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A GENERALIZED SOFTWARE EXECUTIVE FOR MULTIDISCIPLINARY COMPUTATIONAL STRUCTURAL DYNAMICS

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INTRODUCTION TO DYSCO

The objective of this presentation is to introduce the attendees to the DYSCO program. The emphasis will be on the features which make it "multidisciplinary."

DYSCO is a very general and versatile software program which couples and solves dynamic systems. It was initiated in the late '70s in response to a helicopter analysis requirement. The system development, however, resulted in an executive which was completely separated from any particular area of technology, except that of second order ODE. During the course of its development, it was funded by the Army Aviation Applied Technology Directorate, the Air Force Wright Aeronautical Laboratories, and by the Kaman Aerospace Corporation. It is completely written in FORTRAN and is operational on IBM and VAX computers. The size is indicated in figure 1.

- o DYNAMIC SYSTEM COUPLER (DYSCO)
- o INITIAL DEVELOPMENT - 1979
- o FUNDED BY ARMY, AIR FORCE, KAMAN
- o PRESENTLY OPERATIONAL ON IBM AND VAX
- o SIZE - 50000+ LINES OF CODE
350+ SUBROUTINES
4+ MEGABYTES OF STORAGE
- o INSTALLATIONS INCLUDE GOVERNMENT FACILITIES AND UNIVERSITIES

Figure 1

DEFINITION OF DOMAIN OF DYSCO

The "domain" is the technical area in which the program is designed to operate. The domain of DYSCO is "coupled sets of second order ordinary differential equations." The Executive of DYSCO recognizes and manages: algorithms for computing equation coefficients; the necessary data; coupling constraints; coupling procedures; algorithms for solving the coupled equations; the resulting data.

Figure 2 illustrates the generic equation of a "component," the coupling constraints, the coupled equations of the system.

DYSCO COUPLES AND SOLVES SECOND ORDER ODE

- $M_I \ddot{X}_I + C_I \dot{X}_I + K_I X_I = F_I$ (COMPONENT I)
- $X_I = T_I X_S$
- $M_S \ddot{X}_S + C_S \dot{X}_S + K_S X_S = F_S$ (SYSTEM)

Figure 2

DEFINITION OF COMPONENT

A component is anything represented by second order ODEs where the coefficients can be any computable function of present or past states of this and other components of the "model." The degrees of freedom (dependent variables) and the independent variable are completely arbitrary. (Figure 3.)

- o "COMPONENT" IS MORE GENERAL THAN "FINITE ELEMENT"
- o M_I, C_I, K_I, F_I = ARBITRARY FUNCTIONS OF STATE
- o X_I = ANY GENERALIZED DOF - PHYSICAL, MODAL, OTHER
- o COMPONENT MAY BE
  - FINITE ELEMENT
  - ASSEMBLY OF FINITE ELEMENTS (SUBSYSTEM, OUTPUT OF FE ANALYSIS)
  - SPECIAL SET OF EQUATIONS (E.G., HELICOPTER ROTOR, SPECIAL MECHANISM)
  - CONTROL ALGORITHM (MIMO, NON-SYMMETRICAL MATRICES, NONLINEAR)
  - FORCE ALGORITHM (M, C, K = NULL, AERO, ELECTROMAGNETIC)
  - ETC., ETC.

Figure 3

DEFINITION OF MODEL

A "model" describes a system made up of coupled components. The description of each component includes the identification of the algorithm for computing the equation coefficients and the identification of the data to be used. In DYSCO the equations may be nonlinear but the coupling is limited to linear relationships between degrees of freedom. (Figure 4.)

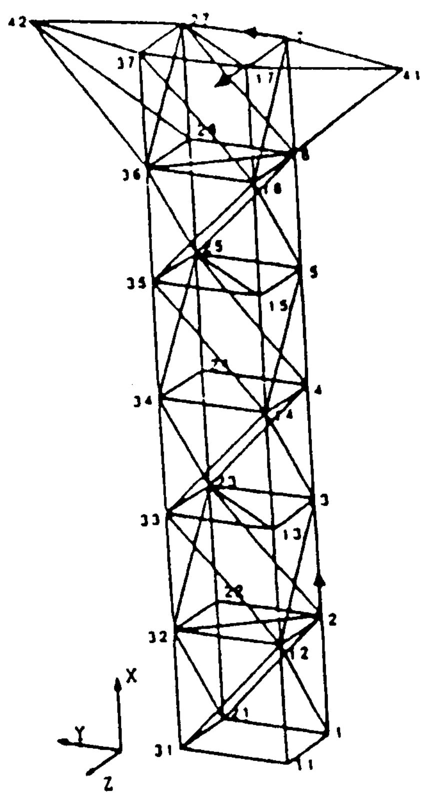
When the model is defined, the DYSCO command "RUN" assembles the equations and prepares for the execution of any user specified solution algorithm.

- **A MODEL IS A DESCRIPTION OF A COUPLED SET OF COMPONENT EQUATIONS**
- **COMPONENT EQUATIONS ARE DEFINED BY**
  - **NAME OF THE ALGORITHM IN "TECHNOLOGY LIBRARY"**
  - **NAME OF DATA SET IN "MODELING DATABASE"**
- **COMMAND "RUN" COUPLES EQUATIONS**
- **NEXT STEP IS TO SPECIFY SOLUTION ALGORITHM**

Figure 4

ILLUSTRATION OF A MODEL

In the illustration in figure 5, a truss structure is modeled with 10 "components." The component "CTR4" defines the equations for a truss bay consisting of 4 vertical members, 4 horizontal members and up to 8 diagonal members. The component number (NO.) represents a feature which automatically couples the components. Note that the odd numbered (as well as the even numbered) bays are identical and thus use the same "DATA SET." Component 9 represents a linear MIMO control algorithm and Component 10 applies single point constraints to ground the model at the base.



	COMPONENT	NO.	DATA SET
1	CTR4	1	ABCD1
2	CTR4	3	ABCD1
3	CTR4	5	ABCD1
4	CTR4	2	ABCD2
5	CTR4	4	ABCD2
6	CTR4	6	ABCD2
7	CSF1		TOPR
8	CSF1		TOPL
9	CSF1		CONTR
10	CLC1		GROUND

Figure 5

DYSCO SYSTEM OVERVIEW

On the next few figures, some of the features of the design of the system will be described. The Executive acts as an intelligent interface between the user, the "technology library," the data. The technology library contains all the algorithms for computing equation coefficients, forces, constraints, solution algorithms ("technology modules"). The database contains data to be used by the technology modules. It is identified by the name of the technology module which is to use it as well as a user supplied "data set" name. It also contains model descriptions and other pertinent types of data. The executive coordinates all the actions of the system: including input and editing of data, forming models, assembling models, solving models, retrieving local state vectors and all other necessary functions to make the system operable. (Figure 6.)

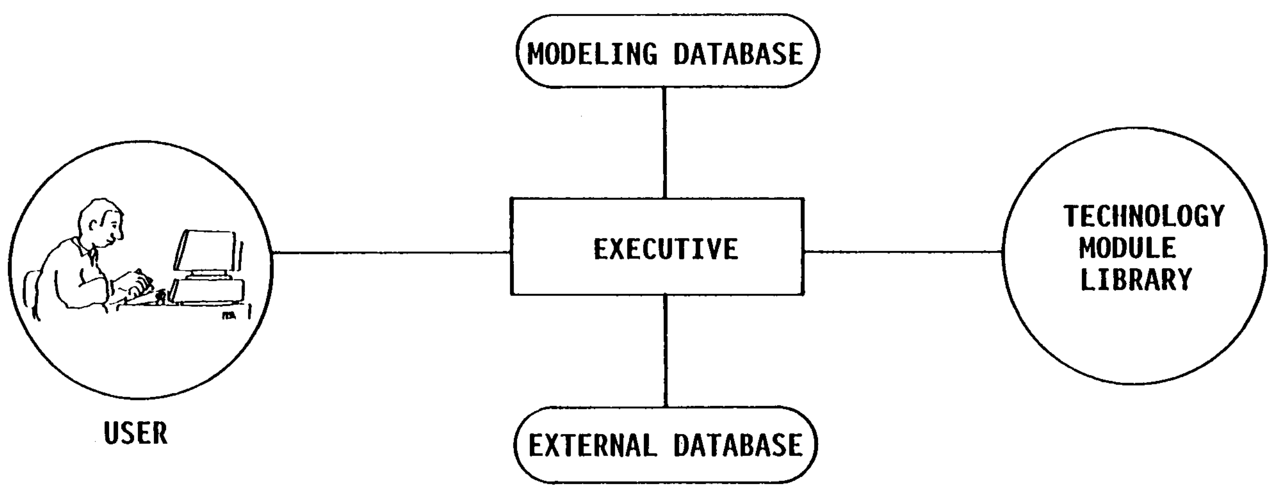


Figure 6

MODELING SCENARIO

Figure 7 is an illustration of the relationship between some of the modeling commands and the operation of the system. The NEW commands allow the user to input the data for a component, a force algorithm, or to define a model. The user specifies the name of the technology modules and is then guided through the input and/or edit process. This data is then stored on the modeling database. When defining a model, the user inputs information such as component algorithm and data set name. The executive validates the existence of this information before acceptance. The model is named and also stored on the database. When the RUN command is issued, the user supplies the model name and the executive then obtains the data, accesses the technology modules in the library, assembles the equations and carries out all preparations necessary to execute a solution module from the technology library, as specified by the user.

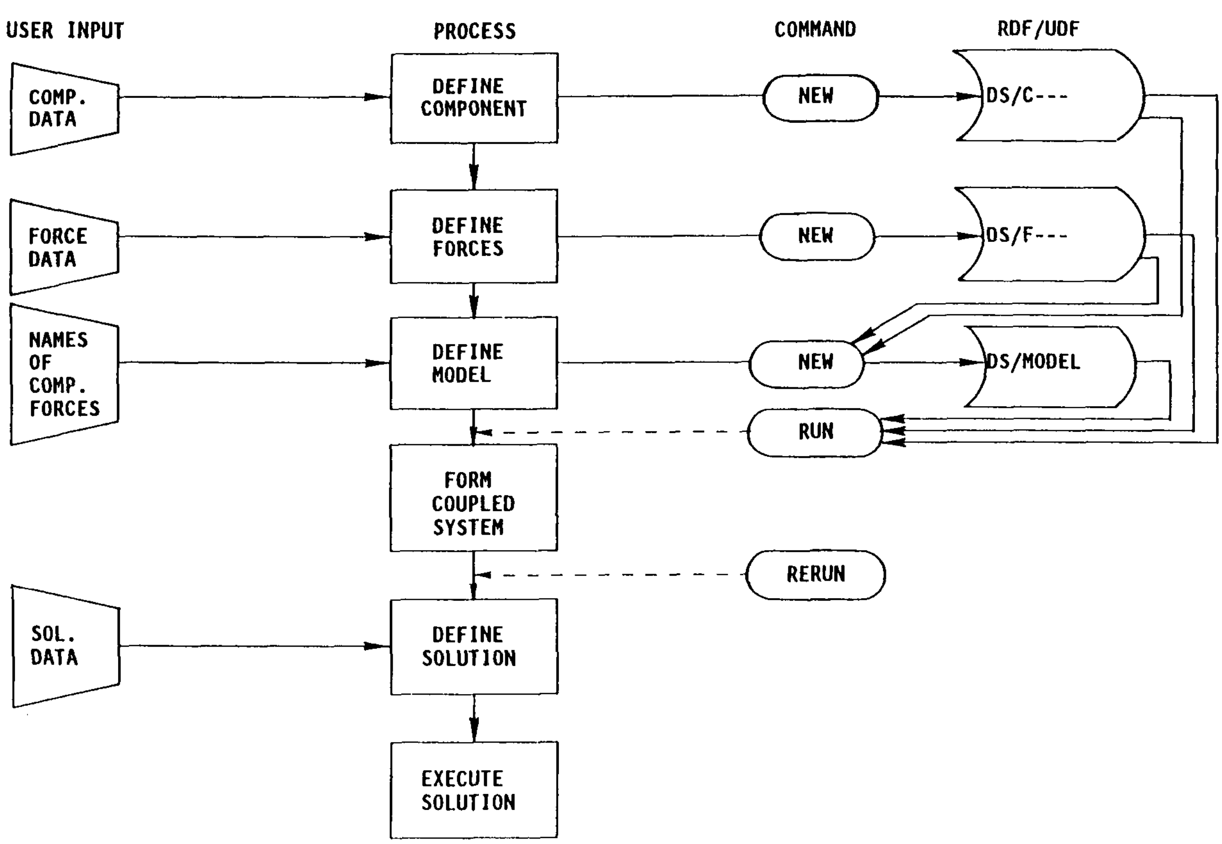


Figure 7

TECHNICAL MODULES

In order for the Executive to perform its functions and to simplify the installation of new components or solution, the technology modules are separated into functional modules as defined in figure 8. The relationships between the commands and the technical modules are shown on the following figure.

A technology module is given a 4 character name. The first character is C (for component), F (for force), S (for solution). The technical modules which comprise the technical modules use the same first 4 characters plus I, D, C, etc. as shown on figure 8. The specific functions of the individual modules are briefly categorized below.

---I	INPUT DEFINITION
---D	DEFINE DEGREES OF FREEDOM
---C	COMPUTE CONSTANT COEFFICIENTS IN EQUATIONS
---A	COMPUTE NON-CONSTANT COEFFICIENTS, FUNCTION OF TIME AND STATE
---0	OUTPUT
---L	INTERNAL LOADS, FUNCTION OF STATE

Figure 8

RELATIONSHIP BETWEEN MODELING SCENARIO AND TECHNICAL MODULES

Figure 9 illustrates how the Executive accesses the appropriate technical modules as necessary during various phases of the modeling and solution process.

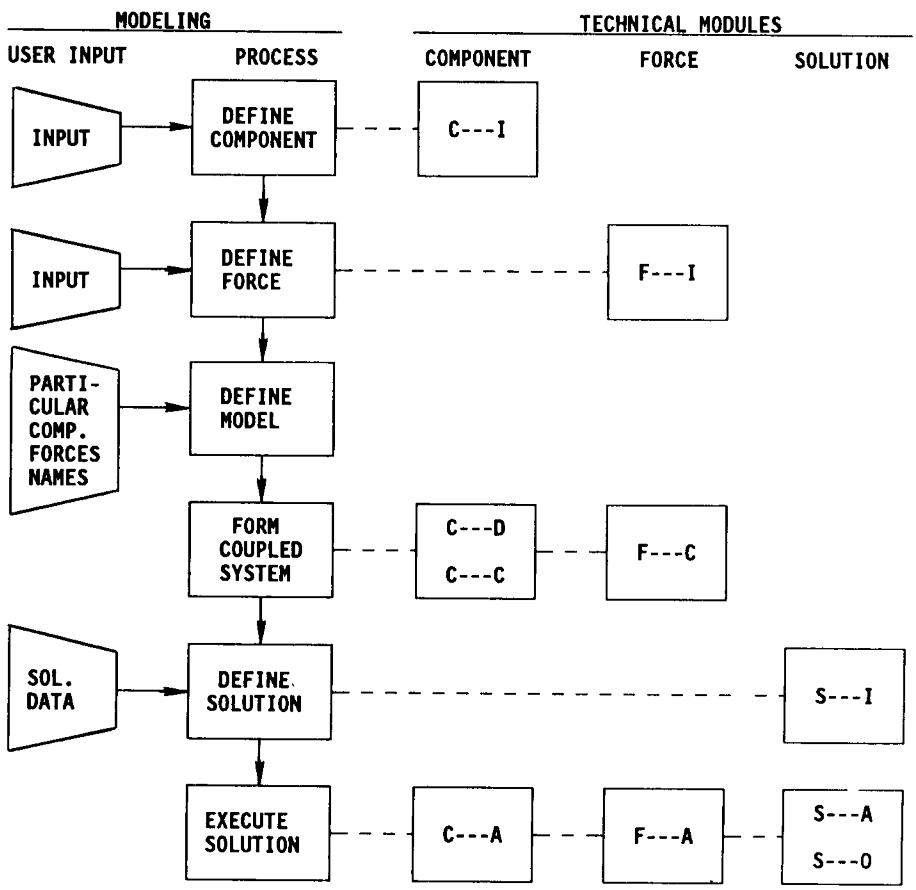


Figure 9

RUN COMMAND

Figure 10 illustrates the functions performed by the Executive after the command RUN. The only input required from the user is the command and the name of the model. All the operations are performed in a manner which is completely transparent to the user.

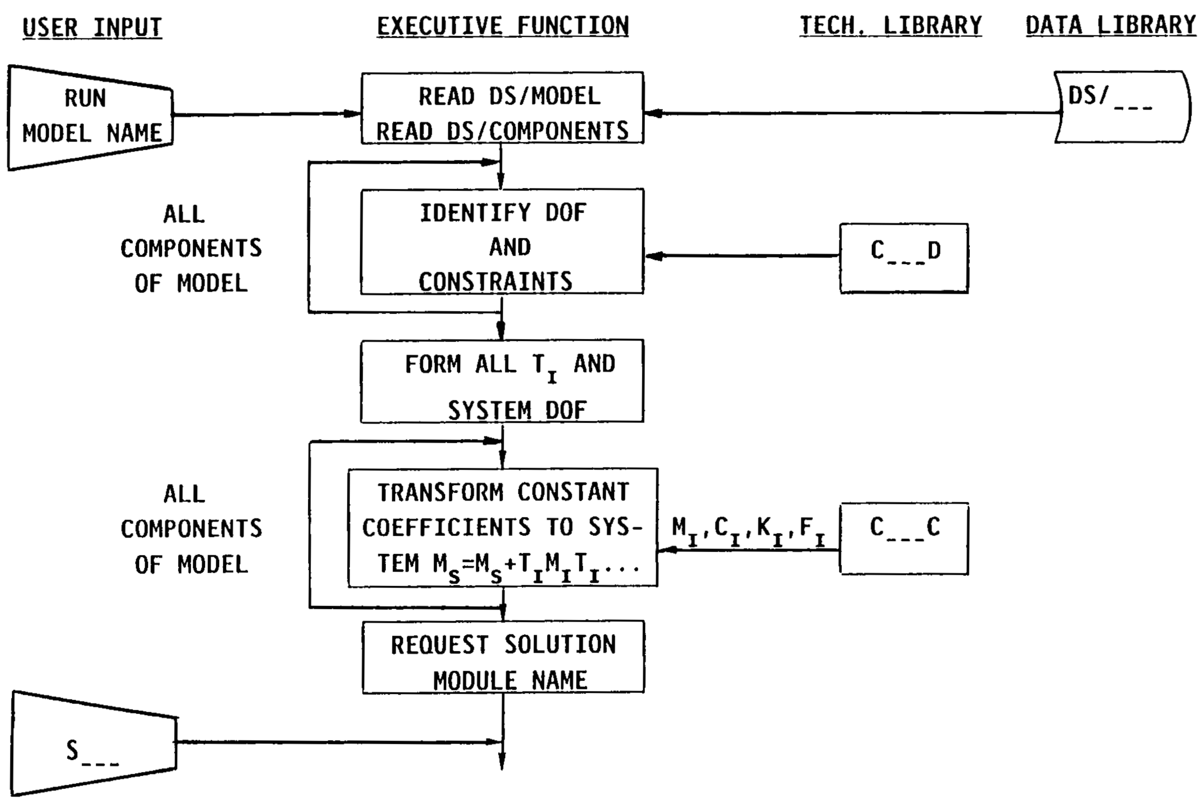


Figure 10

TIME HISTORY

Figure 11 is an illustration of a particular solution performed after execution of the RUN command. Functions such as retrieval of component state and the assembly of the varying matrix coefficients are performed as routine procedures in the Domain Executive.

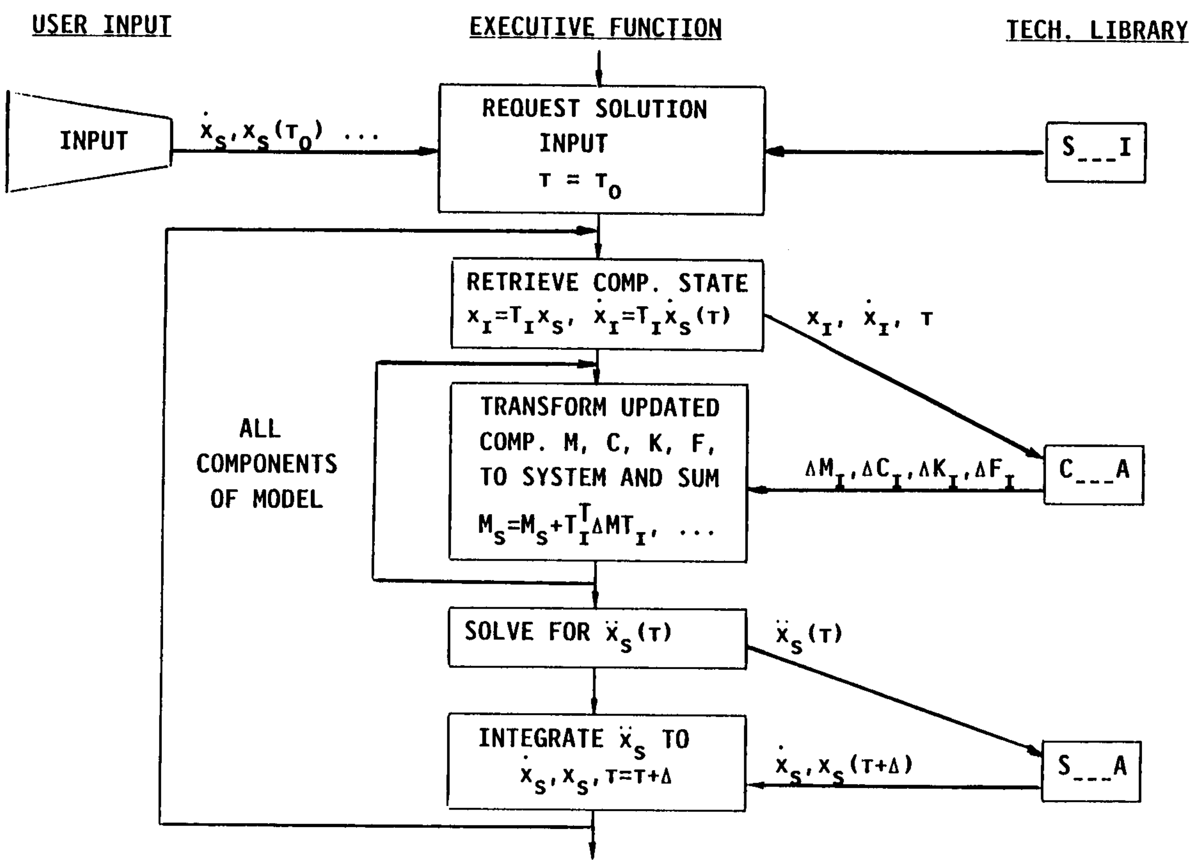


Figure 11

FEATURES OF THE EXECUTIVE

The principal executive characteristics are listed on figure 12. It performs all necessary operations without specific detailed instructions from the user. The Executive treats generic differential equations. None of its characteristics is related to any particular area of technology. This dependence is left to the specific modules in the Technology Library. Since the Technology Library may be readily expanded, any of a broad range of technologies may be treated alone or in conjunction with other technologies.

- **EXECUTIVE IS SPECIFICALLY BUILT TO MANAGE STRUCTURAL DYNAMIC ANALYSIS**
- **IT UNDERSTANDS AND MANAGES**
  - **INPUT: IDENTIFICATION, STORAGE, EDITING**
  - **MODEL BUILDING: RETRIEVAL OF DATA, CALLS TO TECHNOLOGY LIBRARY**
  - **ASSEMBLY OF EQUATIONS: APPLIES MPC, SPC**
  - **SOLUTION OF EQUATIONS: CALLS TO TECHNOLOGY LIBRARY, RETRIEVAL OF LOCAL STATES, INTERFACE LOADS**
- **EXECUTIVE INDEPENDENT OF ANY PARTICULAR AREA OF TECHNOLOGY**
  - **UNIFORM ABSTRACT INTERFACES TO TECHNOLOGY LIBRARY**

Figure 12

FEATURES OF TECHNOLOGY LIBRARY

Figure 13 emphasizes many of the major features of the Technology Library. Because of the modularity and the uniform interfaces to the Executive, it is a simple procedure to add any capability (within the defined domain) to the program. This new capability then may be used in conjunction with all other capabilities which already exist in DYSCO.

- NEW TECHNOLOGY EASILY ADDED
  - COMPONENT, FORCE, SOLUTION
  - UNIFORM INTERFACES TO EXECUTIVE
  - FORTRAN CODING
- COMPONENTS ARE ANY SECOND ORDER ODE, SUCH AS,
  - SINGLE SPRING, DAMPER, OR MASS
  - ANY FINITE ELEMENT
  - COMPLETE NASTRAN MODEL
  - HELICOPTER ROTOR
  - MIMO CONTROL ALGORITHM
- SOLUTIONS ACT ON MODEL EQUATIONS, E.G.
  - EIGENANALYSIS
  - FREQUENCY RESPONSE
  - TIME HISTORY
  - HELICOPTER TRIM (PERIODIC SHOOTING)
  - PERIODIC SYSTEM STABILITY
  - STATE FEEDBACK OPTIMIZATION

Figure 13

OTHER FEATURES

DYSCO contains a number of valuable features which are listed in figure 14. All of these make the program easy and safe to run. Safe means that data is all validated, in correct format, and that aborts or erroneous outputs due to inconsistent or missing data are not possible. The editing of both data and models allows easy modification or correction of data, configuration changes, damage analysis. The coupling procedures are also such that the user is relieved of much effort which is automatically performed by the Executive.

- o VALIDATED INPUT AND EDITING
  - USES KNOWLEDGE TABLE: TYPE, CHARACTERISTICS, EXISTENCE, RANGE
  - PROMPTED INPUT
  - INSTANTANEOUS VALIDATION
  - ASSURED COMPLETE AND CONSISTENT DATA
- o SIMPLE EDITING OF MODEL
  - CONFIGURATION CHANGES
  - PARAMETER VARIATION
  - DAMAGE ANALYSIS
- o INTELLIGENT COUPLING PROCEDURES
  - RECOGNITION OF DOF NAMES
  - MPC OPTIONALLY AUTOMATICALLY FORMED
  - GENERAL MPC SOLVED FOR DOF EQUATIONS

Figure 14

BASIC TECHNOLOGY MODULES - COMPONENTS

Figure 15 lists a number of general purpose components which are presently included in the Government version of DYSCO.

- o CSF1 - LINEAR FINITE ELEMENT

  USER SUPPLIES: NAMES OF DOF
  M, C, K, F

- o CFM3 - 3D MODAL STRUCTURE

  RIGID BODY, ELASTIC MODES (ALL OPTIONAL)
  DOF NAMES AUTOMATICALLY GENERATED
  AUTOMATIC COUPLING AT SPECIFIED NODES

- o CSB2 - GENERAL BAR ELEMENT* (NOT AVAILABLE IN GOVT VERSION)

  MAY BE USED AS A BEAM OR ROD ELEMENT
  SHEAR FACTORS, CONSISTENT MASS, RAYLEIGH DAMPING
  UP TO 12 DOF

- o CES1 - ELASTIC STOP

  NONLINEAR SPRING, DAMPING, WITH GAP

- o CGF2 - GENERAL FORCE

  - POLYNOMIAL, FOURIER SERIES, OR TABULAR
  - PERIODIC

- o CLC0 - SINGLE POINT CONSTRAINTS
- o CLC1 - MULTIPOINT CONSTRAINTS
- o CLC2 - ADVANCED MULTIPOINT CONSTRAINT

Figure 15

BASIC TECHNOLOGY MODULES - SOLUTION

Figure 16 lists basic, general purpose solution routines which are also presently installed.

- o SEA4 - EIGENANALYSIS, REAL
- o SEA5 - COMPLEX EIGENANALYSIS
- o STH4 - TIME HISTORY
  - CONDITION CODES
- o SFD1 - FREQUENCY DOMAIN MOBILITY
  - RESPONSE PER UNIT FORCE
- o STCO - OPTIMIZER FOR LINEAR STATE FEEDBACK* (NOT AVAILABLE IN GOVT VERSION)
  - SOLVES MATRIX RICCATI EQUATION
  - INTEGRATES SYSTEM STATE EQUATIONS
- o SII3 - INTERFACE AND INTERNAL LOADS
  - RESIDUAL FORCES AT INTERFACES
  - FORCES, STRAIN ENERGY, BENDING MOMENTS

Figure 16

SPECIALIZED TECHNOLOGY MODULES

On figure 17 is a listing of technology modules which were developed and installed to perform specialized representation and solutions.

- CRR2, CRR3 - HELICOPTER ROTOR
- CCE0, CCE1 - ROTOR CONTROL SYSTEM
- CRD3 - ROTOR DAMAGE
- CFM2 - HELICOPTER FUSELAGE
- CLG2 - NONLINEAR LANDING GEAR
- CLS2 - LIFTING SURFACE
- FRA0, FRA2, FRA3 - ROTOR AERODYNAMICS
- FFA0, FFC2 - FUSELAGE AERODYNAMICS
- STH3 - TIME HISTORY, HELICOPTER CONTROLS
- STR3 - HELICOPTER TRIM
- SSF3 - FLOQUET STABILITY

Figure 17

LIST OF ILLUSTRATIVE PROBLEMS

In conclusion, figure 18 is a list of actual diverse problems which have been modeled and solved using the DYSCO program.

- o PACOSS TOWER DYNAMIC ANALYSIS
- o TRUSS STRUCTURE WITH ACTIVE ELEMENTS - VIBRATION CONTROL
- o PIEZOELECTRIC SENSORS/ACTUATORS ON BEAM - VARY CONTROL LAWS, ADD ELASTIC STOP, STABILITY, TIME, FREQUENCY DOMAIN
- o POINTING-TRACKING SYSTEM - MOTOR DRIVEN MIRRORS - MOVING, ACCELERATING TARGET, VARY CONTROL GAINS
- o ROTORCRAFT TRIM - DAMAGED BLADE - INTERNAL LOADS
- o RAIL GUN PNEUMATIC ACCELERATOR - GAS PRESSURE - BOLT MOTION
- o ALGORITHM EVALUATION - REDUCED MODELS, SYSTEM IDENTIFICATION, SIMULATE EFFECTS OF MEASUREMENT ERRORS

Figure 18