THE ATLAS INTEGRATED STRUCTURAL ANALYSIS AND DESIGN SOFTWARE SYSTEM

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SUMMARY

The ATLAS System provides an extensive set of integrated technical computer-program modules for the analysis and design of general structural configurations, as well as capabilities that are particularly suited for the aeroelastic design of flight vehicles. ATLAS is intended for use in a production environment in the aerospace industry, and therefore it provides many user-oriented features and much flexibility of use to meet a wide variety of applications. The system is based on the stiffness formulation of the finite element structural analysis method and can be executed in batch and interactive computing environments on the Control Data Corporation (CDC) 6600/CYBER computers. Problem-definition input data are written in an engineering-oriented language using a free field format. Input-data default values, generation options, and data quality checks provided by the preprocessors minimize the amount of data and flowtime for problem definition/verification. Postprocessors allow selected input and calculated data to be extracted, manipulated, and displayed via on-line and off-line prints or plots for monitoring and verifying problem solutions. The sequence and mode of execution of selected program modules are controlled by a common user-oriented language. The modules can be used to perform a variety of single and multidisciplined structural analysis and design tasks in both large and small problem environments. The system is organized to facilitate maintenance and new developments. A data base and data manager are used for automatic communication of data between program modules and for execution of selected modules with interfaced external programs. Utility user interfaces are provided for interactive execution control, data-file editing, and graphical display of selected data.

INTRODUCTION

Development of ATLAS was initiated by The Boeing Commercial Airplane Company in 1969, and was used initially in 1971 for performing preliminary design studies of the National Supersonic Transport. Continued development efforts have resulted in the release and application of a number of extended versions of the ATLAS System. Parts of the efforts were conducted under the NASA Langley contract NAS1-12911 during the period of 1974-1978 and the Army contract DAAG46-75-C-0072 during 1975.

Use of ATLAS in a number of specific airplane design situations is described in references 1-5 in terms of the problem complexity, the results obtained, cost, and the benefits provided through using ATLAS. These applications involved stress, loads, flutter, weights, and aerodynamic technical disciplines. The automated strength resizing of an arrow-wing supersonic cruise aircraft (ref. 2) with approximately 20 000 design variables demonstrated the practicality of using ATLAS during the preliminary design process. The use of ATLAS to perform a stress analysis of a large sports stadium (3400 nodes, 9600 elements, 20 000 freedoms, 70 million words of storage) and a detailed three-dimensional stress analysis of a gas turbine engine blade (3200 nodes, 350 solid elements, 9500 freedoms, 15 million words of storage) is described in references 5 and 6, respectively, in terms of problem definition, solution approach, data management, and cost. A practical substructured stress analysis of a 747 airplane model (8628 nodes, 13 751 elements, 13 substructures, 218 load cases) was recently performed, with the results correlating well with previous analyses, to demonstrate further the large-problem-solving capabilities of ATLAS. Methods to automate the strength/stiffness (flutter) aeroelastic design process for metallic and composite structural components (refs. 3 and 4) have been implemented in ATLAS during its continued development and application. The system has provided capabilities for thorough and cost-effective evaluation of new airplane designs and advanced structures.

This paper presents an overview of the technical capabilities and the functional organization of version 4 of ATLAS which has been in production use on Boeing projects since March 1977, and has been installed at the NASA Langley Research Center. Particular emphasis is given to the design of the user interfaces, and the current and future system developments are previewed. Further detailed documentation of the system is given in reference 7 which describes the input data and program execution, the program design and data management, the engineering methods, and a number of demonstration problems.

ATLAS TECHNICAL CAPABILITIES

The many technical analytical capabilities of ATLAS can be grouped as (1) linear stress analysis, (2) bifurcation buckling analysis, (3) weights analysis, (4) vibration analysis, (5) flutter analysis, (6) substructured analyses, and (7) structural design. The basis of these computations is the stiffness method of finite element analysis. Within the scope of ATLAS development activities, high priority has been placed on the technological disciplines that contribute directly to the evaluation of strength and stiffness (flutter) characteristics of flight structures.

Each of the foregoing general capabilities can be either combined or further subdivided depending on the type of problem being solved, the selected method of analysis, and the desired end results. The various analytical steps required for solving different types of problems are performed by executing a user-selected set of computational modules (preprocessors, processors, and postprocessors) in a particular sequence. The ATLAS computational capabilities are grouped by modules, each of which is related to a particular engineering discipline. The ATLAS modules and their functions are summarized in table 1.

The ATLAS structural element library includes an axial ROD and BEAM with offsets and linear cross section variations, an elastic-support SCALAR element, triangular and quadrilateral membrane PLATE and membrane/bending GPLATE elements with offsets and orthotropic features, a family of BRICK (3-dimensional) elements with up to three optional nodes per edge and orthotropic features, triangular and quadrilateral CPLATE elements with offsets for composite laminates, and built-up SPAR, COVER and CCOVER elements. A SPAR is comprised of a shear web, linearly tapered upper and lower caps with axial stiffness, and two rigid posts at either end of the web. COVER and CCOVER elements are comprised of two PLATE and CPLATE elements, respectively, each of which is separated by rigid posts between the corresponding corner nodes. SPAR elements are used typically to model ribs and spars, whereas the COVER and CCOVER elements are used to model the structural surfaces of box beam constructions and wing-like configurations for aerospace vehicles.

Unsteady aerodynamic loads for performing automated flutter solutions can be based on the following: (1) strip-theory method for subsonic incompressible flow, (2) assumed-pressure function and doublet-lattice methods for subsonic compressible flow, (3) the Mach-box method for supersonic flow, and (4) structural-flexibility effects associated with the truncated vibration modes.

General features of ATLAS, in addition to those described in table 1, include the following: (1) a free-field input data format, (2) many data default values, (3) common data-generation options for all data types, (4) multiple coordinate systems for node geometry definition and structural response, (5) user-selected data printout, and (6) data management and graphics utilities. The multilevel substructuring capability for stress, mass, and vibration analyses provides automatic management of the substructure interact data for any number of interact levels.

Automated interfaces of execution and problem data between ATLAS and a number of computer programs that are external to ATLAS have been established. These capabilities include an interface of ATLAS structural and mass data with FLEXSTAB (ref. 8) for performing aeroelastic and elastic stability analyses, an interface of FLEXSTAB steady-state loads with ATLAS for performing stress analysis and structural-design functions, and input data interfaces between ATLAS and NASTRAN®.

SYSTEM FUNCTIONAL ORGANIZATION

The design of ATLAS has been based primarily on the convenient user-selection of system functions for performing either single or multidisciplined structural analysis/design tasks in a timely, thorough, and cost-effective manner. Continued emphasis has been directed toward the development of a system that

- Provides a common executive module for convenient and versatile user-controlled technical-analysis flow and control of design cycles

- Provides a common data base that eliminates duplicate input-data preparation and centralizes the control of design data

- Provides data-management algorithms for convenient interfacing of the computational modules with external computer programs

- Uses data preprocessing and data generation codes to minimize the amount of input data and the time required for data preparation and debugging

- Uses automated structural-sizing algorithms to minimize the amount of hand-sizing of structural members, particularly during preliminary design studies

- Provides advanced engineering methodologies equally useful for performing design tasks in a small or large problem environment

- Provides data postprocessing codes to extract, manipulate, and display (print/plot) selected data for monitoring analysis/design activities

- Provides interactive capabilities for editing data files, for executing selected system modules, and for generating on-line and off-line graphical displays

- Provides an open-ended, low-cost admission of new program codes

The architecture developed for ATLAS is a modular system of overlaid program codes with common executive and data-base management components as illustrated in figure 1. Each module performs a well-defined engineering, mathematical, or clerical task. This modular design supports the foregoing system attributes and allows for effective development and maintenance activities. Additionally, through centralized management of the program modules, the reliability of the aggregate code is increased.

User interfaces with ATLAS are defined via the problem-definition data deck and the executive control deck. The problem deck contains the data defining the mathematical model of the physical problem to be analyzed, whereas the control deck defines the analysis functions to be performed.

Generally, the only limitations on problem size are those imposed by practical considerations of job-execution time and by the ultimate capacity of the auxiliary storage devices of the computer installation. Computational procedures have been designed particularly to provide reasonable efficiency for solution of large problems. Sparse matrix solution techniques and automatic out-of-core processing are used for increased cost effectiveness.

The characteristics of the primary components of the ATLAS System will be described in the following order: (1) executive modules, (2) computational modules, and (3) the data base management capabilities. Then, a description of the user interfaces with the entire system are presented.

EXECUTIVE MODULES

The executive modules and their basic functions, as they support analysis control and data communication, are as follows:

Precompilers — Translate the user-oriented ATLAS language execution directives, as defined via the control deck, into equivalent FORTRAN statements. The resulting FORTRAN code is compiled at execution time to create an ATLAS Control Program Module.

Control Program — Control the execution sequence of selected computational modules and set run-time execution parameters. Each control statement included in a control deck and each interactive control directive initiate one or more execution steps in the analysis of the problem defined by the data deck.

Interactive Executive — Interpret module-execution control directives, as input via a terminal keyboard during interactive processing, and perform interactive text editing of data files.

ATLAS (0,0) Overlay — Monitor the execution of all computational modules per instructions from the Control Program.

Execution of ATLAS can be performed in a batch, interactive, or mixed computing environment. The user has complete command of the type and method of analysis and the problem-execution steps to be performed by ATLAS. These functions are defined either by the executive control deck or by terminal keyboard input during interactive processing. Execution directives are used to define the sequence of computations, the execution (run-time) parameters, the management of analysis results (e.g., print, plot), the scheduled restart of problem execution, and the contingencies when data errors are encountered.

The control deck can also be used to perform special analytical computations that are not provided directly by the ATLAS program, manipulate ATLAS data, and manage data for interfacing modules (sub-programs) of the ATLAS System with external computer programs. FORTRAN and SNARK (ref. 9) code can be intermixed with ATLAS statements to create a control deck which may include subroutines and overlays.

COMPUTATIONAL MODULES

The three types of ATLAS computational modules and their basic functions are as follows:

Preprocessors — Read, decode and interrogate the problem-definition data deck; generate data based on a minimal number of input parameters; load problem-execution restart data to resume processing.

Processors — Perform technical numerical computations.

Postprocessors — Extract, format and display (print/plot) input data and analysis results; save problem-execution restart data for processing by a subsequent job.

Each module is referenced by a different name. Generally, there are a preprocessor and a print postprocessor associated with each technical processor. The preprocessor reads and interprets the set of input data corresponding to that particular technology, whereas the postprocessor generates user-selected formatted printout of the input and calculated data corresponding to that technology. Table 1 contains a summary of all computational modules and their technical functions.

A technical processor performs a task that is related to a particular engineering theory or discipline. The STIFFNESS Processor, for example, contains the code that represents the finite-element structural theory used in ATLAS. This module computes the stiffness and stress matrices for the finite elements used to define the structural model.

Certain processors are utility in nature in that they are used to perform general-purpose, normally out-of-core, mathematical operations. Examples of such operations include assembling of the elemental stiffness, mass, loads and displacement matrices by the MERGE Module, the solution of sets of linear symmetric equations by the CHOLESKY Module, and the matrix additions and multiplications effected by the MULTIPLY Module.

Certain preprocessors and postprocessors are also utility in nature in that they can be used to perform operations for multidisciplinary tasks. These modules are shown separately in figure 1. Examples of such operations are the identification of node and element subsets for structural and mass models performed by the SUBSET-DEFINITION Preprocessor for selected print/plot displays and subsequent data processing or the generation of on-line and off-line plots of selected input and calculated data effected by the GRAPHICS Postprocessor.

DATA BASE MANAGEMENT

Automatic transmission of data from one module to another is accomplished primarily by the use of named, random-access disk files. All input data interrogated by the preprocessors are stored in one file, whereas the data generated by a processor are stored in a separate file that is reserved for that module. Any of the data stored in the data base, however, can be accessed by any computational module. The data file and data matrix names are predefined in the codes with options provided for user-naming of certain utility matrices, thereby providing greater versatility of data management, particularly during large-problem solving. Additionally, checkpoint-restart procedures are provided for convenient, stepwise problem executions.

The SNARK package (ref. 9), which is an integral component of ATLAS, is used by the ATLAS modules to transfer data matrices directly from/to the data files to/from data arrays in central memory. Zero matrix elements are suppressed when a matrix is written to disk. SNARK is also used by the ATLAS modules to manage the blank-common core (the primary, dynamic work area) during the computational processes. The library routines for management of data matrices and blank common, and the user-oriented language for performing matrix and scalar mathematics as provided by the SNARK package, can be used to create a Control Program. These functions allow convenient access and manipulation of ATLAS data via a Control Program to perform special, user-defined computations, or to interface data with computer programs that are external to ATLAS.

USER INTERFACES

The engineer communicates with ATLAS via the problem deck and the control deck (see fig. 1). These decks can be established either in a card deck form or in a disk file. User-defined comments, which do not affect any of the processing activities, may be embedded in the decks for identification conveniences.

Execution of an ATLAS job can be performed in an interactive mode, a batch mode, or in a mixed mode. Generally, small problems are handled most conveniently by interactive processing of the entire job. Large problems are solved typically by performing selected preprocessing and postprocessing activities in an interactive mode, whereas the remaining computational tasks are performed in the batch mode. Criteria used to select job processing modes are schedules, budget, and the allowable on-line computer central memory.

Generally, only ATLAS language statements are needed to create a Control Program. The statement "READ INPUT", for example, is used to read a data deck, whereas execution of a stress analysis can be initiated by a "PERFORM STRESS" statement. Module execution options (e.g. identify load cases or specify convergence criteria) can be selected via a parameter list included in the control statement. Catalogs of control statement procedures can be referenced directly for performing a number of typical structural analyses.

Activities that can be performed interactively during execution of ATLAS include (1) define, interrogate, and/or edit data and control files via user-oriented text-editor requests, (2) execute selected modules to perform computations and to manage data, and (3) create and manipulate plots of selected data. A module control command can be executed immediately after it is input via the terminal, or multiple commands can be entered and stored to create a procedure. Execution of a command procedure is processed either without any terminal interruption or with execution control returned to the terminal user after processing each command.

When ATLAS is executed using a Tektronix 4000-series graphics terminal, the ATLAS graphics conversational mode can be initiated between any job execution steps to create graphical displays of selected design data. The engineer conducts an interactive dialogue by using a function menu, two plot directories, and a plot transformation menu. Figure 2 illustrates the function menu, as well as example GNAME and plot ID directories. The GNAME directory contains a list of the user-specified plot group names, whereas a list of plot identifiers for a certain GNAME is contained in a plot ID directory. A particular plot is displayed on-line by proper selection of a

GNAME entry followed by the appropriate selection from the plot ID directory. New displays of a selected plot can be created by the transformation menu.

A summary of the plot types that can be created by ATLAS is presented in table 2. Various plot-type options, including exploded-model views, viewing positions, scales, annotation, and superimposed "before and after" deformed model plots, can be requested at execution time. Selected plots viewed on the console screen can also be directed to any of the following off-line plot devices: Gerber, CalComp, COMp80, and the PDP-11/Vector-General minicomputer systems.

During execution, ATLAS attempts to trap all possible anomalies. When an ambiguity in the data is detected that can be resolved without user interaction, a warning message is issued and the job execution proceeds uninterrupted. However, when a system error occurs, or when a fatal inconsistency is detected either in the data or in the user-selected execution logic, an error message is issued. In this case, only the execution directives included in an "ERROR PROCEDURE" within the Control Program are processed prior to terminating the job. Example error conditions are when loads are specified for inactive freedoms or when quadrilateral plates have reentrant corners or excessive warpage.

Many solution-accuracy checks are performed automatically or are provided as execution options. In all cases, the results of the checks are identified in the output. Examples of these types of checks include (1) any singularities and the number of significant digits lost during decomposition of coefficient matrices of the finite element equilibrium equations, (2) load-reaction equilibrium, (3) overall weight and c.g. of the model, and (4) equilibrium and orthogonality of vibration and general buckling solutions.

CURRENT AND FUTURE DEVELOPMENTS

Extended ATLAS capabilities developed by Boeing that are scheduled for near-term release for general use include the following:

- Control program procedures for analysis of structures wherein large displacements (geometry modifications), large strains (geometric stiffness effects), and/or nonlinear materials are pertinent

- Multipoint kinematic constraints defined generally by nonhomogeneous equations

- ATLAS-interfaced finite elements
  —Isoparametric membrane plates with up to three user-specified edge nodes; using the quarter-point singularity options, the residual strength of complex damaged structure can be investigated
  —An isoparametric laminated plate with coupled membrane/bending behavior for analysis of composite structure, particularly interlaminar shear

- Oscillatory aerodynamic effects from steady lift and drag forces on flutter characteristics

- User specification of select vibration modes for parametric flutter studies

- Flutter optimization procedures to modify a flutter-prone structure with a minimum weight penalty

- Conversational input of problem data and module execution directives for select types of analyses

- New plot types for more convenient interpretation of stress data and aerodynamic data

- Interactive graphics query of the ATLAS data base using the current ATLAS dictionary of data components and a relational algebra data model to print and plot user-selected design data

Longer term plans include the use of minicomputers as terminals to the large computer for performing ATLAS analyses (ref. 10) and the integration of capabilities into ATLAS for synthesis of flight-control and propulsion/airframe systems, aero-acoustic structural response, design of detailed structural components, and durability/damage tolerant analyses.

Centralized controlled procedures have been used for development and integration of new analytical capabilities and system concepts, for program version control and for system documentation. Based on periodic reviews of the technical requirements, an extended version of the system is developed and is subjected to exhaustive qualitative and quantitative modular and system-level checkout tests prior to its release for general use. In concert with continued system developments, it is necessary that the following factors be acknowledged: management acceptance, engineering acceptance, control and management of program changes and growth, as well as performance/cost characteristics.

CONCLUDING REMARKS

The ATLAS integrated software system has provided for cost-effective analysis and design of structures in a production environment. Its use in the earliest stages of the interdisciplined aeroelastic design process has resulted in a thorough understanding of complex structural behavior for a variety of applications. Efficient computer processing and user-oriented features have reduced the cost and flowtime for solving large and small problems involving single or multidisciplined design tasks. Continued developments and wider applications have helped define the requirements for extending the ATLAS analytical capabilities and user interfaces toward a complete, unified computer-aided-design system for performing more detailed and timely aerospace vehicle structural designs.

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TABLE 1.- ATLAS PREPROCESSORS, PROCESSORS AND POSTPROCESSORS

MODULE NAME	PREPROCESSOR	PROCESSOR	POSTPROCESSOR	TECHNICAL FUNCTION
ADDINT		●	●	Add and/or interpolate with respect to reduced frequencies those generalized airforce matrices generated by AF1, DUBLAT, FLEXAIR, MACHBOX, RHO3, or by previous execution of ADDINT
AF1	●	●	●	Define aerodynamic model; Calculate subsonic, incompressible-flow aerodynamic loads for FLUTTER; Strip theory method
BC (BOUNDARY CONDITION)	●		●	Define boundary conditions for structural model
BUCKLING		●	●	Calculate bifurcation buckling loads and mode shapes
CHOLESKY		●		Solve systems of linear symmetric equations
DESIGN	●	●	●	Define structural resize data; Perform regional optimization of composite structures; Resize structural models based on a fully-stressed design, thermal and local-buckling effects, and geometric and margin-of-safety constraints
DETAIL	●			Define finite-element cross-section shapes for thermal gradients and stiffener locations for plate-element local buckling
DUBLAT	●	●	●	Define aerodynamic model; Calculate subsonic compressible-flow aerodynamic loads for FLUTTER; Doublet-lattice method
EXTRACT			●	Extract selected problem-definition and analysis data from the primary ATLAS data-base for GRAPHICS
FLEXAIR		●	●	Calculate generalized airforce matrices that include flexibility effects of truncated structural modes
FLUTTER	●	●	●	Define structural damping; Modify and solve the flutter equations
FREEBODY			●	Print internal nodal forces acting on selected finite elements
GEOMETRY	●			Define, generate, and interrogate three-dimensional geometry components for structural and mass models
GRAPHICS			●	Generate online and offline plots of data selected via EXTRACT; Batch and interactive-graphics modes of execution
INTERACT	●		●	Define substructure interaction problem
INTERPOLATION		●		Define mode-shape interpolation functions for AF1, DUBLAT, FLEXAIR, MACHBOX and RHO3
LOAD	●			Load previously-generated problem data from SAVE to restart execution
LOADS	●	●	●	Define static loads; Calculate nodal loads due to inertial forces, pressure gradients, and thermal gradients; Cumulate static loads and specified displacements
MACHBOX	●	●	●	Define aerodynamic model; Calculate supersonic-flow aerodynamic loads for FLUTTER; Mach Box method
MASS	●	●	●	Define mass model that may complement STIFFNESS; Define fuel and payload management data; Generate mass matrices and detailed weight statements for primary and secondary structure, fuel, and payload
MATERIAL	●		●	Define finite-element material property data and design-allowable stresses for STIFFNESS, STRESS, MASS, and DESIGN
MERGE		●		Assemble stiffness, mass, loads, and displacement matrices
MULTIPLY		●		Add and multiply matrices
NODAL	●		●	Define local coordinate systems and nodal data for STIFFNESS and MASS models
PRINT			●	Print system-generated matrices
REACTION			●	Print reaction forces and load-reaction equilibrium checks for structural model
RHO3	●	●	●	Define aerodynamic model; Calculate subsonic compressible-flow aerodynamic loads for FLUTTER; Assumed pressure modes method
SAVE			●	Save problem data for execution checkpoint; Use LOAD to restart execution
STIFFNESS	●	●	●	Define structural model; Generate elastic-stiffness, geometric-stiffness, and stress matrices for elements
STRESS	●	●	●	Assemble nodal displacements; Calculate element stresses and internal nodal forces; Superimpose displacements and stresses
SUBSET DEFINITION	●			Define subsets of nodes and elements in STIFFNESS and MASS models for subsequent processing; Define subsets of data-component labels for EXTRACT
VIBRATION		●	●	Calculate natural vibration frequencies and mode shapes in addition to generalized mass and stiffness matrices

TABLE 2.- TECHNICAL-DATA PLOT TYPES

TECHNICAL DATA DISPLAY	PLOT TYPE					
	UNDEFORMED GEOMETRY	DEFORMED GEOMETRY	SCALAR-GRID	CONTOUR	GRAPH	MATRIX
STRUCTURAL AND/OR MASS MODEL						
• Nodes	●					
• Stiffness finite-element grid	●					
• Stiffness element properties			●	●		
• Mass finite-element grid	●					
• Exploded node/grid subsets	●					
DISPLACEMENTS/STRESSES						
• Nodal displacements		●				
• Element stresses			●	●	●	
STRUCTURAL RESIZE RESULTS						
• Stiffness element properties			●	●		
• Strength-designed margins of safety			●	●	●	
• Thermal-designed margins of safety			●	●	●	
MODE SHAPES						
• Vibration		●				
• Buckling		●				
FUEL/PAYLOAD MANAGEMENT						
• Loadability diagrams					●	
FLUTTER SOLUTION						
• V-g and V-f graphs					●	
MATRIX DATA						
• Any ATLAS matrix						●

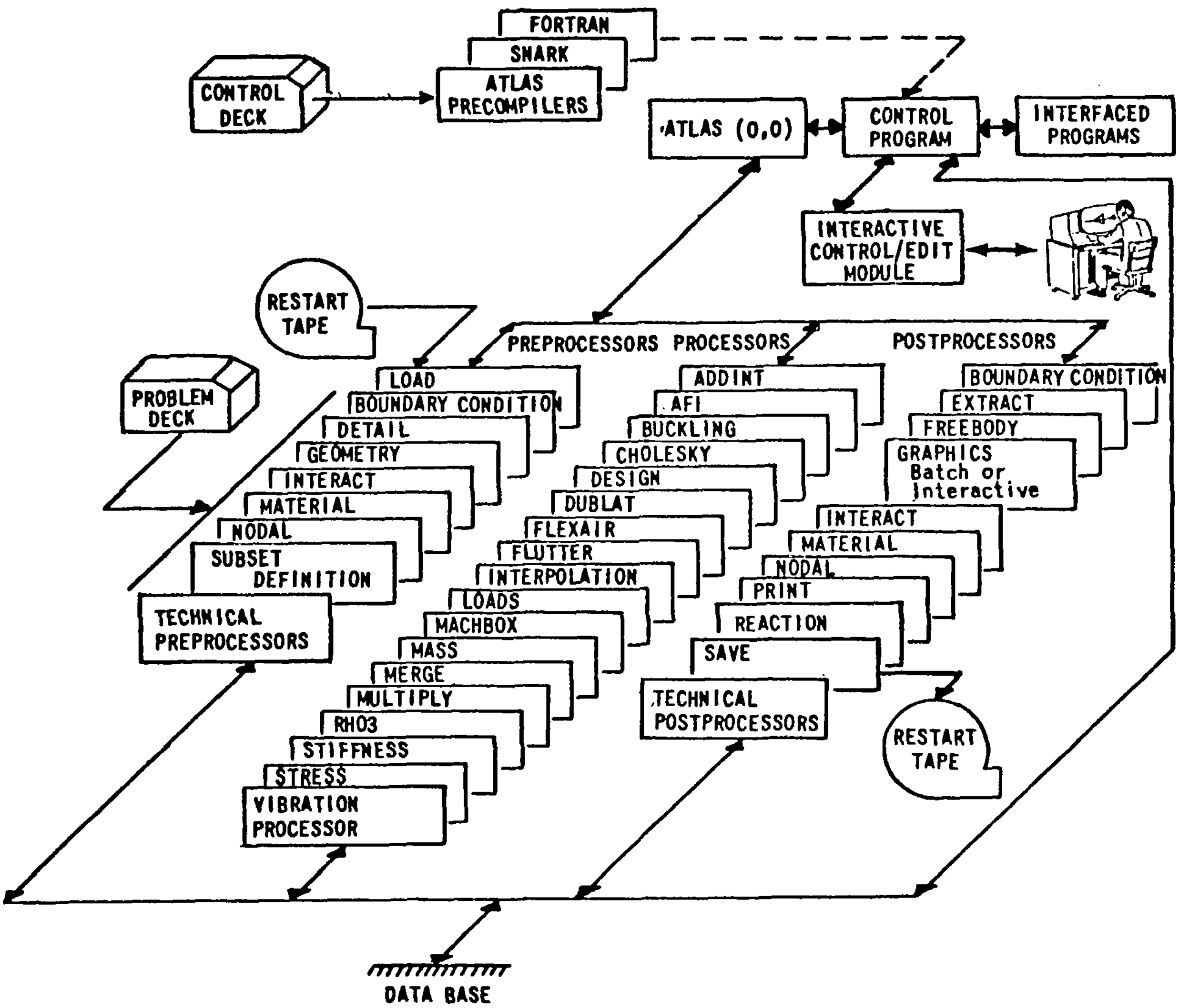
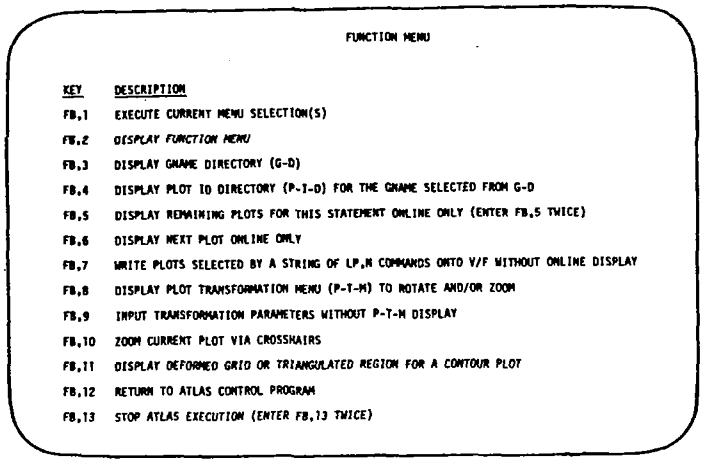
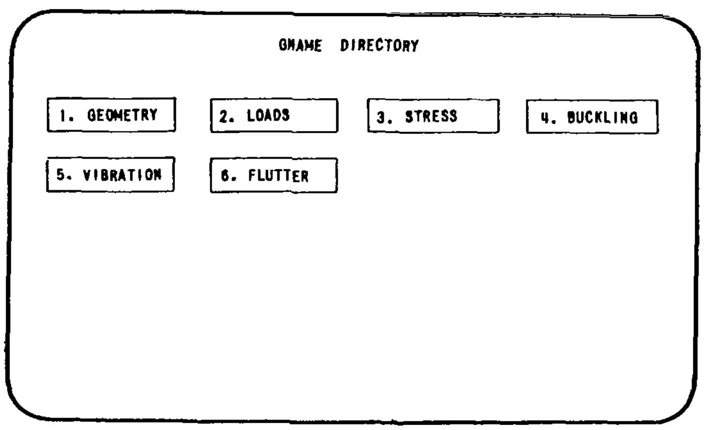


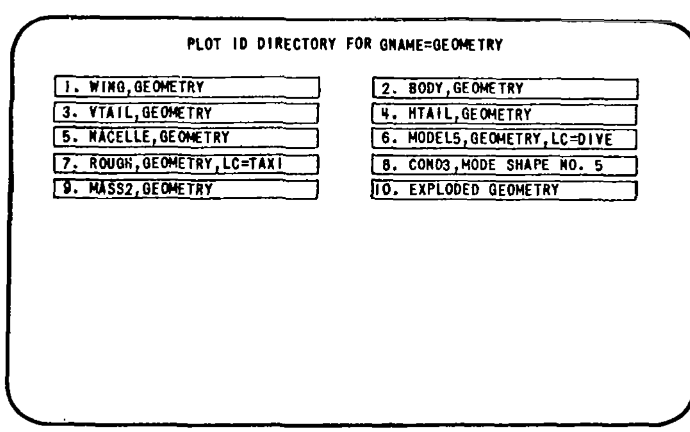
Figure 1.- The ATLAS system modular design.



(a) Graphics function menu options.



(b) Example GNAME directory.



(c) Example plot ID directory.

Figure 2.- ATLAS graphics function menu and example plot directories.