IV-55. Structural Sizing for Strength and Fatigue--Goal: To modify the preliminary detailed sizing of the primary structure for strength and fatigue (fail-safe design) for critical dynamic load conditions and revised static loads resulting from structural flexibility changes.

Using the structural definition (geometry and sizing) established in block IV-28, with the sizing as updated by block IV-44, the primary structure is resized for strength and fatigue for fail-safe design (STR-3, -4, -5, -6, etc.). Static load condition data and the corresponding thermal effects from blocks IV-53 and IV-54, respectively, are used in conjunction with the dynamic load condition data (block IV-49) and the corresponding thermal effects (block IV-50) for the resizing. The sizing activities performed parallel those of block IV-28.

Block IV-56. Flexibility Change Significant--Goal: A computer or man decision on the significance of the change in flexibility.

Loads are calculated for a given flexibility; the resulting strength designed structure is sized; and a new flexibility is calculated. If the change in flexibility is such that a significant loads change would result, the loads sizing routines (blocks IV-53 and -55) are repeated.

If the change is not significant, the resulting structure is weighed (block IV-57).

Block IV-57. Update Weights, Balance, and Loadability (Type C)--Goal: To calculate type C weight, balance, and loadability for the configuration which has been sized for strength, fatigue, flutter, and dynamic loads. To accomplish this involves technical program elements that:

Execute weights update control (WTS-15) that would re-execute only those portions of the weights technical program elements whose input had changed

Update wing primary structure mass elements based on stress sized skin/stringer material (WTS-21)

Update body/empennage primary structure mass elements based on stress sized skin/stringer material (WTS-21)

Update wing secondary structure mass elements (WTS-18)

Update body/empennage secondary structure mass elements (WTS-19)

Update fuel mass elements (WTS-11)

Accumulate mass elements within each structural panel and calculate of weight, center of gravity, and inertia for each structural panel and for the wing, body, and empennage (WTS-12)

Generate a weight statement patterned after the AN 9102-D format based on the previously updated mass elements (WTS-13)

Calculate total airplane mass properties for various points on the balance diagram and determine updated panel mass properties for recycling through the structural analyses (WTS-14)

There will be no updating of the flight control system weights until the effects of the flight control system changes can be reflected in the other airplane systems analyses (block IV-22). Therefore, the flight control system weights will be updated in block IV-23.

Block IV-58. Panel Mass/Intertia Change Significant?--Since the loads analyses are sensitive to panel mass properties, each time the weights analyses update the panel's mass, center of gravity, and inertia, the effect of these changes on the loads analyses should be examined. If the panel mass property changes are significant, the loads and the structural analyses should be examined.

<u>Block IV-59. Loadability/OEW Criteria Met?</u>--Goal (1): To compare the OEW which is calculated by the weights analysis (block IV-57) and the required OEW as sized by the cruise performance analysis (block III-3) and to determine whether the difference between the OEW's is within acceptable limits. If the difference is too great, the geometry module (block III-2) will be required to resize the configuration. The required changes are man-controlled in level IV.

Goal (2): To compare the available forward and aft center-of-gravity limits as determined by the stability and control analysis (block IV-6) and the required forward and aft center-of-gravity balance and loadability limits as determined by the weights analysis (block IV-57). If the difference between the required and available center of gravity limits is too great, the geometry module (block III-2) will be required to resize the empennage. If the OEW c.g. position does not result in acceptable airplane balance, the geometry module (block III-2) will be required to adjust the position of the wing and gear relative to the body. The required changes are man-controlled in level IV.

<u>Block IV-60. Do Flutter Analysis?</u>--Goal: Determine whether further flutter analysis is required.

Manual decision is made to determine whether further flutter analysis should be performed to ensure the proper flutter-free performance of the newly derived configuration with strength design in which dynamic loads and ride quality effects are included.

If the answer to the question is yes, the design flow will go back to design network block IV-35. Otherwise, the configuration will be ready for flight control system synthesis and analysis (through design network blocks IV-62 and -63).

<u>Block IV-61. Start Transonic Flutter Wind Tunnel Model?</u>--Goal: Determine whether design of transonic wind tunnel flutter model should start.

Manual decision will be made here to determine the start of transonic wind tunnel flutter model design. Due mainly to the uncertainties of the theoretically predicted unsteady airloads at transonic, high subsonic, and low supersonic regimes, a transonic wind tunnel flutter model testing program is always required. Once the go-ahead decision is made, the design of the model will begin in blocks V-11 and -12. The start of model design at this event will provide some lead time before a go-ahead in level V.

Block IV-62. Equations of Motion: Quasi-Steady Option--Goal: Develop the equations of motion to be used for flight control system work.

The equations of motion consist of the rigid body modes and about ten elastic modes. Two basic sets of data are produced, namely longitudinal axis equations and the lateral-directional axis equations. Approximately ten operating points are required to cover the flight envelope. Quasi-steady aerodynamics are sufficient for the flight controls problem. Estimates of control surface and actuator dynamics will be adequate at this stage in the design process.

Block IV-63. Flight Control System Synthesis and Analysis - Elastic Body Modes--Goal: Re-examine the flight control system using elastic body modes and modify the control system as needed.

The previous handling qualities control system work (block IV-5) is performed using simplified rigid body equations of motion. Although elastic modes were not used in block IV-5, the static aeroelastic effects were simulated and the gains and compensation networks were tempered to anticipate higher frequency dynamics. It is anticipated that flight control system modifications will be minor. If the flight control system criteria are not satisfied due to presence of elastic modes, the situation will be examined after the end of the level IV computational activity. The decision will then be whether to press for more control system refinements or to modify the airplane or flight envelope.

Block IV-49 evaluated the ride quality of the airplane. If ride improvement is required, a ride quality stability augmentation system (RQSAS) will be developed at this point.

Computational activity will be similar to block IV-5. Technical program elements FCS-1 through FCS-7 may be required. As is the case with the flutter suppression system synthesis (block IV-36), the elastic modes will require more manual intervention and more emphasis on classical controls techniques (FCS-1 or FCS-2). The flight control system hardware will be resized by use of FCS-12.

Block IV-64. Do Dynamic Loads Analysis?--Goal: Man decision to determine whether any significant changes in weight, flexibility, and flight control system synthesis have been made to the system from blocks IV-50 to IV-63 that would affect dynamic loads.

Block IV-65. (1) Manufacturing Review--Goal: To provide operations with design concepts to the extent that company resources can be reviewed and the preliminary manufacturing plan prepared.

Operations must initiate program planning in conjunction with the product technical definition. Based on itemized work statements, the initial make-or-buy and manufacturing plans are developed. Concurrently, available in-house resources are reviewed for compatibility in time and suitability.

(2) Establish Plans and Schedules--Goal: To provide operations, marketing, and finance with initial plans and scheduling information.

Initial planning will include estimates of the engineering release schedule, configuration verification test plan, and manufacturing schedule.

(3) Identify Long Lead Items--Critical long-lead items (e.g., engines, forgings, etc.) will be identified and procurement criteria established.

Block IV-66. Summarize Performance--The design refinement of level IV has been completed. The performance will be summarized by use of PRF-5, finance and cost considerations by FNC-1, and the market suitability predicted by MKT-4, -5, and -6. The effect of schedules on cost will also be assessed by FNC-2, -3, and -4.

The marketing analyses will be supported by an evaluation of the total system in the operational environment within the level of definition available.

Simulation models REL-1 and REL-4, will evaluate interactions, major influences, controlling parameters, special features, and characteristics affecting utilization dispatch reliability, maintenance, and logistics facilities. Cost variables such as fleet size, route structure, scheduled flight time, and ground time are used to assess each change in configuration or design and to evaluate strengths and weaknesses of each airplane in operational environments.

Block IV-67. Will Engine be Available for Product?--Goal: Determine whether the engine availability schedule is compatible with the airframe manufacturing and delivery schedule.

This decision will be manual and will determine whether the airframe manufacturing and delivery schedule allows sufficient lead time for the engine development.

Block IV-68. Technical Review to Determine Next Action--Goal: Determine next action if the engine availability test (IV-67) is negative.

This management-level review will be to decide on further action should the current airframe schedule allow insufficient lead time for engine development.

Block IV-69. Configuration Acceptable?--Goal: This is a man decision based on a review of all tasks undertaken in level IV. To be acceptable means that no reason is found to prevent the design from proceeding to level V.

Block IV-70. Stop Wind Tunnel Model--Goal: In the event that the configuration review in block IV-69 is found to be unacceptable, the design of the cruise shape wind tunnel model and transonic flutter model should stop.

Block IV-71. Start Wind Tunnel Model?--Goal: This event is a man decision to start the design of the cruise shape wind tunnel model and transonic flutter model, if not already in work. The decision is influenced by a management review to commit the IPAD configuration design cycle into level V.

Block IV-72. Wind Tunnel Model Started?--Goal: This event is a man decision to determine whether the design of the wind tunnel models has commenced.

Block IV-73. Modify Configuration or Mission --There are two options from a negative result in block IV-69. The designer may elect to retain the design mission and criteria and return to the beginning of level III to resize, using different sizing rules, or the designer may return the design sequence to level II to evaluate the effects of an alternate design mission.

Block IV-74. Technical Review to Determine Next Action--Goal: This event is a review of the total airplane design by a technical review committee to assist the management decision on the next course of action.

6.3.3.5 Network Activities for Levels V, VI, VII, VIII, and IX

The detail networks at levels V through IX for project 2 (supersonic aircraft design) are identical to those for project 1 (subsonic aircraft design) and are not repeated here. Refer to section 6.2.3 for the descriptions of these networks as noted below:

SUPERSONIC A/C (cont'd.)

See section 6.2.3.5 for network activities description of level V, Configuration Verification.

See section 6.2.3.6 for network activities description of level VI, Product Detail Design.

See section 6.2.3.7 for network activities description of level VII, Product Manufacture.

See section 6.2.3.8 for network activities description of level VIII, Product Verification.

See section 6.2.3.9 for network activities description of level IX, Product Support.

6.4 OTHER VEHICLES

6.4.1 NAVAL HYDROFOIL

A brief study was made of a naval hydrofoil that is intended primarily for patrol and antisubmarine assignments. The ship is powered by a water-jet system, both when hullborne and when foilborne. This study was made because it is not an aircraft geometry yet is a complex, highly integrated vehicle for which considerable experience was available locally within The Boeing Company. Brief design networks for product levels II, III, and IV were established, with the result that the hydrofoil fit the product levels concept as well as did projects 1 and 2. The required technical program elements were not collected and the computing resources required to support this project were not identified. However, the naval hydrofoil evaluated is considered smaller in required computing resources than project 1.

6.4.1.1 Design Networks

The design and analysis network indicating the design tasks for the military hydrofoil is shown on figures 68 through 71. The product levels shown are level II, design criteria selection; level III, configuration sizing; and level IV, configuration refinement. A narrative description follows the networks.

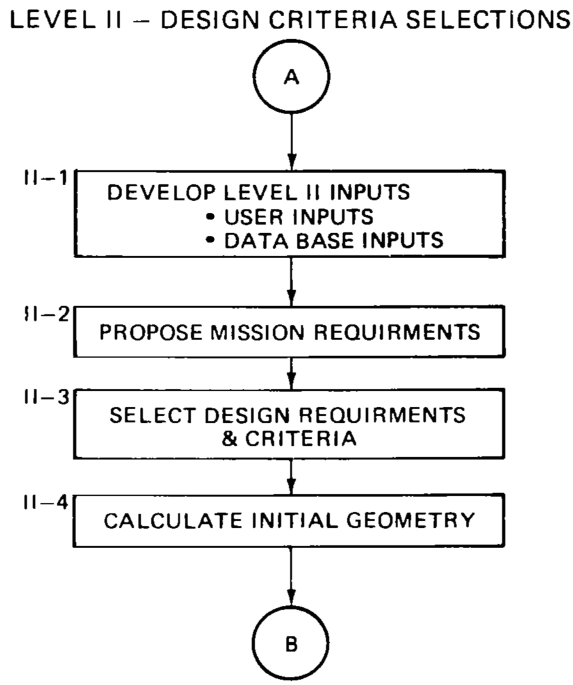


Figure 68.—Design Networks: Naval Hydrofoil, Level II

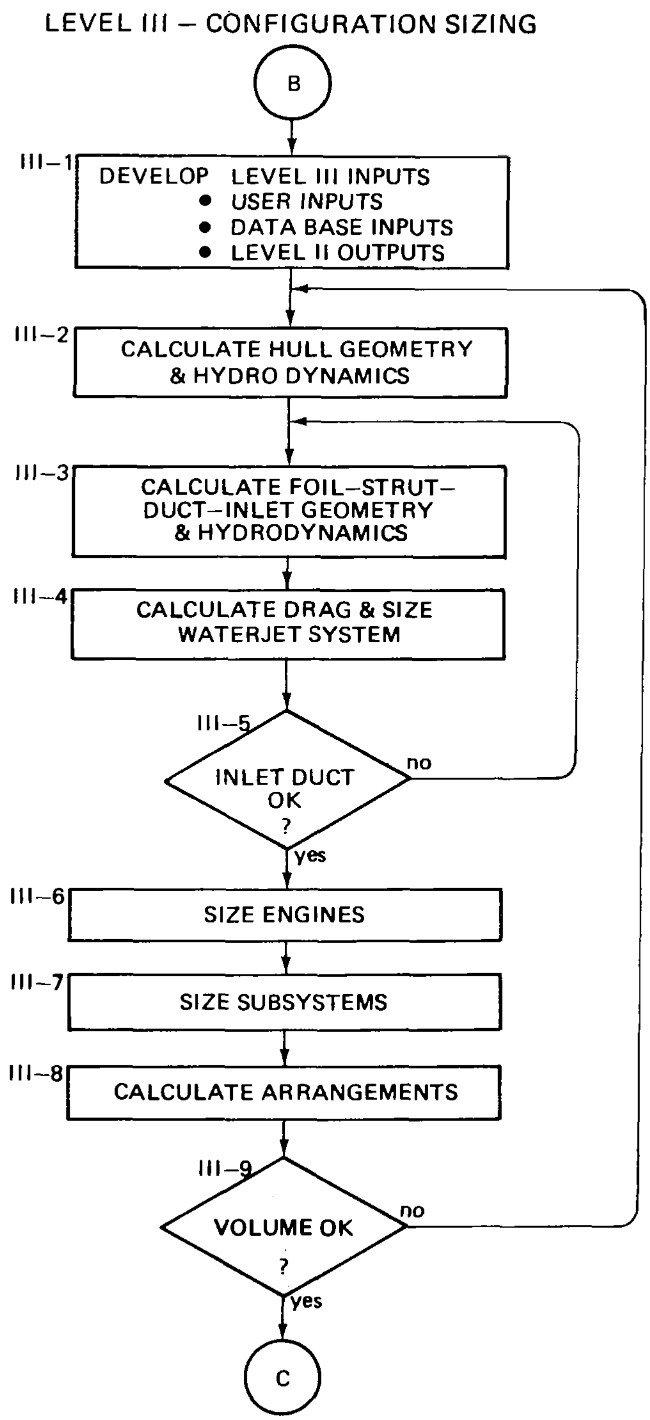


Figure 69.—Design Networks: Naval Hydrofoil, Level III

LEVEL III – (Continued)

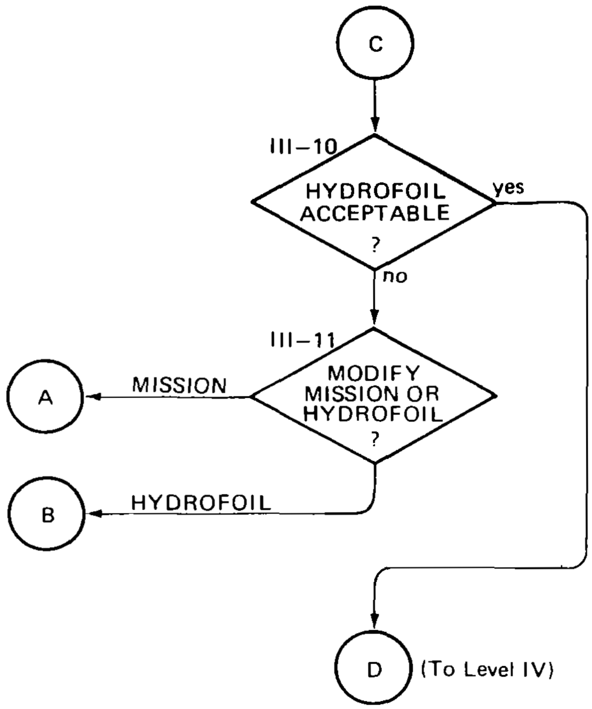


Figure 70.– Design Networks: Naval Hydrofoil, Level III (Continued)

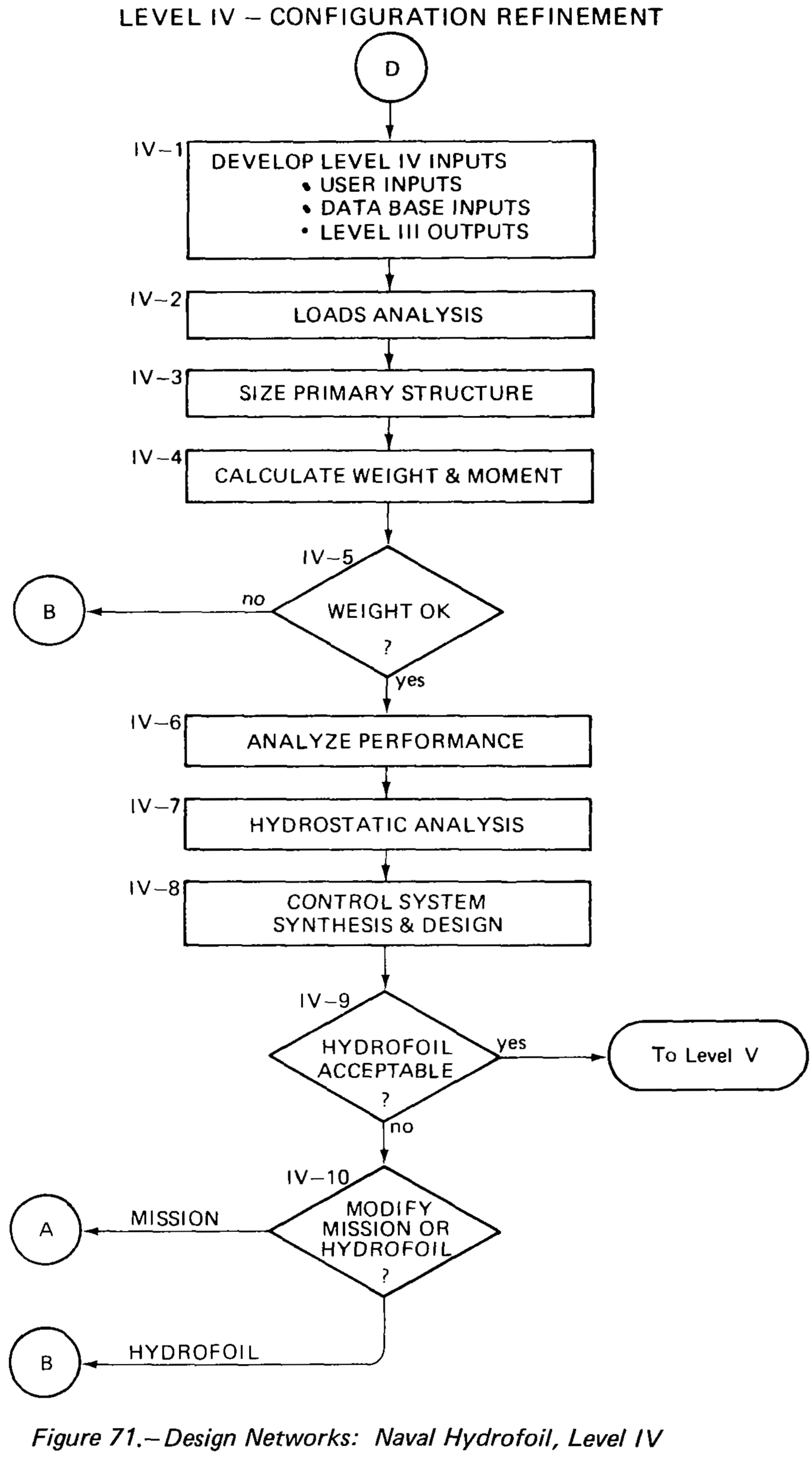


Figure 71.–Design Networks: Naval Hydrofoil, Level IV

6.4.1.2 Network Activities Descriptions

Level II Design Criteria Selection--The goal of level II is to select the design mission and criteria for the subsequent design. Some very brief analysis and design logic will be required to support the selection of these criteria.

Block II-1. Develop Level II Inputs--The data stream for this project begins with level II. The initial inputs will be derived from two sources. The user will provide specific inputs such as the problem constraints, performance requirements, and technology time period. The last item will point to groups of data in the data base required to support the various technical disciplines. Level II is intended to be executed without interruption; therefore, all the inputs required for level II should be given at the beginning.

Block II-2. Propose Mission Requirements--The mission requirements of payload volume and weight, endurance, speed, range and maneuverability are specified. These will be analyzed for comparison against the principal design threat.

Block II-3. Select Design Requirements and Criteria--Given the above statement about the design mission, design requirements are stated or calculated covering takeoff weight, stability, foilborne impact damage, structural criteria and materials, hull types, etc. Some of this information will be user-supplied and some will come from the technology base.

Block II-4. Calculate Initial Geometry--The initial geometry design and interior arrangements will be done to the selected design criteria with building blocks of information. Typical information includes the parent hull shape, foil-strut-duct arrangement, foil section and shape, engine model, pump model, location of decks, bulkheads, major components, etc. These data will guide the subsequent design process.

Level III Configuration Sizing--The goal of level III is to size candidate configuration to the design mission and criteria. The sizing logic should be constructed to be executed with minimal user intervention.

Block III-1. Develop Level III Inputs--The development of inputs for level III will be similar to level II for the categories of user and data base information. However, in many cases a level III execution will begin from a level II solution. In these instances, the preparation of information required by level III from level II results is to be done by automatic processes. These default calculations will be approved and corrected by the user prior to execution of level III.

It will be desirable, but not necessary, to execute level III without interruptions, so that the input information for the entire execution should be available at the beginning. The user may monitor the solution, especially in cases where optimization is being done, to interrupt, correct, then restart a solution.

Block III-2. Calculate Hull Geometry and Hydrodynamics--This activity will produce a hull shape (hull lines) from the parent hull geometry. The design rules will develop a hull that satisfies the current volume constraints; then the load capability, drag, and righting moments of the hull while waterborne are determined.

Block III-3. Calculate Foil-Strut-Duct Inlet Geometry and Hydrodynamics--The foils are sized to provide the required lift. The strut is sized to contain the duct carrying the water to the pump for the waterjet and to satisfy stiffness criteria. The inlet geometry is fitted to the strut-foil intersection. The lift, drag, and moment characteristics of the total foil-strut-inlet geometry are predicted.

Block III-4. Calculate Drag and Size Waterjet System--The total drag of the configuration, both hullborne and foilborne, is determined. The internal drag of the waterjet ducts is predicted. This allows a calculation of the required thrust for takeoff, hullborne, and foilborne conditions. The maximum thrust required gives the design mass flow of water, which is used to size the waterjet pumps.

Block III-5. Inlet Duct OK?--In block III-3 and -4, an inlet duct was assumed (first pass) or determined by previous analysis (other than first pass). With the mass flow of water determined in block III-4, the flow velocity in the inlet ducts can be determined. If the velocity is too high, the ducts will have to be resized and the solution must return to block III-3.

Block III-6. Size Engines--The hullborne an foilborne engines (if different) are sized to the requirements established in the earlier Blocks.

Block III-7. Size Subsystems--The various ship subsystems (hydraulic, electrical, pneumatic, etc.) are sized to support the design mission and its requirements.

Block III-8. Calculate Arrangements--Now that all the subsystems, engines, and pumps have been sized, an interior arrangement is calculated. These items are placed in the hull, then the stores (fuel and supplies) are calculated and the arrangement is completed by finding space for these and for the remaining deck arrangements.

Block III-9. Volume OK?--This is an automatic decision, unless the user might wish to attempt an arrangement himself. If there is not sufficient volume, the design process must return to block III-2 to enlarge the hull and resize the design. Also, if the current design has too much volume, the design may return to block III-2 to scale down the hull.

Block III-10. Hydrofoil Acceptable?--This is a user review of a correctly sized configuration. The design modules may produce a design that would be unacceptable for some unusual reason. If the hydrofoil is acceptable, design proceeds to level IV.

Block III-11. Modify Criteria for Hydrofoil?--There are two options from a negative result in block III-10. The user may elect to retain the design mission and criteria and return to the beginning of level III to resize, using different sizing rules this time. On the other hand, the hydrofoil configuration sized by level III, although unexpected, may have some desirable features. The user may return the design sequence to level II to alter the design mission and criteria in order to introduce some of these desirable features of the current design.

Level IV Configuration Refinement-- The goal of level IV is to refine a configuration by applying more advanced analysis methods to the design.

Block IV-1. Develop Level IV Inputs--The design and analysis activities of level III have enriched the data base about the configuration. These new data, as well as criteria and constraints from level II, will be put into forms suitable for the level III analysis methods. This action will be supported primarily by the IPAD data base manager. Additionally, user inputs and information from the data base not previously required will be established. This activity is shown symbolically at the head of level IV, but due to the interactive nature of level IV, the data preparation activity may be done selectively throughout level IV.

Block IV-2. Loads Analysis--Detailed hydrodynamic loads are determined in various sea states for waterborne and foilborne conditions. Impact loads are estimated.

Block IV-3. Primary Structural Sizing--The hull and foil primary structure is sized to the loads developed above. Beam theory will be used where possible, but finite element analysis will be used for the more critical areas.

Block IV-4. Calculate Weight and Moment--The hydrofoil weight and moments can be determined with good reliability now that the hull size, systems, and structure are all sized together. This weight determination will use primary weights by analysis, with statistical weights for secondary structure other than known components.

Block IV-5. Weight OK?--A preliminary weight estimate was made back in block III-8 in order to calculate the fuel required. If that weight estimate is not in close agreement with the more accurate estimate of block IV-4, the design sequence must return to the start of level III for resizing.

Block IV-6. Analyze Performance--The performance of the configuration may be accurately determined now that the configuration is sized and the weight is determined for the sized structure.

Block IV-7. Hydrostatic Analyses--The static stability of the hydrofoil is predicted for the intact geometry, damaged geometry, and effect of wind loads.

Block IV-8. Control Analysis--The control system for the foils will be synthesized and analyzed for directional stability, controllability, and sea state response. The hydraulic requirements to actuate the control system will be established.

Block IV-9. Hydrofoil Acceptable?--The designer, with system support, will review the hydrofoil and determine whether it is suitable for continued work in level V.

Block IV-10. Modify Criteria or Hydrofoil?--There are two options from a negative result in block IV-9. The designer may elect to retain the design mission and criteria and return to the beginning of level III to resize, using different sizing rules this time. On the other hand, the hydrofoil configuration refined by level IV may have some desirable features. The designer may return to level II to alter the design mission and criteria in order to introduce some of these desirable features of the current design.

6.4.2 MILITARY AIRCRAFT

No specific study was made of military aircraft; however, they are similar to the commercial aircraft studied, and the following comments apply.

6.4.2.1 Military Transport Aircraft

Tanker, cargo, and passenger aircraft will be identical to the project 1 subsonic transport except where military criteria differ from Federal Aviation Regulations and commercial aircraft design standards.

6.4.2.2 Military Tactical and Strategic Aircraft

Subsonic and supersonic military aircraft will be similar to project 1 and project 2 aircraft; however, new sizing geometry modules for levels II and III are required. These modules must respond to the military mission and design criteria.

6.5 GATHER INFORMATION

6.5.1 DEFINITION

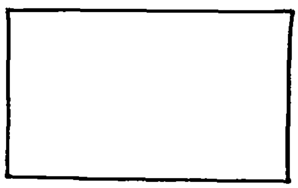
Throughout the design process, from concept to the final detail design, at each individual task, the first requirement is to determine what information is needed to perform the task (data processes). The second requirement is to get that information together, which takes as much as two-thirds of the design time.

This section deals with the process of gathering a piece of information. In the process of design, it may be used many times for a single task.

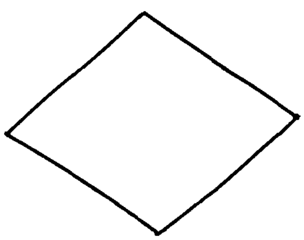
6.5.2 ACTIVITY NETWORK

Figure 72 diagrams the activities involved in the beginning task, "gather information." The network begins when a task is assigned or assumed. The following information is pertinent to the networks:

Network Blocks:



Activity or Event*



Decision

*Any activity which has a "do" connotation, such as: display, develop, revise, etc., includes the "Gather Information" network described in section 6.5.

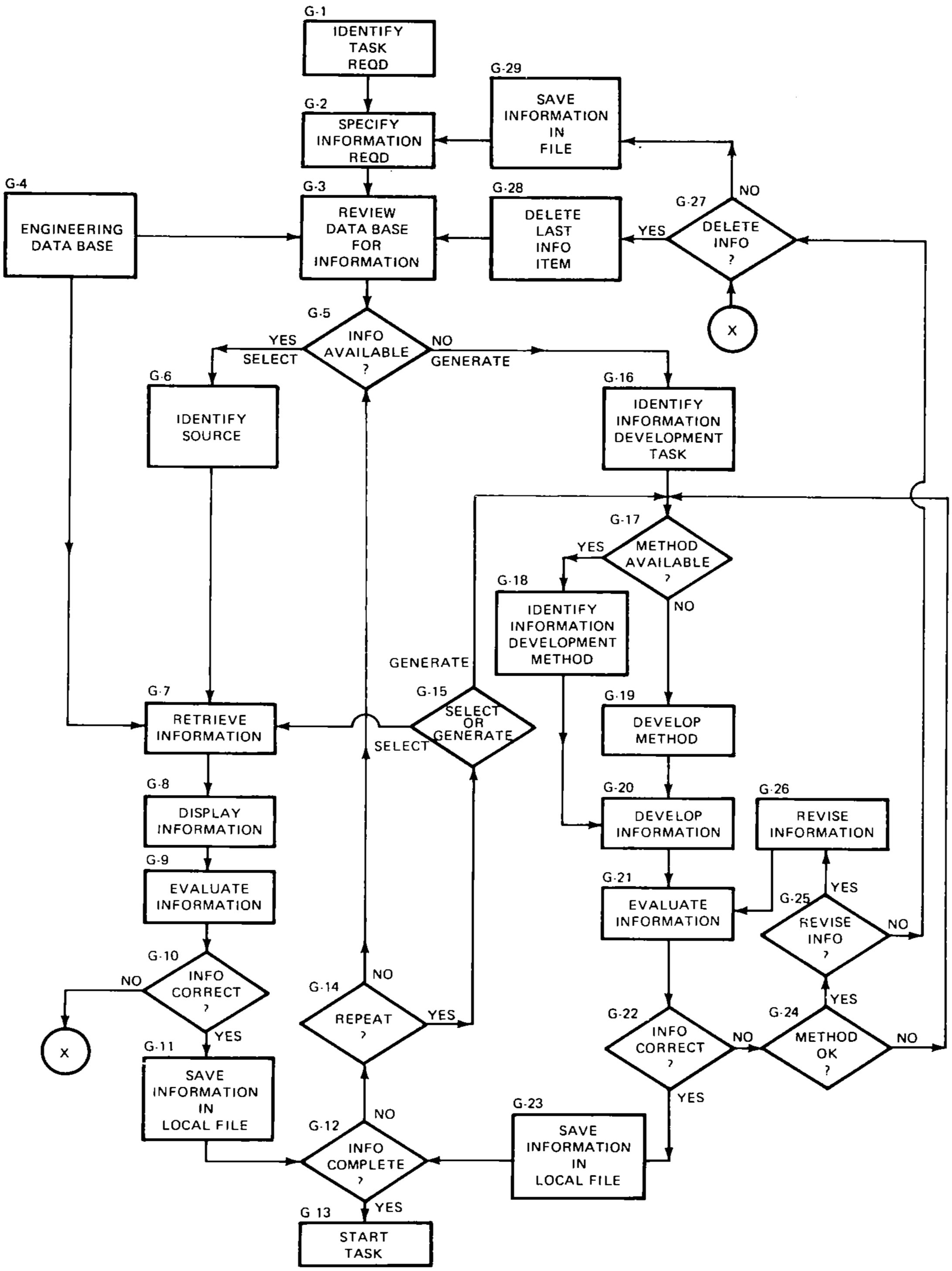


Figure 72.–Gather Information Network–Design

6.5.3 NETWORK ACTIVITIES DESCRIPTION

The purpose is to describe the gather information process network shown in figure 72.

Block G-1. Identify Task Required--The first question to be answered is "What is the task?" If the task is not defined, this is a "gather information" task in itself.

To identify a particular task (assuming it relates to design project), the user should:

Read the work breakdown structure (WBS) description of the structural element to be designed

Read the design requirements and objectives document

Read the design criteria

Read applicable design guides

Review structural arrangement developed in task III-12

Review structural layouts developed in task V-11

Read FAA rules and regulations from FAR, part 25, for commercial transport design

Read schedule and evaluate manpower requirements

Block G-2. Specify Information Required--Having identified the task, it then becomes necessary to identify what is needed to begin design. The following list includes some pertinent considerations.

Surface definitions: external/internal contours
Location of adjacent structure, interfaces
Location of systems provisions, interfaces
Loads and loadcases
Durability requirements
Structural element and joint concepts
Approved fastener lists and standards
Material allowables and strength data
Process and fabrication specifications
Finish and sealing documents

Block G-3. Review Data Base--Search data base contents for all information specified above. This information is both project-dependent and/or general in nature, and it will be found in both group and private files.

Block G-4. Data Base--This file is for retention of both general and specific information of interest to engineering, particularly data necessary for new product development.

The general type of information which is quite static or unchanging is exemplified by the following:

Unit conversions
Material allowables
Process specifications
Environmental conditions
Structural properties

General information which is less static than the above is:

Design criteria
Design guides
Standard parts

Relatively specific information which is frequently changed is:

Configuration loft geometry
Structural arrangement
External loads
Structural concepts
Systems Requirements

Block G-5. Information Available?--Determine the availability of each piece of information required above. If available, selection should be made; if not, the information must be generated.

Block G-6. Identify Source--For each information item found to be available, the source must be identified.

Block G-7. Retrieve Information--Search the data base at sources indicated in block G-4 above for the specified information.

Block G-8. Display Information--Display information formatted for the best understanding of the task at hand. Combine alphanumeric and graphic displays as required.

Block G-9. Evaluate Information--Review each information item retrieved from the data base for completeness, accuracy, and appropriateness.

Block G-10. Information Correct?--For each piece of information evaluated above, determine whether it is sufficiently accurate for use in the design. Does it have a sound basis for credibility, and does it satisfy the needs of the design problem?

Block G-11. Save Information for Local Data File--Retain the information selected or generated as part of a local file for future use in development and synthesis of the design.

Block G-12. Information Complete?--Determine whether all of the information needed to develop the design has been collected.

Block G-13. Start Design--At this block (any "do" block in any network), all of the conformation is available and the design task can start. This block requires such action items as develop, draw, calculate, update, etc.

Block G-14. Repeat?--Determine whether another information item, similar to that just generated, should be selected or generated exactly in the same manner as the last information item. When it is decided that more information is required using the same methods, the progression is to block G-15, where the choice is made.

Block G-15. Select or Generate?--The choice made here is automatic, since it parallels the method used to secure the last information. If the choice is "select," the procession is to block G-7, "retrieve information" and if the choice is "generate," the progression is to block G-17, "method available?". Block G-17 will be described later.

Block G-16. Identify Information Development Task--At block G-5, when the decision is made that information is not available and must be generated, the next step is to define how each required information item is to be developed, which tasks must be accomplished, and with what data.

Block G-17. Method Available?--Determine whether the methods selected to perform the tasks required to develop the specified information item are available and appropriate. If the method is available, the progression is to block G-20, "develop information." If the method is not available, it must be developed. (See block G-19 below.)

Block G-18. Identify Information Development Method--Define which method is to be used for each task required to develop the specified information item.

Block G-19. Develop Method--Create a new process or alter an existing process which will, in the manner desired, produce the information item specified with the necessary accuracy. Write an algorithm.

Block G-20. Develop Information--Having developed a method in block G-19 above, create the specified new information item using the selected methods to accomplish the required tasks.

Block G-21. Evaluate Information--Review each information item developed for completeness, accuracy, appropriateness, and credibility.

Block G-22. Information Correct?--For each information item evaluated above, determine whether it is sufficiently accurate to be used in the design. Does it have a sound basis of credibility, and does it satisfy the needs of the design problem?

Block G-23. Save Information In Local Data File--Retain the information selected or generated as part of a local file for future use in development and synthesis of the design.

The progression is to block G-12, which is covered above.

Block G-24. Method Satisfactory?--For each information item found to be incorrect, determine whether the method used in its development is an acceptable process or algorithm.

Block G-25. Revise Information?--With the decision that the method (G-24) was proper but the information generated (G-22) is not usable, it must be decided whether the information can be revised.

Block G-26. Revise Information--Revise information items as required to obtain acceptable accuracy, completeness, and credibility.

Block G-27. Delete Information?--When it has been decided that the information developed (G-21) cannot be revised to be usable for the task, the next decision is its disposition. Has it value for some future activity and is it practical to store it, or is is better to delete the information and generate it at a future time?

Block G-28. Delete Last Information Item--When it is decided (G-27) that the last information item has no value now or for future activities, it is discarded.

Block G-29. Save Information on Local Data File--The information judged to have future use (G-27) is labeled and stored in the local file.

The progression continues until all generated and/or selected information has been gathered and accepted; then the task begins (G-13).

6.6 NETWORK FOR STRUCTURE DETAIL DESIGN

The level VI product detail design shown as activity network in 6.2.2 and 6.3.2 and described in 6.2.3.6 and 6.3.3.6 is a brief picture of a great deal of activity involving many people for an extended period of time.

The design analysis block VI-3 (see figures 37 and 60) listed 18 design areas. Since an in-depth study of the total design process would be an overwhelming task, a structures design and a system design are selected for detail design process studies. This section (6.6) concerns itself with the design process for structure design. (See figures 73 through 80 for system design network.)

6.6.1 STRUCTURAL DETAIL DESIGN DEFINITION

An aircraft body frame is selected for a structural detail design process study. This is necessary because an abstract discussion does not create a sufficiently clear picture to enable a large cross-section of people to visualize the design process involved.

Section 6.6.2 presents the activity network for designing a structural item: an aircraft body frame from preliminary design information. Section 6.6.3 describes the activities networks.

Three basic steps are inherent in the detail design process: a layout is made of the design; the design is evaluated; and detail production drawings of the design are made and released. Figure 73 provides an overview of the structural detail design process.

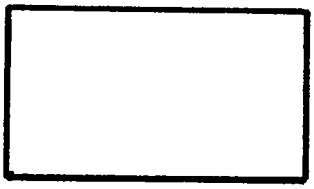
6.6.2 STRUCTURE DESIGN NETWORK

The detail design process is divided into three major activities: laying out the design, evaluating the design, and preparing and releasing the drawings. For convenience and visibility the detail networks and description will be identified with the Roman numeral VI, indicating level 6 of the detail design area (see section 6.2 and 6.3), followed by a letter A, B, or C indicating layout phase, evaluation phase, or drawing phase, respectively. The letter will be followed by consecutive numbers to identify the block.

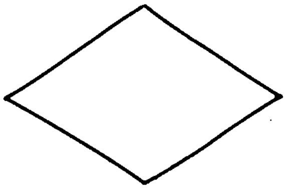
For example: VI B-3 indicates the activity is at level VI (detail design), block 3 (design evaluations phase).

The detail design network (level VI) begins where the decision has been made to commit the design to project status (sections 6.2.3.6 and 6.3.3.5). The following information is pertinent to the network:

Network Blocks:



Activity or Event*



Decision

* Any activity which has a "do" connotation, such as display, develop, revise, etc., includes the "gather information" network described in section 6.5.

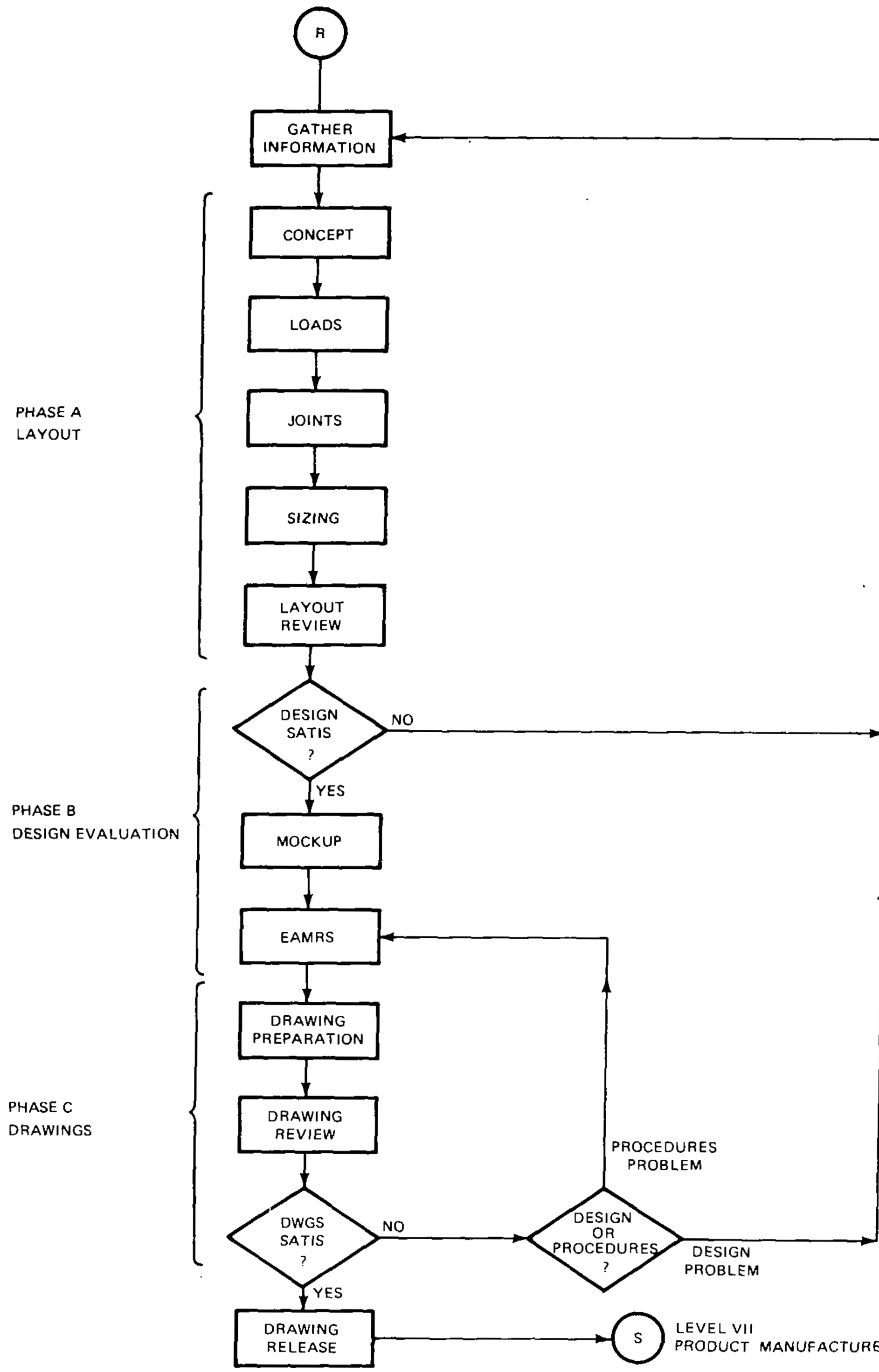


Figure 73.—Overview Network: Structural Detail Design (SDD), Level VI

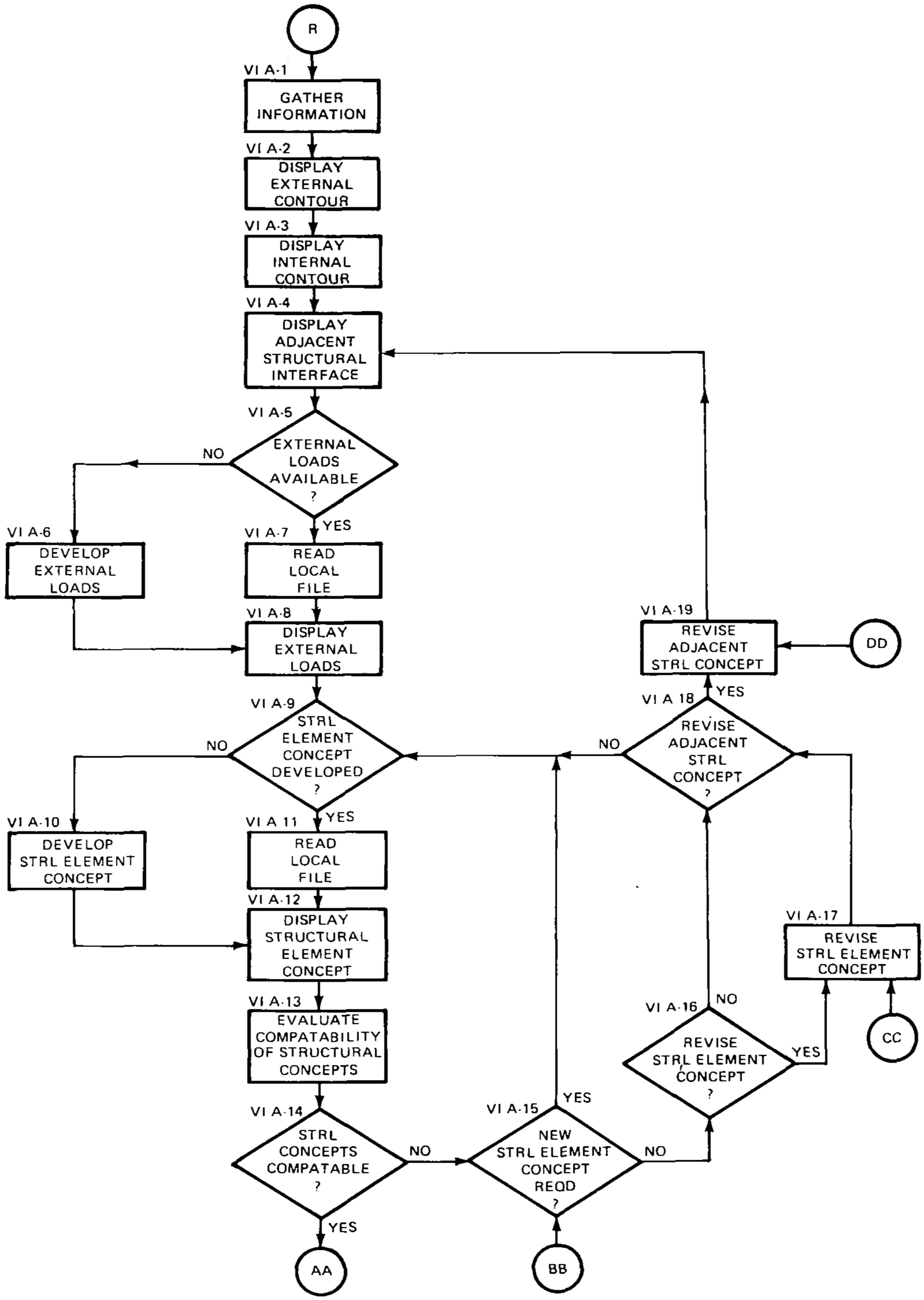


Figure 74.–Layout Network: SDD, Level VI

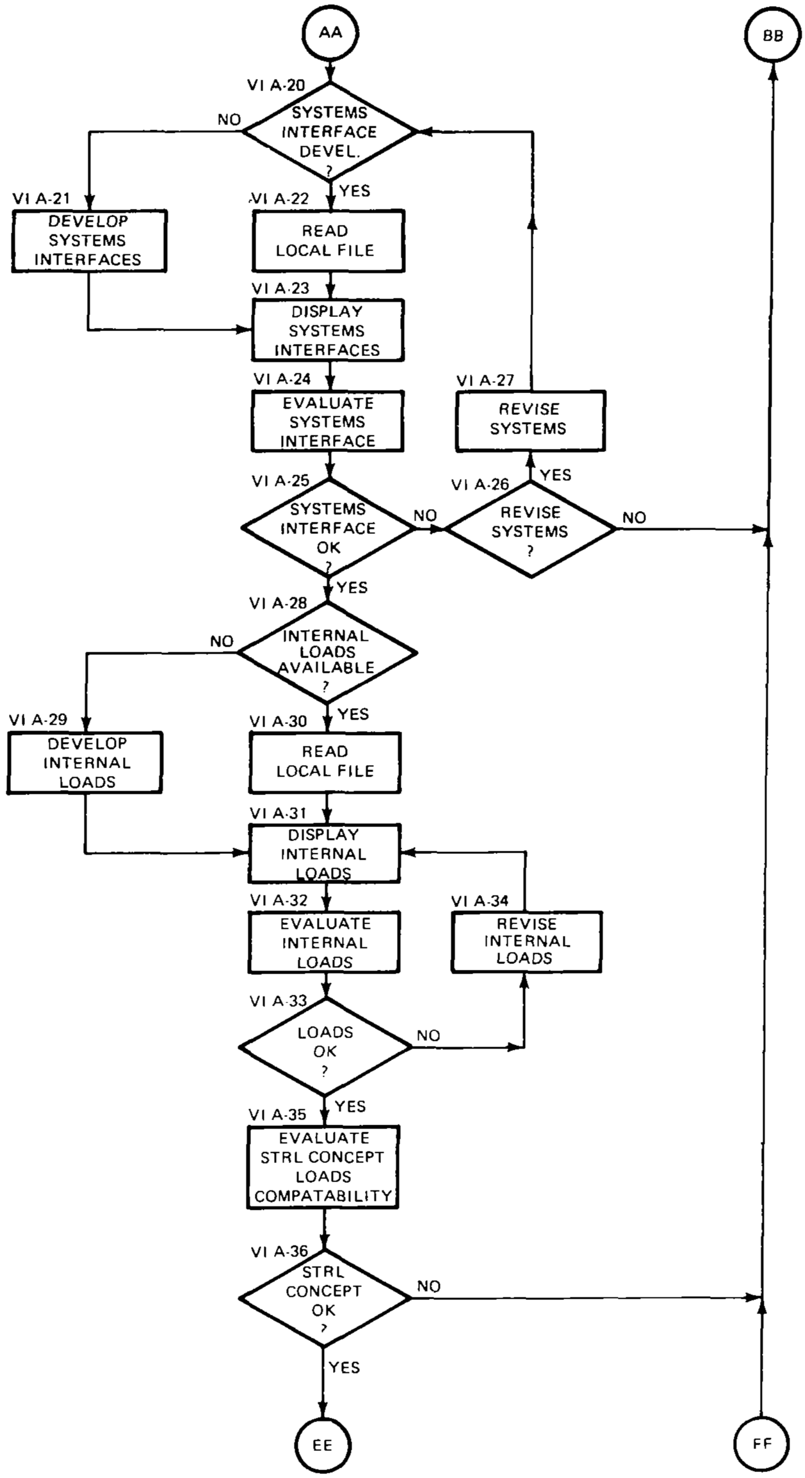


Figure 75.—Layout Network: SDD, Level VI (Continued)

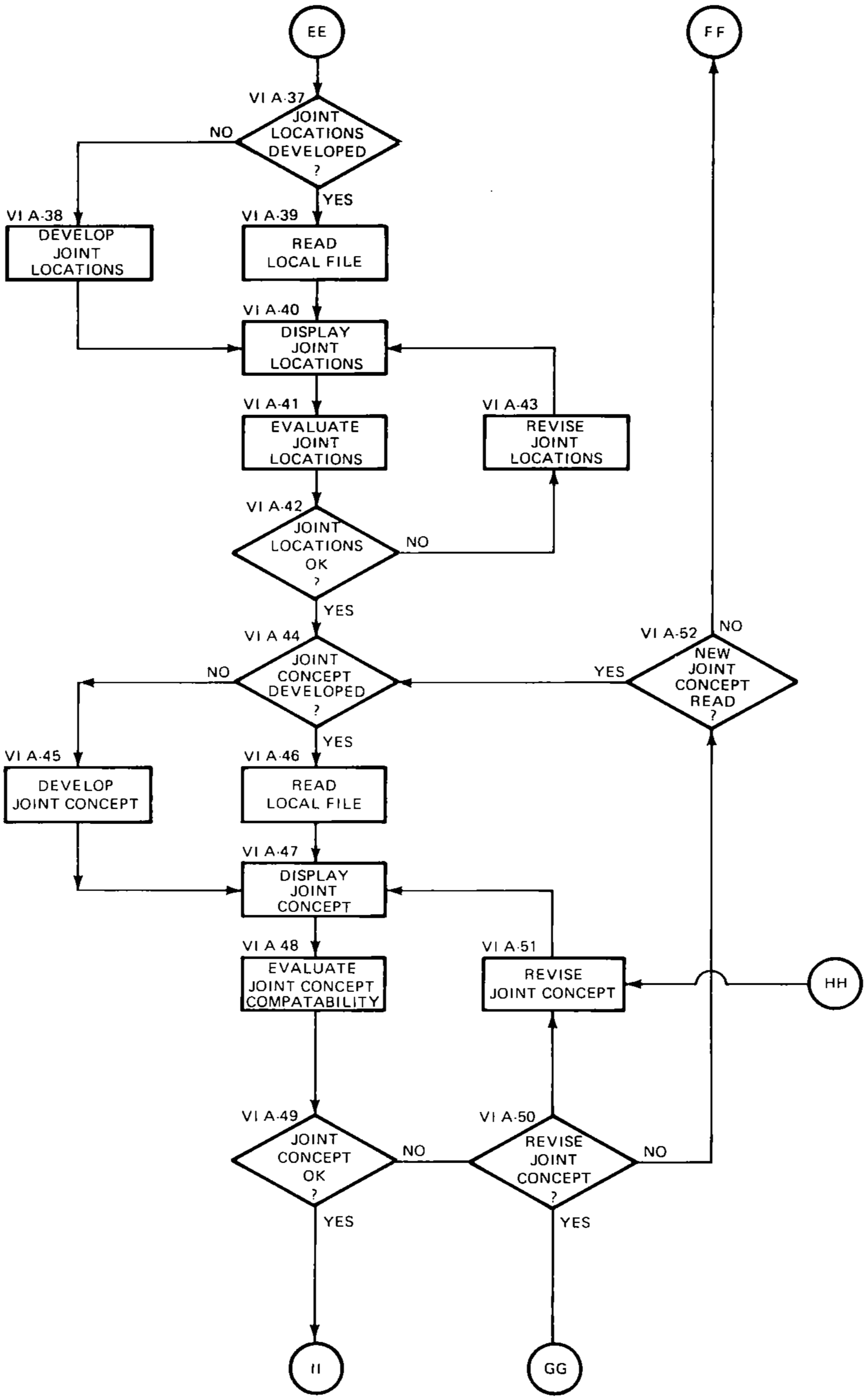


Figure 76. –Layout Network: SDD, Level VI (Continued)

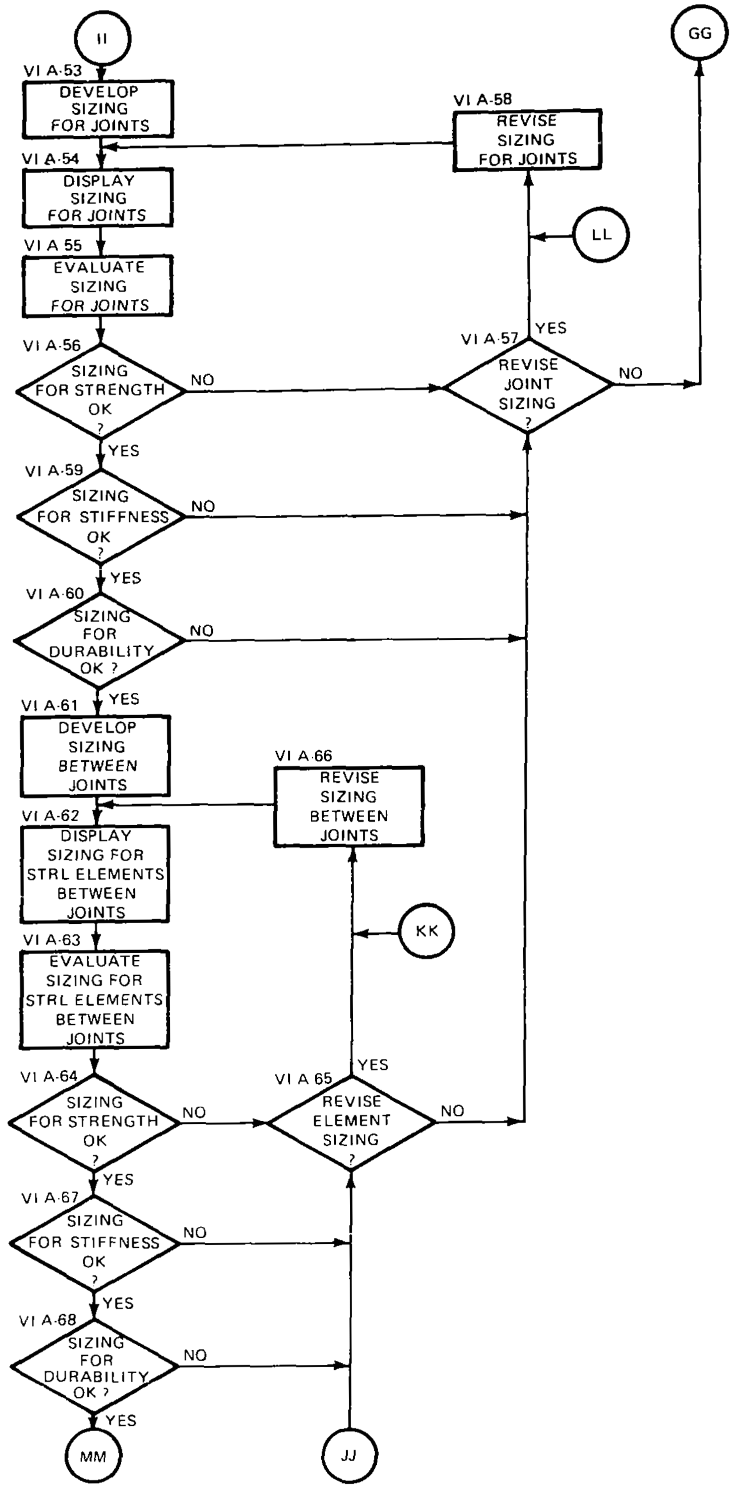


Figure 77.—Layout Network: SDD, Level VI (Continued)

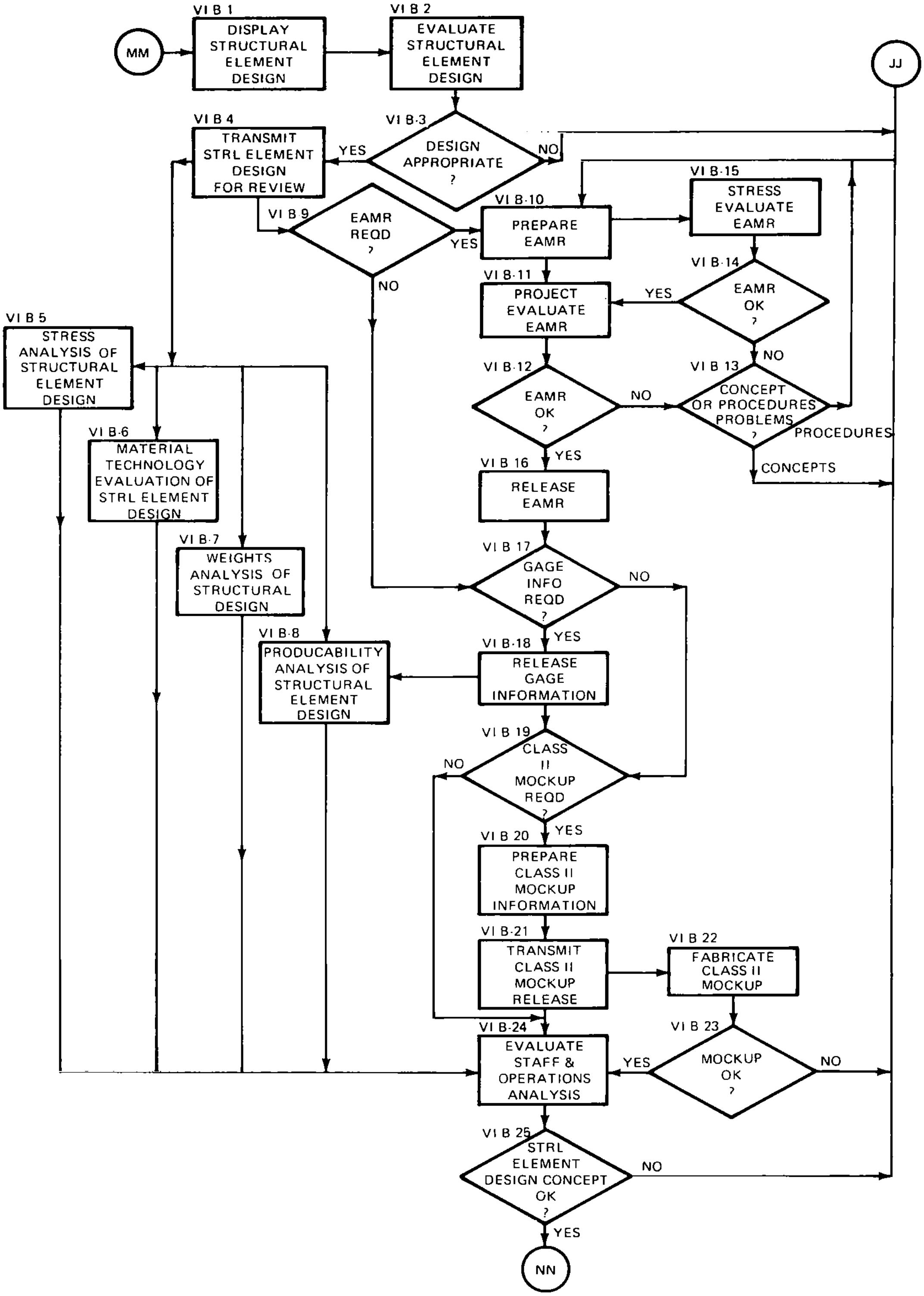


Figure 78.–Evaluation Network: SDD, Level VI

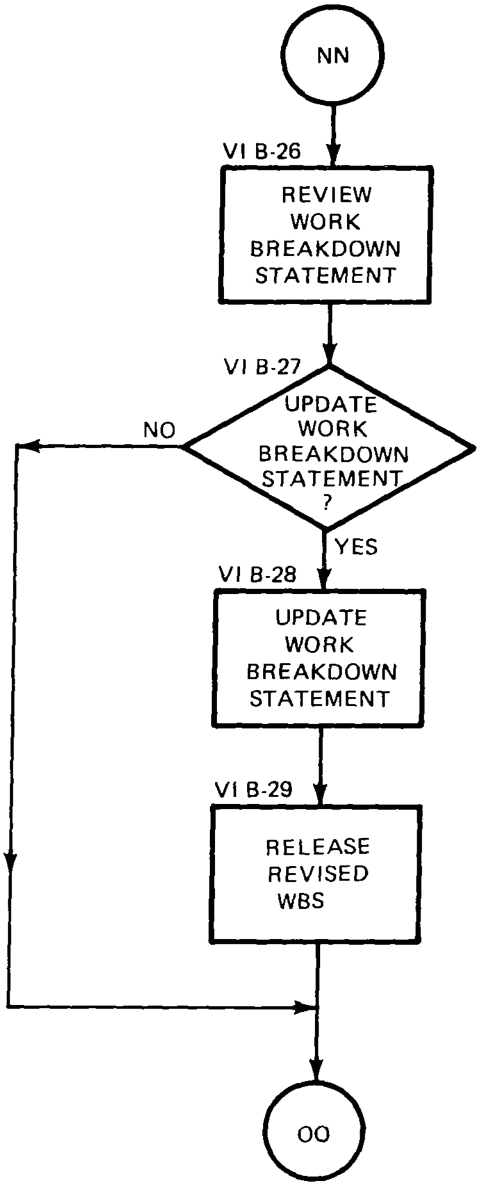


Figure 79.–Evaluation Network: SDD, Level VI (Continued)

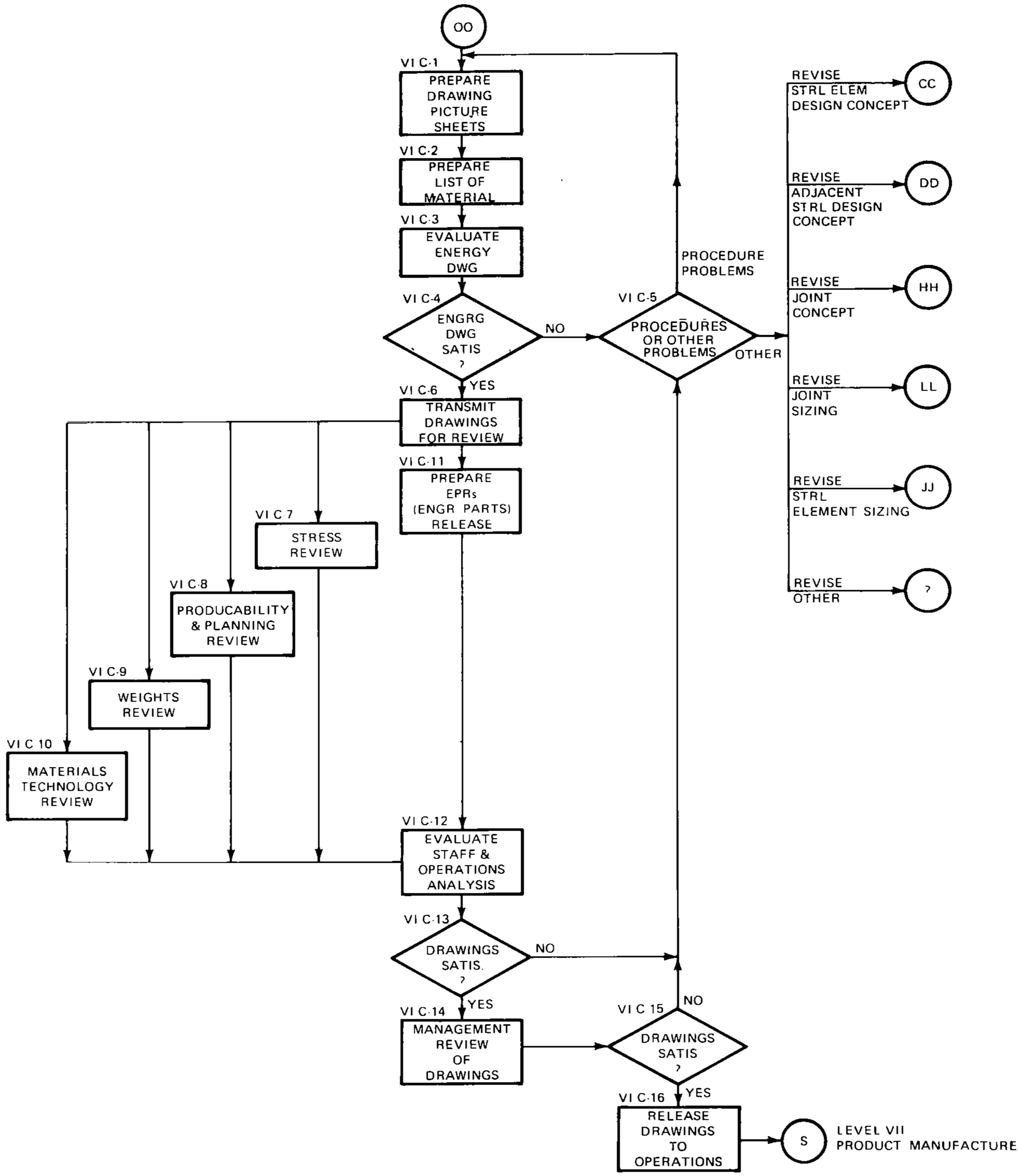


Figure 80.–Drawing Network: SDD, Level VI

6.6.3 NETWORK ACTIVITIES DESCRIPTION

The layout phase of detail design begins with block VI A-1.

Block VI A-1. Gather Information--At the beginning of a task it is necessary to completely identify the requirements to be satisfied and gather the information and processes required. The "gather information" procedure (section 6.5) is employed here.

Block VI A-2. Display External Contour --Provide graphic pictures of the external shape of the structure, with all views required for development of the design displayed at any desired scale and orientation. Provisions are required for merging this information with other pictures and graphic displays developed at another time.

Block VI A-3. Display Internal Contour--Provide graphic pictures of the internal shape of the structure, with all views required for development of the design displayed at any desired scale and orientation. Provisions are required for merging this information with other pictures and graphic displays developed at another time.

Block VI A-4. Display Adjacent Structural Interface--Provide locations of adjacent structural elements and their structural concepts. Graphic pictures of this information with all views required for the development of the design will be displayed at any desired scale and orientation. Provisions are required for merging this information with other pictures and graphic displays developed at another time.

Block VI A-5. External Loads Available?--Determine whether the external loads for the structure have been developed at an earlier level and are available.

Block VI A-6. Develop External Loads--Develop external loads-gathering data and process according to "gather information" (section 6.5).

Block VI A-7. Read Local Data File --Retrieve information from a local file which was stored for use in the "gather information" step (VI A-1 or section 6.5).

Block VI A-8. Display External Loads--Display external loads formatted for best understanding and use.

Block VI A-9. Structural Element Concept Developed?--Determine whether a structural concept has been developed for this structural element which will be suitable for this design.

Block VI A-10. Develop Structural Element Concept--Design the desired structural element concept by merging or synthesizing existing information items selected from the data base with new information items generated as required to provide the new concept. The "gather information" process (section 6.5) is used here.

Block VI A-11. Read Local Data File--From a local file, retrieve information stored for use in the "gather information" step.

Block VI A-12. Display Structural Element Concept--Provide graphic pictures of the structural element concept with all views required for development of the design displayed at any desired scale and orientation. Provisions are required for merging this information with pictures and graphic displays developed at another time.

Block VI A-13. Evaluate Compatibility of Structural Concepts--Study how well the structural element concept fits within the envelope boundaries provided by the inner and outer contours and the interfacing structural elements, and how well it fits together with the latter.

Block VI A-14. Structural Concepts Compatible?--Determine whether the structural element concept is compatible with the envelope boundaries provided by the inner and outer contours and with the interfacing structural elements.

Block VI A-15. New Structural Element Required?--Determine whether revision of the proposed structural element concept would provide an acceptable concept or if an entirely new concept is required.

Block VI A-16. Revise Structural Element Concept?--Determine whether the structural element concept should be revised or if the adjacent structural concept should be altered.

Block VI A-17. Revise Structural Element Concept--Design the desired structural element concept by modifying a previously proposed concept. Merge or synthesize existing information items from the data base with new information items generated as required to provide the new concept.

Block VI A-18. Revise Adjacent Structural Concept?--Determine whether the adjacent structural concept must be revised if there is not compatibility.

Block VI A-19. Revise Adjacent Structural Concept--Design the desired adjacent concept by modifying a previously proposed structural element concept. Merge or synthesize existing information items from the data base with new information items generated as required to provide the new concept.

Block VI A-20. Systems Interface Developed?--Determine whether a systems interface has been made for this structural design concept.

Block VI A-21. Develop System Interface--Develop the location and provisions for interfacing systems and their peculiar requirements.

Block VI A-22. Read Local Data File--When the systems interface has been developed, read the local data base for information gathered accordng to section 6.5.

Block VI A-23. Display Systems Interface--Provide the locations and graphic pictures of the interfacing systems and their provisions displayed at any desired scale and orientation. Provisions are required for merging this information with other pictures and displays developed at another time.

Block VI A-24. Evaluate Systems Interface--Study how well the structural element concept accommodates the interfacing systems and their provisions while retaining its functional capability.

Block VI A-25. Systems Interface Satisfactory?--Determine whether the structural element concept is compatible with the interfacing systems and their required provisions.

Block VI A-26. Revise Systems?--Determine whether relocating or changing the interfacing systems and their provisions would be the appropriate manner of improving their compatibility.

Block VI A-27. Revise Systems--Relocate or revise the interfacing systems and their provisions as required for compatibility with the structural element concept.

Block VI A-28. Internal Loads Available?--Determine whether the structural element external loads have been developed and are available.

If the loads are available proceed to block VI A-30; if the loads are not available in the data file, they must be generated.

Block VI A-29. Develop Internal Loads--Calculate, or extract from a finite element or other analysis, the structural element external loads for all significant load conditions in the ground-air-ground service cycle. The "gather information" (section 6.5) is involved in this development action.

Block VI A-30. Read Local Data File --Retrieve information from a local data file. This information was stored for use in the "gather information," block VI A-1. (See section 6.5 for details.)

Block VI A-31. Display Internal Loads--Provide loads information formatted for best understanding of their impact on the structural element concept being considered. Combine alphanumeric and graphics displays as necessary. Provisions are required for merging this information with other pictures and graphics displays developed at another time.

Block VI A-32. Evaluate Internal Loads--Study how well the loads are accommodated by the structural element concept. Continuity of load paths and load transfer provisions are important considerations.

Block VI A-33. Internal Loads Satisfactory?--Determine whether the internal loads are complete and credible and appear to be in line with the adjacent family structure.

Block VI A-34. Revise Internal Loads--Using the "gather information" process, block VI A-1 (see section 6.5), recheck the source of data, the methods, and concept used and revise the internal loads.

Block VI A-35. Evaluate Structural Concept and Loads Compatibility--The structural concept is evaluated for efficiency in handling the internal loads. Are there redundancies, sufficient margin, etc.?

Block VI A-36. Structural Concept Satisfactory--Determine whether the loads are accommodated by the structural element concept in an acceptable manner.

If the structural concept is not satisfactory it is necessary to re-examine the structural element concept: return to block VI A-15 and continue the design process.

Block VI A-37. Joint Locations Developed?--Because of its size, material, and manufacturing limits, a body frame must have structural joints. The information gathered in block VI A-1 is examined for joint location.

Block VI A-38. Develop Joint Locations --Using data from "gather information," block VI A-1, or the system shown in section 6.5 to gather what is needed (i.e., material sizes, part forming capabilities, manufacturing suggestions, locations of interfacing structure, and location areas of lower loads and moments), the joint locations are selected.

Block VI A-39. Read Local Data File--If joint locations have been developed previously, the information would be taken from the data file identified at block VI A-1.

Block VI A-40. Display Joint Locations--Provide graphic pictures of the structure with joint locations to gather with interface structures and pertinent information used in selecting the location.

Block VI A-41. Evaluate Joint Locations--Evaluate the joint location selection against all interfacing data and structure criteria.

Block VI A-42. Joint Locations Satisfactory?--Does the location selection satisfy all of the criteria?

Block VI A-43. Revise Joint Location--Using original criteria, the joint location selection is again made as in to block VI A-38.

Block VI A-44. Joint Concept Developed?--Determine whether joint concepts have been developed that will be suitable for this design.

Block VI A-45. Develop Joint Concept--Design the desired joint concepts by merging or synthesizing existing information items from the data base with new information items generated as required to provide the new concepts.

Block VI A-46. Read Local Data File--Retrieve information from a local file stored for use in the "gather information," block VI A-1. (See section 6.5).

Block VI A-47. Display Joint Concept--Provide graphic pictures of the joint concepts with all views required for development of the design displayed at any desired scale and orientation. Provisions are required for merging this information with pictures and graphic displays developed at another time.

Block VI A-48. Evaluate Joint Concept Compatibility--Study how well the joint concepts fit the structural element concepts.

Block VI A-49. Joint Concepts Satisfactory?--Determine whether joint concepts are compatible with structural element concepts.

Block VI A-50. Revise Joint Concept?--Determine whether revising the joint concepts would be the appropriate way to improve the compatibility of the joint concepts with the structural element concepts.

Block VI A-51. Revise Joint Concept--Revise the joint concepts as required for compatibility with the structural element concepts.

Block VI A-52. New Joint Concept Required?--Determine whether new joint concepts must be developed or if some change to the structural element concepts is required for compatibility with the joint concepts.

Block VI A-53. Develop Sizing for Joints--Calculate the geometric sizing required for the joints to accommodate the load transfer between structural elements. This includes the material thicknesses, width, length, fastener size spacing, and edge margin which are the interdependent variables affecting joint strength. Other important characteristics are centroids and moments of inertia and gyration.

The gather information process described in section 6.5 is used here.

Block VI A-54. Display Sizing for Joints--Provide graphic pictures of the joint geometry sizing with all views required for development of the design displayed at any appropriate scale and orientation. Provisions are required for merging this information with pictures and graphic displays developed at another time. The load intensity and direction must be displayed with the geometry sizing.

Block VI A-55. Evaluate Sizing for Joints--Judge how well the geometry sizing of the joints fits the joint concepts and the structural element concepts. Important characteristics are structural continuity, or directness of the load paths, and simplicity of design.

Block VI A-56. Sizing for Strength Satisfactory?--Determine whether the geometry sizing of the joints is adequate to sustain the loads imposed.

Block VI A-57. Revise Joint Sizing?--Determine whether revising the joint geometry sizing will provide an acceptable design which will accommodate the loads imposed or whether a change to the joint concepts or structural element concepts is required.

Block VI A-58. Revise Sizing for Joints--Recalculate joint sizing, adding to the data used in block VI A-53 any design direction or restraints that are discovered subsequent to block VI A-53. Continue by displaying joint sizing in activity block VI A-54.

Block VI A-59. Sizing for Stiffness Satisfactory?--Determine whether the geometry sizing of the joints will sustain the load imposed without unacceptable deflection of any of the structural elements.

Block VI A-60. Sizing for Durability Satisfactory?--Determine whether the geometry sizing of the joints will sustain the loads imposed throughout the service life of the airplane without fatigue or stress corrosion of any of the structural elements.

Block VI A-61. Develop Sizing Between Joints--Calculate the geometric sizing required for the structural element between the joints to accommodate the loads imposed. The material thicknesses, width and length, fastener size spacing, and edge margin are the interdependent variables affecting strength. Other important characteristics are centroids and moments of inertia and gyration. The process of "gather information" block VI A-1 (or section 6.5), is used here.

Block VI A-62. Display Sizing for Structural Elements Between Joints--Provide graphic pictures of structural element geometry sizing with all views required for development of design displayed at any scale and orientation. Provisions are required for merging this information with pictures and graphic displays developed at another time. Also, load intensity and direction are displayed with geometry sizing.

Block VI A-63. Evaluate Sizing for Structural Elements Between Joints--Study how well the geometry sizing of the structural element between the joints fits structural element and joint concepts. Important characteristics are structural continuity (or directness of load paths) and simplicity of design.

Block VI A-64. Sizing for Strength Satisfactory?--Determine whether geometry sizing of the structural element between joints is adequate to sustain loads imposed.

Block VI A-65. Revise Structural Element Sizing?--Determine whether revising structural element geometry sizing will provide an acceptable design that will accommodate the loads imposed or whether a change is required to the joint sizing, joint concepts, or the structural element concept.

Block VI A-66. Revise Sizing Between Joints--Revise the geometric sizing for the structural element between joints as required to accommodate the loads imposed, correcting deficiencies where they exist.

Block VI A-67. Sizing for Stiffness Satisfactory?--Determine whether geometry sizing of the structural element between joints will sustain the load imposed without unacceptable deflection, vibration or flutter.

Block VI A-68. Sizing for Durability Satisfactory?--Determine whether the geometry sizing of the structural elements between the joints will sustain the loads imposed throughout the service life of the airplane without fatigue or stress corrosion.

When the design process has progressed through this point, the layout process is complete and the design task enters a design evaluation phase.

The design evaluation stage of detail design begins with block VI B-1.

Block VI B-1. Display Structural Element Design--Provide graphic pictures of the complete structural element design with all views required for understanding the design displayed at any desired scale and orientation. The geometry sizing must be to correct scale and load intensities, and directions must also be displayed. Provisions are required for merging this information with pictures and graphic displays developed at another time.

Block VI B-2. Evaluate the Structural Element Design--Study how well the Structural Element Design would perform its intended function. Would it be cost effective, lightweight, and durable? Examine it for complete definition of all details required to define the completed parts and assemblies.

Block VI B-3. Design Appropriate?--Determine whether the structural element design would be appropriate and perform its intended function. When the design appears correct, the layouts are transmitted for review. However, in the event the design appears to be lacking, the activity returns to the layout stage for evaluation of needed changes.

Block VI B-4. Transmit Structural Element Design Layouts for Review--Deliver copies of the structural element design (layout) to all effected and interested organizations and personnel for critical review and comment.

Project activities take a parallel path at this time while reviews are taking place: material is ordered, gage information is released, and mockups are built.

Block VI B-5. Stress Analysis of Structural Element of Design--Stress staff personnel make a semiformal analysis of the design. (See section 5.2.4 for stress staff activities.) The location of this activity in the network is not the first dialog between design engineering and the stress staff; the block is shown here as a milestone that must be passed before formal drawings are made.

Block VI B-6. Materials Technology Evaluation of Structural Design--Materials technology examines the design for best use of materials, fasteners, forming methods, finishes, sealants, etc., to perform the structural task.

Block VI B-7. Weights Analysis of Structural Element Design--Weights staff personnel evaluate design and perform balance estimates, c.g. calculations, growth studies, weight reductions, etc. (See section 5.2.1.)

Block VI B-8. Producibility Analysis of Structural Element Design--Manufacturing reviews the design in the layout phase to ensure that design decisions support cost effective fabrication and assembly practices. The reviews are initiated at the discretion of the design project in order to augment trade studies at critical decision points. Manufacturing looks at various design aspects such as material, size, and assembly arrangements from the viewpoint of available company resources and fabrication capabilities. The layouts are also used to develop preliminary manufacturing and tooling plans, which in turn may initiate design revision requests from manufacturing. The producibility reviews constitute a continuous dialogue between design and manufacturing on both a formal and informal basis. Quality Control aspects are also reviewed during this process for considerations pertaining to the verification that design intent is achieved. See Document D6-IPAD-70011-D, "Product Manufacture Interactions with the Design Process."

<u>Block VI B-9. EAMR Required?</u>--An engineering advance material requirement (EAMR) is a list of materials that, by their nature, have a long lead time in procurement. Items falling in this category are extruded shapes, forgings, castings, exotic materials, specialty items, etc. When these items or materials can be identified with assurance that they are to be used, the materiel department is requested to issue purchase orders. A decision is made in response to the question: "Are there any items to be ordered early?"

<u>Block VI B-10. Prepare EAMR</u>--The EAMR is prepared and, for assurance, is coordinated with the stress staff for their concurrence as to gage, material, etc.

<u>Block VI B-11. Stress Staff Evaluate EAMR</u>--The stress staff evaluates materials for compatibility with the design.

<u>Block VI B-12. EAMR Satisfactory?</u>--When the stress staff concurs with detail design materials selection, the EAMR is routed for engineering project approval. If there is no concurrence with the EAMR, a decision must be made as to whether a design or a procedure error exists.

<u>Block VI B-13. Project Evaluate EAMR</u>--Responsible engineering management evaluates the EAMR from a cost and risk view.

<u>Block VI B-14. EAMR Satisfactory?</u>--A decision is made that the EAMR is either proper or disapproved.

A proper EAMR is released through the data processing activity, but a disapproved EAMR requires a decision.

<u>Block VI B-15. Concept or Procedure Problem?</u>--Was disapproval of the EAMR due to disagreement with the design concept or due to a procedure error (an error in preparation of the paper itself)?

<u>Block VI B-16. Release EAMR</u>--The EAMR is released through the data manager to the activity requiring it.

Block VI B-17. Gage Information Required?--At this stage in design, the manufacturing department planned for their production activity using preliminary drawings and now need specific data as to final geometry and major joint location. Major joint locations include attach pin location, hinge locations, production break locations, etc.

Block VI B-18. Release Gage Information--Gage information is prepared and submitted through the data manager to manufacturing and other activities as required.

Block VI B-19. Class II Mockup Required--A decision is made whether or not a class II engineering mockup is needed for detail design activity. (See mockup description in section 6.2.3.6, block description VI-4.)

Block VI B-20. Prepare Class II Mockup Releases--Drawings are prepared and/or layouts furnished to describe the mockup areas to be built.

Block VI B-21. Release Class II Mockup Drawing--Class II mockup drawings are released through the data manager to manufacturing.

Block VI B-22. Fabricate Class II Mockup--This is a manufacturing activity and is placed here to show a sequence of engineering/manufacturing-related events.

Block VI B-23. Mockup Satisfactory?--Is the mockup of the structural concept and interfaces correct? The class II mockup examined here is primarily for design engineering's use to prove out and give visibility to the design in those dimensions with interfacing structure and systems located. (The accuracy of the mockup, reflecting the engineering drawings, is a quality control problem within the manufacturing department.)

Block VI B-24. Evaluate Staff and Operations Analysis--Stress, weights, material technology staffs, and manufacturing analysis of the detail design are evaluated.

Block VI B-25. Design Satisfactory?--When the evaluation performed above appears not to be satisfactory, the design activity must return to earlier activities to solve the problem. If the solution is not identified, a search is begun at block VI A-65 and continues through the network until it is found.

Block VI B-26. Review Work Breakdown Structure (WBS)--The WBS outlined in section 4.1.1 lists all major parts and assemblies and describes their physical makeup and function. The WBS is updated to be current at any design stage. The WBS is reviewed at the end of the design evaluation phase.

Block VI B-27. Update Work Breakdown Structure?--Determine whether the structural element design reflects the original work breakdown statement description.

Block VI B-28. Update Work Breakdown Statement--Revise the work breakdown statement description to reflect the structural element design.

Block VI B-29. Release Revised WBS--Release the revised WBS through the data manager.

Having proceeded through detail design layout (phase A), detail design evaluation (phase B), the next phase is prepare the formal drawing (phase C). When the detail design layouts are prepared accurately and in depth, the following detail drawing phase becomes primarily a drafting operation.

The detail drawing activity begins at block VI C-1.

Block VI C-1. Prepare Drawing Picture Sheets--The "gather information" process (section 6.5) is used in preparation for the formal drawing activity.

The formal drawing completely describes the part to be made including a geometric description, material description, finish, identification, any proofs required, and any production processes that control its manufacture.

The drawing is produced using the most effective process for the type of part to be drawn. In the IPAD environment, the formal drawing of a family of structures is 100 percent computer-produced. A family of structures is a series of similar general-structure items that vary only in contour and small details. For example: a series of body frames would have a similar cross-section and be interfaced with floors, floor beams, skin panels, interiors, systems, and exterior and interior contours with geometry variables. Such a series of frames would be a family structure. Any computer program made to draw one of this series is easily and economically altered to fit any of the "family" members.

The drawing of a one-of-a-kind piece of structure (such as a bulkhead) might be the most cost effective if only the contour and interfacing structure were produced while flag notes, identification, etc., were being done manually.

Block VI C-2. Prepare List of Material--A list of all parts, materials, processes, reference information, etc., is prepared. This data, an integral part of the drawing, describes the part characteristics that the picture does not. Drawings of large parts or assemblies of many parts may be divided into several drawing sheets or in book form, yet each sheet is an integral part of the drawing. The list of materials, computer-prepared using business systems, is released through a data manager to the areas needing its information. Recipients include engineering management, schedules, manufacturing, etc.

Block VI C-3. Evaluate Engineering Drawing--Evaluate the engineering drawing: Is the design still the best and most effective for the design task? Does the drawing and parts list describe the structure completely and in a manner that is easily understood?

Block VI C-4. Engineering Drawing Satisfactory?--Does the engineering drawing answer all of the questions that were asked of it in block VI C-3 above?

Block VI C-5. Procedure or Other Problem?--When an engineering drawing is not satisfactory, the problem must be identified and dealt with. A procedures problem is solved by returning the drawing activity to "prepare drawing pictures or parts list," blocks VI C-1 and C-2. Any other problem is handled by returning through any gate that deals with the problem. For example: a structural element concept design problem would require returning to activity block VI A-7; an adjacent structure problem is investigated at block VI A-19; a joint problem is investigated at block VI A-51; a joint size problem is considered at block VI A-58; a structural element sizing problem is investigated at block VI A-66, etc.

Block VI C-6. Transmit Drawings for Review--Detail production drawings are transmitted to stress, weights, materials technology staffs, and manufacturing for review. A dual activity path is intiated here and release confirmation is prepared for distribution while reviews are in progress.

Block VI C-7. Stress Review--The stress staff makes a final review of the detail design shown on the drawing to ensure that latest loads are adequately handled.

Block VI C-8. Producibility and Planning Review--Manufacturing reviews drawings prior to release for considerations similar to the layout phase (block VI B-8) and, in addition, to monitor schedule aspects. At this point, only minor revisions can be recommended without jeopardizing release schedules on schedule sensitive items. Any discrepancies in the design can be noted at this stage and corrections requested. Again, quality control reviews the drawings to verify that design intent can be verified during fabrication and assembly operations.

Block VI C-9. Weights Review--The weights staff makes a final accounting of structure weights and its affect on aerodynamics, stability and control, loads and flutter, stress, propulsion and noise, flight controls and systems, and other design areas. An interstaff data base dialog alerts danger areas.

Block VI C-10. Materials and Technology Reviews--Material and technology staff reviews the design for best use of materials, fasteners, forming techniques, finishes, and sealants at the state of the art.

Block VI C-11. Prepare Parts Release--While reviews are in progress, release information is prepared. Engineering information calling for the manufacture of a quantity of airplanes with the required number of detail parts for each is prepared for the data manager to distribute when authorized.

Block VI C-12. Evaluate Staff and Operations Analysis--Analyses made by stress, weights, and materials technology staffs and manufacturing are evaluated for possible action.

Block VI C-13. Drawings Satisfactory?--Decide whether or not the design and drawings are satisfactory. Should a design or drawing be inadequate, the process is to return to activity block VI C-5 and continue until the problem is cleared.

Block VI C-14. Management Review of Drawings--Management reviews drawings of design together with any pertinent reviews of staffs and manufacturing.

Block VI C-15. Drawings Satisfactory?--When the management review indicates the drawings of the detail design are satisfactory, the data is released. Should there be a questionable drawing or design area, the design activity process returns to activity block VI C-5 and continues until a solution to the last problem is found.

Block VI C-16. Release Drawings to Operations--Drawings and data are released to operations through the data manager, and production begins.

6.7 NETWORK FOR SYSTEM DETAIL DESIGN

6.7.1 SYSTEM DETAIL DESIGN DEFINITION

This section describes the detail design process for a system. The purpose is to illustrate the parallelism of design tasks in any design area. The same three stages of detail design exists here for systems as for structure: layout, evaluation, and formal drawing phases. (See figures 81 through 85.) The design process begins with the same task, "gather information." (See V sec. 6.5.)

The fuel system is selected as a representation system to give visibility to a system network. Within the fuel system are several major subsystems including fuel tank, engine fuel flow, fuel vent, refueling, fuel dump, etc.

The engine fuel system is chosen to demonstrate a systems detail design network and show the parallelism of detail design networks of structures and systems.

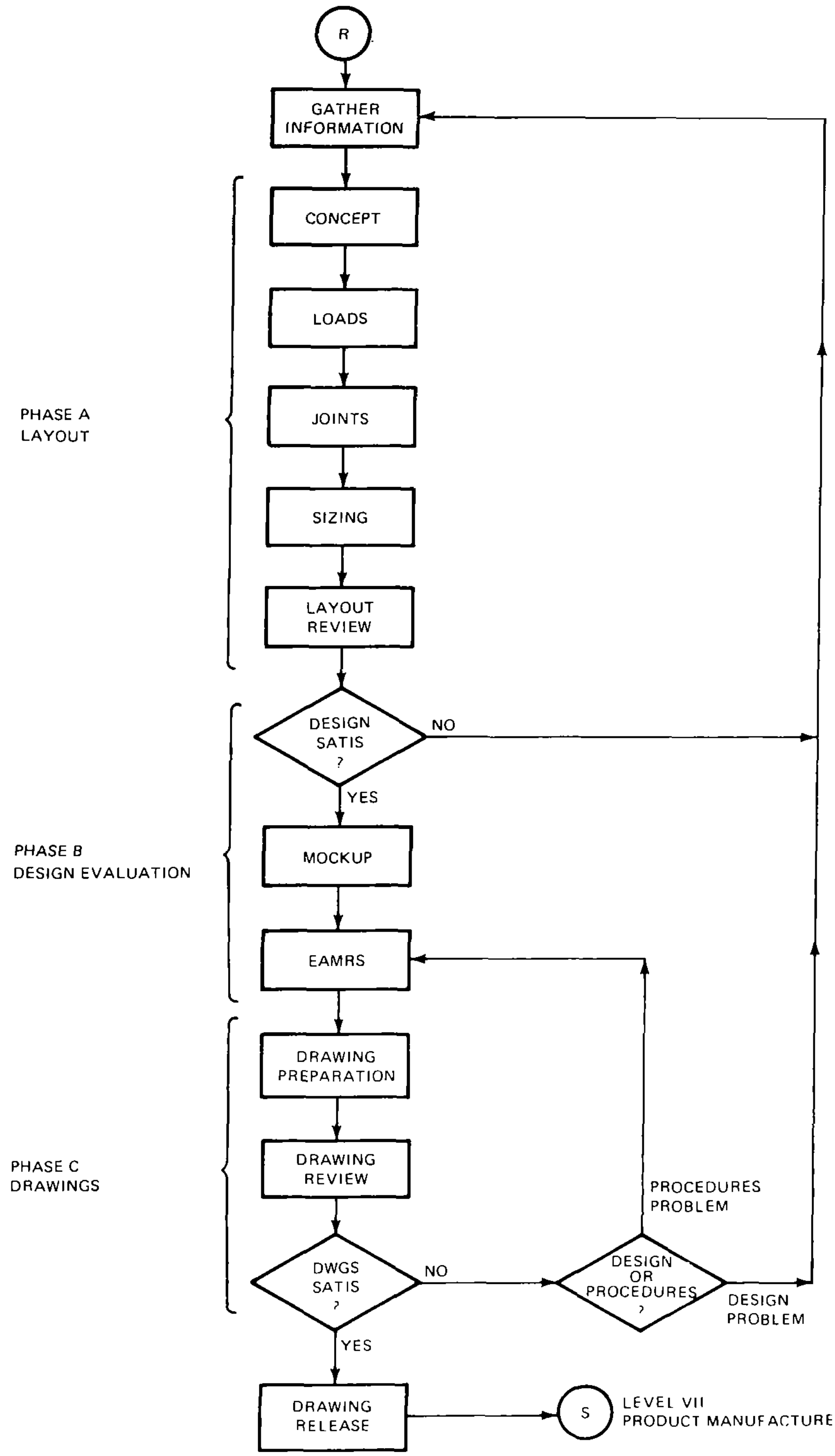


Figure 81.—Overview Network: SDD, Level VI

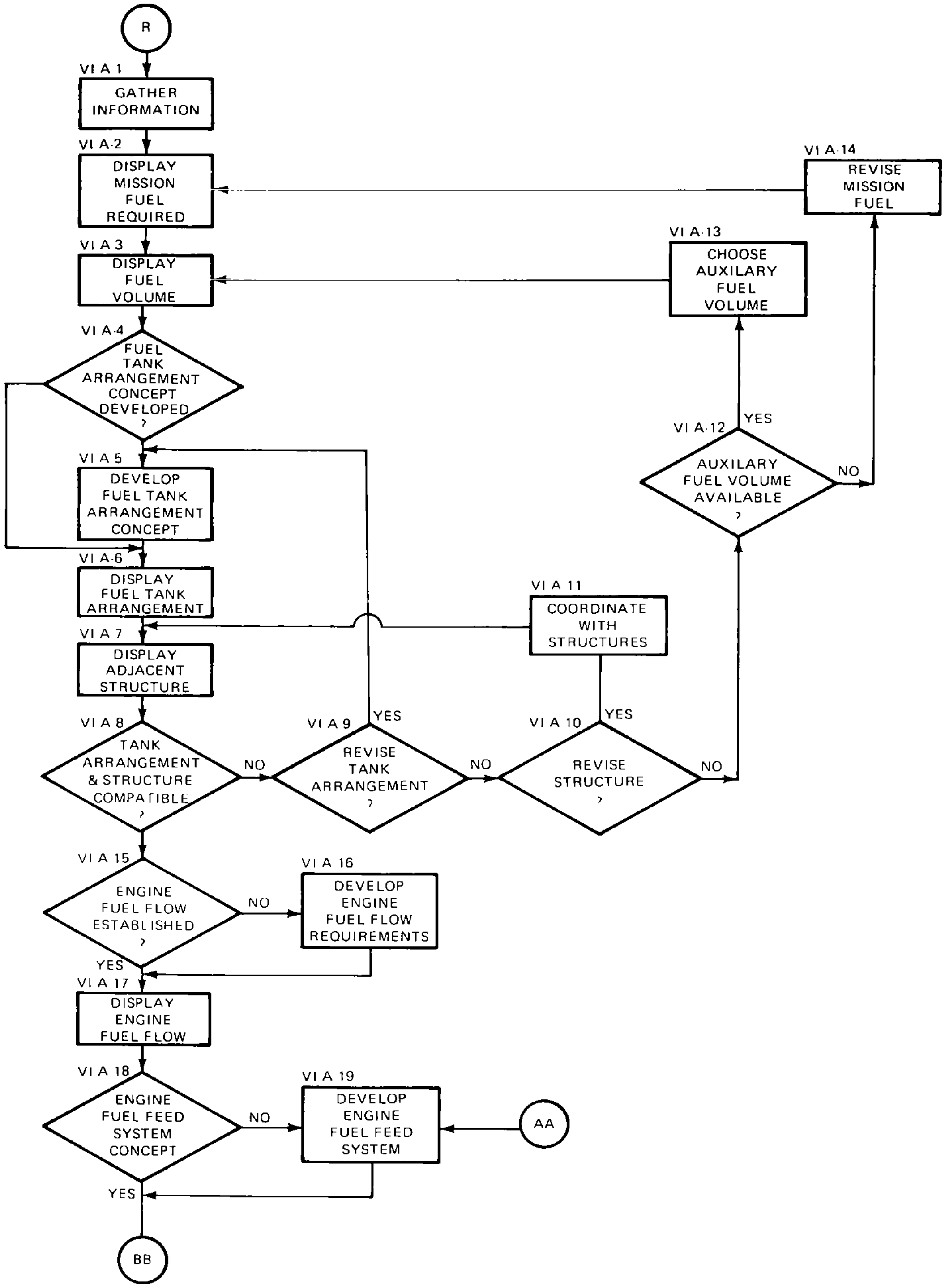


Figure 82.—Layout Network: SDD, Level VI

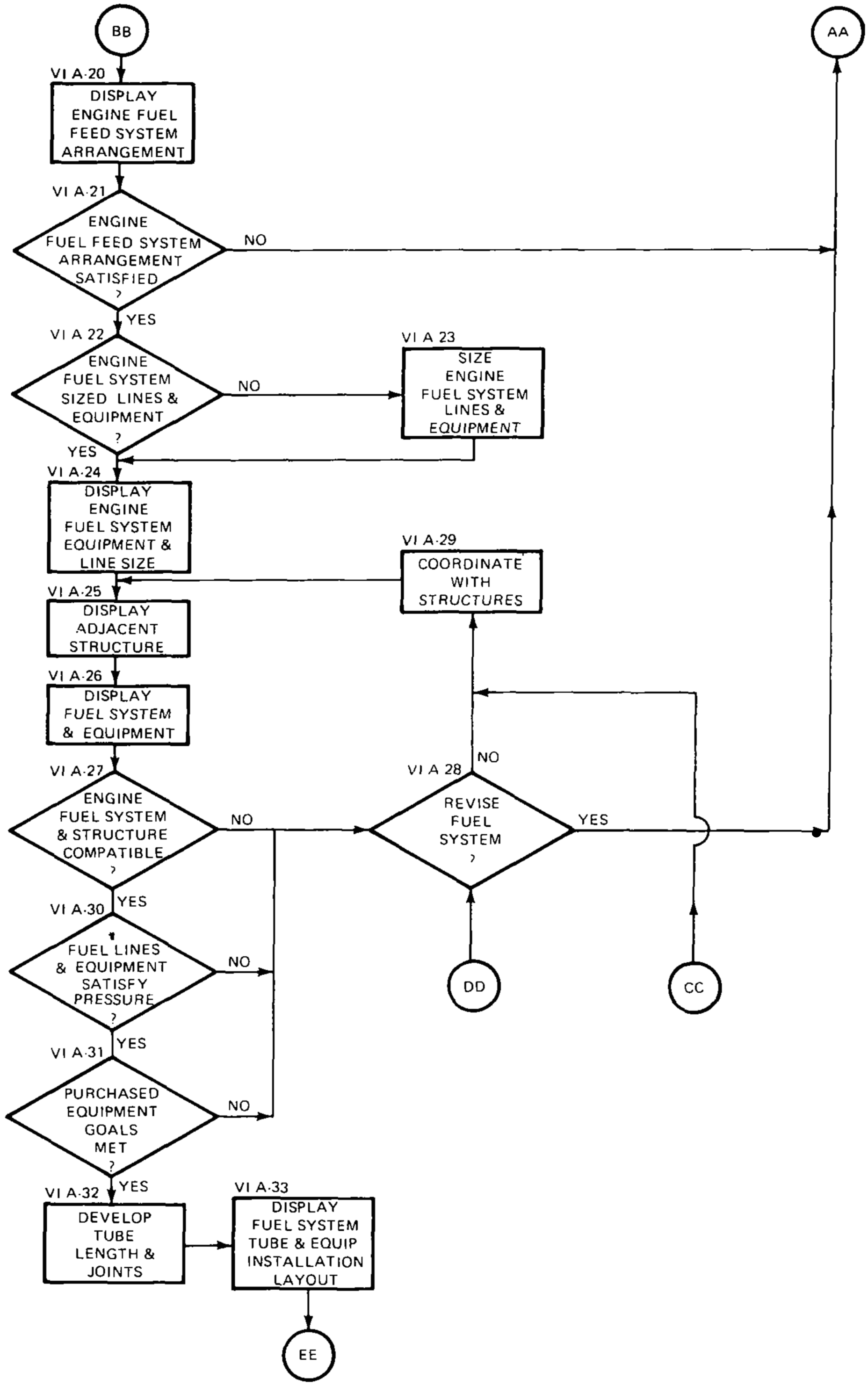


Figure 83.– Layout Network: SDD, Level VI (Continued)

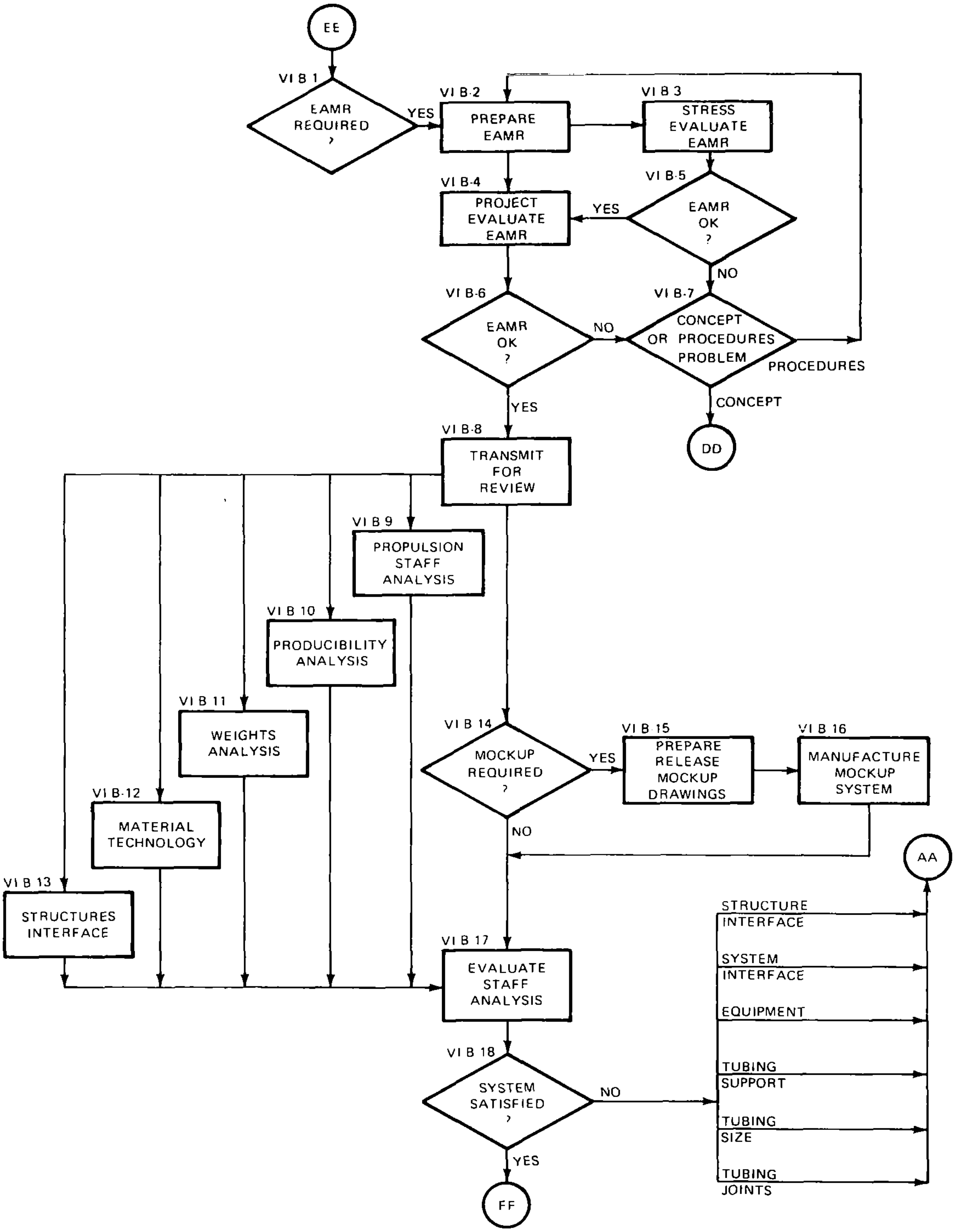


Figure 84.—Evaluation Network: System Detail Design, Level VI

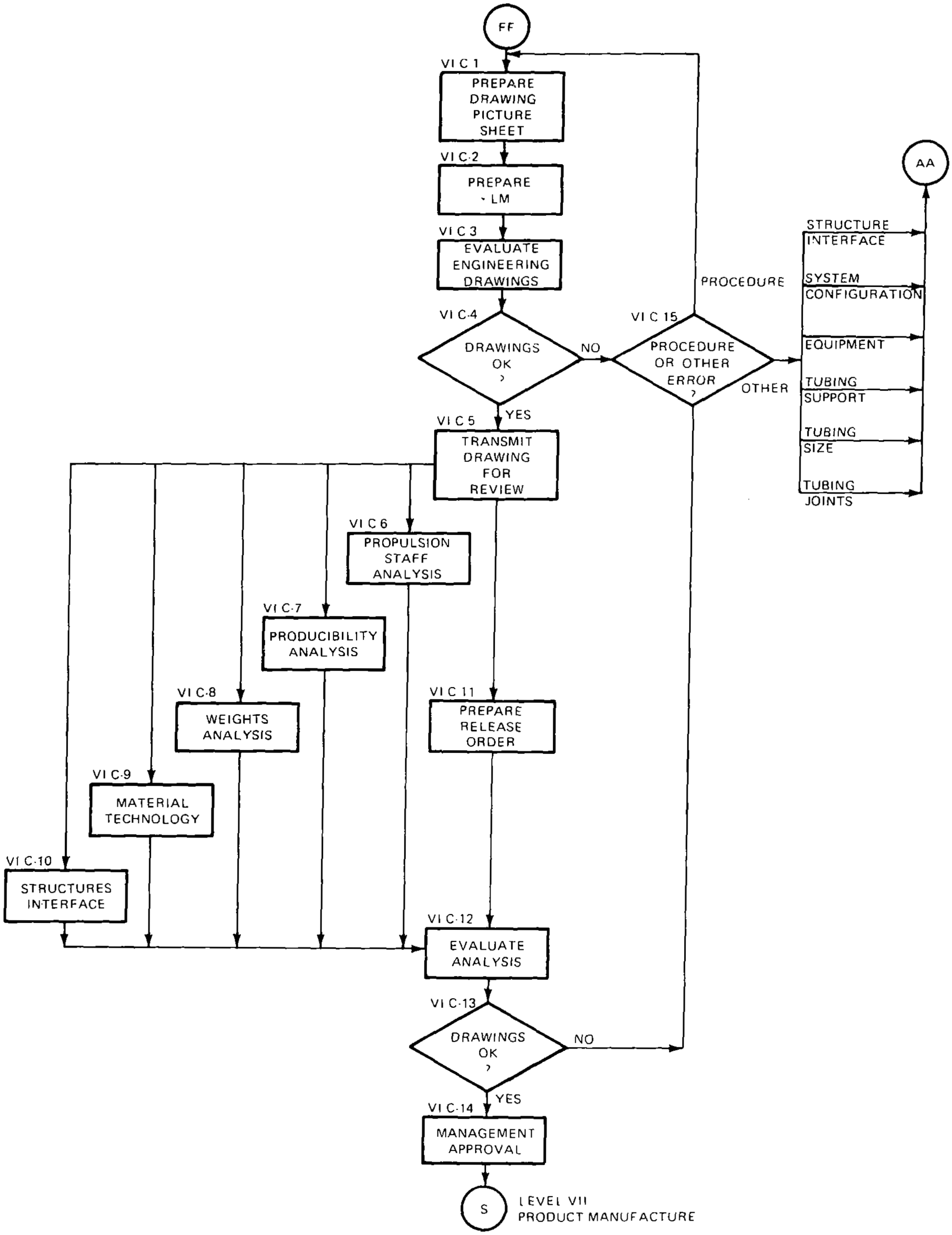


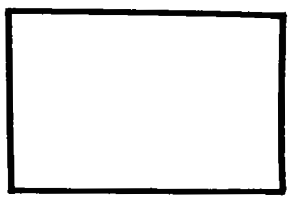
Figure 85.– Drawing Network: System Detail Design, Level VI (cont.)

6.7.2 SYSTEM DESIGN NETWORK

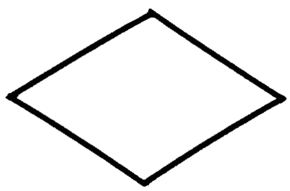
An activity network for the detail design of an engine fuel feed system follows. It assumes that level V design evaluation is complete and management has committed the design to project status.

The following information is pertinent to the network:

Network Blocks



Activity or Event*



Decision

*Any activity which has a "do" connotation, (e.g., display, develop, revise, etc.) includes the "gather information" network described in section 6.5.

The blocks are identified with the Roman numeral VI indicating level VI of the design process. The letters A, B, or C that follow indicate:

A. Layout phase

B. Evaluation phase

C. Drawing phase

Following the letters are sequential numbers of the block. For example:

VI B-7 indicates level 6 detail design in the evaluation phase at block 7.

6.7.3 NETWORK ACTIVITY DESCRIPTION

The design layout phase begins at block VI A-1.

Block VI A-1. Gather Information--The task is identified, and required data and processes are gathered from that generated and gathered in level V, etc. (See "gather information" process, section 6.5.)

Block VI A-2. Display Mission Fuel Required--The mission fuel requirement is a product of the propulsion staff who have progressively refined the fuel requirements through the design levels and now have fixed the mission fuel requirement.

Block VI A-3. Display Fuel Volume Available--Assuming, for this study, that the fuel is to be carried in an integral wing fuel tank, the wing volumes available for fuel are displayed. The volumes are separated into individual tanks by "tank end" ribs and "tank end" bulkheads at "dry bay" areas. The wing structures group coordinates with the fuels group in selecting these structural tank ends.

Block VI A-4. Fuel Tank Arrangement Concept Developed?--Do the wing structure design and the fuel tank system design agree in the location of tank, ribs, and bulkheads dividing the wing volume into desired groups of tanks for fuel capacity and management?

Block VI A-5. Develop Fuel Tank Arrangement--The fuel tank arrangement is designed to satisfy fuel management, fuel capacities, structural weight, engine position, etc. Coordination among all participating design disciplines is necessary.

Block VI A-6. Display Fuel Tank Arrangement--Display fuel tank arrangement in scale detail, at required accuracy, and with auxiliary views that best describe the arrangement.

Block VI A-7. Display Adjacent Structure--Display wing/body structure adjacent to tank area. Display is to scale, detail, and accuracy, with views that best describe the structure/tank arrangement.

Block VI A-8. Tank Arrangement and Structure Compatible?--A decision is made as to whether tank arrangement (volume) and required structure volumes and strengths are compatible.

Block VI A-9. Revise Tank Arrangement?--When the tank and structural arrangements are incompatible, the decision follows as to whether the tank arrangement should be revised to fit the fuel volumes offered by the wing structure design, or the wing structure should be realigned to relocate tank end ribs and fuel bulkheads. A decision to revise the tank arrangement returns the progression to block VI A-5.

Block VI A-10. Revise Structure?--When the impact of changing the fuel tank arrangement appears excessive, the alternate decision to change the structure is considered.

Block VI A-11. Coordinate with Structure--A structural change is made only after considerable study as to the effects (costs/advantage, etc.) of the change. Should the progression be in this direction, the next step is block VI A-7.

Block VI A-12. Auxiliary Fuel Volume Available?--When the fuel tank arrangement is inadequate and the confining structure change is not to optimum configuration, a solution might be the use of some auxiliary fuel volume.

Block VI A-13. Choose Auxiliary Fuel Volume--A search for adequate usable auxiliary volume begins "gather information" sec. 6.5). A wing tip or body tank may be the solution.

Block VI A-14. Revise Mission Fuel?--At level VI this is a relatively unlikely activity. Although fuel volume is short, refueling, a change in range, and/or a change in mission fuel may provide a solution.

Block VI A-15. Engine Fuel Flow Established?--A search of the data base will answer this decision block. This is a propulsion staff responsibility, since final fuel flow values are needed for line and equipment sizing.

Block VI A-16. Develop Engine Fuel Flow Requirement--Gather information (sec. 6.5) for the data and process to develop engine fuel flow requirements at all flight conditions.

Block VI A-17. Display Engine Fuel Flow Requirement--Display engine fuel flow at all flight conditions. Display should be arranged to meet design detail and accuracy requirements and in a manner that will be directly usable by the system designer.

Block VI A-18. Engine Fuel Feed System Concept Developed?--A search of the data base gives an answer to this question.

Block VI A-19. Develop Engine Fuel Feed System--Using engine location and fuel tank arrangement, an engine fuel feed system concept is developed. Impact of system equipment (support and access) and line penetration on structure is coordinated with structural design. Boost pump locations are dictated by flight altitude. The most direct routing between boost pumps and engines, while avoiding highly stressed structural areas, is a design goal.

Block VI A-20. Display Engine Fuel Feed System Arrangement--Display fuel feed system arrangement to scale, accuracy, and views that best describe the arrangement for the user.

Block VI A-21. Engine Fuel Feed System Plan Satisfactory?--Evaluate engine fuel feed system plan for line direction; pump location, support, and access; wing structure involvement; etc.

Block VI A-22. Engine Fuel System Sized for Lines and Equipment?--Determine line and equipment size for the engine; select airplane and mission; check local data file.

Block VI A-23. Size Engine Fuel System Lines and Equipment--Gather data and processes. (See section 6.5.) Using takeoff fuel flow, line length, hot fuel vapor pressure, and equipment pressure drop, the line and equipment sizes are calculated to achieve a system pressure drop that will allow suction feed to the engines. Engine inlet pressure requirements (maximum altitude), hot fuel vapor pressure, and supply-line pressure-drop data jointly dictate the size of the boost pumps.

Block VI A-24. Display Engine Fuel System Equipment and Line Size--Display size data calculated in block VI A-23 is in a form and detail that the user may use directly in future design activities (installing and supporting lines, selecting equipment, etc.).

Block VI A-25. Display Adjacent Structures--Adjacent structure detail is gathered (section 6.5) from the data base and displayed to the scale, accuracy, and view that will assist the designer in installing lines and equipment.

Block VI A-26. Display Fuel System and Equipment--The fuel system and equipment is displayed to a required accuracy and scale in any view or section and superimposed on the structure displayed in block VI A-25.

Block VI A-27. Engine Fuel System and Structure Compatible?--Review the superimposed displays of structure and fuel lines and equipment. Is the equipment supported adequately by structure? Does the supporting of the equipment involve a highly stressed structure; and, if so, is the structure adequately reinforced against reduced fatigue life? Do fuel lines penetrate structure in low-stressed areas or are highly stressed and penetrated areas adequately reinforced?

Block VI A-28. Revise Fuel System?--If a fuel system and structure incompatibility exists, the best candidate for change must be selected. A proposed structure revision requires coordination with the structures group (block VI-29), while a fuel system revision is within the fuel system design area (block VI A-

19). To minimize redesign costs, the interfacing groups' activities must be timed so that interfaces are satisfied during the design of each instead of at the completion of design.

Block VI A-29. Coordinate with Structures?--A decision to retain the fuel system design at the expense of structures design requires coordination with the structures design group for solution.

Block VI A-30. Fuel Lines and Equipment Satisfy Pressure?--Fuel lines and equipment sizes and their performance capabilities are examined. Any performance lack will require a system revision block VI A-28. The activity blocks VI A-27, -30, and -31 have approximately equal importance as to timing.

Block VI A-31. Purchase Equipment Goals Met?--Purchased equipment (boost pumps, valves, fuel gages, etc.) capabilities are examined for compliance with specifications.

Block VI A-32. Develop Tube Lengths and Joints--This activity involves practical aspects of design. Installation, assembly, and repair problems serve as guides to locating joints and tubing length. The mockup is a solution tool.

Block VI A-33. Display Fuel System Tube and Equipment Layout--A graphic display in scale, accuracy, and detail, with views required to describe the system, is produced.

The layout phase is now complete and the design ready for evaluation.

The evaluation phase of the systems design network begins when the layout is complete. Evaluation and dialog with interested groups has taken place through the layout stage; however, at this time a more complete evaluation is made.

Block VI B-1. EAMR Required?--When the layout is complete, and while design evaluation is going on, the design is examined for long-lead equipment items and materials that must be ordered early to be on hand to meet production dates and rates. The engineering advance material release (EAMR) is an instrument used to transmit this data to the purchasing section of manufacturing.

Block VI B-2. Prepare EAMR--Gather the information required, select the long-lead items and materials (extruded shapes, forgings, forged blocks, castings), and prepare the release data.

Block VI B-3. Stress Evaluate EAMR--If no formal drawing has been prepared at this time, stress staff concurrence is requested for procurement of the materials to be used on items released.

Block VI B-4. EAMR Satisfactory?--Does the stress staff concur with the designer that the EAMR is satisfactory for materials, etc.?

Block VI B-5. Project Evaluate EAMR--The project engineer evaluates the EAMR for content and quantities.

Block VI B-6. EAMR Satisfactory?--Does the project engineer concur with the choice and quantity of the items released and with the EAMR in general?

Block VI B-7. Concept or Procedure Problem--If the evaluation of the EAMR at blocks VI B-4 and -6 revealed an error, the type of error determines the next step. If error was procedural, the EAMR is returned to block VI B-2, "prepare EAMR." If there is a design concept error, (e.g., choice of material, extrusion shape, etc.), the process returns to decision block VI A-28.

Block VI B-8. Transmit for Review--Layouts are transmitted for review by propulsion staff, manufacturing, weights staff, materials technology staff, and structures interfacing groups. This is the first semiformal review; however, dialog has occurred throughout the layout stage between the designer and these staffs.

Block VI B-9. Propulsion Staff Analysis--The propulsion staff analyzes the design for assurance that it fulfills all of the requirements established (e.g., fuel flow, fuel capacity, fuel expansion, fuel tank volumes) for fuel management, line sizing, equipment sizing, valve location, sump location, etc.

Block VI B-10. Producibility Analysis--The product manufacture department reviews the layout for producibility involving the procurement of material and equipment and the production assembly and installation of parts and equipment, as well as for accessibility for maintenance.

Block VI B.11. Weights Analysis--The weights staff evaluation includes updating weight and balance calculations, checking loadability goals, reviewing fuel management versus tank arrangement, evaluating design weights versus target weights, etc.

Block VI B-12. Materials Technical Unit--Evaluate materials, standards, and equipment used from a cost, installation, reliability, and state-of-the-art viewpoint.

Block VI B-13. Structures Interface--Interfacing structures review the design layout for impact on structure as to fatigue life, accessibility, etc.

Block VI B-14. Mockup Required?--The decision is made as to whether a mockup or portion of the system is required to provide a further design visibility check. Boost pump location and installation and fuel lines installation are typical candidates for mockup.

Block VI B-15. Prepare and Release Mockup Drawings--When it is decided to build a mockup, drawings are prepared and furnished to the mockup shops to facilitate fabrication. This data is often the layout drawing itself with some supplementary information prepared expressly for the mockup or from interfacing design group's design layouts.

Block VI B-16. Manufacturing Mockup System--This is a manufacturing activity. An engineer is assigned the task of coordinating all mockup direction and feedback between the manufacturing mockup shop and engineering design groups.

Block VI B-17. Evaluate Analysis--Analyses made by the staffs and groups are evaluated. These analyses call for the next activity decision block.

Block VI B-18. System Satisfactory?--After weighing the analyses of all inputs for the design, the decision is made whether to prepare formal drawings of the design or to revise the design and layouts, when the latter is recommended by the analyses. The progression for system redesign is to return to block VI A-19 (develop engine fuel feed system) and proceed to redesign the particular area of questionable design.

Drawing preparation begins after layout is completed to the satisfaction of all involved.

Block VI C-1. Prepare Drawing Picture Sheet--The drawing is prepared on a suitable medium to the indicated scale and accuracy level. Views are developed and shown to completely describe the system and its installation for all the users (engineering, manufacturing, inspection, customer, service support, etc.).

Block VI C-2. Prepare List of Materials--The list of materials, sometimes called parts list, is an integral part of the drawing event, though on large drawings it may be a separate sheet or book. The parts list contains all information (other than the picture itself) required to build, assemble, and/or install the part. This information includes identification, material, heat treatment, protective finish, color, part usage, etc. The IPAD environment will use the engineering data system, which will compose, contain, and distribute parts list information through a data base manager. (See section 5.3.4.)

Block VI C-3. Evaluate Engineering Drawing--After the required data has been gathered, the engineering drawing is evaluated for conformance to the design objective, design layout, and all procedural requirements.

Block VI C-4. Drawings Satisfactory?--This decision block follows the drawing evaluation. If the drawing is satisfactory the activity proceeds along a dual path. Drawings are evaluated while design release authorization is prepared. If the final drawing of the design is not satisfactory, the reason is determined in activity block VI C-15 and the progress continues from there.

Block VI C-5. Transmit Drawings for Review--The completed drawing is submitted for final formal review for the areas and subjects involved. This review is similar to the review in block VI B-8 but to a greater depth with completed background data. The data used in evaluation at block VI B-8 was the current data at that time.

Block VI C-6. Propulsion Staff Analysis--The propulsion staff analyzes the design for assurance that it fulfills all of the established requirements. (See block VI B-9 description).

Block VI C-7. Producibility Analysis--The production department reviews the final design for producibility. (See block VI B-10.)

Block VI C-8. Weights Analysis--Weights unit reviews the final design for conformance to final updated weights data design objectives, etc., and makes recommendations as required. (See block VI B-11.)

Block VI C-9. Material Technology Review--The materials technology reviews the design and drawings for conformity to latests state-of-the-art materials and process. (See Block VI B-12.)

Block VI C-10. Structures Interface--The interfacing structures group conducts a final review for interfacing design problems that may come to light during formal drawing preparation.

Block VI C-11. Prepare Release Order--While the final formal design drawings are being analyzed by supporting groups, release data is prepared for the data manager. The design, which may include several drawings, is packaged for design management approval.

Block VI C-12. Evaluate Analysis--The analysis of each of the interfacing activity groups or staffs is evaluated. The overall effect on the airplane, its service life, and its ability to perform the mission are considered. Some comments may require a design revision; some are considered but not accommodated.

Block VI C-13. Drawings Satisfactory?--If the design, drawings, and data describing the design are satisfactory, the drawings proceed to design management for final approval and release through the data manager.

Block VI C-14. Management Approval--When the drawings and design are declared satisfactory, they are approved by management and distributed to the user by a data manager. The progression is to level VII (product manufacture).

Block VI C-15. Procedure or Other Error?--Any final design drawing found unsatisfactory may violate one or several design objectives. A procedural error in drawing preparation will require a drawing revision and the progression is to block VI C-1. If the problem is more serious (that of a design deficiency in some area) the progression is back to block VI A-19 for redesign.

6.8 SUSTAINING DESIGN

This section deals with the design support required to sustain the product during its production, testing, and service life where problems continually occur.

Design activities for follow-on models, growth models, etc., are not considered here as sustaining design but rather as new design even if much of the previous design is still used. In these cases where major design activity is required for certain product areas, all of the design process levels may be involved as described in sections 6.2 through 6.7.

Detail design and sustaining design involve identical activities and differ only in the initiator and timing of the action. Detail design (level VI) follows sequentially after preliminary design (level V), while sustaining design occurs anywhere during the time span from the release of detail design to production until the last production item is no longer in use by the customer.

During product manufacture (level VII), even though considerable dialog between engineering and production has taken place prior to design completion, production problems and other reasons for design change become apparent and result in requests for changes to drawing data and design. Product manufacturing activities (planning, material procurement, tool design, and part manufacture) initiate sustaining design activities with requests for: correction of data errors; correction of design errors involving fit and function of parts; changes to simplify parts and their manufacture; consolidation of several parts into one for assembly economics; separation of assembly parts for ease of installation; relocation of system and structural joints to facilitate manufacturing methods; and minor changes in parts for utilization of existing materials, tools, or production methods, etc. (See figures 37, 38, 39, 60, 61, and 62.)

During product verification (level VIII), sustaining design involves correcting any design or production deficiencies that may exist when structural, flight, and/or functional testing are performed. (See figures 37 through 40 and figures 60 through 63.)

Sustaining design during the service life of the product (product support, level IX) involves accommodating all of the surprises that the customer can produce. (Anticipated problems have been covered in service bulletins and maintenance manuals.) Sustaining design problems may involve such areas as equipment, systems, spares, and structure. The problems within those areas may be any one or a combination of fatigue, corrosion, wear, rework, appearance, maintenance, access for maintenance and inspection, misuse, accidents, part performance, airplane performance, and operating procedures. (See figures 37 through 41 and figures 60 through 64.)

Sustaining design is also initiated within the design area itself. These are changes to accommodate the state of the art, cost savings, weight savings, and performance improvements. Sustaining design of this character is introduced at any convenient point in a product series, depending on the product usage and anticipated impact on the product quality, function, or cost.

The scope and severity of any problem or deficiency will determine the design levels involved in sustaining. Most sustaining design activities are introduced at the detail design level VI. (See figures 37 and 60.) When a problem appears, the "gather information" process (sec. 6.5) initiates the sustaining activity.

7.0 TECHNICAL PROGRAM ELEMENTS

In 1973 a survey was conducted within an aircraft manufacturing company to identify the typical technical code required to support the IPAD design networks of section 6.0. (The timing and depth of this study did not permit extending this technical code survey outside of this company or updating at this time.) The purpose of this survey was to identify existing code suitable for incorporation into IPAD and to identify the areas where suitable code does not exist. A catalog of 304 items denoted technical program elements (TPE) collected by the team was presented in volume V of the IPAD feasibility study. Due to the volume and age of the data, this compilation will not be reproduced here. (See "Volume V: Catalog of IPAD Technical Program Elements" D6-60181-5, dated September 21, 1973.)

8.0 CONCLUSIONS

Task 1.1 directed the review and updating of the feasibility study design process and the development of supplemental networks for detail/sustaining design.

The design process has been reviewed and updated, and supplemental networks of detail/sustaining design are developed for both a structure and a system. Detail and sustaining design differ only in the timing of the activity.

During the update and the new development two premises surfaced:

> The design processes for a structure (section 6.6) and for a system (section 6.7) are alike.
>
> The process of gathering information (section 6.5) is invoked whenever there is a task or subtask to be performed.

APPENDIX
SI–U.S. CONVERSION TABLE

METRIC TABLES

LENGTH

Myriameter	10,000 meters	6.2137 miles.	Meter	1 meter	39.37 inches.
Kilometer	1,000 meters	0.62137 mile.	Decimeter	0.1 meter	3.937 inches.
Hectometer	100 meters	328 feet 1 inch.	Centimeter	0.01 meter	0.3937 inch.
Dekameter	10 meters	393.7 inches.	Millimeter	0.001 meter	0.0394 inch.

AREA

Hectare	10,000 square meters	2.471 acres.
Are	100 square meters	119.6 square yards.
Centiare	1 square meter	1,550 square inches.

WEIGHT

Name	Number of grams	Volume corresponding to weight	Avoirdupois weight
Metric ton, millier or tonneau	1,000,000	1 cubic meter	2.204.6 pounds.
Quintal	100,000	1 hectoliter	220.46 pounds.
Myriagram	10,000	1 dekaliter	22.046 pounds.
Kilogram or kilo	1,000	1 liter	2.2046 pounds.
Hectogram	100	1 deciliter	3.5274 ounces.
Dekagram	10	10 cubic centimeters	0.3527 ounces.
Gram	1	1 cubic centimeter	15.432 grains.
Decigram	.1	0.1 cubic centimeter	1.5432 grains.
Centigram	.01	10 cubic millimeters	0.1543 grain.
Milligram	.001	1 cubic millimeter	0.0154 grain.

CAPACITY

Name	Number of liters	Metric cubic measure	United States measure	British measure
Kiloliter or stere	1,000	1 cubic meter	1.308 cubic yards	1.308 cubic yards.
Hectoliter	100	0.1 cubic meter	2.838 bushels; 26.417 gallons.	2.75 bushels; 22.00 gallons.
Dekaliter	10	10 cubic decimeters	1.135 pecks; 2.6417 gallons.	8.80 quarts; 2.200 gallons.
Liter	1	1 cubic decimeter	0.908 dry quart; 1.0567 liquid quarts.	0.880 quart.
Deciliter	.1	0.1 cubic decimeter.	6.1023 cubic inches; 0.845 gill.	0.704 gill.
Centiliter	.01	10 cubic centimeters.	0.6102 cubic inch; 0.338 fluid ounce.	0.352 fluid ounce.
Milliliter	.001	1 cubic centimeter	0.061 cubic inch; 0.271 fluid dram.	0.284 fluid dram.

COMMON MEASURES AND THEIR METRIC EQUIVALENTS

Common measure	Equivalent	Common measure	Equivalent
Inch	2.54 centimeters.	Dry quart, United States	1.101 liters.
Foot	0.3048 meter.	Quart, imperial	1.136 liters.
Yard	0.9144 meter.	Gallon, United States	3.785 liters.
Rod	5.029 meters.	Gallon, imperial	4.546 liters.
Mile	1.6093 kilometers.	Peck, United States	8.810 liters.
Square inch	6.452 square centimeters.	Peck, imperial	9.092 liters.
Square foot	0.0929 square meter.	Bushel, United States	35.24 liters.
Square yard	0.836 square meter.	Bushel, imperial	36.37 liters.
Square rod	25.29 square meters.	Ounce, avoirdupois	28.35 grams.
Acre	0.4047 hectare.	Pound, avoirdupois	0.4536 kilogram.
Square mile	259 hectares.	Ton, long	1.0160 metric tons.
Cubic inch	16.39 cubic centimeters.	Ton, short	0.9072 metric ton.
Cubic foot	0.0283 cubic meter.	Grain	0.0648 gram.
Cubic yard	0.7646 cubic meter.	Ounce, troy	31.103 grams.
Cord	3.625 steres.	Pound, troy	0.3732 kilogram.
Liquid quart, United States	0.9463 liter.		

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15. Supplementary Notes

Robert E. Fulton, NASA IPAD Project Manager (Technical Monitor)
Ralph E. Miller, Jr., Boeing IPAD Program Manager — Topical Report

16. Abstract

This document has been prepared in accordance with task 1 (section 3.0) of the statement of work (1-15-4934A) for the development of Integrated Programs for Aerospace-Vehicle Design (IPAD). Study results concerning the airplane design process and its interfaces with manufacturing and customer operations are documented herein to be used as criteria for the development of IPAD.

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Unclassified	Unclassified	375	$12.50

* For sale by the National Technical Information Service, Springfield, Virginia 22161

WEIGHT TECHNOLOGY STAFF

location - wing, payload, etc.
trade & optimization studies
risk analysis
Visibility reports
Proposal weight estimates
Weight istributions
Moment of inertia data
Loadability studies
Budget quote estimates
Growth studies
Competitive analysis
Manpower & budget estimates

Moment of inertia data
Loadability studies
Customer OEW & change estimates
Growth studies
Competitive analysis
Manpower & schedule es
Alternate design studies
Fuel management/volum data
Weight guarantees
Weight control programs
Design to cost data
Weight substantiations
Acoustical weight penalt
Wind tunnel support
Work statement evaluati
AMPR & section weight distribution

MARKETING, SALES, CUSTOMER ENGINEERING

Route & mission requirements
Competitor data
Standard & customer airplane definition

Route & mission requirements
Competitor data
Standard airplane definition
Customer change requests
Field service problems

FLIGHT TEST

MANUFACTURING

CUSTOMER

Route, mission & cargo data & requirements
Request for proposals

Route, mission & cargo requirements
Change requests
Field service reports
RFP'S

Manpower & schedule estimates
Alternate design studies
Fuel management data
Specification weights
Weight & balance control programs
Weight substantiations
Weight & balance manuals
Flotation & ditching data
Ballast system data & requirements
Flight simulation mass data
Vendor weight compliance
Onboard weighing system data
Cargo handling limitations
Jacking requirements
Weight reduction programs
Actual weighings
Control surface balancing
Weighing requirements & procedures
Test airplane weight & balance manifests
Test airplane weight tracking
Weight & balance placards
Fuel test support

Specification weights
Weight and balance control programs
Weight substantiations
Weight & balance manuals
Flotation & ditching data
Competitive analyses
Flight simulation mass data
Vendor weight compliance
On board weighing system data
Cargo handling limitations
Jacking requirements
Weight reduction programs
Actual weighings
Control surface balancing
Weighting requirements and procedures
Weight & balance placards
Service bulletin and mod. kit weight & balance estimates
Post design analyses
PRR weight & balance estimates
Demonstation flight weight and balance
Special operational procedures
Crew training manifests & loading schedules
Delivery manifests
Customer information

WEIGHT TECHNOLOGY STAFF

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Route & mission req'mts
Competitor data
Standard airplane definition
Customer airplane definition
Customer change requests
Field service problems
Service bulletin data sheets
Demonstration flight requirements

MARKETING, SALES, CUSTOMER ENGINEERING

test schedule
test weight
envelope

FLIGHT TEST

M data
information

CAD/CAM data
Planning information

MANUFACTURIN(

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requirements
equests
ice reports

Route, mission & cargo requirements
Change requests
Field service reports
Operational weight & CG requirements
Training requirements

CUSTOMER

Addenda

WEIGHT TECHNOLOGY STAFF TASK OVERVIEW

MIZATION)

PRELIMINARY DESIGN
(VEHICLE DEFINITION)

INPUTS

Performance data and requirements
Design criteria and requirements
Sizing & limitation data
Noise & thermodynamic requirements
Structure & system definition
Safety requirements
CG limitations

3 View
Inboard profile
Layouts & schematics
Design requirements
Work statements
Structure & system definition
Safety requirements
Trade study definition

Risk & cost assessment
Configuration selection
Scheduling
Design philosophy

Management directives
Data requests

TASKS

Class II weight & balance
Configuration estimates
Trade & optimization studies
Risk Analysis
Weight record system, visibility reports & meetings
Proposal weight estimates
OEW & payload distributions
Moment of inertia data
Loadability studies
Customer OEW & change request estimates
Growth studies

DETAIL DESIGN
(GO AHEAD TO DRAWING RELEASE)

INPUTS

Performance data and requirements
Design criteria and requirements
Sizing & limitation data
Noise & thermodynamic requirements
Structure & system definition
Safety requirements
CG limitations

3 Veiw
Inboard profile
Layouts & schematics
Released drawings
Work statements
Structure & system definition
Safety requirements
CAD/CAM Data
Trade study definition
Vendor proposals & specifications

Risk & cost assessment
Configuration control
Schedule control
Spec weight control
Target weight control
Preliminary design reviews
Critical design reviews

Management directives
Data requests

TASKS

Layout weight & balance estimates
Drawing weight & CG calculations
Configuration estimates
Trade & optimization studies
Risk analyses
Weight record system, visibility reports and meetings
Proposal weight estimates
OEW & payload distributions panel loads, AMPR & section weight distributions
Material distributions
Moment of inertia data
Loadability studies & schedules
Customer EW and change request estimates
Budget quote estimates
Growth studies
Competitive analyses

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DESIGN VERIFICATION
(FIRST ARTICLE MANUFACTURE & TEST)

PRODUCTION
(SUSTAINING AND IMPROVEMENT)

JTS

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TASKS

Drawing weight & CG calculations
Configuration estimates
Trade & optimization studies
Risk analyses
Weight record system, visibility
reports & meetings
Proposal weight estimates
OEW & payload distributions
Moment of inerta data
Loadability schedules & devices
Customer OEW & change
estimates
Budget quote estimates
Growth studies
Competitive Analysis
Manpower & schedule estimaties
Alternate design studies
Fuel management data
Specification weights
Weight & balance control programs
Weight substantiations

INPUTS

Performance monitoring
Design criteria
Safety requirements
Qualification testing
Jacking limitations
Surface balance
requirements
CG limitations
Derivative study
definition

Released drawings
ADCN'S, DCN'S
CAD/CAM data
PRR'S
Qualification testing
Service bulletins
Mod kit drawings
Derivative study
definition
Trade study definition

Risk & cost assessment
Configuration control
Schedule control
Spec weight control
Production design
modification control
Derivative program
control

Management directives
Data requests

TASKS

Drawing weight & CG calculations
Configuration estimates
Trade & optimization studies
Risk analyses
Weight record system & visibility
meetings
Proposal weight estimates
OEW & payload, distributions
Moment of inertia data
Loadability schedules & devices
Customer OEW and change
request estimates
Budget quote estimates
Growth studies
Manpower & schedule estimates
Fuel management data
Specification weights
Weight and balance control
programs
Weight substantiations
Weight & balance manuals

INTERFACING GROUPS

TECHNOLOGY STAFF

DESIGN PROJECT

MANAGEMENT

COST AND FINANCE

WEIGHT TECHNOLOGY