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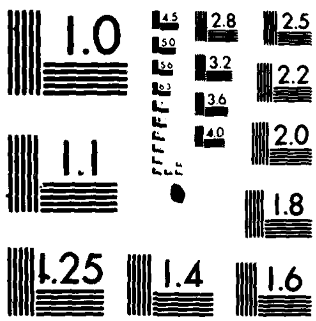

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DYNAMIC SYSTEM COUPLING (DYSCO) PROGRAM
Volume I - User's Manual

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Final Report

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Prepared for

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Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report documents the design, implementation, and use of a prototype computer program developed to demonstrate the feasibility of representing a rotorcraft system by dynamically coupling representations of individual system components and performing user specified solutions. Descriptions of hypothetical component, force, and solution algorithms and their use as required to treat a variety of typical rotorcraft problems not treatable with the prototype program and a technology complex based on the program design are provided. The design of Dynamic System Coupling program, DYSCO, should provide a sound basis for the development of comprehensive rotorcraft analysis systems.

The DYSCO program, though limited to consideration of articulated rotors having rigid blades and teetering rotors having rigid blades, can be used to obtain insight regarding the time history, mobility, and eigenanalysis characteristics of moderately complex rotorcraft configurations. Successful use of the DYSCO program, intended primarily for interactive use by a user familiar with the fundamental rotorcraft dynamic system, requires that the user be knowledgeable of the modeling and coupling techniques involved in the program.

Messrs. Paul Mirick, H. I. MacDonald, and Lawrence R. Sutton of the Aeromechanics Technical Area, Aeronautical Technology Division, provided technical direction for this effort.

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Dynamic System Coupling (DYSCO) is a computer program which allows an interactive user to couple arbitrary components and force algorithms into a model of a helicopter or other dynamic system. The equations of the system may then be solved by a choice of analytical methods. The components available are rigid blade rotor, elastic fuselage, rotor control system, and other structures representable by general linear second-order differential equations. The force methods available are linear rotor loads, tabular rotor aerodynamics with

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Block 20. Abstract - continued.

optional induced velocity map, fuselage flat plate drag, and sinusoidal shaker. The solution methods available are time history, linear constant coefficient eigenanalysis, and complex frequency response. The program has the capability of being expanded in its level of complexity by the addition of other technology modules.

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INTRODUCTION

DYSCO is a computer program for analyzing rotorcraft dynamic and aerodynamic phenomena based on coupling independent, arbitrary component representations into a valid representation of a complete system.

The mathematical basis, the specific coupling algorithms, and the design of DYSCO and examples of the coupling technique are presented in Volume II of this report.

In this volume, the general capabilities and use of the program and the specific capabilities of the technology modules are presented. Notes on installation are given in Appendix B.

The Contracting Officer's Representatives (Technical) have been Mr. Paul H. Mirick, Mr. Herman I. MacDonald, Jr., and Mr. Lawrence R. Sutton of the Applied Technology Laboratory. The participants in the contract effort were A. Berman, F. S. Wei, and N. Giansante of Kaman Aerospace Corporation, M. Anderson and P. Tyeryar of Control Data Corporation, and P. Baucom of P. B. Associates.

GENERAL CAPABILITIES

The DYSCO program includes a library of component representations, applied force algorithms, and solution methods. The user specifies a set of components and selects an appropriate force algorithm for each component and supplies the necessary data. DYSCO defines the control logic for definition of the equations of motion of the coupled dynamic system, then the user selects a solution method, and DYSCO forms the equations and carries out the solution. The equations are sets of second-order ordinary differential equations. The coefficients and forces may be nonlinear and time dependent. The solutions may be in the time or frequency domain.

The present release of DYSCO contains several component, force, and solution technology modules. The details of the implemented technology modules are given in later sections of this report.

NAMING CONVENTIONS FOR TECHNOLOGY MODULES

For convenience the technology modules are named according to the conventions described in the following paragraphs.

Component Modules

All component representations ("modules") have a four character name; the first character is the alpha "C", the second and third are general descriptors, and the fourth is an integer which indicates a general level of complexity.

Those implemented in DYSCO are:

- CRR2 - Rotor, rigid blades
- CCE1 - Control system, elastic control rods
- CSF1 - Structure, finite element
- CFM2 - Fuselage, modal representation

Force Modules

All force modules have a four character name defined as above except the first character is "F".

Those implemented in DYSCO are:

- FRAØ - Rotor aerodynamics, linear
- FRA2 - Rotor aerodynamics, tabular
- FFAØ - Fuselage aerodynamics, flat plate drag
- FSS1 - Sinusoidal shaker

Solution Modules

All solution modules have a four character name as defined above except the first character is "S".

Those implemented in DYSCO are:

STH3 - Time history
SFD1 - Frequency domain (mobility)
SEA3 - Eigenanalysis

COUPLING

Coupling by Name

The degree of freedom names in DYSCO are of great importance since the coupling is completely controlled by joining structures where the degree of freedom names are identical. The names are established in the C--- modules and all the other necessary processes (development of transformation tables and multipoint constraint relationships) are automatic. Some of the degree of freedom names are automatically formed and some require user input as described in following sections.

Naming Convention for Degrees of Freedom

The convention used for each degree of freedom name is in the format (A4, I4), that is, a four character literal word followed by a four character integer. The user must be familiar with the degree of freedom names which are developed in the component technology modules in order to use the DYSCO program. The specifications for each of these modules include a description of the standardized degree of freedom names.

Some examples of degree of freedom names associated with components are:

<u>CRR2</u> (r = rotor number, b = blade number)
Flapping angle: BETArb00
Hub aft displacement: XHUBr000

<u>CFM2</u> (s = structure number, m = mode number)
Rigid body vertical: ZCG s000
Elastic modes: QFUSsm00

Thus, a three-bladed rotor with flapping and hub aft displacement would have the following degrees of freedom (rotor number 1):

BETA1100
BETA1200
BETA1300
XHUB1000

In order to couple the hub to another structure, there must be a degree of freedom named XHUB1000 on the other structure at the proper point of attachment. This method is discussed in more detail in later sections and in Volume II of this report.

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USE OF THE SYSTEM

The major use of DYSCO is intended to be on a completely interactive basis. Thus, only interactive input is described in this report.

In preparation for the use of DYSCO, the user must become familiar with the capabilities of the available technology modules. (See following sections.) He must then formulate a model of the vehicle or structure he is to simulate in terms of the available component and force representations. He should also have available the appropriate input data for each of these modules. The user must also select an appropriate solution technology module and define the necessary data to control the solution process.

INITIALIZATION

DYSCO uses a run data file (RDF) that is temporary and is initialized automatically at the start of each run of the program. In addition, there are provisions for up to four user data files (UDF) and up to five sequential files. In the present version of DYSCO the UDFs and sequential files may be used only for aerodynamic tables and induced velocity maps in conjunction with the force module, FRA2. See Appendix A for such usage.

The first query of the program at the start of a run asks for the number of UDFs to be used. If tabular aerodynamics are not to be used, the response should be "Ø". Otherwise, see Appendix A for instructions.

COMMANDS

Virtually all the input is prompted. The only exceptions are the requested commands. The commands presently implemented are: MODE, NEW, RUN, CREA, and QUIT; they are used in response to the query: COMMAND. The format for command input is A4. The functions of the commands are as follows:

MODE - This is used to select a batch mode if desired. (Interactive is assumed if MODE is not used.)

NEW - This indicates the creation of a new "model". The program will then request a "model name" (up to eight characters) which is used to identify the model to be formed. All models are retained for the remainder of the run. A 72 character heading (model title) will also be requested. This is followed by requests for a component name and an associated force module name and appropriate data. (See the following section for details of component input.) These requests will be repeated until the user responds "END". This indicates the model is complete and the name of a solution module will be requested.

RUN - When the model has been formed and the solution module has been specified, the command RUN will result in the request for a model name of a previously formulated model. At this point, the program will display a summary of the model including components, data sets, degrees of freedom, and transformation tables. This will be followed by requests for data relevant to the solution and the specified solution module will be executed. At the end of the solution, a command will be requested and any of the allowed commands may be entered.

CREA - This command is used to create an airfoil table on a user data file (permanent) or on the run data file (temporary). See Appendix A for details on this usage.

QUIT - This command terminates the run.

COMPONENT INPUT

Component Name

After the command NEW is followed by the "model name" and "model title", the program will request a "component name". The user then supplies one of the available component technology module names (C---) associated with a physical component to be represented. The order of specification of "component names" is arbitrary (except for CCE1, which must be specified after the rotor it controls has been specified).

Component Number

The program will then request a "component number". Each physical component of the model must be identified by an integer (1-9). Rotors and other structures may each have a separate set of numbers. Thus, there may be a rotor number 1 and a structure number 1. A special case is the rotor control system (represented by CCE1) which must have a component number identical to that of the rotor it controls.

Data Set Type and Name

An arbitrary data set name (8 character maximum) for the input data associated with the component just specified will be requested. If the data has been previously entered in the current run of the program, the user indicates this by specifying that it is old by entering "O" followed by a blank and the data set name. If a new data set is to be created, the user enters "N" followed by a blank and a new name.

If "O" is indicated and the program verifies that the data set specified exists, no further input is requested. If "N" is indicated and the program verifies that the data set name specified has not been previously specified, then the appropriate data will be requested at the end of the input for this component. If the "O" or "N" is not verified, the program will print an error message and allow the user to correct his input.

Old data sets may be used repeatedly for duplicate components, such as identical rotors of a tandom helicopter. The same data sets may be used in different models in the same run of DYSCO.

The data set name is automatically associated with the component (or force) module for which it was specified. The same name may thus be used with different component modules or force modules. An example of such a usage would be:

COMPONENT	DATA SET	FORCE	DATA SET
CRR2	AH1	FRAØ	AH1
CFM2	AH1	FFAØ	AH1

Force Module

The name of the force module to be used will then be requested. If forces are not to be applied to the component, then a blank (space) must be entered. If forces are to be applied then the name (F---) of an available component compatible force module is entered.

If a force module is specified, a new or old data set name is requested as above.

Component and Force Inputs

For each new component and force data set name a specific set of input data will be requested. The data input is completely prompted and is special to the particular technology modules used. (See following sections for data requirements for each module.)

It is acceptable to use an "old" data set for a component and a "new" one for a force module (or the reverse). In such a case only the new data will be requested. In the above example the original rotor with a different wind velocity could be represented as follows:

COMPONENT	DATA SET	FORCE	DATA SET
CRR2	AH1	FRAØ	AH11

where the first data set is "old" and the second data set is "new".

Completion of Model

The component input as described above is repeated for each component of the model. When the last component has been defined, the user inputs "END" in response to the request for a component name. At this point the model definition has been completed.

SOLUTION INPUT

When the model has been completed, a solution name will be requested. The user then supplies the name of one of the available solution modules (S---). This will be followed by COMMAND. The user may elect to form a new model (enter "NEW") or he may have the specified solution module executed by entering "RUN". In the latter case the program will request a model name. The user may specify any of the previously defined models. This will be followed by the listing of a summary of the model and the request of input data necessary for the control of the solution process. (Details are given in a following section.)

TECHNOLOGY MODULE DESCRIPTIONS (COMPONENTS)

In this section the implemented component technology modules are described to supply necessary information to the program user for developing a model and carrying out solutions.

All the component module input data which might be requested is presented in this section. In general, the program will only ask for required data. For example, if blade lag is not selected as a degree of freedom, no request will be made for a lag spring stiffness.

Unless otherwise noted, numeric inputs are free form and alpha inputs (Y,N for "yes", "no") are of format A2, A2,...

CRR2, ROTOR, RIGID BLADES

General Description, CRR2

The primary features of the CRR2 component module are:

- Up to 9 identical rigid hinged blades.
- Optional flap, lag, pitch degrees of freedom (at least one required).
- Coincident hinges with springs and dampers.
- Flap-lag coupling parameters for spring and damper effects.
- Coupling to control rod through pitch horn.
- Uniform or nonuniform blades.
- Small angles assumed.
- Up to six hub degrees of freedom in nonrotating system.
- Maximum of four rotors in any model.
- Aerodynamic options are none or FRAØ and FRA2 modules (described in following sections).

Degrees of Freedom, CRR2

All degree of freedom names are automatically formed. All are optional, except that at least one blade degree of freedom is required. The allowed degrees of freedom are depicted in Figure 1 using only the literal portions of their names. In the figure, ψ is the azimuth angle of a reference blade.

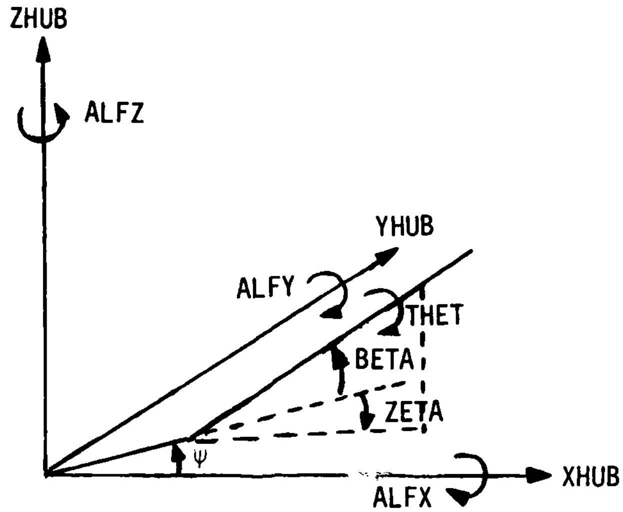

Figure 1. CRR2 Degrees of Freedom.

In the following list of the allowed degrees of freedom, r = rotor number, b = blade number.

Blade degrees of freedom (rotating system), one set for each blade

BETArb00	-	flap angle, positive above plane of rotation
ZETArb00	-	lag angle, positive opposite to direction of rotation
THETrb00	-	pitch angle, positive nose up

Hub degrees of freedom (nonrotating system, angles positive for right-hand rotation)

XHUBr000	-	aft displacement
YHUBr000	-	lateral displacement
ZHUBr000	-	vertical displacement
ALFXr000	-	roll angle
ALFYr000	-	pitch angle
ALFZr000	-	yaw angle

Implicit (or interface) degrees of freedom

RODRrb00 = PHL * THETrb00

The implicit relationship is automatically established if PHL (pitch horn length) ≠ 0 and THETrb00 is a degree of freedom. This is used to automatically couple the rotor representation to its associated control system representation (CCE1).

Maximum number of degrees of freedom = 33. Note that implicit degrees of freedom are not included since they will be degrees of freedom of another component representation and no corresponding differential equation is generated in this module.

Definition Input, CRR2

The definition input is that data required to establish the degrees of freedom to be used and any implicit relationships and is listed below.

Degree of freedom selection (each, Y or N, for yes or no)

Blade: BETA, ZETA, THET
Hub translation: XHUB, YHUB, ZHUB
Hub angles: ALFX, ALFY, ALFZ

Pitch horn length, + fwd of feathering axis, inches
(used for coupling to control system, 0 = no coupling)
Number of blades (1 - 9)

Coefficient Input, CRR2

This input data (along with previous inputs) supplies the information necessary to compute the coefficients of the component equations. All units are in in., lb, sec, deg, RPM.

Rotor radius
RPM
Direction of rotation (-1 = clockwise, +1 = counterclockwise)
Azimuth of reference blade at t (time) = 0
(meaningful for more than one rotor)
Hinge offset
Damper and spring rates (flap, lag, pitch)
Flap-lag coupling factors (0-1) (damping, spring)
Hub weight
Hub moments of inertia about reference blade axis,
inplane axis perpendicular to reference blade axis,
shaft axis (lb-in.^{2})
Root pitch angle

Uniform blade? (Y or N response)

If Y (yes)

Weight per unit length
Total feathering moment of inertia (lb-in.^{2})
Cg offset (+ forward of feathering axis) (in.)
Built-in twist (+ when tip pitch > root pitch) (from hinge)
Chord
Number of blade stations (5-20)(for integrals and aerodynamic force calculations)

If N (nonuniform), for each spanwise station the following data at that station is required. Stations start at hinge and end when a station = rotor radius (20 stations max).

Station
Weight/unit length
Feathering moment of inertia per unit length ($lb\text{-}in.^2/in.$)
cg offset (+ forward of feathering axis) (in.)
Built-in pitch angle (not including root pitch angle), positive for leading edge up
Chord

CCE1, CONTROL SYSTEM, ELASTIC RODS

General Description, CCE1

The primary features of the CCE1 component module are:

- Control system is associated with particular rotor.
- Collective and cyclic swashplate.
- Elastic, damped control rods to each blade*.
- Springs and dampers (optional) from swashplate to ground.
- Collective force, cyclic moments are inputs.
- Optional n/rev collective force input.
- Force modules not accepted.
- Component must be specified after corresponding rotor.

Degrees of Freedom, CCE1

All degree of freedom names are automatically formed. These degrees of freedom using only the literal part of their names are depicted in Figure 2. Note relationship to Figure 1. 3 B

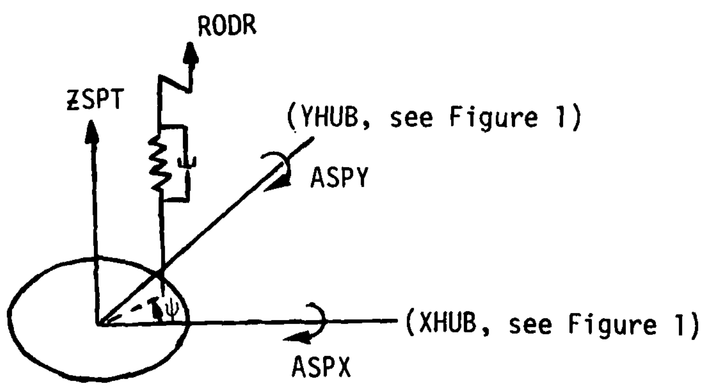

Figure 2. CCE1 Degrees of Freedom.

ASPX and ASPY are positive for right-hand rotation.

*Control rods interface blades at pitch horn and interface swashplate at same azimuth angle as corresponding blade.

In the following list, r = rotor number, b = blade number.

Degrees of freedom (r, b automatically set to corresponding rotor and blade number value, respectively, see CRR2, above)

RODRrb00	-	Displacement of upper end of rod (rotating system)
ZSPTr000	-	Collective displacement
ASPXr000	-	Roll of swashplate (fixed system)
ASPYr000	-	Pitch of swashplate (fixed system)

Maximum number of degrees of freedom = 12.

Definition Input, CCE1

Since there are no optional degrees of freedom, there is no definition input for this module. Information previously input to the corresponding CRR2 module is used.

Coefficient Input, CCE1

This input data is used to compute the coefficients of the component equations.

All units are in in., lb, sec, deg.

Weight of swashplate (lb)
Moment of inertia of swashplate about its diameter ($lb\text{-}in.^2$)
Collective damping rate (to ground) (lb/in./sec)
Cyclic damping rate (to ground) (lb-in./deg/sec)
Collective spring rate (to ground)
Cyclic spring rate (to ground)
Distance from axis of rotation to control rod
Control rod damping (lb/in./sec)
Control rod stiffness (lb/in.)
Applied collective force
Applied moment about XHUB axis (+ in ASPX direction) (lb-in.)
Applied moment about YHUB axis (+ in ASPY direction) (lb-in.)
Harmonic of higher harmonic collective (if none, enter 0)
Sine, cosine values of higher harmonic force

CSF1, STRUCTURE, FINITE ELEMENT

General Description, CSF1

The CSF1 component module represents an arbitrary, linear, constant coefficient set of second-order differential equations of the form $M\ddot{v} + C\dot{v} + Kv = 0$ where the M, C, and K matrices and degree of freedom names are supplied by user. This module may also be used for elastic coupling of other components (see below, Modeling Techniques). It may use FSS1 for sinusoidal forcing (see later section).

Degrees of Freedom, CSF1

All degree of freedom names are supplied by user.

Maximum number of degrees of freedom = 40.

Definition Input, CSF1

This data defines the degrees of freedom associated with the component modeled.

Number of degrees of freedom
Degree of freedom names (A4,I4 format)

Coefficient Input, CSF1

This data defines the coefficients in the equations of the component.

All units are physical: lb, in., sec, rad, e.g., mass = lb-sec^2/in.

Mass, damping, and stiffness matrix inputs are completely prompted. Options include null, diagonal, symmetric, and general matrices.

CFM2, FUSELAGE, MODAL REPRESENTATION

General Description, CFM2

The primary features of the CFM2 component module are:

Elastic beam model.
Up to six rigid body modes.
Up to six elastic modes including vertical, lateral deflections and slopes, and torsional deflections.
Interfaces with up to four rotors through rigid pylons.
Interfaces with up to 12 other displacement degrees of freedom along centerline.
May use FFAØ (see later section for description) for flat plate drag.
Maximum of four usages in model.

Degrees of Freedom, CFM2

All degrees of freedom are optional. Rigid body modes and interface degrees of freedom using only the literal portions of the names are depicted in Figure 3.

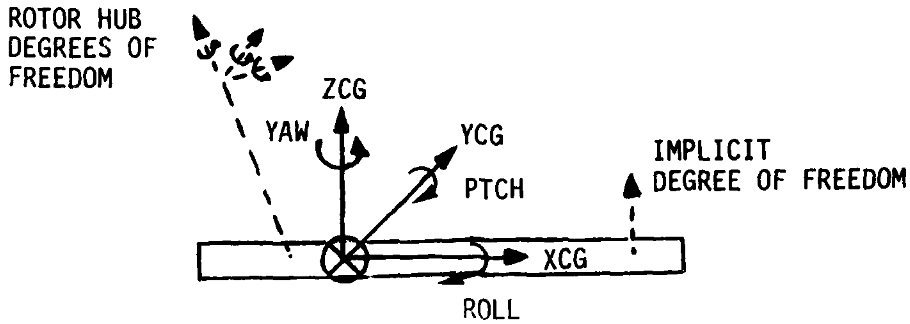

Figure 3. CFM2 Rigid Body Degrees of Freedom.

In the following list, s = structure number, m = mode number.

Rigid body degrees of freedom (angles positive for right hand rotation)

XCG s000 - aft translation
YCG s000 - lateral translation
ZCG s000 - vertical translation
ROLLs000 - roll angle
PTCHs000 - pitch angle
YAW s000 - yaw angle

Elastic mode degrees of freedom (max = 6)

QFUSsmoo

Maximum number of degrees of freedom = 12.

The rotor hub degrees of freedom and other implicit (interface) degrees of freedom are automatically formulated into linear combinations of the rigid body and elastic mode degrees of freedom.

Definition Input, CFM2

The definition input is that data required to establish the degrees of freedom and any implicit relationships.

Rigid body modes (Y or N for yes or no)
XCG (Y or N)
YCG "
ZCG "
ROLL "
PTCH "
YAW "

Cg station (in.)*
Number of elastic modes (6 max.)
Modal input, as prompted, including number of stations (5-20), longitudinal station locations*, z, z', y, y', θ as required for each station

Number of rotors (0 - 4)

For each:

Rotor number
Longitudinal station of hub (in.)*
Vertical height of hub (in.)
Forward shaft angle from vertical ** (deg)
Lateral shaft angle from vertical ** (deg), (+ to port)
Hub degrees of freedom (6 Y or N as prompted)

Number of other implicit degrees of freedom (0-12)
For each:

Degree of freedom name (A4, I4)
Longitudinal station (in.)*
Forward angle from vertical** (deg)
Lateral angle from vertical** (deg), (+ to port)

Coefficient Input, CFM2

The coefficient input is that data required to compute the coefficients of the component equations.

Fuselage mass (lb)
Moments of inertia (slug-ft^2 about cg.)
roll, pitch, yaw
For each elastic mode
Modal mass (slugs)
Damping (% critical)
Natural frequency (Hz)

---

* origin for definition of station locations is arbitrary
** one of the 2 angles must be small

TECHNOLOGY MODULE DESCRIPTIONS (FORCES)

In this section, the implemented force technology modules are described to supply necessary information to the program user for developing a model and carrying out solutions. All numeric input is free form.

FRAØ, ROTOR AERODYNAMICS, LINEAR

The FRAØ force module is the simplest aerodynamic rotor force module with a linear lift curve cut off at the stall angle and constant drag and pitching moment coefficients and uniform inflow. The quarter chord location is assumed coincident with the feathering axis of the blade. This module is used with CRR2.

Input, FRAØ

This input is all the data required, along with previously supplied blade data (in CRR2) and the component state vector, to compute the lift, drag, and pitching moment distributions.

- Wind velocity (ft/sec)
- Velocity of sound (ft/sec)
- Air density ratio (nondimensional), relative to standard atmosphere
- Induced velocity (nondimensional), (+ up with regard to shaft reference axis)
- Rotor shaft axis angle (deg), (+ aft tilt from perpendicular to wind)
- A/C offset from 1/4 chord, (% of chord), (+ forward)
- Lift curve slope (/deg)
- Alpha for 0 lift (deg)
- Drag and moment coefficients
- Stall angle (deg)

Note: The wind velocity specified for the last usage of this module in any model will be used for all the FRAØ applications in that model.

FRA2, ROTOR AERODYNAMICS, TABULAR

The FRA2 force module performs the same function as FRAØ except that an optional induced velocity map may be used and an airfoil table is required. The table is addressed by an assigned name and may reside on a permanent user data file or it may have been temporarily created on the run data file. (See Appendix A for details of use, table formats, etc.) The tables consist of lift, drag, and moment coefficients as functions of angle of attack (0-360°) and Mach number. Other pertinent data input of FRAØ is also required.

FFAØ, FUSELAGE AERODYNAMICS, FLAT PLATE DRAG

This module simulates a simple flat plate drag force along the rigid body XCG axis of a CFM2 component.

Input, FFAØ

This input supplies the data required, along with the state vector of the component, to compute the drag force.

Wind velocity (ft/sec)
Air density ratio (nondimensional), relative to standard atmosphere
Total drag coefficient (nondimensional)
Angle between wind axis and XCG axis (deg)

FSS1, SINUSOIDAL SHAKER

The FSS1 module simulates a sinusoidal applied force at any degree of freedom of CSF1. It may also be used to simulate a constant or gravity force (see discussion in a following section). Note that the degrees of freedom of CSF1 are general and may represent displacements or rotations.

Input, FSS1

This input data supplies the information required to compute the applied force at any time.

Name of degree of freedom*
Frequency (Hz)
Cosine and sine components (lb or lb-in.)

*The name supplied must be a degree of freedom of the CSF1 component with which it is used. If it is not, no force will be applied and no warning will be given.

TECHNOLOGY MODULE DESCRIPTIONS (SOLUTIONS)

In this section the implemented solution technology modules are described. All numeric input is in free form.

STH3, TIME HISTORY

The STH3 module performs a Runge-Kutta integration of the system equations with optional error check and a displacement initial condition. Integration increment is automatically halved until specified accuracy (error check) is achieved.

Input, STH3

This input is the data required to initiate and carry out the solution of the system differential equations.

Time at start of solution (sec), normally 0
Initial integration increment (sec)
Time at end of solution (sec)
Error check* (in. or rad)
Degree of freedom** for error check (A4, I4)
    (omitted if error check = 0)
Initial condition (in. or rad)
Degree of freedom** for initial condition (A4, I4)
    (omitted if initial condition = 0)

Output, STH3

The time history of the system degree of freedom displacements are printed at each time step. Optional termination is available at end of each page (approx. 50 lines).

SFD1, FREQUENCY DOMAIN, MOBILITY

The SFD1 solution module computes the complex displacement mobility of the system constant M,C,K matrices at specified frequencies and prints the values obtained for specified degrees of freedom.

---

*an input of zero omits the error check and is more efficient but may cause inaccuracies or numerical instability.
**must be system degree of freedom (or error message printed)

Input, SFD1

The input defines the matrix elements to be printed and the specific frequencies at which the mobilities are to be computed.

Number of degree of freedom names for output (max 8)
Degree of freedom names (must be system degrees of freedom)
Starting frequency (Hz)
Incremental frequency
End frequency

SEA3, EIGENANALYSIS

The SEA3 module computes system eigenvalues and eigenvectors of the constant M,K matrices and prints the values obtained.

Input, SEA3

Number of modes

4
B

MODELING TECHNIQUES

In this section, some general methods of applying the capabilities of DYSCO are discussed.

COUPLING USING STANDARD DEGREES OF FREEDOM

All of the implemented component technology modules, except CSF1, have standardized degree of freedom names. Coupling one or more rotors (CRR2) with optional control systems (CCE1) to a rigid or elastic fuselage (CFM2) only requires that the user supply the component information as requested and no further consideration need be given to the couplings.

A simple example is shown in Figure 4. The components CRR2 and CFM2 are used. CRR2 input would specify that the flapping degree of freedom is to be used for two blades and vertical, longitudinal and pitch degrees of freedom are to be used for the hub, in addition to defining the necessary physical parameters. The input to CFM2 would specify rigid body degrees of freedom in the vertical, longitudinal, pitch directions. In addition the rotor location and orientation and the hub degrees of freedom to be coupled to the fuselage would be specified in the CFM2 input. Other input would include the physical parameters.

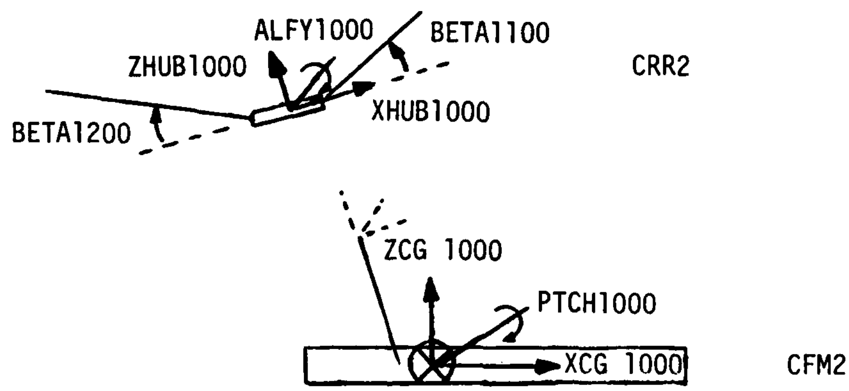

Figure 4. Simple Rotor Fuselage Model.

In the system equations for this example, the system degrees of freedom would be:

BETA1100
BETA1200
XCG 1000
ZCG 1000
PTCH1000

Any of the available solution methods may be applied to this model.

Simple variations of this model may vary the number of blades and the blade degrees of freedom, and the fuselage may contain elastic modes. Aerodynamic forces may be applied to the rotor and the fuselage through the use of appropriate force modules.

More complex examples are given in Volume II of this report.

SIMPLE CSF1 APPLICATIONS

CSF1, representing a general set of linear, constant coefficient differential equations, can be used for rather general purposes, such as an elastic pylon, vibration isolator or absorber, and landing gear, or to dynamically couple any degrees of freedom of the system. In addition, CSF1 along with FSS1 can be used to apply a sinusoidal force or moment to any system degree of freedom.

Simple Test Rig Simulation

One of the simple CSF1 applications is the simulation of a one degree of freedom test rig. Such a configuration is schematically illustrated in Figure 5.

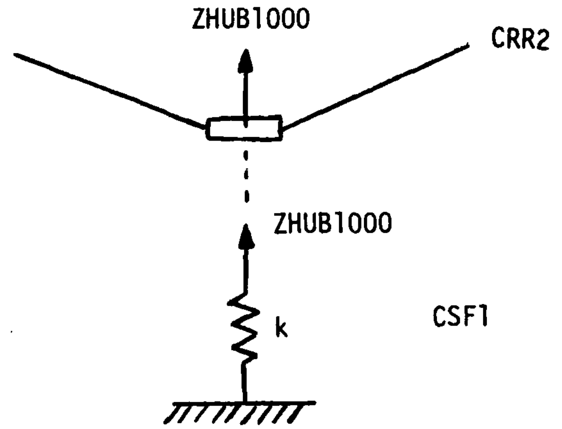

Figure 5. Simple Test Rig

In this case, the rotor CRR2 is identified as rotor number 1 and any blade and hub degrees of freedom may be selected in addition to the hub vertical degree of freedom which is automatically given the name ZHUB1000. The model of the simple rig uses CSF1 where one degree of freedom is specified, specifically named ZHUB1000 by the user. This will automatically couple the two structures in the vertical direction.

The model of the rig, then, is

$$M = [0]$$
$$C = [0]$$
$$K = [k]$$

The test rig may also be modeled with up to 40 degrees of freedom. If named degrees of freedom correspond to those of the hub, the coupling will take place with no other user interaction.

In-plane Hub Vibration Absorber (Nonrotating)

The addition of a vibration absorber at the top of the rotor pylon which acts in the longitudinal direction may be modeled as shown in Figure 6.

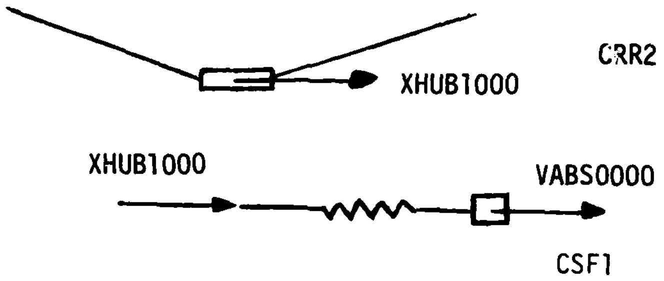

Figure 6. In-plane Hub Vibration Absorber (Nonrotating).

The rotor is modeled as in the previous example, but must include the hub longitudinal degree of freedom.

The vibration absorber has two degrees of freedom:

XHUB1000
VABS0000

The first name is necessary for the coupling and the second is completely arbitrary (except for format).

The model of the absorber is:

$$M = \begin{bmatrix} 0 & 0 \\ 0 & m \end{bmatrix}$$

$$C = \text{Null}$$

$$K = \begin{bmatrix} k & -k \\ -k & k \end{bmatrix}$$

There is no restriction on other components which may be included in the full model.

Gravity Forces

The present version of DYSCO does not specifically include gravitational forces. When a vehicle is modeled in free flight such effects are essential. Gravity may be simply simulated by the use of a CSF1 component module with an FSS1 force module supplying a force at zero frequency (cosine component) equal to the total weight of the vehicle. The CSF1 degre of freedom should be at the center of gravity of the vehicle and properly oriented and may be an explicit or implicit degree of freedom (see below). The mass, damping and stiffness matrices of this component may all be null.

As an example consider a CFM2 model of a fuselage of an 8000-lb vehicle (see Figure 7). The cg of the fuselage is at station 200 but the cg of the vehicle is at station 250. During the input to CFM2 the user would specify an implicit degree of freedom at station 250 with the user-designated name CG 0000. A CSF1 component with a single degree of freedom, CG 0000, and M = C = K = 0 would then be specified and a constant force of -8000 lb defined for FSS1.

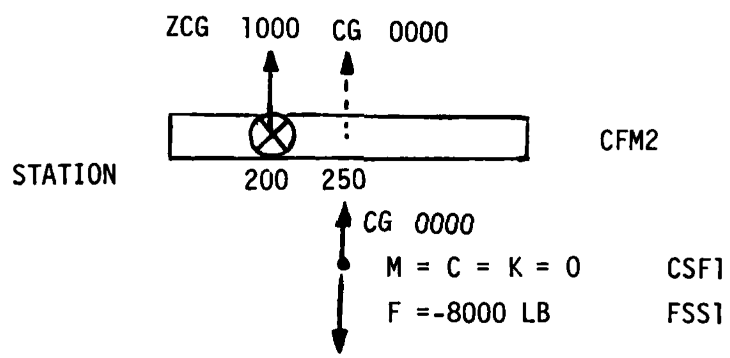

Figure 7. Example of Gravity Force.

In a similar fashion gravitational forces could be applied to individual components.

IMPLICIT (INTERFACE) DEGREES OF FREEDOM

Some of the component modules (CFM2, in particular) have the capability to treat implicit degrees of freedom. These are not degrees of freedom of the component itself but of another component where a linear relationship exists between the degrees of freedom of the two components.

Fuselage Vibration Absorber

The addition of a vibration absorber to a fuselage may be modeled as shown in Figure 8.

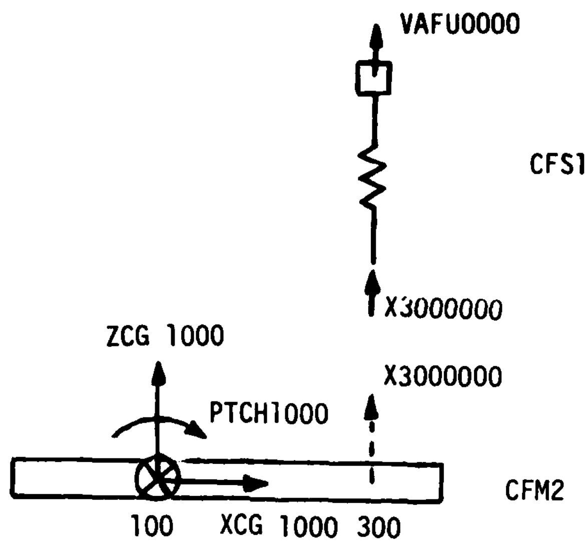

Figure 8. Fuselage Vibration Absorber.

In this figure, the vibration absorber is attached at station 300 of the fuselage. The vibration absorber has an interface which is not a degree of freedom of the fuselage. Input to CFM2 allows the user to specify the name of an implicit degree of freedom (X3000000*, in this case) and to specify the location and angular orientation. CFM2 will automatically develop the relationship

X3000000 = ZCG 1000 - 200 * PTCH1000

if only rigid body modes are used, and will also include the elastic modes, if any are used. If X3000000 were tilted forward 45°, the relationship would be:

X3000000 = -.707 * XCG 1000 + .707 * ZCG 1000 - 141. * PTCH1000

This process is completely transparent to the user, and all the proper couplings are automatically performed.

*Since degree of freedom names are arbitrary (except for A4,I4 format), convenient designations are possible, such as the inclusion of the station value.

Elastic Pylon

In a similar fashion, an elastic pylon may be modeled as shown in Figure 9.

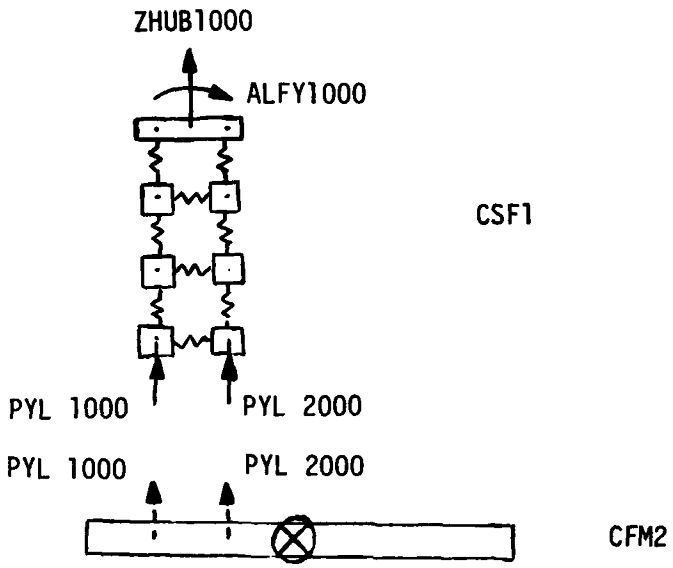

Figure 9. Elastic Pylon.

In this figure, an 8-degree-of-freedom pylon is shown attached to the fuselage at two points and to rotor 1 (hub vertical and pitch degrees of freedom).

All the degrees of freedom of the pylon must be named and all are arbitrary except those used as interfaces. The only other input is to describe PYL 1000 and PYL 2000 in the input to CFM2.

SPECIAL EFFECTS

Several examples of special effects are given below.

Elastic Coupling

It is possible to connect any two degrees of freedom with a spring and damper. In Figure 10 two CFM2 components are so connected.

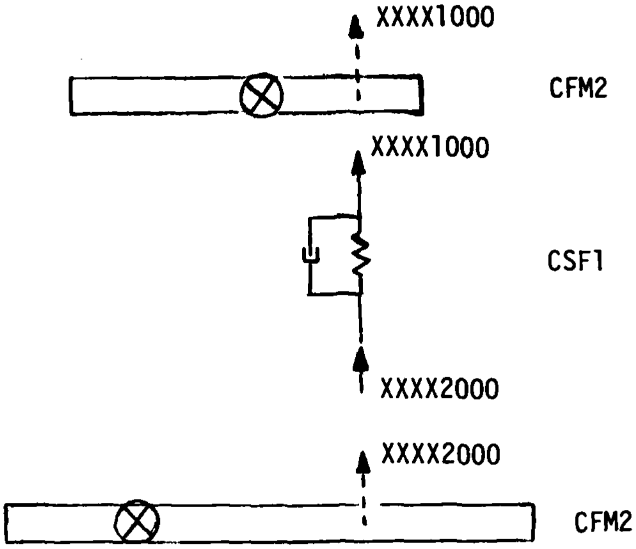

Figure 10. Elastic Coupling of Two CFM2 Components.

Damage Analysis

It is possible to model certain damage to structures and springs or dampers conveniently with CSF1. The loss of a single blade lag damper, for example, is represented simply by

1 degree of freedom: ZETA1100

$M = K = \text{null}$

$C = [-c]$

Where c is the damping value of the lag dampers specified in CRR2 for rotor number 1. Partial failure may be similarly modeled.

Similarly, lumped masses may be added or removed from any nonrotating component. For a rotating component, only terms in the equations which are constant may be modified with CSF1.

Direct Linkage

Any two (or more) degrees of freedom may be made equal by a simple process using CFM2. Select only a rigid vertical mode and define implicit degrees of freedom on the structure. This constraint will force all of these degrees of freedom to be equal. In Figure 11, the degrees of freedom X1, X2, X3, X4, and X5, using literal names only, will all be equal and replaced by ZCG 5000 in the system degrees of freedom. In this example the stations of the implicit degrees of freedom are arbitrary and may all be the same (e.g., 0).

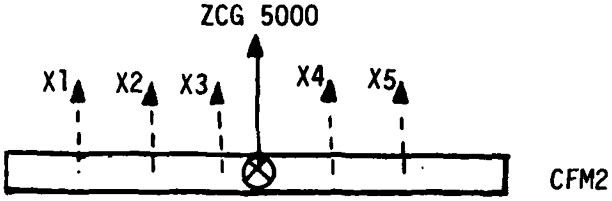

Figure 11. Constraint of Degrees of Freedom.

Teetering Rotor

In a manner similar to the above example, a rigid teetering rotor may be simulated by adding the CFM2 component shown in Figure 12 to a CRR2 component model of a two-bladed articulated rotor with a hinge offset equal to zero.

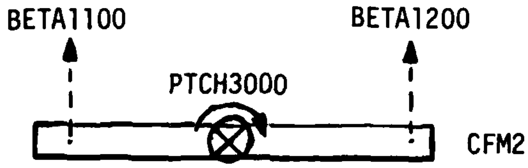

Figure 12. Constraint to Simulate Teetering Rotor.

In this case, BETA1200 is forced to equal -BETA1100. These two degrees of freedom will be replaced by (+ and -) PTCH3000 in the system degrees of freedom. The stations of the implicit degrees of freedom must be equally spaced with regard to the center of gravity (e.g., 1, + 1, with center of gravity station equal to 0). Note that even though the flapping degrees of freedom are actually angles and the implicit degrees of freedom are displacements, the relationships as shown are still valid.

APPENDIX A

FRA2 TABLES

In the present implementation of DYSCO the data base is invisible to the user, except when airfoil tables or induced velocity maps are used in FRA2. For this usage the following information is required.

DATA BASE DEFINITION

The DYSCO data base for a particular run is composed of all direct access and all sequential files which may be referenced during the run.

Direct Access Files

There are two types of direct access files: The run data file (RDF) and the user data file (UDF).

The RDF is a specific file that is always present during a run; it is used by the program to pass information and data between different execution steps. It's structure is identical to a user data file and may be specified by the user wherever a UDF is appropriate. The RDF is a temporary file and is always initialized automatically at the start of the DYSCO run. The logical unit for the RDF is 11.

There can be up to four UDFs present in a run. A UDF is used to store data that are more permanent in nature than the data stored on the RDF. Typically the user may create data, use the data within the run, and save it for a subsequent DYSCO run. Each UDF is inspected by DYSCO and is initialized or not, as described below. Currently, UDFs may be used only to create (CREA command) airfoil tables to be saved permanently and used by the force module FRA2.

Sequential Files

The user may assign up to five sequential files to a run. The logical unit numbers available are 21-25; however, the units must be assigned sequentially, starting with 21.

DATA BASE INITIALIZATION

At the start of the DYSCO run the user is prompted for information to initialize the DYSCO data base. The user inputs the number of user direct access files (UDF) for the run (Ø-4).

If the number of UDFs is not zero, each UDF is inspected for initialization requirements. The first record is read (Format 20A4) and one of the following actions is taken:

1. If all blanks - the file is initialized in DYSCO format.

2. If recognized as previously initialized by DYSCO - it is assumed to be a good DYSCO file and no action is taken.

3. If otherwise - an error condition results in run termination.

The UDFs are assumed to be assigned sequentially to units 12-15. Thus, if there are two UDFs, they must be assigned units 12 and 13.

The sequential files are assumed to be assigned sequentially to units 21-25. No validation is performed with respect to the presence of the files.

AIRFOIL TABLES

The user has options regarding the use of airfoil tables. He may establish one or more UDFs containing various sets of data or he may create a temporary file in the RDF for the current run only. The user uses the command CREA to transfer data from a sequential file to a UDF or the RDF. If a UDF is used, the file may be treated as permanent and need not be recreated in future runs of DYSCO.

Command CREA

This command is used to create an airfoil table on a direct access file. The table must have been written to a sequential file in a specified format (see below) prior to the DYSCO run. The user is prompted for the unit number of the sequential file containing the table and for the direct access file on which the table will be created.

The user also supplies a name (up to 8 characters) by which the table will be known to the DYSCO program. The name must be unique with respect to other airfoil tables which may already be on the direct access file specified or any other direct access file known to the current run.

The FORTRAN statements used to write an airfoil table on a sequential file in proper format prior to the DYSCO run are as follows:

```
      REWIND   NFILE
      WRITE (NFILE,100) NOALFA,NOMACH,(IHEAD(I),I=1,18)
      WRITE (NFILE,200) ((AMACH(J),ALPHA(I),CL(I,J),CD(I,J),CM(I,J),
                   I=1,NOALFA),J=1,NOMACH)
  100 FORMAT (2I10/18A4,8X)
  200 FORMAT (7X,F6.4,F7.2,3F10.6)
```

The variables are defined as

NFILE	-	Logical unit number of the sequential file
NOALFA	-	Number of angles of attack (Ø<NOALFA≤49)
NOMACH	-	Number of Mach numbers (Ø<NOMACH≤5)
IHEAD	-	72 character user description
AMACH(J)	-	Jth Mach number
ALPHA(I)	-	Ith angle of attack, deg
CL(I,J)	-	Lift coefficient corresponding to the Ith angle of attack and the Jth Mach number
CD(I,J)	-	Drag coefficient corresponding to the Ith angle of attack and the Jth Mach number
CM(I,J)	-	Moment coefficient corresponding to the Ith angle of attack and the Jth Mach number

The angles of attack for each Mach number are from 0 to 360. The chordwise reference is the 1/4 chord.

INDUCED VELOCITY MAP

An induced velocity map is an option in FRA2. In DYSCO it is treated as temporary data and no provisions are made for permanent storage on one of the UDFs but it is read directly from a sequential file.

The required prompted input is the unit number of a sequential file containing the table.

The FORTRAN statements used to create a table in the proper format are as follows:

```
      REWIND NFILE
      WRITE (NFILE,1ØØ) NX1,NOPSI,(XIN(J), J=1,NX1)
      DO 1Ø I=1, NOPSI
      WRITE (NFILE,2ØØ) BPSI (I)
1Ø    WRITE (NFILE,2ØØ) (ALAMØ(I,J),J=1,NX1)
1ØØ   FORMAT (2I1Ø/(8F1Ø.6))
2ØØ   FORMAT (8F1Ø.6)
```

The variables are defined as:

NFILE	-	Logical unit numbers of sequential file
NX1	-	Number of blade stations (Ø<NX1≤2Ø)
NOPSI	-	Number of azimuth stations (Ø<NOPSI≤36)
BPSI(I)	-	Ith azimuth station at which induced velocity is available in table, deg (0-360)
XIN(J)	-	Jth radial station at which induced velocity is available in table, in.
ALAMØ(I,J)	-	Induced velocity corresponding to the Ith azimuth station and the Jth radial station, nondimensional, positive up, shaft reference

It should be noted that the radial stations need not directly correspond to the blade stations used in the component module.

APPENDIX B

INSTALLATION NOTES

DYSCO is written entirely in FORTRAN IV and is compatible with IBM systems. It consists of approximately 120 subroutines. The subroutines are self documented.

For convenience all the subroutines are listed in alphabetical order, preceded by BLOCK DATA subprograms and the MAIN program.

The input, output, and file unit numbers are established in the first BLOCK DATA subprogram and the DEFINE FILE statements are in SUBROUTINE XB. The input and output logical unit numbers are 5, 6 and the direct access file unit numbers are 11 - 15. Only file 11 is required unless aerodynamic tables are used (see Appendix A).

The define file statements are of the form:

```
DEFINE FILE 11 (5ØØ, 8Ø, E, ASSO11)
```

The free form numerical input statements are of the form:

```
READ(IN,*)
```

The program was installed on the TSARCOM St. Louis IBM 4341 computer and was demonstrated on the Applied Technology Laboratory computer terminal using CMS.

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