SOME EXPERIENCES IN AIRCRAFT AEROELASTIC
DESIGN USING PRELIMINARY AEROELASTIC
DESIGN OF STRUCTURES [PADS]

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ABSTRACT

Preliminary design for an optimal aircraft configuration requires the integration of aeroelastic analysis into the configuration selection process. Configurations of aircraft in the early design stage are usually based on analytical and statistical weight methods from past experience, and approximate loads and stress analyses. This often leads to the freezing of external geometry before strength and flutter analyses are complete, thereby decoupling the powerful but time-consuming process of structural design to minimum weight from the configuration optimization process. If the lengths of time could be shortened to perform accurate loads, structural design, and flutter optimization analyses, then structural optimization could proceed in concert with the overall configuration optimization. Better aircraft of advanced types could then be designed.

A methodology was developed to upgrade current capabilities in ASSET (Automated System Synthesis and Evaluation Technique) for including results from aeroelastic considerations. ASSET provides the traditional rapid and cost-effective solution to configuration selection for any aircraft mission, within the limitation that the structural weight is based on statistical data. PADS (Preliminary Aeroelastic Design of Structures) is being developed to generate structural weight data that include aeroelastic considerations which in turn could be used to update ASSET's data base during configuration trade-off studies. Aeroelastic inputs to ASSET will lead to significant improvements in the configuration selection process especially when advanced designs combine composite structures with unusual planform geometry and operating conditions.

The paper discusses the design experience associated with a benchmark aeroelastic design of an out of production transport aircraft, and reports on current work being performed on a high aspect ratio wing design. The PADS system will be briefly summarized and some operational aspects of generating the design in an automated aeroelastic design environment will be discussed.

456

INTRODUCTION

Preliminary design for an optimal aircraft configuration may require the integration of aeroelastic considerations into the configuration selection and design process. Aeroelastic design incorporates the effects of aircraft structural flexibility on static and dynamic loads, control effectiveness, and aeroelastic stability into the sizing of the structure. Configurations of aircraft in the early design stage are usually based on statistical and analytical weight methods computed from approximate loads and stress analyses. This often leads to the freezing of external geometry before strength and flutter analyses are sufficiently advanced, thereby decoupling the powerful but time-consuming process of structural design to minimum weight from the configuration optimization process. If the elapsed time to perform more accurate loads, structural design, and flutter optimization analyses is shortened, then structural optimization can proceed in concert with the overall configuration optimization, and more efficient advanced types of aircraft can be designed.

ACRONYMS & DEFINITIONS

ACS   - active control system
ASSET   - Advanced Systems Synthesis and Evaluation Technique
CADAM[o] - Lockheed's computer aided design system
CBUS   - Continuous Batch User Specification
CPP   - command processor program in CBUS
DBM   - data base management
DMS   - data base management system
DOF   - degree of freedom
FAMAS   - Lockheed's matrix data based computing system for aeroelastic analysis
FINDEX   - Lockheed's DMS for matrices and NASTRAN tables
FSD   - fully stressed design algorithm
Lockheed - Lockheed-California Company
MLC   - maneuver load control
NASA   - National Aeronautics and Space Administration
NASTRAN - structural finite element program developed by NASA
PADS   - Preliminary Aeroelastic Design of Structures
PSASA   - panel sizing and stress allowables
RAP   - resource allocator program in CBUS
RDMS   - run data management system
SIC   - structural influence coefficients
SMG   - structural model generator, a finite element model generator which represents a family of aircraft designs.

[o] Registered trademark of CADAM, Inc.

Aeroelastic analysis of an aircraft structure is a substantial undertaking involving many disciplines and complex data paths. A short time ago, preliminary aeroelastic analysis was reserved for projects on the verge of achieving go-ahead status while preliminary aeroelastic design was not even attempted.

In the past, the level of effort required for an accurate aeroelastic design was not justifiable relative to the answers provided by statistical methods which were supported by historical data bases. Today, however, there are many combinations of advanced technologies and configurations, such as supercritical airfoils, high aspect ratio wings, forward swept wings, active controls, aeroelastic tailoring, and new materials, that have no historical data base from which to derive the statistical or parametric weight equations. Two questions (Figure 1) regarding the role of aeroelastic design in preliminary design are:

1) How to integrate aeroelastic design in P.D.?

2) How to make aeroelastic design timely?

- **HOW TO INTEGRATE AEROELASTIC DESIGN PROCESS INTO AIRCRAFT CONFIGURATION SELECTION?**

- **HOW TO REDUCE ELAPSED TIME FOR AEROELASTIC DESIGN?**

Figure 1

APPROACH

There are two options available for acquiring a rapid aeroelastic analysis and design capability: generate or acquire special programs tailored to rapid analysis procedures; or adapt existing engineering methodology and the associated computer tools to requirements of rapid analyses. Software maintenance is a major part of any proposed computer-aided design system. Lockheed-California Company (Lockheed) has an extensive library of computer programs which support airplane design through final and production design phases. It would be convenient to extend the application of that software into the preliminary design phase instead of creating specialized software and to update statistical based weight equations used in the design process (Figure 2).

Airplane design involves complex interactions between the conceptual designer, the customer with design specifications, and the engineers with final design and manufacturing requirements. Since many facets of the engineering process defy quantification, the computer methodology used to improve the flow of design information must be: 1) flexible and 2) highly modular. Flexibility will permit inputs into the design process from many sources, and modularity will deter obsolescence when new engineering design processes become available.

Against the background of existing data management systems, existing computing systems of great sophistication, and high-level languages oriented to the user-friendly atmosphere, the company decided to use the production design computing tools and to attack directly their known deficiencies with respect to preliminary design applications. A computer system was postulated which would act as a bare tree from which existing computer programs could be hung as needed in a user-friendly and highly modular environment.

● **UPDATE STATISTICAL BASED WEIGHT EQUATION USED IN CONFIGURATION SELECTION PROCESS**

● **USE EXISTING DESIGN AND ANALYSIS PROGRAMS**
  — **STATIC AND DYNAMICS LOADS**
  — **FINITE ELEMENT METHODS FOR STRUCTURE**
  — **FULL STRESS REPRESENTATION**
  — **WEIGHT DISTRIBUTION**
  — **STRUCTURAL SIZING FOR LOADS**
  — **FLUTTER**
  — **STRUCTURAL SIZING FOR FLUTTER AND DEFLECTION**
  — **ACTIVE CONTROLS**

● **AGGRESSIVE USE OF PRE- AND POSTPROCESSORS**

● **UNINTERRUPTED COMPUTING CAPABILITY**

Figure 2

GOAL

The goal of Preliminary Aeroelastic Design of Structures (PADS) is to develop computer operating system architecture and design methodology to be used to generate an accurate aeroelastic design within the conceptual and early preliminary design phases. This aeroelastic design data base will permit more accurate weights to be established during the configuration trade-off studies. The long term goal is to define an accurate aeroelastic design within an elapsed time which is measured in weeks and to perform a design perturbation within elapsed time which is measured in days (Figure 3). Design perturbations include changes to any variable which does not require significant data preparation. For the wing, these variables will include sweep, planform definition, taper, airfoil sections, t/c, and aspect ratio.

The work to achieve these goals is in progress. PADS capabilities currently include a structural finite element model generator, weight distribution, grid transformations, steady maneuver loads for symmetric conditions, dynamic gust loads, landing loads, brake loads, flutter analysis, and structural sizing.

This paper will address four areas:

1. The formulation of computer operating system technology and data management techniques which will permit the definition and execution of engineering processes in a continuous, user-friendly computing environment

2. The definition of engineering processes for preliminary aeroelastic design of structures which may be used to derive an accurate structural weight for a wing in the elapsed time normally available for a conceptual design phase

3. The presentation of results from the PADS validation effort, computer software as well as engineering processes, using a known airplane design data base

4. The presentation of results from a high aspect ratio wing design

AEROELASTIC CONSIDERATIONS
FOR ADVANCED DESIGN

	BEFORE PADS	AFTER PADS (GOAL)
● ELAPSED TIME	2 TO 6 MONTHS	● 5 DAYS SETUP
		● 1 DAY DESIGN PERTURBATIONS
● COSTS	MODEL COMPLEXITY MUST COVER ALL POSSIBLE ANALYSIS REQUIREMENTS — NO QUICK LOOK CAPABILITY	MODEL COMPLEXITY MATCHES ANALYSIS REQUIREMENTS —
	4 TO 10 MAN MONTHS	2 MAN WEEKS

Figure 3

460

PADS/ASSET INTERFACE

Lockheed's Advanced Systems Synthesis and Evaluation Technique (ASSET) computer program provides a rapid and cost-effective solution to configuration selection for any aircraft mission, but only within the limitation that the structural weight must be based on semianalytical and statistical data. An ASSET study usually requires that a baseline aircraft model be created and exercised in ASSET to represent an actual known aircraft data base. This model then is modified through adjustments to parametric coefficients to simulate changes to baseline aircraft systems, structural arrangement, material usage, design parameters, and mission requirements. Once complete, the model is passed into the ASSET design cycle for sizing, configuration trade-off analysis, and performance evaluation.

The PADS goal is to update the weight data base during configuration trade-off studies as well as to perform general aeroelastic analysis and design in a highly computerized environment. Figure 4 shows the interaction between PADS and ASSET during a typical configuration trade-off study. Aeroelastic inputs to ASSET will lead to significant improvements in the configuration selection process, especially when advanced designs combine advanced structural materials, such as composites, with unusual geometry.

PADS development consists of two distinct efforts:

- The development of the computer operating system which will permit continuous computing capability in a user-friendly and engineering-defined environment.

- The definition and mechanization of basic engineering processes for use in aeroelastic design and analysis.

The computer operating system will have applications outside of PADS whenever a requirement exists to integrate diverse computing programs under one operating system.
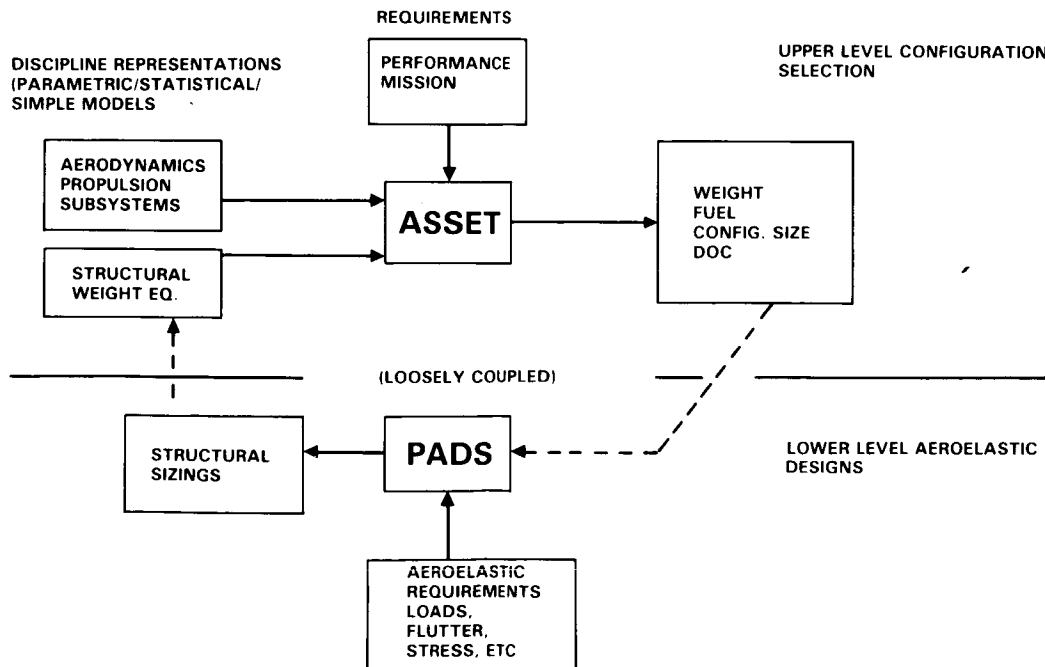

Figure 4

The design specifications of the operating system for PADS mirror the specifications of a computer hardware bus. The specifications of the computer hardware bus define an interfacing system for use in interconnecting data processing, data storage, and peripheral data control devices in a closely coupled configuration. Two objectives of a hardware bus are 1) to provide communication between two devices on the bus without disturbing the internal activities of the other devices interfaced to the bus, 2) to specify protocols that precisely define the interaction between the bus and devices interfaced to it.

If the word "devices" is replaced by "load modules/programs", the above specifications for a hardware bus come close to defining the specifications for a computer operating system in terms of a software bus. One of the reasons the operating system was named Continous Batch User Specification was to carry over the bus concept into the operating system acronym, namely CBUS.

The user normally accesses the computer through areas designated as "TARGET PROGRAMS" and Data Bases as shown in the Figure 5. While this level gives the user most of the flexibility, the user usually must address a lot of detailed work just to execute a simple task. CBUS provides the interface between target programs and data bases and commands that define a computing function or process. The user under this architecture executes processes which may contain hundreds of target programs executions and data base references.
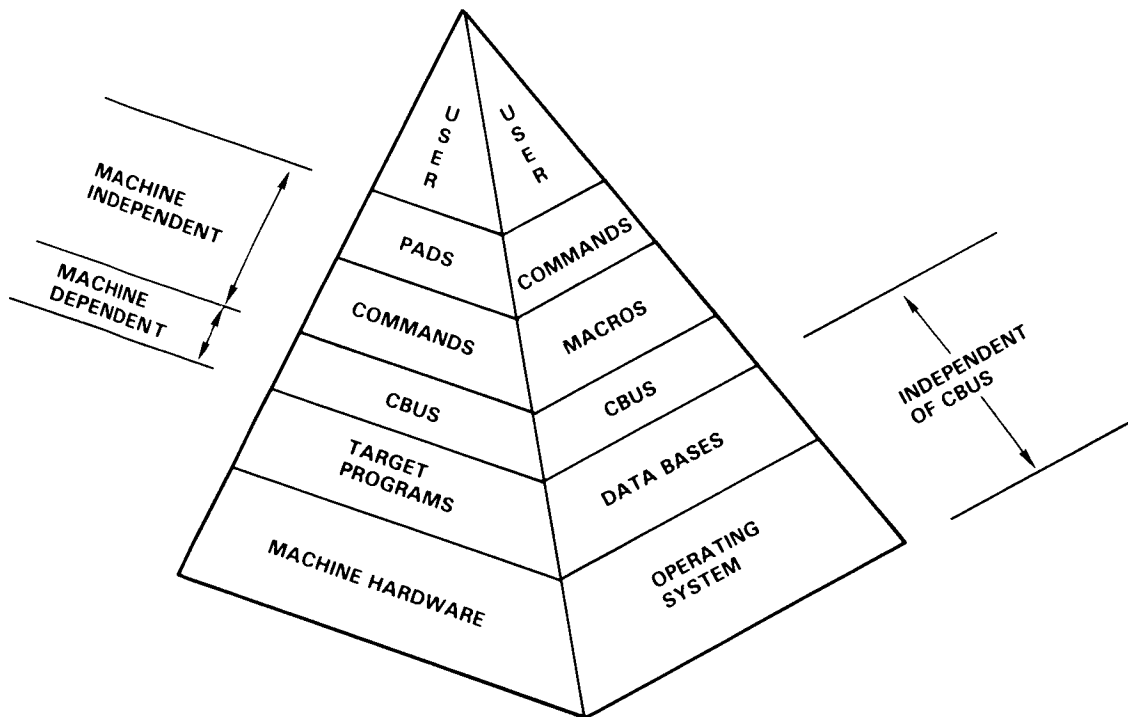

Figure 5

CBUS OPERATING SYSTEM SPECIFICATIONS

The CBUS operating system (Figure 6) will 1) access and make use of any existing data base, 2) be able to use any existing or independently developed program, 3) impose no requirements on programs to be integrated into the operating system, 4) interface with the user with high-level, user-friendly language, 5) allow the command language names/keywords and computing processes to be definable outside of the operating system, 6) use existing data base management systems for storage of permanent data, 7) enable the computing process to be uninterrupted, and 8) permit the execution of an unlimited number of equivalent batch jobs in one computer run, in one uninterrupted computing segment.

- **ACCESS AND USE ANY EXISTING DATABASE SYSTEM**

- **IMPOSE NO REQUIREMENTS ON EXISTING PROGRAMS FOR INTEGRATION**

- **INTERFACE WITH HIGH-LEVEL, USER-FRIENDLY LANGUAGE**

- **ALLOW USER DEFINED NAMES AND KEYWORDS**

- **USE EXISTING DBMS FOR STORAGE OF PERMANENT DATA**

- **ALLOW THE COMPUTING PROCESS TO BE UNINTERRUPTED**

- **PERMIT THE EXECUTION OF UNLIMITED NUMBER OF EQUIVALENT BATCH JOBS**

Figure 6

CBUS GENERAL CHARACTERISTICS

The CBUS operating system consists of four players: 1) the monitor, 2) the resource allocator, 3) the command processor, and 4) the target (Figure 7). Each player is a separate executable load module in its own right, with the monitor, command processor, and resource allocator having a special interrelationship.

The monitor is the upper level program which loads other executable load modules into core for execution. The resource allocator is a program which allocates and re-defines computer resources as required by the next target. The target is any executable load module (program) which the monitor will attach and execute during the continuous computing sequence.

The command processor program (CPP) interprets user supplied information and builds a stream of data which instructs the resource allocator on how to arrange the resources of the computer to satisfy the needs of the next program to be executed, while under the umbrella of the monitor. The command processor data source is a library of macros/commands, including the names of the macros/commands, which are user-generated. Figure 7 illustrates the essential features of the operating system.
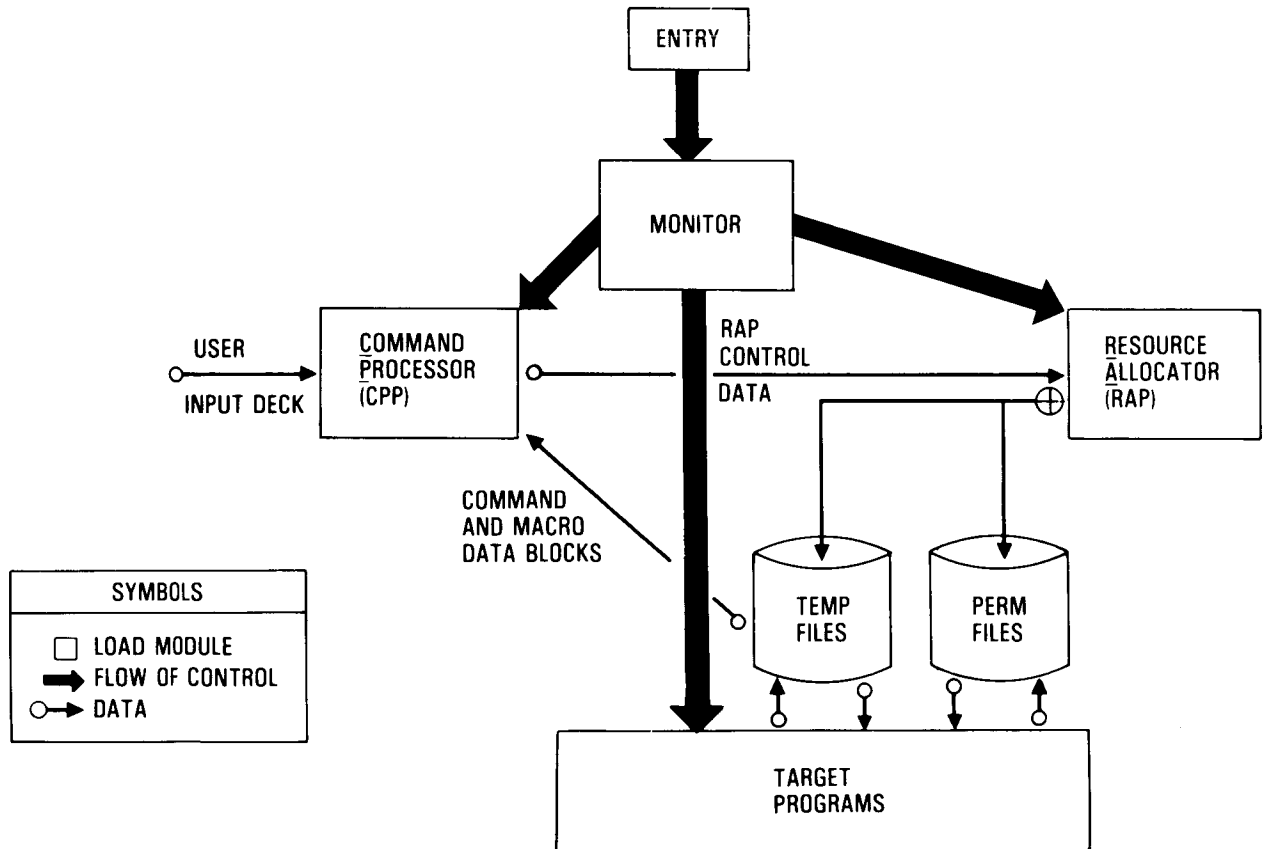

Figure 7

The user interfaces with the CBUS operating system through commands and through the command processor language. A command specifies a process in a language which is interpretable by the CBUS command processor at the user input level. A process is a particular method of doing something, generally involving a number of computer programs and/or operations. A command contains all the defaults necessary for executing a process. The command processor recognizes four levels of macro configured data structures; namely, macro, subcommand, command, and supercommand. The different levels of macros, as illustrated in Figure 8, make possible the definition of primitive processes which can be used as building blocks for any number of higher level processes. The macro and subcommand are building blocks for commands while commands are building blocks for supercommands.

A subcommand is a self-contained instruction set which defines a process to be performed and is accessible in the CBUS operating system by the same naming convention as is available for a macro.

A command contains, in a fixed sequence, a collection of references to subcommands as well as all defaults for attributes associated with subcommands and macros.

A supercommand contains references to commands and supercommands, and includes all defaults necessary to perform its function. Supercommands, therefore, permit recursive operations because a supercommand can reference itself.
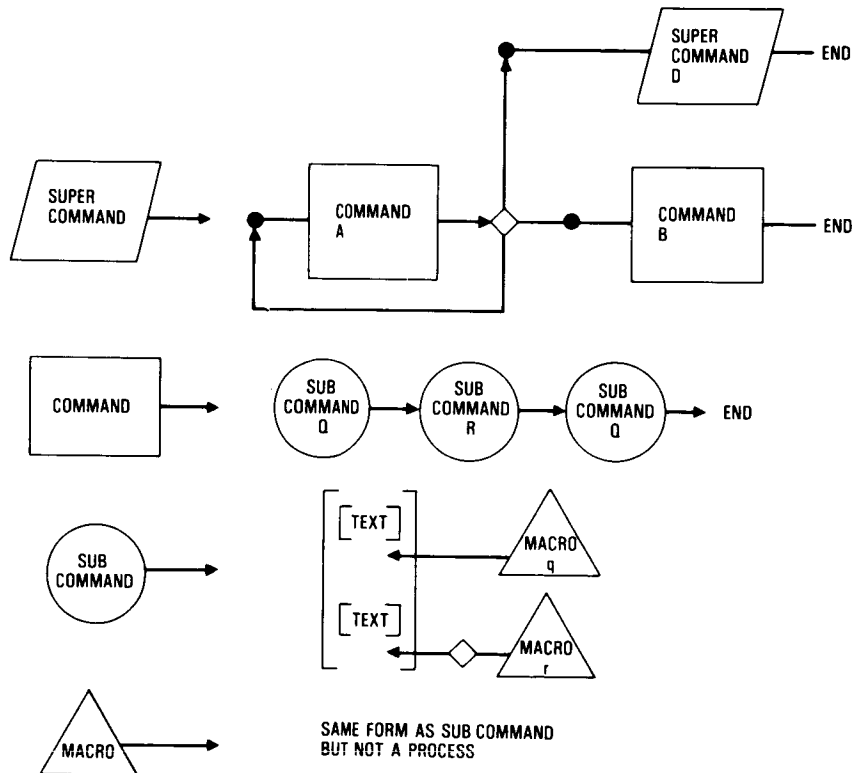

MACRO STRUCTURE EXAMPLES

Figure 8

A command includes all instructions and attribute default assignments necessary for execution. The functionality concept requires that the user be able to alter the command's default attributes. Attributes which could be candidates for change are names of data sets to be incorporated into the process, constants to be used in the computations, and naming of output data sets associated with the process. The alter capability also permits the complete definition of the function with all defaults, while retaining the flexibility to generate a radically new version of the function without creating and storing a new version of an existing command/macro code.

As shown in Figure 9, an alter capability is made available at every level of the command/macro tier by providing an alter command card after the data line which is to be altered. The alter command line executes the prescribed alter function when the user supplies an altercard with the identical keyword which is also imbedded in the alter command line.

The altercards can be grouped into four categories: global, command user-supplied, subcommand default, and altermacro. Global altercards are those that the user can specify to apply to the entire run. Altercards supplied by the user under the command definition have the highest priority, and will override the global alter-cards. The altermacro, altercards imbedded in a macro, is placed below the global altercards and above the default cards supplied in the subcommand.
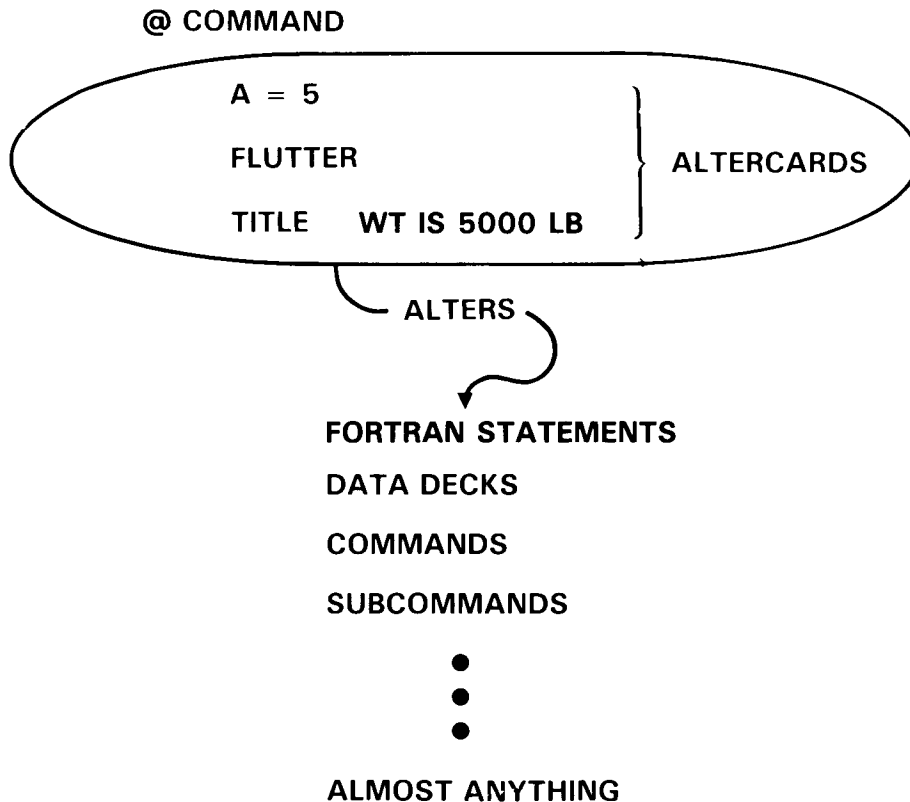
@ COMMAND

A = 5

FLUTTER   } ALTERCARDS

TITLE   WT IS 5000 LB

ALTERS

FORTRAN STATEMENTS

DATA DECKS

COMMANDS

SUBCOMMANDS

●
●
●

ALMOST ANYTHING

Figure 9

COMMAND PROCESSOR LANGUAGE

The user command language is a high level language which permits the typical user to define complex computing functions through commands and branch capabilities. Some of the essential features will be demonstrated by example.

Figure 10 shows the format for invoking a (super) command, executing an unconditional branch, a conditional branch, and a call to an internal procedure, and computing scalars, as well as a three level altercard capability. Each qualifier may contain up to eight characters. The altercard may be as simple as a name ABC.

@ NAME; INVOKES (SUPER) COMMAND

@ GO TO _____ ;

@ IF (A*B − 3.0. GT.R) THEN _____

@ CALL _____ ; CALL TO INTERNAL PROCEDURE

A < 3.4 * 30 − B; CALCULATOR MODE

ABC __ DEF __ __ GHI __ __ __ JKL = _____ ; ALTERCARD (THREE LEVELS)

Figure 10

C-6

THE DESIGN PROCESS

The first step in the design process is to define the objectives of the task and the necessary level of design detail required to satisfy those objectives. The design team must then review the requirements, cost out the project, and define a schedule. This is an iterative process between the customer and the design team as with any project with a specific amount of available resources. This phase is labelled "DESIGN OBJECTIVES" in Figure 11.

The next step is the generation of the structural finite element model, initial weight distributions, and initial entries into the various modules to generate geometry tables for each grid system to be used in the design.

The initial internal loads intensities are generated from static loads for a rigid airplane and uniform properties for those structural finite elements to be sized. A panel sizing and stress allowable (PSASA) process then generates from the load intensities the initial sizing for the specified margins of safety.

The computations for static loads and internal loads intensities are repeated using the sizing derived from rigid airplane loads.

The first flex sizing data provides a basis for updating the weight data and for generating dynamic loads input (gust, taxi, landing) along with the flutter minimum sizing constraints.
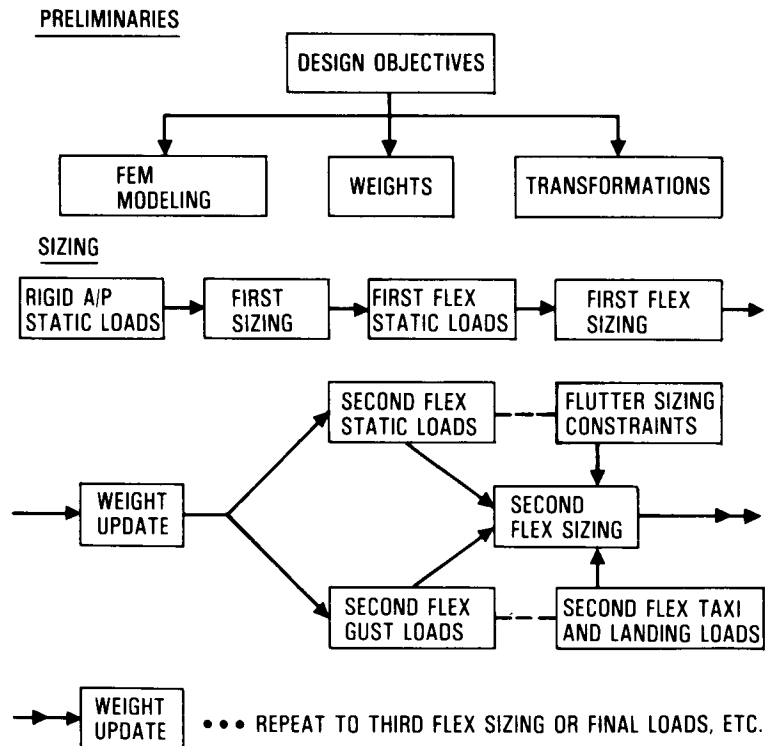
Figure 11

GRID TRANSFORMATIONS

The underlying premise to the development of PADS capability is the use of production tools and proven procedures to formulate the necessary analytical processes to be used in weight, flutter, loads, etc. This approach results in a general proliferation of grid/coordinate systems. A method was devised to generate systematically the transformations between the many grid systems without sacrificing flexibility (Figure 12).

The grid transformation process requires location and type-of-displacement labeling of the degrees of freedom (DOF) for the two grids involved in the transformation. However, certain sections of the airplane have special requirements concerning the transformation process; for example, aileron control surface mass elements should be beamed to flexibility degrees of freedom on the aileron and not to the degrees of freedom on the outer wing. So in addition to location and DOF information, the geometry table includes group identifications, such as inner wing, outer wing, aileron, pylon, and fuselage. The transformation between grids therefore is limited to boundaries defined by the airplane groups. The responsibility of generating geometry tables resides with the discipline which defines the grid.

--THE KEY TO COMMUNICATION BETWEEN DISCIPLINES--

AERODYNAMICS

STRUCTURES (MODELLING AND STRESS)

WEIGHT

STATIC LOADS

DYNAMIC LOADS

FLUTTER

Figure 12

Each engineering discipline will define the modeling requirements according to its functions and responsibilities. There will be no outside constraints except where more than one discipline will be affected.

There are practical limits to reducing the elapsed time required to generate and checkout a 3-D finite element model. Experience gained with the use of user coded programs which generate, correct, and manipulate computer files led to the engineering development and coding of computer programs for rapid generation of principal parts of the finite element model using relatively few input variables.

A finite element model generator (Figure 13) will be assembled from this technology. Data for the model generator will be defined to represent a specific family of aircraft designs which may be generated using relatively simple inputs. The collection of model generator programs and the input data required to represent a particular family of aircraft designs will be referred to as a structural model generator (SMG).

Wing geometric data for input to the finite element model generator will consist of certain key variables that define the wing planform together with a 3-D parametric representation of the wing section shapes. The section shape representation is available from the aerodynamics department and serves as the input data for ASSET. This arrangement will permit variations in aspect ratio, t/c, planform, taper, sweep, and dihedral with relatively simple inputs.

NASTRAN MODEL GENERATOR

Figure 13

There are two forms of finite element modeling: 1) that which is required for stress considerations, and 2) that which is required for structural flexibility/ stiffness considerations. The task here is to generate a finite element structural model computer data deck which will serve the objectives of both. Critical to the quick design concept as shown in Figure 14 is a structural model generator (SMG) which would generate a family of finite element models using relatively simple inputs. These inputs would primarily be a function of the airplane external geometry and generally not a function of model configuration arrangements.

The 3-D modeling of the structure begins with a "bones" drawing of critical geometric control points to be used in the programs which generate and assemble finite element program input decks. The 3-D description for the wing is derived from a data base which Aerodynamics generates as part of their aerodynamic configurations studies. Control surfaces, flaps, and the associated actuation systems are modeled as necessary. Leading and trailing edge surfaces are modeled for load carrying requirements and not stress sizing.

STRUCTURAL MODEL GENERATOR

--THE KEY TO QUICK DESIGN CONCEPT--

GENERATES A FAMILY OF 3-D FINITE ELEMENT STRUCTURAL MODELS USING RELATIVELY SIMPLE INPUTS

- AERODYNAMICS PARAMETRIC REPRESENTATION OF THE WING

- "BONES" DRAWING OF CRITICAL GEOMETRIC CONTROL POINTS

THE OBJECTIVE IS TO HAVE A STRUCTURAL MODEL GENERATOR FOR EACH CLASS OF AIRPLANES

- JET TRANSPORT/ASW AIRPLANE (AVAILABLE)

- PROP DRIVEN TRANSPORTATION/ASW AIRPLANE (NOT AVAILABLE)

- FIGHTER (DELTA PLANFORM) (NOT AVAILABLE)

Figure 14

STRUCTURAL FINITE ELEMENT MODEL DEFINITION

The finite element model consists of three parts: 1) the wing, which is a full 3-D model (Figure 15) with a medium degree of detail, inculding control surfaces, flaps, gears, and leading and trailing edge structure; 2) the fuselage over the wing box, which is a full 3-D barrel section; and 3) the forward fuselage, aft fuselage, and the empennage, which are modeled with beam elements. There are 3,741 degrees of freedom in the NASTRAN F-set, 228 degrees of freedom for the definition of the structural influence coefficients, and 161 for the A-set stiffness matrix. The wing contour data base was obtained from the aerodynamics representation used in drag and lift studies. The ribs were modeled one model rib to two airplane ribs.
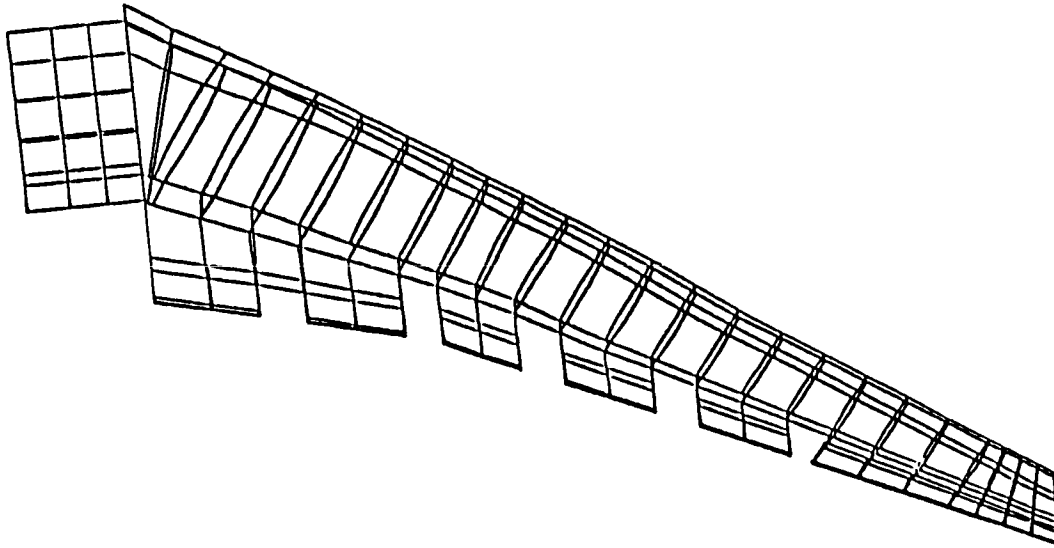

Figure 15

FINITE ELEMENT MODEL GENERATOR

Generation of NASTRAN bulk data decks for families of high aspect ratio wing designs, in order to modify model parameters such as thickness ratio, sweep angle, aspect ratio, taper ratio, or wing area, has been automated and integrated into PADS. From the relatively simple inputs, key planform coordinates and cross-section definition datasets are created. Figure 16 shows an example of the program interfaces in the NASTRAN model generator for a typical high aspect ratio wing airplane design.

REWING generates the initial datasets which contain geometric keypoints and airfoil definition for a desired planform layout. From the datasets produced by REWING, a program called WBONES defines locations/orientations, such as spar and aileron layout, locations for planar grid points, and initial identification numbering for the production of NASTRAN grid cards. SLICE provides the airfoil definition for the three-dimensional finite element model. Input to SLICE consists of airfoil definition in the streamwise direction as well as outputs from REWING and WBONES. SLICE interpolates from the input airfoil definition to obtain the airfoil definition for the desired cuts.

Additional grid locations and connectivity necessary for structural elements between the fuselage and wing are created by a program called QUILT. PROCARD outputs a deck of wing grid cards which is in final form.

Program SICTAB generates additional NASTRAN bulk data cards such as ASETS, LDREF, FORCE, MOMENT, LMAT, and some of the MPC cards.
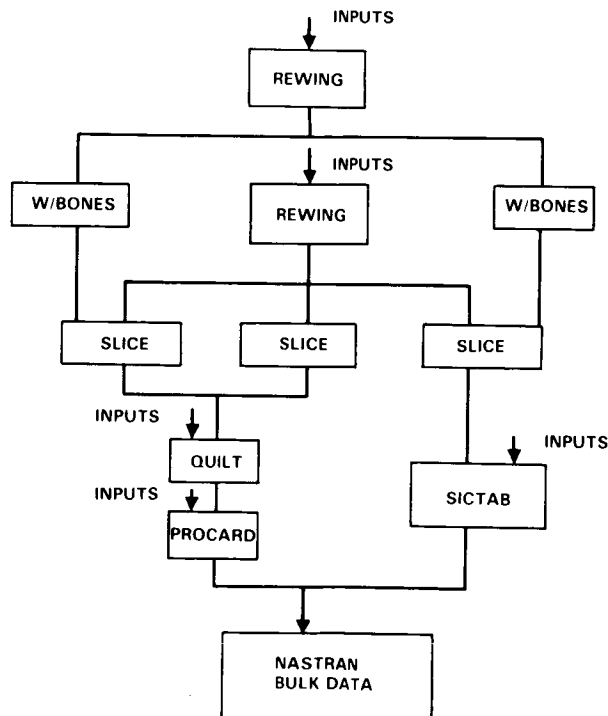
NASTRAN MODEL GENERATOR PROGRAM INTERFACE

Figure 16

PLANFORM DEFINITION

In the PADS system, the geometry of a wing is described by data files which contain the coordinates of the planform outline, the airfoil contour, and keypoints for major structural elements. With use of similarity transforms, the geometry description of new wings can be formed from existing wings. The layout of a new wing is defined by values of selected geometric parameters, such as aspect ratio, sweep, span, and thickness ratio. REWING creates the data files necessary for geometric description of wings. REWING allows creation of new planforms by variation of one or more geometric parameters.

Figure 17 displays creation of new planforms from existing planforms for subsonic and supersonic designs, respectively. The figure represents the creation of an aspect ratio 12 wing planform from an aspect ratio 7.64 wing planform. In this example, additional input to REWING included specifications to locate the 1/4 chord point of the MAC at the same fuselage location on the new planform as it was on the original. The location of this reference point is shown as an x for the original planform and as a + for the new planform. The figure shows a combined variation of sweep and taper angle for an arrow wing planform.
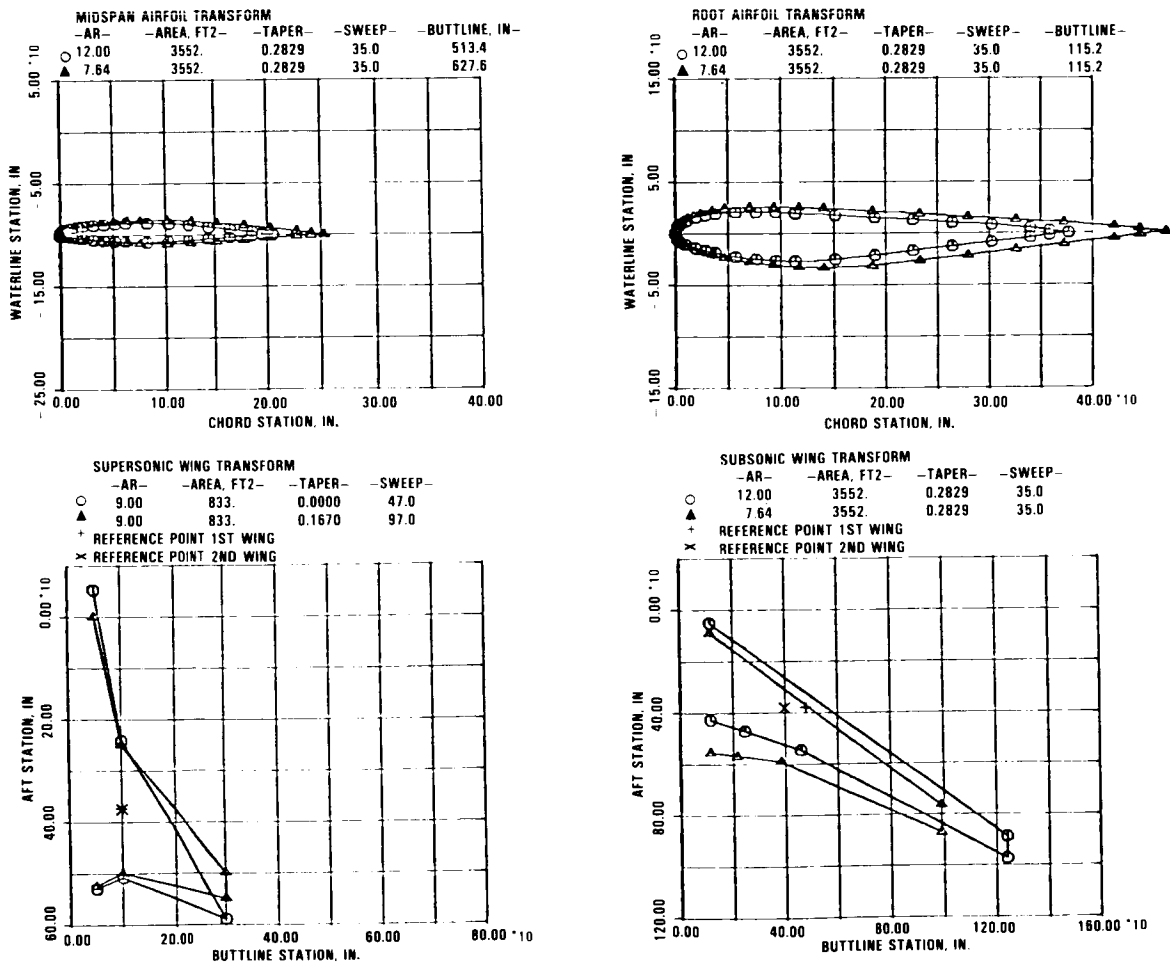

Figure 17

STRUCTURAL MODEL GENERATOR CAPABILITIES

A summary of the NASTRAN model generator capabilities is shown in Figure 18. The quick response capability is derived from a flow of data and program executions that represents a family of aircraft configurations.

- **REPOSITIONS THE WING DUE TO ASPECT RATIO, SWEEP, AND AREA CHANGES**

- **FORMS THE EXTERNAL GEOMETRY FROM PARAMETRIC WING GEOMETRY SUPPLIED BY AERODYNAMICS**

- **GENERATES COMPLETE NASTRAN BULK DATA DECK WITHIN 2 DAYS FOR ASPECT RATIO, SWEEP, AND AREA CHANGES**

Figure 18

The procedures described above were used in the formulation of a NASTRAN model for aspect ratio 12 wing. Figure 19 shows location of the wing and fuselage barrel section along with the stick model grid points for the fore and aft fuselage.
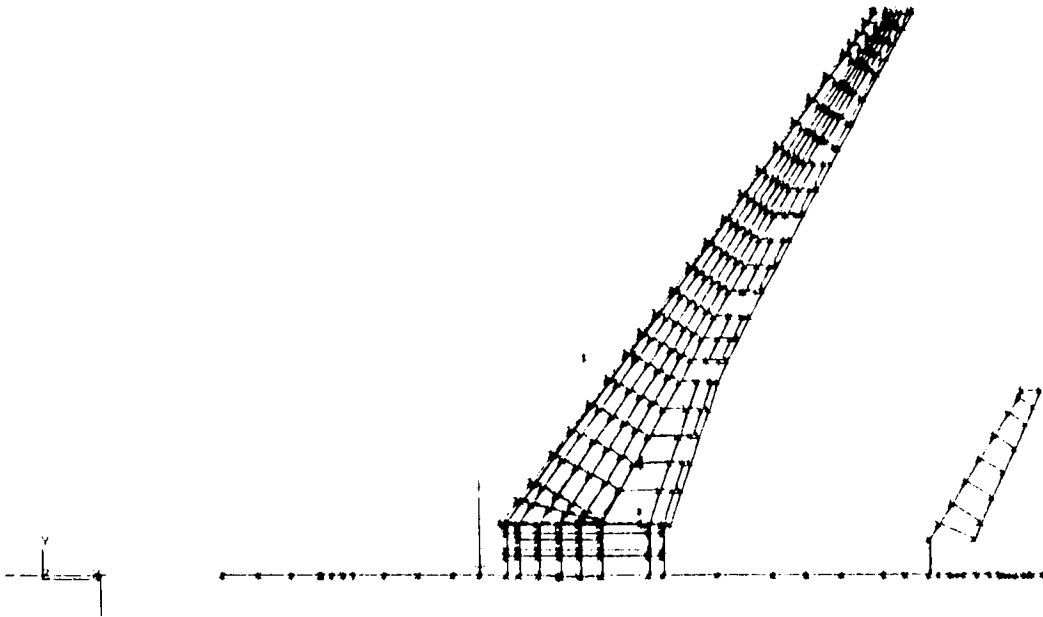
Figure 19

AR12 SWEEP 35 NASTRAN MODEL WITHOUT WING

Figure 20 shows the NASTRAN model without wing. Fuselage attachments are more clearly seen in this figure. Gear up/down attachment points exist on the fuselage as well as on the wing.
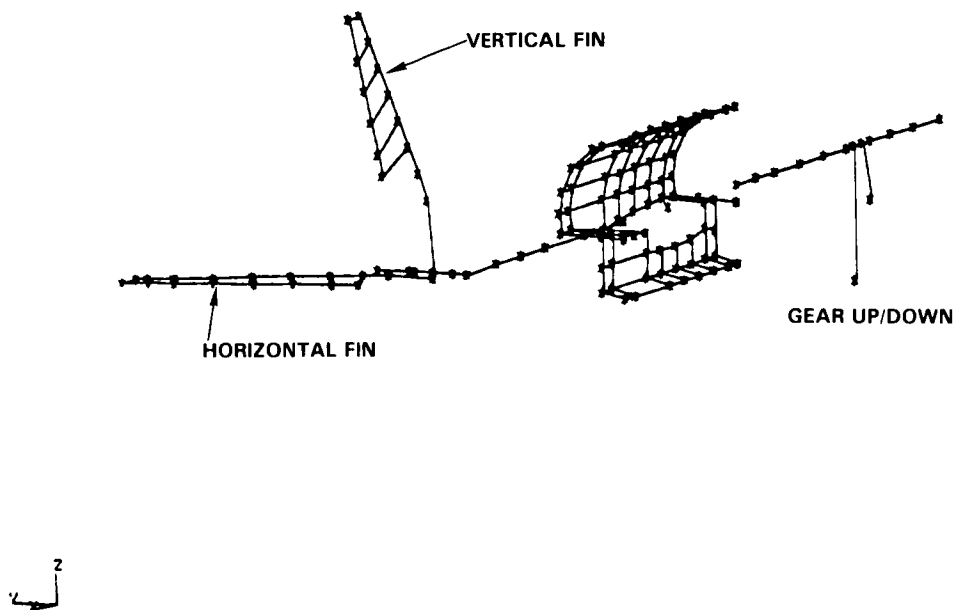

Figure 20

NASTRAN MODEL BARREL SECTION DETAIL

Figure 21 shows barrel section detail. The fuselage stick model and the barrel
section interfaces are defined by multipoint constraint equations. The wing carry-
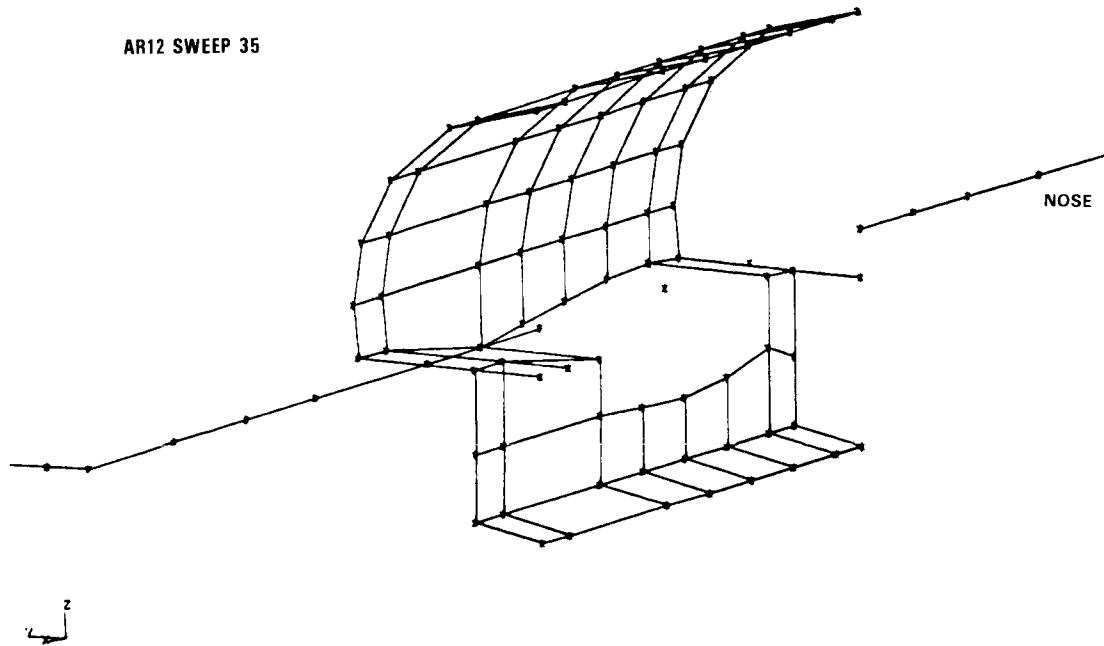through structure fits in the barrel section cavity.

Figure 21

GRID LOAD DISTRIBUTION

Complex aircraft such as the high aspect ratio wing design require a structural grid corresponding to a large number of degrees of freedom for the structural representation. Loads analyses, on the other hand, usually require a somewhat smaller grid. For this reason, application of external loads to a finite element model is normally performed through a load transformation process from a small to a large grid (Figure 22). In the PADS operation, the LDREF-LGROUP method is used. The LDREF cards contain load reference application information and the LGROUP cards contain information as to which grid points receive loads for a loaded reference point and how they are distributed. For changing planforms, the bulk data cards, for the LDREF-LGROUP method, are subject to change. For this reason, certain PADS modules were developed for purposes of automating the production of these cards.
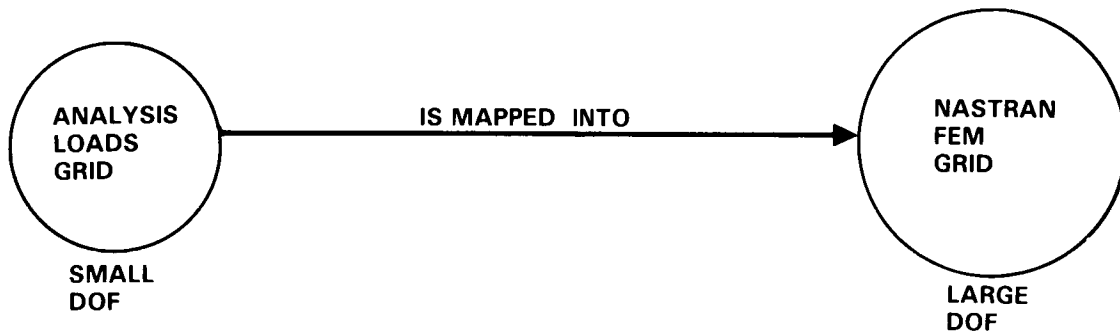
ANALYSIS LOADS GRID — IS MAPPED INTO → NASTRAN FEM GRID

SMALL DOF

LARGE DOF

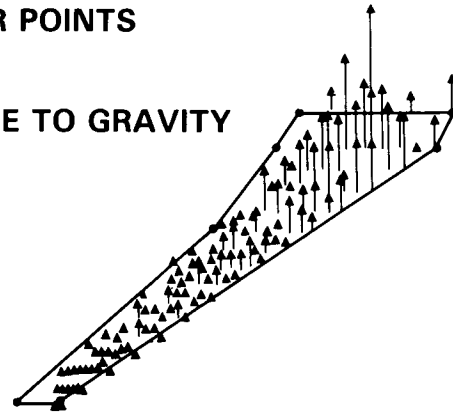Figure 22

FUEL TANK LOADING PROCEDURE

With capabilities for changing planform and airfoil definitions in an automated procedure, a requirement surfaced to quickly form fuel tank weight distributions for changed planforms in an automated manner. Issues to be addressed were 1) what will the new volume capacity be? 2) how can distributions for varying flight conditions be formed? 3) how can fuel tank weight distributions be entered into the model? A program called TANK was developed to automate computation of fuel tank loading distributions for preliminary design.

TANK receives inputs from other PADS modules as well as inputs defining desired flight orientations and fuel loadings, and constructs a lumped fuel distribution which reflects the flight configurations considered in the design. TANK computes definition of the tank boundaries from airfoil definition contained in the grid cards for the finite element model and corner point inputs. With tank boundaries known, the fuel tank total volume can be computed. Basic data input such as fuel density, attitude angles, and desired total fuel weight allow TANK to form elementary fuel boxes and distribute the fuel weight as lumped fuel masses to the finite element grid locations. Balance and center-of-gravity computation data, as well as the fuel distribution, are then supplied as output.

TANK, in the PADS environment, is called upon several times for aircraft with multiple tanks. Then, a postprocessor combines the various fuel tank weight distributions and performs a transformation to other desired grids. Typical plot output from the PADS fuel tank lumping procedure is shown in Figure 23.

An automated fuel tank weight distribution program was needed to complement the capabilities for quickly changing planform and airfoil contours.

- **FUEL VOLUME COMPUTED FROM FEM GEOMETRY DATA**
- **TANK BOUNDARIES DEFINED BY CORNER POINTS**
- **ACCEPTS LESS THAN FULL VOLUMES**
- **ACCEPTS TANK ORIENTATIONS RELATIVE TO GRAVITY**
- **BATCH ENTRY PROGRAM**

TYPICAL FUEL DISTRIBUTION

Figure 23

INTERLOP GUST PROGRAM

     INTERLOP (INTERnal LOad Procedure) computes the internal loads combinations directly in the gust analysis. This requires the input of all internal loads of interest due to all unit loads at each structural grid point separately. Figure 24 shows the various elements of INTERLOP.

     The advantages of the use of INTERLOP are substantial. Not only is the costly and time-consuming process of matching conditions avoided, but the internal vs. external loads matrix is used for other loads analyses besides gusts. Furthermore, since the internal loads are computed directly, no additional conservatisms need to be introduced, which is next to unavoidable if matching conditions are used.

     Two new computer programs are created for this purpose: a preprocessor and a modified gust analysis program. The preprocessor forms the input to the gust analysis program defining the flexibility and the inertia properties (weights and moments of inertia of concentrated masses.) The new gust analysis program is a modified version of a standard gust loads program. The modifications include accepting as input the aerodynamic influence coefficients (AIC) which are also used in the flutter analysis. (These include AIC's at several reduced frequencies.) The program is extended to compute the 8 corners of the octagons of equal probability, and includes the bias formed by the 1-g steady loads. The latter is obtained using the 1-g (external) structural grid point loads computed by STATICS. The dimensions of the octagon are determined by an input value, which is the predicted gust intensity factor in feet/second. This is based on the use of the design envelope approach rather than a mission profile analysis. The former, because of its simplicity, is considered to be more appropriate for a preliminary design effort, in particular because the missions may not yet be completely defined.
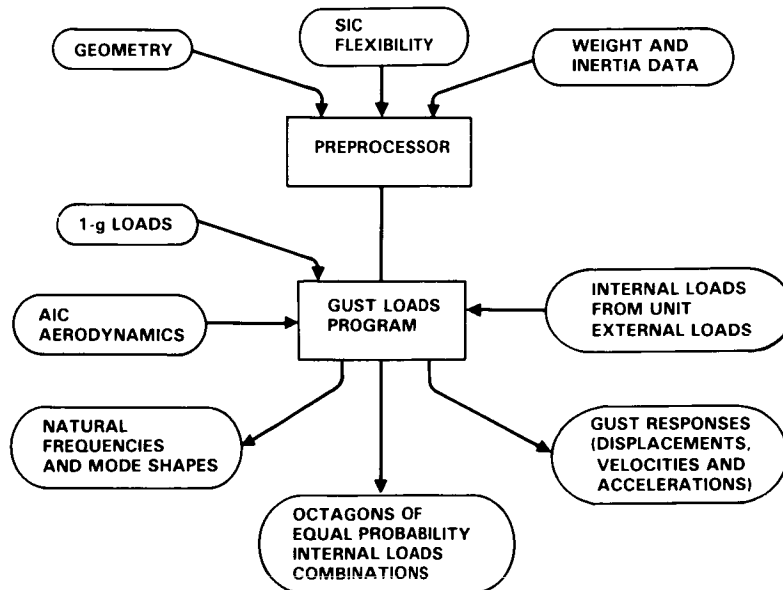
Figure 24

481

TYPICAL OCTAGONS OF EQUAL PROBABILITY – STRUCTURAL ELEMENT NO. 171 AND NO. 172
UPPER AND LOWER WING SURFACE

For a preliminary design, or in the absence of defined missions, the responses can be computed for a number of points of the design speed-altitude envelope, much in the same way that static gust analysis is done.

The design envelope contains the critical values of weight distribution, flight speed, and altitude. In this case the responses are found by multiplying the r.m.s. values of responses due to 1 ft/sec. gust by the gust intensity factor. This gust intensity factor is a function of altitude, comparable to specified gust velocities used in static analyses. In order to properly account for the phasing between the various responses, correlation coefficients between these responses are also computed. From these correlation coefficients and using the r.m.s. values of the responses, ellipses of equal probability of selected response combinations are formed. These are biased by the response due to 1-g steady flight for the pertinent design envelope point. In order to limit the number of conditions to be analyzed for stress, the ellipses are circumscribed by octagons. Thus each load combination results in 8 points of an octagon of equal probability.

Figure 25 shows a typical result of this new analysis approach. It consists of two equal probability ellipses and their circumscribing octagons. These are for one element of the upper wing surface and the corresponding element on the lower wing surface.
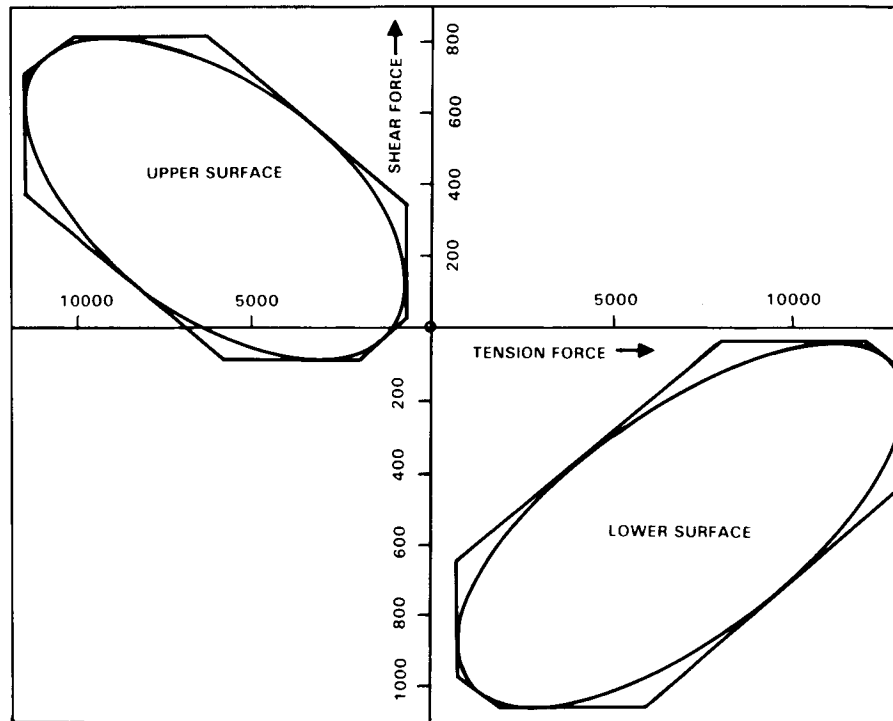

Figure 25

482

There were two requirements associated with structural sizing procedures (Figure 26) as applied to preliminary design: 1) the sizing must be based on project sizing procedures, and 2) the adoption of the production sizing procedures must accommodate the cost constraints of preliminary design.

A panel sizing and stress allowable process used internal load intensities from the finite element model to select the sizing necessary to satisfy strength, fatigue, and many other design criteria. This inhouse procedure is used to compute margins of safety for production designs. The process also makes use of a special data base to reduce the computer run times, an important factor in an iterative procedure. The data base is keyed to two configurations, namely Z-stringers for the upper surface and J-stringers for the lower surface. Materials for both configurations were 7075-T7651 plate for the skin and 7075-T6511 extrusion for the stringers.

The reference airplane production minimum margins of safety were taken from the stress reports. The grid in the stress report did not coincide with the panel layout. A linear interpolation was performed on the production margins of safety without regard to loading conditions compatibility. The margins of safety for the wing box, however, did not exist. The wing box margins of safety were therefore set to zero.

SIZING PROCEDURES

Figure 26

STRESS SIZING FUNCTION

Two tools are available at Lockheed to size structural elements based on strength criteria: the fully stressed design (FSD) program and the panel sizing and stress allowable (PSASA) program. Figure 27 shows the possible paths to structural sizing, 1) PSASA for stress allowables and FSD for sizing, and 2) PSASA for sizing.

PSASA generates the stress allowables and new sizings for use in the fully stressed design (FSD) program. PSASA is a complex array of programs which permit production level computations of stress interactions for a variety of conditions including panel buckling and several local buckling modes. If the design involves only panels, then sizing is possible using PSASA. PSASA is currently limited to combined uniaxial and shear loadings. However, PSASA does accept as input, margins of safety for each element being sized.

FSD requires a stress allowable for each element to be sized. The stress allowables remain constant within NASTRAN as the elements are sized to the internal loads. The internal loads are computed from the updated sizings and the external loads. Two to four iterations are necessary for the process to converge.
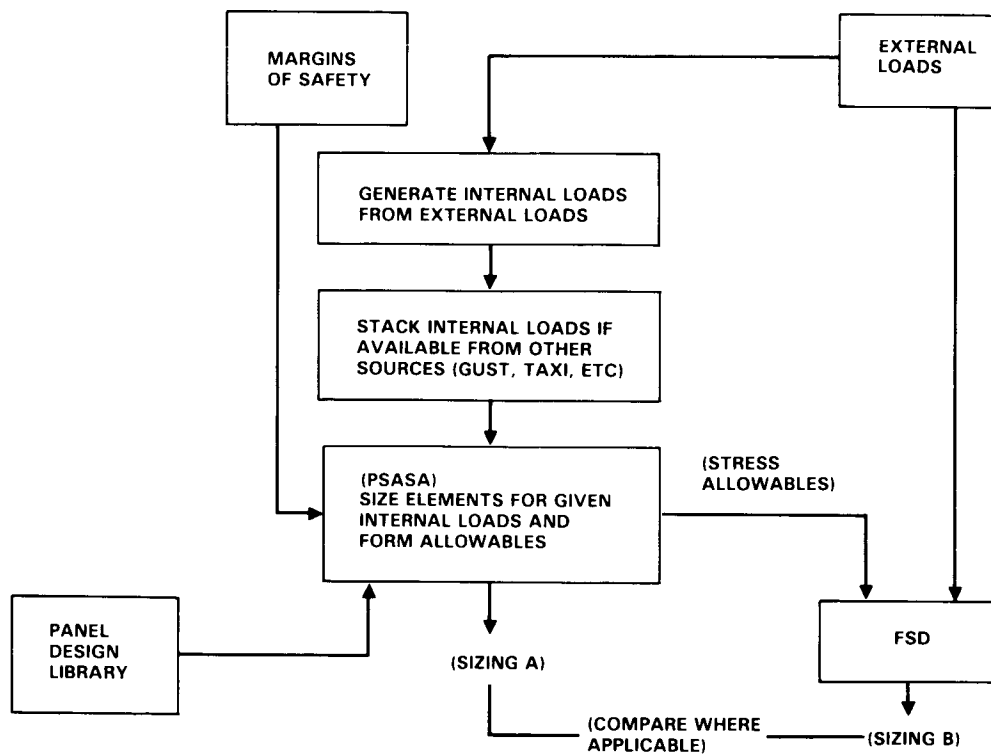
Figure 27

There are two phases to the process by which PADS is being evaluated: 1) the validation of CBUS operating system and the analysis programs, and 2) the validation of the design process for the objectives of preliminary design. Both phases require an existing production airplane design which has an extensive data base for weight, design loads, sizing, etc., for comparisons. These quantities are required not only for reasonableness checks but also to quantify the areas of design that may not be properly represented in the design process (Figure 28).

All major computing programs (FAMAS, NASTRAN, etc.) except the weight distribution program, the panel sizing and allowable program, the fully stressed design sizing program, and the program for structural resizing for flutter were used in the production design of the basic L-1011 and its derivatives.

The validation process reduces to the following tasks: 1) to verify that the existing computer programs and systems operate properly in the CBUS environment, 2) to verify that the many pre- and post-processor modules do what they were designed to do, 3) to verify that the CBUS data management systems properly function in their storing and retrieving modes, and 4) to generate comparative data for programs not extensively used.

The panel sizing and stress allowable procedure was checked against known allowable and sizing data for certain internal load conditions and the fully stressed design procedure was compared to the panel sizing procedure. The weight distribution program has internal checks for mass and moments of inertia quantities. The structural resizing for flutter programs also will contain internal checks in terms of reconciling the modules and sizing changes with the flutter results using the resized structural properties.

● CBUS

● NEW PROGRAMS

● DESIGN PROCESS

Figure 28

485

The airplane selected as a reference design is the L-1011-500 ACS. The airplane 3-view is shown in Figure 29. This configuration has a maximum gross weight of 504,000 pounds and a payload of 40,000 pounds at a range of 5200 nautical miles. The cruise Mach number is 0.83 and the cruise altitude is 37,000 feet. This version is a long-range derivative of the L-1011-1. Active control technology was used to minimize structural wing changes when the -500 wing span was extended to improve fuel economy. The maximum design zero fuel weight is 338,000 pounds. The typical operating empty weight is 252,000 pounds.
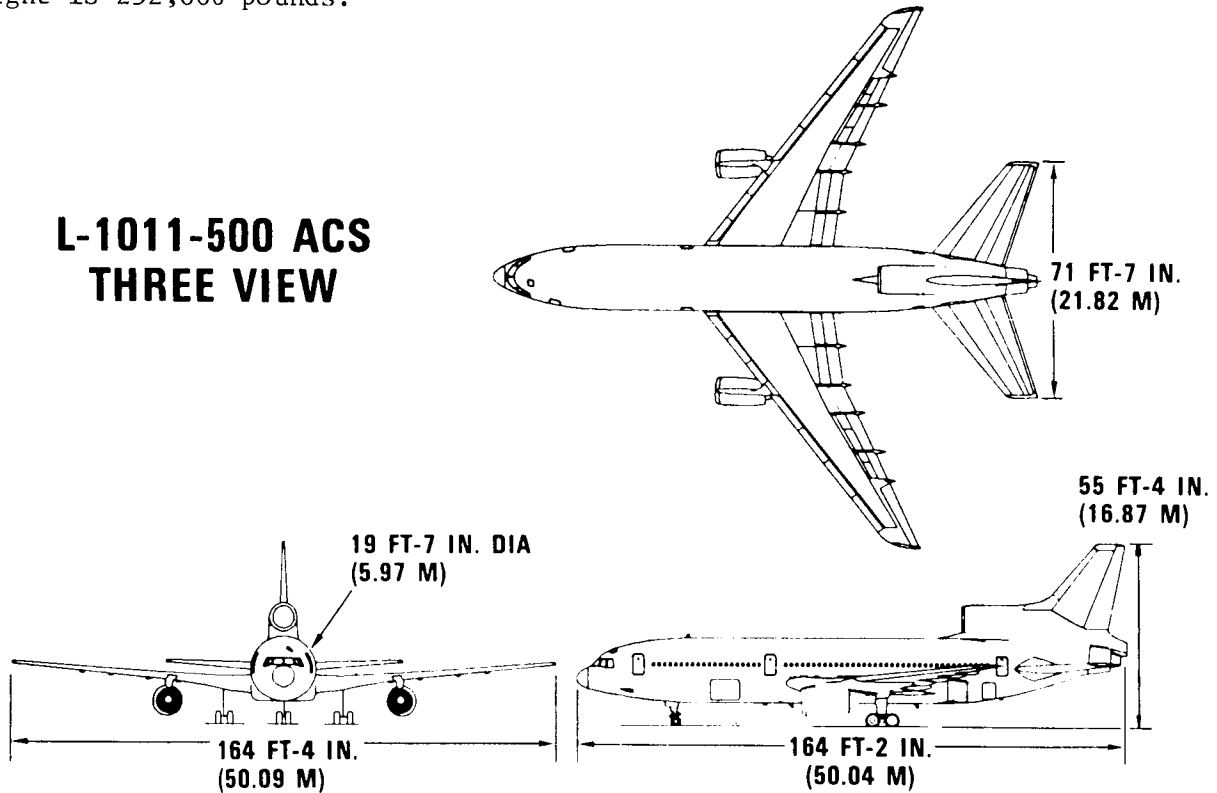
L-1011-500 ACS THREE VIEW

71 FT-7 IN.
(21.82 M)

55 FT-4 IN.
(16.87 M)

19 FT-7 IN. DIA
(5.97 M)

164 FT-4 IN.
(50.09 M)

164 FT-2 IN.
(50.04 M)

Figure 29

WING UPPER SURFACE PANELS

The NASTRAN structural representation had 3741 degrees of freedom (DOF). The load reference or SIC locations numbered 228. The weight distribution module generated 500 panel weights and the static loads grid was defined with 289 load points. Weight and maneuver conditions were chosen to be a basis for the baseline design (Figure 30).
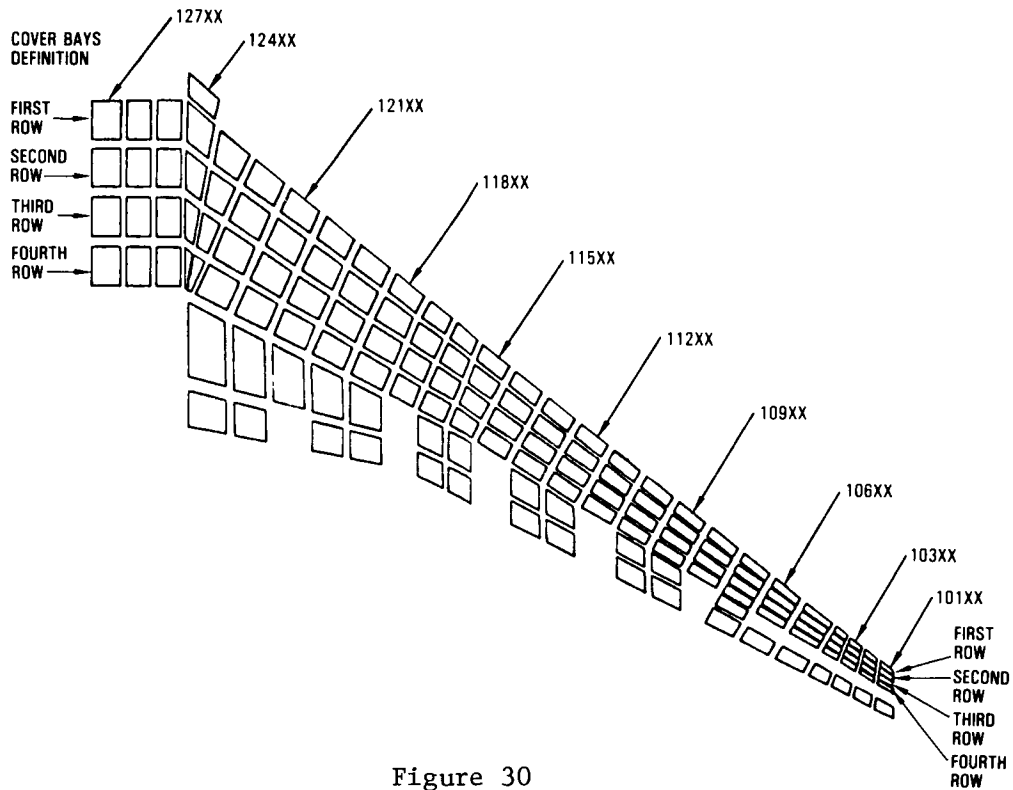

Figure 30

STATIC LOADS

Flight conditions were selected on the basis of a subset of the critical loads for the production airplane wing box. Both active controls on and active controls off conditions were used for symmetric manuevers. Ground handling (brake roll, etc.), and a pseudo taxi condition were also included. The airplane was trimmed for each flight condition, thereby producing net balanced airplane loads. The 25 load conditions are listed in Figure 31.

LOAD COND.	A	B	C	D	E	F	G	H
FLIGHT COND. NO.	1101	1102	1103	1104	1105	LANDING	TAXI	BRAKE ROLL
WEIGHT – 1000 LB	350.3	504.0	504.0	504.0	504.0	368.0	506.0	506.0
C.G. – % MAC	12.5	17.13	17.13	17.13	17.13	26.9	14.1	26.9
FLIGHT COND.	MID-CRUISE	VA	VC	VD	FLAP	–	–	–
MACH NO.	0.8	.48	.82	.88	.33	.28	–	–
VE – KEAS	360.0	316.0	356.0	418.0	220.0	182.0	–	–
ALTITUDE–1000 FT.	20.0	0.0	21.3	17.3	0.0	0	–	–

MANEUVER CONDITION	ACTIVE CONTROL (MLC)	LOAD CONDITION
1G LEVEL FLIGHT – (BASIC)	ON	A
POSITIVE STEADY MANEUVER – (PSM)	ON	A THRU E
NEGATIVE STEADY MANEUVER – (NSM)	ON	A THRU E
POSITIVE STEADY MANEUVER – (PSM)	OFF	A THRU E
NEGATIVE STEADY MANEUVER – (NSM)	OFF	A THRU E
LANDING	ON	F
LANDING	OFF	F
TAXI	–	G
BRAKE ROLL	–	H

Figure 31

SUMMARY OF NUMERICAL RESULTS FOR VALIDATION DESIGN

There are many design details which can not practically be included in a preliminary design effort. However, if these details add significantly to weight and strength, then some accountability must be made in the design process. One objective of this numerical exercise is to quantify some of the detail design effects in terms of two approximate processes. The first process, model design factors, will account for model sizing increases required to accommodate design details which currently do not have any design criteria. Two PADS sizings will be presented in the study of the model design factors: 1) structure sized to zero margins of safety, and 2) structure sized to production margins of safety. The second process, model to hardware weight adjustments, will account for the differences between model weight derived from a finite element model representation of structural components and hardware weight derived from actual weighing of structural components.

Another objective of the design exercise is the evaluation of FSD in conjunction with the panel sizing (PSASA) program, which also produces stress allowables. Finally, the results of each engineering process will be checked for accuracy using the data base available for the reference airplane, namely the L-1011-500 ACS which is described in the validation section. The reference airplane has an active control system for maneuver load control (MLC). As part of exercising the PADS system, a wing panel sizing will be performed on the reference airplane with and without MLC for zero margins of safety. The results of the numerical study are summarized in Figure 32.

PADS SIZINGS: NORMALIZED SURFACE WEIGHTS

	ZERO MARGINS			PRODUCTION MARGINS		
	UPPER SURFACE	LOWER SURFACE	BOTH SURFACES	UPPER SURFACE	LOWER SURFACE	BOTH SURFACES
REFERENCE AIRPLANE				1	1	1
PSASA SIZING W/MLC	.83	.764	.792	.89	.88	.89
FSD SIZING W/MLC	.845	.781	.808	–	–	–
PSASA SIZING W/O MLC	.89	.85	.868	–	–	–

WEIGHT FACTORS: HARDWARE WEIGHT/PRODUCTION MODEL WEIGHT = 1.2

Figure 32

LOAD CONDITIONS YIELDING MINIMAL MARGINS OF SAFETY FOR STATIC
AND DYNAMIC LOADS FOR REFERENCE AIRPLANE

New methodology development during 1983 made possible structural sizing for continuous turbulence in preliminary design. With techniques for computing panel octagons of equal probability for responses due to gust, static and dynamic loading conditions could be combined for purposes of determining aircraft sizing. In 1983, a sizing validation exercise, using combined gust and static loads, was performed on the PADS baseline design.

The design regions include the 1st through 4th rows of surface panels for both upper and lower surfaces. These panels were represented by a CALAC developed quadrilateral finite element (CMEMQ) in the structural model. Internal loads for the wing were computed in a NASTRAN static solution run. The Panel Sizing and Stress Allowable (PSASA) module was used for sizing of the surface panels. Optimized dimensions in PSASA are skin thickness, stringer web thickness, stringer flange thickness, and stringer height.

The loads applied to the structure for sizing include 21 static loads maneuver conditions, 4 ground handling conditions, and the 8 loads of equal probability which make up the octagons for the gust loads. Figure 33 shows the load conditions which have the minimal margin of safety for each panel for upper and lower surfaces. The margin of safety is the ratio of internal load which the panel can withstand over the applied internal load for an external load condition. Normally, this value is an input margin for the design. In cases when fail safe or fatigue conditions are imposed, the minimal margin may be somewhat greater. Gust conditions were found to be the designing factor for sections near the root rib and wing tip for both upper and lower surfaces. These areas are marked with Gs. Braking conditions determined the sizing around the main gear. Wing mid-section panels were designed by a 2.5g maneuver and these panels are indentified by the symbol x.
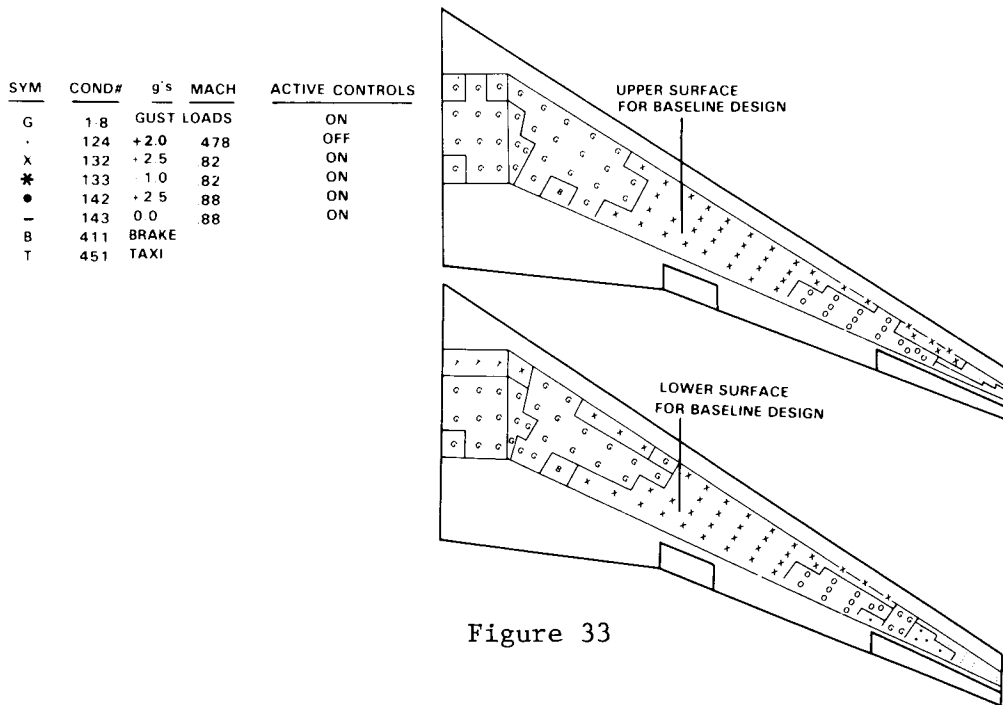
SYM	COND#	g's	MACH	ACTIVE CONTROLS
G	1-8	GUST LOADS		ON
.	124	+2.0	478	OFF
x	132	+2.5	82	ON
*	133	-1.0	82	ON
●	142	+2.5	88	ON
—	143	0.0	88	ON
B	411	BRAKE		
T	451	TAXI		

Figure 33

HIGH ASPECT RATIO WING DESIGN

A major portion of the work in 1982 dealt with the validation of the PADS modules by exercising them and making comparisons against a known database (baseline design). This exercise proved to be very fruitful for proposes of tuning the PADS system. In 1983 the PADS system was used to formulate an aeroelastic model of an aspect ratio 12 wing design (AR12) (Figure 34). With the incorporation of the new capabilities for the finite element generation, the grid load distribution scheme, and the fuel tank loading procedures, PADS built the necessary database and processed the high aspect ratio design through sizing for various MLC gains on the outboard aileron.

ASPECT RATIO 12

SWEEP 35°

(NO GUST OR FLUTTER EFFECTS)

Figure 34

AR12 MIDDLE 1/3 SECTION OF WING INTERNAL LOADS

The sizing procedure for the AR12 incorporated the methodology for computing the design element internal loads for applied unit external loads at the load reference points. The initial internal loads were formed for an arbitrary unit sizing. Internal loads due to the constructed 25 load conditions were formed by multiplying the load condition matrix and the internal load matrix for unit external loads. Figure 35 shows the intensity of the internal loads for the panels in the middle 1/3 section of the wingspan. Each square represents a combined normal (N) and shear (Q) internal load (lb/in) formed by one of the 25 load conditions in the middle 1/3 section of the wing.

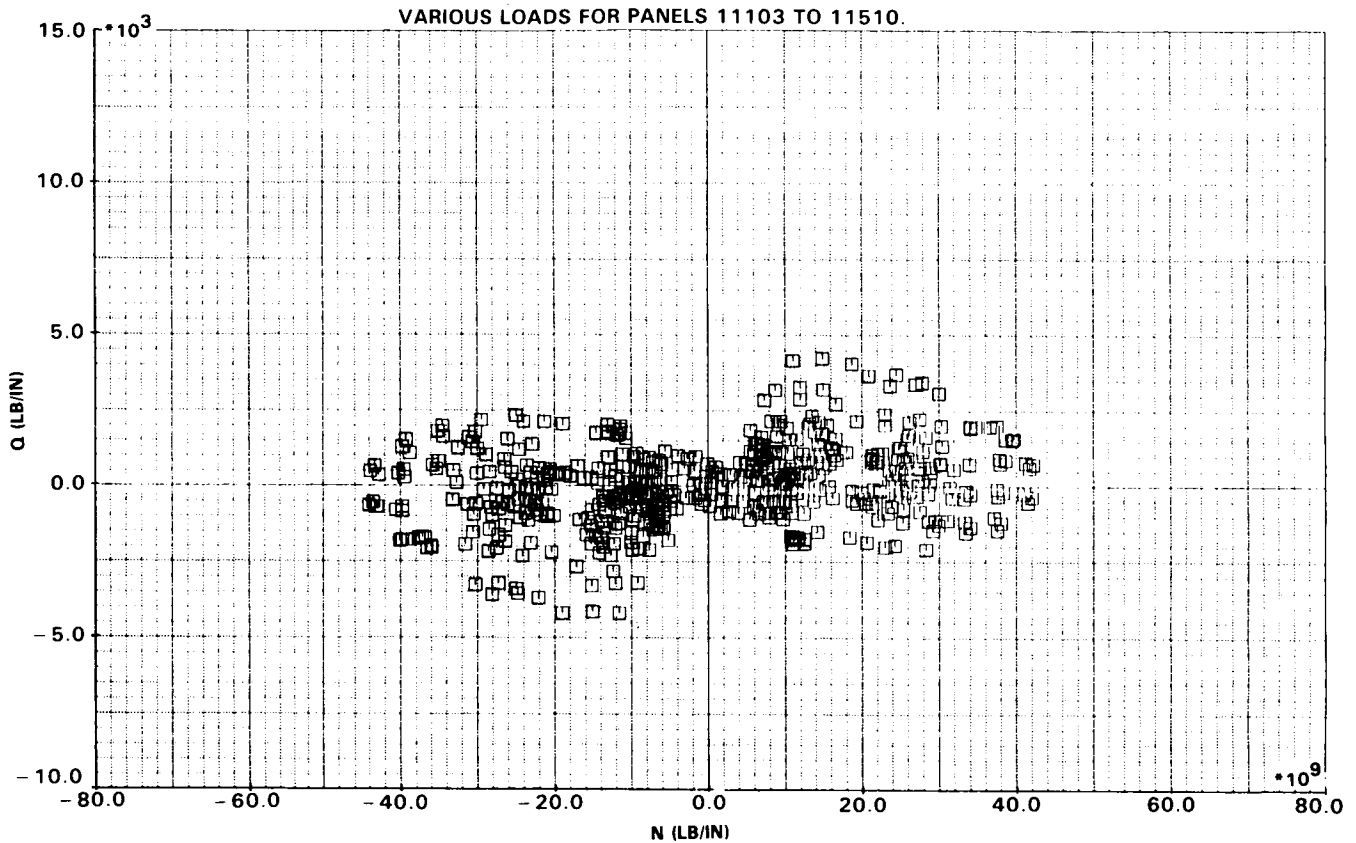VARIOUS LOADS FOR PANELS 11103 TO 11510.

Figure 35

AR12 SWEEP 35 SIZING UPPER SURFACE 3RD FROM FRONT ROW
COMPARISON OF WEIGHT

Sizing for the internal loads was accomplished with the sized panel database approach for selection of optimal panel dimensions. The database approach consists of forming a database which contains families of optimized panels for various loading combinations. Each of the panel definitions in the database has a weight per unit area associated with it. From the database, the sizing routine selects two panels as a starting point for optimization of each panel in the design region of the airplane. The first panel is the lightest panel in the database which is sufficient to withstand all applied loads for that panel and the second is the next lightest panel in the database. These two panels are used to set the bounds on panel dimensions in the sizing procedure. The final optimized panel for each element in the design region is then computed. Variables for optimization are skin thickness, stringer web thickness, stringer flange thickness, and stringer overall height.

Figure 36 shows a comparison of the weight per unit area for upper surface panels in the third bay for rigid, first flex and second flex A/P loads.
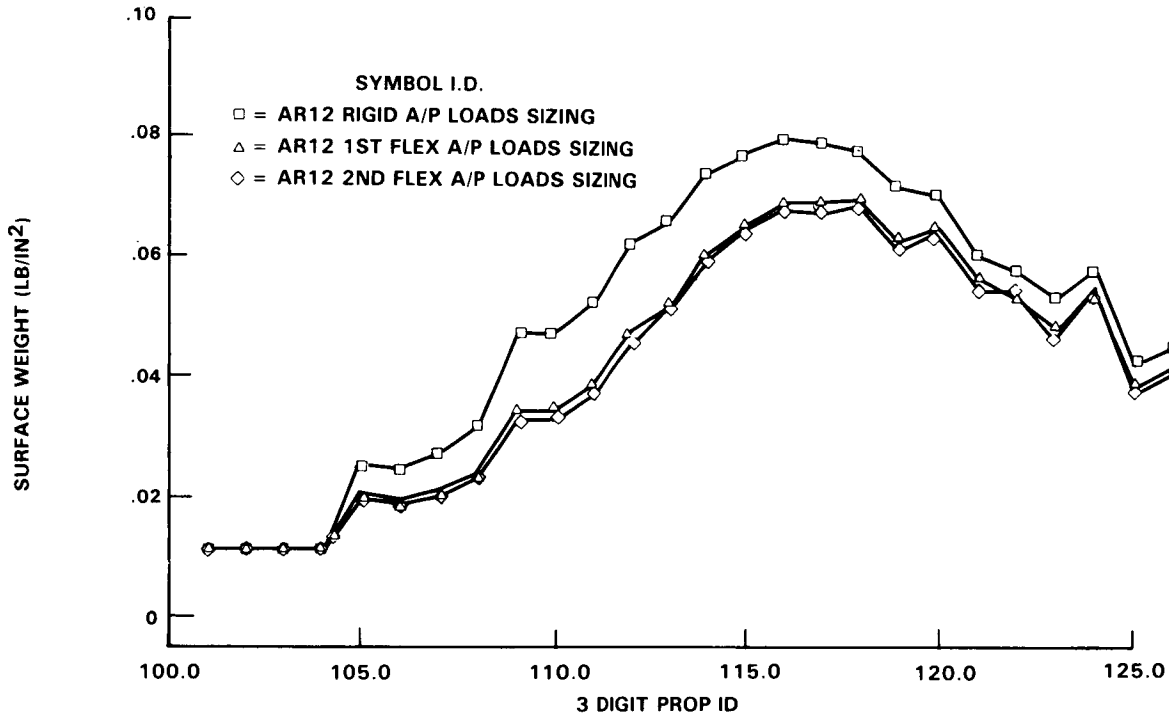

Figure 36

493

AR12 SWEEP 35 SIZING LOWER SURFACE 3RD FROM FRONT ROW
COMPARISON OF WEIGHT

Figure 37 shows the lower surface. The 3-Digit Prop ID refers to the panel station on the wing. The layout of the panels is the same for both models with Figure 35 showing the baseline surface panel numbering convention. The first 3 digits of the numbers along the 1st row represent the 3 Digit Prop ID.

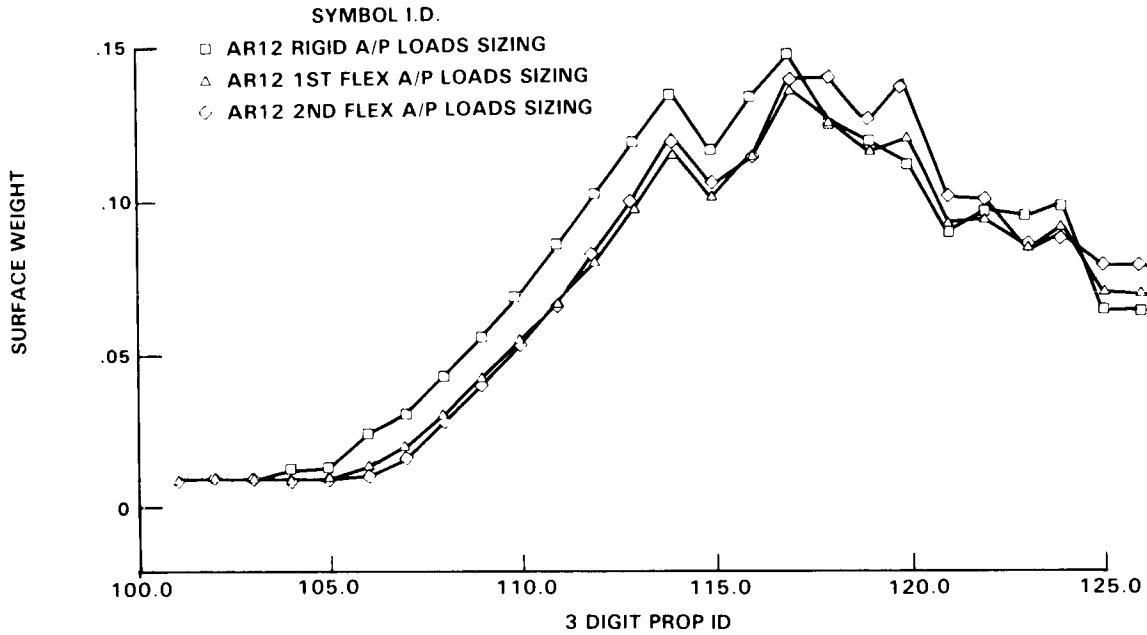ID 100 refers to panels on the wing tip while ID 125 refers to panels on the wing box.

Figure 37

STRUCTURAL SIZING ITERATIONS

Wing cover weights vs. number of structural sizing iterations is shown in Figure 38 for both upper and lower surfaces. This rapid convergence on wing cover weights has been the norm for both the baseline and the high aspect ratio designs.
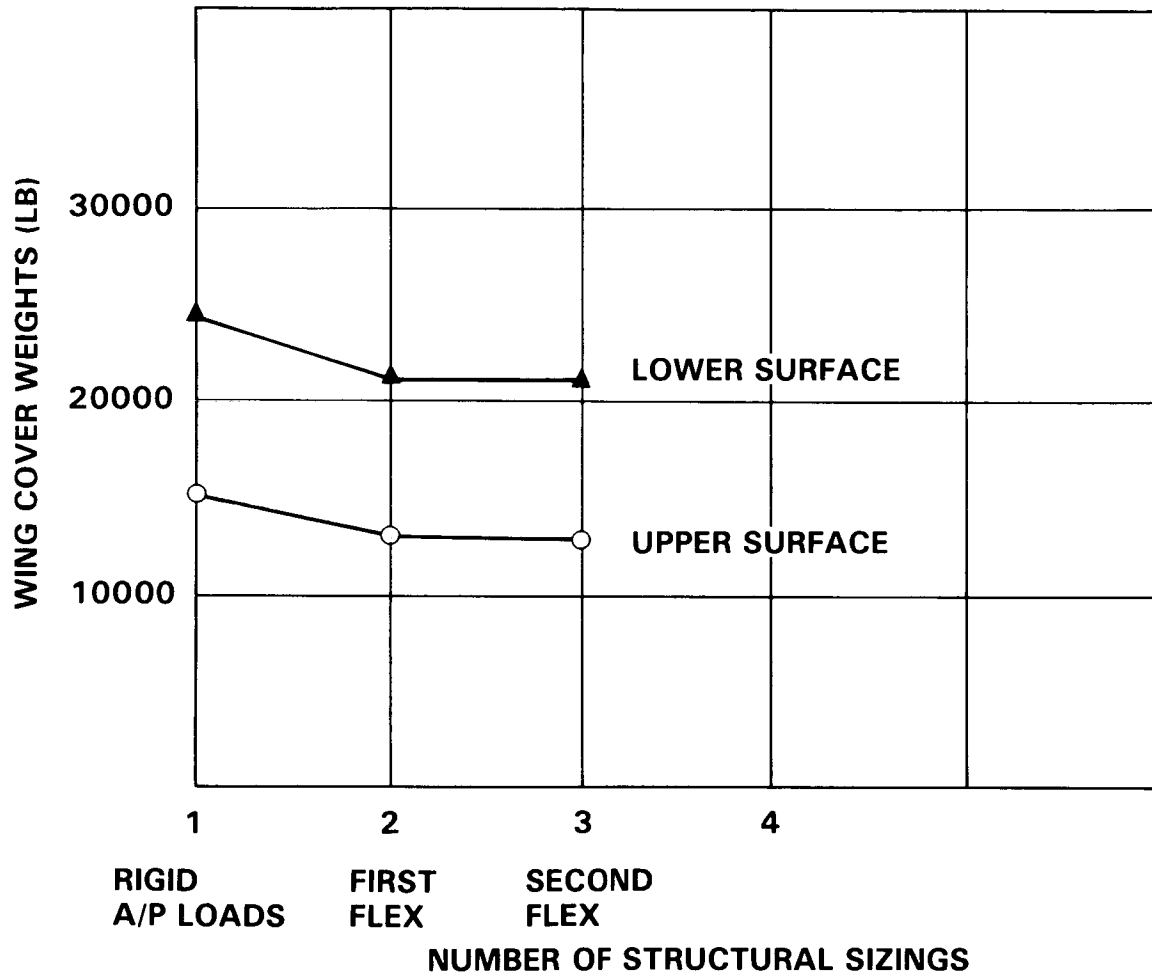
Figure 38

NET LOADS CASE 132 (X) 2ND FLEX A/P LOADS

Distribution for net loads, case 132 (X), are shown on Figure 39.

Load case 132 condition is defined by the following: GW/524354, CG/17.3, M/.82,
V/356 KEAS, ALT/21300 ft., G/2.5, ACT/ON, FLAPS/0°. This case and the case shown in
Figure 40 contribute to the design shown in Figure 41. The case shown in Figure 39
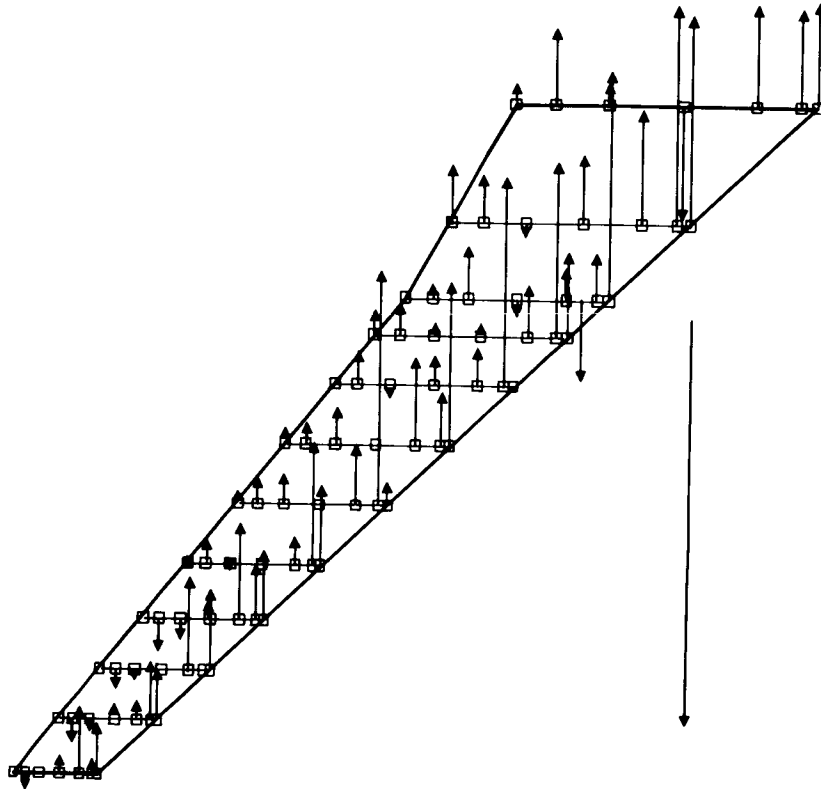designs the upper and lower surface panels represented by (X) in Figure 41.

Figure 39

NET LOADS CASE 124 (+) 2ND FLEX A/P LOADS

Distribution for net loads, case 124 (+), are shown in Figure 40. Load case 124 condition is defined by the following: GW/524354, CG/17.3, M/.478, V/316 KEAS, ALT/O FT, G/25, FLAPS/0°. This case designs the upper and lower surface panels represented by (+) in Figure 41.
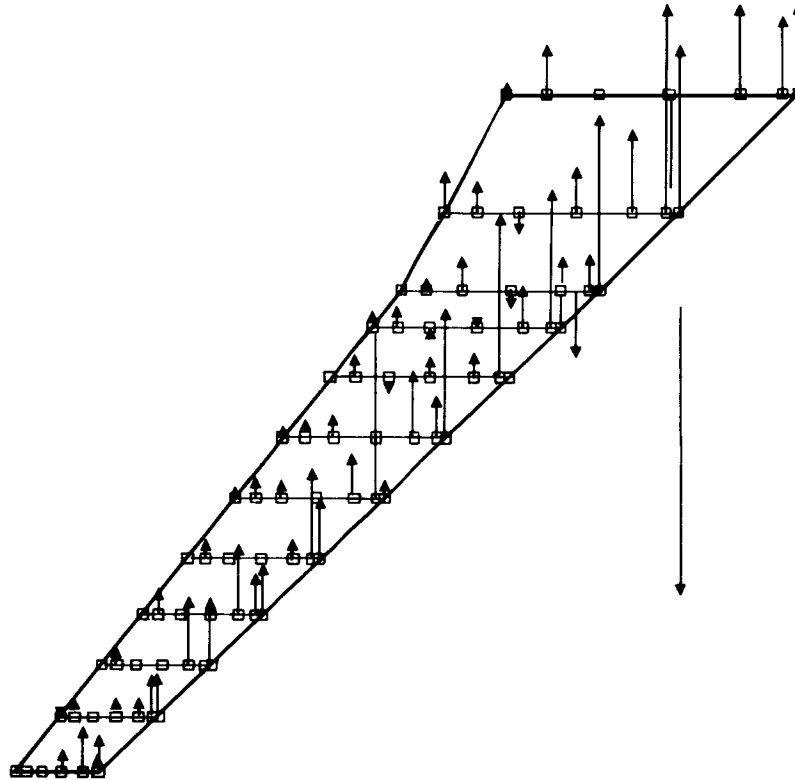
Figure 40

LOAD CONDITIONS YIELDING MINIMUM MARGINS ON UPPER SURFACE
PANELS AR12 SWEEP 35 2ND FLEX SIZING

Load cases which yield the minimal margin of safety after considerations in the optimization process for effects such as fatigue and fail safe conditions are shown in Figure 41. Each symbol corresponds to a load condition in the key. The symbol defines the load condition yielding the minimal margin for the corresponding panel.
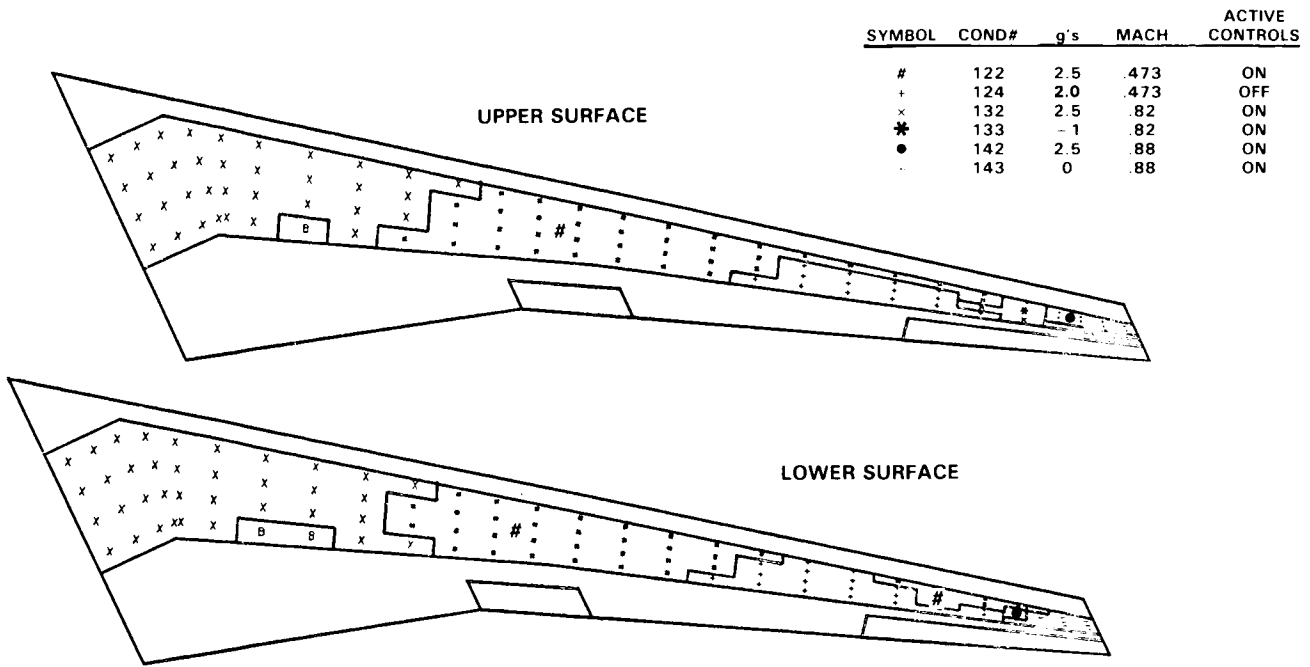
SYMBOL	COND#	g's	MACH	ACTIVE CONTROLS
#	122	2.5	.473	ON
+	124	2.0	.473	OFF
×	132	2.5	.82	ON
*	133	- 1	.82	ON
●	142	2.5	.88	ON
.	143	0	.88	ON

UPPER SURFACE

LOWER SURFACE

Figure 41

498

COVER WEIGHTS FOR DIFFERENT MLC AILERON GAINS

Different aileron-degree-per-g gains were used to generate the wing cover weights and indicate that a bucket exists for a gain of 20 degrees/g. If 20 degrees/g were selected, then the area around the aileron would have to be increased by almost a factor of 2 to reduce the gain around the 10 degrees/g. Eighty-six percent of the weight reduction takes place within 50 percent of the optimum gain factor (Figure 42). These results were produced for fixed spar web sizings.
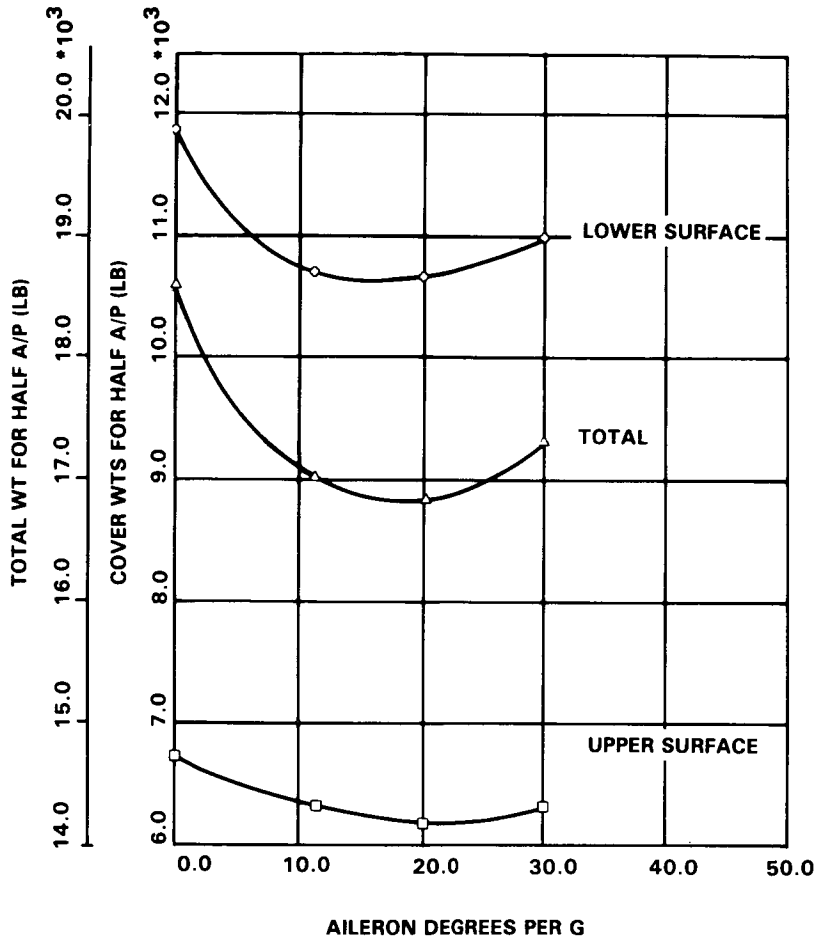

Figure 42

WING WEIGHT PERCENT REDUCTION VS. LIMIT MANEUVER FACTOR

For an MLC gain of 11.33 degrees per g on the outboard aileron, wing weight percent reductions were computed for designs with and without MLC and for changing the limit maneuver load factor from 2.5 to 2.0 g's (Figure 43). The MLC increment is the percentage reduction of wing weight when MLC is added to the wing cover design. The maneuver limit increment is the percentage reduction of wing weight when the maneuver limit factor is reduced from 2.5 g to 2.0 g. Both columns are additive. For the AR12 SWEEP 35 design, the wing weight would be 16.8% less for a design incorporating both MLC and 2.0 g maneuver limit load factor than for a design with a maneuver limit factor of 2.5 g and no MLC.

AIRCRAFT	MLC INCREMENT	MANEUVER LIMIT = 2 G INCREMENT FROM 2.5 G
REFERENCE AIRCRAFT AR 7.63 SWEEP 35	4.5	
AR12 SWEEP 35	5.1	11.7

Figure 43

PADS DESIGN ACTIVITY IN PROCESS

This Lockheed inhouse work is being coordinated with the NASA Langley Research Center multilevel design research activity under a cooperative effort to design an aircraft wing for fuel efficiency. The primary objective of this effort is to study and evaluate the multilevel and the PADS/ASSET approaches to aircraft wing design. Lockheed is providing a common design data base for this effort to NASA under the contract NAS1-16794. The contract technical monitor is Dr. J. Sobieski. The first phase of this study is projected for completion in December 1984 (Figure 44).

- **ASPECT RATIO 12 SWEEP 35**

  - **VERTICAL GUST LOADS**

  - **FLUTTER**

- **ASPECT RATIO 12 SWEEP 25**

  - **MANEUVER, BRAKE, LANDING LOADS**

  - **VERTICAL GUST LOADS**

  - **FLUTTER**

Figure 44

501

SUMMARY AND CONCLUSIONS

The following observations are provided as a summary review in support of the conclusions (Figure 45):

CBUS Operating System

- An operating system has been defined and coded which provides the user with a continuous computing option without interfering with the standalone function of any participating program or system.

- The concept of a command has been developed as a driver for the data flow control and program execution requirements of an engineering process.

- The concept of altercards provides data paths into the command to change default attributes and/or to invoke other options.

- A command processor language has been developed which provides logical branching capabilities but leaves the naming of the commands/macros to the user.

- The concept of a supercommand provides the grouping of commands and other supercommands and includes all the command processor language capabilities.

Data Management System

- All existing data management systems are available to provide retrieval and storage of permanent data blocks and communication with these systems is achieved by means of commands and subcommands.

- An internal data management system has been defined which supports the retrieval and storage of data by simple qualifiers so as to retain the simple functionality of a command.

Design and Engineering Processes

- An aeroelastic design process has been defined in terms of production design computing tools and without violating the conceptual and early preliminary design phase elapsed time constraints.

- The design process has been modularized into specific engineering processes that closely followed the production design definitions.

- The concept of a finite element model generator for a family of aircraft structures has been formulated to satisfy the elapsed time constraints.

Validation Using a Known Design Data Base

- The model to hardware weight ratios showed greater than expected variations with span.

- The engineering processes defined as the panel sizing and stress allowable generator, fully stressed design, weight, static loads, gust loads, and flutter were exercised and checked using a known aircraft design data base.

- The PADS wing panel sizing of a reference airplane design produced panel model weights that were 21 percent below the reference airplane values for zero structural margins of safety. The difference was reduced to 11 percent when production structural margins were used in sizing the panels.

SUMMARY AND CONCLUSIONS (Continued)

High Aspect Ratio Wing Designs

- Aspect ratio 12, sweep 35 design is almost complete.
- Aspect ratio 12, sweep 25 design has been started.

  - **ACQUIRED A RAPID AEROELASTIC ANALYSIS AND DESIGN CAPABILITY**

  - **DEMONSTRATED PADS CONCEPT OF USING EXISTING COMPUTER TOOLS TO GENERATE AEROELASTIC DESIGNS**

  - **SATISFIED REQUIREMENTS OF FLEXIBILITY AND MODULARITY WITH CBUS**

  - **VALIDATED CBUS OPERATION AND RUN DATA BASE MANAGEMENT SYSTEM**

  - **VALIDATED SOME OF THE ENGINEERING PROCESSES; NOT COMPLETED**

  - **DEMONSTRATED THE NEED FOR ADEQUATE DESIGN VISIBILITY AND CONTROL**

Figure 45

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Radovcich, N.A., "Preliminary Design of Structures [PADS], Methods Development and Application," AGARD paper, Conference Proceedings No. 354, presented at the 56th Structures and Materials Panel Meeting, London, United Kingdom, April 1983.