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

Volume II: The Design Process

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16 Abstract

Volume II of the Boeing report on the IPAD feasibility study identifies the extent to which IPAD is to support the design process. Case studies of representative aerospace products were developed as models to characterize the design process and to provide design requirements for the IPAD computing system. The user requirements to support the case studies are presented in Volume III. The existing and new technical code required to support the subsonic and a supersonic commercial transport case studies are cataloged in Volume V.

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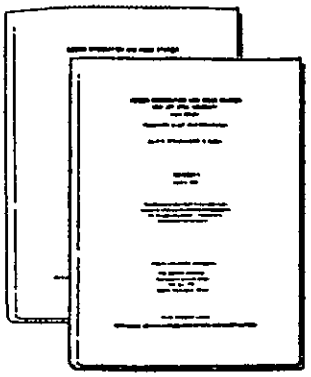

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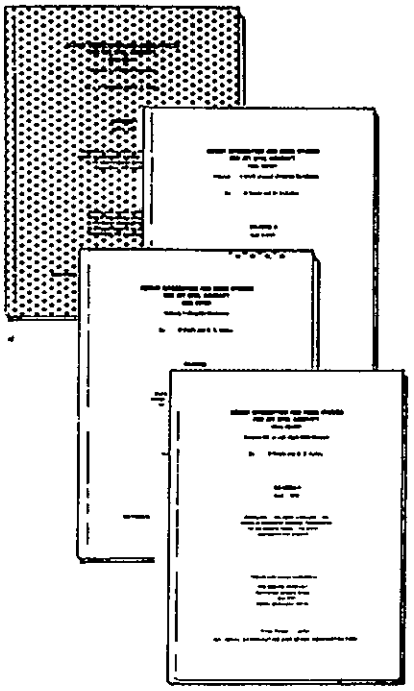
Summary of IPAD Feasibility Study
D6-60181-1A

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

Part I—Final Report, Tasks 1 and 2



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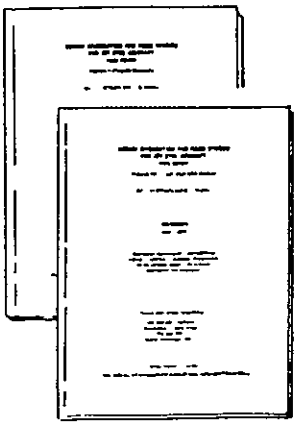

Volume VI
IPAD System Development and Operation
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Volume VII
IPAD Benefits and Impact
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SUMMARY

Volume II of the Boeing report on the IPAD feasibility study establishes the extent to which IPAD is to relate to the design process. This is achieved by recommending the kind and degree of design that is to be done within IPAD, and by developing a catalog of the technical computer code required to do that design.

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

The first section is the IPAD interface with continuing research, from which new technical code elements and data are incorporated into IPAD. This section has only one Level. The second section is comprised of four Levels and is concerned with the preliminary design of the product. The four Levels in this section are: Design Mission and Criteria Selection, Design Sizing, Design Refinement, and Design Verification. The third section is concerned with the detail design and manufacture of the product, and is also comprised of four Levels. They are: Product Detail Design, Product Manufacture, Product Verification and Product Support. For each of these Levels, the extent of design and analysis, the computational resources required, and the resultant accuracy of the answers will be known to management. After review of the results of each Level, management may commit the design sequence to the next Level.

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

Optimization techniques and a recommended strategy for their application to the design networks are are discussed. Three classes of optimization are identified for the IPAD environment. They are direct or mathematical programming, which is computer controlled; trade-off studies, which are done by a

combination of user control and computer control; and sequential model refining, which is entirely a user-controlled process.

The information drawn from the study of Projects 1 and 2 is used to prepare requirements for the support of the design process. These requirements are presented in Volume III.

A recommended implementation strategy is presented. The initial implementation should provide a suitable balance between technical capability and system capability. There must be adequate Technical Program Elements available to support the development and check-out of the IPAD System software and to provide the minimum technical capability which will justify the initial development cost of IPAD. This would include the first parts of the Preliminary Design Levels for Projects 1 and 2, and the design-manufacturing interface, which would be somewhat product independent. The long term development would complete the technical capabilities for all the Levels. Then, for future development, the IPAD System will support the changing nature of the tasks associated with the design of the product, by improving existing technical disciplines, and adding or discarding other technical disciplines as the state of the art advances.

The questions of Task I and selected questions of Task 2 are answered. In general, these answers state that IPAD should eventually be applied to any product that requires control of a large data base. It should be applied to all parts of the product design process and manufacturing interface. The division of product activity into levels gives management the ability thru IPAD to control the optimum balance between level of analysis, computing cost and flow time. It is clear to those who have conducted this feasibility study that an IPAD which meets the objectives established in this Volume will be a national resource, and will contribute significantly to the advancement in the state of the art of aerospace vehicle design.

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1.0 INTRODUCTION

This volume reports the findings of Task 1 of the IPAD feasibility study relative to the required support of the design process. The purpose of Task 1 was to determine the extent to which IPAD should support the design process and to identify the following: (1) the aspects of the design process which should be carried out by IPAD and the degree of design detail to be modeled; (2) the availability and adequacy of computer programs which are currently available for IPAD and (3) the areas where suitable programs are not available and to recommend the areas where programs should be developed.

1.1 OBJECTIVES.

The following objectives were established to determine the required support of the design process: (1) to identify design logic which an IPAD executive and data base management system would be required to support; (2) to identify strategy for optimization; (3) to determine the aspects for a short term and a long term IPAD implementation strategy and (4) to provide a library of technical program elements (existing and required computer code) which perform the design and analysis required to support the design logic.

1.2 BACKGROUND

The studies reported in this volume were to define technical requirements for the IPAD system, based on needs identified by a representative group of experienced users. Initial tasks involved the construction of network models of the design process for two representative projects of the type that IPAD must support. These models have provided essential background for team discussions of critical interdisciplinary problems and for the appraisal of existing computational capabilities, identification of current deficiencies. Information from Section 4 (design and analysis iteration loops in the design networks, and associated task descriptions) and from the Catalog of Technical Program Elements in Volume V have provided background for the analysis of optimization strategies reported in Section 5 and answers to the Task 1 and Task 2 question reported in Section 2.

It is emphasized that the project design networks presented in Section 4 are examples only, not fixed models of the design and decision process. Rather they should be viewed as an engineering input which is pertinent to the IPAD system design.

Since the design and analysis of the IPAD system itself should be viewed as an iterative process, the information in this Volume should in fact be regarded as the initial user inputs. Finally, the material presented here should provide some basis to judge the need for an IPAD system and to evaluate potential benefits from its implementation.

2.0 ANSWERS TO TASK QUESTIONS

2.1 GENERAL

The answers to Task 1 and Task 2 questions which relate to the support of the design process are presented in the following sections. All Task 1 questions and several Task 2 questions are answered here. The remaining Task 2 questions relate to user requirements or to the IPAD system design and are answered in Volumes III and IV. A discussion has been included following each answer to clarify or expand the information and in some to relate the answers to sections of this document where additional information may be found. Many of the answers to the task questions refer to Design Levels. These levels are discussed in detail in Section 3 and 4 and are considered essential to permit rigorous management control of the IPAD design process.

2.2 TASK 1 QUESTIONS (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 & 12)

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

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

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

Discussion--The technical design and analysis capability must include all disciplines which influence the size, arrangement and performance of a product. In addition, the finance, marketing and manufacturing factors which influence the product size and performance must be identified and accounted for in the technical definition of the product.

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

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

Discussion--Of the twenty technical disciplines identified during the characterization of the design process, the disciplines of geometry lofting, mathematics, noise and product assurance (reliability) are adequately represented by existing code. The disciplines of aerodynamics, flight control systems, finance, propulsion, static and dynamic loads, flutter and stress have over half the indicated code presently available. The disciplines of configuration design, marketing, performance, stability and control, systems and weights have less than half the required code available now, although code is under development in many of these areas. The discipline of structural design and the preliminary design management information system are missing, and no code is currently under development. These indications are based on a Boeing survey, and are subject to some change at other sources. This subject is discussed in Section 6.0.

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

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

Discussion

(1) In Design Levels V and VI, several disciplines are highly dependent upon experimental data. In the context of this answer, experimental data is taken to mean information

pertaining specifically to the particular configurations under consideration. Stability and control data will be almost exclusively derived from wind tunnel model testing at all of the various speed regimes. Static loads on secondary structure will also be determined exclusively by wind tunnel model testing. Noise levels and patterns will be predicted using noise rig testing. The answers above pertain to both Project 1 (Subsonic Commercial Transport) and Project 2 (Supersonic Commercial Transport). In addition, representative experimental data will be required in Design Level IV by the stability and control discipline, for the case of Project 2.

(2) In Design Levels V and VI, the disciplines of aerodynamics and flutter are dependent to a lesser degree on experimental data for the particular configuration, as a sizable portion of the design and analysis work in these disciplines can be done analytically.

(3) The disciplines representing the propulsion systems will be represented by experimental information that begins at Design Level IV and increases in depth through the higher levels.

(4) In Design Levels II, III and IV, all of the disciplines, excluding the avionics part of any flight control systems and excluding the configuration lofting, are dependent to some degree on statistical data. This class of data is distinct from experimental data and is discussed more fully in Task 1, Question 6.

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

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

Discussion--The test facility will repeatedly take data in a similar manner for a succession of configurations or components. Consequently, the personnel at the test facility will develop the best understanding of the errors and limitations of the test techniques. This understanding provides corrections to the acquired data and cautions concerning limits to its validity. The reduction of the raw recorded data into some useful coefficient form would best be done by personnel representing the test facility. Hopefully, this data reduction itself will be done in the IPAD environment, using all the

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features of the IPAD system to reduce and enter the data into the appropriate community libraries.

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

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

Discussion--If an aspect of the design process can be quantified, then it can be automated. Thus, the parts of the design process that cannot be written in sets of mathematical processes cannot be automated and must remain under the control of the user. There are three main parts of the design process that cannot be quantified.

Firstly, management control over the selection of the designs to be examined is based on many intangibles. Some of these, for example certain market requirements, can be of a mathematical or statistical nature. But many of the criteria controlling selection of design classes are based on diverse and undocumented customer needs, human factor concepts and poorly understood yet powerful user preferences. Thus, in many cases the beginning design will simply be legislated by management. The early Design Levels (II and III) will provide dependable analysis rapidly to point out poor designs or design features that have been advocated.

Secondly, a large part of the evaluation of a design is not quantifiable. These points of evaluation will range from "it just doesn't look right" to serious objections based on engineering evaluations that have merit, but cannot be stated mathematically. In the IPAD environment, these evaluations will be aided by the data base management and display features of the IPAD system.

Thirdly, an entire class of optimization, namely tradeoff studies (see Chapter 5, section 5.2.2) will work to improve certain design parameters simultaneously. In most cases no single merit function weighing relative gains among the parameters can be written. It will be left to the user to control this class of optimization, aided by the data base management and display features of the IPAD System.

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

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

Discussion--The development of a project begins as an identifiable form at Design Level II. In this level, most of the required information will be statistical in nature. In the context used herein, statistical information will mean information of a general nature, rather than uniquely pertaining to the configuration under consideration (see Task 1, Question 3). This statistical information will be used starting in Level II and will continue until the information can be replaced by specific experimental and analytical information which will pertain uniquely to the configuration under consideration.

The statistical information will enter the pertinent data base for three reasons. Firstly, information representing technological advances will enter the IPAD environment at Level I. This is the viewpoint through which IPAD will watch the broad areas of research and development that pertain. Secondly, statistical information representing in-service histories of actual products will be recorded and stored by the activities of Level IX. Thirdly, many of the Technical Program Elements will generate statistical information (e.g., Type A Weights) in the early design levels.

As the design progresses through the design levels, each technical discipline will begin to replace its statistical information with experimental data and analytical information which pertains to the specific configuration under consideration. Statistical information never disappears completely from the data bank of a particular product because it is not always cost effective to go to the trouble of replacing the information with experimental and/or analytical information.

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

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

Discussion--For purposes of this discussion, non-optimum structural material is assumed to be that material associated with the primary structure that is over and above the theoretical material which can be derived using the available structural models and is based on the conditions which are expected to design the structure and that can be accommodated by the model, e.g., static loads, dynamic loads, flutter, thermal loads, etc. The non-optimum material includes such items as fasteners, edge members, access doors, cutout reinforcements, manufacturing tolerances and constraints, cores, clips, splices, and miscellaneous attachments.

From the time that the non-optimum material weight appears as an identifiable item in the second part of Level III until the time when detail part layout drawings are released, the non-optimum weights will be calculated in a statistical manner and will probably be based on a percentage of the optimum (theoretical) primary structure material weights. There are three primary reasons why a statistical approach is used:

1. Sufficient detail design information is not available.

2. The cost of determining the non-optimum weights in other than a statistical manner is high.

3. There is limited experience available from associated structural models that produce theoretical weight.

Also in some cases, errors in the non-optimum material weight might be tolerated because of the relatively small portion of the total weight that is contributed by the non-optimum weight. As the structure is modeled in greater depth in the higher preliminary design levels, the absolute value of the non-optimum weight factors can be improved.

The secondary structure weights will be handled in a similar manner. Beginning in the second part of Design Level III and continuing through the product design levels when detail part layout drawings are released, there will be a heavy reliance on statistical information to generate secondary structure weights. The reasons for this are similar to those associated with the non-optimum weights, together with the difficulties of formulating the conditions which will size the secondary structure items. As the structure is modeled in greater detail in the higher preliminary design levels, many of the "secondary" structure items will be included in the structural model and will be sized by analysis based on the pertinent design conditions.

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

a. Preliminary design?

b. Detailed design?

c. Final analysis?

d. Can all be included in the system as a natural progression of the design process?

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

Discussion--Figure 4.1 (page 24) divides the product environment into nine levels of involvement, which are then collected into three groups. These groups and levels within groups are presented in detail in sections 4.1 to 4.4. The IPAD system will be involved in all nine levels. The Data Base Manager will be very obvious in all levels. It will provide the tie, in terms of data base, between all of the levels. Thus, when the IPAD system is developed, it will be able to support any design or product level.

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

a. Commercial vehicles?

b. Military vehicles?

c. Aerospace vehicles?

d. All?

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

simply await development of the necessary Technical Program Elements.

Discussion--Application of IPAD is limited only by the development of required Technical Program Elements. It is recommended that the first application be to commercial aircraft vehicles, as the largest pool of available Technical Program Elements from which to draw is in this area. It is further recommended that in support of a future national priority that Technical Program Elements be selected which will support the design of an advanced supersonic transport. It is strongly maintained that IPAD could become an invaluable tool for identifying a suitable configuration for this vehicle among the myriad of options and variations that must be considered. A parallel selection of Technical Program Elements for a subsonic transport is also recommended. This would provide the capability to check out the IPAD system software and to calibrate the Technical Program Elements.

Once the IPAD system is operational, application to other products merely awaits the development of a suitable library of Technical Program Elements. Obvious collections will develop for military and aerospace vehicles, as funding is made available.

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

Answer--With the nine Product Levels as provided in figure 4.1, the conflict is avoided. For each of these levels, the extent of analysis, the computational resources required, and the resultant accuracy of the answers will be known to management. After review of the results of each Level, management will commit the design sequence to the next higher level.

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

Discussion--The development of the nine design levels shown on figure 4.1 (Page 24) was done by first establishing the trend

of accuracy versus response time. This trend is a management requirement. The cost of attaining the solution in each level is a second constraint, established by the user. The resulting requirements of accuracy, cost and response time for each level become a goal to be met during the characterization of the design process within a given level. This goal also determined the nature of the Technical Program Elements required by each technical discipline to produce a balanced answer. It may be necessary to develop a sizable number of new Technical Program Elements in order to keep near the optimum trade of accuracy, cost and timing.

Once a given design level is operational for a certain class of products, a series of calibration cases will have to be run. These will be known examples of actual product hardware. The calibration will indicate the precise trades between accuracy, cost and timing. To achieve the desired accuracy, it may be necessary to exchange certain of the Technical Program Elements among the levels.

The final, documented performance of each of the design levels for a particular class of product in terms of accuracy, cost and timing becomes a powerful guide to management. With this information available, the commitment of the design to higher levels can be made by management with high confidence that the step will be cost effective.

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

Answer--The design strategy is completely represented by the nine design levels of figure 4.1. This forms an orderly sequence of design steps that increase the accuracy and reliability of the design for a known additional cost. Because of the orderly development of the product design arising from the design levels, the generation of trade-off data should be carefully controlled. Trade-off data should be collected from generalized studies thus providing related parametric data having established trends. Designers may extract specific information from data in this form and with reasonable accuracy predict the capability of specific cases. This data will be used in Levels II, III and IV and should speed up the design process. A trade study plan must be implemented and continually updated to achieve the final optimum design selection.

Discussion--The design strategy has been developed and established in general by the design levels of figure 4.1. This general outline has been developed in detail for Project 1 and

Project 2 (see figures 4.2, page 32 and 4.6, page 142). The detailed design networks serve as the guide for the optimum design strategy for these two classes of products, a subsonic and a supersonic commercial transport. New classes of products, for example, a large naval vessel, should have the detailed design network planned in a similar manner prior to beginning implementation of relevant Technical Program Elements.

Trade-off data should be developed from theory and by testing. For example, a wing sweep versus wing thickness generalized testing would develop data for a family of related wing designs. A base test configuration which meets a specified mission would be selected using the design networks for Levels II, III and IV. A family of test configurations would then be developed from the base configuration such that a grid of parametric data can be developed using the Level V design network. The IPAD data mangement capability will allow recall of all trade data recorded during past investigations. Using generalized methods should provide greater confidence in past studies. Every effort should be made to keep the number of trade studies for a given problem as few as possible.

Conducting comparative trade studies to select the optimum configurations is possible using only the design network for Levels II and III but is limited to investigation of similar configurations for which the analysis methods are identical. This capability will greatly speed up the design process. However, investigations of non-similar configurations such as comparing engines on the wing to engines on the body—must be extended through the Levels IV and V design networks to gain the accuracy and empirical data required to select an optimum engine location.

Trade studies will also be conducted by specific technical disciplines on detail designs in Levels IV, V and VI. An example might be the comparison of two versus three actuators for a specific control surface. These detail trade studies are conducted in a similar manner to overall configuration trade studies and may use generalized parametric data as well as specific test data.

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

Answer--The data base management features of the IPAD system will provide for very efficient data communication between code within IPAD. Inefficiencies will arise when codes

brought together in IPAD have significant engineering overlaps. As this situation raises the question of integrity of the results, editing the overlaps in the code is more than a question of economics, and should be eliminated whenever possible.

Discussion--Independently developed code will be sufficiently efficient in its present form, or it would not likely be considered for IPAD. The IPAD system should not make this code less efficient when the code is a part of IPAD. Two such sets of code, when used together in IPAD, should have a very efficient data communication, as supported by the IPAD system's data base manager.

However, it is likely that two sets of independently developed code will have some overlaps in their engineering calculations. Each overlap of this nature reduces the efficiency of the calculations, but more important, the overlap could decrease the integrity of the final results. There will be no assurance that the repeated calculations will produce the same answer in the various sets of code. Whenever the manpower is available to do so, these overlaps should be removed from the technical code in IPAD.

2.3 TASK 2 QUESTIONS (4, 5, 6, 7, 8, 9, 13)

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

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

Discussion--The user will have the option in IPAD of making his presence felt during the entire sequence involved in getting his job done. This will begin in the first stages where both the code to be executed and the data sets to be used as input are prepared. These operations will typically be interactive, with text editing done to both code and data from the personal terminal.

Once execution begins, the type of user presence in the control of the solution varies with the design level. Taking

Project 1, the subsonic commercial transport, as an example (see figure 4.2, page 32), the user will begin a Level II solution by interactive text editing of both code and data. Once in execution, the mode becomes one of interdiction, with the user monitoring the solution and interrupting that solution should an undesirable path be taken. The execution times will be so short in Level II that the user would best monitor the solution rather than interactively control it.

Much the same approach is taken in the first half of Level III, where the geometry is sized. Beginning with the second half of Level III, where the primary structure is sized for the first time, the sizes of the Technical Program Elements and their computational times become large enough that the user can provide control over the direction of the solution without the risk of penalizing to an unacceptable extent the execution of these larger programs. In fact, as the solution tends to become more complex, interaction will increase. In the earlier levels, the design algorithms relating the various design and analysis processes can be written. For the more detailed problems found in the higher levels, the design algorithms cannot always be written. As repetitive sequences are recognized during interactive design activities, these sequences will be automated. This process will result in an evolutionary development of design technical code. Thus, the sequence of solution must be directed by the user through the interactive mode.

The user will also monitor and interdict optimization processes during their solution. This refers to the direct, or mathematical optimization processes that execute automatically. These will be monitored to interrupt and restart a solution that is not performing correctly.

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

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

Discussion--The data base for a given product will contain the engineering definition of all of the variables known by IPAD relating to the product. There are three classes of these variables. Firstly, a small set of the variables are important as design variables at the start of the design in Levels II and the first half of Level III. But in the higher design levels, these variables are discarded in favor of variables that give a more precise expression. For example, in Levels II and III, a

wing section will be parametrically generated from perhaps ten parameters, such as leading edge radius and maximum thickness. But in the higher levels, as wind tunnel models are being designed, a more precise definition will be required for the wing sections, and these parameters will become inactive.

Secondly, there are design variables that are important throughout the entire design process. An example would be takeoff gross weight, or the design range-payload curve.

Thirdly, there are variables that become active in the higher levels. This class will contain by far the largest number, and will dominate the data base storage situation. To continue the example above, once wind tunnel models are being designed, the wing section that was at first completely specified by ten parameters will now be specified by 100 points. These points, although they will be pairs of coordinates, are truly parameters and will be treated by both the user and the IPAD system as such.

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

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

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

Discussion--Each new Technical Program Element that is added to the library becomes available for use in design and analysis tasks and increases the degree of completeness that can be achieved for the design. At some point, there will be enough of these Elements available to do essentially the total design of the product. The entry of a new Element into the dictionary will be accompanied by a declaration to the dictionary of the variables that appear at its boundaries. When the user chooses a set of Elements to do a certain design or analysis task, the

IPAD system will help him to realize all of the variables of the total set known in the community library that are active for that task.

The number of variables may become large, and there may be many variables that have logical relationships. The user can group related variables into sets of data, to make the portability of groups of data easier. There is no restriction that all the variables in a data set be logically related, but in most cases they will be. The variables collected in data sets are entirely at the user's discretion, and the user will reorder his data sets from time to time.

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

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

Discussion--The total set of design variables known to the community library is directly related to the design and analysis capability currently available. To reduce this number of design variables known to the community library would require deletion of some of the design and analysis capabilities. There are two alternatives to the user rather than this drastic one. Firstly, the subset of variables needed by the user depends on the task he is performing. In Level II, the user will spend only a short time getting his result. The number of Technical Program Elements is small and so is the number of variables. At the other extreme, Level VI will use nearly all the variables known to the community library. The time frame for Level VI will be very long, so there will be time available to work with large numbers of variables. However, Level VI is actually made up of many users doing many small jobs. Each of these will use a small subset of data; no single user will need all the variables at any one time.

Secondly, any user at any level can collect his data into data sets. Data sets will help the user in the lower levels. In the higher levels, data sets will greatly enhance communication between users.

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

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

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

Discussion--Overall optimization means that the whole product is seen by the design and analysis processes to be used during the optimization. Whereas the product is not totally specified unless all the variables are used, the magnitude of this set of variables is many times larger than can be accommodated by a formal optimization process. In order to do the overall optimization, the detail of the product definition must be reduced until the number is small enough to allow formal, mathematical optimization techniques. The number will be on the order of twenty variables or less. This does not mean that the product is represented by only twenty variables, but that these are the variables that are directly modified during the optimization sequence.

Once the total optimum is achieved, then sufficient detail is developed to allow suboptimization. At this stage, none of the variables of optimization from the previous level of optimization can be modified. The suboptimization stage is a sequence of growing detail until the detail part design stage is reached. At no point, however, can any level of optimization use as a variable of optimization any variable that has been used as a variable of optimization in a previous stage of optimization. This causes the optimization loops to be nested, rather than overlapping.

As an example, consider the optimization and eventual detail part design of a hydraulic actuator for the horizontal tail. The optimization would begin in Levels II and III, where,

among other things, the optimum tail size would be found. Included in the analyses of these levels would be statistical data that would represent the total weight of the entire bydraulics package. But this particular actuator would not be uniquely identified.

Further into the design, in Level IV for example, elevator hinge moment data, structural stiffness data and the stability and control requirements of the flight envelope would allow suboptimization on the number, location and size of the individual actuators. This particular actuator would be first identified at this point.

Finally, in Levels V and VI, the detailed design of the actuator would occur. Optimization of the detailed design of the actuator would be done by the designer to achieve objectives of control function, weight and reliability.

In this example, the aeroelastic feedback loop would be considered in design of actuator and empennage structure. This is illustrative of a technical risk that is incurred by oversimplification in overall optimization (or configuration definition) and excessive constraint in suboptimization (subsystem or detail design). Some risk of this sort is unavoidable. IPAD will contribute to the reduction of that risk by providing an improved capability for interdisciplinary analysis. It will also provide a tool for research on design or optimization methodology with fewer constraints (integration of subsystems).

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

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

Discussion--Direct optimization works to maximize or minimize a single function. In some cases, it may be easy to select a single variable. However, in other cases, there may be several variables to be optimized where a weighting must be developed to tell the optimization process the relative importance of these variables. If a weighting cannot be

achieved, then the optimization will have to be done by trial and error.

The best situation is for the customer of the product to specify the weightings for the merit function. Where this cannot be done, then the designer has to make the choice. There is no formal process for making this selection. It might be suggested that the designer try several groups of weightings, and evaluate the resulting optima from each group in terms of the sales appeal. But if the designer can make this evaluation, then direct optimization could have been done using total predicted sales as the single merit function.

There is another possibility in determining a set of weightings. That is to state the variables of optimization (i.e., direct operating cost, field length, initial cruise altitude, etc.) and develop a statistical set of weightings by using previous aircraft as a source. However, this will be a backward-looking set of weightings, and as such may penalize a technological advance.

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

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

1. Operational Technical Program Elements for design and analysis of a subsonic commercial transport for Levels II and III of the design networks for Project 1.

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

Discussion--The initial implementation of IPAD should be primarily involved in the development and checkout of the system software. Therefore, the development of Technical Program Elements should be restricted to modification of existing code and limited development of new design code where none exists. It is considered possible to develop Levels II, III, and IV of Project 1 and Levels II and III of Project 2 during an implementation period of two to three years. This capability is required to checkout the IPAD system and it will also provide the minimum initial technical capability to justify the development cost of IPAD. The answer to Task 1, Question 9 also supports this selection. Refer to Volume IV for the answer to

3.0 PROCESS FOR SELECTING TECHNICAL TASKS

3.1 OBJECTIVES AND APPROACH

The major objective of this part of the feasibility study was to characterize the design process in order to establish technical requirements for the IPAD System design. This objective was realized by selecting a suitable set of design and development projects and to describe the related tasks in sufficient detail to provide a design logic upon which the definition of technical requirements for IPAD can be based. This has been accomplished by a team effort involving experienced representatives of all of the major aerospace disciplines. In a series of conferences and group discussions this task force has analyzed representative examples of the design-analysis-decision processes that IPAD must support. Members of the group have also prepared an inventory of existing and required technical elements (computer programs) to perform the tasks related to each technical discipline. Task descriptions have been written to explain how the technical elements are employed in performing each task of the design projects. Group conferences were held to prepare a collective estimate of design and analysis iterations. This estimate, when used with the information gathered about the technical tasks, determines the magnitude of the data storage, data access, and computational activity. These computational requirements are contained in Volume III.

3.2 SELECTED PROJECTS

The primary consideration in selecting representative projects for study was to achieve technical task descriptions and computing hardware and software specifications that would support a broad range of product applicability. Therefore, it was decided that one of the selected design projects should make maximum use of existing technology, which would be conducive to a high level of design application. A subsonic commercial transport was selected as the first project to be used in identifying IPAD technical and system requirements. This was regarded as a logical initial choice since extensive design and analysis experience is available within The Boeing Company for the 707/727/737/747 class of airplanes.

It was felt that the second design project should focus attention on limitations of current technology and on a high degree of interaction between different disciplines, since these characteristics will help to identify critical areas requiring new program development. Also, this project should represent

the largest product scope to be undertaken in the IPAD environment. To satisfy these requirements a supersonic commercial transport was chosen for the second project. This project requires considerable depth of analysis in the early stages of design and a particularly heavy computational work load in the later stages.

Finally, to provide background for consideration of non-aerospace applications of IPAD, a Naval Hydrofoil was selected.

3.3 PRODUCT DESIGN NETWORKS AND LEVELS OF PRODUCT INVOLVEMENT

The product involvement by levels which relate to design depth and computational flow time was considered essential and levels were used to form the work flow logic for each design project. These levels must provide management with control of the desired depth of design refinement, the schedules and the budget control for solving problems in a cost effective manner. Goals for flow time and computational time were established for each product in several levels of design involvement.

As a result of the group meetings mentioned above in section 3.1, the design and analysis tasks comprising each successive level have been identified. Consideration of data requirements, interrelationships between tasks, and design and analysis iterations required to satisfy design requirements and to support decisions has provided the basis for construction of the design networks for each of the design projects.

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

3.4 TECHNICAL TASK DESCRIPTIONS

On the basis of common understanding of individual tasks established in constructing the project networks, team members have prepared narrative descriptions of activities identified with each network block. These narratives generally describe the application of particular technical elements in performing

the specific tasks. Task descriptions are included in the following sections dealing with the individual networks.

Each task was characterized as entirely manual or computer supported. Each computer supported task would be performed by one or more pieces of computer code, denoted Technical Program Elements. A catalog of these has been assembled into a library of IPAD computational elements and are presented in Volume V.

Information such as number of boxes of source cards, central processor time required, and input/output volume is collected for each Technical Program Element. Also, the status of each Element is given. These data aid in the development of the computing hardware and software specifications, and indicate those parts of the design network that require new code to be written.

4.0 DESIGN NETWORKS FOR SELECTED PROJECTS

4.1 GENERAL PRODUCT LEVELS

The purpose of product 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 4.1 shows the generalized product levels in the IPAD environment. There are nine product levels divided into three sections.

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

The second section is made up of the Preliminary Design Levels. The four levels in this section are design criteria selection, design sizing, design refinement and design verification. Design goals for the four levels must be chosen to balance analysis versus computing time. This will prevent a conflict between the level of analysis and computer time. Control of the required engineering resources is the principal criterion for the establishment of the preliminary design levels. Accordingly, the activities relating to preliminary design will be collected by types of activities and hierarchies of analysis capabilities to achieve the objective of meaningful design results in a usable time period. Thus the capability will be provided to develop a product design and consistent data base definition in a time sequence which is responsive to management control of costs, schedules and technical depth of analysis for each competing configuration under investigation. 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 3 months flowtime and a large budget expenditure.

The following terms (computational flow time, execution time, design cycle time and converged design cycle time) are referred to frequently, therefore, they are defined here.

1. Computational flow time - the total elapsed working time from the start to the end of the computational process. This computational process begins with the

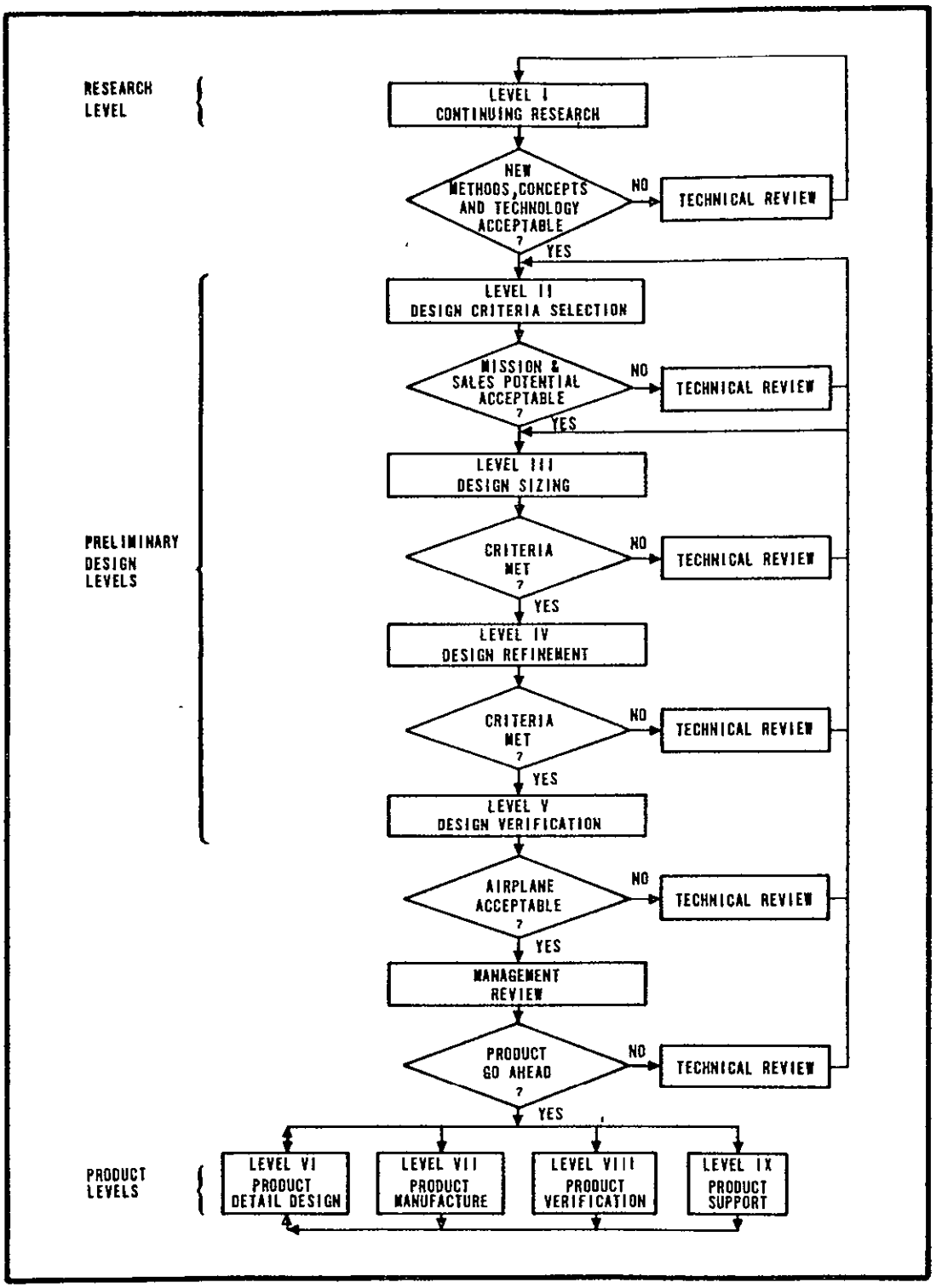

Figure 4.1 IPAD Product Levels

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user collecting data already within the library and making minor revisions or updates. The user then commits the job into execution. If the job is small, he will remain at the terminal. If the job is long, he will enter the job into a batch execution mode. After execution is complete, the user will do some cursory examination to determine if the results are essentially complete and correct. This marks the end of the computational flow time.

2. Execution time - actual execution of the host CPU, measured relative to 3rd generation equipment for this document.

3. 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 time will analyze, recycle and suggest redesign for the input design.

4. 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.

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 highest 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, compuational flow time and design cycle time are synonymous. The representations of the pertinent technologies would be in very 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 and 1/2 to 3 months with execution times of approximately 40 to 200 hours. The converged design cycle time would be 3 to 6 months.

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, then 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.

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 the Product Verification. As soon as components, and then the completed product are available from manufacturing, testing will begin 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 4.1 shows the four levels in the Product Level group to be in parallel. 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 levels of the Product Levels group. 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 to select host hardware. Also, the design and manufacture of complex products should have greater benefits from the IPAD environment. Two product classes have been chosen for examination in this feasibility study. They are a subsonic commercial transport and a supersonic commercial transport. 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 Level II and III match the design (configuration) size to the mission and design requirements. These levels treat

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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 pre-selected propulsion design concept which includes number and location of the engines. Level IV refines the sized configuration by developing a more complete definition of structure and non-structure items and by providing greater confidence thru increased analysis. This level also treats the configuration as a unit, 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 that the nacelle integration is valid.

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

It is emphasized again that the design networks presented in Sections 4.2 and 4.3 are examples only, they are not rigid 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 which 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 would extend the configuration designers capability to search for benefits from designs which may depart from tradition and 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 large degree of similarity between the network descriptions of Project 1 and Project 2. For the sake of completeness, each description is presented in total. 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. Optimization is considered separately in Section 5, because it is applied with discretion

to selected parts of the design network, as the circumstances require. The discussion in Section 5 will relate the most effective use of the various types of optimization to each part of the design process.

4.2 PROJECT 1 - SUBSONIC COMMERCIAL TRANSPORT

4.2.1 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 as applicable to the general category. Consequently, the project defined as Project 1 is constrained only to be a typical, high subsonic speed, moderate aspect ratio wing commercial transport, with two to four engines located in conventional arrangements. This does not mean to imply that the Project 1 network will not support the design and analysis of unusual configurations, only that the computing times developed will be for typical geometries.

4.2.2 Design Networks

The general Product Level concept of figure 4.1 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	1 design cycle	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

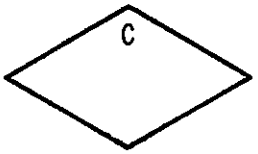
* One design cycle provides a converged design at levels II and III. A management decision is required to continue until a converged design is obtained at levels IV and V. This provides management control of the costs for computing and development testing (see section 4.1).

4.2.2.1 Project 1 Subsonic Commercial Transport Detailed Design Networks for the Product Levels

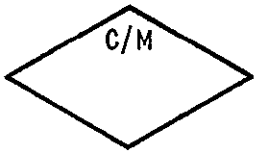
Figure 4.2 presents the detailed design networks for Project 1. The following information is pertinent to the networks:

Network blocks

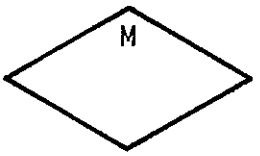
activity or event



computer decision



computer or man decision



man (or men) decision

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.

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 on page 50.

Narrative Descriptions

A narrative describing the design and analysis activities is presented in section 4.2.3 (page 51). Each network narrative is identified by a reference network block number. References to Elements contained in Volume V, the catalog of Technical Program Elements, are made throughout the narrative. An example would be ARO-1. This 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.

LEVEL I – CONTINUING RESEARCH

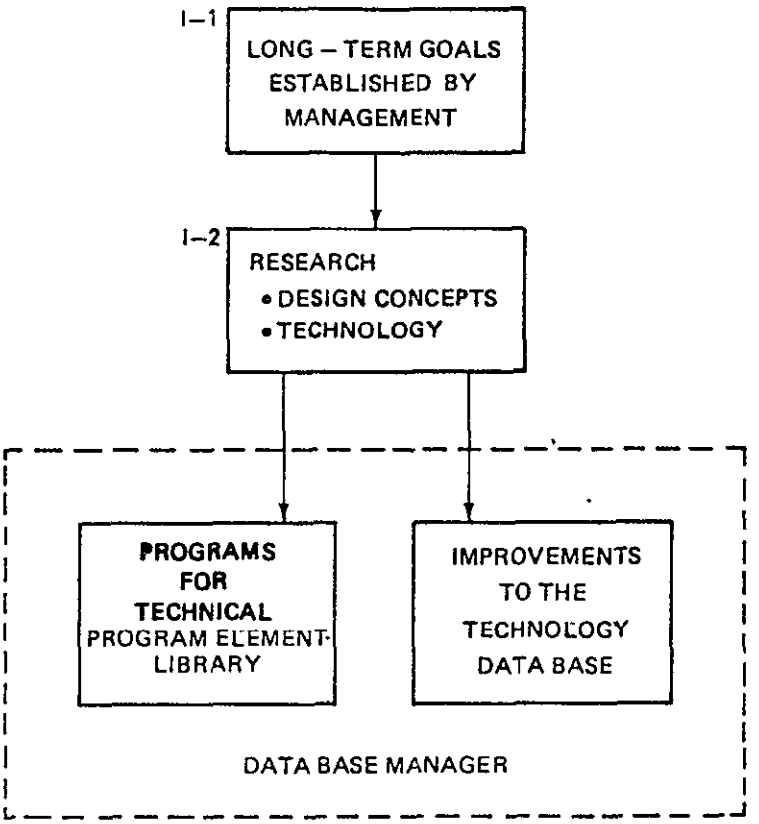
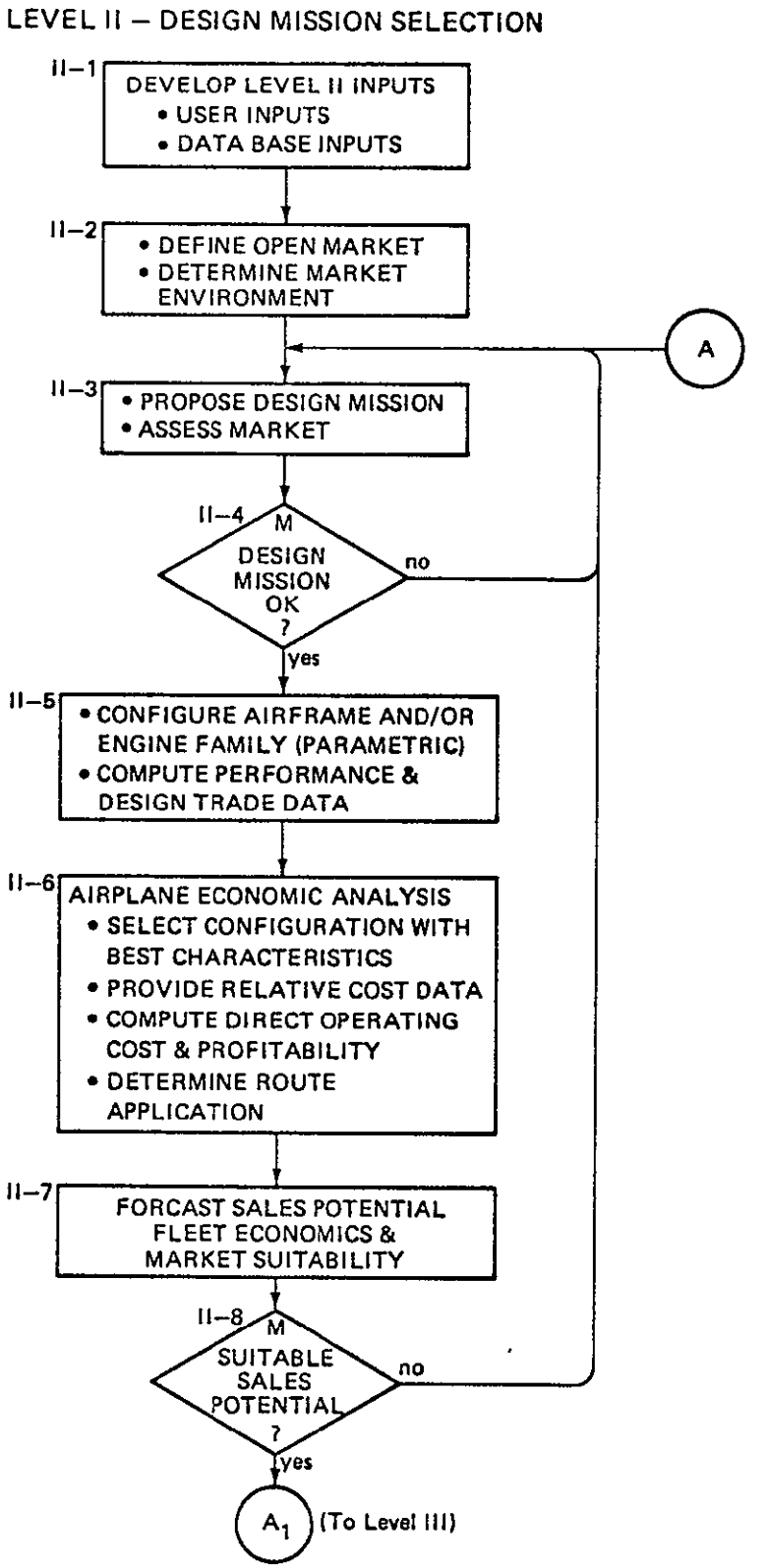


Figure 4.2 Design Networks – Project I Subsonic Commercial Transport



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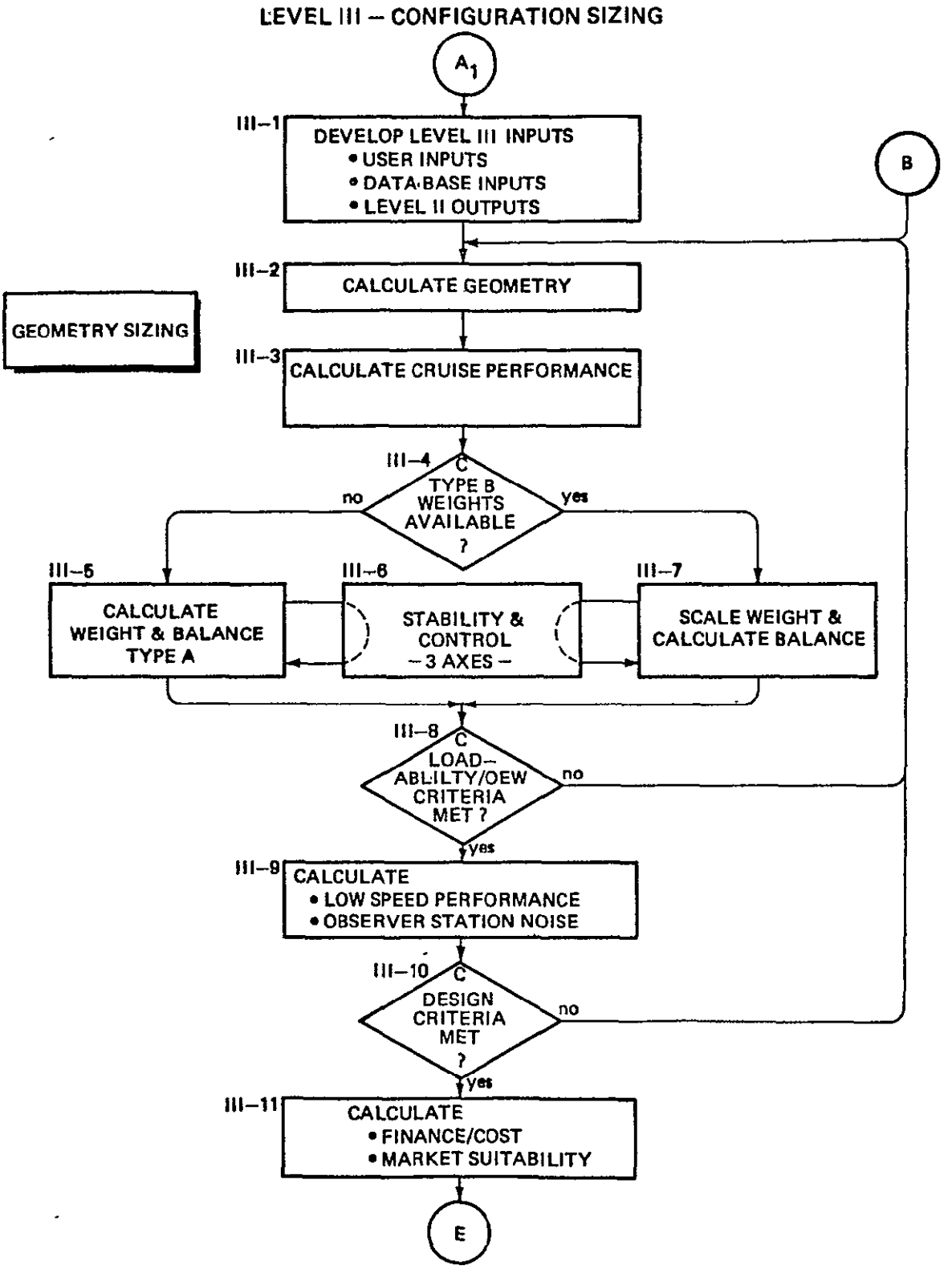

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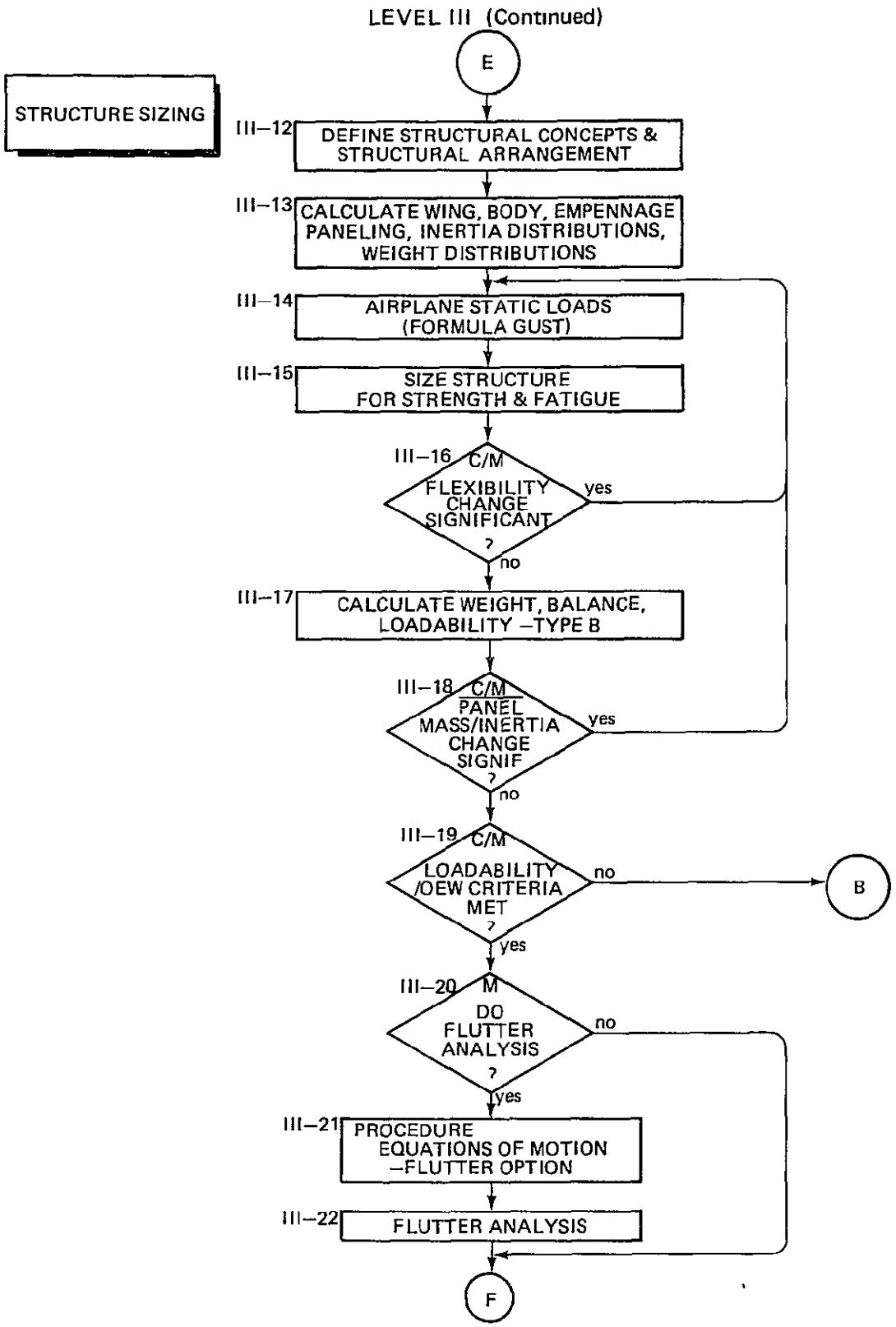

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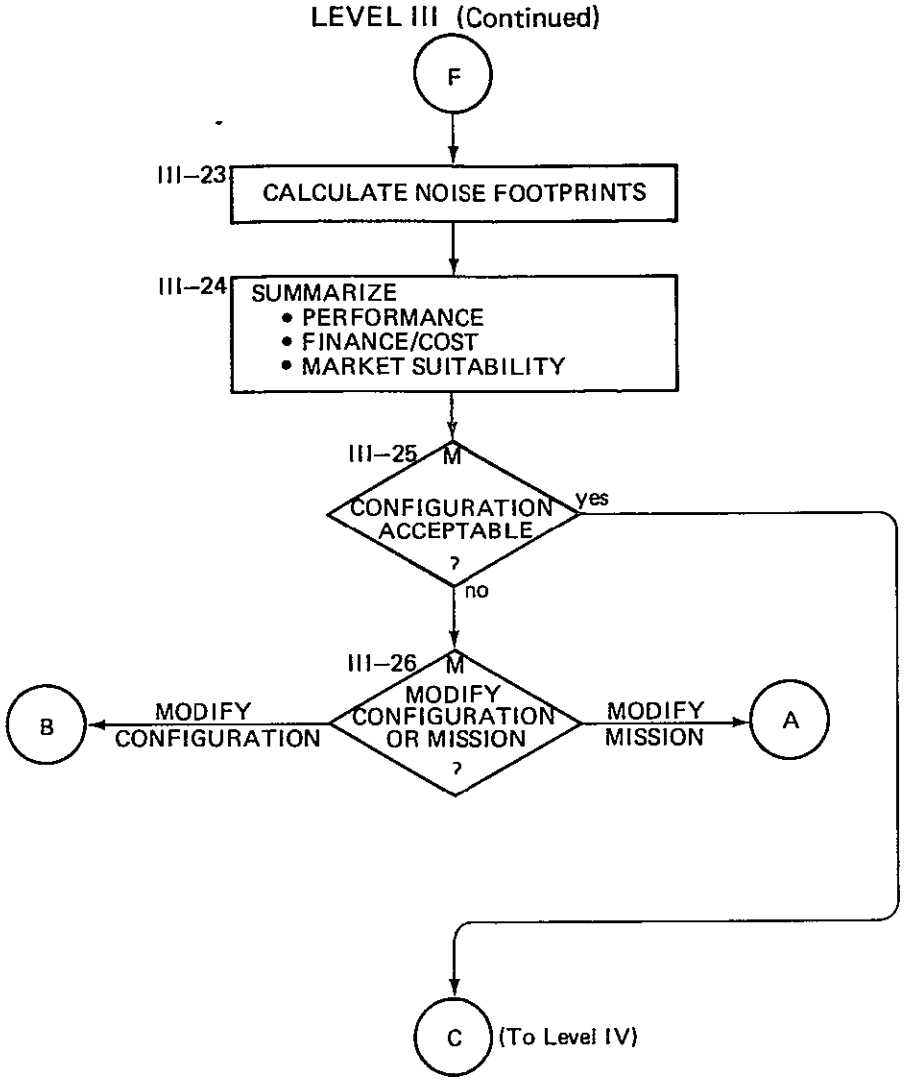

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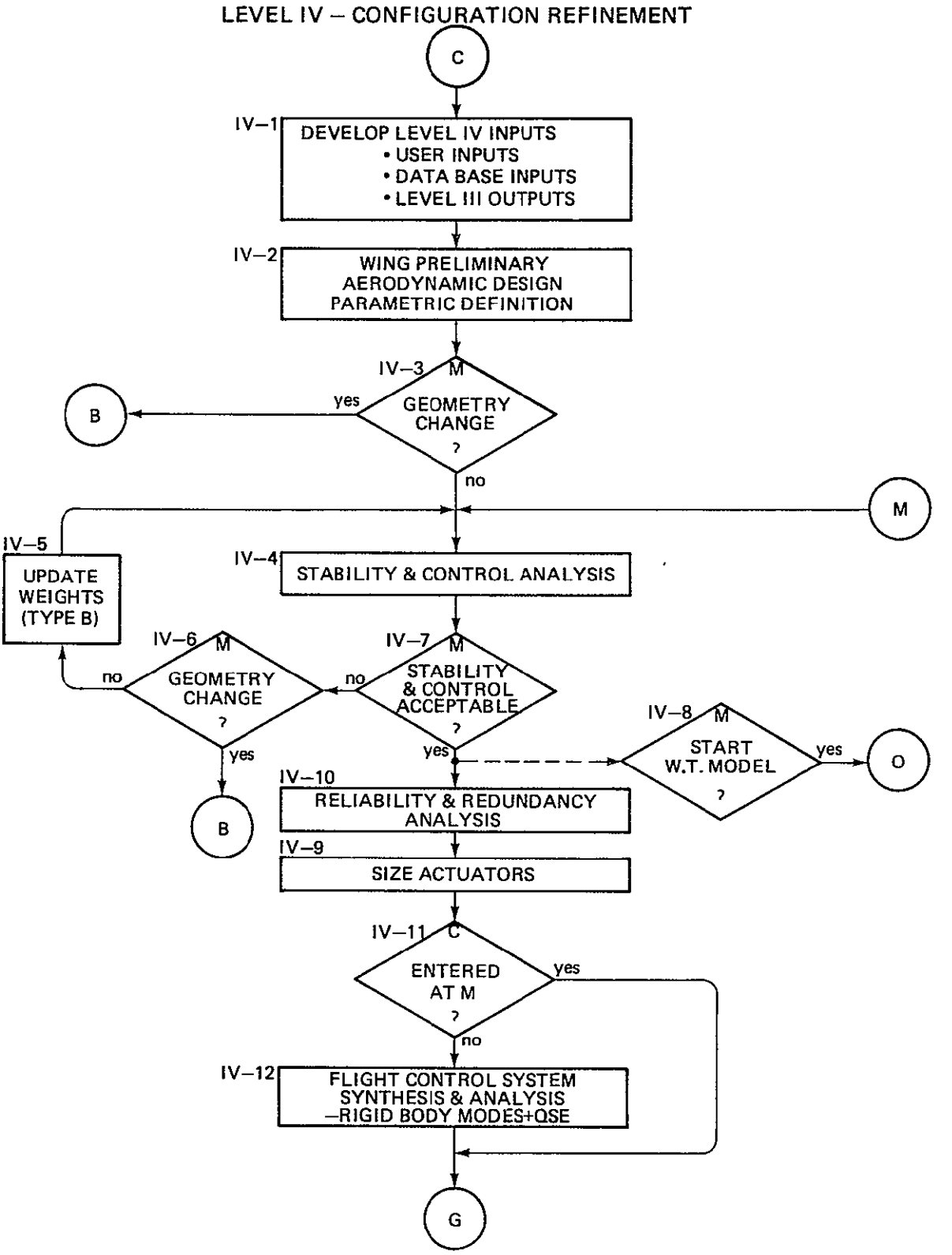

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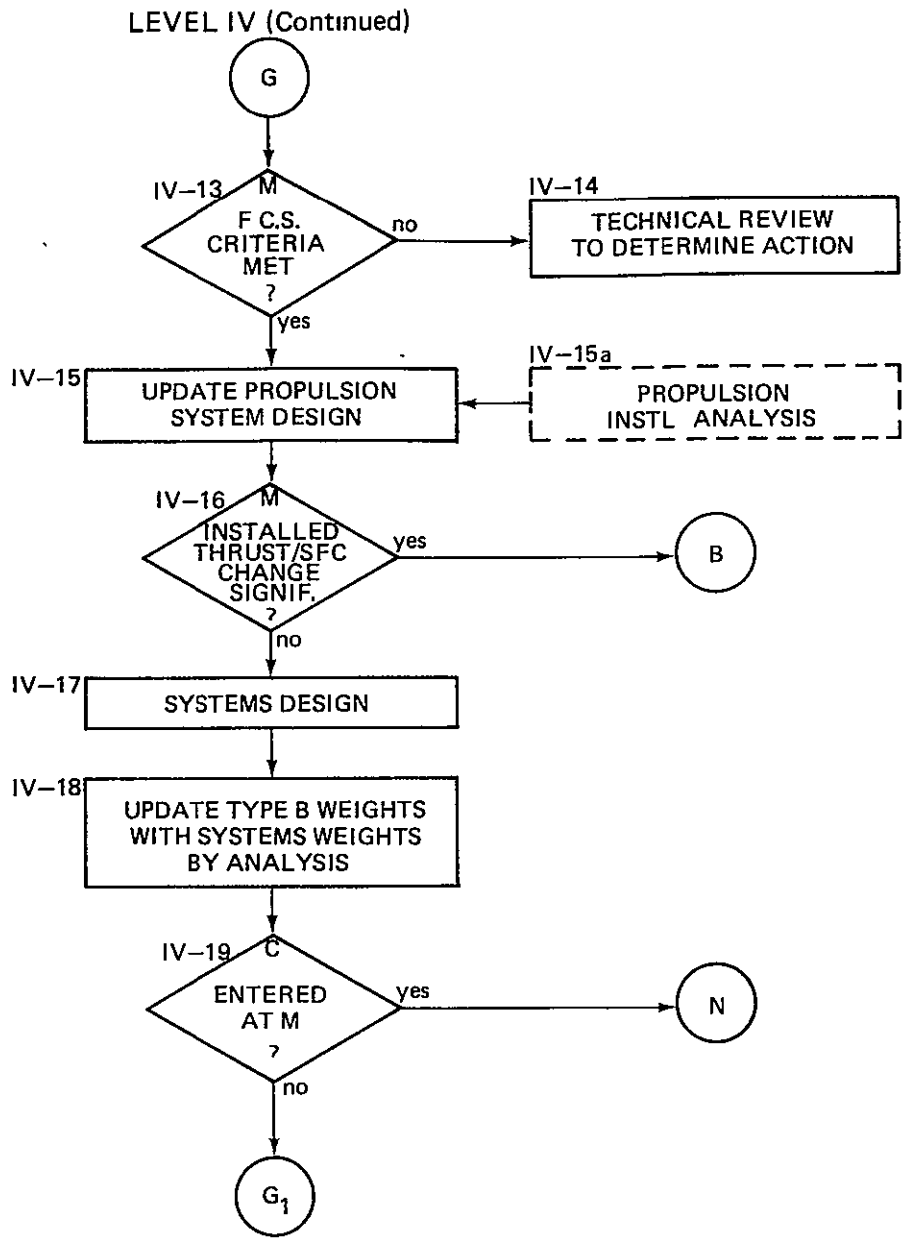

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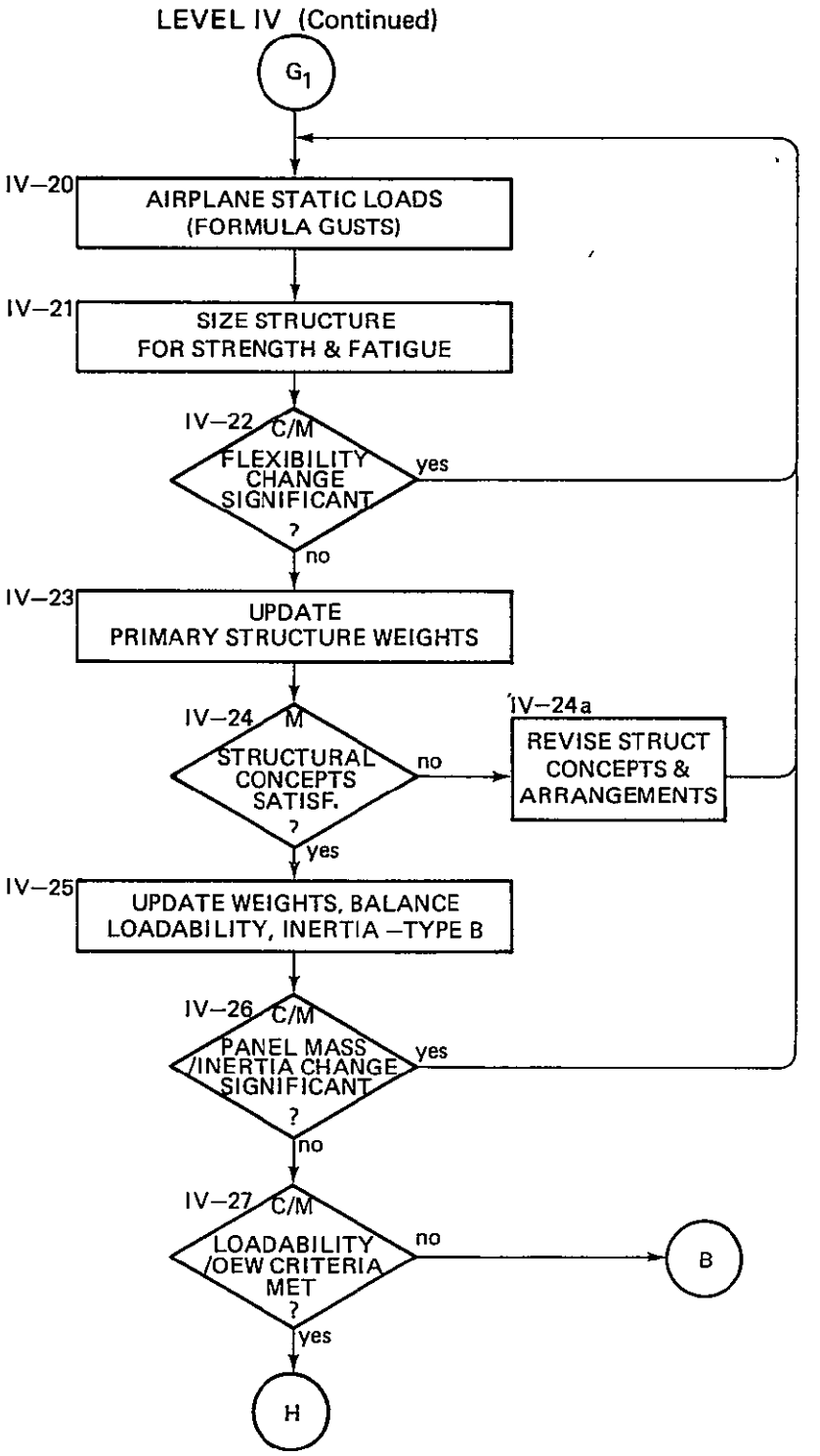

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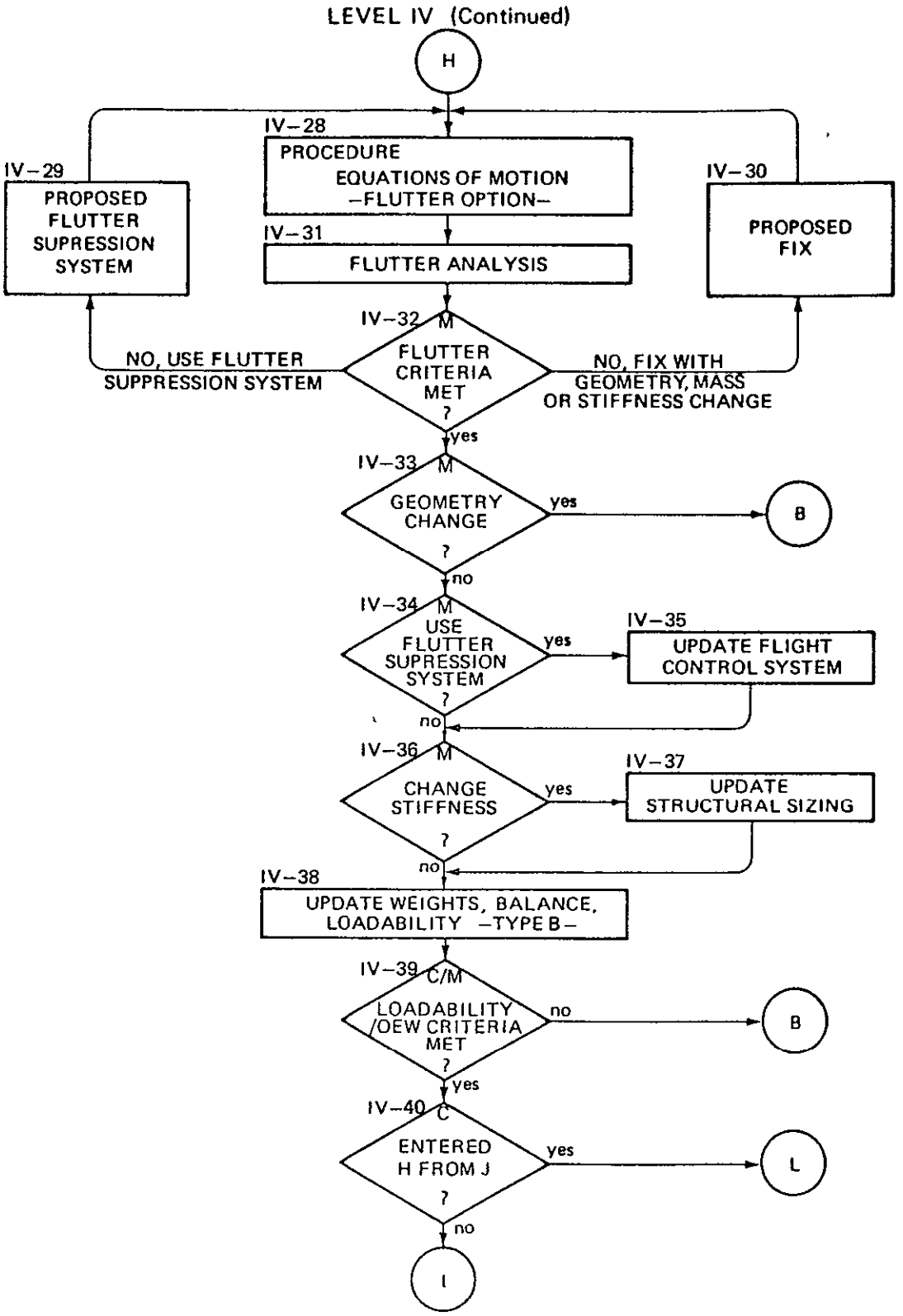

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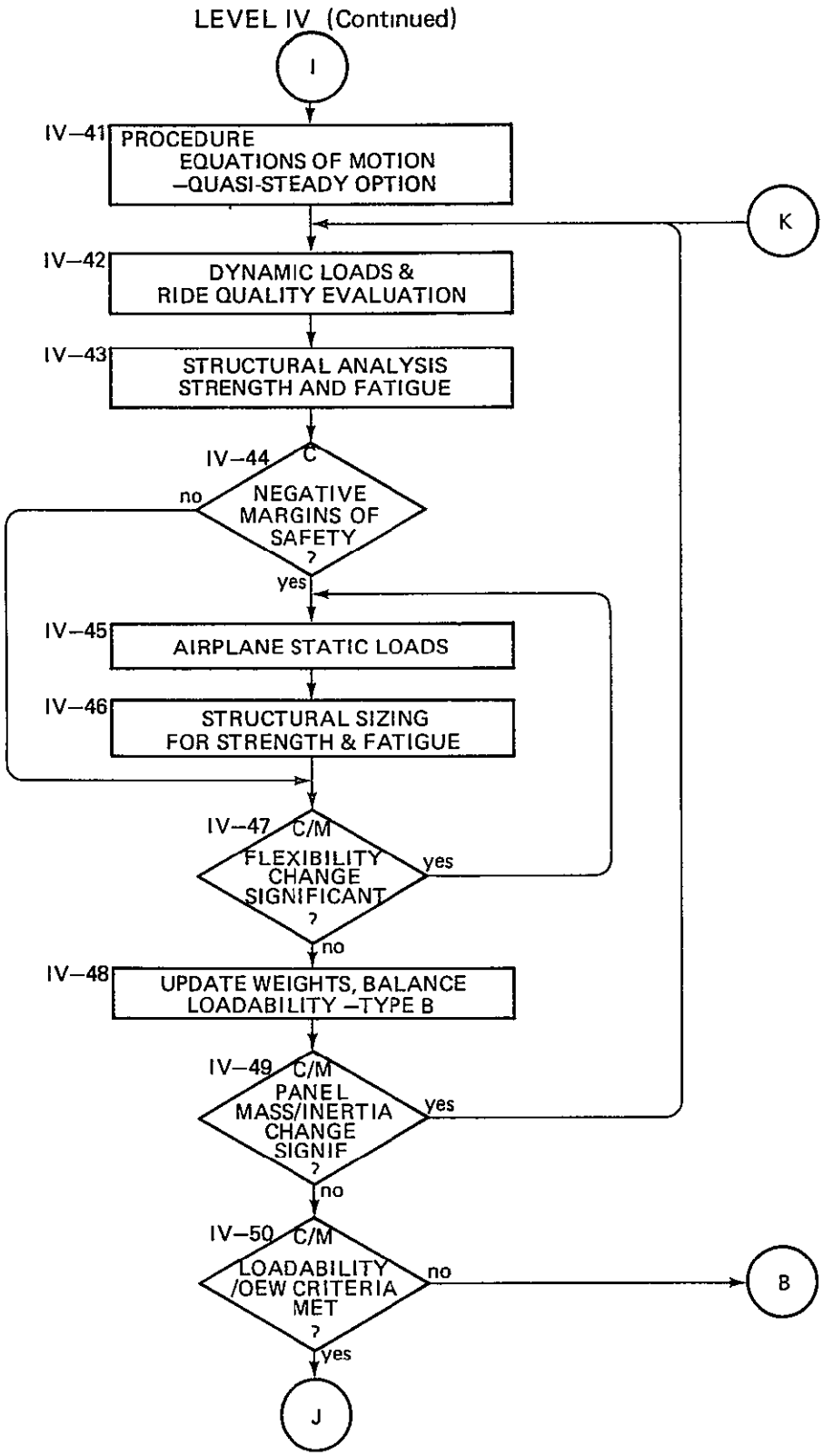

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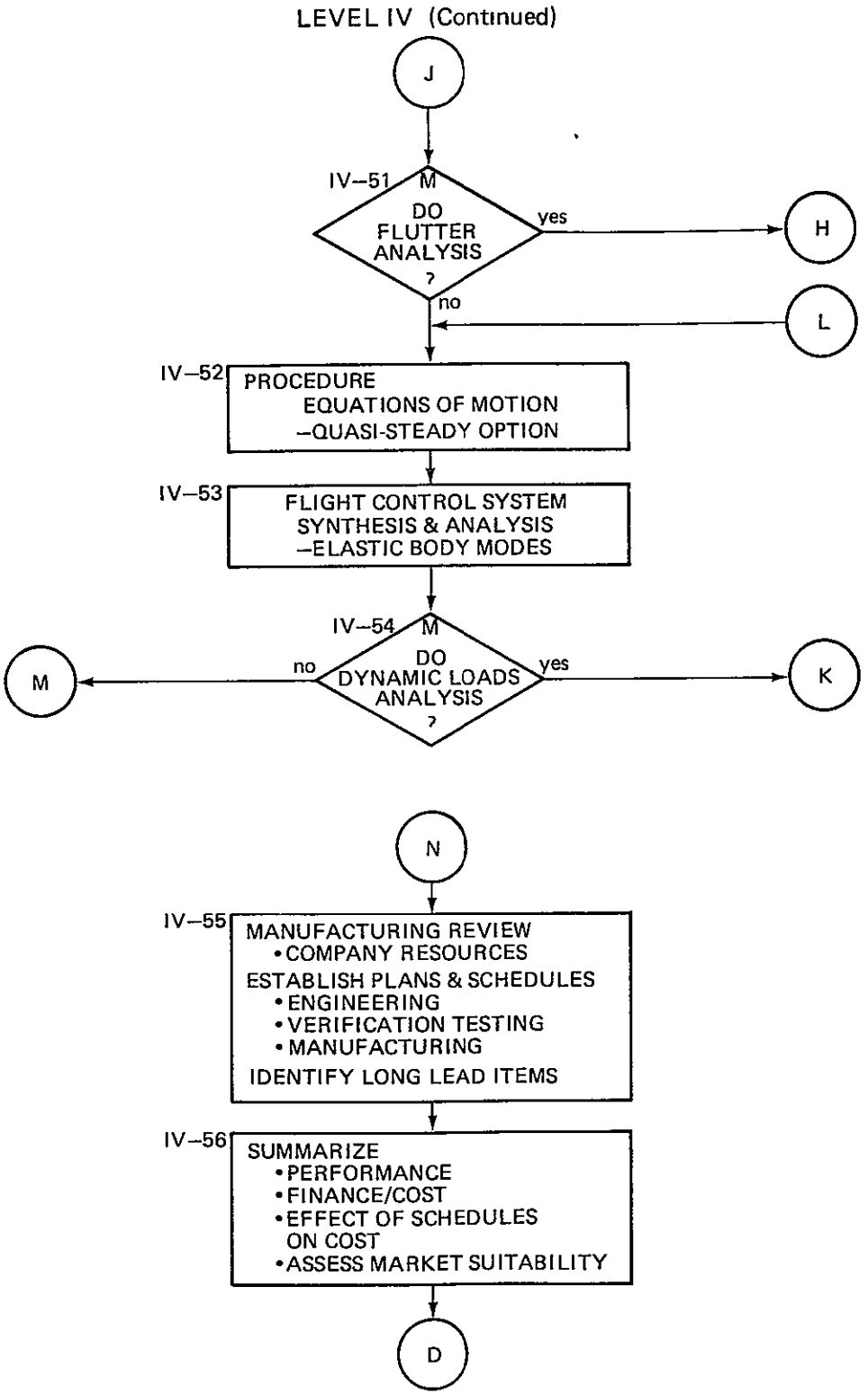

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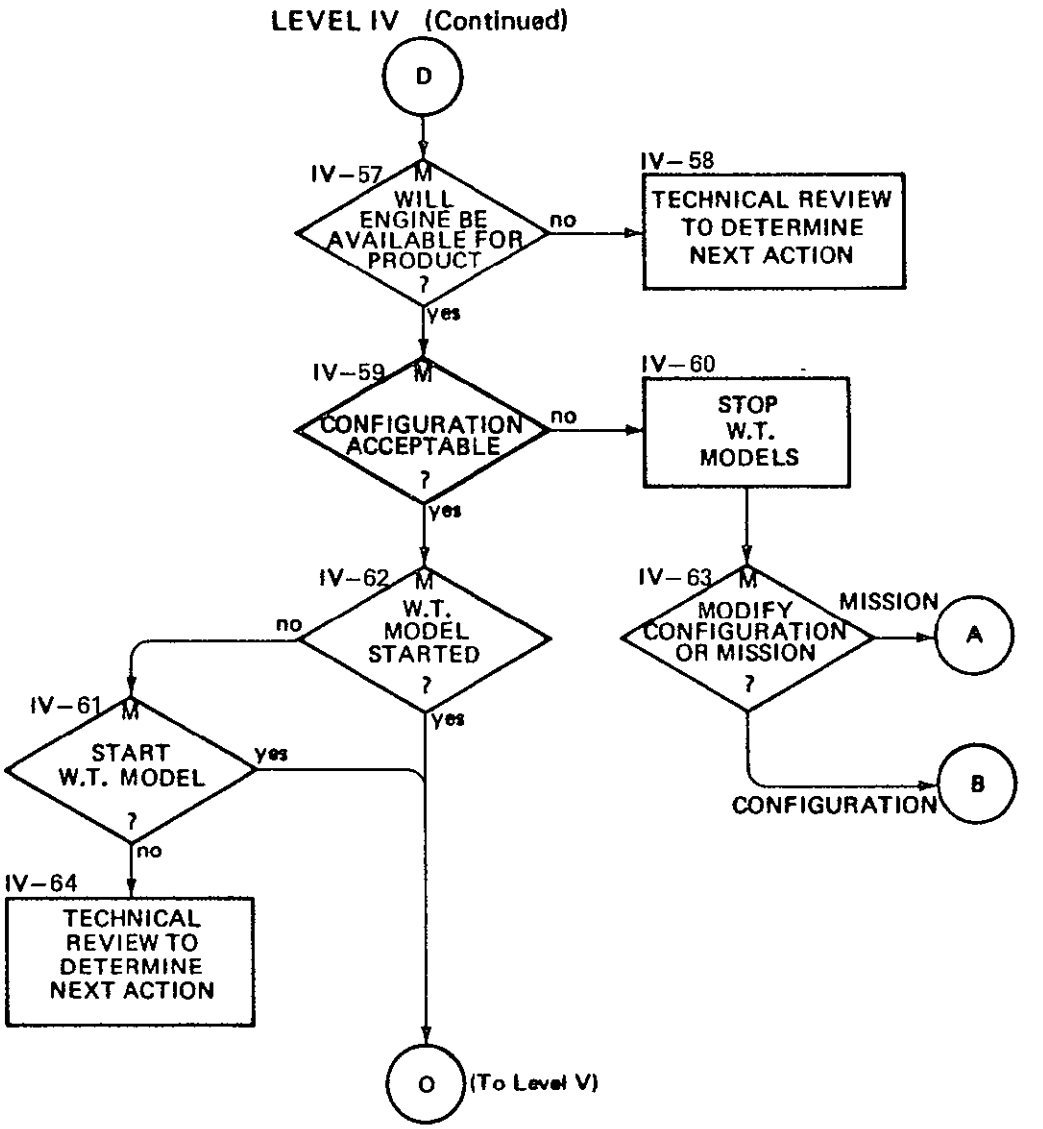

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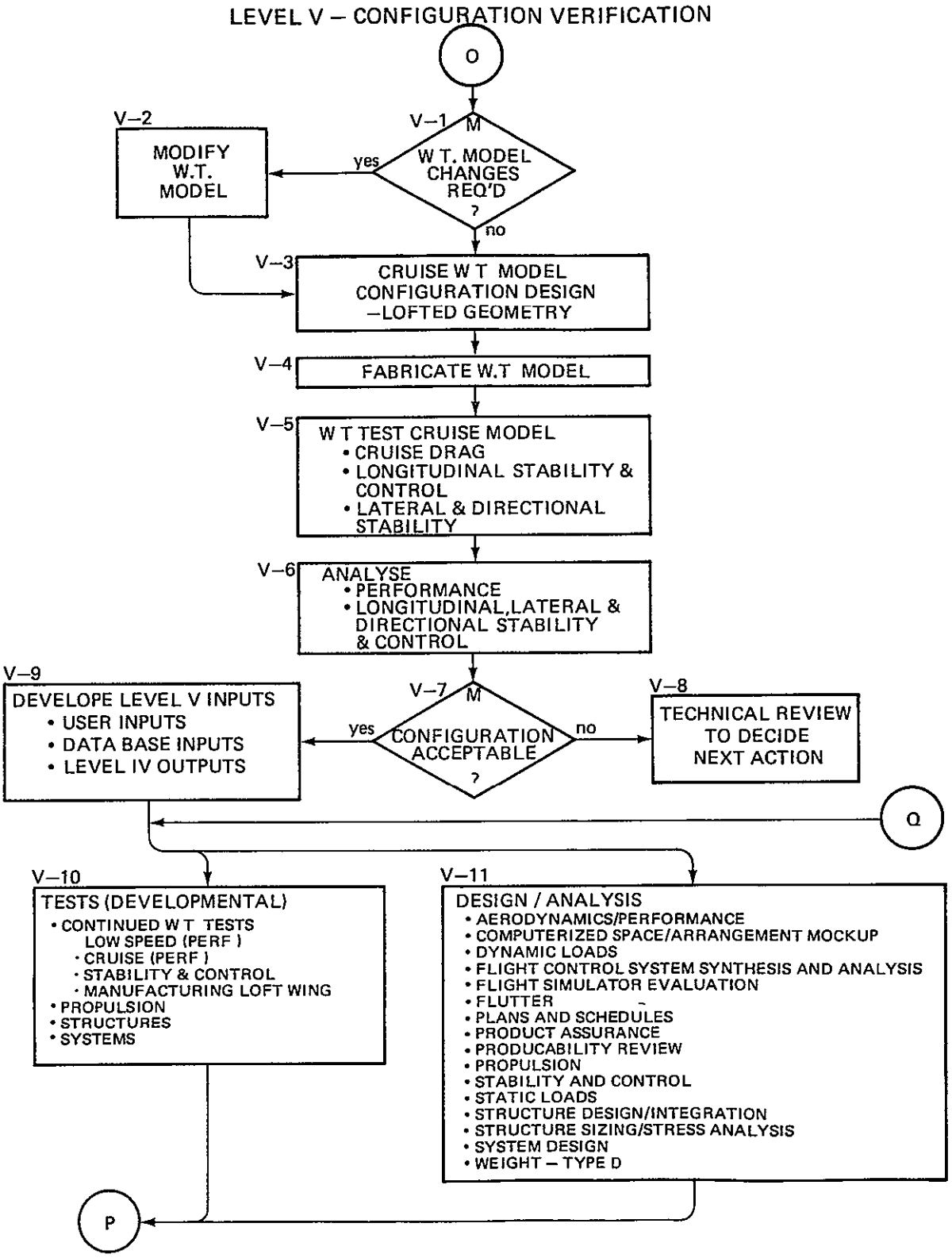

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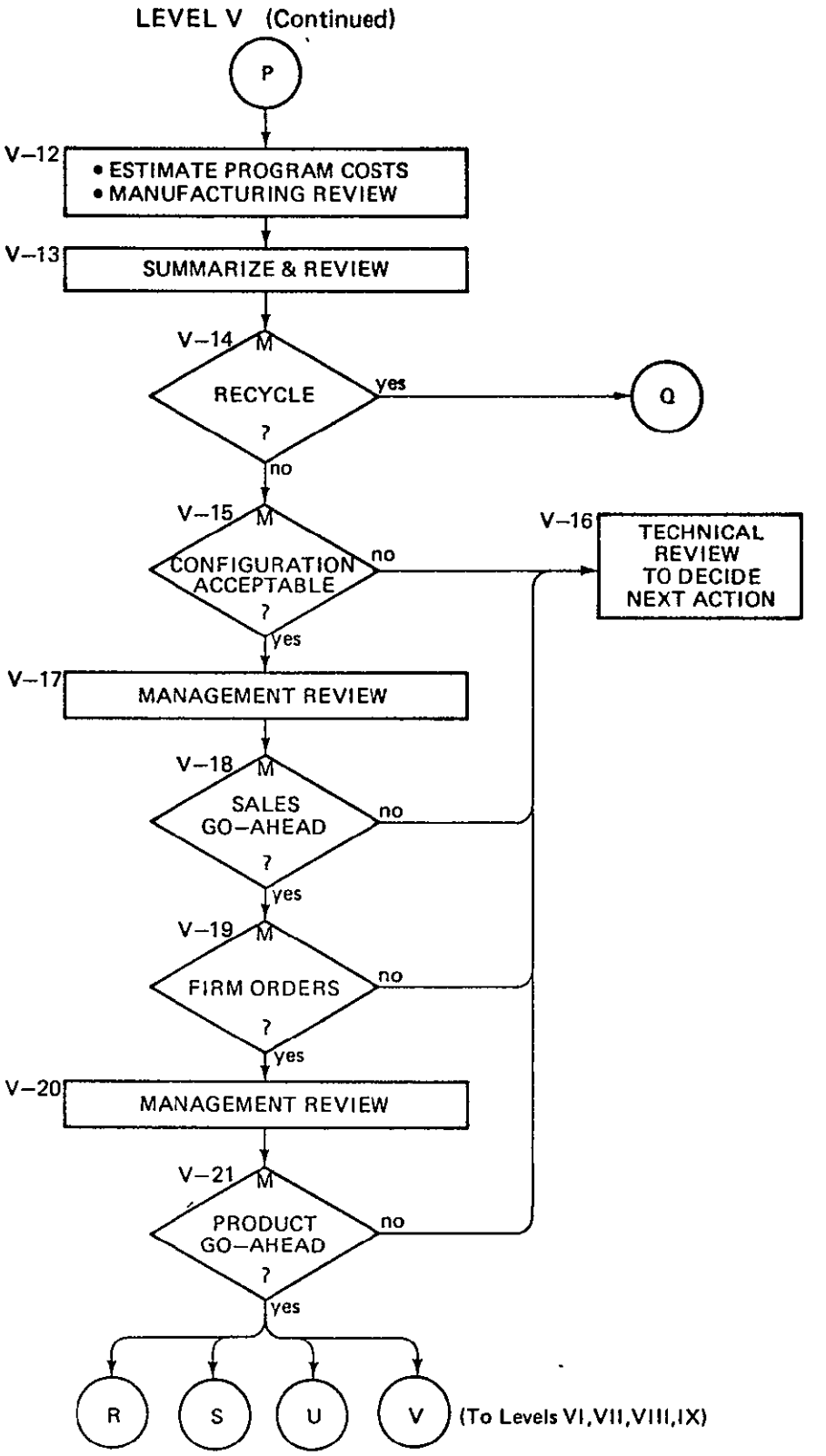

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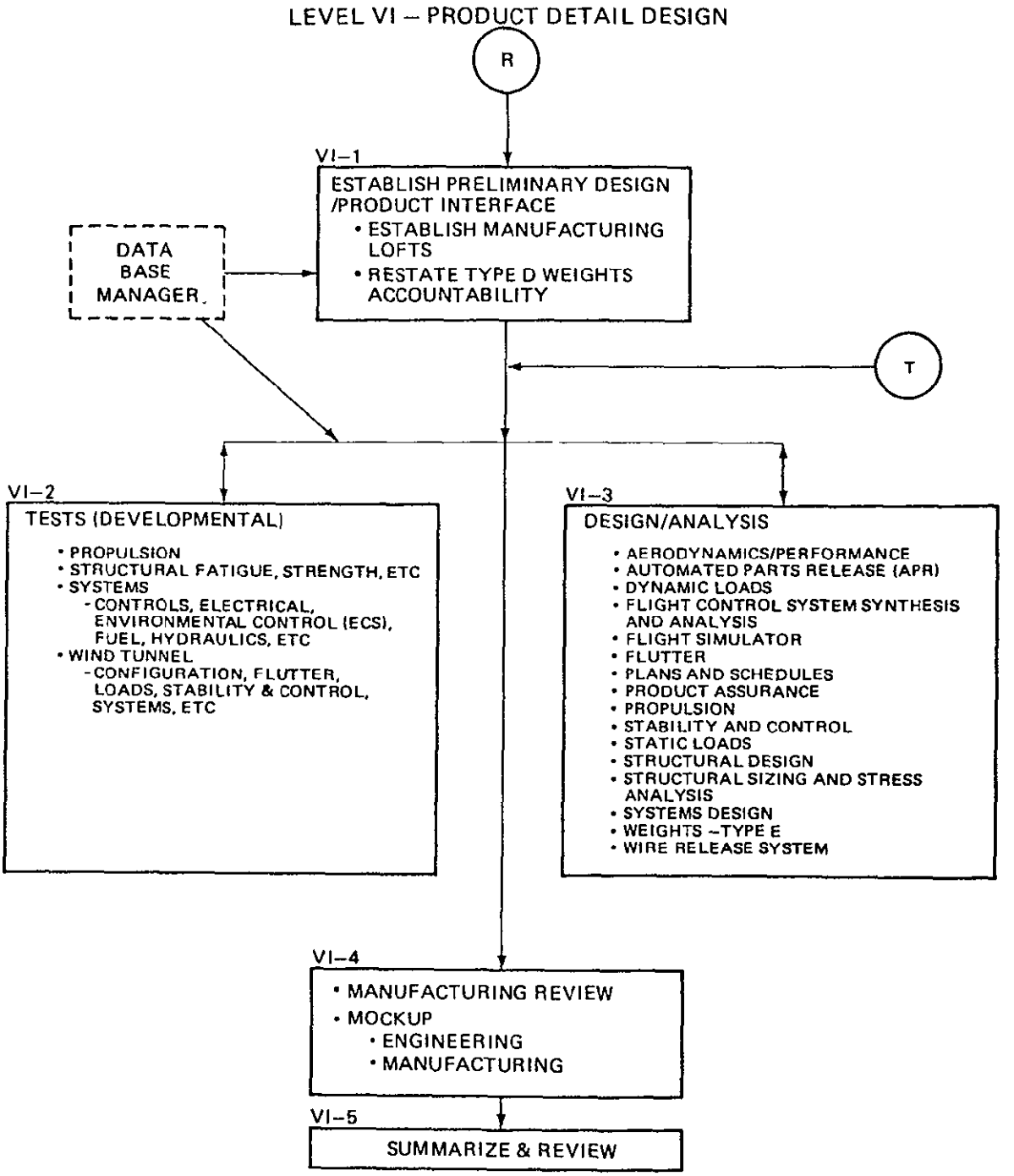

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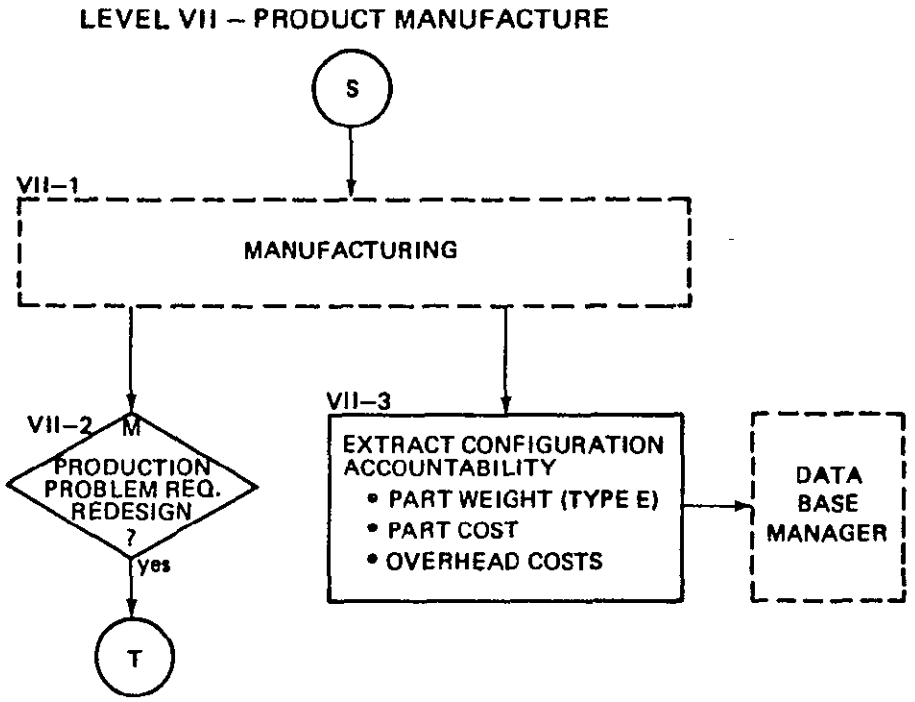

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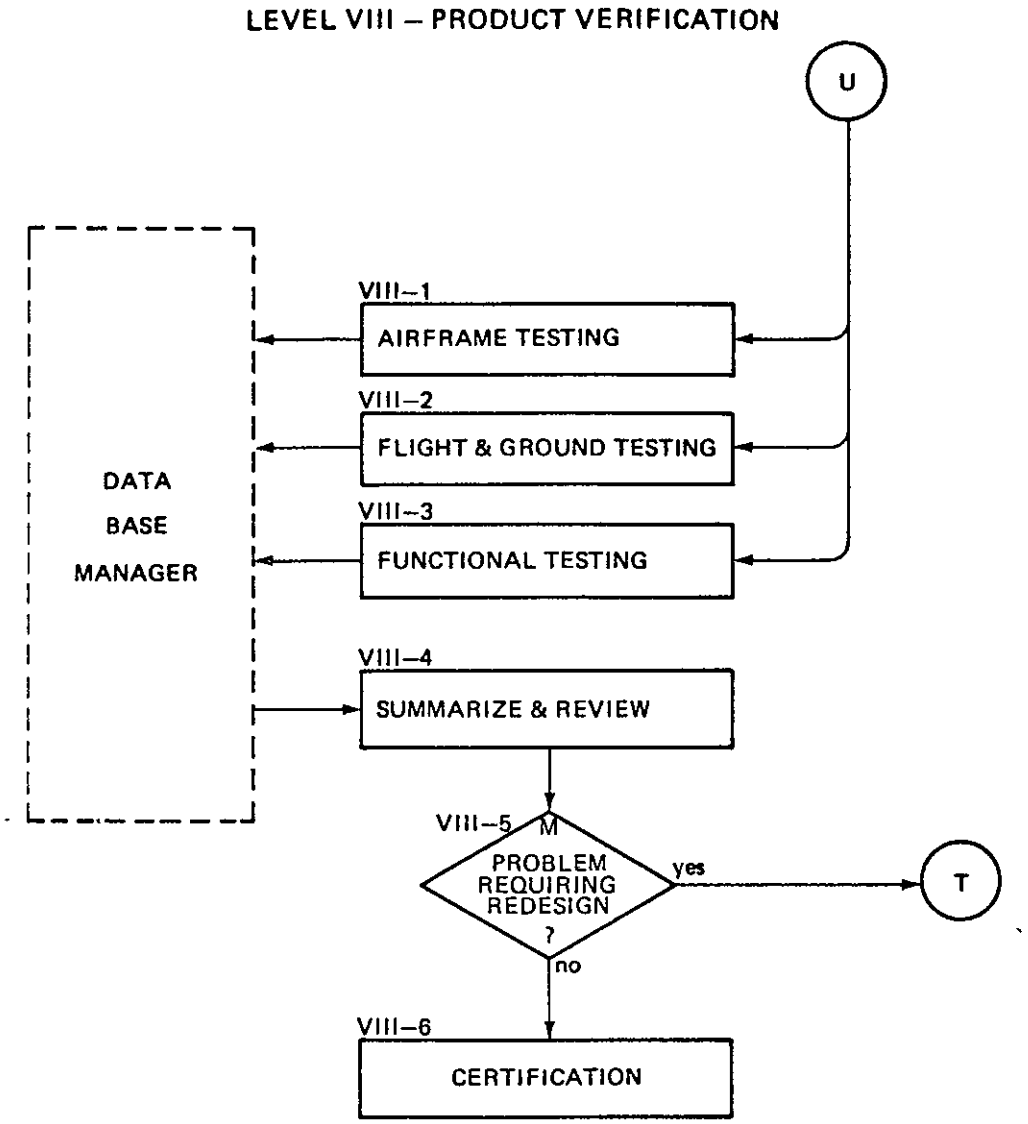

Figure 4.2 Design Networks – Project I (Continued)

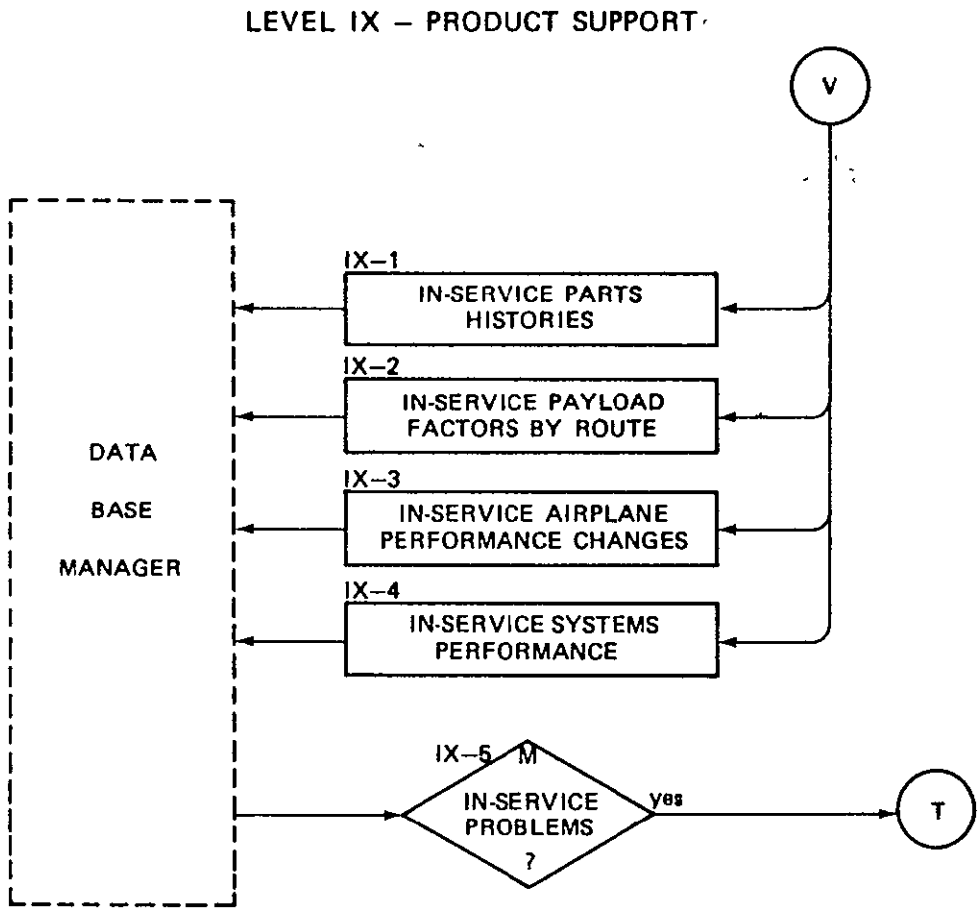

Figure 4.2 Design Networks – Project I (Continued)

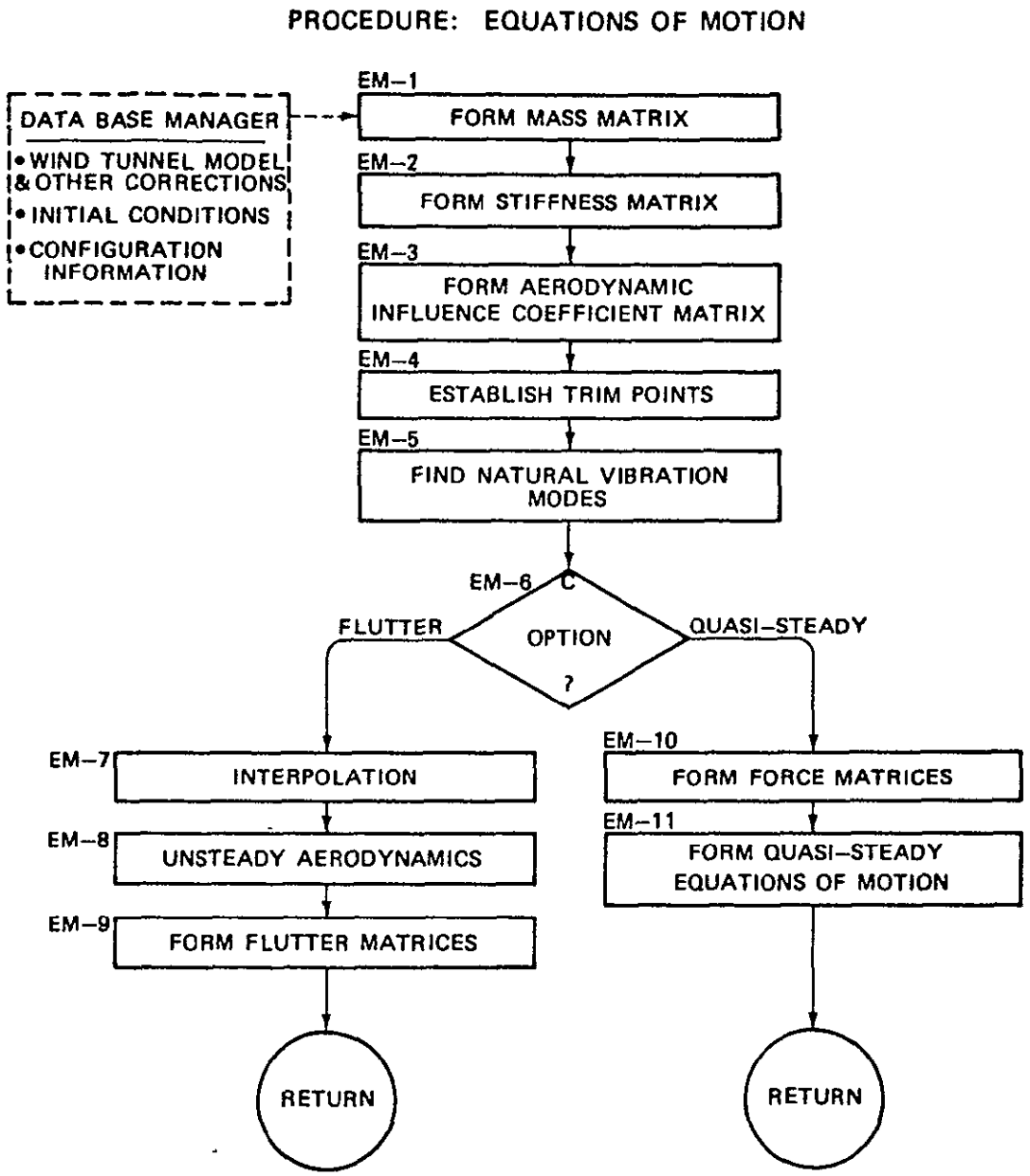

Figure 4.2 Design Networks—Project I (Continued)

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4.2.3 Network Activities Description

4.2.3.1 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.

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: Design Concepts, Technology--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 by-pass 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 such as characteristics of composite materials. The users of the IPAD system will monitor these activities to enter new technical program elements into the library and to improve the technology data bases.

4.2.3.2 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.

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.

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Block II-2. Define Open Market, Determine Market Environment--Goal: To identify the open market for a new airplane and to 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 and 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 weights and balance module (WTS-2).

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The weight and balance module will contain the following analyses:

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

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

3. Fuel volume and fuel maragement calculation,

4. Passenger, cargo, and fuel loading calculations,

5. 3-axis mass moment of inertia about the airplane c.g. calculation,

6. 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 (see figure 4.3). The iteration is performed for each geometry of the T/W vs 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, that is, 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.

<u>Block II-6. Airplane Economics Analysis</u>--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.

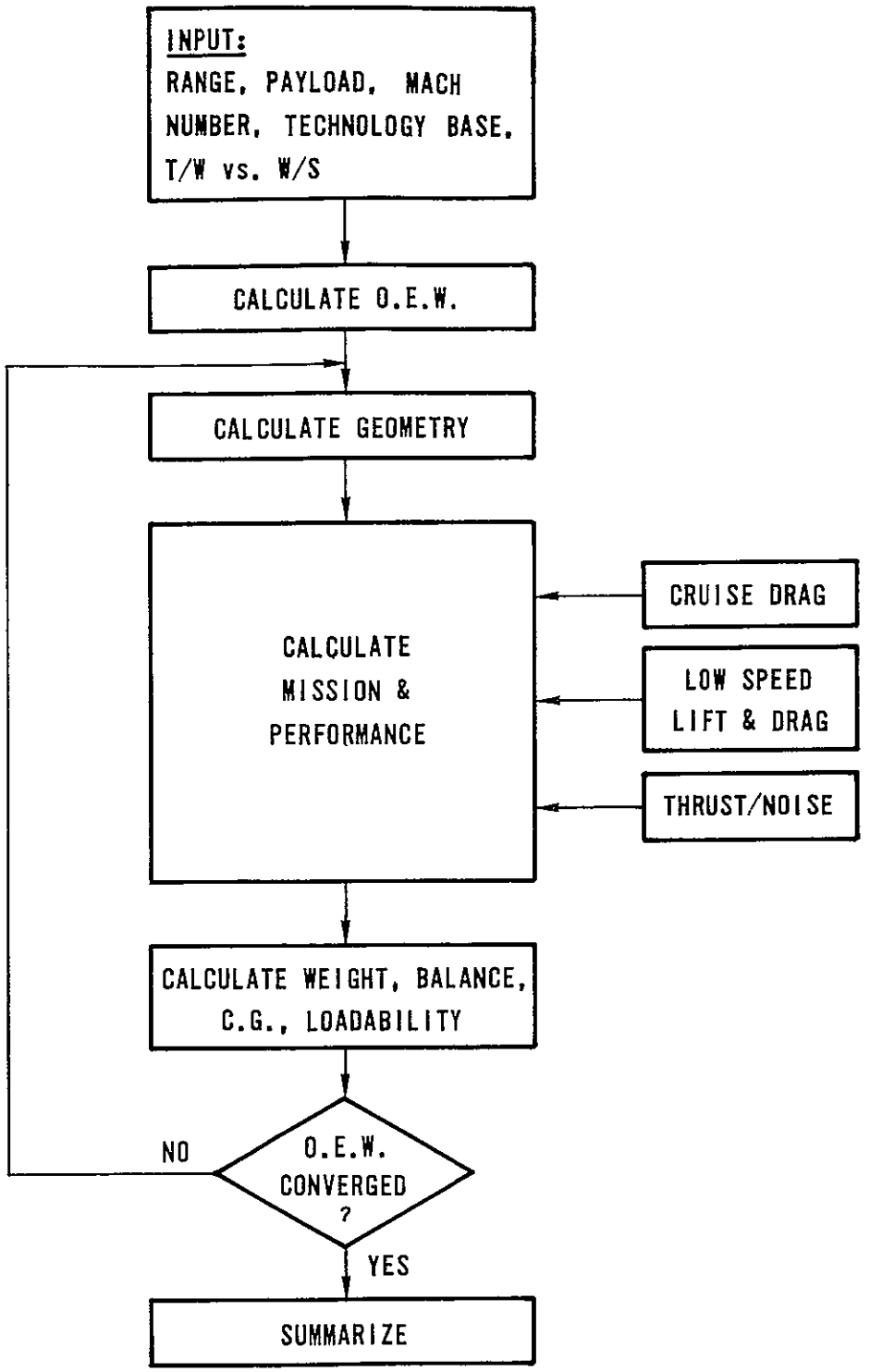

Figure 4.3 Convergence Loop for Configuration Size and Performance

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 assess if the sales potential is enough for the related development cost.

Man decision based on a review of the sales potential for each candidate configuration under investigation.

4.2.3.3 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.

The Level III network has been divided into two parts, i.e., "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 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 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 from the following disciplines: 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 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 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 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 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 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), 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 to 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, it would be more accurate to scale 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 if the configuration under consideration is acceptable from the standpoints of weight, balance and loadability.

The Technical Program Element (WTS-2) which provides this information contains the following analysis:

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

2. Statistical OEW balance arm prediction methods which produce a 30 item horizontal center of gravity (cg) statement,

3. Fuel volume and management calculations,

4. Passenger, cargo, and fuel loading calculations,

5. 3-axis mass moment of inertia about the airplane cg calculations,

6. 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 in conjunction with a practical cg 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 to 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 is provided by S&C-2 which 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 cg 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 which provides this output contains the following analysis (WTS-2):

1. Statistical OEW weight prediction methods which produce a 30 item group weight statement (scaling options),

2. Statistical OEW balance arm prediction methods which produce a 30 item horizontal cg statement,

3. Fuel volume and management calculations,

4. Passenger, cargo, and fuel loading calculations,

5. 3-axis mass moment of inertial about the airplane cg calculations,

6. 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 which are normalized to reflect changes in the 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 if 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 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 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 performance is 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 climbout performance (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 climbout 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, -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 & Structural Arrangement--Goal: Define the structural concepts and materials of the airframe primary structure. Synthesize the structural 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 which 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.

Geometrical 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:

1. Airplane planform and section geometry,

2. Airplane aerodynamic and structural panel definitions,

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

When operating within the IPAD system, items 2 and 3 will be performed by this activity, while item 1 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 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 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 suitably modify the theory via the 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 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.

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To accomplish this activity involves Technical Program Elements which do the following:

1. Execution of the weights update control module (WTS-15) which would re-execute only those portions of the weights Technical Program Elements whose input had changed,

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

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

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

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

6. Calculation of landing gear mass elements (WTS-9,

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

8. Calculation of fuel mass elements (WTS-11),

9. 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).

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

11. 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 4.4 and will be similar in Level IV.

<u>Block III-18. Panel Mass/Inertia Change Significant?</u>--Since the loads analyses are sensitive to panel mass properties, each time the weights analyses updates the panel's mass, center

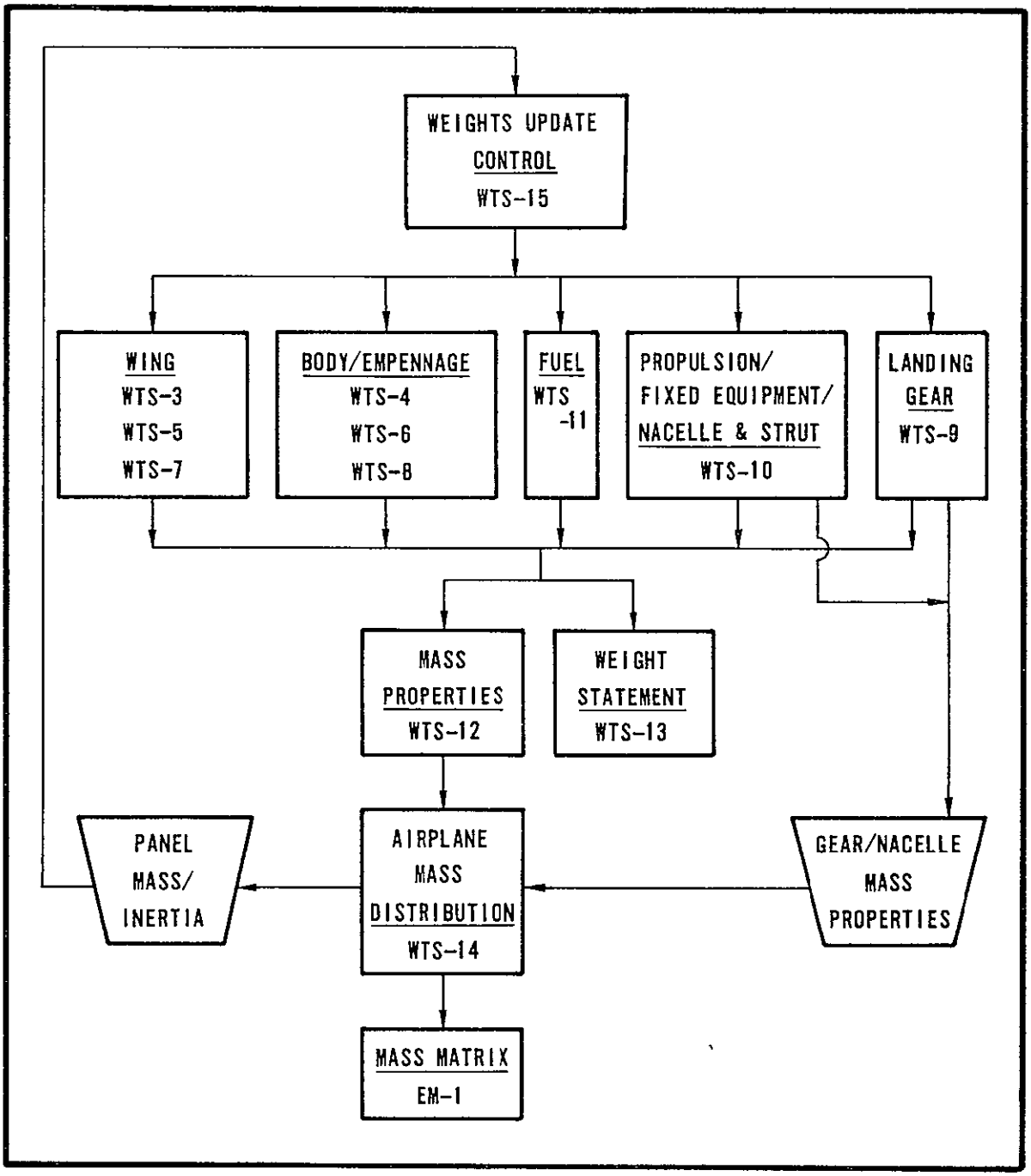

Figure 4.4 Weights Analysis - Data Communication

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 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 if 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 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 cg position does not results 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?--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 or the initial structural sized configuration.

The equations of Motion for the 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), or the classic British method (SFL-11), or an automated scheme (SFL-12). Flutter results will be hand

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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 sensitities with respect to the placements 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, -6.

The utilization, maintenance and dispatch reliability will be assessed. Probable route structures, aircraft fleets, airport facilities, 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 RSL-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.

4.2.3.4 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 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.

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 if 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 if the wing so generated is sufficiently close to an aerodynamically suitable definition. If not, then 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 or not to modify the Level III wing definition.

The design/analysis of Block IV-2 will determine if the wing from Level III can be developed with only minor modifications into a wing that will likely 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, then 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, then 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 surfaces 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, 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, III-15) and finally from Level IV analysis (Blocks IV-45, IV-46) (when additional passes through Level IV occur).

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 the following requirements:

1.	Takeoff rotation	Adequate control to meet low speed performance
2.	Landing flare	
3.	Minimum control speed, ground	
4.	Minimum control speed, air	
5.	Roll response criteria	All speeds

Block IV-5. 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 which would affect the entire design, but 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:

1. 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,

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

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

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

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

Block IV-6. Geometry Change--Goal: Determine if changes in tail surfaces or flight control surfaces are required.

This decision is manual and human judgment will be required. If the stability and control characteristics (IV-7) clearly show a stability deficiency or a control effectiveness well below the requirement then 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 decision is manual and human judgment will be exercised in the interpretation of the criteria and whether the need to recycle the event is required.

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 and stability and control design analyses performed in Blocks IV-2 and IV-4. Wind tunnel model construction requires up to 3 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-9. Size Actuators--Goal: The preliminary sizing of all control system actuators is made 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 is dependent 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, as well as 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 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 sub-systems 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.

Block IV-12. Flight Control System Synthesis and Analysis --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 knowledgable operator is required to intervene if problems develop during on-line operation.

Block IV-13. FCS Criteria Met?--Goal: Determine if the flight control system criteria has 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, 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-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 per 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, 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, -6 and PNZ-1.

Block IV-16. 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, then 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 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, -17 and STM-2, -3, -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, to establish distribution paths and to size pumps. Load balancing and component sizing trades are conducted (STM-2, -3 and -4). Critical hydraulic system items are identified and design criteria are 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 are 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 are 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 are 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 are 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 factor selected for evaluation.

Block IV-18. Update Weights - Type B (Non-Structural)-- Goal: To calculate updated mass properties for the non-structural items which have changed since the analysis which was made by Block III-17 was performed. 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:

1. For purposes of increasing the accuracy and decreasing the computational time required to perform the weights analysis, it could 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,

2. Update of landing gear mass elements (WTS-9),

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

4. Update of fuel mass elements (WTS-11),

5. 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),

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

7. 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 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 a need to repeat Blocks IV-20 through IV-53 is not required, because this is the last cycle thru 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 would 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 semimonocogue 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 suitably 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 calculated. If the change in flexibility is such that a significant loads change would result the 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.

To accomplish this activity involves Technical Program Elements which do the following:

1. Execution of the weights update control module (WTS-15) which would re-execute only those portions of the weights Technical Program Elements whose input had changed,

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

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

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

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

6. Generation of 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 a more optimum 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 Concept 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, DGL-7 and -9).

Block IV-25. Update 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. 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:

1. Execution of weights update control (WTS-15),

2. Update of fuel mass elements (WTS-11),

3. 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),

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

5. 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 if 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 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-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 if 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; 2) active flutter suppression system. A decision will be made whether 1) or 2) or both should be used to satisfy flutter requirements.

Block IV-33. 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-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 or not 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 if 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 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 (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.

To accomplish this involves Technical Program Elements which do the following:

1. Execution of weights update control (WTS-15) which would re-execute only those portions of the weights Technical Program Elements whose input had changed,

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

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

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

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

6. Update of fuel mass elements (WTS-11),

7. 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),

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

9. 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 (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 to determine if 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-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 do 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) which 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 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-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 which 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 that the airplane is designed for. 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 be both a vertical and a lateral gust 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 criteria 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 calculation 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 if 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 would 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 performed 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 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 which do the following:

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

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

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

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

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

6. Update of fuel mass elements (WTS-11),

7. 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),

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

9. 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 (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 updates 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 properties 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 which is calculated by the weights analysis Block IV-48 and the required OEW as sized by the cruise performance analysis (Block III-3) and to determine if 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-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 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-51. Do Flutter Analysis?--Goal: Determine if further flutter analysis is required.

Manual decision is made to determine if 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 is 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-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 which 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, the configuration verification test plan and the manufacturing schedule.

(3) Identify Long Lead Items--Critical long lead items such as engines, forgings, etc., will be identified and procurement criteria will be 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 will be predicted by MKT-4, -5, -6. The effect of schedules on cost will also be assessed by FNC-2, -3, -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 model REL-1 and REL-4 will evaluate interactions, major influences, controlling parameters, special features and characteristics affecting utilization dispatch reliability, maintenance and logistics facilities. Costs-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 if the engine availability schedule is compatible with the airframe manufacturing and delivery schedule.

This decision will be manual and will determine if 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 hinder progress of the design to Level V.

Block IV-60. Stop Wind Tunnel Model--Goal: In the event that the configuration review in Block IV-59 is found to be unacceptable then the design of the cruise shape wind tunnel model, commenced in Block IV-8, should stop.

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 check if 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.

4.2.3.5 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 analysis. 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.

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 to 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. There will usually be some modification to these early model lines as a result of 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 sub-critical 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 of the airplane and longitudinal stability characteristics.

If confirmation of the drag estimates (and particularly wing design) made in Level IV is achieved, then 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 charactersitics 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, 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 follwoing 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, etc., and the concepts of the structure and systems.

Continued Wind Tunnel (W.T.) Tests

1. Low Speed W.T. Model--Goal: Measurement of drag and lift characteristics for the low speed configuration performance identified in Level III.

2. S&C Longitudinal and Directional Low Speed W.T. Test--Goal: Measurements of stability and control characteristics to compare with the low speed stability and control estimates made for the airplane in Level IV. High angle of attack data will be taken to show satisfactory stall recovery. Engine failures will be simulated.

3. Additional Cruise Configuration W.T. 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.

4. W.T. Test - "Manufacturing Loft" Wing--Goal: To test the aerodynamic difference between the wing defined by aerodynamics and the wing considered to be manufacturable.

Manufacturing considerations invariably require some modification to the wing lofted by aerodynamics. If these changes are sizable, then the performance degradation should be established by wind tunnel test.

5. 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, elevator and rudder deflections (singly and in combination).

On the low speed model additional pressure would be required, including high lift devices, gear doors, gear

cavities, leading and trailing edge cavities for example. Again configurations resulting from various flap and control surface deflections would 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 pressure data becoming available 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 and 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.

Structural Development Tests--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 insure complete technical confidence in the configuration must be accomplished at this level.

Theoretical requirements: This group of problems includes testing such as 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, be it; stability, fatigue or fail-safe allowables, etc., in order to prepare for the full scale test assemblies to follow.

Empirical evaluations: The purpose of this testing is to establish design guidelines for situations where theoretical approaches fail or become unreliable. It covers problem areas such as:

1. bird impact on windshield,

2. detail fatigue ratings for design details not previously used or tested,

3. strength of fittings,

4. hail impact,

5. crack propagation.

The purpose is to establish; minimum gages, edge margins, baselines for fatigue analysis, required area ratios for fail-safe design, etc.

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 to 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 will 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, such as wing-body fairings, nacelle pylon-wing geometries, and so forth, 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 to 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, auxiliary power unit, etc. Also, smaller space envelopes are defined which represent fixed equipment such as actuators, pumps, filters, heat exchangers, oxygen cylinders, etc. Raceways are defined which provide for routing control cables, wiring, ducting, tubing, etc. (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 receive use similar to their use 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 equations of motion network).

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 are 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; 1) main structure cut-outs, 2) stiffness of major strúcture junctions, 3) mounting stiffness of localized masses, and 4) 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:

1. 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.

2. 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.

3. 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 factor selected for evaluation.

4. 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 ARMR (REL-2) and CTS (REL-14 and 41) Programs.

5. 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.

6. 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.

7. 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 to evaluate strengths and weaknesses of each airplane in operational environments.

8. 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.

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 that are 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 enable 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, -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 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, CAA) are met together with any special Boeing requirements.

Loads on secondary structure (high lift devices, control surfaces, fairings, doors, etc.) 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 anywhere between a simple hinge moment to a full pressure contour map.

In addition, many studies are performed, such as definition of fuel transfer weights, and definition of penalties resulting from non-standard flight configurations such as spare engine carriage.

The network shown in figure 4.5 represents typical data paths through a subsonic static loads analysis (e.g., figure 4.2, Block IV-26). It should not be assumed that a module shown

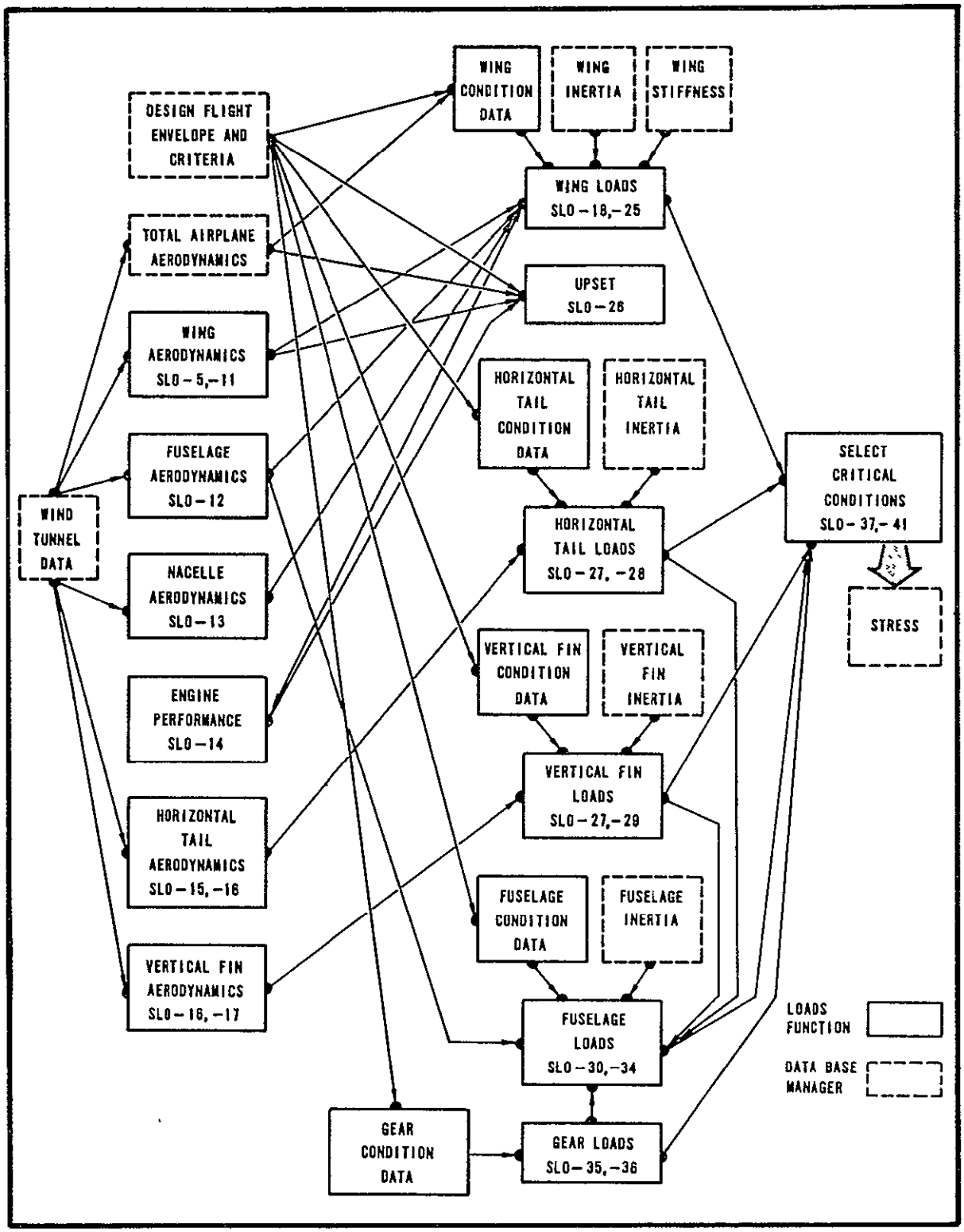

Figure 4.5 Static Loads Analysis - Data Communication - Subsonic Configuration

is executed only once per pass, is executed on every pass, or the order of execution is fixed.

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 together will all other airplane sytems.

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.

Special Structural Design Considerations:

1. Body: Control cab windows, access doors and cutouts, pressure shell integrity and fail safety, structural continuity and compatibility with the wing and empennage.

2. Wing: Structural continuity and fail safety, fuel containment, control surface installation and systems equipment, and integration with the body and landing gear.

3. Empennage: Structural continuity and fail safety, control surface installation and systems equipment and integration with the body.

4. Nacelles: Structural integrity, service access segments and integration with the engine and propulsion system.

5. 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.

6. Structures-System 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 it 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 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, it also 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, fail safe, and local optimization will take place. The optimization will be directed toward items such as: stringer configuration and spacing, rib spacing, frame spacing, 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 (STR-7 to -13).

System Design--Goal: To continue definition of systems until all design requirements have been identified and until all equipment items are identified as either existing or can be developed.

All systems design activities are similar in Level V and consist primarily of the following:

1. 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),

2. System schematic diagrams developed in Block IV-17 are updated,

3. 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,

4. Selection of existing "off-the-shelf" equipment is completed and preliminary procurement specifications for new equipment items are initiated.

5. The testing required to verify system performance is initiated,

6. 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 will be conducted such as alterante APU locations (STM-9).

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 which do the following:

1. Execution of weights update control (WTS-15) which would re-execute only those portions of the weights Technical Program Elements whose input had changed,

2. 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),

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

4. Update of body/empennage secondary structure mass elements (WTS-19),

5. Update of landing gear mass elements (WTS-9),

6. Update of 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,

7. Update of fuel mass elements (WTS-11),

8. 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),

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

10. 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 (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 by section and components of the airplane are summarized (FNC-2). An assessment of the production cost over a time period accounting for changes in the manufacturing schedule for introduction of new customer configurations and the impact of derivatives from the base model is made (FNC-3). An estimate of return on investment and cash flow by year is made (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.

Review the design with associated program costs, marketing, product assurance and manufacturing requirements (Block V-12). Identify if design and analysis tasks in Block V-11 are coordinated with the same technology level. Identify need for further tests in Block V-10.

Block V-14. Recycle?--Goal: Man decision to recycle, or not, 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 for a management recommendation for product go-ahead.

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 which will support preliminary decisions. PMO must have assurance that the design intent meets the customer requirements. Manufacturing begins selection of sub-contractors 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 which includes the market analysis, airline interest, firm orders, program costs, etc.

Block V-21. Product Go-Ahead--This is a major program milestone. Management authorizes go-ahead with product design, manufacture, verification and support.

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4.2.3.6 Level VI - Product Detail Design

Level VI will begin when the decision has been made to commit the design to project status. This Level will be dominant in 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.

Block VI-1. Establish Preliminary Design/Product Interface--
Goal: To provide Program Management, the Engineering Design Project, Engineering Technology Staff Organizations, 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 are finalized, i.e., the program plan, the engineering cost and schedule plan, the design development and verification test plans, customer support plan, etc. 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 weight accountability (Type D weights) is revised as required for Engineering, Finance and Manufacturing (WTS-22). The weights accountability has been structured as follows:

1. To provide a meaningful definition of the product in terms of weight data and descriptions,

2. To provide a meaningful weight history for evaluation of the final product design,

3. To provide the flexibility to handle a variety of design projects,

4. To provide a system which can interface with the previously executed weights analyses programs,

5. To provide a system which is efficient in terms of:

   a. Data and input, editing, and verification

   b. Internal data storage and manipulation

   c. Output data report generation.

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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 again 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 and its prime purpose is to correlate between analytical and factual stress distributions.

This testing 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, empennage local concentration areas, 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.

1. 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 boiler plate 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 conduction of the tests.

2. 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 which is 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, to improve areas of low lift, high drag, interference, etc., to support the aerodynamic cleanup program, and to do 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 the low speed tests, the flutter characteristics and critical flutter speeds of the primary surfaces of the airplane and the sensitivity of flutter to various design parameters will be determined. In the transonic tests, the Mach effects (especially the high subsonic region) on the overall airplane flutter and the buzz characteristics of the control surfaces

will be determined. If a flutter suppression system is required, the flutter model test shall verify the 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 the stability margins of the model. Finally, system tailoring tests such as APU and air conditioning inlets, pitot static provisions, etc., will be done.

Block VI-3. Design/Analysis--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 the production configurations.

Automated Parts Release (APR)--Goal: To control the listing and release of parts information to Manufacturing.

The Automated Parts Release System is a related set of computer programs which produce new and revised part cards and assembly lists from data supplied by the Engineering and Manufacturing Departments. The part and assembly information is maintained on two separate master files, one containing engineering or configuration data and the other containing manufacturing or production data. Each of the two master files is updated by a separate computer program using a distinct set of input transactions, one primarily from engineering sources, the other entirely from manufacturing sources. Information from the two master files is collated by a report generator system to produce printed part cards and assembly lists and also to provide a record containing transactions for direct input to the Manufacturing Department's program.

A change in the usage of an assembly implies a corresponding change in component parts of the assembly. The APR System is design to effect these implied changes automatically. To accomplish all implied changes in one pass through the master file, it is required that every component of

every assembly be located in the file beyond the assemblies of which it is a component.

The concept of level (not the IPAD Levels) is used to make this ordering of parts possible. The master or top drawing for the airplane model is at level 1. All drawings that reference the top drawing as their "used-on-drawing" are at level 2.

This relationship between a part (detail, assembly, installation, drawing) and its used-on part continues down to detail parts. The lower the level the greater the magnitude of the level number.

When a part is used on more than one assembly, and if these assemblies are at different levels, the part is assigned a level one greater than the used-on assembly with the largest level number. About 15 levels are required for an airplane master file. The level numbers are assigned by the computer program, and do not appear on any input transactions. The engineering master file is arranged in level number order, and within each level in part number order. The master record for each part on the engineering file indicates all usages of the part, both active and cancelled, and all components of the part, unless it is a detail part.

The level concept does not apply to the manufacturing file. It is arranged completely in part number order. There are entries in this file for each active part, and for each active usage of the part for which distinct manufacturing information is supplied.

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 of the type such as 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, 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 shot) 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 which are pertinent to the 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. That simulation will be performed 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. However, the detail will be sufficient for final drawing release. 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-10 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 such as 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 assure schedule integration between these 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 which represent the following schedule dependencies:

1. Design project group schedule requirements for key interface design data from another design project group upon which their effort is dependent,

2. Design project group schedule requirements for key technical data from a technology staff discipline group upon which their design effort is dependent,

3. Technology staff discipline group schedule requirements for key design data from a design project group upon which their technical tasks are dependent,

4. 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:

1. Airplane System Detail Design Reliability Safety Analyses--Goal: To incorporate additional design detail into the Level V reliability and safety analyses and to 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.

2. 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.

3. 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.

4. 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 to 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, to analyze all wind tunnel testing, to size actuators from control surface wind tunnel tests in Block VI-2, to do detailed control surface effectiveness analyses to assist control system design, to do 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 as complete as possible understanding of the basic flying qualitites of the configuration. Wind tunnnel 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 controllers 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 the assessment of failure modes (mechanical, hydraulic, engine thrust, etc.). 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 then 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, CAA) are met together with any special Boeing requirements.

Loads on secondary structure (high lift devices, control surfaces, fairings, doors, etc.) 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 anywhere between 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 non-standard flight configurations such as spare engine carriage), the output of which may not be passed to other technologies.

The network shown in figure 4.5 (page 105) 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 that the order of execution is fixed.

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 hard copy such as engineering drawings, documents, specifications, or reports.

It is intended that no new structure design definition be accomplished at Block VI-3, 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 considerations, criteria and constraints of Block 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.

One possible 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 engineering 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 are based on the same considerations as in Level V, however, qualitatively this is going to result in 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.

Continue Level V activities and complete the following additional activities.

1. Identify all hardware required and release preliminary information to the mockup. Finalize and release design of detailed parts and installation information.

2. Finalize and release procurement specifications for new equipment items.

3. Finalize and release maintenance information including the following.

   a. 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.

   b. 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:

      (1) Test Provisions: self test or test-in-place.

      (2) The component removal basis in one of three categories: (a) Time-controlled components with predictable wear-out rates which will be removed and replaced in accordance with the scheduled time between overhauls (TBO); (b) 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; (c) Failure-controlled components which can continue in service until failure. This category is generally related to parts which fail abruptly and their failure does not impose any hazard.

c. Procurement specifications: Each procurement specification contains a maintainability requirement to meet the intent of b.(1) and b.(2) above, and a test to prove satisfactory operation at a specified deteriorated performance level.

4. 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 the current status of the configuration's definition in terms of weight and weight related items in a form which 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.

1. Engineering

a. Input of wire and equipment to data files.

b. Verification of agreement between data files and wiring diagrams.

c. Reference information for configuration of any airplane.

2. Mockup

   a. Input of wire lengths and subassembly groupings.

   b. Reference information from which formboards and production illustration (P.I.) drawings are produced.

3. Planning

   a. Input assembly sequencing information.

   b. Issue production orders for every bundle required.

4. Material

   a. Purchase wire, connectors, etc.

5. Manufacturing

   a. Cut and mark wire.

   b. Preassemble connectors

   c. Assemble bundles

   d. Test bundles

   e. Connect bundles together after installation in airframe.

6. Customer Airlines

   a. Maintenance

   b. Identification of spare wires

   c. Identification of bundles and equipment for ordering spares.

   d. Input of information on post-delivery modifications.

Program Descriptions:

Manufacturing Plan (Includes Bundle Equipment List)--This program provides a report containing production information, how many to build, what parts are used, where to install the bundles, 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, assembly sequence, and references the wiring diagram which shows the wire.

Equipment List--This program shows part number, description, next assembly, reference wiring diagram, etc., for each equipment items 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 3 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 the following:

Assembly connection list--is a report showing how long to cut each wire, from what wire type and size to cut it, how to mark it, and how to connect it. A separate list is issued for each group of wires within a bundle.

Plug maps--are physical layouts of connector insert arrangements with the wire number for each pin printed immediately below the pin number.

Formboard list--is similar to the assembly connection list except that it is sorted by equipment item number rather than wire number to enable the worker to finish one item before starting another.

Manufacturing plan--is 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 Are:

Part Requisition Cards are 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 those wires which 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 are used for automated testing of completed wire bundles.

Bundle Sequence List provides planning with a complete list of bundles required for an airplane, sorted in production sequence.

Hook-up Charts provide final assembly workers with hook-up information required at the time bundles are installed in the airframe.

Other Non-Manufacturing Reports include:

Diagram Check List is an extract of the wire file, sorted by wiring diagram. It is used to check compatibility between the data base and the wiring diagrams.

Equipment Check List is analogous to the Diagram Check List but is extracted from the equipment file.

Wire Compare List shows only the differences between any two airplanes of the same model.

Part Number Summary is an extract of the equipment file sorted by part number.

Bundle Assembly Index shows which bundles are used on what airplanes.

Diagram Equipment List part of the Diagram Manual Report (DMR) is an equipment list for one customer only and is sent to the airline for maintenance information as part of the 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) is a full wire listing for all bundles for one customer block.

Hook-up Charts, Ground List, Splice List, Terminal List are all part of the DMR and give 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.

Block VI-4. Manufacturing Review--Goal: To monitor schedule sensitive item releases from Engineering to assure that manufacturing activities can be responsive.

Operations refine manufacturing plans and make 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 per 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 a continuous interaction between Engineering and Operations as the part drawings are released. There must be quick response by Engineering 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 which do not require detail information from engineering.

Manufacturing prepares production illustrations (PI drawings) which are co-signed 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).

4.2.3.7 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.

Block VII-1. Manufacturing --Goal (1): Provide a manufacturing process to build the end product to fulfil the engineering specifications and assure that the "as built" configuration matches the "as designed" configuration.

The manufacturing process utilizes extensive computer systems to produce shop paper, collect cost data, report execptions, 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 re-checks, both manual and automated, with decision making data available to management as a by-product. 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):

1. Fabricating bundles (Cutting wire, marking it, installing connectors, grouping and tying wire into bundles),

2. Testing bundles (Using card controlled Automatic Test Equipment),

3. Installing bundles (Making connections between bundles after bundles are installed 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 (sub-assembly level) and production illustration drawings (final assembly level).

Goal (2): To provide 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, there must be a fast response by engineering to the manufacturing request for a design change, in order that the matter be resolved with the least possible delay in the production process. The liaison activity provides the response and also feeds the information to the parent organization to assure that the affected design media are corrected.

Block VII-2. Production Problem Requiring Redesign?--Goal: To provide a process by which required design changes are made known to the engineering design project. These changes are of the type which cannot be made by the engineering liaison organization supporting the manufacturing effort.

Block VII-3. 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 that are 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, the Wire Release System (STM-22) provides reports containing the amount of wire in an

airplane, by type and gage, its 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.

4.2.3.8 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 outside the IPAD man/machine environment, but the results will be recorded by the IPAD data base management system.

Block VIII-1. Airframe Testing--Goal: To verify the static strength and fatigue life of the airframe and 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 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, 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 cerify the performance guarantees and regulations.

Proof of guarantees and federal safety requirements requires extensive flight tests. Aerodynamics will in the main be concerned with measuring flight quantities that relate to performance. The low speed lift capability is determined. The

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 the experimental results 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 reduced into 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 will be determined. Engine operating limits will be described, and fuel usage will be 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.

A review of the Flight and Ground Test Plan prior to testing and review and analysis of test data is performed.

This assessment is manual for pre-test review. Test data reductions will be by REL-6, REL-8, REL-9, REL-13.

Stability and Control--Goal: To certify the flying qualities of the airplane to meet appropriate regulations for desirable, handling qualities, for normal and foreseeable abnormal failure conditions, require extensive flight testing to meet requirements for the Federal Aviation Administration and possible other authorities such as the British Air Registration Board.

Stability and control are concerned with measuring flight behavior and the correlation with estimated characteristics and the registration requirements. Also of importance in these tests are those characteristics which affect the performance of the airplane and its ability to meet guarantees, i.e., takeoff rotation speed and rotation rate, landing flare capability, 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 taken 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; flight simulator documents used for design as well as flight training and demonstration will be updated similarly.

Block VIII-3. Functional Testing--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.

A review of functional test plans prior to testing and review and analysis of test data is performed.

This assessment is manual for pre-test review. Test data reductions will be by REL-6, REL-8, REL-9, REL-13.

Block VIII-4. Summarize and Review--Goal: To provide the Engineering, Finance, Manufacturing organizations, Program Management and the Customer (according to contractual obligations) a current status of the product definition.

Block VIII-5. Problem Requiring Redesign?--Goal: To monitor the verification processes and determine which parts need redesign. These parts will be returned to Level VI for review and redesign. 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.

4.2.3.9 Level IX - Product Support

This Level is concerned with collecting information required to support the product once it is in service. Its performance and other inservice information will be continually monitored by entering data in the data base and using the capabilities of the IPAD data base management system.

Block IX-1. In-Service Parts Histories--These will be monitored to detect problems, and to 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, both scheduled and unscheduled, retrofit kit installation and system failures are important to develop improvement 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.

Block IX-2. In-Service Payload Factors by Route--This information enters the marketing data base for marketing estimates of current and projected new products.

Block IX-3. In-Service Airplane Performance Changes--This information is made available to the data bases of the affected technical disciplines, where serious degradations will modify future designs.

Block IX-4. In-Service Systems Performance--Performance of various systems will be recorded as the airplane is operated.

Block IX-5. In-Service Problem?--This will refer in-service problems back to Level VI for analysis and design revisions.

4.2.3.10 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.

Block EM-1. Form Mass Matrix--Goal: To form standardized mass matrices which will contain for each pre-defined panel:

1. Weight

2. Center of Gravity

3. Moments and products of inertia about the cg

This data will be subsequently modified by the analysis in Block EM-5 to transfer the mass data from the panel cg to a reference axis used by the dynamic loads, flutter and flight controls analyses.

In order to facilitate the analysis of various flight conditions, there should be separate mass matrices developed for:

1. Wing (flaps up and down),

2. Body,

3. Horizontal tail;

4. Vertical tail,

5. (each) nacelle and strut,

6. Landing gear (up and down),

7. Payload,

8. 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.

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-panelled (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 consist of only a table look-up.

Block EM-5. Natural Vibration Modes--Goal: Modal analysis is used throughout the industry when doing a flutter, dynamic loads, or an elastic flight control system analysis. The initial step in any of these analysis is to obtain the natural vibration modes of the airplane.

The natural vibration modes program (SDL-1) is used to calculate both symmetric and anti-symmetric 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 this design level.

Block EM-6. Option?--Goal: Determine which 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, 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 a chain of cubics exact fit 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 forces matrices are generated using lifting line theory (SFL-2). The 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 of predicting oscillatory airloads on single planar lifting surface, 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 are consisted of generalized mass and stiffness matrices (Block EM-5) and generalized forces matrices (Block EM-8). These matrices are formulated, along with speed, altitude, and Mach number, as coefficient matrices of a system of second order ordinary differential equations (SFL-10, SFL-11, SFL-12). Additional equations may be required to account for the presense of actuators (FCS-13) and control system feedbacks.

Block EM-10. Force Matrices--Goal: The generalized force matrices are required to calculate both the quasi-steady

equations of motion (EM-11) and the 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 knowledgable 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 as 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 semi-automatic and would require an engineer to guide it during off-line operation.

4.3 PROJECT 2 - SUPERSONIC COMMERCIAL TRANSPORT

4.3.1 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 be low enough that cooling by using the fuel as a heat sink would be adequate. The range and payload are unspecified.

4.3.2 Design Networks

As in Project 1, the general Product Level concept of figure 4.1 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	1 design cycle	converged design cycle
II	2 days	*
III	1 month	*
IV	2 months	4 months
V	3 months	6 months

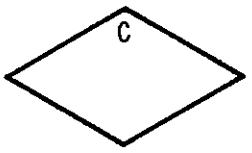
* One design cycle provides a converged design at levels II and III. A management decision is required to continue until a converged design is obtained at levels IV and V. This provides management control of the costs for computing and development testing (see section 4.1).

4.3.2.1 Project 2 Supersonic Commercial Transport Detailed Design Networks for the Product Levels

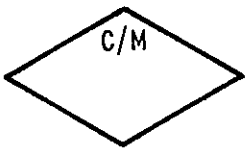
Figure 4.6 presents the detailed design networks for Project 2. The following information is pertinent to the networks:

Network blocks

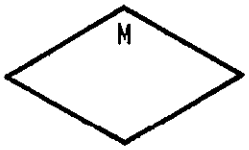
activity or event



computer decision



computer or man decision



man (or men) decision

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.

Equations of Motion

The equations of motion are a large group of Technical Program Elments 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 on page 160.

Narrative Descriptions

A narrative describing the design and analysis activities is presented in section 4.3.3 (page 161). Each network narrative is identified by a reference network block number. Some parts of this narrative are the same as that of Project 1, however, they have been included here for those who might choose to read only the Project 2 description. References to Elements contained in the Volume V, the catalog of Technical Program Element, are made throughout the narrative. An example would be ARO-9. This is an Aerodynamics Technical Program Element for Wave Drag and Supersonic Area Rule. It is an existing computer program which has been identified as a candidate for IPAD.

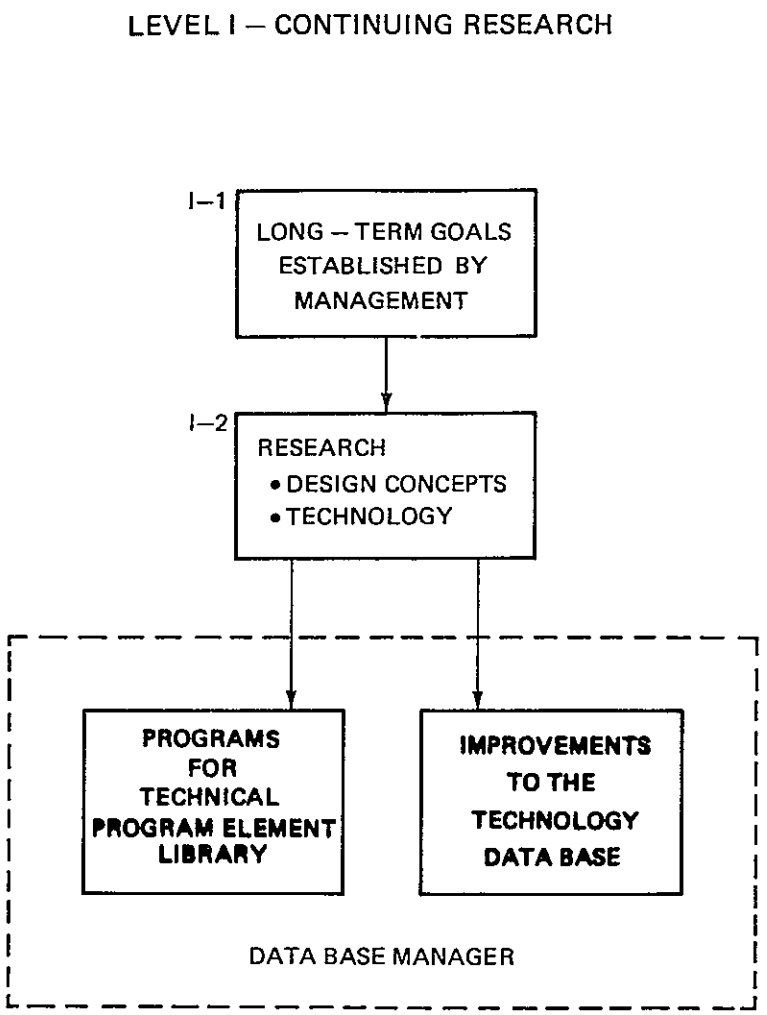


Figure 4.6 Design Networks - Project 2 Supersonic Commercial Transport

LEVEL II – DESIGN MISSION SELECTION

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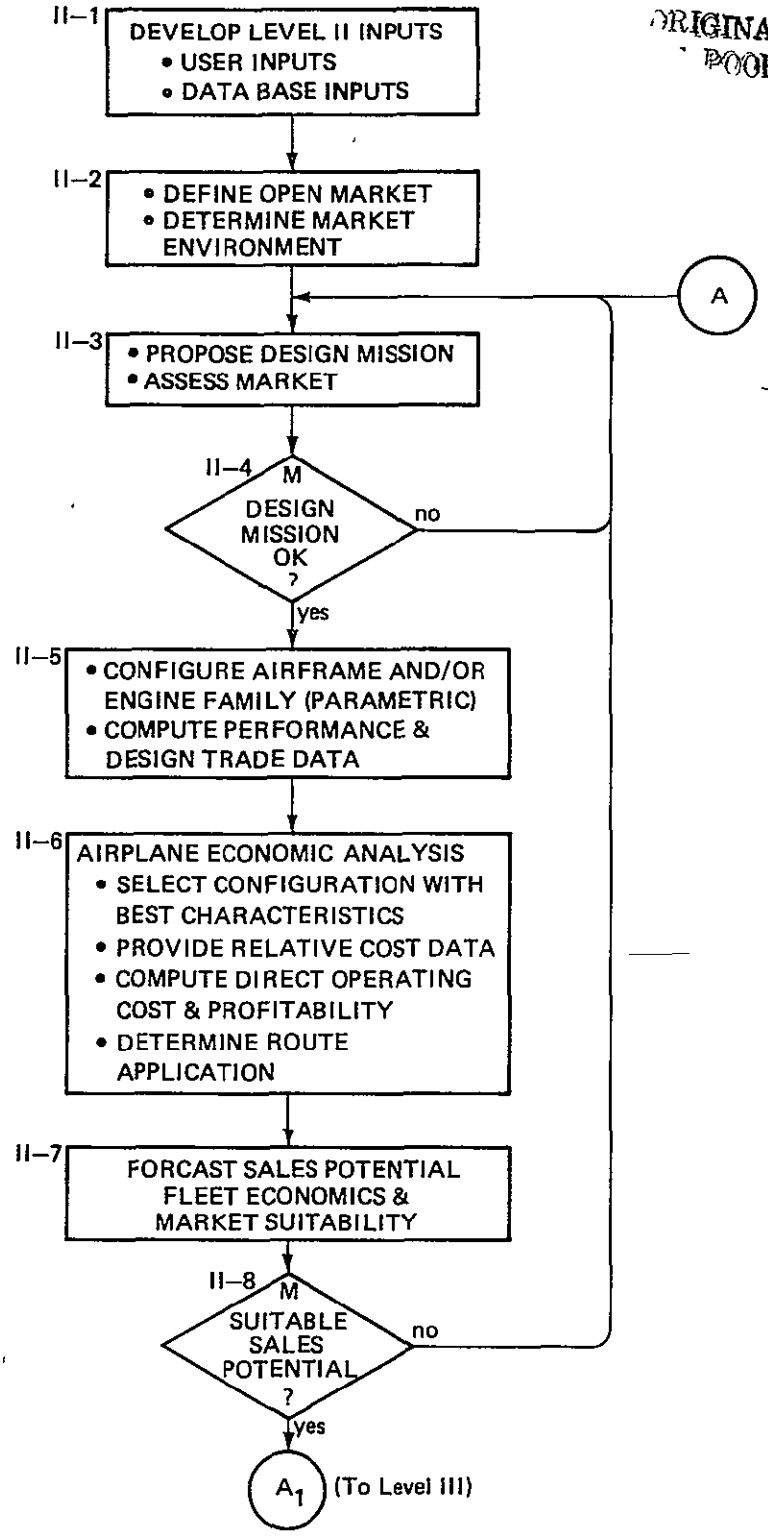

Figure 4.6 Design Networks – Project 2 (Continued)

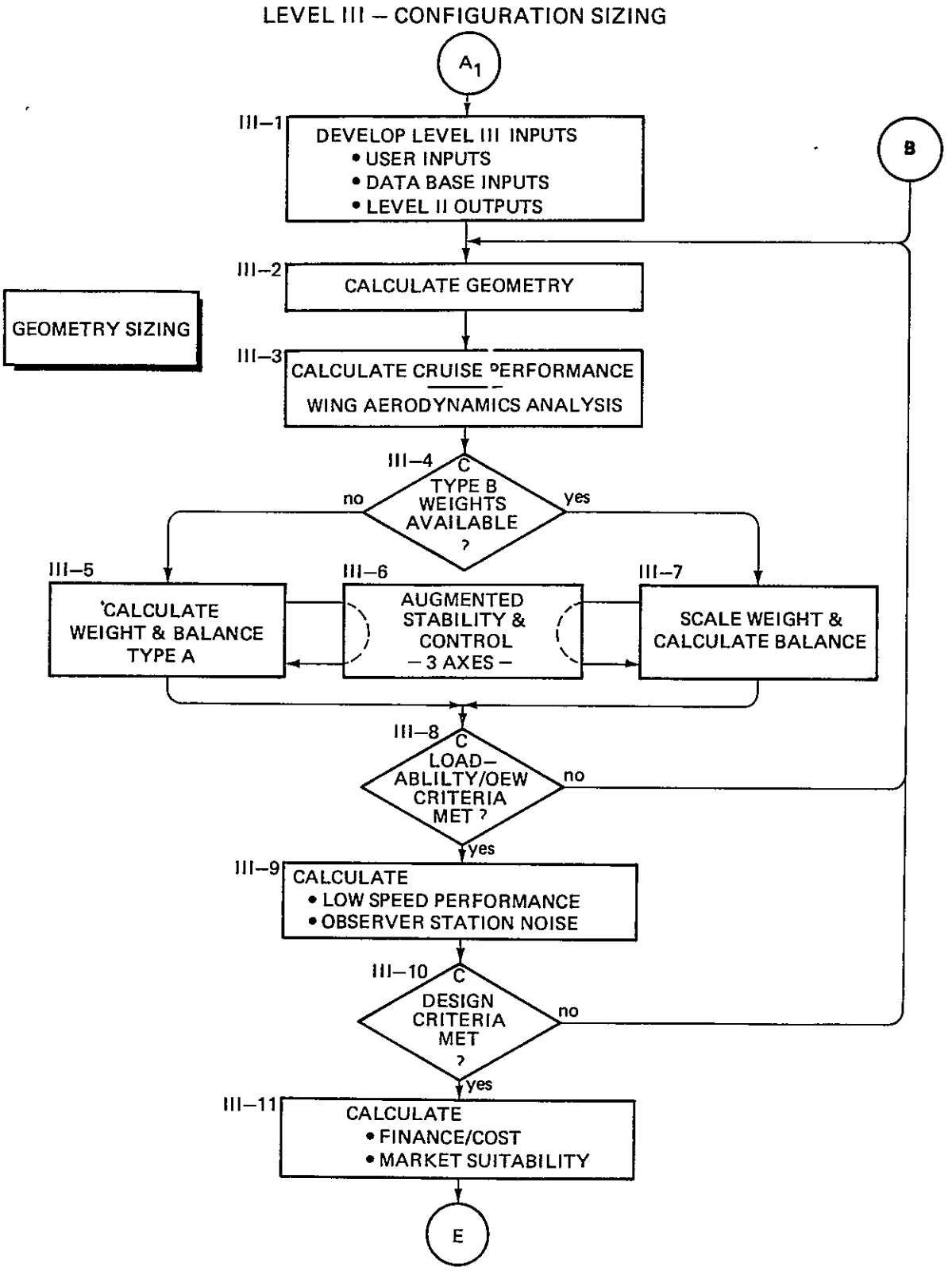

Figure 4.6 Design Networks – Project 2 (Continued)

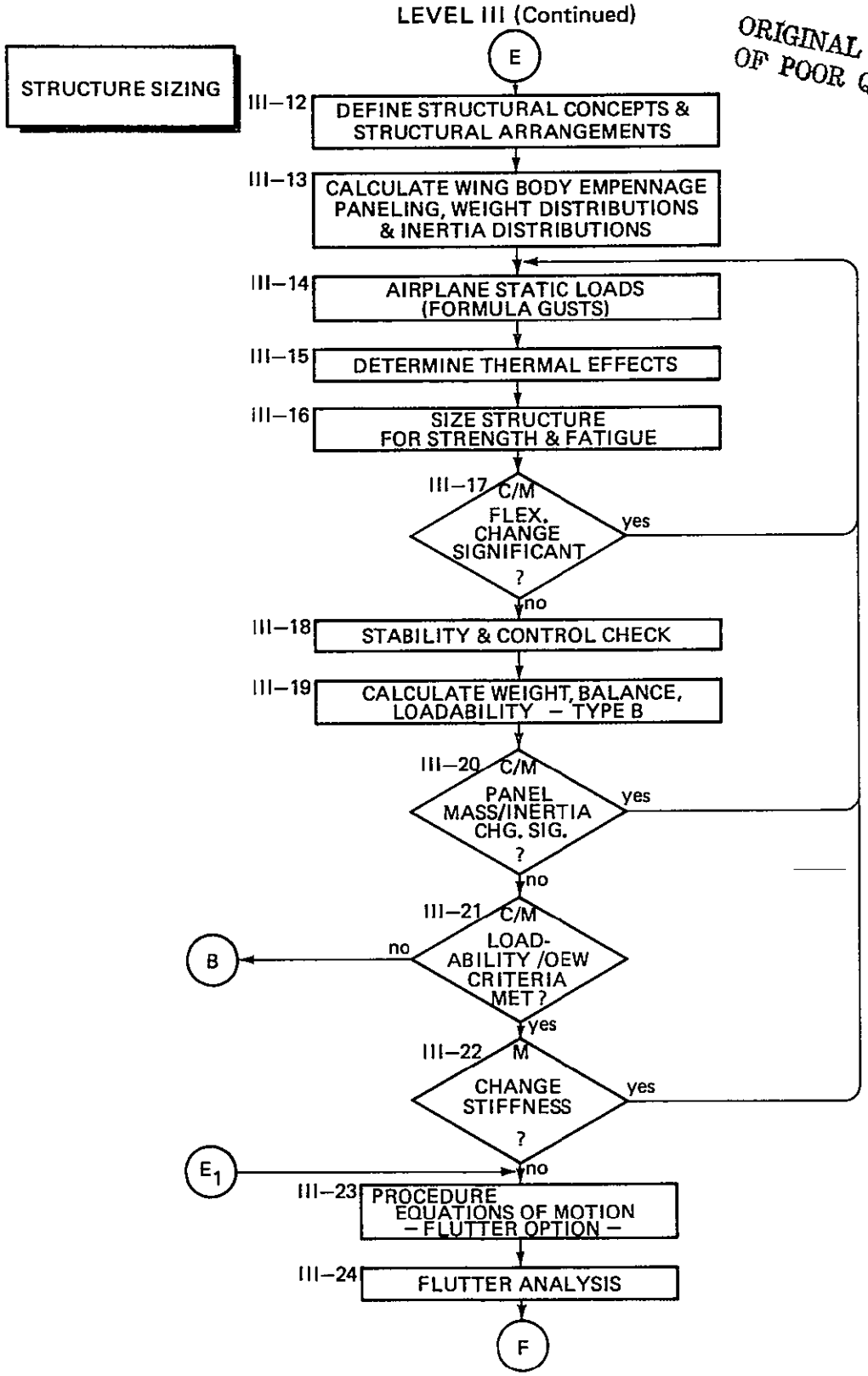

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Figure 4.6 Design Networks– Project 2 (Continued)

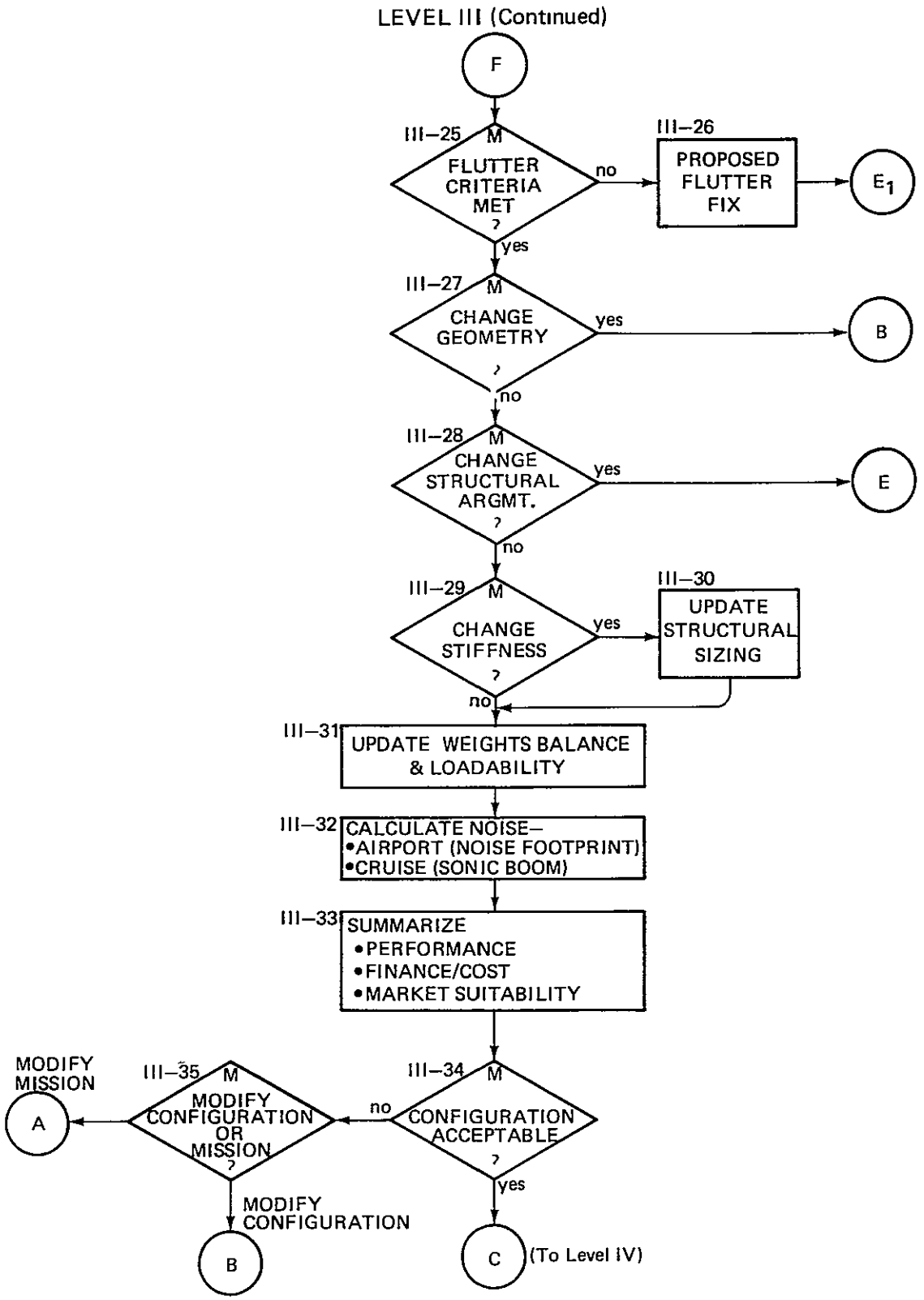
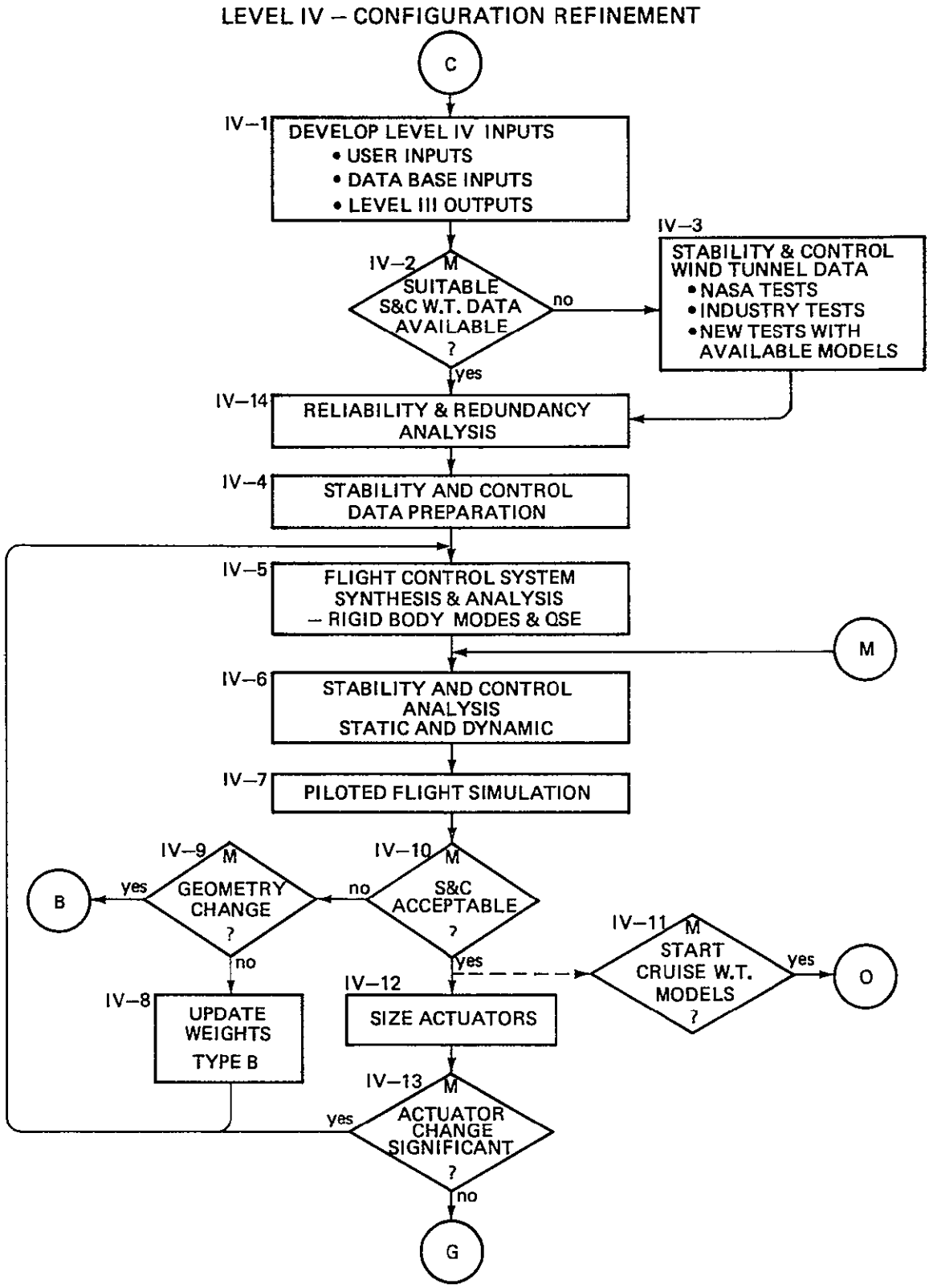


Figure 4.6 Design Networks– Project 2 (Continued)



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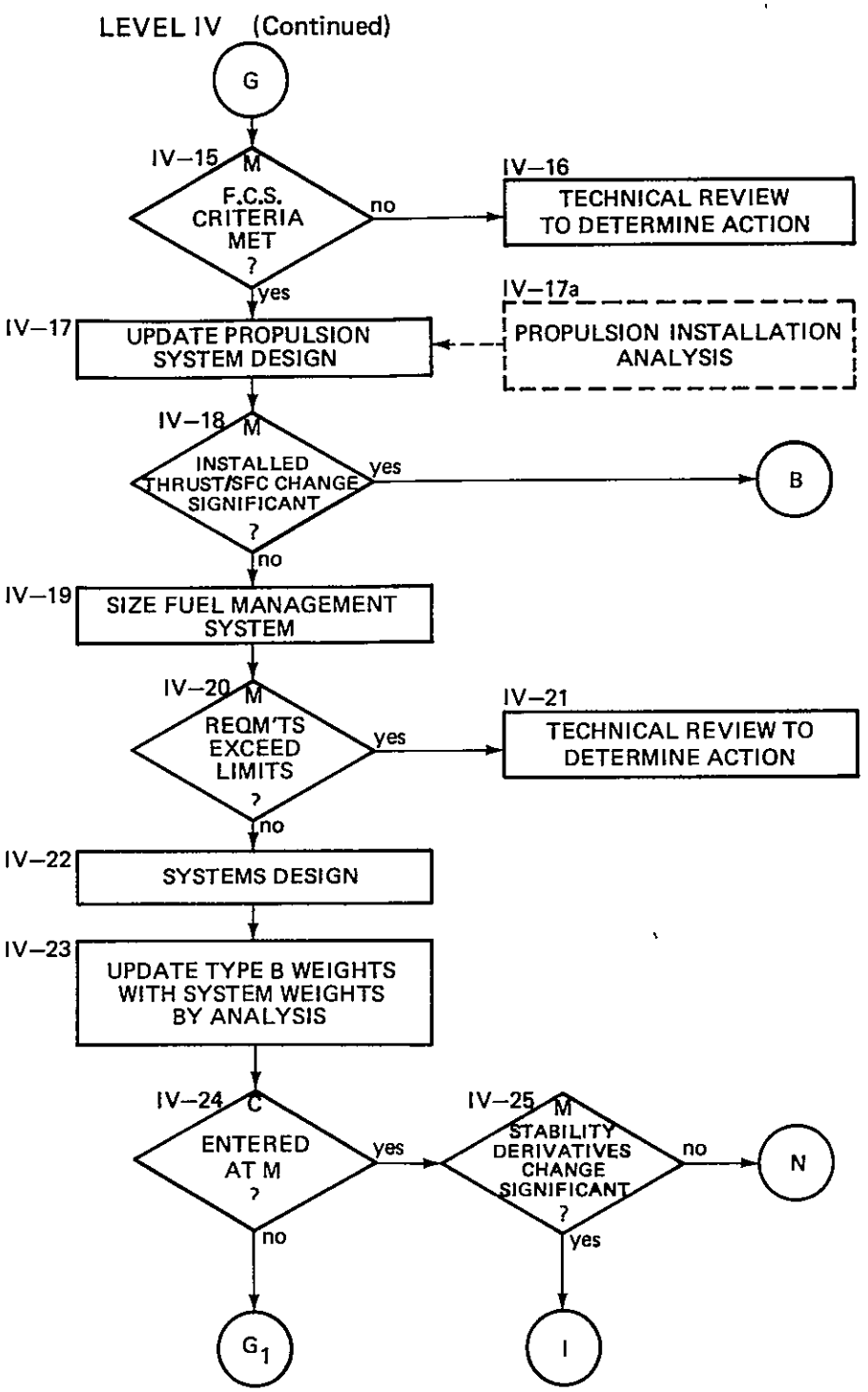


Figure 4.6 Design Networks– Project 2 (Continued)

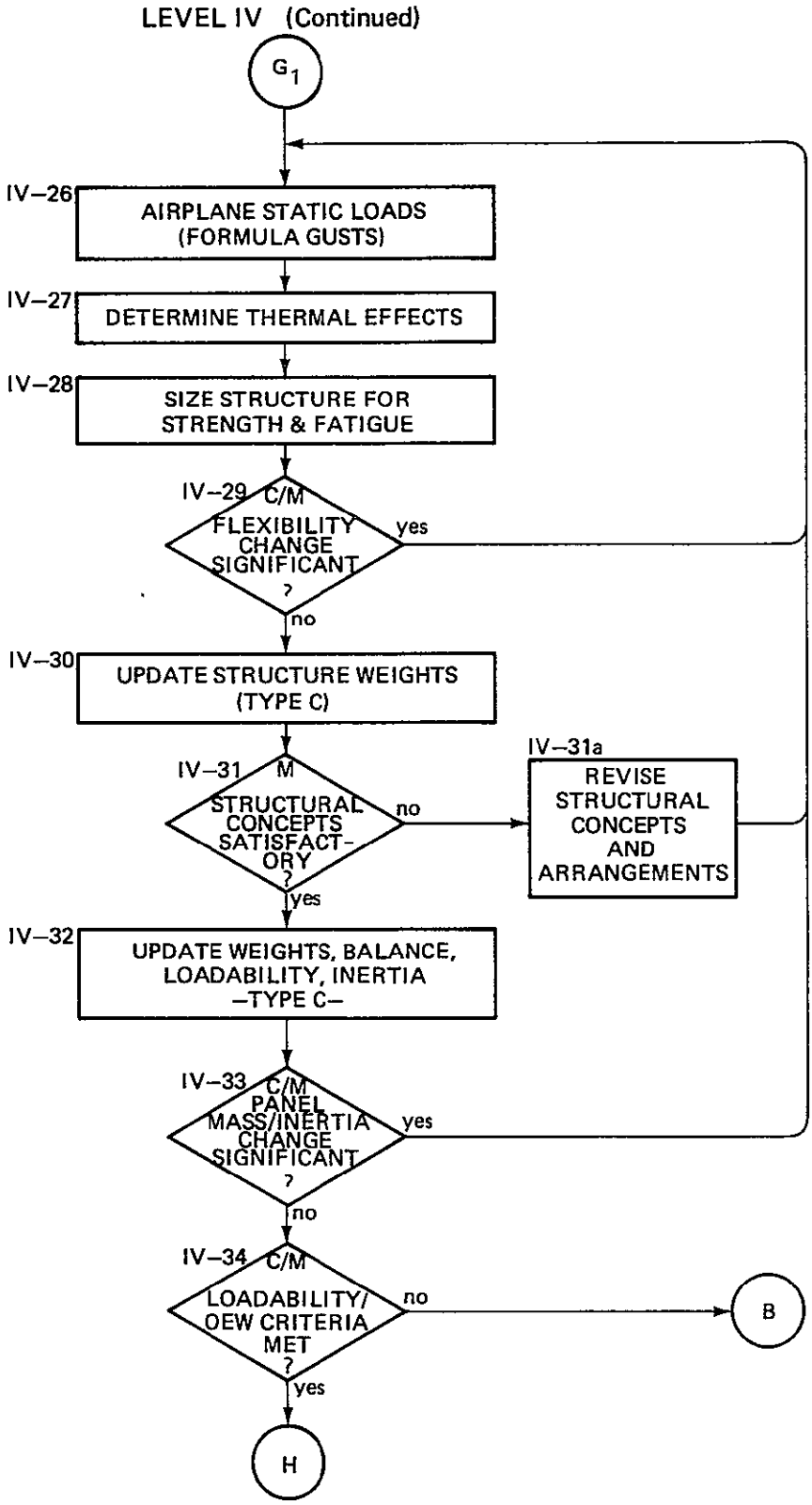


Figure 4.6 Design Networks – Project 2 (Continued)

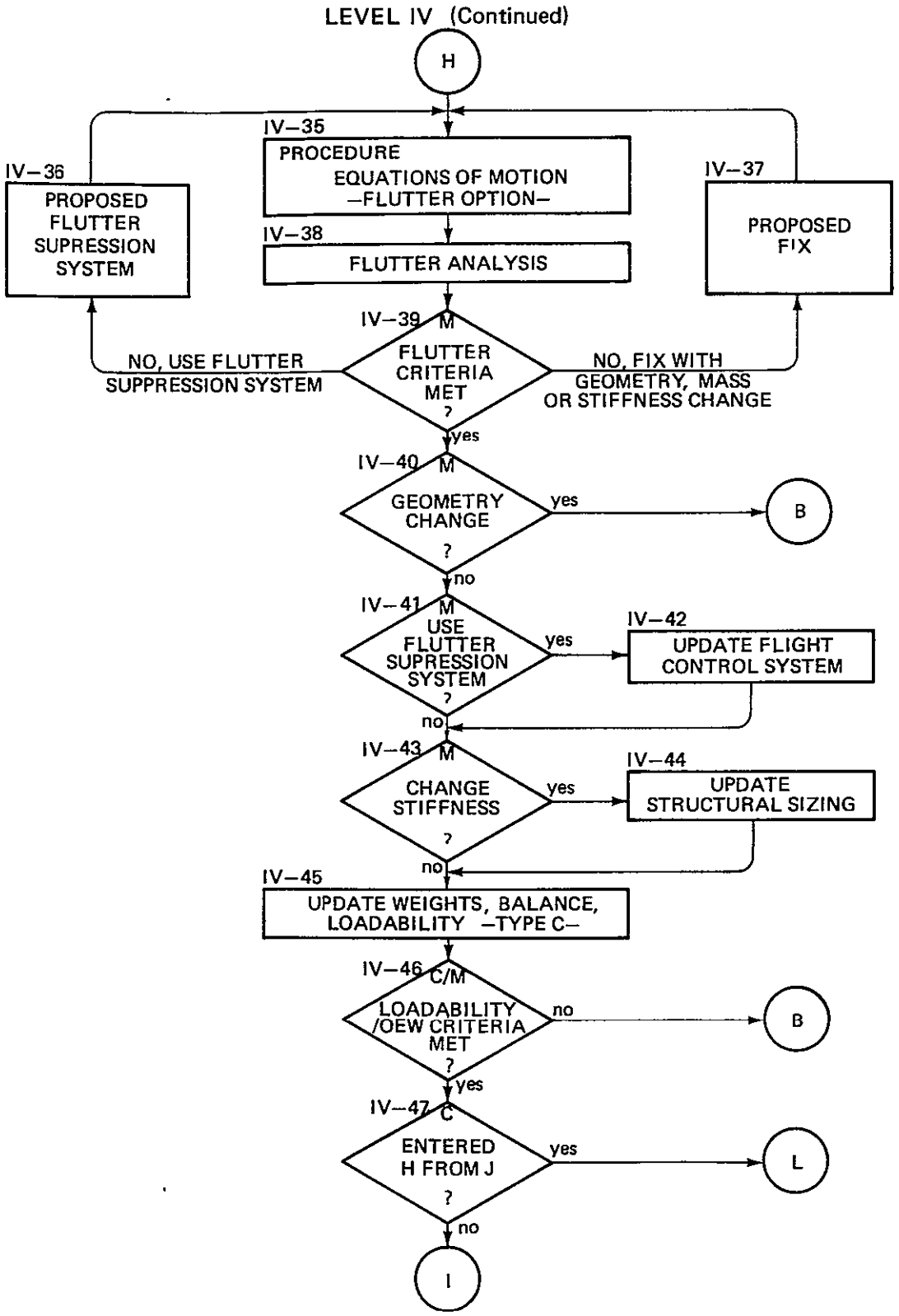
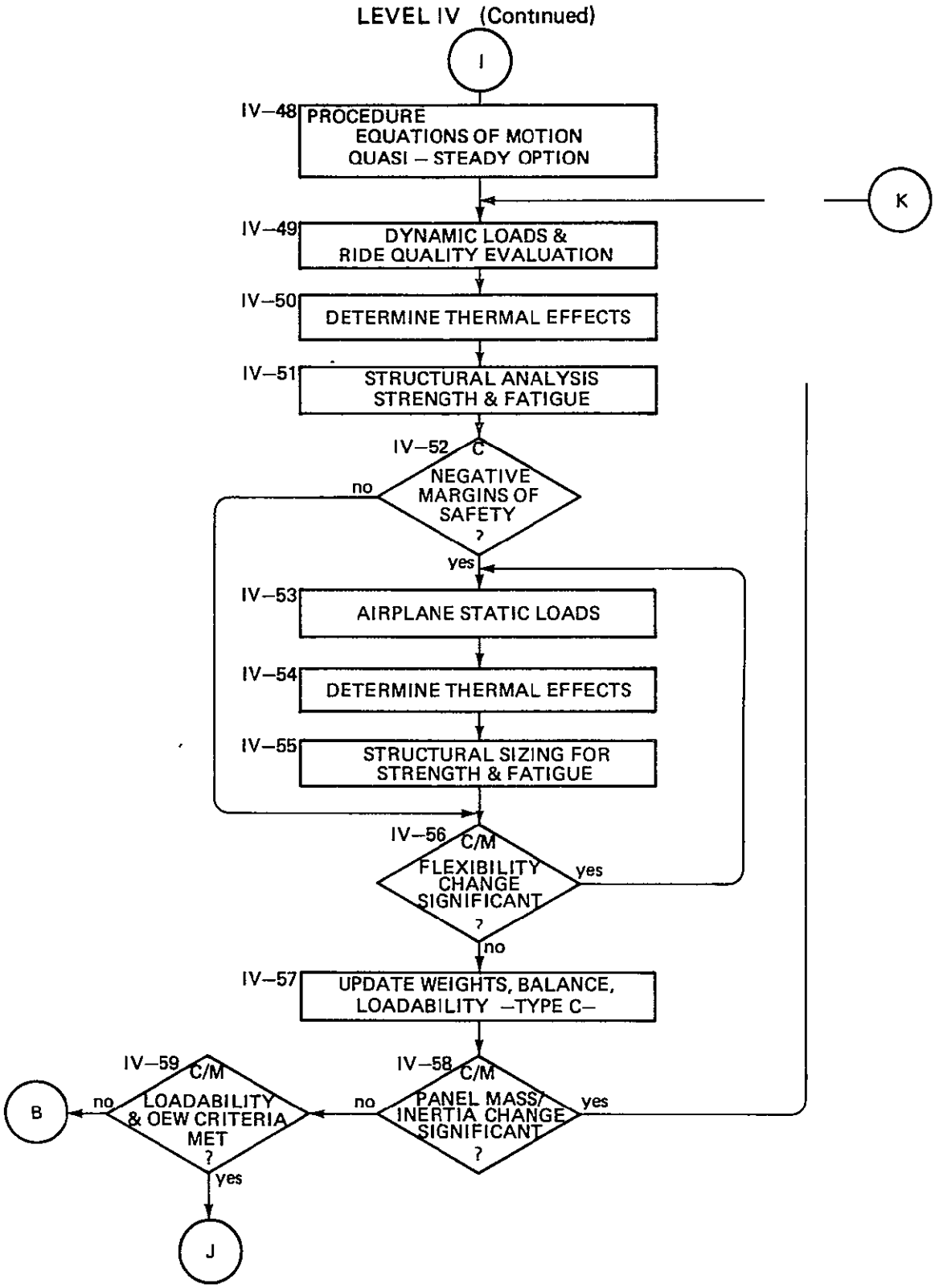


Figure 4.6 Design Networks– Project 2 (Continued)



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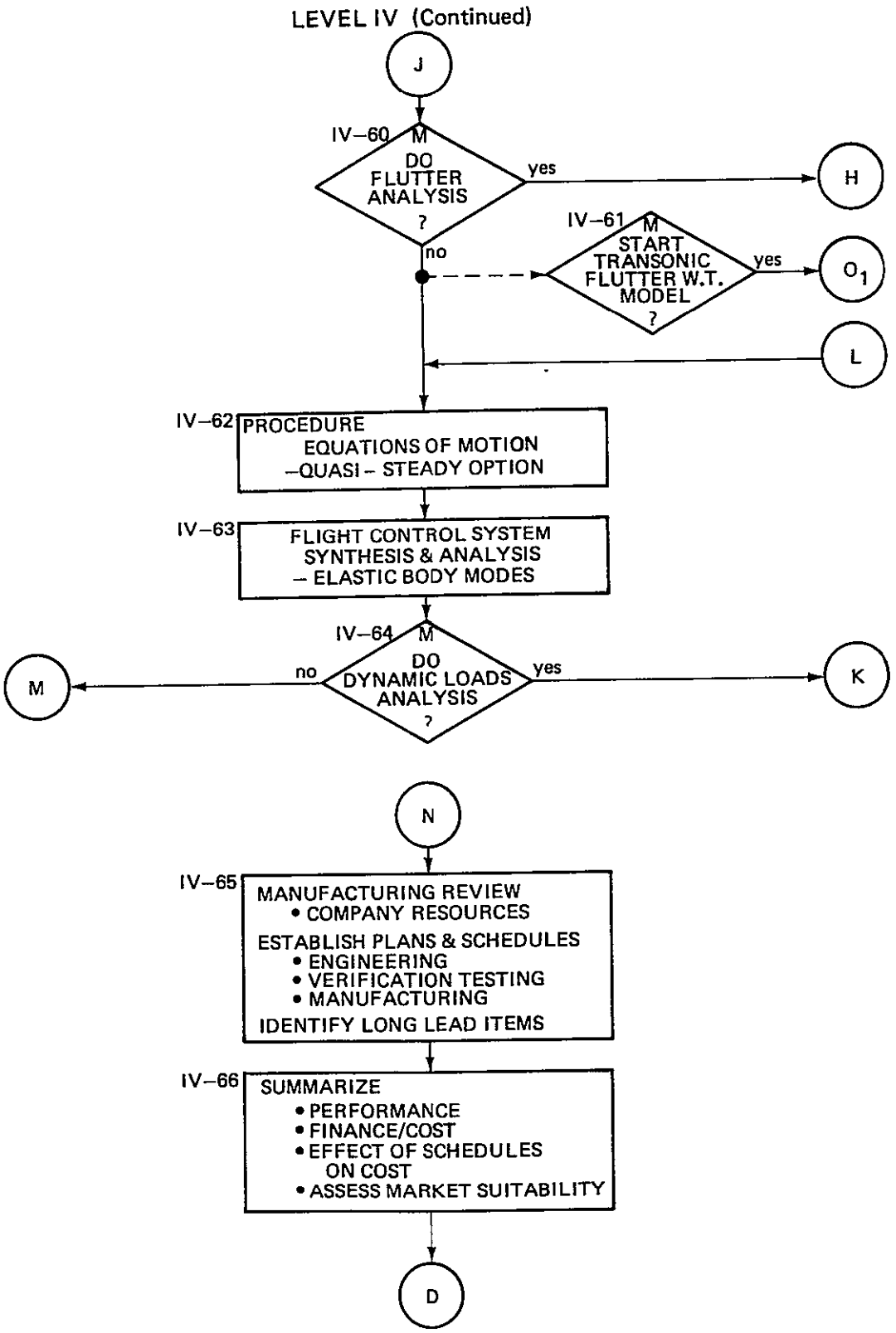
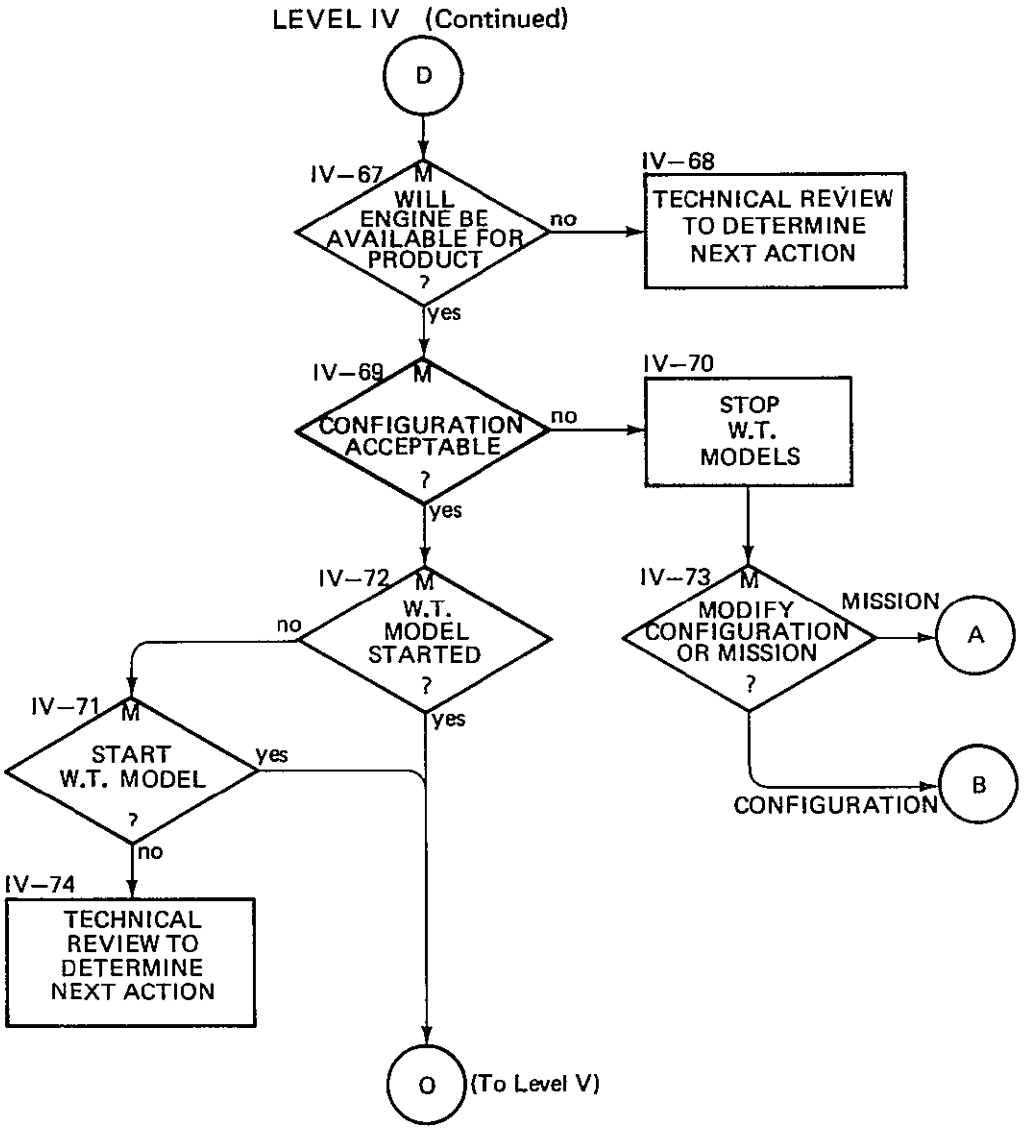


Figure 4.6 Design Networks – Project 2 (Continued)



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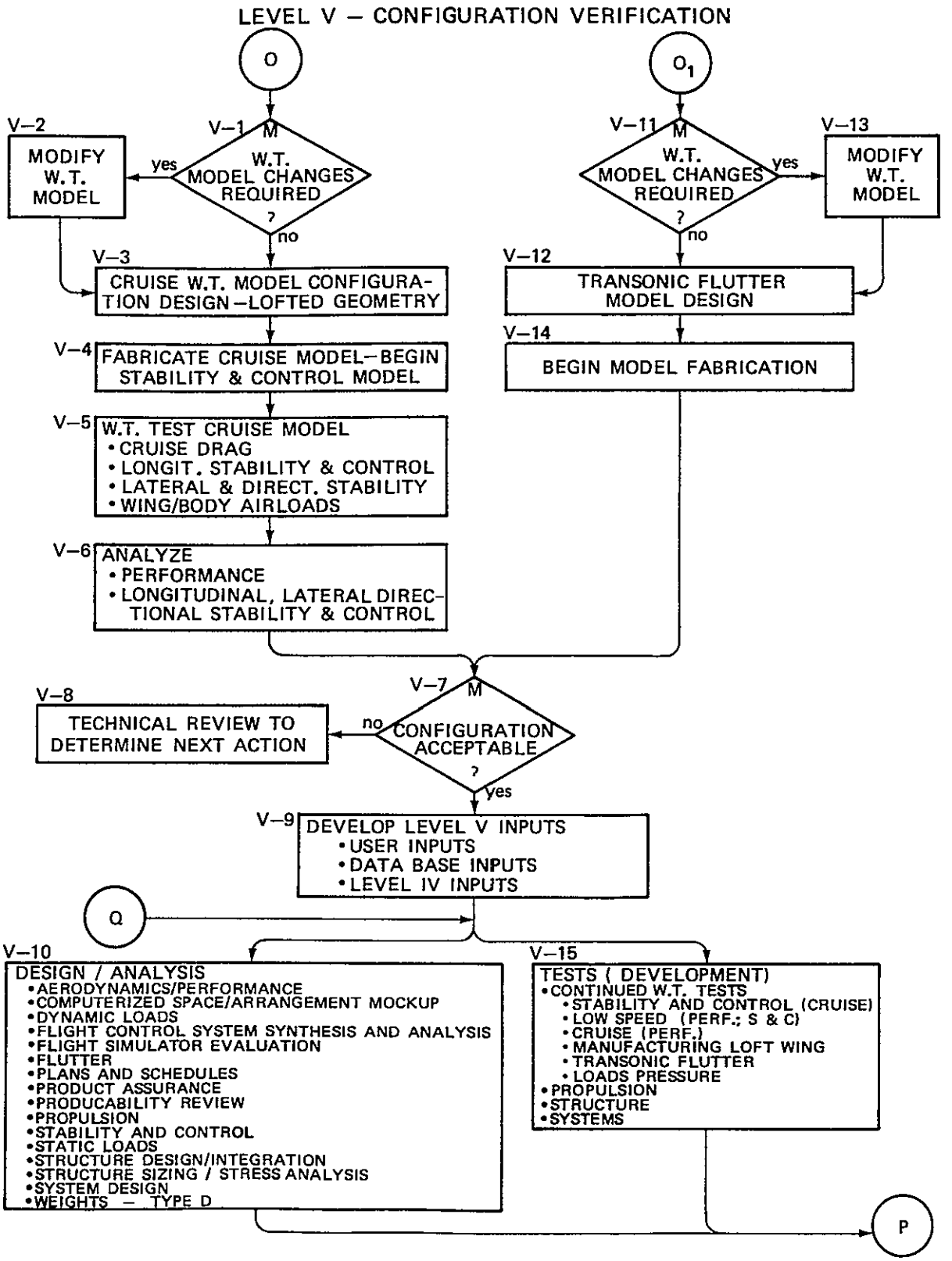

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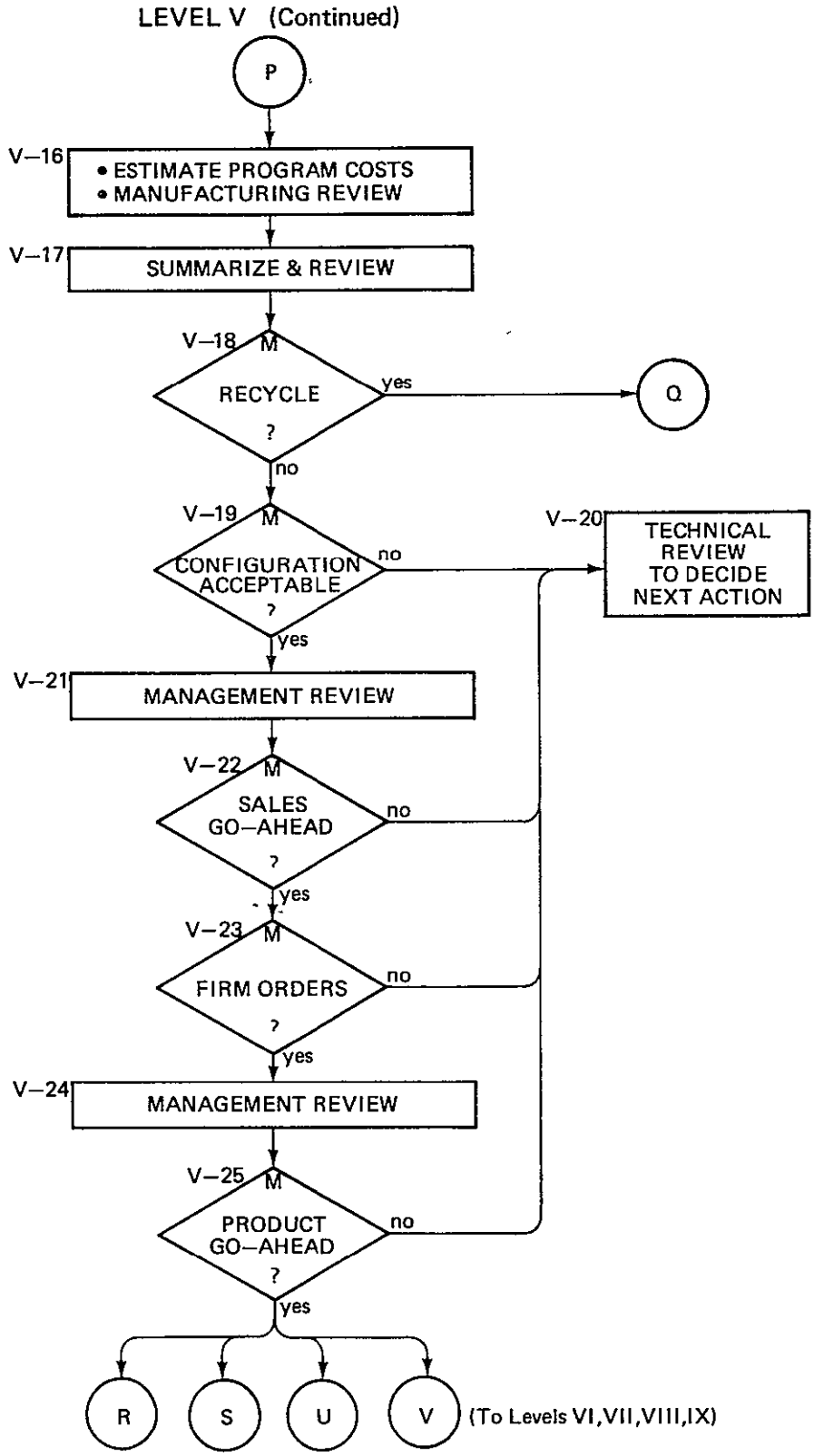
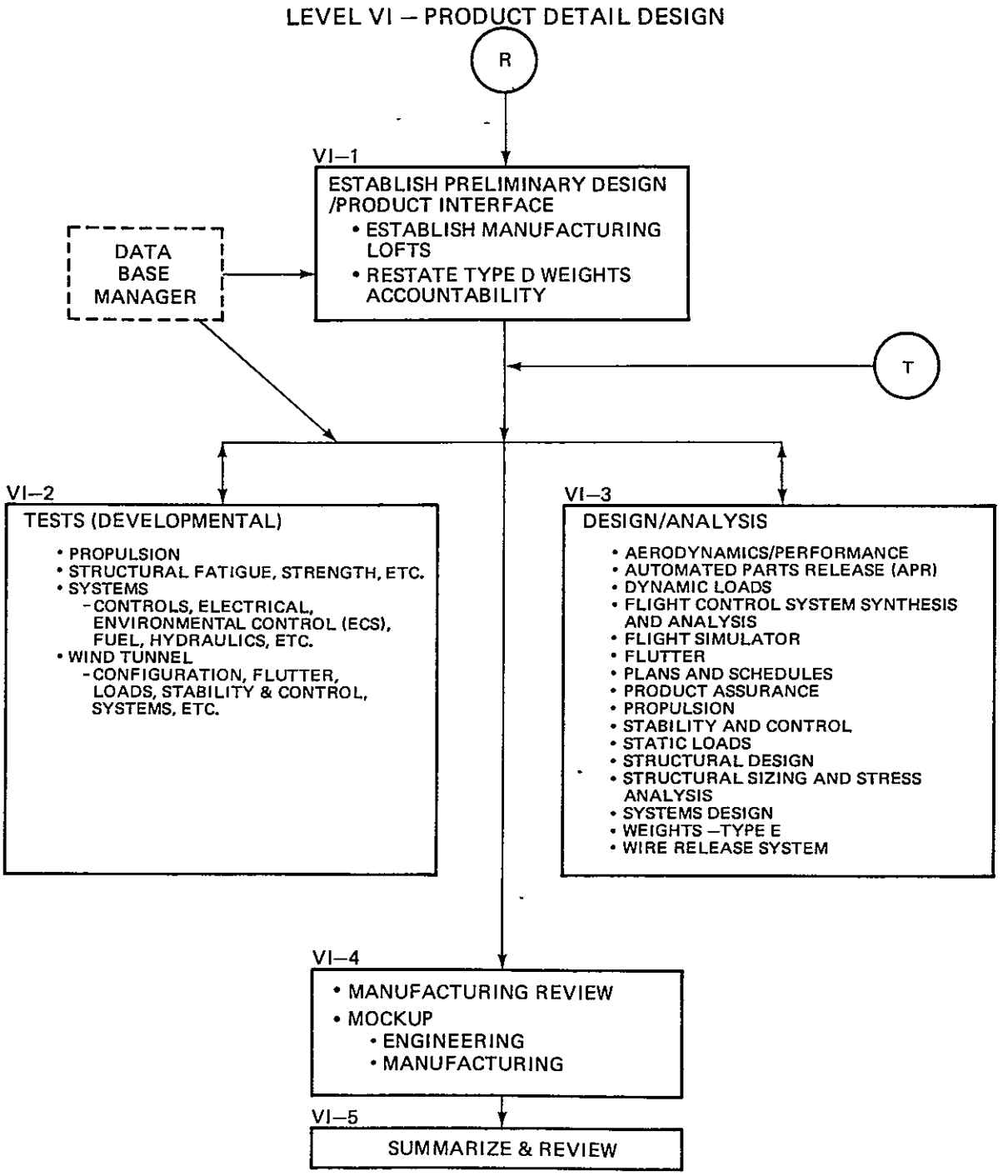


Figure 4.6 Design Networks – Project 2 (Continued)



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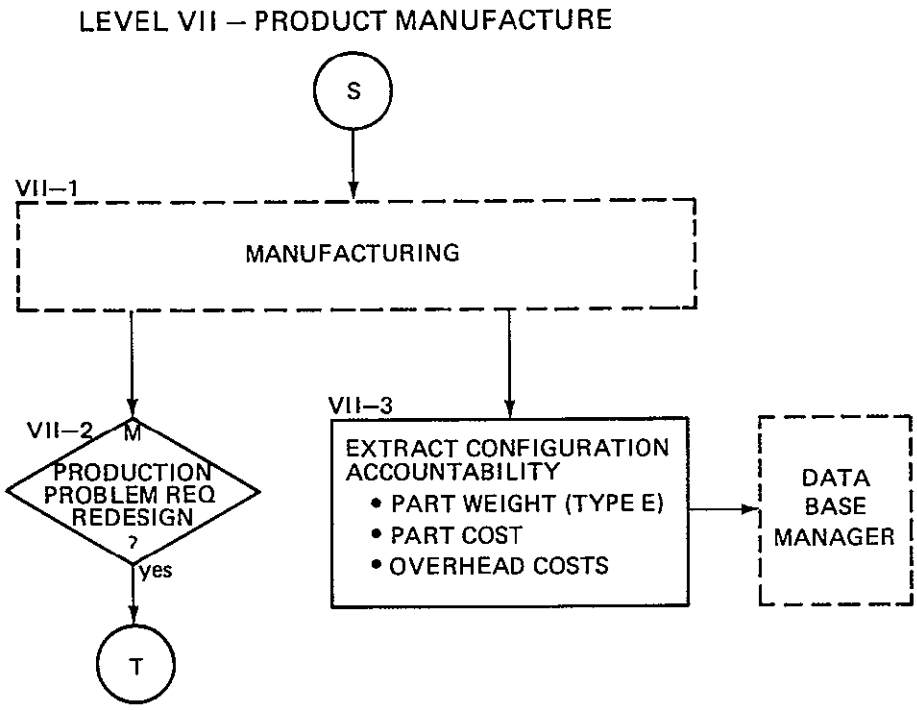

Figure 4.6 Design Networks – Project 2 (Continued)

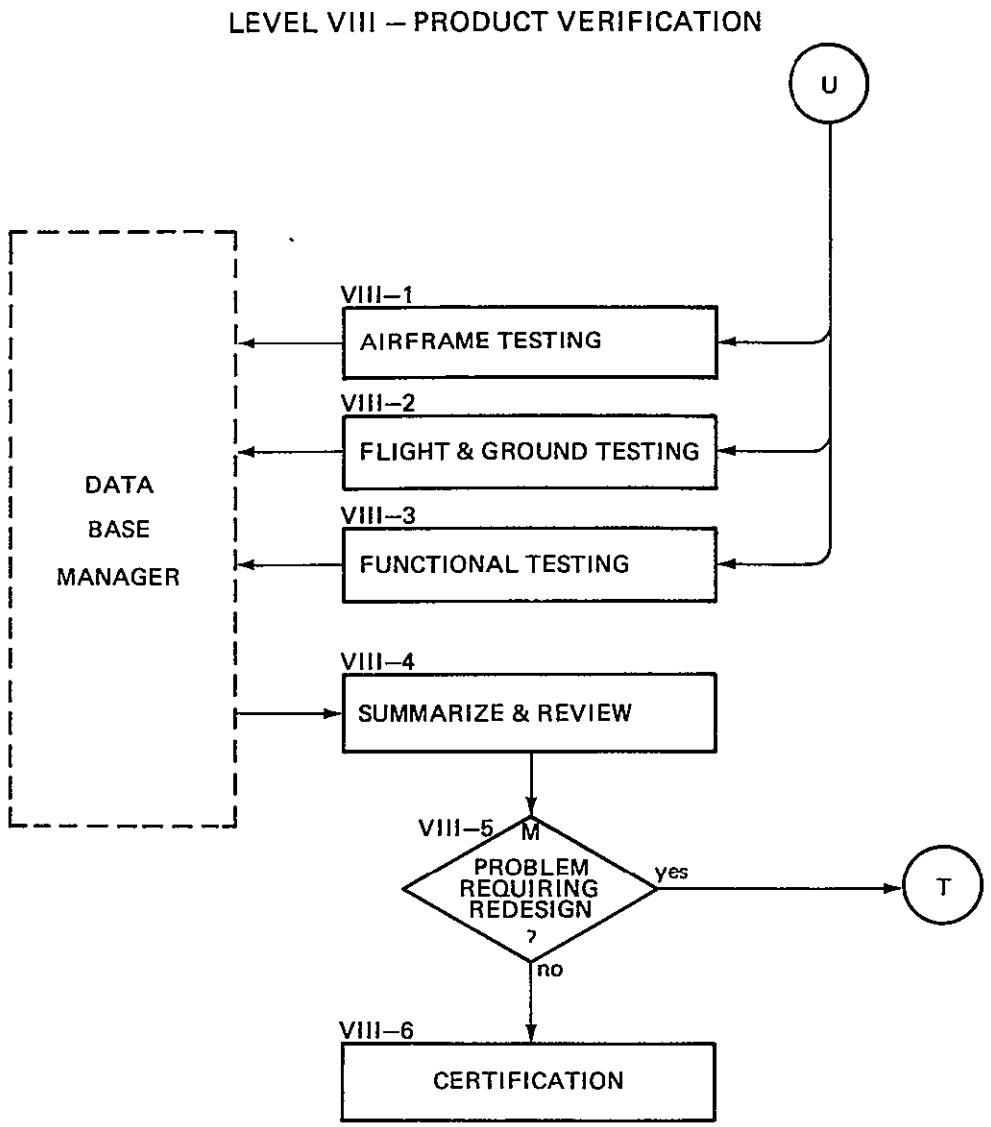

Figure 4.6 Design Networks – Project 2 (Continued)

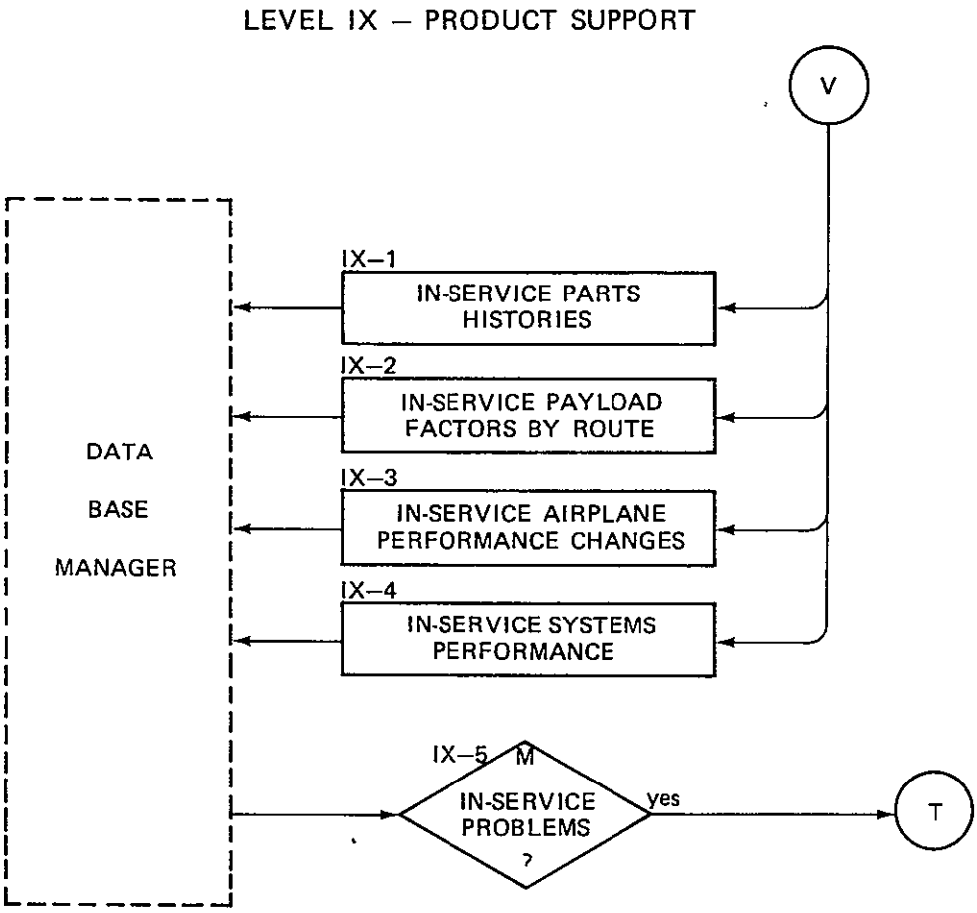

Figure 4.6 Design Networks – Project 2 (Continued)

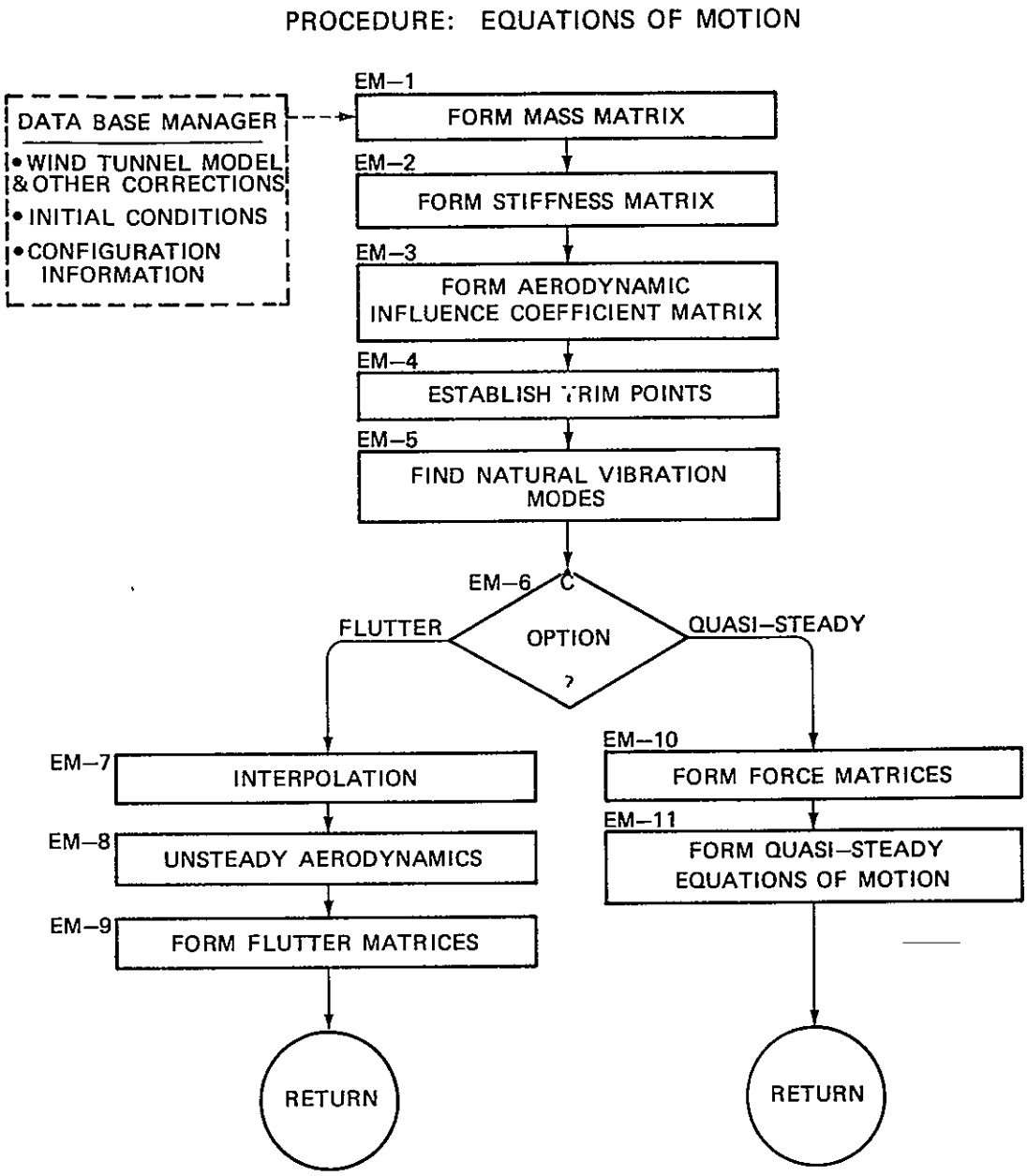

Figure 4.6 Design Networks – Project 2 (Continued)

4.3.3 Network Activities Description

4.3.3.1 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.

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: Design Concepts, Technology--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 by-pass 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 such as characteristics of composite materials. The users of the IPAD system will monitor these activities to enter new technical program elements into the library and to improve the technology data bases.

4.3.3.2 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.

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 to 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 and 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). 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.

The weight and balance module will contain the following analyses:

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

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

3. Fuel volume and fuel management calculation,

4. Passenger, cargo and fuel loading calculations,

5. 3-axis mass moment of inertia about the airplane cg calculation,

6. 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 (see figure 4.4 on page 65). The iteration is performed for each geometry of the T/W vs 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, that is, 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.

<u>Block II-6. Airplane Economics Analysis</u>--Goal: To evaluate the operating economics of an airplane.

Airplane relative cost values are determined (FNC-1). 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.

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 assess if the sales potential is enough for the related development cost.

Man decision 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, i.e., "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 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.

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 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. 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.

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 to 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, then descent and deceleration portion of the mission is 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, 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 infer 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, it would be more accurate to scale 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 if the configuration under consideration is acceptable from the standpoints of weight, balance and loadability.

The Technical Program Element which provides this information should contain the following analysis:

1. Statistical OEW weight prediction methods which produce a 30 item group weight statement (base buildup option),

2. Statistical OEW balance arm prediction methods which produce a 30 item horizontal cg statement,

3. Fuel volume and management calculations,

4. Passenger, cargo, and fuel loading calculations,

5. 3-axis mass moment of inertia about the airplane cg calculations,

6. 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 cg location and range. A flight control system will provide increments in maneuver margin that will be required for handling qualities with aft cg's located for optimum trim drag. Lateral control surfaces are sized and located on the wing. The main landing gear location and size is 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 cg 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 effected 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.

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 which provides this output should contain the following analyses:

1. Statistical OEW weight prediction methods which produce a 30 item group weight statement (scaling options),

2. Statistical OEW balance arm prediction methods which produce a 30 item horizontal cg statement,

3. Fuel volume and management calculations,

4. Passenger, cargo, and fuel loading calculations,

5. 3-axis mass moment of inertial about the airplane cg calculations,

6. 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 which are normalized to reflect changes in the configuration. In this instance, the 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 if 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 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 performance is 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 climbout performance (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 climbout 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, -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 & Structural Arrangement--Goal: Define the structural concepts and materials of the airframe primary structure. Synthesize the structural 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 which 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.

Geometrical 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:

1. Airplane planform and section geometry,

2. Airplane aerodynamic and structural panel definitions,

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

When operating within the IPAD system, items 2 and 3 will be performed by Technical Program Element WTS-25 while item 1 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 AILAS system (STR-6).

Flight condition data would be input by a knowledgeable user.

Block III-15. Determine Thermal Effects--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.

Block III-16. Size Structure for Strength and Fatigue--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.

Block III-17. 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 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.

To accomplish this activity involves Technical Program Elements which do the following:

1. Execution of the weights update control module (WTS-15) which would re-execute only those portions of the weights Technical Program Elements whose input had changed,

2. Calculation of wing primary structure mass elements based on finite element analysis (WTS-21),

3. Calculation of body/empennage primary structure mass elements based on finite element analysis (WTS-21),

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

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

6. Calculation of landing gear mass elements (WTS-),

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

8. Calculation of fuel mass elements (WTS-11),

9. 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),

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

11. 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),

12. Determination of fuel management requirements (WTS-26).

The Type B weights are suited for scaling. Data communication is similar to figure 4.4 on page 65 .

Block III-20. 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.

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 if 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 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 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 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 (for a horizontal tail configuration, for example).

An increase in aft body stiffness is made to the structural matrix. The re-cycle through Blocks III-14 to III-21 will show the trade for the improved aiprlane 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), or 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 placements of engines and external stores and to the fuel distributions will be presented.

Block III-25. Flutter Criteria Met?--Goal: Determine if the flutter criteria have been satisfied.

This decision is manual. If flutter deficiency exists, improvements will be made by changing geometry, structural arrangement, or stiffness or mass.

Block III-26. Proposed Fix--Goal: To determine changes of configuration geometry, mass, stiffness and structural arrangement for flutter clearance.

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 re-calculated, and re-merged with the unchanged substructures (SFL-21). These trend studies are performed through Blocks III-23, III-24, III-25, III-26. This loop is terminated when the desired flutter clearances are achieved.

Block III-27. Geometry Change?--Goal: Determine if 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 if 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 if 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 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 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 - Type B--Goal: To calculate Type B weight, balance and loadability for the configuration which has been sized for strength, fatigue, and flutter.

To accomplish this involves Technical Program Elements which do the following:

1. Execution of weights update control (WTS-15) which would re-execute only those portions of the weights Technical Program Elements whose input had changed,

2. Update of wing primary structure mass elements based on stress sized skin/stringer material (WTS-21),

3. Update of body/empennage primary structure mass elements based on stress sized skin/stringer material (WTS-21),

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

5. Update of body/empennage secondary structure mass elements (WTS-8),

6. Update of fuel mass elements (WTS-11),

7. 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),

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

9. 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 (WTS-14).

Block III-32. Calculate Noise - Airport (Noise Footprints): Cruise (Sonic Boom)--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 on figure 4.7. The first activity is to input the intented 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.

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, -6.

The utilization, maintenance and dispatch reliability will be assessed. Probable route structures, aircraft fleets, airport facilities, operational and environmental factors are used by REL-1 and -4. Additional inputs to these are ground

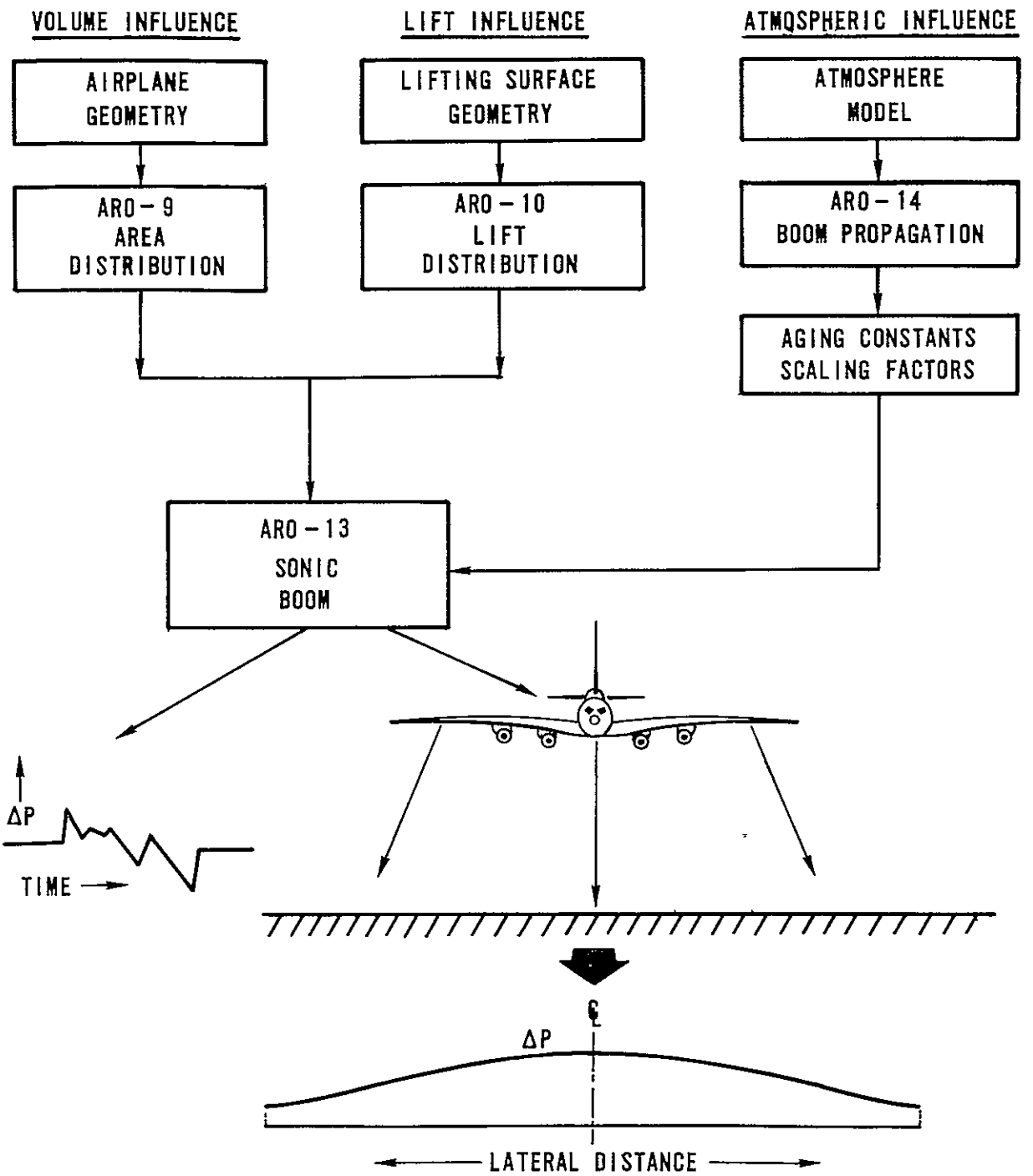

Figure 4.7 Calculation of Sonic Boom

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.

4.3.3.4 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.

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, III-16, III-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 computes 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:

1. Aerodynamic estimating sub-routine can be bypassed by inputting actual wind tunnel data,

2. 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 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, 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. 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:

Takeoff rotation Landing flare	pitch control for low speed performance
Minimum control speed, ground Minimum control speed, air	directional control for low speed performance
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

which would affect the entire design, but 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:

1. 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,

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

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

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

5. 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 if a change in flight control surface or tail stabilizing surface size, location or deflection is required.

This decision is manual and 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 if 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 3 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 either estimated 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 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, as well as 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 if the flight control system criteria has 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.

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, 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, -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, then the design must be returned to Level III to be resized.

Block IV-19. Size Fuel Management System--Goal: This activity will 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, -9 to -12), thrust modules (PRO-3 to -6), and weight and balance modules (WTS-7 to -15, -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 if 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 and power requirements and the fuel line diameters are acceptable, then 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 to 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, -17 and STM-2, -3, -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, to establish distribution paths and to size pumps. Load balancing and component sizing trades are conducted (STM-2, -3 and -4). Critical hydraulic system items are identified and design criteria are 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 are 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 are 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 are 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 are 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 factor selected for evaluation.

Block IV-23. Update Weights - Type B (Non-Structural)--Goal: To calculate updated mass properties for the non-structural items which have changed since the analysis which was made by Block III-19 was performed. 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:

1. For purposes of increasing the accuracy and decreasing the computational time required to perform the weights analysis, it could 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,

2. Update of landing gear mass elements (WTS-9),

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

4. Update of fuel mass elements (WTS-11),

5. 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),

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

7. 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 a need to repeat 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. 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 structure 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.

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 which do the following:

1. Execution of the weights update control (WTS-15) which would re-execute only those portions of the weights Technical Program Elements whose input had changed,

2. Update of wing primary structure mass elements based on stress sized skin/stringer material (WTS-21),

3. Update of body/empennage primary structure mass elements based on stress sized skin/stringer material (WTS-21),

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

5. Update of body/empennage secondary structure mass elements (WTS-19),

6. Generation of 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 a more optimum 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, 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:

1. Execution of weights update control (WTS-15),

2. Update of fuel mass elements (WTS-11),

3. 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),

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

5. 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 if 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-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, 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-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, 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, IV-38, IV-39, and IV-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 if 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; 2) 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 IV-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 if 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 which do the following:

1. Execution of weights update control (WTS-15) which would re-execute only those portions of the weights Technical Program Elements whose input had changed,

2. Update of wing primary structure mass elements based on stress sized skin/stringer material (WTS-21),

3. Update of body/empennage primary structure mass elements based on stress sized skin/stringer material (WTS-21),

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

5. Update of body/empennage secondary structure mass elements (WTS-19),

6. Update of fuel mass elements (WTS-11),

7. 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),

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

9. 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 (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 to determine if 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-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.

Block IV-47. Entered H From J?--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 IV-46) but no recycle of events (Blocks IV-48 through IV-60) which are primarily updated analyses.

Block IV-48. 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-49.

Block IV-49. 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 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 which 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 that the airplane is designed for. 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 be both a vertical and a lateral gust 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 criteria 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 if 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 aircrart'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-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 calculated. If the change in flexibility is such that a significant loads change would result the loads sizing routines (Blocks IV-53 and IV-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 which do the following:

1. Execution of weights update control (WTS-15) which would re-execute only those portions of the weights Technical Program Elements whose input had changed,

2. Update of wing primary structure mass elements based on stress sized skin/stringer material (WTS-21),

3. Update of body/empennage primary structure mass elements based on stress sized skin/stringer material (WTS-21),

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

5. Update of body/empennage secondary structure mass elements (WTS-19),

6. Update of fuel mass elements (WTS-11),

7. 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),

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

9. 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 (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 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 examined.

Block IV-59. Loadability/OEW Criteria Met?--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 if 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-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 cg 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.

Block IV-60. Do Flutter Analysis?--Goal: Determine if further flutter analysis is required.

Manual decision is made to determine if 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 IV-63).

Block IV-61. Start Transonic Flutter Wind Tunnel Model?--Goal: Determine if 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 V-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 10 elastic modes. Two basic sets of data are produced, namely 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-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 is 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 empnasis of 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 which 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, the configuration verification test plan and the manufacturing schedule.

(3) Identify Long Lead Items--Critical long lead items such as engines, forgings, etc., will be identified and procurement criteria will be 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 will be predicted by MKT-4, -5, -6. The effect of schedules on cost will also be assessed by FNC-2, -3, -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 model REL-1 and 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, scheduled flight time, and ground time are allowed 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 if the engine availability schedule is compatible with the airframe manufacturing and delivery schedule.

This decision will be manual and will determine if 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 hinder progress of the design 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 then 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 check if the design of the wind tunnel models have 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.

4.3.3.5 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 analysis. 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.

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 to 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. There will usually be some modification to these early model lines as a result of 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--Goal: To design the various configurations to be tested for cruise drag, stability and control characteristics and wing-body airloads.

The wing-body design will use modules ARO-5, -9, -11, -15, -16, -18, -19. These will provide for optimum camber design, body contouring and favorable nacelle interference. The nacelle design will be aided by ARO-11. The geometries will be lofted using the geometry control system GCS (DGL-2 and DGL-3), which provides numerical control data for the components to be fabricated by the numerical control processes.

Block V-4. Fabricate Cruise Model and Begin Stability and Control Model--Goal: To construct the cruise shape wind tunnel model designed in Block V-3 and to commence construction of a second cruise model designed with control surfaces for stability and control testing.

The fabrication of these models will utilize Numerical Control processes. 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 Cruise Model--Goal: Obtain wind tunnel data on first cruise shape wind tunnel model.

Test at planned cruise speeds for performance lift and drag data. Obtain longitudinal stability and control data with longitudinal pitch control surfaces (the only control surfaces on the model). Obtain yawed data for lateral-directional stability characteristics. Obtain wing-body pressure data for airloads analysis.

Block V-6. Analyze--Goal: Analyze cruise drag, stability and control data, and wing-body airloads.

Cruise performance, calculated from data of wind tunnel test Block V-5 is compared with estimated performance in Level

IV analyses (Block IV-66). 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 are compared with estimates made for the configuration in Level IV data preparation (Block IV-4) and analyzed in Blocks IV-5, -6 and -7.

The stability and control data are analyzed using the same Technical Program Elements FCS-1, S&C-7, S&C-8, S&C-9, S&C-10, S&C-11 that were used in the analysis (Block IV-6) and Elements S&C-18, S&C-19 that were used in the piloted flight simulation (Block IV-7). The wind tunnel data are for the cruise configuration and only longitudinal stability and control and lateral directional stability data are evaluated.

The analyses and simulation performed will be compared with those in Level VI (Blocks IV-6 and IV-7) to evaluate the changes required for the configuration with use of more accurate wind tunnel data.

The wing-body airloads will be entered into the data bank for use in the analysis tasks of Level V.

Block V-7. Configuration Acceptable--Goal: Determine if the cruise performance and stability and control analyses performed in Block V-6 are acceptable for the airplane and establish configuration changes to make trades if required.

These decisions are manual and human judgment will be exercised.

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. Design/Analyses--Goal: To do the design and analysis activities required to support the configuration verification process, and to 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 will 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 design and analysis elements available within aerodynamics will be used at this level. ARO-4 to -6, -9 to -12, -15 to -20 will be used for detailed wing, body, empennage, nacelle and pylon design and analysis for both wind tunnel models and for the prototypes. ARO-13 and -14 will keep track of the sonic boom characteristics of the configuration.

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 to 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, auxiliary power unit, etc. Also, smaller space envelopes are defined which represent fixed equipment such as actuators, pumps, filters, heat exchangers, oxygen cylinders, etc. Raceways are defined which provide for routing control cables, wiring, ducting, tubing, etc. (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: To refine and expand definition of flight control system. To perform response calculations to ascertain compliance with the criteria. Complete definition of flight control system mechanization and redundancy concepts. To 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-5 must provide acceptable airplane handling qualitites. Analysis of the ride improvement and flutter suppression control systems which may have been identified in Blocks IV-63 and IV-36 respectively will be continued. The autopilot and autoland design concepts will be finalized. Computer programs FCS-1 through FCS-7 will receive use similar to their use in Block IV-5. 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 equations of motion network).

Flight Simulator Evaluation--Goal: To 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 controls, 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 qualities. 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 are 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-3 through SFL-21) in Level IV will be carried out on these updated configurations to ascertain compliance with the flutter requirements. Important structural detail information on; 1) main structure cut-outs, 2) stiffness of major structure junctions, 3) mounting stiffness of localized masses, and 4) 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 when applicable in unsteady airloads predictions. Control surface flutter and panel flutter analyses (SFL-20, -22 and established design criteria) 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-65 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.

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Product Assurance:

1. 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.

2. 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.

3. 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 factor selected for evaluation.

4. 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.

5. 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.

6. System Design Maintainability Analyses--Goal: Assessment of system design configuration against the maintainability requirements and allocations.

This assessment is manual. It supports the Reliability/Safety analyses of Block V-11. Accessibility will be studied and optimized through use of the computerized space arrangement mockup.

7. 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 to evaluate strengths and weaknesses of each airplane in operational environments.

8. 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.

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-17a 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 aerodynamics data with applicable wind tunnel data, to update the aeroelastic effects, to update the stability and control analyses to show adequacy of control effectiveness, and to analyze the control system aerodynamics for all combinations of surface actions including gearing relationships, interference effects, engine failure effects, hydraulic system failures, mechanical failures.

Technical Program Elements S&C-21, -22, -23, -24 for data preparation (Block IV-4) are utilized. Aeroelastic correction factors are updated with loads and structural analyses performed in Level IV (Blocks IV-53, IV-55).

Analyses of control effectiveness (S&C-7, -8, -9, -10, -11) are updated. These analyses will provide a basic understanding of the configuration with wind tunnel data support. The aeroelastic correction data will be updated during recurring passes through this level from loads and structural analyses in Block V-10. A range of flight conditions covering the flight envelope will be studied on the flight simulator for constraints and problem areas that must be identified and incorporated in the design before project go-ahead in Level VI is commenced. 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--Static load for a supersonic configuration would be computed to meet the requirements of the appropriate certification authority and any additional Boeing criteria. The methods used would be extensions of those used in lower Levels with improved and more extensive input data. Additional Technical Program Elements would be developed as specific needs arise and it is unlikely that they would bear a marked similarity to any modules available today. For this reason no descriptions are presented.

Structural Design--Goal: Provide optimum feasible design solutions for all major structural components (wing, body, empennage, nacelles and landing gear), and integrate these components together will all other airplane sytems.

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-11), 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.

Special Structural Design Considerations:

1. Body: Control cab windows, access doors and cutouts, pressure shell integrity and fail safety, structural continuity and compatibility with the wing and empennage.

2. Wing: Structural continuity and fail safety, fuel containment, control surface installation and systems equipment, and integration with the body and landing gear.

3. Empennage: Structural continuity and fail safety, control surface installation and systems equipment and integration with the body.

4. Nacelles: Structural integrity, service access segments and integration with the engine and propulsion system.

5. 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.

6. Structures-System 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 it would permit all system 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 input refined in Block IV-22 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 for accomplishing it will be the interactive design program DSA-5, which will be used in the interactive design tool DSA-5 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, it also 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, fail safe, and local optimization will take place. The optimization will be directed toward items such as: stringer configuration and spacing, rib spacing, frame spacing, joint configurations, thermal insulation, etc. (STR-6). 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 computations for the integrated substructural runs (STR-6).

System Design--Goal: To continue definition of systems until all design requirements have been identified and until all equipment items are identified as either existing or can be developed.

All systems design activities are similar in Level V and consist primarily of the following:

1. 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),

2. System schematic diagrams developed in Block IV-22 are updated,

3. 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,

4. Selection of existing "off-the-shelf" equipment is completed and preliminary procurement specifications for new equipment items are initiated,

5. The testing required to verify system performance is initiated,

6. 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 will be conducted such as alterante APU locations (STM-9).

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 which do the following:

1. Execution of weights update control (WTS-15) which would re-execute only those portions of the weights Technical Program Elements whose input had changed,

2. Update wing, body, and empennage mass elements based on stress sized skin/stringer material refined by local applications of finite element structural analysis (WTS-21),

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

4. Update of body/empennage secondary structure mass elements (WTS-19),

5. Update of landing gear mass elements (WTS-9),

6. Update of nacelle and strut, propulsion, fixed equipment, and standard and operational mass elements; this will require development of a new Technical Program Element, WTS-23, which will accommodate a greater level of detail, especially in the systems areas, than is available by using Technical Program Element WTS-10,

7. Update of fuel mass elements (WTS-11),

8. 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),

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

10. 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 (WTS-14).

Block V-11. Wind Tunnel Model Changes Required?--Man decision is to be made as to whether any change in the design of the transonic wind tunnel flutter model is required as a result of the cycles of Level IV.

Block V-12. Transonic Flutter Model Design--Goal: Design transonic wind tunnel flutter model.

The wind tunnel model will be designed with a complex finite element idealization as used in the theoretical structural analysis. The model will simulate a scaled replica of the airplane.

If a flutter suppression system is required, the model will simulate control surfaces, actuators, and the feedback control system.

Block V-13. Modify Wind Tunnel Model--Goal: Modify the design of transonic wind tunnel flutter model as decided in Block V-11.

Block V-14. Begin Model Fabrication--Goal: Start construction of the transonic wind tunnel flutter model designed in Block V-12.

Block V-15. Tests (Developmental)--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, etc., and the concepts of the structure and systems.

Continued Wind Tunnel (W.T.) Tests

1. Stability and Control Model W.T. Test and Additional Cruise Configuration W.T. Tests--Goal: Detailed cruise model stability and control tests to establish a more complete base of aerodynamic data to be used for analysis, flight simulation and design. Control surface hinge moments and engine failure effects are measured.

The cruise W.T. model tested in Block V-5 is built essentially for performance testing and carries only longitudinal pitch control surfaces. The cruise W.T. model of these present tests (identified in Block V-4) has control surfaces for all three axes instrumented for hinge moments and engine nacelles configured to simulate engine failure conditions.

2. Low Speed W.T. Model--Goal: Measurements are made of the drag and lift characteristics for the low speed configuration identified in Levels III and IV and of the stability and control characteristics (all axes) for comparison with the low speed estimates made for stability and control data preparation in Block IV-4.

The low speed model is built for performance and stability and control testing. The model is fully representative of the airplane in the low speed takeoff and landing high lift configurations with control surfaces for all three axes.

3. W.T. Test - "Manufacturing Loft" Wing--Goal: To test the aerodynamic difference between the wing defined by aerodynamics and the wing considered to be manufacturable.

Manufacturing considerations invariably require some modification to the wing lofted by aerodynamics. If these changes are sizable, then the performance degradation should be established by wind tunnel test.

4. Transonic Flutter Wind Tunnel Flutter Model Tests--Goal: Confirm and complement analytical flutter predictions of

Levels IV and V. Verify the control system stability margins if a flutter suppression system is employed.

Analytical flutter predictions made in Levels IV and V are verified and complemented with wind tunnel testing to provide substantiating information particularly in the areas where structural and aerodynamic uncertainties exist. A dynamically scaled flutter model of the airplane and its components is tested in a transonic wind tunnel. The buzz characteristics of the control surfaces will be determined to verify the criteria used in the design of the airplane. Only the transonic regime is investigated experimentally in Level V because it has the least chance of being predicted correctly by analysis.

If a flutter suppression system is required, the flutter model test shall verify the 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 the stability margins of the model.

5. Loads Wind Tunnel Pressure Models--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 nacelles. 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, elevator and rudder deflections (singly and in combination).

On the low speed model additional pressure measurements would be required, including high lift devices, gear doors, gear cavities, leading and trailing edge cavities for example. Again configurations resulting from various flap and control surface deflections would 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 pressure data becoming available and as a check of integrated pressure data.

<u>Propulsion Tests</u>--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, and thrust reversers, acoustic treatment, etc.). Questions which must be answered include: performance of the propulsion system at altitude (may

require flight testing on new engines), flight cycle fatigue, inlet distortion, oil flow indication, anti icing, water ingestion, sand ingestion, low and high temperature starting, etc.

Structural Development Tests--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 insure complete technical confidence in the configuration must be accomplished at this level.

Theoretical requirements: This group of problems includes testing such as 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, be it stability, fatigue or fail-safe allowables, etc., in order to prepare for the full scale test assemblies to follow. Tests of temperature related phenomena also belong in this category. This kind of testing would concern itself with temperature distribution and stresses and quite possibly also composite material properties under varying temperature conditions.

Empirical evaluations: The purpose of this testing is to establish design guidelines for situations where theoretical approaches fail or become unreliable. It covers problem areas as:

1. bird impact on windshield,

2. detail fatigue ratings for not previously used design details, or details subject to cg biaxial loading or temperature conditions, for which present experience has no answers,

3. strength of fittings,

4. hail impact, lightning strike,

5. crack propagation

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 and 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-electronic "fly-by-wire" process.

Block V-16. 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 by section and components of the airplane are summarized (FNC-2). An assessment of the production cost over a time period accounting for changes in the manufacturing schedule for introduction of new customer configurations and the impact of derivatives from the base model is made (FNC-3). An estimate of return on investment and cash flow by year is made (FNC-4).

Block V-16. 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-65. 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-17. Summarize and Review--Goal: Summary of all design and analysis tasks, test results, etc.

Review the design with associated program costs, marketing, product assurance and manufacturing requirements (Block V-16). Identify if design and analysis tasks in Block V-10 are coordinated with the same technology level. Identify need for further tests in V-15.

Block V-18. Recycle?--Goal: Man decision to recycle, or not, Blocks V-10, V-15 and V-16 (tests, design and analysis, program costs) resulting from the summary and review undertaken in Block V-17.

Block V-19. Configuration Acceptable--Goal: Man decision to review integrity of the technical design for a management recommendation for product go-ahead.

Block V-20. Technical Review--Goal: Review by technical committee on the action to be taken following unacceptable results for the configuration (Block V-19), sales (Block V-22), firm orders (Block V-23) and product go-ahead (Block V-25).

Block V-21. Management Review--A technical review is presented to management, based on engineering report in Block V-19.

The Program Management Office (PMO) and Manufacturing participate in the Management Review and receive design information which will support preliminary decisions. PMO must have assurance that the design intent meets the customer requirements. Manufacturing begins selection of sub-contractors for long-lead items.

Block V-22. Sales Go-Ahead--This is a major program milestone. Management authorization is granted to proceed with a sales effort.

Block V-23. Firm Orders--This is a major program milestone and supports a decision to recommend a product go-ahead to management.

Block V-24. Management Review--Goal: Review by management of all sales activities which includes the market analysis, airline interest, firm orders, program costs, etc.

Block V-25. Product Go-Ahead--This is a major program milestone. Management authorizes go-ahead with product design, manufacture, verification and support.

4.3.3.6 Level VI - Product Detail Design

Level VI will begin when the decision has been made to commit the design to project status. This Level will be dominant in 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.

Block VI-1. Establish Preliminary Design/Product Interface--Goal: To provide Program Management, the Engineering Design Project, Engineering Technology Staff Organizations, 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 are finalized, i.e., the program plan, the engineering cost and schedule plan, the design development and verification test plans, customer support plan, etc. 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 weight accountability (Type D weights) is revised as required for Engineering, Finance and Manufacturing (WTS-22). The weights accountability has been structured as follows:

1. To provide a meaningful definition of the product in terms of weight data and descriptions,

2. To provide a meaningful weight history for evaluation of the final product design,

3. To provide the flexibility to handle a variety of design projects,

4. To provide a system which can interface with the previously executed weights analyses programs,

5. To provide a system which is efficient in terms of:

   a. Data and input, editing, and verification

   b. Internal data storage and manipulation

   c. Output data report generation.

Block VI-2. Tests (Development)--Goal: To perform the tests necessary to complete 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-15 and again 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. These tests will usually be a continuation of Level V testing and will include general tests, such as inlet distortion and noise suppression, as well as tests unique to the particular configuration.

Structural Tests--Goal: This testing is directed toward subassemblies and its prime purpose is to correlate analytical and factual stress distributions.

This testing concerns itself mainly with structural details, such as wing body joints, cutouts, wheelwell for

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landing gears, areas of load distribution (attachments in general, bulkhead, etc., and another candidate would be "the pivot" on a variable wing geometry airplane).

The results constitute a verification of the structural idealization and provide 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.

This testing is general and is an extension of the system testing conducted in Level V. The following are two examples of flight control system testing.

1. Control System Development Fixture (Iron Bird)--Goal: Design and fabricate the test hardware. Perform the control system tests.

The control system development fixture consists of flight quality control system hardware attached to a boiler plate 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 conduction of the tests.

2. 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 which is 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 - Configuration, Flutter, Stability and Control, Loads--Goals: To provide configuration testing to improve the aerodynamic description of the airplane, detailed testing to improve areas of low lift, high drag, interference, etc., to support the aerodynamic clean up program, to improve high lift flap devices for low speed, and to do final performance testing to supply aerodynamic data to support performance guarantees. Other goals include flutter tests at low speed, transonic speed and supersonic speed to verify criteria and flutter predictions made in Levels IV and V, stability and control testing to solve problems and uncertainties arising from analysis of Level V wind tunnel data, further testing of control surface deflections, combinations and gearings, etc., further engine failure simulation tests, extensive pressure model tests to establish flight loads, and system tailoring such as APU and air conditioning inlets, pitot static provisions, etc.

Block VI-3. Design/Analysis--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-4 to -6, -9 to -12, -15 to -20 will be used for detailed wing, body, empennage, nacelle and pylon design and analysis for both wind tunnel models and the production configurations. ARO-13 and -14 will estimate the sonic boom characteristics of the configurations.

Automated Parts Release (APR)--Goal: To control the listing and release of parts information to Manufacturing.

The Automated Parts Release System is a related set of computer programs which produce new and revised part cards and assembly lists from data supplied by the Engineering and Manufacturing Departments. The part and assembly information is maintained on two separate master files, one containing engineering or configuration data and the other containing manufacturing or production data. Each of the two master files is updated by a separate computer program using a distinct set of input transactions, one primarily from engineering sources, the other entirely from manufacturing sources. Information from

the two master files is collated by a report generator system to produce printed part cards and assembly lists and also to provide a record containing transactions for direct input to the Manufacturing Department's program.

A change in the usage of an assembly implies a corresponding change in component parts of the assembly. The APR System is design to effect these implied changes automatically. To accomplish all implied changes in one pass through the master file, it is required that every component of every assembly be located in the file beyond the assemblies of which it is a component.

The concept of level (not the IPAD Levels) is used to make this ordering of parts possible. The master or top drawing for the airplane model is at level 1. All drawings that reference the top drawing as their "used-on-drawing" are at level 2.

This relationship between a part (detail, assembly, installation, drawing) and its used-on part continues down to detail parts. The lower the level the greater the magnitude of the level number.

When a part is used on more than one assembly, and if these assemblies are at different levels, the part is assigned a level one greater than the used-on assembly with the largest level number. About 15 levels are required for an airplane master file. The level numbers are assigned by the computer program, and do not appear on any input transactions. The engineering master file is arranged in level number order, and within each level in part number order. The master record for each part on the engineering file indicates all usages of the part, both active and cancelled, and all components of the part, unless it is a detail part.

The level concept does not apply to the manufacturing file. It is arranged completely in part number order. There are entries in this file for each active part, and for each active usage of the part for which distinct manufacturing information is supplied.

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 of the type such as 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-10, 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 shot) 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 which are pertinent to the 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. That simulation will be performed 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. However, the detail will be sufficient for final drawing release. 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 such as forgings, mockups, etc., is continued.

An integrated engineering schedule is initiated to identify and define the scheule 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 assure schedule integration between these 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 which represent the following schedule dependencies:

1. Design project group schedule requirements for key interface design data from another design project group upon which their effort is dependent.

2. Design project group schedule requirements for key technical data from a technology staff discipline group upon which their design effort is dependent.

3. Technology staff discipline group schedule requirements for key design data from a design project group upon which their technical tasks are dependent.

4. 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:

1. Airplane System Detail Design Reliability Safety Analyses--Goal: To incorporate additional design detail into the Level V reliability and safety analyses, and to 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.

2. 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.

3. 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.

4. 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 to 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, to analyze all wind tunnel testing, to size actuators from control surface wind tunnel tests in Block VI-2, to do detailed control surface effectiveness analyses to assist control system design, to do flight simulation of all design conditions including failures and of turbulence and gust effects.

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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 as complete as possible understanding of the basic flying qualitites of the configuration. Wind tunnnel 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 Technical Program Elements S&C-21, -22, -23, -24. Aeroelastic corrections will originate from structural load analyses undertaken in Block V-10 and VI-3. Control surface actuators will be resized using rigid hinge moment data from wind tunnel tests Block V-15 and VI-2 with aeroelastic corrections obtained from structural load analysis in Block V-10 and VI-3. Actuator rate requirements will be specified from the flight simulator tests undertaken in Block V-10, and further simulator testing in this Level VI. Piloted simulation will be extensive and will incorporate the current flight control system. Pilot displays and controllers 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 the assessment of failure modes (mechanical, hydraulic, engine thrust, etc). Models to simulate discrete gusts and turbulence will be incorporated in the flight simulation.

Static Loads--Static loads for a supersonic configuration would be computed to meet the requirements of the appropriate certification authority and any additional Boeing criteria. The methods used would be an extension of those used in lower levels with improved and more extensive input data. Additional Program Elements would be developed as specific needs arise and it is unlikely that they would bear a marked similarity to any Elements available today. For this reason no Element descriptions are presented.

Structural Design--Goal: Expand and refine the structural design as defined in Block V-10 into a completely detailed engineering package. This package would consist primarily of data filed in the computer data bank library, but could also include any desired hard copy such as engineering drawings, documents, specifications, or reports.

It is intended that no new structure design definition be accomplished at Block VI-3, only expansion and refinement of solutions and concepts of Block V-10. 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-10 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-10, 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-10 and the improved design efficiency of the interactive tool DSA-5 and the design analysis programs DSA-6 and on.

All of the design considerations, criteria and constraints of Block III-12, IV-31a, and V-10 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.

One possible 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 engineering 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: A complete detail design (DSA-5, -6, -7, etc.) of structural components and subassemblies is performed at this level. The resulting gages and areas are used to update and refine the finite element idealization for recycling of loads. The end product is an airplane where all detail designs have been performed.

The final result of this structural sizing should include optimization of the component sizes and corrections from test results. The results also will be in a form which can be directly used for making the production drawings.

The sizing of the components and subassemblies are based on the same considerations as in Level V, however, qualitatively this is going to result in more accurate sizings and margins of safety as the internal loads are based on a more refined structural idealization, the results of which are updated with respect to Level V and to some extent Level VI test results.

The finite element idealizations will be done in two ways. Primarily a complete airplane model will be established for recycling of loads and determination of overall internal loads distributions where local conditions promote steep gradients. In the internal loads distribution, separate local detailed idealization will be established. These latter models will be used for comparison with the test results from Level V and VI and ultimately serve as a basis for detail designs of these local areas (STR-6).

System Design--Goal: To complete final design and development of all systems.

Continue Level V activities and complete the following additional activities.

1. Identify all hardware required and release preliminary information to the mockup. Finalize and release design of detailed parts and installation information.

2. Finalize and release procurement specifications for new equipment items.

3. Finalize and release maintenance information including the following:

   a. 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.

b. 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:

(1) Test Provisions: self test or test-in-place.

(2) The component removal basis in one of three categories: (a) Time-controlled components with predictable wear-out rates which will be removed and replaced in accordance with the scheduled time between overhauls (TBO); (b) 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; (c) Failure-controlled components which can continue in service until failure. This category is generally related to parts which fail abruptly and their failure does not impose any hazard.

c. Procurement specifications: Each procurement specification contains a maintainability requirement to meet the intent of b.(1) and b.(2) above, and a test to prove satisfactory operation at a specified deteriorated performance level.

4. 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 the current status of the configuration's definition in terms of weight and weight related items in a form which 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. It 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.

1. Engineering

   a. Input of wire and equipment to data files.

   b. Verification of agreement between data files and wiring diagrams.

   c. Reference information for configuration of any airplane.

2. Mockup

   a. Input of wire lengths and subassembly groupings.

   b. Reference information from which formboards and production illustration (P.I.) drawings are produced.

3. Planning

   a. Input assembly sequencing information.

   b. Issue production orders for every bundle required.

4. Material

   a. Purchase wire, connectors, etc.

5. Manufacturing

   a. Cut and mark wire.

   b. Preassemble connectors

c. Assemble bundles

d. Test bundles

e. Connect bundles together after installation in airframe.

6. Customer Airlines

a. Maintenance

b. Identification of spare wires

c. Identification of bundles and equipment for ordering spares.

d. Input of information on post-delivery modifications.

Program Descriptions:

Manufacturing Plan (Includes Bundle Equipment List)--This program provides a report containing production information, how many to build, what parts are used, where to install the bundles, 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, assembly sequence, and references the wiring diagram which shows the wire.

Equipment List--This program shows part number, description, next assembly, reference wiring diagram, etc., for each equipment items 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 3 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 the following.

Assembly connection list--is a report showing how long to cut each wire, from what wire type and size to cut it, how to mark it, and how to connect it. A separate list is issued for each group of wires within a bundle.

Plug maps--are physical layouts of connector insert arrangements with the wire number for each pin printed immediately below the pin number.

Formboard list--is similar to the assembly connection list except that it is sorted by equipment item number rather than wire number to enable the worker to finish one item before starting another.

Manufacturing plan--is 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 are:

Part Requisition Cards are 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 those wires which 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 are used for automated testing of completed wire bundles.

Bundle Sequence List provides planning with a complete list of bundles required for an airplane, sorted in production sequence.

Hook-up Charts provide final assembly workers with hook-up information required at the time bundles are installed in the airframe.

Other Non-Manufacturing Reports include:

Diagram Check List is an extract of the wire file, sorted by wiring diagram. It is used to check compatibility between the data base and the wiring diagrams.

Equipment Check List is analogous to the Diagram Check List but is extracted from the equipment file.

Wire Compare List shows only the differences between any two airplanes of the same model.

Part Number Summary is an extract of the equipment file sorted by part number.

Bundle Assembly Index shows which bundles are used on what airplanes.

Diagram Equipment List part of the Diagram Manual Report (DMR) is an equipment list for one customer only and is sent to the airline for maintenance information as part of the 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) is a full wire listing for all bundles for one customer block.

Hook-up Charts, Ground List, Splice List, Terminal List are all part of the DMR and give 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.

Block VI-4. Manufacturing Review--Goal: To monitor schedule sensitive item releases from Engineering to assure that manufacturing activities can be responsive.

Operations refine manufacturing plans and make 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 per 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 a continuous interaction between Engineering and Operations as the part drawings are released. There must be quick response by Engineering 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 which do not require detail information from engineering.

Manufacturing prepares production illustrations (PI drawings) which are co-signed 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).

4.3.3.7 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.

Block VII-1. Manufacturing --Goal (1): Provide a manufacturing process to build the end product to fulfil the

engineering specifications and assure that the "as built" configuration matches the "as designed" configuration.

The manufacturing process utilizes extensive computer systems to produce shop paper, collect cost data, report execptions, 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 re-checks, both manual and automated, with decision making data available to management as a by-product. 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):

1. Fabricating bundles (Cutting wire, marking it, installing connectors, grouping and tying wire into bundles),

2. Testing bundles (Using card controlled Automatic Test Equipment),

3. Installing bundles (Making connections between bundles after bundles are installed 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 (sub-assembly level) and production illustration drawings (final assembly level).

Goal (2): To provide engineering liaison to manufacturing for rapid engineering response to manufacturing design change requests as 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, there must be a fast response by engineering to the manufacturing request for a design change, in order that the matter be resolved with the least possible delay in the production process. The liaison activity provides the response and also feeds the information to the parent organization to assure that the affected design media are corrected.

Block VII-2. Production Problem Requiring Redesign?--Goal: To provide a process by which required design changes are made known to the engineering design project. These changes are of the type which cannot be made by the engineering liaison organization supporting the manufacturing effort.

Block VII-3. 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 that are 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, the Wire Release System (STM-22) provides reports containing the amount of wire in an airplane, by type and gage, its 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.

4.3.3.8 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 outside the IPAD man/machine environment, but the results will be recorded by the IPAD data base management system.

Block VIII-1. Airframe Testing--Goal: To verify the static strength and fatigue life of the airframe and 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 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 distributions, shear lag, stiffness

characteristics (impact of joint and fastener flexibilities), material effectivity under buckled conditions.

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 cerify the performance guarantees and regulations.

Proof of guarantees and federal safety requirements requires extensive flight tests. Aerodynamics will in the main be concerned with measuring flight quantities that relate to performance. The low speed lift capability is determined. The 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 the experimental results 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 reduced into 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 will be determined. Engine operating limits will be described, and fuel usage will be measured. The effectiveness of the thrust reversers will be demonstrated. The control and recovery characteristics of the inlet system will be established.

Reliability Assessment--Goal: To assure adequacy of the flight and ground testing from the standpoint of reliability and safety.

A review of the Flight and Ground Test Plan prior to testing and review and analysis of test data is performed.

This assessment is manual for pre-test review. Test data reductions will be by REL-6, REL-8, REL-9, REL-13.

Stability and Control--Goal: To certify the flying qualities of the airplane to meet appropriate regulations for desirable handling qualities, for normal and foreseeable abnormal failure conditions, require extensive flight testing to meet requirements for the Federal Aviation Administration and possible other authorities such as the British Air Registration Board.

Stability and control are concerned with measuring flight behavior and the correlation with estimated characteristics and the registration requirements. Also of importance in these tests are those characteristics which affect the performance of the airplane and its ability to meet guarantees, i.e., takeoff rotation speed and rotation rate, landing flare capability, 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 taken 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: flight simulator documents used for design as well as flight training and demonstration will be updated similarly.

Block VIII-3. Functional Testing--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.

A review of functional test plans prior to testing and review and analysis of test data is performed.

This assessment is manual for pre-test review. Test data reductions will be by REL-6, REL-8, REL-9, REL-13.

Block VIII-4. Summarize and Review--Goal: To provide the Engineering, Finance, Manufacturing organizations, Program Management and the Customer (according to contractual obligations) a current status of the product definition.

Block VIII-5. Problem Requiring Redesign?--Goal: To monitor the verification processes and determine which parts need redesign. These parts will be returned to Level VI for review and redesign. 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.

4.3.3.9 Level IX - Product Support

This Level is concerned with collecting information required to support the product once it is in service. Its performance and other inservice information will be continually monitored by entering data in the data base and using the capabilities of the IPAD data base management system.

Block IX-1. In-Service Parts Histories--These will be monitored to detect problems, and to 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, both scheduled and unscheduled, retrofit kit installation, and system failures, are important to develop improvement 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.

Block IX-2. In-Service Payload Factors by Route--This information enters the marketing data base for marketing estimates of current and projected new products.

Block IX-3. In-Service Airplane Performance Changes--This information is made available to the data bases of the affected technical disciplines, where serious degradations will modify future designs.

Block IX-4. In-Service Systems Performance--Performance of various systems will be recorded as the airplane is operated.

Block IX-5. In-Service Problem?--This will refer in-service problems back to Level VI for analysis and design revisions.

4.3.3.10 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.

Block EM-1. Form Mass Matrix--Goal: To form standardized mass matrices which will contain for each pre-defined panel:

1. Weight,

2. Center of Gravity,

3. Moments and products of inertia about the cg.

This data will be subsequently modified by the analysis in Block EM-5 to transfer the mass data from the panel cg to a reference axis used by the dynamic loads, flutter and flight controls analyses.

In order to facilitate the analysis of various flight conditions, there should be separate mass matrices developed for:

1. Wing (flaps up and down),

2. Body,

3. Horizontal tail,

4. Vertical tail,

5. (each) nacelle and strut,

6. Landing gear (up and down),

7. Payload,

8. Fuel.

The mass matrix will be developed by WTS-20.

Block EM-2. Form Stiffness Matrix--Goal: To form a stiffness matrix (reduced) for specified kinematic freedoms.

The airframe is structurally represented by finite element models idealized to levels of detail dependent upon the design level attained. From the appropriate finite element model, a reduced stiffness matrix may be generated for a given 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-panelled (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 consist of only a table look-up.

Block EM-5. Natural Vibration Modes--Goal: Modal analysis is used throughout the industry when doing a flutter, dynamic loads, or an elastic flight control system analysis. The initial step in any of these analysis is to obtain the natural vibration modes of the airplane.

The natural vibration modes program (SDL-1) is used to calculate both symmetric and anti-symmetric 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 this design level.

Block EM-6. Option?--Goal: Determine which 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, 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 at the lifting surface structural node points (calculated in Block EM-5). The interpolation is done by either a general beam spline (SFL-15) or by a surface spline method (SFL-14). 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.

The state-of-the-art lifting surface unsteady aerodynamics are used for flutter analysis of refined configurations. Programs identified as SFL-3 through SFL-8 and SFL-16 through SFL-20, will provide the capability of predicting oscillatory airloads on single planar lifting surface, 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 are consisted of generalized mass and stiffness matrices (Block EM-5) and generalized forces matrices (Block EM-8). These matrices are formulated, along with speed, altitude, and Mach number, as coefficient matrices of a system of second order ordinary differential equations (SFL-10, SFL-11, SFL-12). Additional equations may be required to account for the presense of actuators (FCS-13) and control system feedbacks.

Block EM-10. Force Matrices--Goal: The generalized force matrices are required to calculate both the quasi-steady equations of motion (EM-11) and the 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 knowledgable 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 as 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 semi-automatic and would require an engineer to guide it during off-line operation.

4.4 OTHER VEHICLES

4.4.1 Naval Hydrofoil

A brief study was made of a naval hydrofoil, intended primarily for patrol and antisubmarine assignements, 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 Project 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.

4.4.1.1 Design Networks

The design and analysis network indicating the design tasks for the military hydrofoil is shown on figure 4.8. The product levels shown (see fig. 4.1, page 24), are Level II, Design Criteria Selection, Level III, Configuration Sizing, and Level IV, Configuration Refinement. A narrative description follows the networks.

4.4.1.2 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.

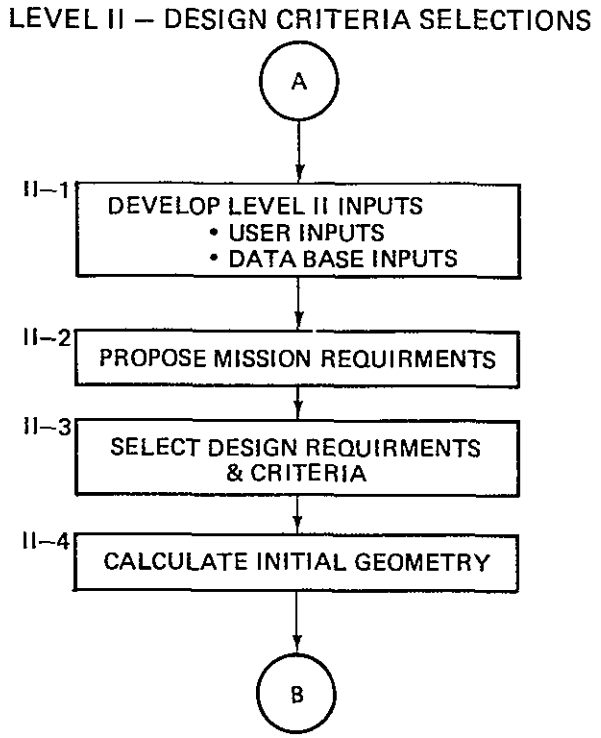

Figure 4.8 Design Networks – Naval Hydrofoil

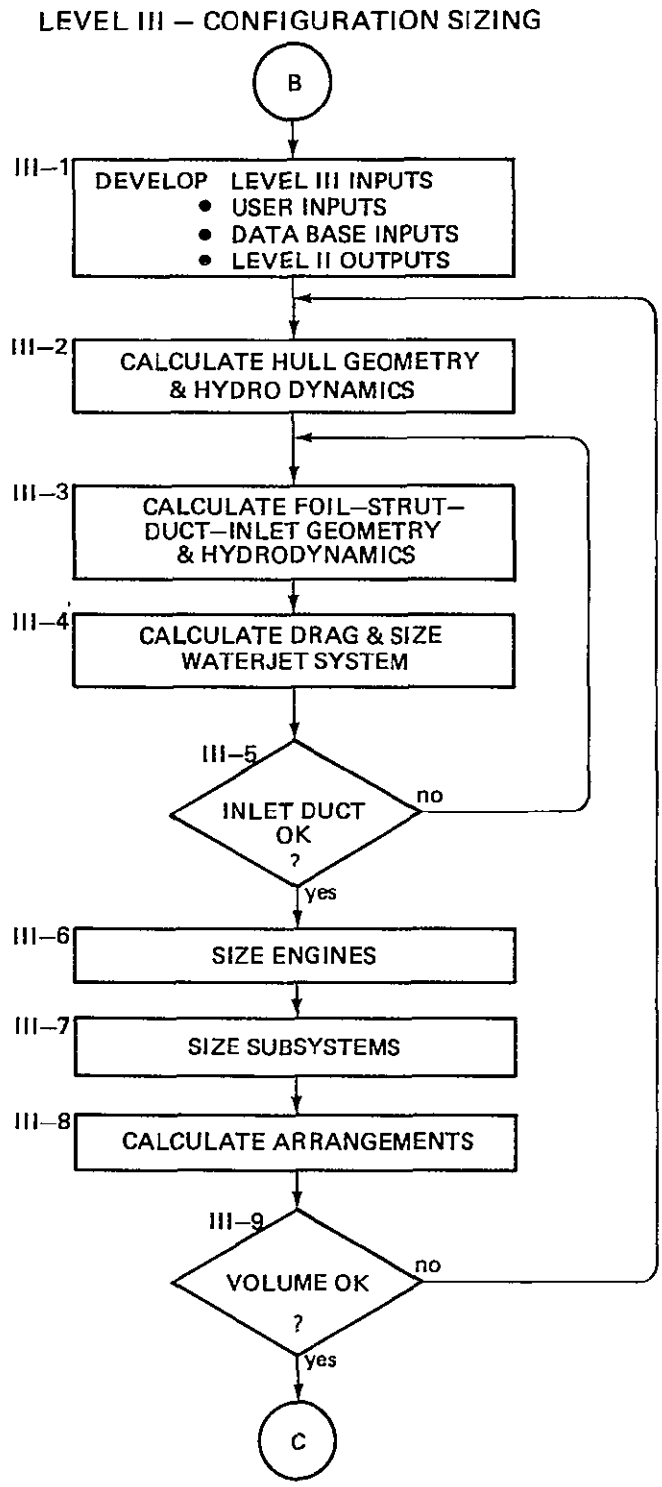

Figure 4.8 Design Networks– Naval Hydrofoil (Continued)

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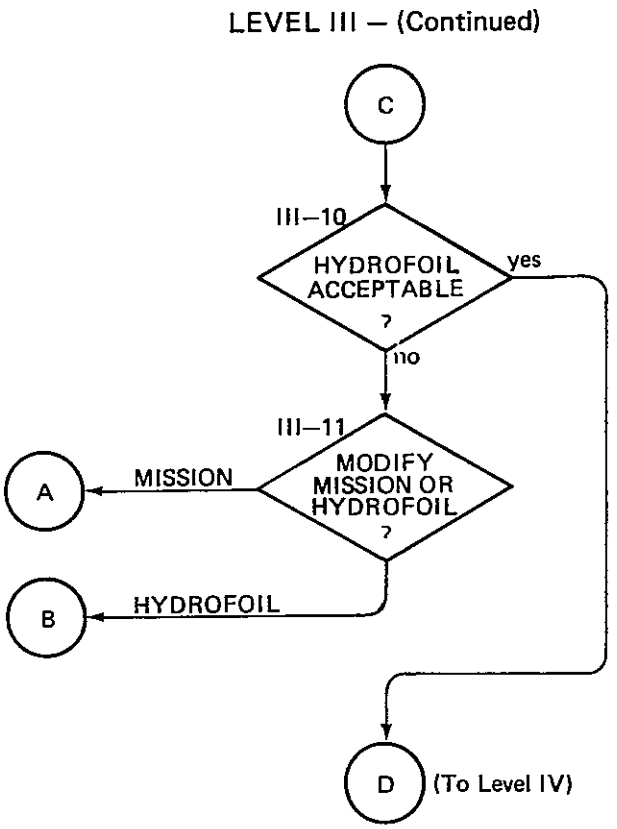


Figure 4.8 Design Networks- Naval Hydrofoil (Continued)

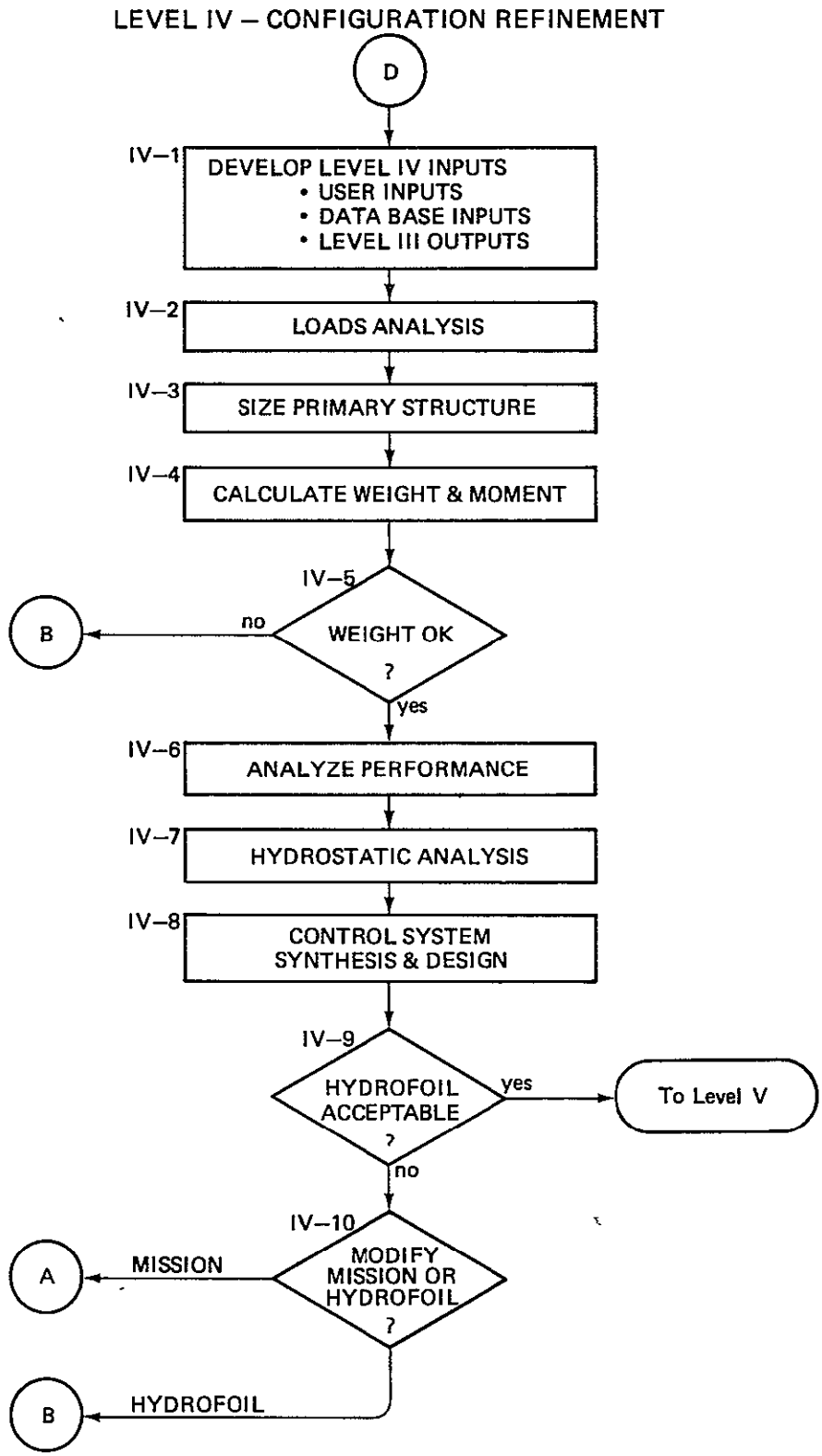


Figure 4.8 Design Networks – Naval Hydrofoil (Continued)

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 to see how they compare 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, and so forth. 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, and so forth. 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 geomtry 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 to do an arrangement himself. If there is not sifficient 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, then 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 for the effect of wind loads.

Block IV-8. Control Analysis--The control system for the foils will be synthesized and analyzed for directional stability, controlability 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 if 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.

4.4.2 Military Aircraft

No specific study was made of military aircraft, however, they would be similar to the commercial aircraft studied and the following comments apply.

4.4.2.1 Military Transport Aircraft

Tanker, cargo and passenger aircraft will be identical to the Project 1 subsonic transport except where military criteria differs from Federal Aviation Regulations and commercial aircraft design standards.

4.4.2.2 Military Tactical and Strategic Aircraft

Subsonic and supersonic military aircraft will be similar to Project 1 and Project 2, however, new sizing geometry modules for Levels II and III are required. These modules must respond to the military mission and design criteria.

5.0 OPTIMIZATION

5.1 OPTIMIZATION CONSIDERATIONS IN IPAD

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

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

Wing and Empennage

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

Fuselage

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

Propulsion

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

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

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

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

Variables to be minimized

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

Variables to be maximized

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

5.2 OPTIMIZATION STRATEGY

The application of three basic optimization strategies are proposed for IPAD. First, the strategy of direct optimization uses mathematical processes to perform automatic optimization. Various algorithms are collected into a "driver" that controls the process of the solution to an optimum. The number of variables is restricted to a small number (less than 10) and there is only one figure of merit. Second, the strategy of trade-off studies allows the user to evaluate a range of solutions around the local optimum. These solutions are needed because of multiple objectives that cannot be stated, or because there are too many variables for the direct optimization process. Third, the user optimizes the design thru a process of successively more accurate analytical modelling. This process is termed sequential model refining.

These optimization strategies and their potential applications to the design networks are discussed in more detail in the following sections. However, before proceeding, some mathematical definitions must be stated. The principle objective of preliminary design is to determine an airplane configuration (defined by design variables) that meets a set of specified performance requirements (design constraints). Design variables can be denoted by $x = (x_1, x_2, \ldots, x_n)$, and it is assumed that they can take any value within predetermined bounds,

$$a_1 \leq x_1 \leq b_1, \; a_2 \leq x_2 \leq b_2, \; \ldots \text{ etc.} \qquad (5.1)$$

Design constraints can be expressed as a series of inequalities

$$g_j(\underset{\sim}{x}) \geq 0, \; j = 1, 2, \ldots, J \qquad (5.2)$$

or equations

$$h_i(\underset{\sim}{x}) = 0, \; i = 1, 2, \ldots, I \tag{5.3}$$

It is desirable to relate an airplane satisfying Equations (5.1), (5.2) and (5.3) to a selected set of objectives <u>(objective or merit functions)</u>. The design problem can be put into the following form:

$$\text{minimize } f_1(x), \text{ maximize } f_2(x), \text{ maximize } f_3(x),$$

$$\text{maximize } f_4(x), \ldots \text{ etc.} \tag{5.4}$$

subject to the design constraints

$$g_j(\underset{\sim}{x}) \geq 0, \; h_i(\underset{\sim}{x}) = 0, \; \underset{\sim}{a} \leq \underset{\sim}{x} \leq \underset{\sim}{b} \tag{5.5}$$

$$j = 1, 2, \ldots, J \text{ and } i = 1, 2, \ldots, I$$

The functions $f_1(x)$, $f_2(x)$, ... constitute a number of <u>objective functions</u> of the design process and usually no one of them can be picked out as the sole objective. To obtain a mathematically tractable problem, Equations (5.4) and (5.5) need to be transformed into a problem with a single objective function. One approach is to use as the objective function a weighted sum of $f_1(x)$, $f_2(x)$,...,:

$$\phi(\underset{\sim}{x}) = w_1 f_1(\underset{\sim}{x}) + w_2 f_2(\underset{\sim}{x}) + \ldots\ldots$$

The weighted sum approach introduces the difficulty of selecting proper values for the weighting factors w_i, which represent the relative importance of the objective functions, and makes it difficult to interpret the meaning of the final optimum solution. A better approach is to select one of the partial objectives $f_1(\underset{\sim}{x})$, $f_2(\underset{\sim}{x})$, ... as the new objective function $f(x)$ and constrain the others. Therefore:

$$\text{minimize } f(\underset{\sim}{x})$$

subject to

$$f_1(\underset{\sim}{x}) \leq c_1, \; f_2(\underset{\sim}{x}) \geq c_2, \ldots \text{ etc.} \tag{5.6}$$

$$g_j(\underset{\sim}{x}) \geq 0, \; h_i(\underset{\sim}{x}) = 0, \; \underset{\sim}{a} \leq \underset{\sim}{x} \leq \underset{\sim}{b}$$

5.2.1 Direct (Explicit) Optimization

Equation (5.6) belongs to a class of optimization called nonlinear programming and will be further referred to as direct or explicit optimization. Mathematical processes representing these algorithms are programmed into a "driver" that controls the optimization process. The driver is capable of searching an optimum without human intervention. The choice of reliable and efficient techniques for handling any particular optimization problem is a function of the problem's complexity, structure and size. The characteristics of the configuration optimization problem are as follows:

1. Relatively few design variables, typically of the order of ten or less.

2. The starting configuration for the optimization process is a feasible solution, and it usually well approximates the optimal solution.

3. The variable ranges in which the optimum is to be located are limited in size.

4. The variables and functions that are the partial objectives of the optimization are competitive and are functions of many of the design variables.

5. The mathematical processes involved in computing the objective function and constraints in terms of the design variables are complicated and their derivatives cannot be computed analytically.

Items 1 and 2 insure a reasonable speed (small number of iterations) and a reasonable cost for the optimization process. Item 3 helps locate the global solution and limit the tendency for the number of iterations to increase unreasonably. Item 4 indicates the need to reduce the original formulation of the configuration optimization with several partial objectives to one with a single objective function. Finally, Item 5 suggests that optimization algorithms which do not require partial derivatives would be easier to implement than methods which do require derivatives.

5.2.2 Trade-Off Studies

A single optimum solution may be of limited value to the designer, who typically desires to explore some range of solutions about an optimum (or several local optima) before committing to a final configuration. This desire for a range of

solutions is met by trade-off studies achieved by sensitivity analysis, where the designer controls the trade by modifying the formulation of the optimization problem. Trade-off studies are required for many reasons. For example, multiple objective functions, such as designing the first member of a family of airplanes, may prevent a clear formulation of the merit variables or functions. Also, competing configuration arrangements such as engines on the wing as opposed to engines on the aft body, may have features that cannot be assigned a definite merit value, such as center of gravity limits required for passenger and cargo loadability. In general, it is frequently impossible to include in the mathematical model every consideration that must be taken into account. Also, special customer requirements may alter one or more objectives of the optimization process from those desired for the general case.

Finally, it may also be desirable to test the sensitivity of the optimal solution to any data inaccuracies, by repeating optimization with different sets of input data or parameters describing a particular mathematical model of the designed vehicle. The sensitivity analysis will be carried out in the IPAD system by the following types of computations:

1. Change of the objective function and constraints caused by changes in the value of x (single design variable) with other variables fixed.

2. Change in the optimum solution due to modifications of constraints, (e.g., tightening or relaxing the constraints).

3. Effect on the objective function of reducing or enlarging the set of design variables and repeating the optimization process with the modified set of design variables.

5.2.3 Sequential Model Refining

Sequential model refining is not a formal mathematical process. It is the process whereby a given design is optimized as a result of successively more accurate analytical modeling. The sequence will in general start at a lower design level, then proceed upward through the higher levels. Trade-off studies or even direct optimization may be performed at each stage of the model refinement. This optimization technique is entirely at the control of the user.

5.3 OPTIMIZATION APPLICATION FOR PROJECT 1 AND 2

5.3.1 Configuration Optimization

Figure 5.1 shows the application of the optimization strategies discussed in Section 5.2 to the Design Levels of Projects 1 and 2. In Level II and the geometry sizing portion of Level III, the entire configuration will be optimized. Mathematical programming (direct) techniques will be used as the main optimization tool and will be supplemented by trade-off studies to explore the neighborhood of a locally optimal solution. The purpose of trade-off studies is to identify a range of designs in this neighborhood and determine their sensitivity to changes of the design variables and problem formulation (performance requirements and objectives).

Figure 5.2 relates configuration optimization to the detail design networks for Projects 1 and 2. In Level II, the process of finding the most desirable design criteria and mission will be aided by determining an optimum configuration. This will provide reasonably optimistic performance data for the marketing analysis. In the first part of Level III (Configuration Sizing), the configuration optimization will benefit both from a more thoroughly defined configuration and from a more exact performance analysis. The latter is important in that the Level II approximations in performance methods can result in underestimation of vehicle capabilities.

Figure 5.3 shows the type of information required for a configuration optimization problem. The configuration arrangement is given first. The basic geometry, for example, the number and location of engines, or the wing technology, is selected and defines the class of configuration being optimized. The objective function f(x), which will be the measure of the optimization process, is selected. This may be a single variable, for example, direct operating cost or airline profits. There may also be several other partial objectives to be optimized, in which case one of them is selected as a principal objective function, and others are constrained (added to the set of constraints).

The design variables which are automatically adjusted by the optimization driver are selected, for example, wing area and wing aspect ratio. Variations in these design parameters will control the configuration sizing as an optimum is sought. Lastly, the constraints and requirements bounding the range of the solutions are given. These may be expressed as either equality or inequality constraints. Examples would be airplane range and field length. The final formal definition of the configuration optimization will be based on problem (5.6).

IPAD DESIGN LEVEL		APPLICATION	STRATEGY
II	DESIGN MISSION SELECTION	CONFIGURATION OPTIMIZATION (Given Arrangement)	• DIRECT (EXPLICIT) • TRADE-OFF STUDIES
III	GEOMETRY SIZING	CONFIGURATION OPTIMIZATION, (Given Arrangement)	• DIRECT (EXPLICIT) • TRADE-OFF STUDIES,
	STRUCTURE SIZING	SUBOPTIMIZATION	• DIRECT (EXPLICIT) • TRADE-OFF STUDIES • SEQUENTIAL MODEL REFINING
IV	CONFIGURATION REFINEMENT	SUBOPTIMIZATION	• DIRECT (EXPLICIT) • TRADE-OFF STUDIES • SEQUENTIAL MODEL REFINING
V	CONFIGURATION VERIFICATION	SUBOPTIMIZATION	• DIRECT (EXPLICIT) • TRADE-OFF STUDIES • SEQUENTIAL MODEL REFINING
VI	PRODUCT DETAIL DESIGN	SUBOPTIMIZATION	• DIRECT (EXPLICIT) • TRADE OFF STUDIES • SEQUENTIAL MODEL REFINING

Figure 5.1 Optimization Strategy – Project 1 and Project 2

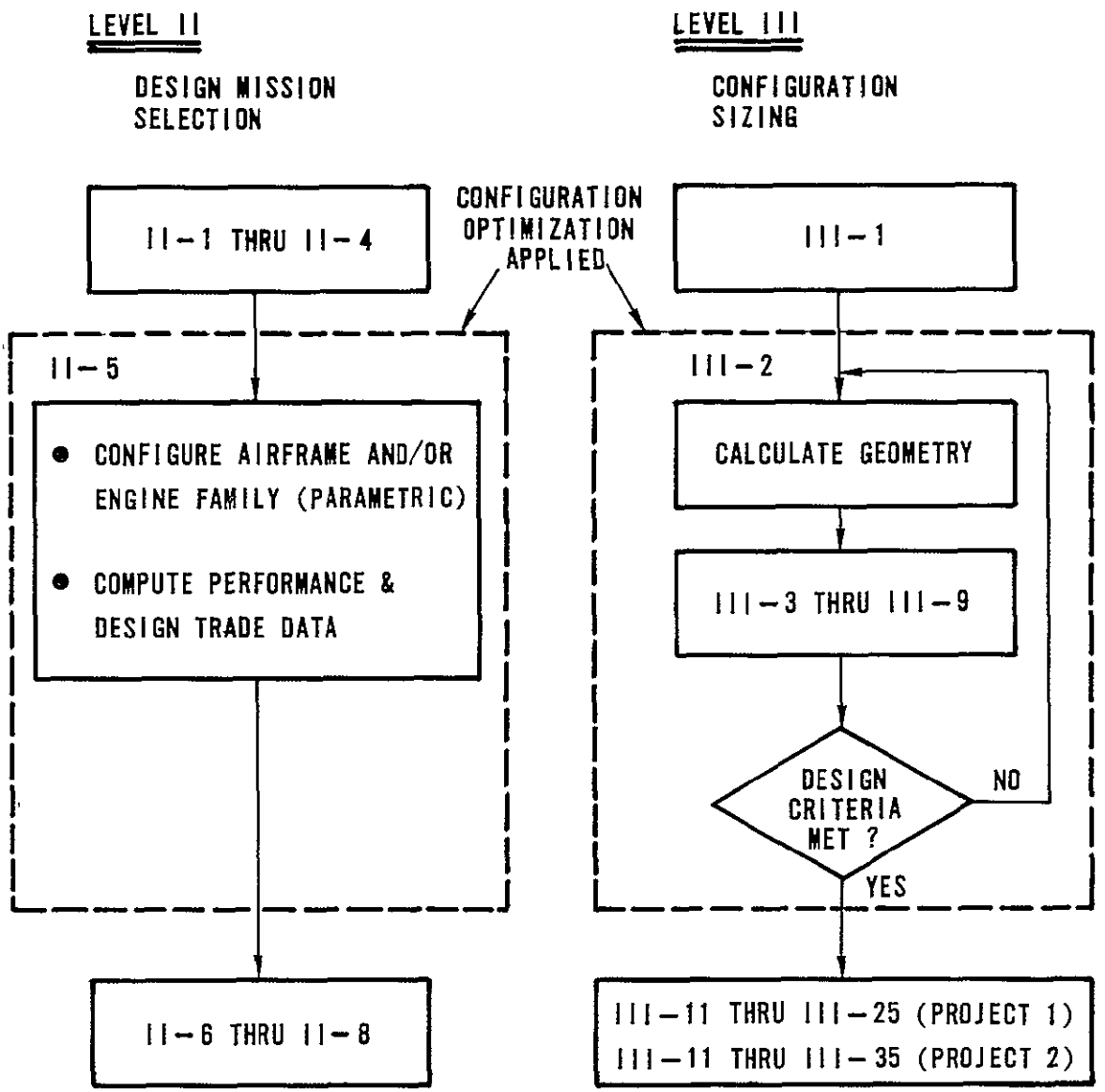


Figure 5.2 Configuration Optimization - Project I and Project 2

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

Figure 5.3 Example - Configuration Optimization

5.3.2 Suboptimization

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

1. Optimization of engine performance - the specific fuel consumption is optimized for given flight conditions.

2. Optimization of wing structures - weight or drag and weight under the stress, natural frequency and geometric limitations are minimized.

3. Optimization of stability and control - a control vector is searched such that the performance index is minimized.

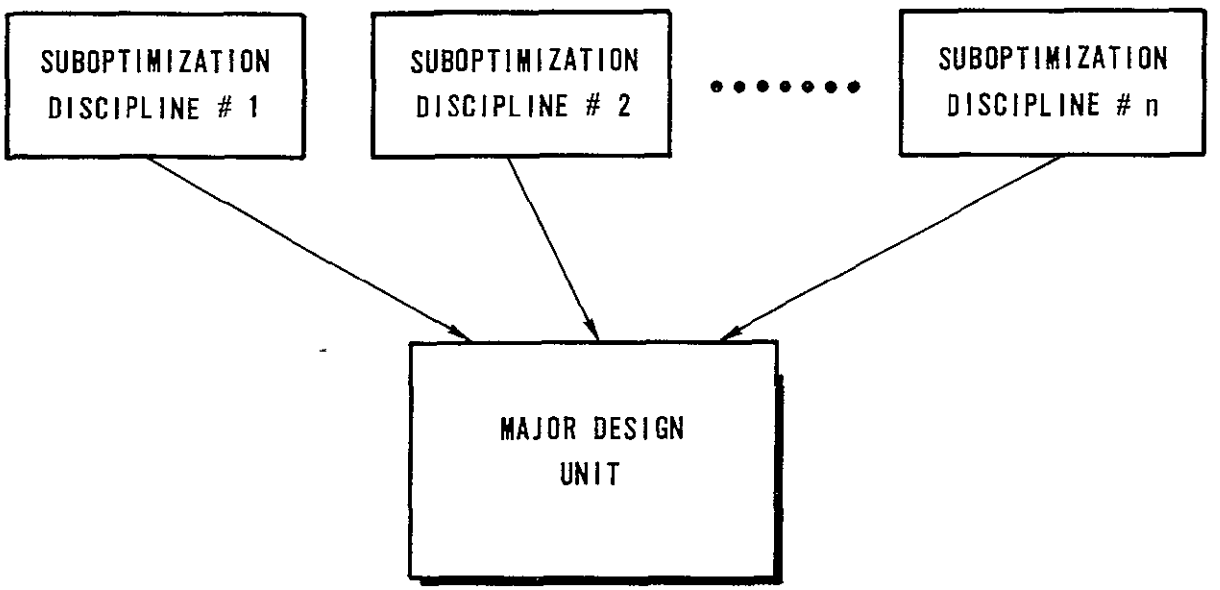
4. Optimization of flutter prevention designs - the structural weights and fixed weights which are added to the structure in order to obtain a desirable flutter performance are minimized. Principal design variables are rescaling factors of the structural stiffness and corresponding structural weights. Constraints of the problem include the configuration limitations and the specified flutter speed.

The results of suboptimization within disciplines and subdisciplines are coordinated and synthesized to yield an optimal (or nearly optimal) solution for each major design unit. An example might be the wing design which involves several disciplines such as aerodynamics, structures and weights, stability and control, and flutter analysis (see Fig. 5.4). The basic idea behind the concept of suboptimization is to decompose design problems which are too large to be solved in one place. The decomposition of this type results in:

1. Reduction of the complexity of analysis and related optimization problem,

2. Separation of objective functions and design variables into smaller groups within one discipline or subdiscipline.

Furthermore, the formulation of a major design unit such as a wing can be considered as a suboptimization problem related to the design of an entire airplane. Thus, the airplane design can



EXAMPLE:	WING DESIGN
DISCIPLINES INVOLVED:	AERODYNAMICS STRUCTURES AND WEIGHTS STABILITY AND CONTROL FLUTTER

Figure 5.4 Suboptimization Concept (Decomposition and Multilevel Optimization)

be viewed as a pyramid-structured multilevel analysis and optimization process.

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

5.4 OPTIMIZATION METHODS AND ALGORITHMS

As shown in Section 5.3 the configuration optimization problem is formulated on the constrained optimization problem and will be solved by mathematical programming methods. The methods should be able to use initial feasible or nearly feasible solutions and to obey the requirement constraints in the form of inequalities.

If the most accurate models defining the objective function, constraints, and variables were used for the optimization process, then the cost of an optimized solution might be so large as to restrict its effective use. To bring the costs into acceptable range three techniques will be used:

1. Method simplification, where coding changes are made to simplify the operational modules which define the functions involved in optimization,

2. Model simplification, where the solution methods are made faster by using the same method but reducing the detail of the mathematical modelling,

3. Limit variable range, which may allow coding reductions by easing requirements on some of the methods.

All three techniques may be used in a sequential manner, i.e., may be applied to a sequence of problems in the order of increasing level of technical detail. This approach implies that special Technical Program Elements (TPE's) may be written for the purpose of optimization, as opposed to the TPE's used in the analysis mode. These TPE's will represent simplified models and methods used in the design process and will lead to

efficient computations in the optimization mode. After the optimization process is completed, a final check of the computations will be performed using the more detailed analysis modules.

The candidate mathematical programming methods for the configuration optimization should satisfy the following requirements:

1. Use a small number of function evaluations in the total optimization process (rapid convergence).

2. Accept non-optimum but feasible initial configuration.

3. Handle inequality constraints.

4. Distinguish between soft constraints (desirable limitations) and hard constraints that must be satisfied by an optimal solution.

All the existing optimization methods will, in general, yield the position of one of the constrained local optima of the objective function which may not be the global optimum. It is usually desirable to find the global optimum as well as all the local optima, at least those close in value to the global solution. The multiple solution provides the designer with different options of design within the framework of the model and data being considered. The multiple optimal solutions can be obtained by repeated optimizations starting from different initial designs.

It is unlikely that any single constrained optimization method would satisfy all these requirements. It is, therefore, suggested that a package of optimization methods be used. Such a package will include several methods, e.g., steepest descent, variable metric, evolutionary operation simplex, random jumping, etc. An example of a combination program of this nature is AESOP or GROPE (Ref. 1 and 2). Detailed descriptions of a wide variety of methods that may be included as optimization Technical Program Elements for the IPAD system can be found in Reference 3. These combination programs will also require other methods related to the configuration optimization and sub-optimization problems; e.g., overdetermined system of algebraic equation solver which is used to find designs satisfying constraints (feasible) but not necessarily optimal.

5.5 SYSTEM IMPLICATIONS

The use of optimization imposes several requirements on the IPAD system. The user will have to be able to specify the objective function, the constraints and the independent design variables. The user will also specify the computational flow, that is, the execution sequence of the modules that will provide the optimizer Technical Program Elements with the required information.

Having formulated the problem, the user will select the methods or algorithms of optimization to be used. Once the program execution has begun and the optimization driver is controlling the solution, the user will want to have intermediate results reported. These may cause the user to interrupt the solution, modify some of the initial information and restart the optimization process.

The requirements imposed by the use of optimization will be accommodated by the IPAD capabilities of 1) job construction and 2) interactive mode of computing. A substantial level of man-machine interaction can save a great deal of computation time required for optimization. Users of IPAD will have to learn how to use IPAD's optimization capabilities, match their problem with proper methods and interpret the results of optimization.

5.6 REFERENCES

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6.0 TECHNICAL PROGRAM ELEMENTS

6.1 BOEING TECHNICAL CODE SURVEY

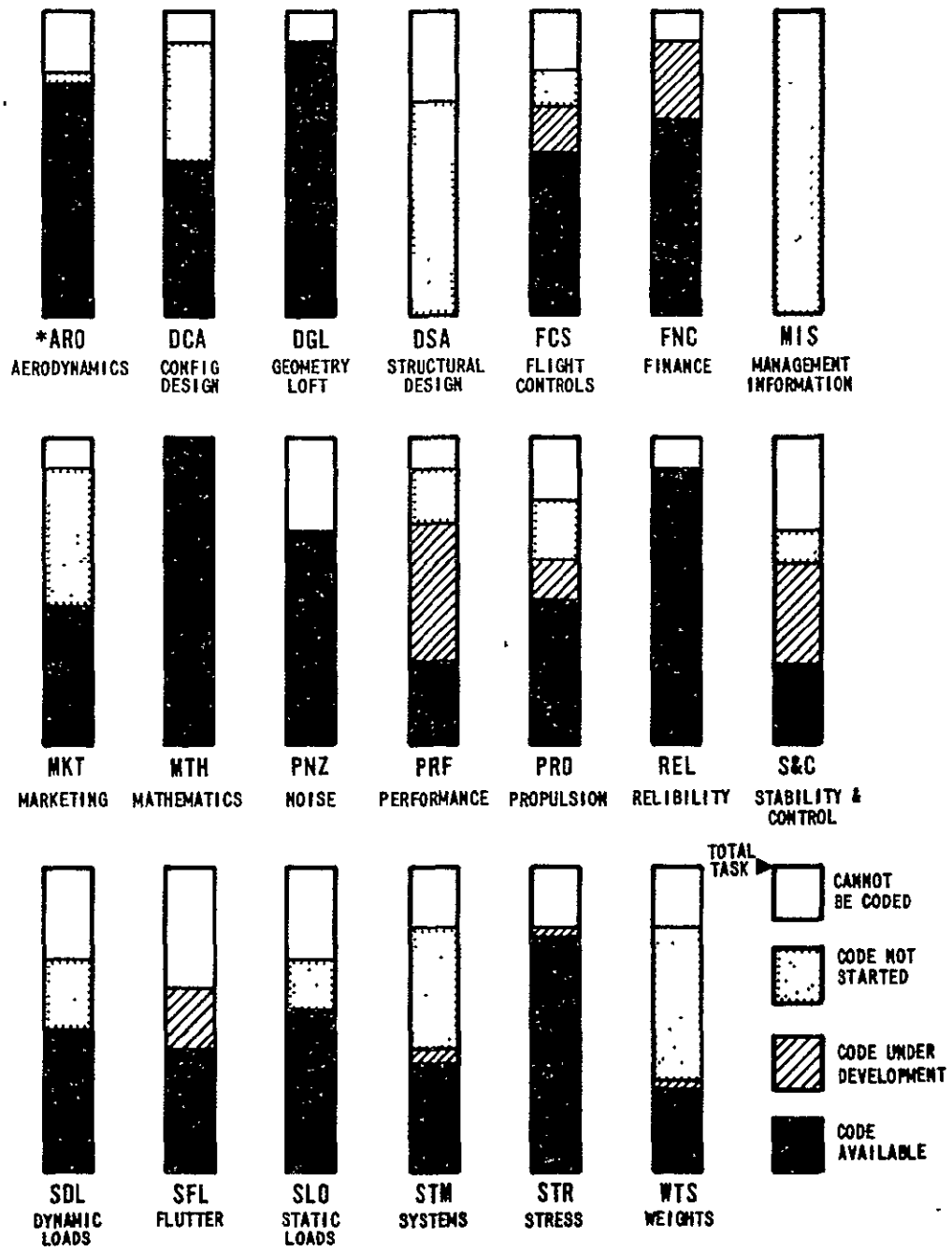
A survey was conducted within Boeing to identify the technical code required to support the IPAD design networks of section 4.0. The timing and depth of this study did not permit extending this technical code survey outside of Boeing. The purpose of this survey was to identify existing code suitable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

6.2 STATUS OF TECHNICAL PROGRAM ELEMENTS

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

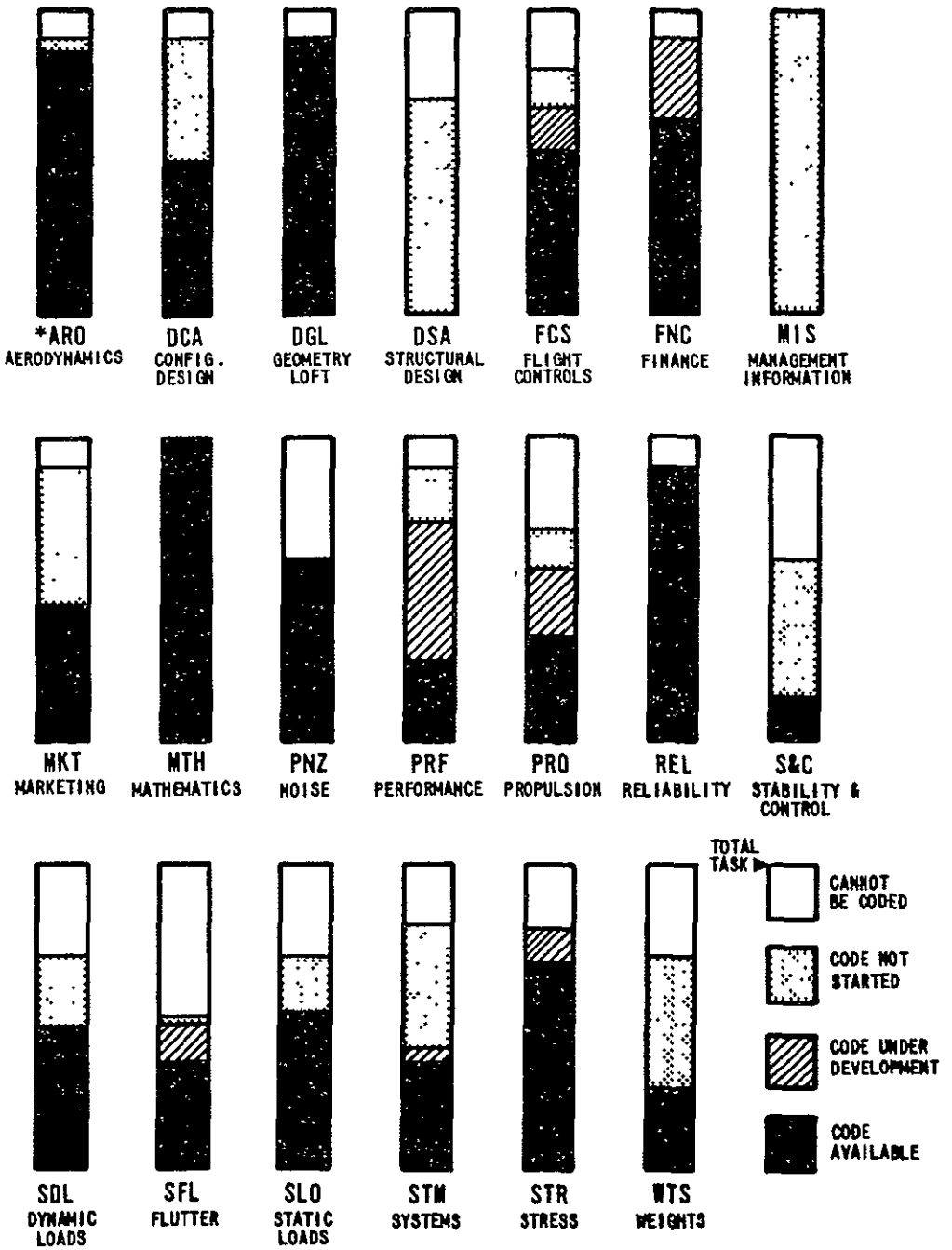
The status of the entire Boeing TPE survey is presented in seciton 2 of Volume V. The status of each TPE has been identifed in one of three categories: Category 1 (Code available) indicates that the TPE is in current use or has been used. Category 2 (code under development) indicates that a TPE is being developed but is not yet operational. Category 3 (code not started) indicates that a TPE is required for IPAD but is not currently being developed at Boeing. In addition, a fourth category (cannot be coded) has been estimated. The fourth category cannot be measured and represents an estimate of that portion of the total man activities which cannot be brought into the man-machine environment in the sense that supporting code cannot be written for these activities. For example, this category includes judgmental decisions, day-to-day verbal and written communication, development testing, and sundry activities which require personal attention such as study, research of library information and trade journals, travel, etc.

Figure 6.1 and 6.2 show the status of code identified for the two projects studied. Project 1 is a subsonic commercial transport and Project 2 is a supersonic commercial transport. This status includes the code required for the preliminary



* ABBREVIATION USED IN CATALOG OF TECHNICAL PROGRAM ELEMENTS (VOLUME V)

Figure 6.1 Technical Program Element Status - Project I - Subsonic Commercial Transport



* ABBREVIATION USED IN CATALOG OF TECHNICAL PROGRAM ELEMENTS (VOLUME V)

Figure 6.2 Technical Program Element Status – Project 2 – Supersonic Commercial Transport

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

7.0 CONCLUSIONS

It is concluded that product design in the aerospace field can be organized into a well-defined activity, and that a computing system can be specified which will allow the user community to improve the quality of the design and reduce the cost of the manufactured product. Specific conclusions have been drawn from the Task 1 work.

1. The design processes for products such as subsonic and supersonic commercial transports can be characterized by subdividing the design process into manageable levels or hierarchies of activity. These levels must balance computing cost and time with the required accuracy of the results thus allowing management the control it needs to get cost-effective results at each stage of the design. Design networks can be used to plan design logic and the required computing sequence.

2. Most of the tasks which require calculated data can be brought into the man-machine environment. These tasks will be done by individual users selectively executing the appropriate code using data taken from a carefully maintained data base. Also, the development of a design network for each product will produce a catalog of the existing and required code for that product.

3. The design networks and the Management Information System will provide the capability to establish cost targets and a process to track and compare cost information to the established cost targets. Since the Technical Program Elements for each technical discipline have increased computational requirements at each successive design network Level, the commitment to proceed to successive design Levels may be controlled by management to balance the degree of technical risk with the Level of design for each problem under investigation.

4. Optimization will be applied throughout the product design process to improve the design solutions. The optimization processes will range from entirely automatic to entirely user-driven.

5. The required support of the design process can be derived from design case studies. The IPAD System must support the user by maintaining the data base, providing the user with the ability to assemble and

execute programs with ease, and giving management the information and means for effectively controlling the design of the product. During all of the user activity, the System must provide the means of preserving the integrity of both the Technical Program Element (technical code) and the data that is used, and must establish continuity of the tasks in the user community over the time it takes to do the tasks. These requirements are presented in Volume III.

6. An implementation goal can be given for the preferred technical development of IPAD:

   (a) Provide the code to do the preliminary design of the product first, as this will have the greatest effect on the performance of the product and will support the development of the IPAD system.

   (b) Develop the interface between the detail design and the manufacturing next, as this will produce the greatest product cost reduction.

   (c) Initiate development of some technical capability at all levels during the initial implementation phase. Subsequent extension will incorporate new capabilities as they are developed.

8.0 USER RECOMMENDATIONS FOR IMPLEMENTATION

8.1 PURPOSE

The purpose of user recommendations for implementation is to identify a brief concept which may provide guidance for an initial plan and an initial strategy for the development of the IPAD technical capability. Subsequent extension during the long term development is also considered.

8.2 INITIAL IMPLEMENTATION

The initial implementation of IPAD should provide a suitable balance between technical capability and system capability. There must be adequate Technical Program Elements available to support the development and check out of the IPAD System software and to provide the minimum technical capability which will permit an evaluation of of the IPAD concepts on some meaningful design case studies.

8.2.1 Design and Analysis Capability

Broad user acceptance of IPAD should be enhanced if some initial technical capability is developed for each level during the initial implementation. The initial design and analysis capability for IPAD should be limited to modification of existing code and to the development of new code in a few design areas which are required to make the initial IPAD a useful design tool. This initial capability based primarily on existing code should establish an incentive which will lead toward immediate incorporation of new code into IPAD. The technical capability of all Levels can be expected to grow rapidly provided a minimal useful capability exists at the beginning for each Level.

8.2.1.1 Development of Technical Capability

The initial implementation of the Project 1 subsonic class of airplanes should include Levels II AND III of the design networks. This technical capability should be adequate to support the development and check out of the IPAD system. It will also provide a basis for calibration since it will be possible to relate the subsonic class of airplane to both existing in-service airplanes and to studies which are continually in progress for this class of airplane.

The initial implementation of the Project 2 supersonic class of airplanes should include Level II and the geometry sizing part of Level III of the design networks. This technical capability would orient IPAD to future vehicles. This should help demonstrate the value of the IPAD System for evaluation of complex design studies for which past experience is limited.

In addition, it is recommended that the interface with manufacturing at Level VI be initiated during the first implementation. This interface will be similar for both Project 1 and Project 2 and should make IPAD complement Computer Aided Manufacturing (CAM).

8.2.2 Technical Program Elements Needed

As a minimum, the Technical Program Elements identified in the Volume V for Levels II and III of Project 1 and Level II and the geometry sizing part of Level III of Project 2 are required. Also begin development of the Technical Program Elements to support the Management Information System for all Levels and the interactive part design at Levels V and VI for both Projects.

8.2.3 Benefits of Initial Implementation

The benefits of the initial IPAD are expected to impact the aerospace industry in three major ways.

8.2.3.1 Design Cycle Time

The time to develop a configuration size matched to market requirements should be greatly reduced. For example, the integrated sizing analysis in Level III for a subsonic airplane should only require about two and one half weeks compared to approximately eight weeks using standalone programs. Such reduction in time will be accomplished by reducing the input data requirements, through linking OM's using the facilities of the IPAD System and by establishing a set of default variables which do not routinely change for specific classes of problems.

8.2.3.2 Data Base

The data base management capabilities provided by the IPAD System should improve the communication of technical data between all disciplines. The development of a consistent data base for all design, analysis and evaluation activities would be supported by this capability. The computational tasks of the

design networks could be done with the proper data, and in a timely manner as the correct data sets become available.

The IPAD System should also provide for integrity of the data base. Sets of data should be protected from accidental or malicious tampering. The Technical Program Elements that calculate the values in the data sets should also be protected. In addition, it should be possible to trace the origin of a questionable data set, and to repeat the process of its generation.

8.2.3.3 Manufacturing

Many present manufacturing facilities are highly computerized. In addition, Computer Aided Manufacturing (CAM) Systems are in various stages of study, implementation, or are presently in use. The IPAD System should provide technical information at the interface between design and manufacturing which can be transferred directly to computing facilities that support manufacturing.

Providing manufacturing with a more accurate product technical definition early in the manufacturing process should reduce the number of changes required during manufacturing. The reduction in manufacturing changes and the improved communications between engineering and manufacturing may provide the greatest economic benefits from IPAD.

8.3 LONG TERM DEVELOPMENT

The long term development of IPAD should proceed as an orderly continuing process which is open ended. A development plan should be established which identifies the required funding and makes provision for implementation on advanced computing systems.

8.3.1 Design and Analysis Capability

The design and analysis capability should be extended to include the remaining Levels of each project. This extension will likely be done with technology that is similar to today's capability. In the future, however, the technical disciplines in IPAD will tend more toward science and less toward art. The models of the product will be based on more fundamental physical laws than on compartmental empirical observations. For an example, the energy being produced by the airframe as acoustic

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energy may be theoretically calculated for the entire geometry, rather than being statistically predicted.

As the trend to more scientific principles continues, some of the present technical disciplines may disappear and new ones may come into existence. These changes cannot be predicted, however, the IPAD System must support the changing nature of the tasks associated with the design of the product.

8.3.2 Technical Program Elements Needed

As a minimum, a capability equivalent to the Technical Program Elements in Volume V is recommended. Then, each technical discipline will add Elements as the state of the art advances.

8.3.3 Benefit of Long Term Development

The benefits of long term development will include those of short term implementation. But over the long term, these benefits will spread to more products and more technical disciplines. This expansion will cover a long time period, and will expose the IPAD System to improvements not only in the technical disciplines but in the host hardware that IPAD exists on.

The requirement that the IPAD System be adaptable and thus long lived will give continuity to the evolution of technology. Data banks developed with current technologies will become valuable bases for the development of technical advances. The design processes contained in the short term IPAD development will be able to advance as the state-of-the-art of the technical disciplines advance. Over the long term, a long-lived IPAD System will provide valuable continuity to the evolution of products designed in the IPAD environment.