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USER'S GUIDE FOR THE ROTORCRAFT FLIGHT SIMULATION COMPUTER PROG--ETC(U)
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**USER'S GUIDE FOR THE ROTORCRAFT FLIGHT SIMULATION
COMPUTER PROGRAM C81, AGAP80 VERSION, CDC CONVERSION**

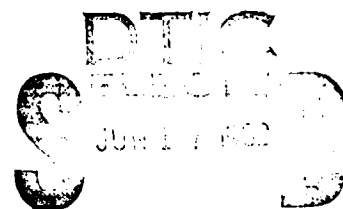
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Warminster, Pennsylvania 18974

MARCH 1982

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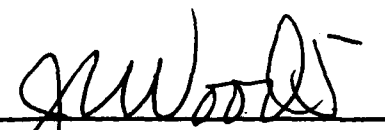
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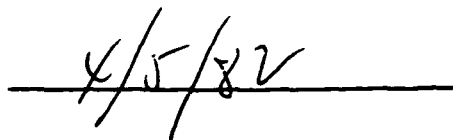
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The current version of the Rotorcraft Flight Simulation Program C81, AGAP80, was installed in a CDC converted form on the CDC CYBER 175/CDC 6600 Computer System at NAVAIRDEVCON. The problems encountered in validating this CDC conversion, using the TR-80-D-38A User's Manual sample case as a test case, are described. The program capabilities in the area of Flight Dynamics analysis are repeated as a quick guide to the user in order to maintain continuity with the USAAVRADCOM-TR-80-D-38A User's Manual. This report is (continued on other side)		

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not meant to supercede TR-80-D-38A. An effort is made throughout the description of the program capabilities to provide the user with a description of the inputs required to perform that particular program operation and the output data that resulted. The user is referred to the TR-80-D-38A User's Manual for the information necessary for assembling a complete input data deck and to successfully execute the program. There were two program operation problems identified while running test cases on this CDC conversion of the AGAP80 version. These two were the inability to perform any of the postprocessing operations of GDAP80 and the inability to compute eigenvalues in the rotorcraft stability analysis. The cost of running this program at NAVAIRDEVCON to perform a trimmed flight analysis, a rotorcraft stability analysis, and a maneuver simulation is discussed.

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INTRODUCTION

The purpose of this document is to provide an abbreviated user's guide for the current version of the Rotorcraft Flight Simulation Program C81 as installed at NAVAIRDEVCEEN. This document is to be used as a quick guide to the program capabilities of C81 in the area of Flight Dynamics analysis. It also describes the problems encountered with the current version of the program, designated AGAP80, as delivered to this Center. It should be noted that the problems that are described herein are associated with the copy of the CDC converted program that is installed on the CDC CYBER 175/CDC 6600 Computer System at NAVAIRDEVCEEN and are not considered universal.

The Rotorcraft Flight Simulation Program C81 has been developed and under continual update/revision since the early 1960's by Bell Helicopter Textron under contract with the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Ft. Eustis, VA. All versions of the program have been developed for usage on an IBM computer system. Early in 1980 the Naval Air Development Center and the NASA Langley Research Center expressed interest in a CDC conversion of the program for their CDC CYBER computer systems. A successful conversion of the program was completed in June, 1980 by Mr. Robert Tomaine of the Army Structures Laboratory and a magnetic tape of the program source was delivered to NAVAIRDEVCEEN in July, 1980.

This conversion was done to the most current version of the computer program and is referred to as AGAP80.

After many installation problems were overcome, the program was installed on the CDC CYBER 175/CDC 6600 Computer System at NAVAIRDEVCEEN in March, 1981. The period from March through September, 1981 was devoted to validation of the CDC conversion on NAVAIRDEVCEEN's computer system and understanding of the program capabilities and applications.

A complete input data deck for an AH-1G helicopter was provided with the source tape as a sample case for validating the program at NAVAIRDEVCEEN. This AH-1G data deck is used throughout this report to illustrate the program capabilities.

An effort is made throughout the description of the program capabilities to provide the user with a description of the inputs required to perform that particular program operation and the output data that resulted. The user is referred to the user's manual for the AGAP80 version (reference 1) for the information necessary for assembling a complete input data deck and to successfully execute the program.

Two program operation problems were identified while running test cases to check out each of the program operational capabilities. These two were the inability to perform any of the postprocessing operations of GDAP80 and the inability to compute the rotorcraft characteristic equation roots and associated transfer functions in the rotorcraft stability analysis. Both of these problems are associated with the copy of the AGAP80 version that is installed at NAVAIRDEVCEEN and are not universal problems with this program. The cause of the postprocessing problem has been identified and is relatively easy to fix, while the eigenvalue calculation problem is still under investigation.

This program provides the capability to analytically examine the flying qualities characteristics of a given model of helicopter, whether it be single, tandem, or tilt rotor. The input data can be minimal for a rough first-cut examination of a preliminary design, or extensive for a simulation of an existing aircraft for which fuselage aerodynamic, airfoil, aeroelastic blade, and rotor induced velocity distribution data are already known through previous testing.

This program can perform a trimmed flight analysis, a rotorcraft stability analysis, parameter sweeps of trimmed flight conditions, and a maneuver simulation. It also can retrieve maneuver time-history data stored on magnetic tape, print plots of time-history data, and store maneuver time-history data on tape. The program has other postprocessing capabilities which are performed on time-history data which would be of interest to structural analysis engineers. All of these operational capabilities are discussed in this report.

PROGRAM CAPABILITIES

AGAP80 OPERATIONS

The AGAP80 version of the C81 program is capable of performing the following general operations:

- 1) Compute a trimmed flight condition
- 2) Perform a rotorcraft stability analysis
- 3) Perform parameter sweeps of trim conditions, with or without a rotorcraft stability analysis
- 4) Compute a maneuver with or without a rotorcraft stability analysis
- 5) Retrieve maneuver time-history data stored on magnetic tape

These five operations are illustrated in the flow charts given in figures 1 through 8. The block labelled "OPERATIONS ON TIME-HISTORY DATA" represent the execution of the postprocessing program, GDAP80.

Each of the AGAP80 operations or combination of operations is controlled by input data. Since the amount of data to be read depends on the operation or operations desired, a data deck in this context consists of a message card, an "NPART" card telling the program which primary operation or operations to perform, and the additional data necessary to perform the indicated operations. In some cases the additional data are contained on 500 or more additional cards, while in other cases, as little as a few cards of additional data is required for the AGAP80 input deck.

The second step in several of the flow charts is "CALCULATE PROBLEM CONSTANTS." In each operation containing this step, a number of quantities which remain constant throughout the performance of the operations must be defined using the input data. Performing such computations drastically reduces the number of program inputs and also provides program flexibility necessary for incorporating such operations as parameter sweeping.

TRIMMED FLIGHT

In finding the trim point, the program iterates on the control positions, fuselage orientation, rotor attitude and/or engine power to reach desired values of the rotor flapping moments, forces and moments on the aircraft center of gravity and/or engine horsepower. When these desired values are achieved the rotorcraft is trimmed.

The program also permits the calculation of two steady but accelerated flight conditions. In one, the rotorcraft is in a pushover or pullup condition at an input g-level. In the other, the rotorcraft is in a banked turn, either level or spiral, at an input g-level. In these cases, the desired net forces and moments on the rotorcraft are not all zero, but depend on the user-requested g-level. Either an unaccelerated or steady accelerated flight condition may be used as the starting point of a maneuver simulation.

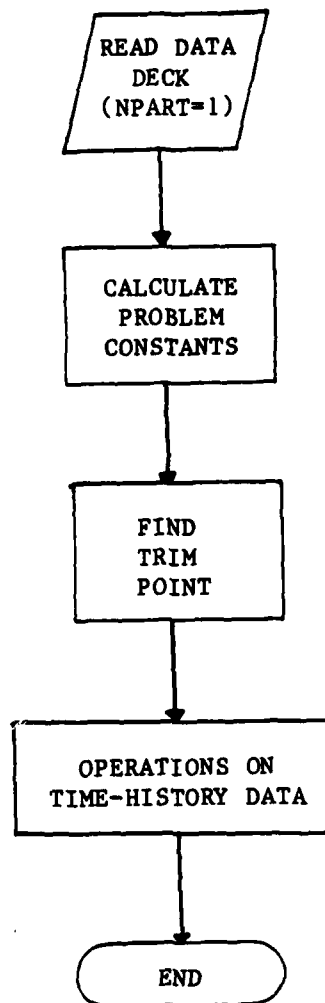


Figure 1. Trim-Only Operation.

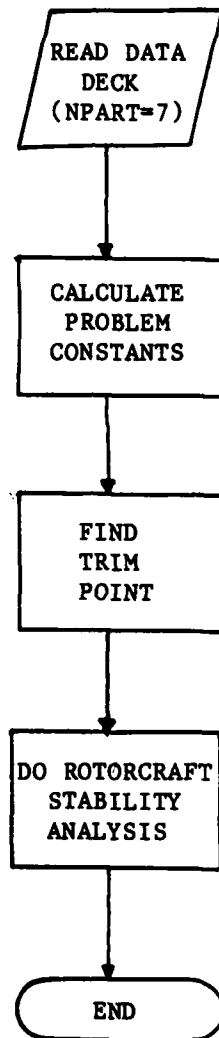


Figure 2. Trim and Rotorcraft Stability Analysis.

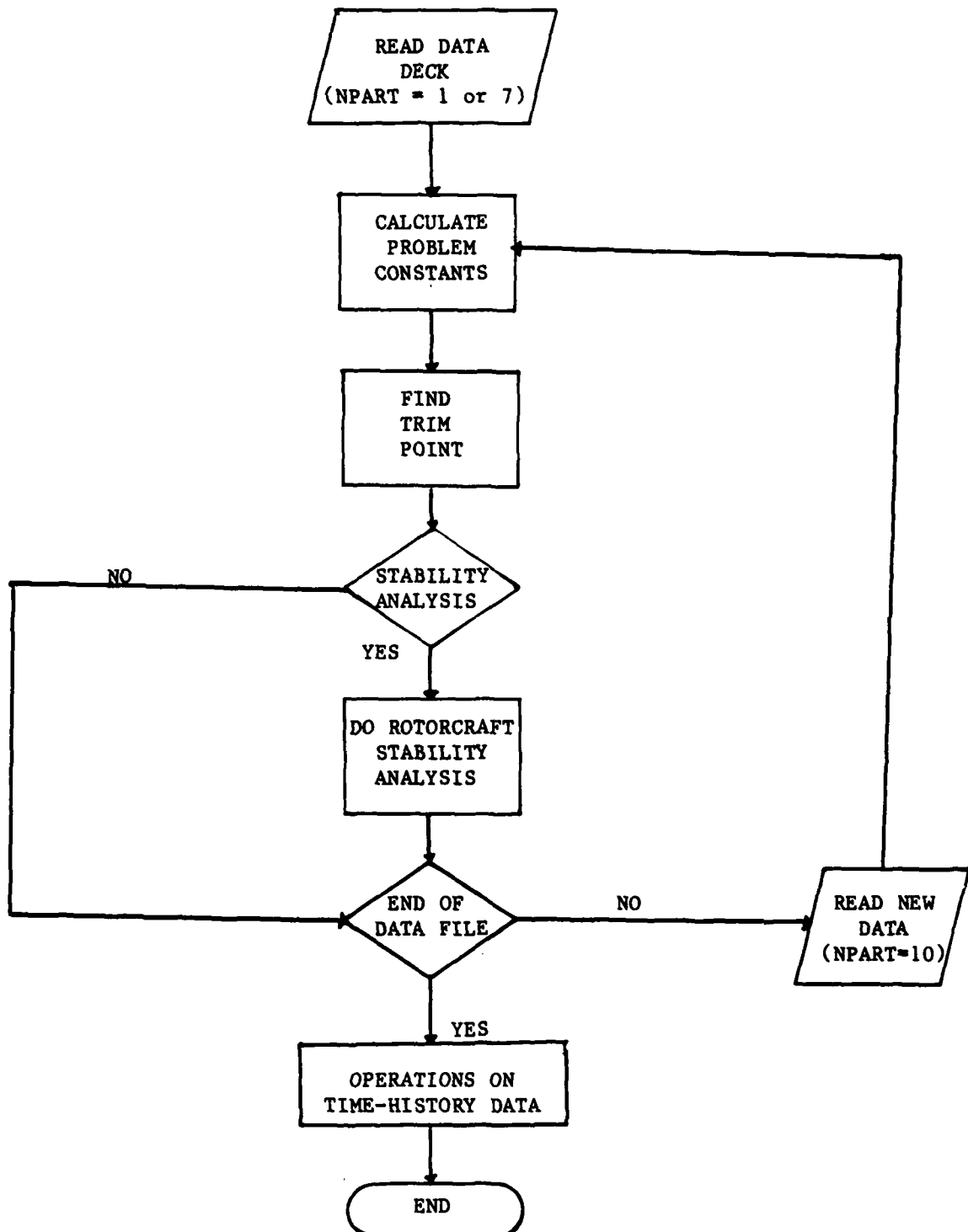


Figure 3. Trim or Trim and Rotorcraft Stability Analysis Followed by Parameter Sweep.

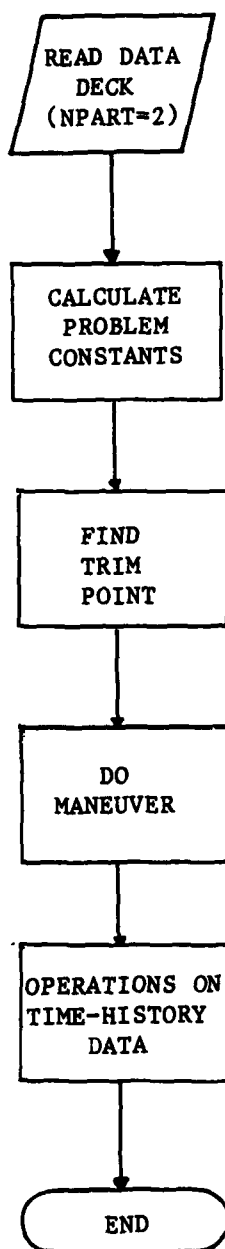


Figure 4. Trim Followed by Maneuver.

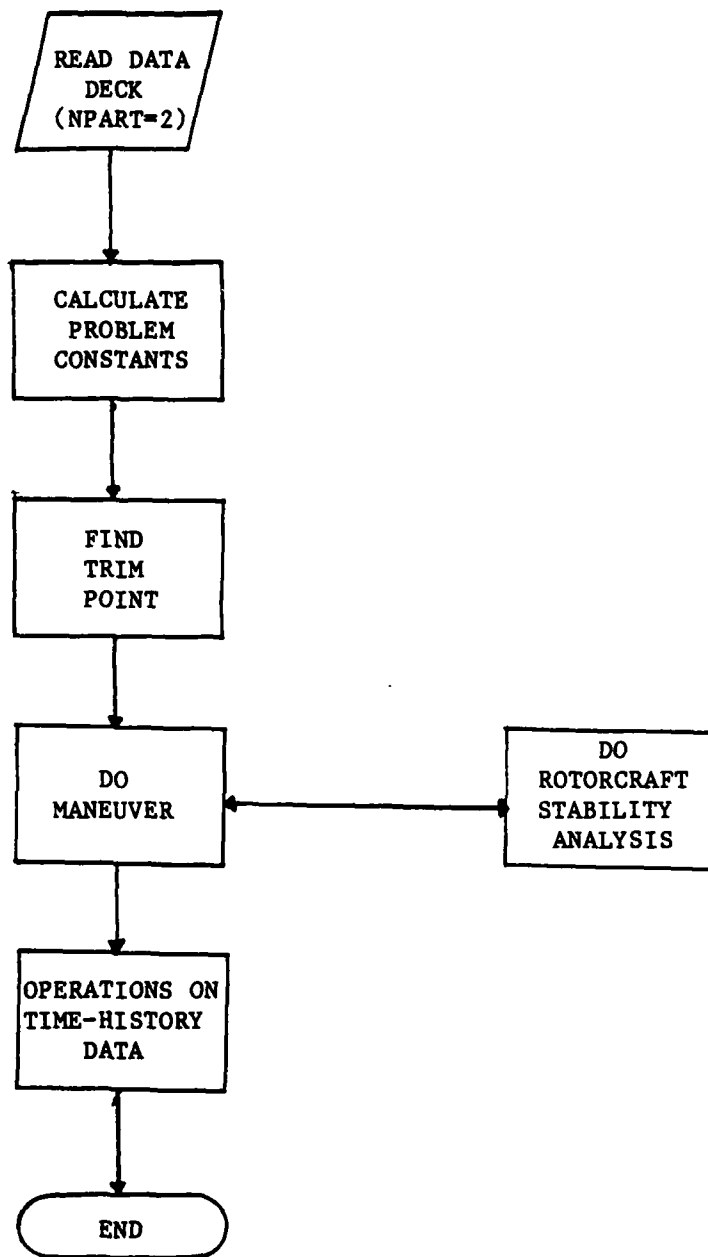


Figure 5. Trim Followed by Maneuver with Rotorcraft Stability Analysis.

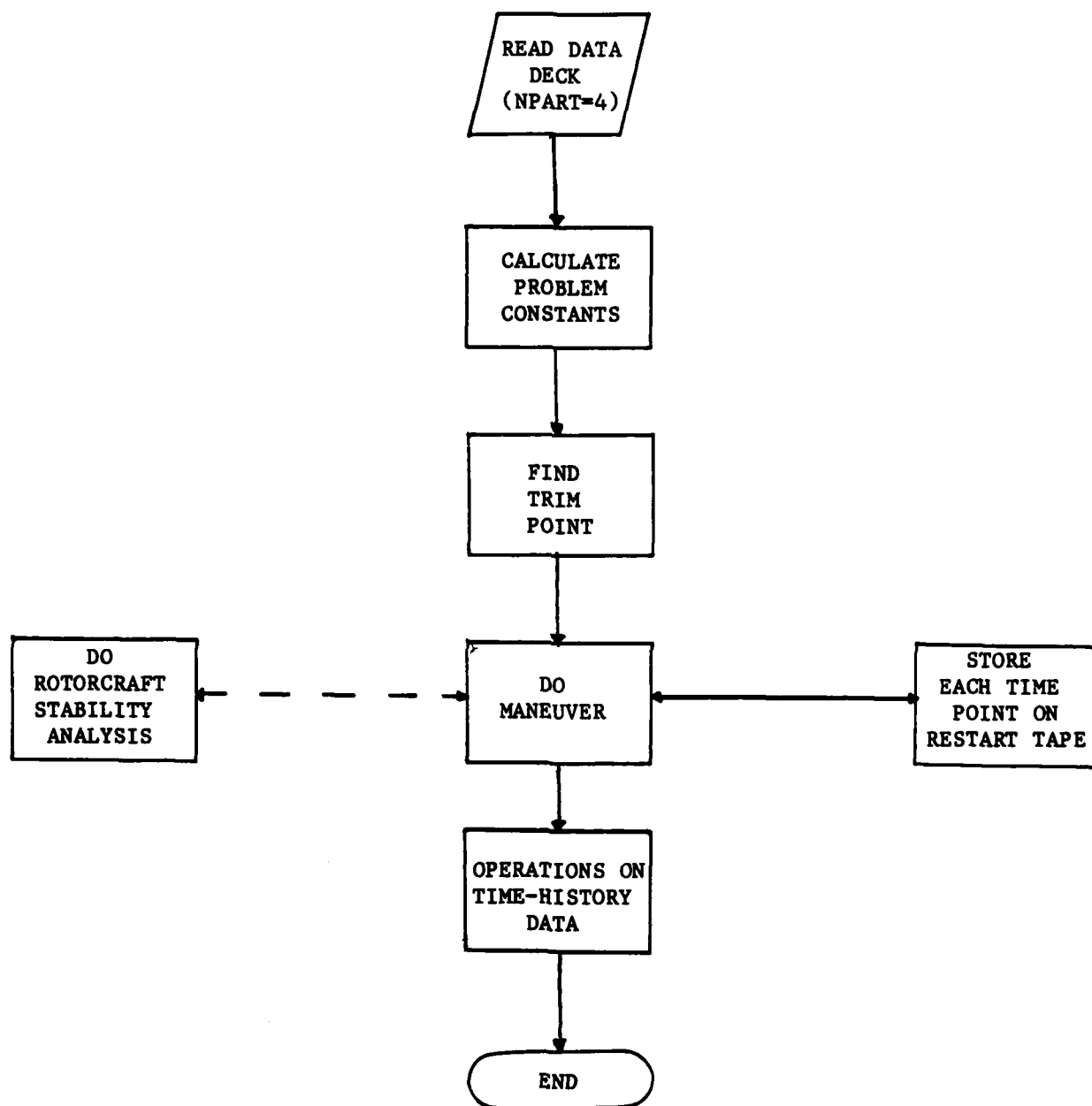


Figure 6. First Maneuver in Restart Procedure.

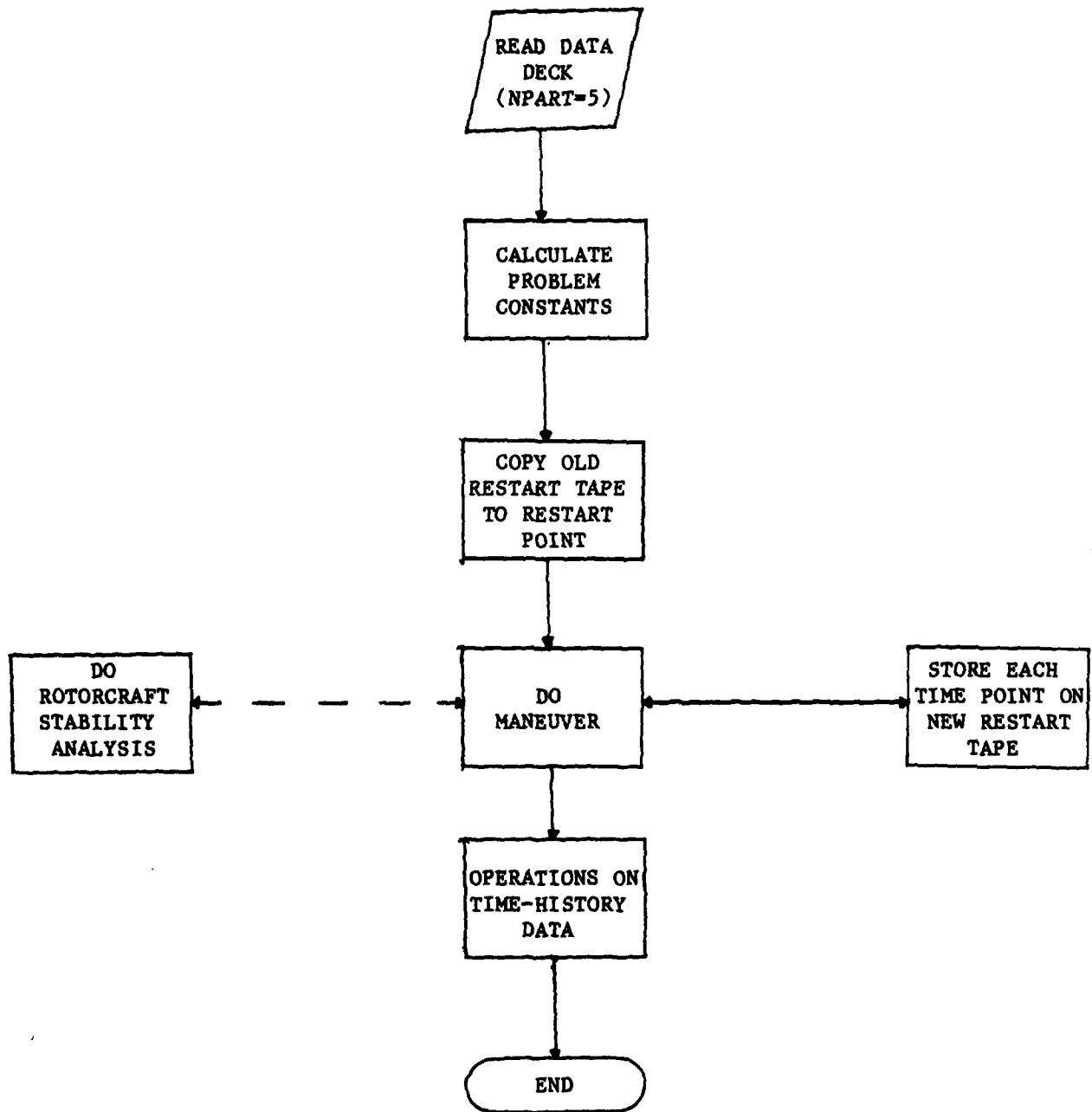


Figure 7. Second and Later Restart Maneuvers.

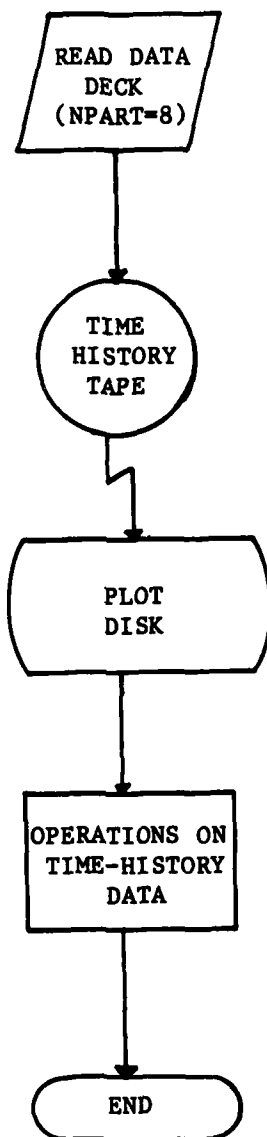


Figure 8. Retrieving Maneuver Data Stored Permanently.

A complete input data deck for AGAP80 can be divided into the 53 groups or sets of cards listed in table I. The first 45 groups form the basic card deck, which is used for trim-only and trim-and-rotorcraft-stability-analysis-only program operations. The remaining eight groups are only included in the deck when a maneuver is to be simulated.

A sample input data deck for a trim followed by maneuver is presented in Appendix A. Some of the more significant inputs will be discussed here, but for a more detailed explanation of all the inputs see reference 1. In discussing the input data, attention will be directed to the card numbers printed in columns 73-80.

NPART Card

In order to compute a trimmed flight condition the NPART card (card 002) requires a "1" in column 1-2. This card includes the primary program control variable, NPART. Permissible values of NPART on this card are 1,2,4,5,7, and 8. The value of NPART specifies the type of operation to be performed.

- 1 = Trim only
- 2 = Trim followed by maneuver (maneuver not to be restarted)
- 4 = Trim followed by maneuver (maneuver to be restarted)
- 5 = Maneuver restart
- 7 = Trim followed by rotorcraft stability analysis
- 8 = Retrieve maneuver data from tape for analysis

Program Logic Group

The Program Logic Group (cards 006-013) is one of the most important groups in the deck because it contains the bulk of the program logic controls. It controls which groups must be included in the deck and the program options that will be used in the computations. This group consists of seven cards with 14 integer inputs per card. Each element of the IPL array is identified as IPL(1-98). Sections 2.3 and 4.3 of reference 1 describe in brief and in detail respectively all of the program logic inputs. The logic inputs control the three phases of the C81 program:

- 1) Input group control logic - controls the data groups which must be included in the input data.
- 2) Analysis logic - controls the program options to be used such as unsteady aerodynamics, time-variant rotor analysis, etc.
- 3) Output control logic - controls the data to be output.

The logic has been chosen so that for the simplest cases most inputs are zero. In general, nonzero inputs activate the options and/or necessitate inputs of additional data.

Quasi-Static vs. Time-Variant Trim Analysis

IPL (49) and (50) are the program logic inputs that control the type of trim analysis performed. AGAP80 includes three types of trim procedure:

- 1) Quasi-Static (QS) Trim
- 2) Quasi-Static followed by Time-Variant Rotor (QS-TV) Trim
- 3) Fully Time-Variant (FTV) Trim

TABLE I SEQUENTIAL SUMMARY OF INPUT GROUPS

GROUP TITLE	AGAP80 SEQUENCE NUMBER OF ID CARD *	AGAP80 SEQUENCE INPUT CARD NUMBERS **	REFERENCE CARD SEQUENCE NUMBER ****
Deck Identification & Program Flow Control Cards	None	00 - 04	001 - 005
Program Logic Group	10	10 - 17	006 - 013
Airfoil Data Table Group			
Airfoil Data Table Set No. 1	21	21/A,/B1,/C1,/D1	014 - 295
Airfoil Data Table Set No. 2	22	22/A,/B1,/C1,/D1	296 - 506
Airfoil Data Table Set No. 3	23	23/A,/B1,/C1,/D1	N/A
Airfoil Data Table Set No. 4	24	24/A,/B1,/C1,/D1	N/A
Airfoil Data Table Set No. 5	25	25/A,/B1,/C1,/D1	N/A
Airfoil Data Table Set No. 6	26	26/A,/B1,/C1,/D1	N/A
Airfoil Data Table Set No. 7	27	27/A,/B1,/C1,/D1	N/A
Airfoil Data Table Set No. 8	28	28/A,/B1,/C1,/D1	N/A
Airfoil Data Table Set No. 9	29	29/A,/B1,/C1,/D1	N/A
Airfoil Data Table Set No. 10	2A	2A/A,/B1,/C1,/D1	N/A
Rotor 1 Group	30	30 - 3P	507 - 524
Rotor 1 Elastic Pylon Group	40	40 - 4V	N/A
Rotor 1 Elastic Blade Data Group	50	50 - 5C	525 - 765
Rotor 2 Group	60	60 - 6P	766 - 774
Rotor 2 Elastic Pylon Group	70	70 - 7K	N/A
Rotor 2 Elastic Blade Data Group	80	80 - 8C	N/A
Rotor Aerodynamic Group	90	90 - 9AE	775 - 785
Rotor 1 Rotor-Induced Velocity Distribution (RIVD) Table	100	100 - 100/F	786 - 1029
Rotor 2 RIVD Table	110	110 - 110/C	N/A
Rotor-Wake-at-Aerodynamic- Surface (RWAS) Table Group			
RWAS Table No. 1	***	***	N/A
RWAS Table No. 2	***	***	N/A
RWAS Table No. 3	***	***	N/A
RWAS Table No. 4	***	***	N/A
RWAS Table No. 5	***	***	N/A
RWAS Table No. 6	***	***	N/A
RWAS Table No. 7	***	***	N/A
RWAS Table No. 8	***	***	N/A
RWAS Table No. 9	***	***	N/A

TABLE I (Continued)

GROUP TITLE	AGAP80 SEQUENCE NUMBER OF ID CARD *	AGAP80 SEQUENCE INPUT CARD NUMBERS **	REFERENCE CARD SEQUENCE NUMBER ****
RWAS Table No. 10	***	***	N/A
RWAS Table No. 11	***	***	N/A
RWAS Table No. 12	***	***	N/A
Basic Fuselage Group	120	120 - 125	1030 - 1032
Fuselage Aerodynamic Group or Fuselage Aerodynamic Table	130	130 - 13C	1033 - 1044
Wing Group	140	140 - 14C	1045 - 1055
Stabilizing Surface Groups			
Stabilizing Surface No. 1	150	150 - 15B	1056 - 1065
Stabilizing Surface No. 2	160	160 - 16B	1066 - 1077
Stabilizing Surface No. 3	170	170 - 17B	1078 - 1089
Stabilizing Surface No. 4	180	180 - 18B	N/A
Jet Group	190	190 - 192	N/A
External Store/Aerodynamic Brake Group	200	200 - 204C	N/A
Rotor Controls Group	210	210 - 21B	1090 - 1094
Iteration Logic Group	220	220 - 22B	1095 - 1098
Flight Constants Group	230	230 - 234	1099 - 1103
Bobweight Group	240	240 - 241	N/A
Weapons Group	250	250 - 251	N/A
SCAS Group	260	260 - 264	N/A
Stability Analysis Times Group	270	270 - 272	N/A
Blade Element Data Printout Times Group	280	280 - 282	N/A
Maneuver Time Card	None	291	1104
Maneuver Specification Cards	None	301 - 30Z	1105 - 1110
Maneuver Analysis Cards	None	GDAP80 Input Cards	1111 - 1117

* "None" indicates that the group does not have an identification (ID) card.

** C81 Program AGAP80 version sequence card numbers for input data deck as described in Reference 1.

*** No specific sequence number on RWAS Table Cards.

**** Refers to card sequence number in columns 73 - 80 of sample input data deck in Appendix A.

"N/A" indicates that the group is not included in the sample input data deck.

The terms Quasi-Static and Time-Variant refer to the primary rotor analyses that are used in the procedure. Both analyses can include the effects of blade elasticity (mode shapes other than the rigid body mode shape), but only the Time-Variant analysis can include the interaction of the aerodynamic loads and blade elasticity, i.e., aeroelasticity. In the QS trim procedure, the Quasi-Static rotor analysis is used for both rotor systems. In the QS-TV trim procedure, the standard QS trim is performed first. The rotor modal equations of motion are then numerically integrated for a prescribed number of rotor revolutions using the Time-Variant rotor analysis with the control positions and fuselage orientation held fixed at the positions determined by the QS trim. It is assumed that after a number of revolutions, the aeroelastic effects included in the Time-Variant analysis will have caused the rotor either to stabilize or diverge, depending on the basic stability of the rotor system. The user may select that such Time-Variant trims be computed for either or both rotors. If both rotors are selected, the two Time-Variant trims are computed independently of each other. In the FTV trim procedure, the user specifies the rotor or rotors which use the Time-Variant analysis. In doing so, any reference to the QS trim procedure is deleted for the specified rotor(s). A rotor which does not use the Time-Variant analysis uses the Quasi-Static analysis. Table II shows the type of rotor analysis used for each rotor as a function of the values of IPL(49) and (50).

Trim Procedure

The basic program flow, which is the same for all three types of trim, is shown in figure 9. The three basic blocks in the figure are the computation of the partial derivative matrix (shown in figure 10), the Time-Variant portion of the QS-TV trim (shown in figure 11), and the rotor force and moment computations (shown in figure 12).

Trimmed Flight Printout

Two types of printouts are possible for the data computed in the last trim iteration, the standard trim page (figure 13) and the optional trim page (figure 14). The standard trim page follows the final trim iteration. The final trim iteration occurs either when all forces and moment imbalances are within their respective allowable errors or after the iteration limit for trim has been reached. These allowable errors and the iteration limit are inputs of the Iteration Logic Group.

Printout of the optional trim page is controlled by IPL(73) (Program Logic Group). The optional trim page is most useful for presenting data from a wind tunnel simulation. The optional trim page contains the following information: 1) problem identification; 2) a parameter listing of rotor controls, rotor parameters, wind tunnel parameters, and program options; 3) rotor forces and moments listed in both wind reference and shaft reference systems, and 4) a summary of the beam, chord, and torsional rotor loads is printed if rotor blade elastic mode shapes have been included in the analysis.

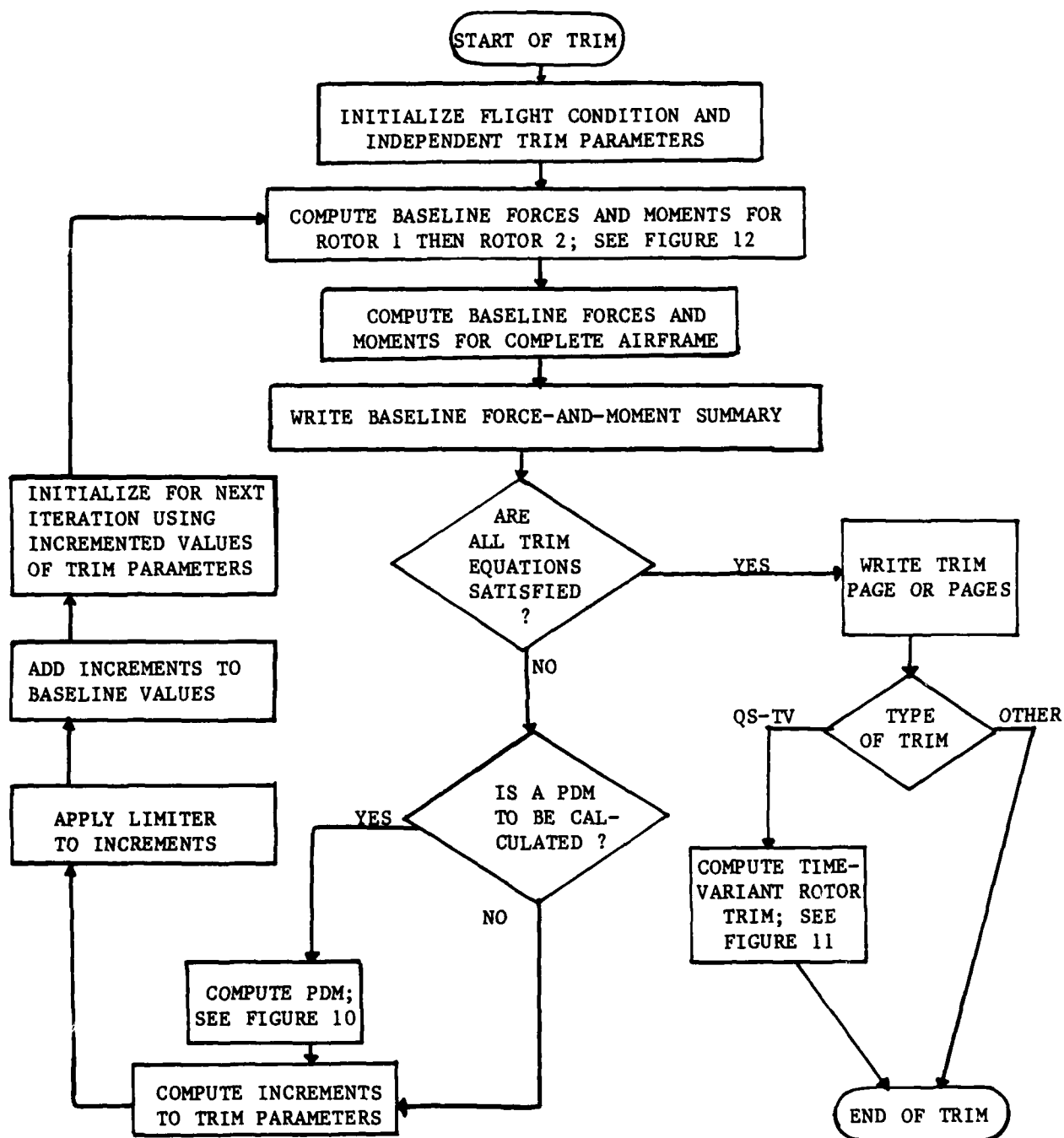
TABLE II ROTOR ANALYSIS USED DURING TRIM AND MANEUVER

<u>Inputs</u>		<u>Analysis Used</u>		
<u>IPL(49)</u>	<u>IPL(50)</u>	<u>Rotor</u>	<u>In Trim</u>	<u>In Maneuver</u>
0	(Ignored)	{ 1 (Main) 2 (Tail)	QS QS	QS QS
1	0	{ 1 2	QS-TV QS	TV QS
	1	{ 1 2	QS QS	TV QS
	2	{ 1 2	TV QS	TV QS
	0	{ 1 2	QS QS-TV	QS TV
	1	{ 1 2	QS QS	QS QS
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	2	{ 1 2	TV TV	TV TV

QS = Quasi-Static rotor analysis

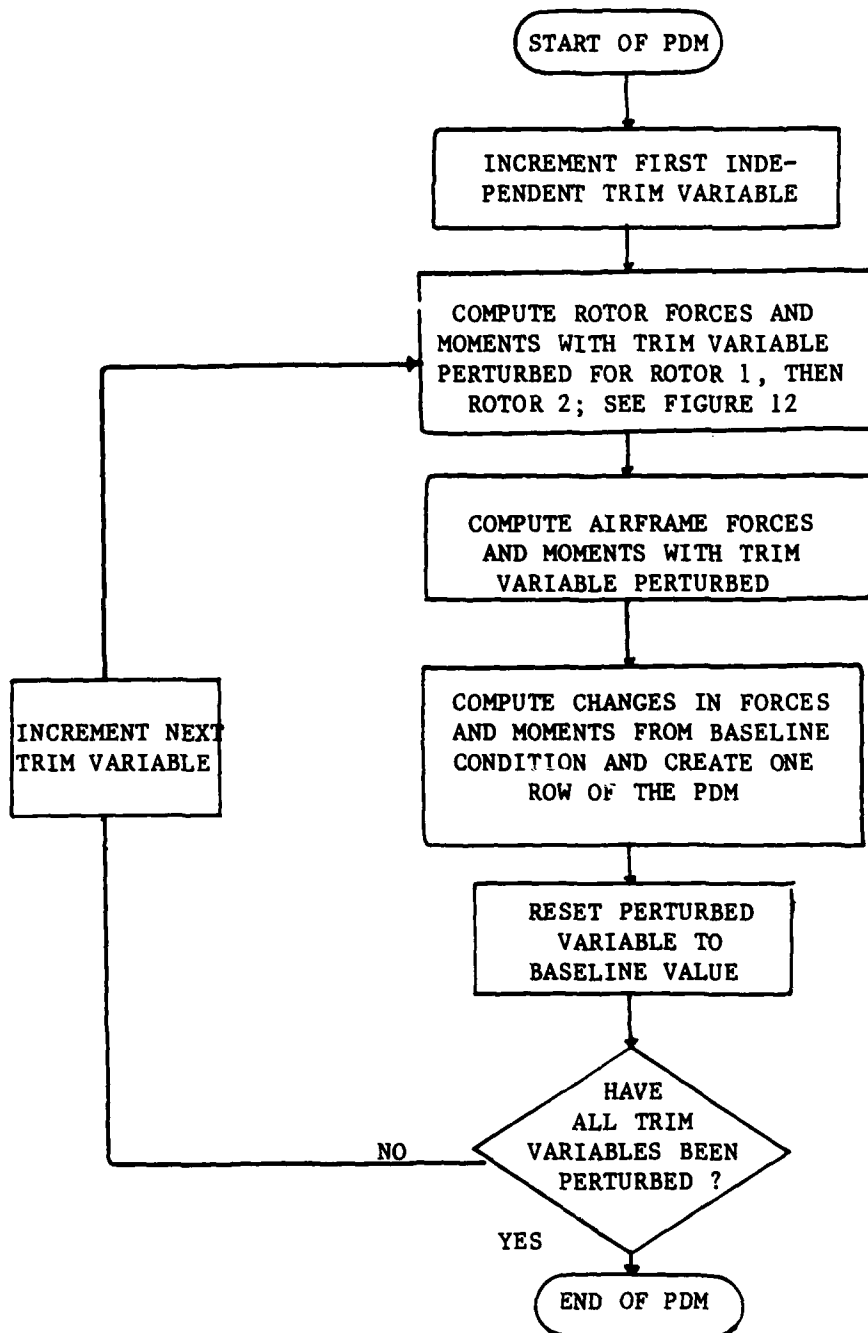
TV = Time-Variant rotor analysis

QS-TV = Quasi-Static trim followed by a Time-Variant trim. During the time-variant portion of this type trim, only the flapping, pylon, and mast windup angles of the time-variant rotor are allowed to vary; the fuselage and control positions are held fixed at the values determined by the quasi-static trim. If both rotors are time-variant, they are trimmed independently of each other.



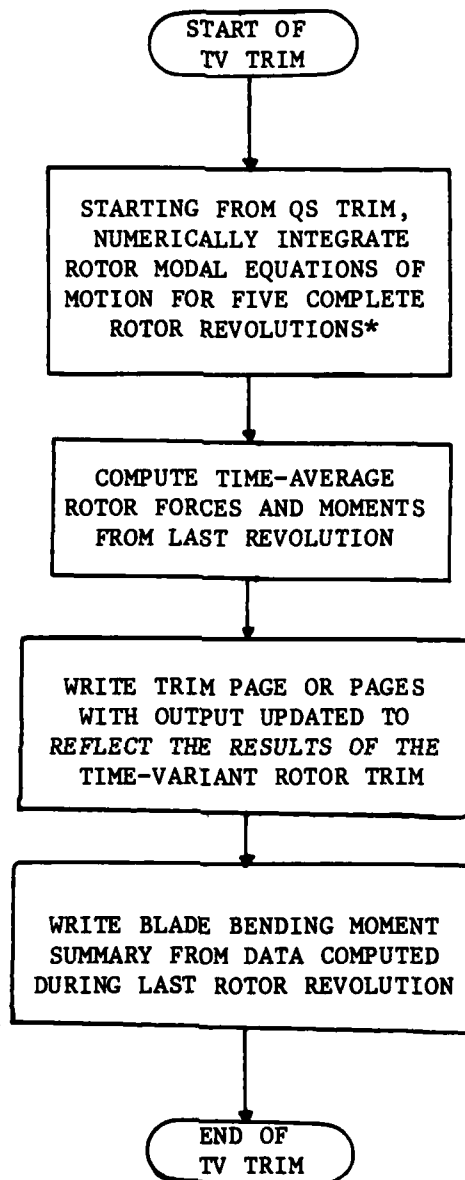
PDM = Partial Derivative Matrix
 QS-TV = Quasi-Static Trim Followed
 by Time-Variant Rotor Trim

Figure 9. Flow Chart of Trim Procedure.



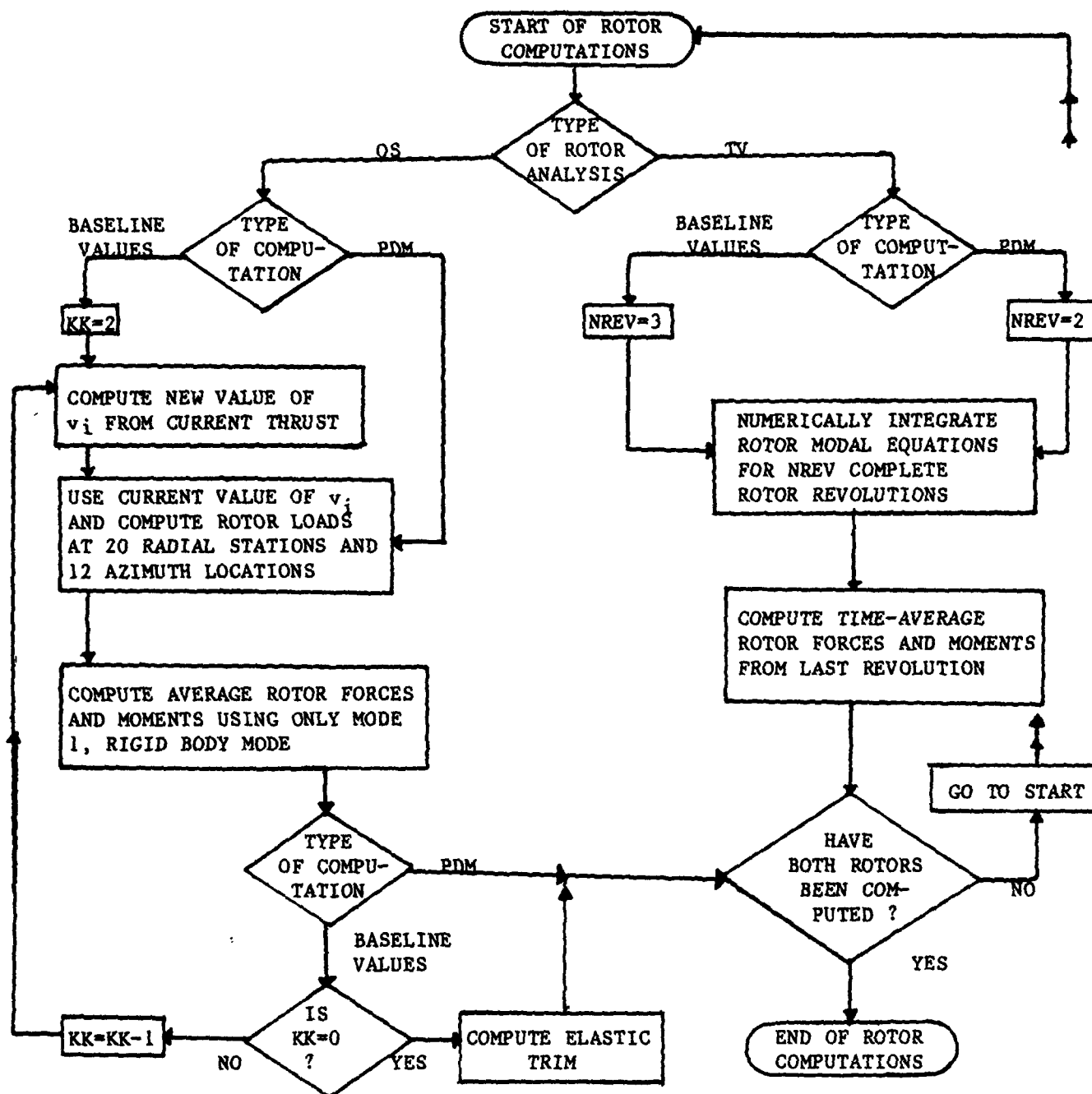
PDM = Partial Derivative Matrix

Figure 10. Flow Chart of Partial Derivative Matrix Computation.



*Control positions and fuselage degrees of freedom held fixed at the final values computed during the QS trim.

Figure 11. Flow Chart of Time-Variant Rotor Trim.



v_i = Rotor-Induced Velocity
 PDM = Partial Derivative Matrix
 KK = Thrust/ v_i Looping Variable

QS = Quasi-Static Rotor Analysis
 TV = Time-Variant Rotor Analysis
 NREV = Number of Rotor Revolutions in TV Analysis

Figure 12. Flow Chart of Rotor Force and Moment Computations During Trim Procedures.

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BELL HELICOPTER TEXTRON ROTORCRAFT FLIGHT SIMULATION PROGRAM AGAP8001 COMPUTED 81/

AM-16 + OLS ROTOR SIMULATION AGAP800 USERS MANUAL CASE
SAMPLE TRIM CASE INPUT DATA = DATA
129 KT LEVEL FLIGHT AT 29000 HP, 27 DEG C 8319 LB AFT CG

ROTOR CONTROLS				ROTOR PARAMETERS				TUNNEL PARAMETERS				PROGRAM OPTIONS			
COLLECTIVE PITCH				ROTOR SPEED				FORWARD SPEED				NO INPUT MODES			
F/A CYCLIC PITCH				SOLIDITY				ADVANCE RATIO				MAX YAW FLOW, TIP			
LAT CYCLIC PITCH				BLADE RADIUS				ADV TIP MACH NO				AERODYNAMICS, TIP TABLE			
TOT CYC FEATHER				CHORD, AVG				SIGMA PRIME				TORSION			
DELTA 3				PRECONE				MAST TILT ANGLE				NON STEADY AERO			
F/A FLAP ANGLE				CONING				TYP ANG OF ATTACK				FLAP ITERATION			
LAT FLAP ANGLE				TWIST				CNT PL ANG OF ATTACK				FREQUENCY CHANGE			
TOTAL FLAP ANGLE				TIP SWEEP				ROTOR TIP SPEED				ELASTIC PYLON			
***** FORCES AND MOMENTS *****															
WIND AXIS SYSTEM				DIMENSIONAL				SHAFT AXIS SYSTEM				DIMENSIONAL			
HELICOPTER				FIXED-WING				HELICOPTER				FIXED-WING			
LIFT FORCE				7375.30 LBS				THRUST				7375.30 LBS			
DRAG FORCE				-72.46 LBS				H FORCE				-0.006595			
LAT FORCE				-167.19 LBS				Y FORCE				-0.015217			
ROLL MOMENT				.00 FT-LBS				ROLL MOMENT				.00 FT-LBS			
PITCH MOMENT				.00 FT-LBS				PITCH MOMENT				.00 FT-LBS			
YAW MOMENT				10696.07 FT-LBS				YAW MOMENT				10696.07 FT-LBS			
								POWER				.2783048			
***** ROTOR LOADS *****															
BEAM LOADS (IN-LBS)				CHORD LOADS (IN-LBS)				TORSION LOADS (IN-LBS)							
MEAN				MEAN				MEAN				OSC / MAX AZ/MIN AZ			
R/R				R/R				R/R				OSC / MAX AZ/MIN AZ			
0.0				3.99				32122.72 / 330 / 150				0.00 / 0. / 0.			
.02				1497.55				31045.26 / 330 / 150				0.00 / 0. / 0.			
.08				7099.47				27988.09 / 330 / 150				-3024.94			
.14				8279.89				24310.08 / 330 / 150				-3013.97			
.20				8756.26				21534.58 / 330 / 150				-3003.83			
.25				8821.29				19337.13 / 330 / 150				-3057.12			
.31				8695.62				16907.79 / 330 / 150				-3074.51			
.35				8474.74				15326.31 / 330 / 160				-4030.10			
.40				8141.31				13906.37 / 330 / 160				-4089.08			
.45				7463.21				11885.60 / 330 / 160				-4213.25			
.50				6758.37				10304.34 / 330 / 160				-4334.92			
.55				5941.01				8923.00 / 330 / 160				-4357.03			
.60				5183.28				7743.74 / 330 / 150				-4398.61			
.65				3473.21				6219.84 / 330 / 150				-4440.45			
.70				2951.87				5019.47 / 330 / 150				-4198.95			
.75				1989.14				3879.10 / 330 / 150				-3979.33			
.80				1125.58				2686.15 / 330 / 150				-3696.55			
.85				561.13				1780.65 / 330 / 150				-3071.13			
.90				177.55				875.57 / 330 / 90				-2313.85			
.95				22.91				274.61 / 330 / 90				-1302.16			
1.00				0.00				0.00 / 0. / 0.				0.00 / 0. / 0.			

Figure 14. Optional Trim Page.

ROTORCRAFT STABILITY ANALYSIS

The rotorcraft stability analysis operation uses a trim point or a time point during a maneuver as its initial condition. The stability derivatives are computed by making small independent perturbations to each of the rotorcraft rigid-body degrees of freedom and primary flight controls, computing the forces and moments in the perturbed flight condition, subtracting the values of the forces and moments in the initial condition from those at the perturbed condition, and finally dividing the differences by the appropriate perturbations. Using these derivatives, the roots of the rotorcraft equations of motion, mode shapes associated with the roots, and transfer functions for the rotorcraft system are computed.

Input

The input cards required are the same as for trim only (NPART=1). In order to compute a trimmed flight condition followed by a stability analysis, an NPART=7 card is required. Note that if the Time-Variant rotor analysis is activated for either rotor, a rotorcraft stability analysis cannot be performed. A stability analysis should not be performed for $V = 0$. That flight condition should be simulated with some small, nonzero, airspeed (typically, 0.001 knot).

Output of Rotorcraft Stability Analysis

The operation of the rotorcraft stability analysis routine (STAB) depends on the numerical evaluation of a number of partial derivatives that appear in the equations of motion for the rotorcraft.

Control Partial Derivative Matrices

Force and Movement Derivatives

Figure 15 presents the control partial derivative matrix as printed out in three ways by the AGAP80 version of C81. The first version of the control partial derivative matrix is printed with units of pounds per inch or foot-pounds per inch. The response to each of the 14 degrees of freedom available in STAB is evaluated and ratioed to be the response to a 1-inch step input from each of the four controls. The rotor flapping angles are changed to reduce the rotor flapping moments to less than the allowable error if the rotor degrees of freedom are not turned on.

Control Derivatives In Terms Of Accelerations

The second version of the control partial derivative matrix contains the same information as the first. In this matrix, the force and moment derivatives have been divided by the appropriate masses or inertias to give the units of linear or angular acceleration per inch of control. These numbers may be thought of as the accelerations at the instant immediately after a step input from the controls.

Conventional Fixed-Wing Nondimensional Derivatives

If the rotorcraft does not have a wing or if the airspeed is less than 1.0 knots, this matrix is not printed. Refer to reference 2 for the nondimensionalizing factors and for interpretation of the first six rows of the third matrix. No attempt will be made to interpret or explain the last four rows of this matrix because conventional fixed-wing concepts do not apply to helicopter rotors and pylons.

Partial Derivatives For Rotorcraft Stability Analysis Degrees Of Freedom

The next pages of output contain detailed information used for the calculation of the partial derivatives for each degree of freedom that is activated in STAB. The partial derivatives are evaluated in the same order in which the variables are listed in the following paragraph. See figure 16.

CONTROL PARTIAL DERIVATIVE MATRICES

POUNDS/INCH OR FOOT-POUNDS/INCH

	COLLECTIVE	F/A CYCLIC	LAT CYCLIC	PEDAL
X-FORCE	139.4	43.01	-32.74	-19.60
Y-FORCE	-139.9	113.0	114.4	518.6
Z-FORCE	-5252.	2931.	33.18	-4.098
YAW MOM	3113.	2048.	-853.1	-1381E+05
PITCH MOM	-721.8	-1053.	229.6	-102.9
ROLL MOM	-988.5	797.9	807.9	2188.
M.R. F/A FLAP MOM	706.9	-51.81	-2829E+05	.2348E-07
M.R. LAT FLAP MOM	.3564E+05	-5836E+05	-28.25	-.274E-06
T.R. F/A FLAP MOM	0.	0.	0.	31.24
T.R. LAT FLAP MOM	0.	0.	0.	-523.2

FT/SEC2 OR RAD/SEC2 PER INCH

	COLLECTIVE	F/A CYCLIC	LAT CYCLIC	PEDAL
X-FORCE	.5390	.1663	-.1266	-.7580E-01
Y-FORCE	-.5412	.4371	.4424	2.006
Z-FORCE	-20.31	11.34	.1283	-.1585E-01
YAW MOM	.3042	.2001	-.8336E-01	-1.349
PITCH MOM	-.6074E-01	-.8859E-01	.1932E-01	-.8658E-02
ROLL MOM	-.3404	.2767	.2782	.7465
M.R. F/A FLAP MOM	.4702	-.3446E-01	-18.82	.1562E-10
M.R. LAT FLAP MOM	23.70	-38.82	-.1879E-01	-.2178E-09
T.R. F/A FLAP MOM	0.	0.	0.	20.39
T.R. LAT FLAP MOM	0.	0.	0.	-341.5

CONVENTIONAL FIXED WING NON-DIMENSIONAL DERIVATIVES

	COLLECTIVE	F/A CYCLIC	LAT CYCLIC	PEDAL
X-FORCE	.1012	.3124E-01	-.2378E-01	-.1424E-01
Y-FORCE	-.1017	.8211E-01	.8309E-01	.3767
Z-FORCE	-3.815	2.129	.2410E-01	-.2977E-02
YAW MOM	.2169	.1427	-.5945E-01	-.9624
PITCH MOM	-.1982	-.2832	.6175E-01	-.2768E-01
ROLL MOM	-.6889E-01	.5560E-01	.5630E-01	.1511
M.R. F/A FLAP MOM	.1902	-.1394E-01	-7.609	.6315E-11
M.R. LAT FLAP MOM	2.483	-4.067	-.1969E-02	-.2281E-10
T.R. F/A FLAP MOM	0.	0.	0.	.8405E-02
T.R. LAT FLAP MOM	0.	0.	0.	-.3646E-01

Figure 15. Control Partial Derivative Matrix from STAB.

FUS. U = 217.84752 FUS. W = -7.55214 FUS. Q = 0.00000 FUS. V = 3.21600 FUS. P = 0.00000 FUS. R = 0.00000
 M.R. F/A FLAP RATE = 0.0000 M.R. LAT FLAP RATE = 0.0000 T.R. F/A FLAP RATE = 0.0000 T.R. LAT FLAP RATE = 0.0000
 M.R. F/A FLAP DISP = -1.6825 M.R. LAT FLAP DISP = -0.7389 T.R. F/A FLAP DISP = -1.1250 T.R. LAT FLAP DISP = 1.0583

BODY AXIS	THRUST		TORQUE		IND. V.		JET THRUST	
	M-FORCE	Y-FORCE	Z-FORCE	ROLL	PITCH	YAW	RIGHT/CENTER	LEFT
MAIN ROTOR	8750.	-121.	10678.	89.	0.	0.	0.	0.
TAIL ROTOR	-262.	17.	-4.	-5.729	0.	0.	0.	0.
FORCE AND MOMENT SUMMARY								
FUSELAGE	-375.3	-26.4	43.4	-176.1	-954.5	-805.0		
MAIN ROTOR	121.2	-210.8	-8750.2	-1489.2	-418.4	-10.5		
TAIL ROTOR	-17.4	262.1	-4.1	1093.1	-36.0	-6970.1		
RIGHT WING	-76.8	-33.3	-539.6	-1281.2	489.7	152.5		
LEFT WING	-76.5	27.9	-531.4	1264.1	483.1	-156.6		
STABILIZER #1	-12.9	122.4	.7	297.3	47.6	-3069.6		
STABILIZER #2	-2.9	-0.	.2	-2.	37.9	5.3		
STABILIZER #3	-2.9	-0.	.2	-2.	37.8	-3.8		
GROSS WEIGHT	481.1	-176.6	8303.2	0.	-89.2	10678.0		
M.R. TORQUE				0.0	-401.9	-179.8		
TOTAL	37.4	-36.9	-1476.7	-293.1	-401.9	-179.8		

DELTA

BODY AXIS	X-FORCE		Y-FORCE		Z-FORCE		ROLL		PITCH		YAW	
FUSELAGE	-0.	3.2	-27.9	-30.9	254.9	-19.0						
MAIN ROTOR	42.2	-36.3	-1302.6	-256.4	-232.7	-1.9						
TAIL ROTOR	-1.1	1.2	-4.	4.5	-9.0	-31.3						
RIGHT WING	-1.4	-3.7	-58.4	-138.9	52.9	0.						
LEFT WING	-1.5	2.7	-58.1	138.1	-11.7	-1.2						
STABILIZER #1	.2	-4.0	-5.	-9.7	-255.6	100.9						
STABILIZER #2	-9.	.0	-15.5	-24.1	-253.6	1.2						
STABILIZER #3	-9.	.0	-15.4	23.9	-253.6	-1.5						
GROSS WEIGHT	0.0	0.0	0.0	0.0	0.0	-226.3						
M.R. TORQUE				0.0	-1.	-0.						
TOTAL	37.5	-36.9	-1476.7	-293.5	-402.2	-179.1						

Figure 16. Example of Partial Derivatives for
 STAB Degrees of Freedom.

Rotorcraft Stability Analysis Degrees Of Freedom

At the top of each partial derivative page (figure 16) is a list of the current value of each of the possible degrees of freedom. All FUS (fuselage) parameters are in the body reference system and all M.R. and T.R. (rotor) parameters are in the appropriate shaft reference system. By a comparison of two successive pages, it is possible to tell which variable is being perturbed and by how much.

The 30 variables which may be perturbed are perturbed in the following order:

FUS. U = Velocity in the X direction (FT/SEC)

FUS. W = Velocity in the Z direction (FT/SEC)

FUS. Q = Pitch Rate (DEG/SEC)

FUS. V = Velocity in the Y direction (FT/SEC)

FUS. P = Roll rate (DEG/SEC)

FUS. R = Yaw rate (DEG/SEC)

M.R. PYLON MODE 1 RATE = (DEG/SEC)

M.R. PYLON MODE 2 RATE = (DEG/SEC)

M.R. PYLON MODE 3 RATE = (DEG/SEC)

M.R. PYLON MODE 4 RATE = (DEG/SEC)

T.R. PYLON MODE 1 RATE = (DEG/SEC)

T.R. PYLON MODE 2 RATE = (DEG/SEC)

T.R. PYLON MODE 3 RATE = (DEG/SEC)

T.R. PYLON MODE 4 RATE = (DEG/SEC)

M.R. F/A FLAP RATE = (DEG/SEC)

M.R. LAT FLAP RATE = (DEG/SEC)

T.R. F/A FLAP RATE = (DEG/SEC)

T.R. LAT FLAP RATE = (DEG/SEC)

M.R. PYLON MODE 1 DISP = (DEG)

M.R. PYLON MODE 2 DISP = (DEG)

M.R. PYLON MODE 3 DISP = (DEG)

M.R. PYLON MODE 4 DISP = (DEG)

T.R. PYLON MODE 1 DISP = (DEG)

T.R. PYLON MODE 2 DISP = (DEG)

T.R. PYLON MODE 3 DISP = (DEG)

T.R. PYLON MODE 4 DISP = (DEG)

M.R. F/A FLAP DISP = (DEG)

M.R. LAT FLAP DISP = (DEG)

T.R. F/A FLAP DISP = (DEG)

T.R. LAT FLAP DISP = (DEG)

Each partial derivative page (figure 16) gives rotor performance data, a force and moment summary, and a delta force and moment summary. The forces and moments printed here are computed after the small increment in the pertinent variable has been made. All data are in the body reference system. The delta force and moment summary presents the changes in the force and moment contributions in exactly the same format as the full force and moment summary. Each number in this data block is obtained by taking the corresponding value from the force and moment summary immediately above, less the corresponding value at the trim condition or at the current maneuver time point.

Rotorcraft Stability Partial Derivative Matrices

Total Partial Derivative Matrix

A summary of the partial derivatives computed from the data on the previous pages is then printed (figure 17). Each row gives the partial derivatives of some total aircraft force or moment, as labeled, with respect to the perturbation variables used.

Rotor Partial Derivative Matrix

A summary of the rotor partial derivatives computed from the data on the previous pages is printed on this page as well (figure 17). Each row gives the partial derivatives of some force, moment, or flapping angle, as labeled, with respect to the linear and angular velocities U, V, W, P, Q, and R.

Mass, Damping, and Stiffness Matrices

The mass, damping, and stiffness matrices (figure 18) which are used to calculate the rotorcraft stability characteristics are printed next. Refer to Volume I of reference 3 for the analytical background of these three matrices.

Stick-Fixed Rotorcraft Stability Results

The rotorcraft characteristic equation, with controls fixed, is solved for its complex roots and associated response modes. The results are presented in several ways (figure 18).

STABILITY PARTIAL DERIVATIVES (TOTAL AIRCRAFT)									
	U	W	Q	V	P	R			
X-FORCE	-8.2534	7.4934	57.797	1.8645	44.703	-17.359			
Z-FORCE	-8.6935	-295.74	-121.41	-6.9757	-1163.3	657.08			
PITCH MOMENT	22.591	-80.434	-2357.6	-9.5633	-245.39	64.117			
Y-FORCE	.74759	-7.3835	-19.861	-54.454	-139.40	590.16			
ROLL MOMENT	-3.8791	-58.691	-61.756	-106.96	-760.97	2106.3			
YAW MOMENT	-23.472	-35.811	1368.8	291.67	888.60	-16410.			
M.R. F/A FLAP MOM	44.301	21.681	31546.	420.80	10482E+06	-863.63			
M.R. LAT FLAP MOM	324.34	1130.0	-10435E+06	104.47	33947.	1959.2			
T.R. F/A FLAP MOM	-69175	-1.7627	-44.757	-36629	-535.80	-42.764			
T.R. LAT FLAP MOM	-1.4896	-.97511E-01	5.8013	5.8005	-21.922	340.00			
M.R. F/A FLAP RATE		M.R. LAT FLAP RATE	T.R. F/A FLAP RATE	T.R. LAT FLAP RATE	M.R. F/A FLAP DISP	M.R. LAT FLAP DISP	T.R. F/A FLAP DISP	T.R. LAT FLAP DISP	
X-FORCE	44.182	36.343	43669	-18023E-02	-4506.4	109.70	159.13	143.12	
Z-FORCE	-14.203	-1114.7	-52666	-34991	15016.	-8884.8	251.86	-137.84	
PITCH MOMENT	-311.36	-200.97	-14.754	-5.0107	31079.	-376.84	5737.5	-3549.3	
Y-FORCE	-10.364	-52.031	46426	-7.2366	274.32	2168.1	-22.791	-2712.4	
ROLL MOMENT	-73.203	-267.51	1.3260	-30.727	1937.6	15314.	200.46	-11525.	
YAW MOMENT	1083.0	-988.75	-12.896	193.02	40181.	12342.	420.90	72179.	
M.R. F/A FLAP	31967.	-20.192	-10834E-07	-10834E-07	-22287E+06	10987E+07	-21668E-07	-21668E-07	
M.R. LAT FLAP	-19.697	33194.	15137E-06	15137E-06	-97956E+06	24754E+06	13934E-06	13934E-06	
T.R. F/A FLAP	-18102E-09	-18102E-09	56.005	26472	-18102E-09	-18102E-09	9895.6	10054.	
T.R. LAT FLAP	36204E-09	36204E-09	26471	52.125	36204E-09	36204E-09	-8636.3	10164.	
ROTOR PARTIAL DERIVATIVE MATRICES									
	U	W	Q	V	P	R			
MAIN ROTOR									
THRUST	-1.1226	260.52	8.3509	7.2726	1163.6	-656.92			
M-FORCE	2.9706	-8.4318	-64.175	-92693	-42.734	3.7979			
F/A FLAPPING	0.	0.	0.	0.	0.	0.			
Y-FORCE	-8.0820	-7.2596	-5.7969	-2.5380	-89.984	12.692			
TONGUE	14.027	-45.268	1030.4	9.2164	-922.93	-1400.0			
LAT FLAPPING	0.	0.	0.	0.	0.	0.			
TAIL ROTOR									
THRUST	-69076E-01	-23570	-9.1659	10.444	47.261	-348.15			
M-FORCE	15840	24170E-01	59351	-35165	-1.8022	11.810			
F/A FLAPPING	0.	0.	0.	0.	0.	0.			
Y-FORCE	23355E-01	-71602E-01	-2.0642	85600E-01	73038	-2.3812			
TONGUE	63035	14523E-01	1.0406	19792	6.4466	-15.942			
LAT FLAPPING	0.	0.	0.	0.	0.	0.			

Figure 17. Rotor and Total Partial Derivative Matrices.

MASS MATRIX									
	U DOT	V DOT	Q DOT	V DOT	P DOT	R DOT			
X-FORCE	258.57	0.	0.	0.	0.	0.			
Z-FORCE	0.	258.61	0.	0.	0.	0.			
PITCH MOMENT	0.	56205	11883.	0.	0.	0.			
Y-FORCE	0.	0.	0.	258.57	0.	0.			
ROLL MOMENT	0.	0.	0.	0.	2904.0	585.00			
YAW MOMENT	0.	0.	0.	0.	585.00	10234.			
MASS MATRIX									
M.R. F/A FLAP ACC.	0.	0.	-1503.4	0.	0.	0.			
M.R. LAT FLAP ACC.	0.	0.	0.	0.	-1503.4	0.			
M.R. F/A FLAP ACC.	0.	0.	-27498E-08	0.	0.	1.5320			
M.R. LAT FLAP ACC.	0.	0.	0.	0.	1.5320	0.			
X-FORCE	0.	0.	0.	0.	0.	0.			
Z-FORCE	0.	0.	0.	0.	0.	0.			
PITCH MOMENT	0.	0.	0.	0.	0.	0.			
Y-FORCE	0.	0.	0.	0.	0.	0.			
ROLL MOMENT	0.	0.	0.	0.	0.	0.			
YAW MOMENT	0.	0.	0.	0.	0.	0.			
DAMPING MATRIX									
	U	V	Q	V	P	R			
M.R. F/A FLAP ACC.	-1503.4	0.	0.	0.	0.	0.			
M.R. LAT FLAP ACC.	0.	-1503.4	0.	0.	0.	0.			
M.R. F/A FLAP ACC.	0.	0.	-1.5320	0.	0.	0.			
M.R. LAT FLAP ACC.	0.	0.	0.	-1.5320	0.	0.			
X-FORCE	8.2534	-7.4934	-3303.5	0.	0.	0.			
Z-FORCE	8.6935	295.74	-56308.	0.	0.	0.			
PITCH MOMENT	-22.591	80.434	2357.6	0.	0.	0.			
Y-FORCE	0.	0.	0.	54.454	3385.1	55839.			
ROLL MOMENT	0.	0.	0.	106.96	760.97	-2106.3			
YAW MOMENT	0.	0.	0.	-291.67	-888.60	16410.			
DAMPING MATRIX									
M.R. F/A FLAP ACC.	-44.301	-21.681	-31846.	-420.80	-10482E+06	863.63			
M.R. LAT FLAP ACC.	-324.38	-1130.0	10435E+06	-104.47	-33947.	-1959.2			
M.R. F/A FLAP ACC.	69175	1.7627	44.757	36629	535.80	42.764			
M.R. LAT FLAP ACC.	1.4896	97511E-01	-5.8013	-5.8005	21.922	-340.00			
X-FORCE	-44.182	-36.343	-43669	18023E-02					
Z-FORCE	14.203	1114.7	52666	34991					
PITCH MOMENT	311.36	200.97	14.754	5.0107					
Y-FORCE	10.364	52.031	-46426	7.2366					
ROLL MOMENT	73.203	367.51	-1.3260	30.727					
YAW MOMENT	-1083.0	986.75	12.896	-193.02					
DAMPING MATRIX									
M.R. F/A FLAP ACC.	-31967.	-10202E+06	0.	0.					
M.R. LAT FLAP ACC.	10206E+06	-33146.	0.	0.					
M.R. F/A FLAP ACC.	0.	0.	-56.005	-531.80					
M.R. LAT FLAP ACC.	0.	0.	531.27	-52.125					

Figure 18. Stability Matrices and Stick-Fixed Stability Results.

Figure 18. Concluded

The real and imaginary parts of the roots of the rotorcraft characteristic equation are printed under the headings REAL and IMAG. The units are radians per second. The roots may be used to form the denominator, $d(s)$, of the frequency response polynomial.

$$d(s) = \prod_{i=1}^n (s - \text{REAL}_i + \text{IMAG}_i * j) (s - \text{REAL}_i - \text{IMAG}_i * j)$$

where s = Laplace operator
 $\prod$ = Continued product notation
 $j = \sqrt{-1}$
 n = Number of roots printed
 i = Sequence number of root in printout

Note that in the case of complex conjugate parts of roots, only the root with the positive imaginary part is printed.

Each root or pair of roots generates the terms in one factor of the denominator of the Laplace transfer function, $D(s)$.

$$D(s) = \prod_{i=1}^n (\text{TAU}_i * s^2 + \text{DAMP}_i * s + 1)$$

where

$$\text{TAU}_i = 1 / (\text{REAL}_i^2 + \text{IMAG}_i^2) = 1 / \omega_{n_i}^2$$

$$\text{DAMP}_i = -2 * \text{REAL}_i / (\text{REAL}_i^2 + \text{IMAG}_i^2) = -2 \zeta_i / \omega_{n_i}$$

and $\prod$, n , and i are as defined above.

For the oscillatory roots of the rotorcraft characteristic equation, the PERIOD of the damped oscillation is given in seconds. For the roots with a zero imaginary part, the period is a meaningless concept, so a zero appears in the output.

The column headed TIME TO HALF-DBL depends on the value of the real part of the root. If the real part is negative, the time to half amplitude, in seconds, is printed. If the real part is positive, the time to double amplitude, in seconds, is printed. The column headed CYCLES TO HALF-DBL contains the number of cycles to half or double amplitude based on the damped natural frequency ($\omega_d = \text{IMAG}$) for the oscillatory roots. A zero is printed for aperiodic roots.

The UNDAMPED NATURAL FREQ, ω_n , is based on the absolute value of the complex root.

$$\omega_n = \sqrt{\text{REAL}^2 + \text{IMAG}^2}$$

Thus, ω_n is defined even for an aperiodic root. The calculated value of ω_n is given both in radians per second and cycles per second. The DAMPING RATIO, ζ , in combination with the undamped natural frequency, completely describes the root.

$$\zeta = \text{REAL} / \omega_n ; \quad \text{REAL} = \zeta \omega_n$$

For a stable aperiodic root, the damping ratio is 1. For an unstable aperiodic root, the damping ratio is -1.

In the stability mode shape printout (figure 19), each column represents one mode. The first column on the left is associated with the first root printed, the second with the second root, and so forth. Each component of a mode shape has a relative magnitude (MAGN) and a phase angle (PHASE). The normal printout provides for eight columns (mode shapes of roots). If more than eight roots are computed, the additional roots are printed in the same format below the first set. Columns after the last root are set to zero.

The mode shapes associated with the rotorcraft characteristic roots are first printed as normalized with respect to THETA, then as normalized with respect to PHI, and lastly as normalized with respect to the largest variable for a given root. In all three sets of normalized mode shapes, the normalizing variable always has a magnitude of 1.000 (nondimensional) and a phase angle of 0.0 degrees. The reader should see reference 1, section 6 for a description of the variables used for the mode shapes.

Transfer Function Numerator

Following the mode shapes, the numerators of the transfer functions (figure 20) for aircraft response and/or flapping angles as specified by IPL(93) are printed. Table III gives the value of IPL(93) required to print the numerators of the transfer functions computed by STAB. For each of the numerators printed, the value labeled GAIN is the constant term in the frequency response polynomial; STATIC GAIN is the gain term to be used in the Laplace transfer function.

The complex roots of the frequency response polynomial are printed in pairs of columns labeled REAL and IMAG. Below the real and imaginary roots are the corresponding values in the numerator of the Laplace transfer function, TAU and DAMP. The numerator of the Laplace transfer function $N(s)$, may be written as follows:

$$N(s) = \text{STATIC GAIN} * \prod_{k=1}^m (\text{TAU}_k * s^2 + \text{DAMP}_k * s + 1)$$

The STATIC GAIN is the ratio $N(s)/D(s)$ evaluated for $s = 0$.

The frequency response polynomial as

$$n(s) = (\text{GAIN}) * \prod_{k=1}^m [(s - \text{REAL}_k + \text{IMAG}_k * j) (s - \text{REAL}_k - \text{IMAG}_k * j)]$$

where k = sequence number of root

m = total number of roots printed

only if $\text{IMAG} \neq 0$

Zero roots are not printed for either the stick fixed or control input solutions, so the final order of the transfer function generated as described above may be incorrect. In this case usually one more "s" in the denominator will correct the situation. The need for this correction may be found by inspecting the numerator and denominator polynomials. The transfer function is correct when the highest power of "s" for the denominator is 2 larger than that for the numerator.

Frequency Response

The frequency response of the transfer functions (figure 21) is tabulated following the transfer function numerator printout. The data listed are the frequency in hertz and radians per second, the gain in the decibel equivalent of a magnitude in degrees per inch of control, and the phase in degrees. The range of frequencies is 0.01 to 100 radians per second. Construction of a Bode plot for each transfer function is greatly simplified with these data.

CONTROLS - FIXED MODE SHAPES

ROOT	0 1 MAGN PHASE	0 2 MAGN PHASE	0 3 MAGN PHASE	0 4 MAGN PHASE	0 5 MAGN PHASE	0 6 MAGN PHASE	0 7 MAGN PHASE	0 8 MAGN PHASE
----- NORMALIZED WRT THETA -----								
FUSELAGE								
WAVELOCITY	.7122E-01	.5445	.1842	.1573	.3620	.1023	1.947	2.514
	-75.76	92.51	25.11	14.64	-1.014	-131.6	-83.93	116.9
ALPHA	10.49	.2307	1.349	1.379	.2491	.9972	29.97	2.871
	141.8	72.29	85.91	158.3	-8.153	3.857	-24.58	89.01
THETA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	.0	.0	.0	.0	.0	.0	.0	.0
BETA	.62.69	.4751E-01	.3421	.68.29	.5164	9.979	4.132	66.46
	25.26	-48.34	168.7	175.0	-115.6	-41.75	-2.612	-132.5
PHI	104.4	1.054	2.714	125.9	1.005	8.798	4.212	18.19
	41.44	25.76	134.7	159.6	139.8	-80.89	-82.43	186.9
PSI	369.6	.5278	.7891	79.69	.5066	11.69	2.342	24.39
	-106.4	-65.19	-17.78	-6.266	33.23	130.4	159.2	-23.04
M.R. F/A FLAP	7.240	.5901E-01	.3348	2.751	32.88	1.252	1817.	.9946
	156.9	75.36	25.28	-70.31	-5.698	-75.72	-112.6	-169.8
M.R. LAT FLAP	-11.17	.4139E-01	.2639	30.74	20.28	11.61	1820.	19.18
	50.13	-84.27	88.36	76.06	139.4	156.1	22.03	-23.03
T.R. F/A FLAP	9.562	.6729E-02	.5202E-01	7.819	.8463	946.6	2.573	.3367E+06
	143.6	56.86	-117.3	-142.7	-51.78	-56.44	-169.2	-151.8
T.R. LAT FLAP	20.56	.3723E-01	.0045E-01	13.46	.4081	941.3	5.888	.3367E+06
	-175.9	182.8	-57.47	-60.56	-12.19	36.19	71.08	116.2
----- NORMALIZED WRT PHI -----								
FUSELAGE								
WAVELOCITY	.6823E-04	.5166	.6789E-01	.1249E-02	.1000	.1172E-01	.4423	.1310
	-117.2	66.74	-189.5	-14.99	-140.8	-81.31	-1.494	-39.94
ALPHA	.1004E-01	.2189	.1970	.1095E-01	.1413	.1148	7.117	.1496
	108.4	46.53	-71.75	-1.265	-148.0	53.05	57.85	-76.83
THETA	.9500E-03	.9499	.3685	.7941E-02	.5249	.1198	.2374	.8212E-01
	-41.44	-25.76	-134.7	-159.8	-139.8	56.25	81.43	-156.9
BETA	.6004E-01	.4508E-01	.1261	.5423	.2710	1.144	.8810	3.464
	-16.18	-74.10	34.88	15.46	164.6	8.037	78.82	70.68
PHI	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	.0	.0	.0	.0	.0	.0	.0	.0
PSI	.3541	.5008	.9008	.6388	.2659	1.342	.3560	1.375
	-17.08	-90.98	-182.4	-185.8	-108.6	-176.3	-176.9	-176.9
M.R. F/A FLAP	.6949E-02	.5600E-01	.1234	.2185E-01	17.26	.1428	.4314	.5181E-01
	117.4	49.60	-105.4	97.34	-145.6	-23.43	-30.21	33.34
M.R. LAT FLAP	.4802E-01	.3627E-01	.9728E-01	.2441	19.37	1.333	.4321	.9008
	-62.61	-116.0	-42.29	-83.51	-45.12	-184.6	-119.8	-176.9
T.R. F/A FLAP	.9106E-02	.4384E-02	.1939E-01	.4209E-01	.4442	189.7	.618	.1793E+08
	102.1	30.29	108.0	87.66	188.4	-8.153	-88.79	51.34
T.R. LAT FLAP	.1970E-01	.2844E-01	.3332E-01	.1069	.2192	108.1	1.208	.1793E+08
	142.7	77.03	167.9	146.1	-152.0	86.48	11.37	-38.66

Figure 19. Mode Shapes of Stability Results.

----- NORMALIZED WRT LARGEST -----									
FUSELAGE	WAVELENGTH								
ALPHA									
THETA									
BETA									
PHI									
PSI									
M.R. F/A FLAP									
M.R. LAT FLAP									
T.R. F/A FLAP									
T.R. LAT FLAP									

Figure 19. Concluded

T R A N S F E R F U N C T I O N D A T A									
T H E T A / L O N G C Y C			P H I / L A T C Y C			P S I / P E D A L			
----- N U M E R A T O R S -----									
G A I N = .81003E-01			G A I N = -.30594			G A I N = 1.4051			
REAL			REAL			REAL			
- .34930			- .80827E-02			- .87665E-02			
- .24734E-01			.61130E-02			.24955			
- 1.2275			- .83665			- .86816			
- 1.1385			- .85934			- 1.4659			
- 10.056			- 9.3657			- 9.6502			
- 17.379			- 16.720			- 17.546			
- 34.650			- 17.471			- 11.460			
- 3.8917			- 7.5434			- 15.219			
- 17.658			- 17.657			.0			
IMAG			IMAG			IMAG			
.37822			.0			.26312			
.0			.25909			.67966			
.0			.83089			.79566			
2.0634			2.1074			.0			
.0			.0			.18123			
17.133			.0			14.688			
.0			17.047			68.401			
63.499			65.226			361.84			
364.10			364.10			.0			
STATIC GAIN =			STATIC GAIN =			STATIC GAIN =			
.75377E-01			-.11928E-01			.59577			
TAU			TAU			TAU			
3.7727			123.72			14.428			
.0			- .18204			1.9076			
.0			1.2035			.72110			
.18005			.33181			.0			
.0			.10677			.10734E-01			
.16791E-02			.59810E-01			.19099E-02			
.0			.58643E-01			.20790E-03			
.24708E-03			.34993E-02			.76245E-05			
.75254E-05			.26575E-03			.0			
DAMP			DAMP			DAMP			
2.6356			123.72			- .25297			
40.430			- .18204			- .95208			
.81469			1.2035			1.2521			
.40999			.33181			.68216			
.99445E-01			.10677			.20716			
.58362E-01			.59810E-01			.67021E-01			
.28860E-01			.58643E-01			.47650E-02			
.19232E-02			.34993E-02			.23207E-03			
.26577E-03			.26575E-03			.0			

Figure 20. Numerator of Transfer Functions.

TABLE III VALUES OF IPL(93) TO PRINT THE NUMERATORS OF THE TRANSFER FUNCTIONS

Denominator Of Transfer Function	Numerator of Transfer Function							
	u	w	θ	v	ϕ	ψ	M/R Flapping	
							Long.	Lat.
Collective	2	1	1	3	3	3	4,-1	4,-1
Long. Cyclic	2	1	0,-1	3	3	3	4,-1	4,-1
Lat. Cyclic	3	3	3	2	0,-1	1	4,-1	4,-1
Pedal	3	3	3	2	1	0,-1	4,-1	4,-1

F R E Q U E N C Y R E S P O N S E					
FREQ(RAD/SEC)	GAIN(DB)	PHASE(DEG)	GAIN(DB)	PHASE(DEG)	FREQ(HZ)
0.0100	13.377	31.890	40.725	-10.474	0.0014
0.0125	13.715	30.408	40.059	-20.798	0.0018
0.0150	14.057	32.715	39.828	-20.643	0.0023
0.0200	14.442	38.731	39.197	-20.643	0.0032
0.0300	15.442	45.022	38.971	-20.740	0.0046
0.0400	16.749	50.156	38.842	-19.668	0.0064
0.0500	18.090	54.359	38.761	-18.359	0.0086
0.0600	19.445	57.024	38.640	-17.546	0.0111
0.0700	20.988	63.133	38.569	-16.840	0.0159
0.0800	22.495	66.958	38.509	-16.549	0.0225
0.1000	24.123	69.017	38.448	-16.086	0.0318
0.1250	25.933	72.026	38.385	-15.913	0.0477
0.1500	27.942	75.043	38.323	-15.822	0.0657
0.1750	30.042	80.041	38.263	-15.832	0.0905
0.2000	32.448	84.979	38.204	-15.846	0.1114
0.2500	45.971	109.78	38.043	-15.860	0.1599
0.3000	58.448	123.05	37.887	-15.872	0.2379
0.3500	70.448	112.25	37.734	-15.887	0.3183
0.4000	81.448	113.44	37.580	-15.900	0.4775
0.5000	102.448	116.57	37.427	-15.911	0.6570
0.6000	125.448	120.65	37.274	-15.922	0.9549
0.7000	150.448	125.73	37.121	-15.934	1.141
1.0000	225.448	134.85	36.968	-15.946	1.2732
1.2500	259.448	145.06	36.815	-15.958	1.5915
1.5000	294.448	155.28	36.662	-15.970	2.5465
2.0000	389.448	171.49	36.509	-15.982	3.1831
2.5000	484.448	187.70	36.356	-15.994	3.9789
3.0000	579.448	203.91	36.203	-16.006	4.775
4.0000	766.448	240.12	36.050	-16.018	6.446
5.0000	953.448	276.33	35.897	-16.030	8.0959
6.0000	1140.448	312.54	35.744	-16.042	1.1141
7.0000	1327.448	348.75	35.591	-16.054	1.2732
8.0000	1514.448	384.96	35.438	-16.066	1.5915
10.0000	1901.448	451.17	35.285	-16.078	2.5465
12.0000	2288.448	487.38	35.132	-16.090	3.1831
15.0000	2921.448	553.59	34.979	-16.102	3.9789
20.0000	3854.448	619.80	34.826	-16.114	4.775
25.0000	4787.448	686.01	34.673	-16.126	6.446
30.0000	5720.448	752.22	34.520	-16.138	8.0959
35.0000	6653.448	818.43	34.367	-16.150	1.1141
40.0000	7586.448	884.64	34.214	-16.162	1.2732
50.0000	9419.448	1016.85	34.061	-16.174	1.5915
60.0000	11252.448	1149.06	33.908	-16.186	2.5465
70.0000	13085.448	1281.27	33.755	-16.198	3.1831
80.0000	14918.448	1413.48	33.602	-16.210	3.9789
100.0000	18751.448	1725.69	33.449	-16.222	4.775
					6.446
					8.0959
					1.1141
					1.2732
					1.5915
					2.5465
					3.1831
					3.9789
					4.775
					6.446
					8.0959
					1.1141
					1.2732
					1.5915
					2.5465
					3.1831
					3.9789
					4.775
					6.446
					8.0959
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					1.2732

TRIM SWEEPS

The parameter sweep operation (figure 3) may be used to simulate the stacking of TRIM and TRIM-STAB data decks for a given rotorcraft. Within a sweep deck, the user specifies by input data those cases in the sweep for which a rotorcraft stability analysis is and is not to be performed. The parameters most frequently swept include airspeed, gross weight, center-of-gravity station-line, incidence of an aerodynamic surface, atmospheric conditions, and g-level. Generally, only one parameter is changed from case to case within a single sweep deck. However, any number and combination of inputs except some program logic switches and the values in some data tables may be swept. The assumption is made that each desired trim condition bears some relationship to the previous one, and that the previous trim point is a good starting condition for finding the next trim point. For example, in a speed sweep, a change of 20 or 30 knots is the most that should normally be used between 40 and 150 knots. Outside of this range, the maximum change should not exceed 10 knots.

Following a data set for trim only or trim-and-rotorcraft-stability analysis (NPART = 1 or 7), the parameter sweep option may be exercised by including an NPART = 10 card after the Flight Constants Group (card 234 - labeled with sequence number 1103). An NPART = 10 card permits the changing of user-selected inputs and retrimming the configuration. On the same card, a new input variable is defined (NVARA) which specifies whether a trim or trim-and-rotorcraft-stability analysis is to be performed on this case in the parameter sweep. If NVARA = 0, the program will attempt only to iterate to a new trim condition (equivalent to NPART = 1); if NVARA $\neq$ 0, the program will attempt to trim and, if successful, will also perform a rotorcraft stability analysis (equivalent to NPART = 7).

The data set for NPART = 10 consists of the following cards:

First Card:	Card 01	NPART card with NPART = 10
Subsequent Card(s):	\$Change	Changes to input data using namelist input

An NPART = 10 data set may be followed only by another NPART = 10 data set, and postprocessing program (GDAP80) inputs. Figure 22 shows an example of input data required to perform an airspeed sweep for trim only. Input parameter XFC(1), forward velocity, a parameter in the Flight Constants Group, is changed each time throughout the sweep and the case is retrimmed. The program assumes the last trim point is a good starting point for the next trim case. The reader will note that these NPART = 10 data sets follow immediately behind card 234 of the Flight Constants Group (that card is labeled with a sequence number 00110300 in columns 73-80 of the sample data deck in Appendix A.)

MANEUVER SIMULATION

All maneuvers require a trim point prior to computing the time history of a maneuver. The trim point is used to supply the initial conditions to a system of differential equations that describe the behavior of the rotorcraft in a maneuver. Various external inputs, or forcing functions, may be applied, such as control movements, gusts, store drops, and wing incidence change independent of control motion. At times specified by input data, the maneuver can be suspended while a rotorcraft or rotor aeroelastic stability analysis is performed. The maneuver is then resumed as if no interruption had occurred and continued until it reaches either the next time point to do a stability analysis or the end of the maneuver.

[illegible]

Figure 22. Input Data for Parameter Sweep.

A maneuver restart operation is begun just like an ordinary maneuver using a trim condition as a starting point. The only difference is that the time-history variables and many intermediate variables are saved on the restart magnetic tape. Subsequent maneuver restarts use the condition at one of the saved time points as the initial conditions, and so do not require a trim condition or the complete data set defining the rotorcraft.

Figures 4 through 7 illustrate the type of operations that can be performed that are related to maneuver simulation.

<u>Maneuver Simulation Operation</u>	<u>NPART</u>
a) Trim followed by maneuver	2
b) Trim followed by maneuver with rotorcraft stability analysis	2
c) Trim followed by a maneuver in which maneuver time-point data are stored for a subsequent restart of the maneuver	4
d) Maneuver restart	5

An NPART = 2 card specifies the computation of a trimmed flight condition followed by a maneuver. Subject to the Program Logic Group (IPL) values, a data set of cards 02 through 291 (the maneuver time card) plus at least one 301-type card (maneuver specification card or commonly called J-card) must follow. The maneuver start time on card 291 is set to zero regardless of the input value. The postprocessing program (GDAP80) inputs follow the last J-card.

Whenever a maneuver simulation is called for (NPART = 2, 4 or 5) an additional input parameter, NPRINT, which specifies the frequency of printout of maneuver data, is to be supplied in columns 4-6 of the NPART card. The program prints data showing initial conditions for the maneuver (maneuver time $t = 0$) and for every NPRINTth time point thereafter. A blank or zero input is reset to unity.

An NPART = 4 will do the same as NPART = 2, except that the maneuver data will be stored so that it can be recalled at a later date for a maneuver restart (NPART = 5). The use of this option will require the assistance of the local programmer to set up the restart tape.

For a maneuver restart case (NPART = 5), the maneuver time card has the start time input as the time at which the maneuver is to be restarted. It must be greater than zero and less than the last point of the maneuver being restarted. The time for restart need not be identically equal to a previous time point. Then, at least one maneuver specification (J-card) is required. The inputs to GDAP80 follow these inputs.

Maneuver Time Card and Maneuver Specification Cards

The following information is provided on the maneuver time card (card 291) as input data:

TCI(1) Start time of maneuver (seconds)
 TCI(2) First time or azimuth increment (seconds or degrees)
 TCI(3) Time to stop using first increment (seconds)
 TCI(4) Second time or azimuth increment (seconds or degrees)
 TCI(5) Time to stop using second increment and return to first increment (seconds)
 TCI(6) Time to stop the maneuver (seconds)

TCI(2) is used to specify the first base value of the time increment (Δt) between the calculation of maneuver time points. The Δt computed from TCI(2) will be used during the interval of TCI(1) to TCI(3) seconds of maneuver time. If TCI(2) < 1.0, the input is taken to be Δt in seconds. If TCI(2) $\geq$ 1.0, the input is taken to be the increment in rotor 1 azimuth location in degrees between time points; in this case, the time increment to be used is defined as

$$\Delta t = \text{TCI}(2) / 6 \Omega_1$$

where Ω_1 is the rotational speed of rotor 1 in units of rpm and Δt is in seconds.

It may be desirable to change the value of Δt because of a change in rotor speed. For this case, TCI(4) can be used to specify the value of Δt to be used between TCI(3) and TCI(5) seconds of maneuver time. Like TCI(2), TCI(4) may be either a time or azimuth increment. It is not necessary that TCI(2) and TCI(4) be the same type of increment; e.g., one may be time and the other azimuth.

If TCI(6), the time to stop the maneuver, is greater than TCI(5), the program then uses the Δt based on TCI(2) between TCI(5) and TCI(6) seconds of maneuver time. If TCI(5) is the time to stop the maneuver, as well as the time to stop using the Δt based on TCI(4), the TCI(6) input may be zero or blank. If a second time increment is not desired, then TCI(4) and TCI(5) should be input as 0.0. In this case, TCI(6) will be ignored and TCI(3) is taken as the time to stop the maneuver.

If NPART = 2, 4, or 5, one maneuver specification card (card 301 or J-card) must be included and up to 20 may be included. All have the same format (I1, I4, 5X, 6F10.0). It is not necessary to have the J values in numerical order, and there may be several cards with the same value of J. It is necessary that "next J" (in col 1) be blank on all of these cards except the last one, which must have some symbol in the first column.

Permissible values of J are from 1 to 45. The type of variation that occurs for each value of J is given in the following list.

J = 1	Movement of collective stick
J = 2	Movement of longitudinal cyclic stick
J = 3	Movement of lateral cyclic stick
J = 4	Movement of pedal
J = 5	Inactive
J = 6	Folding rotors aft after tilting forward and stopping
J = 7	Inactive
J = 8	Inactive
J = 9	A vertical ramp gust; ramp length may be zero
J = 10	A vertical sine-squared gust
J = 11	A horizontal ramp gust; ramp length may be zero
J = 12	A horizontal sine-squared gust
J = 13	A change in engine torque supplied
J = 14	A change in auxiliary thrust supplied
J = 15	Inactive
J = 16	Weapon fire
J = 17	Change of longitudinal mast tilt angle and of RPM on both rotors
J = 18	Rotor brake
J = 19	Inactive
J = 20	Sinusoidal movement of controls or mast
J = 21	Inactive
J = 22	Inactive
J = 23	RPM-dependent hub springs
J = 24	SCAS roll channel
J = 25	SCAS pitch channel
J = 26	SCAS yaw channel
J = 27	Folding rotors horizontally after stop
J = 28	RPM dependent flapping stops
J = 29	Connecting and disconnecting helicopter controls
J = 30	Rotor moment balancing mechanism
J = 31	Changing NPRINT
J = 32	Simplified automatic pilot simulation
J = 33	Inactive
J = 34	Deployment of an aerodynamic brake
J = 35	Dropping an external store
J = 36	Changing incidence or control surface deflection angles of aerodynamic surfaces
J = 37	A trailing vortex system
J = 38	Inactive
J = 39	Inactive
J = 40	Inactive
J = 41	Roll rate input to autopilot (P-Tracker)
J = 42	Pitch rate input to autopilot (Q-Tracker)
J = 43	Yaw rate input to autopilot (R-Tracker)
J = 44	Normal load factor input to autopilot (G-Tracker)
J = 45	Rate-of-climb input to autopilot (RC-Tracker)

The input format for each of the currently available J-cards is given in section 4.29 of reference 1. Start and stop times refer to the time from the start of maneuver unless otherwise noted.

Figure 23 presents a sample input for a maneuver that consists of longitudinal, lateral and pedal doublets input sequentially at maneuver time $t = 0.0, 1.0, \text{ and } 2.0$ seconds respectively. The data set required follows immediately behind the flight constants group and in this sample case consists of cards labeled sequentially 1104 through 1110. The maneuver time card (labeled 1104) indicates that the overall maneuver begins at time $t = 0.0$, ends at time $t = 7.5$ seconds, and the time increment (Δt) between the calculation of maneuver time points is .02 seconds.

For this sample case the following input format defines the information contained in the six maneuver specification cards (labeled 1105 - 1110) needed to simulate this maneuver.

Col 1	Blank except for last card in group	
Col 2-5	J, = 2 longitudinal, = 3 lateral, = 4 pedal movement	
Col 11-20	Start time for input rate 1	(sec)
Col 21-30	Input rate 1	(in./sec)
Col 31-40	Stop time for input rate 1	(sec)
Col 41-50	Start time for input rate 2	(sec)
Col 51-60	Input rate 2	(in./sec)
Col 61-70	Stop time for input rate 2	(sec)

For normal control rigging, positive control rates correspond to up collective, forward longitudinal cyclic, right lateral cyclic and up rotor 2 collective.

Maneuver Simulation Output

The program prints the contents of the maneuver time card (card 291) and all maneuver control cards (all 301-type cards, the J-cards) before starting the trim procedure (figure 24). A program-supplied title for the action caused by each J-card is included to the left of the numerical inputs of the J-cards. This serves as a record of the type of maneuver specified as well as a quick way to check the input data.

Prior to performing the maneuver, the program will calculate and print out the trim iteration pages, a standard trim page and an optional trim page.

It is possible to print out data computed during a maneuver at specified time points. The value of NPRINT on CARD 01 specifies that data is to be printed each NPRINTth time point. For the sample case that was run, NPRINT = 5 and Δt (time increment between maneuver time point calculations) = .02 seconds. Then, for this case, the maneuver time point data is printed out every .1 second.

The format of and data on the maneuver-time-point page are identical to those of the standard trim page with the following exceptions. The problem identification data, trim condition specification, and atmospheric parameters are omitted; some data in the aerodynamic surfaces printout are changed; and some data are added at the top of the page to the body and ground reference parameters and to the rotor parameter printouts. Figure 25 illustrates a typical maneuver-time-point printout page. The maneuver-time-point page is followed by a force and moment summary in both body axis and wind axis for that time point (figure 26). The format of the summary is identical to the summary printed during trim iterations.

Figure 23. Maneuver Simulation Input Data.

INPUT DATA FOR MANEUVER

	START (SEC)	DELT1 (SEC)	MAX1 (SEC)	DELT2 (SEC)	MAX2 (SEC)	MAX3 (SEC)
	0.000000	.020000	7.500000	.020000	0.000000	0.000000
J	XCJT(J,1)	(J,2)	(J,3)	(J,4)	(J,5)	(J,6)
F/A CYCLIC STICK	2	0.000	10.000	.100	.400	.600
F/A CYCLIC STICK	2	.900	10.000	1.000	1.000	7.500
LATERAL CYCLIC STICK	3	1.000	-10.000	1.100	1.400	1.600
LATERAL CYCLIC STICK	3	1.900	-10.000	2.000	2.000	7.500
PEDAL MOVEMENT	4	2.000	-5.000	2.100	2.400	2.600
PEDAL MOVEMENT	4	2.900	-5.000	3.000	3.000	7.500

Figure 24. Maneuver Specification Printed as Output

1.500 SECONDS MANEUVER TIME				1.550 MINUTES ELAPSED COMPUTING TIME			
WEIGHTS-----				POWER/TORQUE-----			
BASIC A/C	8319.	S.L. B.L.	0.00	MAIN	600.42	TORQUE	FT-LB
STORES	0.	W.L.	68.00	TAIL	28.24	RPM	324.1
TOTAL	8319.	0.00	68.00	ENG	688.67	11161.4	6600.0
CENTER OF GRAVITY (IN)				SPEED			
VELOCITY	218.324	U	3.558	MAIN	600.42	10703.6	324.1
ACCEL.	.751	V	3.372	TAIL	28.24	89.5	1656.6
BODY REFERENCE				RECD			
VELOCITY	218.324	W	-12.330	ENG	688.67	11161.4	6600.0
ACCEL.	.751	P	6.950	RECD	688.67	11161.4	6600.0
FLIGHT PATH CONDITION-----				AERODYNAMIC SURFACES-----			
TRUE AIRSPEED	(KNOTS)	129.58	ANGLE OF	FLAP	ANGLE	INCIDENCE	ANGLE
GROUND SPEED	(KNOTS)	129.57	SURFACE	NO. 1	4.50	2.71	0.00
RATE OF CLIMB	(FT/SEC)	-2.00	NO. 2	2.71	0.00	0.00	0.00
CLIMB ANGLE	(DEG)	-52	NO. 3	2.71	0.00	0.00	0.00
HEADING ANGLE	(DEG)	.35	NO. 4	0.00	0.00	0.00	0.00
ANGLE OF ATTACK	(DEG)	-3.23	RT WING	14.00	0.00	0.00	0.00
ANGLE OF SIDESLIP	(DEG)	.93	LT WING	14.00	0.00	0.00	0.00
ANGLE OF AERO YAW	(DEG)	-93	ACCELERATIONS	VERT	(G)	.99	.05
ACCELERATIONS	VERT	(G)	.99	FWD	(G)	.05	-.02
ACCELERATIONS	FWD	(G)	.05	LAT	(G)	-.02	
ACCELERATIONS	LAT	(G)	-.02				
EULER ANGLES TO BODY REFERENCE				GROUND REFERENCE			
PSI	-369	THETA	1.571	PHI	-6.178	218.687	1.339
VELOCITY	-570	THETA	-3.759	PHI	-206	327.685	.943
LOCATION							
CONTROL DISPLACEMENTS				SWASH PLATE ANGLE (DEGREES)-----			
COLL	15.43	F/A	0.00	COLL	F/A	LAT	0.00
F/A	0.00	0.00	0.00	COLL	0.00	0.00	0.00
LAT	0.00	0.00	0.00	COLL	0.00	0.00	0.00
PEDAL	0.00	0.00	0.00	COLL	0.00	0.00	0.00
SUM OF PYLON AND SCAS	0.00	0.00	0.00	COLL	0.00	0.00	0.00
TOTAL SWASH PLATE ANG	15.43	5.40	-1.62	COLL	0.00	0.00	0.00
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90	DEG	15.43	THRUST	7387.77	-133.31	-151.75
PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
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PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
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PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
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PSI=90	-5.40	F/A	-2.326	THRUST	-271.99	20.52	-3.30
PSI=90	.72	F/A	-1.467	THRUST	-271.99	20.52	-3.30
PSI=90	-1.47	F/A	-1.467	THRUST	-271.99	20.52	-3.30
BLADE FEATHERING - DEG				FORCES (SHAFT AXIS) POUNDS			
MEAN	PSI=90						

FORCE AND MOMENT SUMMARY						
BODY AXIS	X-FORCE	Y-FORCE	Z-FORCE	ROLL	PITCH	YAW
FUSELAGE	-376.8	-40.0	70.3	-153.3	-1200.6	-865.2
MAIN ROTOR	133.3	-151.7	-7387.8	-1071.8	-572.2	-7.6
TAIL ROTOR	-20.5	272.0	-3.3	1135.5	-2.0	-7230.5
RIGHT WING	-75.9	-30.2	-485.6	-1155.2	441.6	153.1
LEFT WING	-75.4	25.3	-478.0	1137.0	434.7	-156.3
STABILIZER #1	-13.0	124.0	1.0	301.2	56.7	-3110.7
STABILIZER #2	-2.2	-1.1	14.2	21.4	268.5	4.4
STABILIZER #3	-2.3	-1.1	12.9	-20.7	248.0	-2.5
GROSS WEIGHT	545.4	-29.8	8301.0	.0	-0.0	10703.6
M.R. TORQUE				0.0	-89.5	-0.0
T.R. TORQUE				194.1	-414.0	-511.0
TOTAL	112.6	169.4	44.9			

FORCE AND MOMENT SUMMARY						
WIND AXIS	DRAW(AFT) FORCE	SIDE FORCE	LIFT(UP) FORCE	ROLL MOMENT	PITCH MOMENT	YAW MOMENT
FUSELAGE	380.8	-33.8	-49.0	-123.8	-1198.7	-872.5
MAIN ROTOR	-547.1	-160.7	7388.5	-1078.9	-554.7	-68.0
TAIL ROTOR	15.9	272.3	4.4	1541.2	-27.1	-7155.0
RIGHT WING	48.9	-29.4	489.1	-1154.6	460.8	87.7
LEFT WING	47.9	26.1	481.5	1150.9	416.0	-92.0
STABILIZER #1	11.0	124.2	-3.3	477.0	49.0	-3088.0
STABILIZER #2	3.0	-0.0	-14.8	25.5	268.1	5.6
STABILIZER #3	3.0	-0.0	-12.8	-16.4	248.3	-3.7
GROSS WEIGHT	-76.0	-31.0	-8318.6	603.5	9.8	-10466.6
M.R. TORQUE				-1.5	-89.5	-0.0
T.R. TORQUE				215.8	-418.4	-500.1
TOTAL	-112.7	167.6	-51.1			

Figure 26. Maneuver-Time-Point Force and Moment Summary.

Figure 27 illustrates for the sample case a time history of the sequential doublet control inputs and the resulting aircraft attitudes and rates in all three axes. This time history was produced by hand plotting the data from each of the maneuver-time-point printout pages that were computed for this case. It will be shown later in the description of the postprocessing program, GDAP80, that this data can be plotted automatically by the computer.

RETRIEVING MANEUVER TIME-HISTORY DATA STORED ON MAGNETIC TAPE

A small portion of AGAP80 is invoked to read a maneuver data tape that had been created during a previous maneuver simulation. The data read from the tape is transferred to a disk file for subsequent postprocessing by the postprocessing program, GDAP80.

An NPART = 8 card causes data stored on tape to be loaded on the plot disk (see figure 8). The local programmer should be consulted prior to its use. The value of NVARA on this card must not be equal to zero. The three comment cards (cards 02, 03, and 04) and the GDAP80 inputs constitute the remainder of the NPART = 8 deck. Comment card no. 1 (card 02) has a numeric title for the data set for identification purposes. It is printed in the output heading and is titled IPSN. Note that the IPSN in columns 4-10 of card 02 must be identical to the IPSN used in the run which created the tape.

GDAP80 OPERATIONS

During the course of running a trim or maneuver, the values of a large number of time-history variables at each time point are saved on the plot disk. At the conclusion of the trim or maneuver, postprocessing operations specified in the GDAP80 input data are performed on these variables. Eight postprocessing operations can be performed on data created by AGAP80, as outlined in figure 28.

A brief explanation of each of these postprocessing capabilities is given in the following sections. At present (time-history plots and storing time-history data on tape) are planned to be utilized by this group but many of the others are considered valuable analysis tools for rotary wing performance and structural analysis personnel.

TIME-HISTORY PLOTS (FIGURE 29)

The user may request time-history plots of any of the variables saved during trim or maneuver simulations. Section 9 of reference 1 provides a table of over 2300 variables whose values are saved at each time point during a maneuver simulation. Code numbers are used to identify the variables to be plotted. The code number for each variable saved is given in table 27 of reference 1. These plots may be output on the printer, a CALCOMP drum plotter, or both. Plots created as part of a maneuver restart run will contain data for the entire maneuver.

AEROELASTIC STABILITY ANALYSES (FIGURES 30 AND 31)

Program GDAP80 contains two analyses capable of identifying the frequency and damping of a perturbed multi-variable system. The user can select either the Moving Block Fast Fourier Transform Analysis (NPART = 6) or the Prony Analysis (NPART = 13) to examine the nonsteady-state response of either rotor. See sections 12.3 and 12.4 of reference 3, Volume I - Engineer's Manual for an understanding of these two analyses. The

C-81 MODEL OF



A/C: AH-1G
 WT=8319 LB
 AFT C.G.
 V=129.3 KT
 ALT=4927 HD
 SCAS OFF

CONTROL INPUT:
 SEQUENTIAL
 DOUBLET
 (CDB, DA, DP)

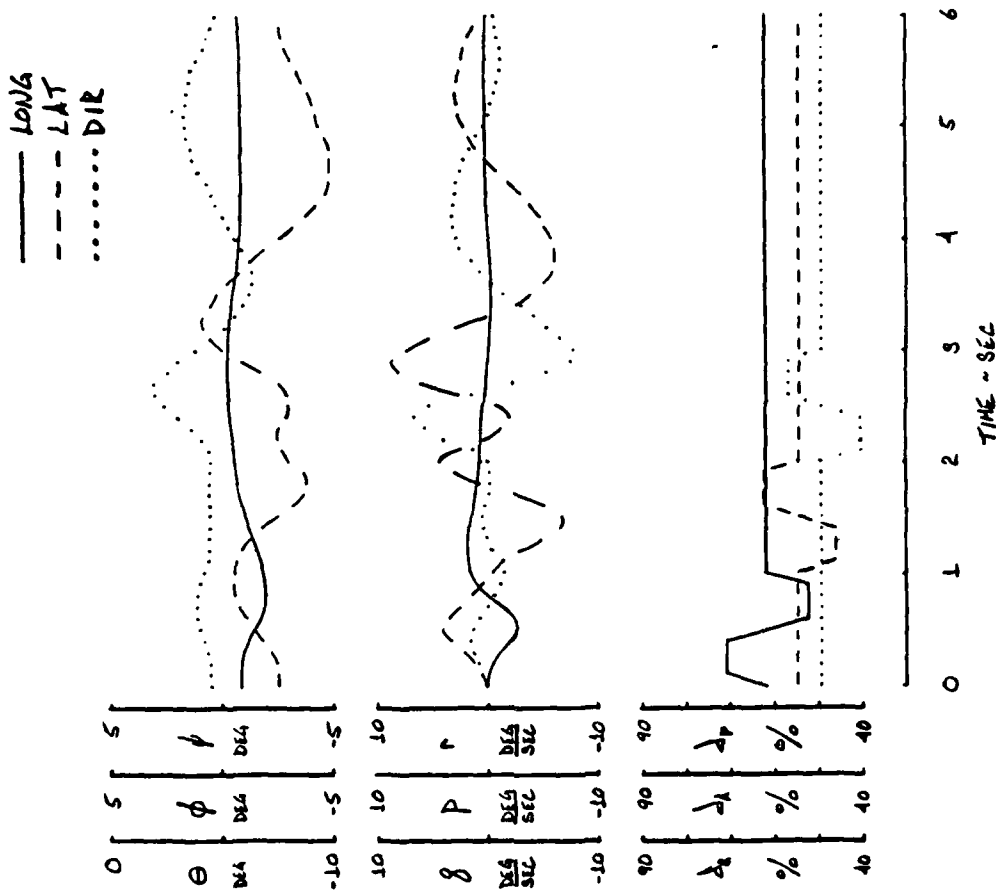


Figure 27. Sample Time-History of
 Maneuver Simulation.

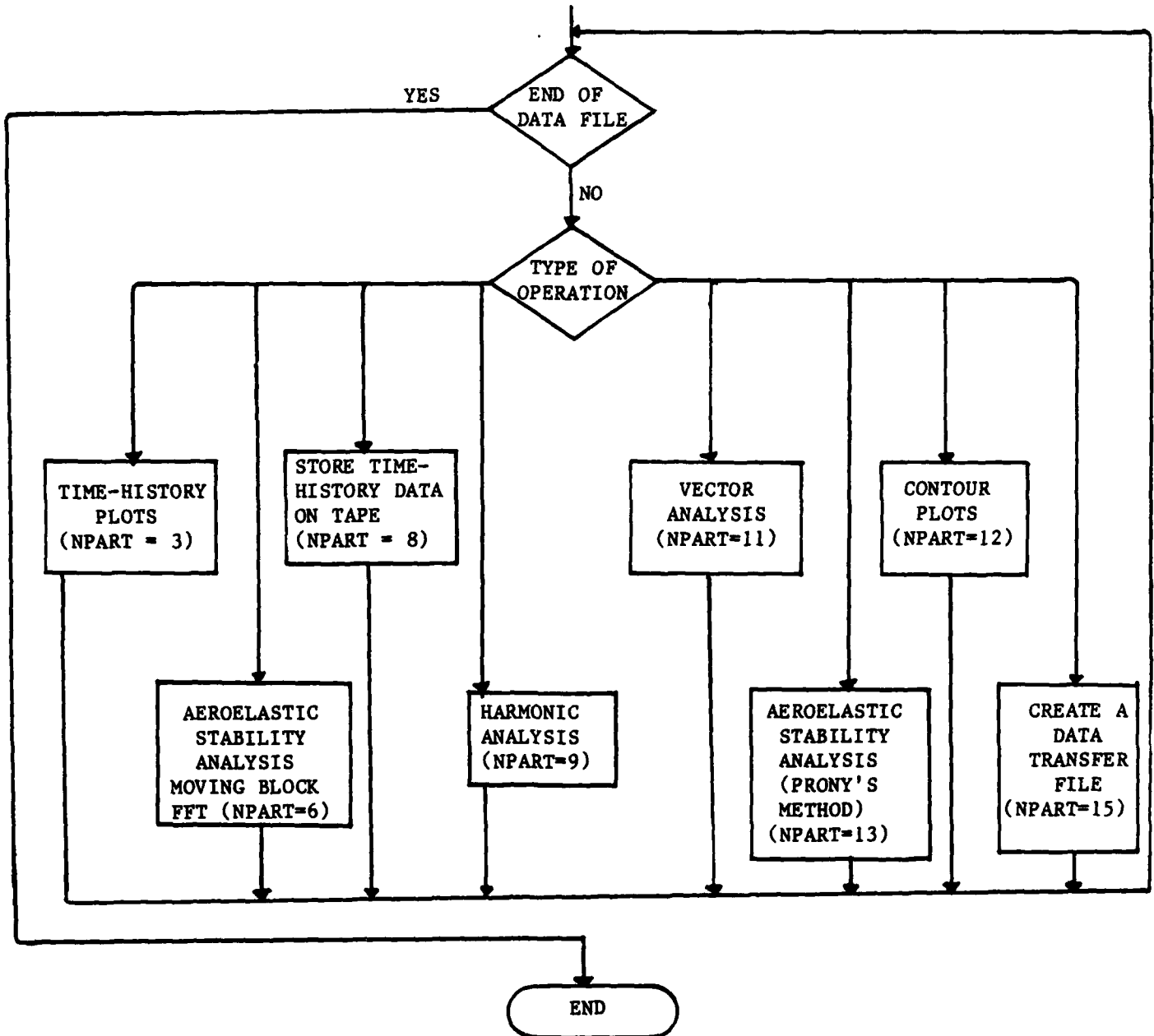


Figure 28. GDAP80 Postprocessing Operations - Performed on Time-History Data Created by AGAP80

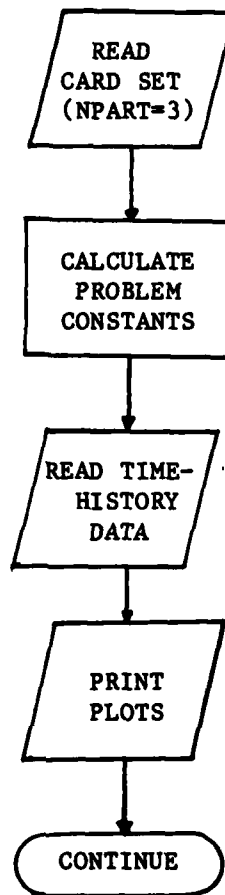


Figure 29. Plotting Operation.

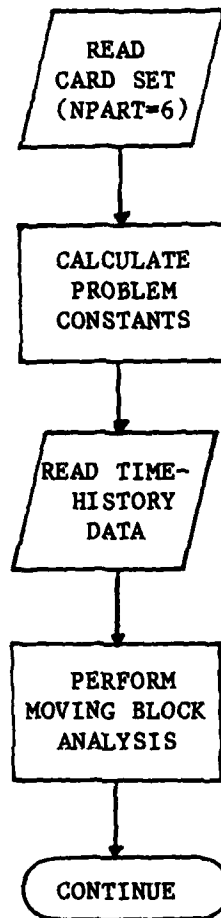


Figure 30. Moving Block Fast-Fourier Transform Operation.

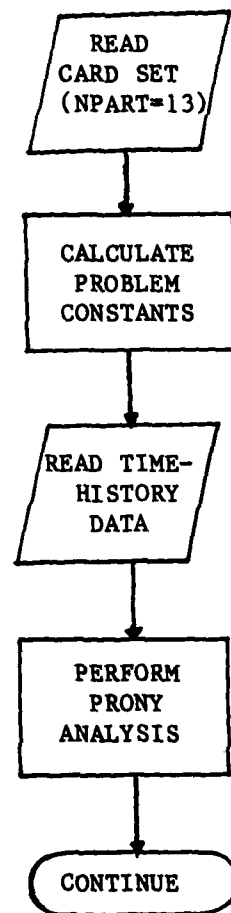


Figure 31. Prony Stability Analysis Operation.

frequency and damping characteristics of airframe motion may also be investigated using these analyses, but that is not their primary function.

STORING TIME-HISTORY DATA ON TAPE (FIGURE 32)

If it is desired to perform additional postprocessing of the saved variables, they may be transferred from the plot disk to a magnetic time-history tape (NPART = 8). The data on the tape may then be reloaded to the plot disk for further use at a later time. Note that time-history data which has been stored on tape can be retrieved with an AGAP80 deck with NPART = 8.

HARMONIC ANALYSIS (FIGURE 33)

A complete harmonic analysis may also be made for any of the saved variables (NPART = 9). A Fast-Fourier-Transform technique is used to examine a broad range of frequencies. This option is especially useful for studying rotor bending moments and related variables.

VECTOR ANALYSIS (FIGURE 34)

Frequently, maneuvers are run where one of the controls or the longitudinal mast tilt angle is varied sinusoidally. In this case, the vector analysis operation (NPART = 11) can be very useful. This analysis uses the least-squared-errors technique to fit the saved data to a curve of the form

$$F_i(t) = A_i \sin(\omega t + \phi_i) + B_i$$

Then, any amplitude ratios, A_i/A_j , and phase angle differences, $\phi_i - \phi_j$, may be computed. Lastly, linear combinations of the variables may be derived in the following form:

$$F_i(t) = C_{ij} F_j(t) + D_{ik} F_k(t) + E_i$$

CONTOUR PLOTS (FIGURE 35)

Rotor aerodynamic quantities can be tabulated versus radial station and azimuth and plotted in plane-polar format using this option (NPART = 12). The data are plotted assuming that the blade stations are equally spaced along the radius. The tabulations and plots are particularly useful for displaying the rotor aerodynamic environment.

CREATING A DATA TRANSFER FILE (FIGURE 36)

This option permits the user to transmit C81-generated data to a temporary file accessed by the DATAMAP File Creation program in order to add the data to the DATAMAP Master File (NPART = 15). The user can then use DATAMAP to postprocess the C81 data and compare it with test data also resident upon the Master File. (The DATAMAP programs are described in detail in reference 4). Note that this option is described here to demonstrate a potential program capability. This installation does not presently have the DATAMAP programs installed.

USER'S GUIDE TO THE INPUT AND OUTPUT FOR GDAP80

Data generated by AGAP80 can be postprocessed using program GDAP80, which is automatically invoked following an AGAP80 run. All inputs to GDAP80 must follow all inputs to AGAP80. Data to be postprocessed must have been generated by the AGAP80 run.

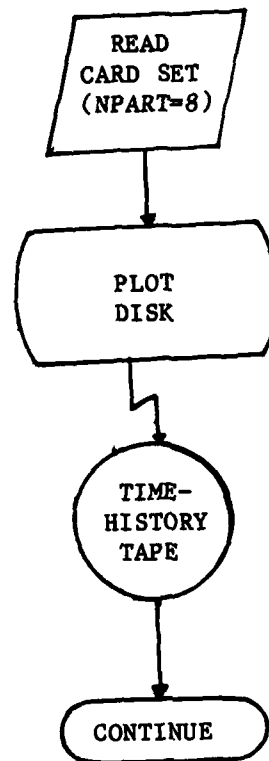


Figure 32. Operation for Storing Maneuver Time-History Data on Tape.

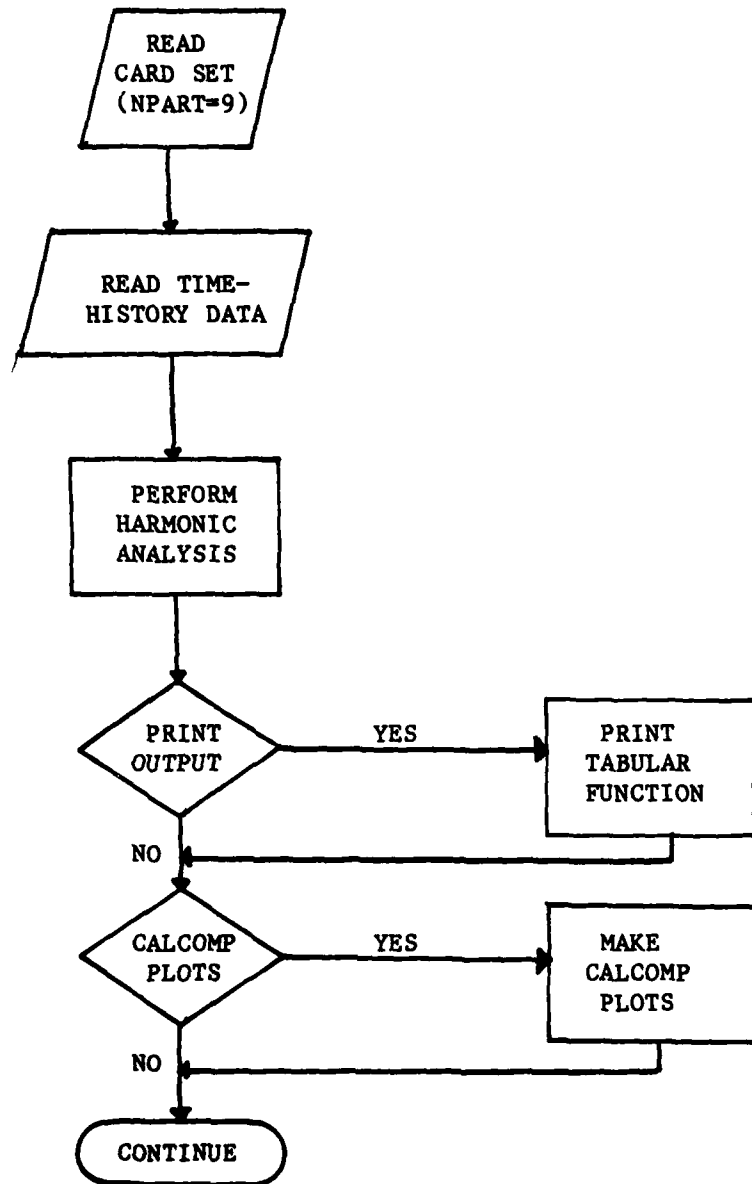


Figure 33. Harmonic Analysis Operation.

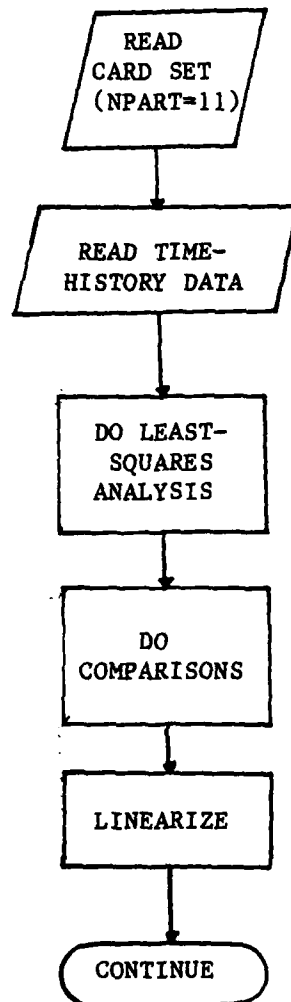


Figure 34. Vector Analysis and Data Reduction Operation.

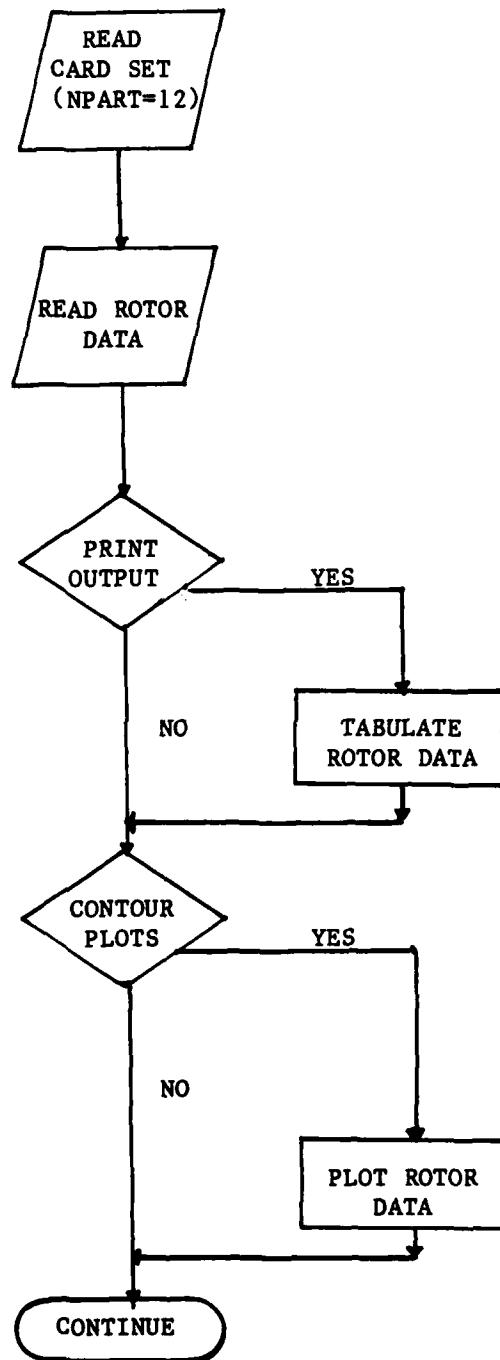


Figure 35. Contour Plot Operation.

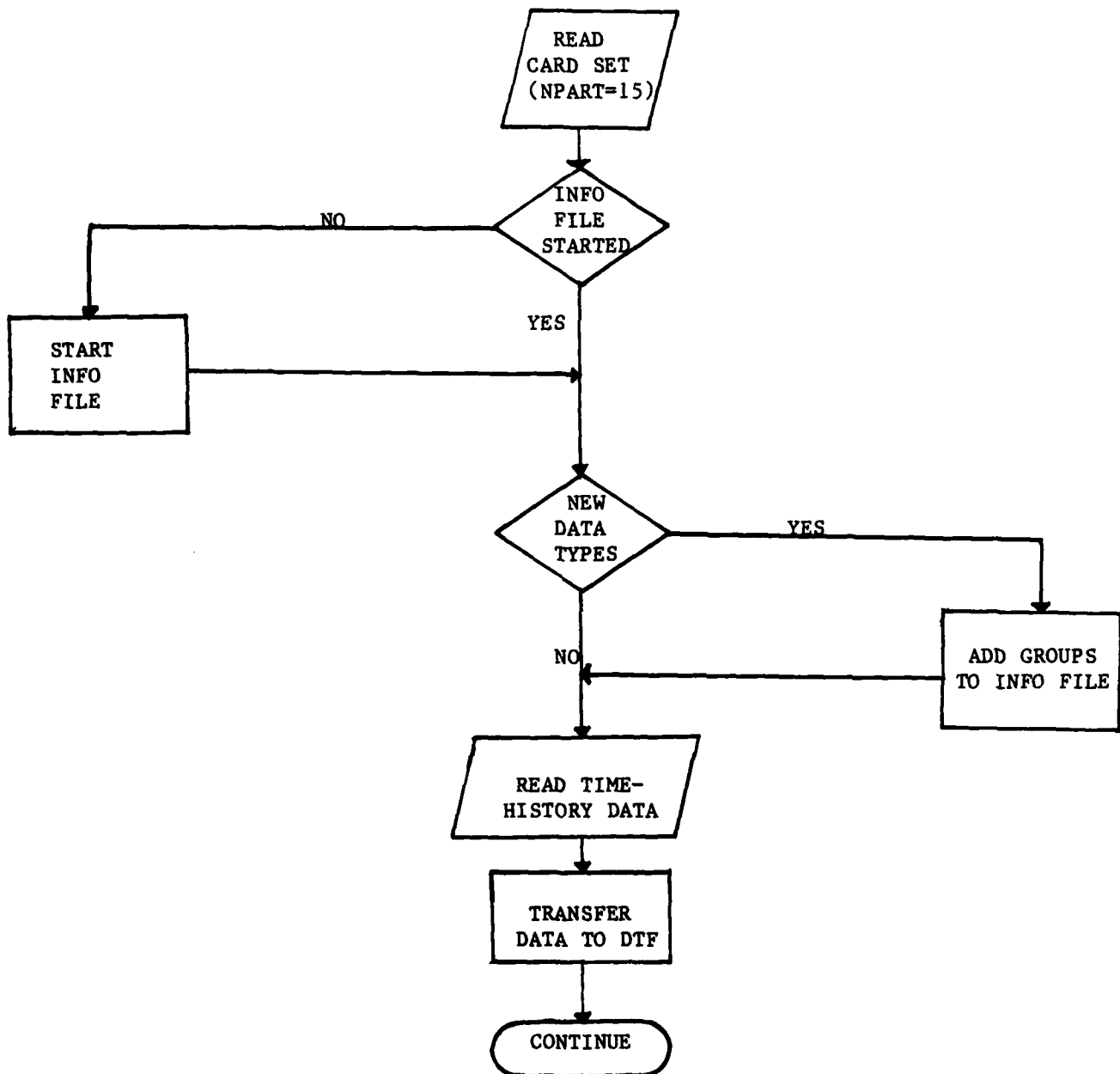


Figure 36. Creation of a Data Transfer File.

The data to be postprocessed by GDAP80 have been stored in one or more Postprocessing Data Blocks (PDB) as they were created by AGAP80. Separate PDBs are created from one of three sources:

- 1) a Quasi-Static trim for which $IPL(79) \neq 0$
- 2) a Time-Variant trim of either rotor
- 3) a maneuver

Note that $IPL(79)$ controls the storing of certain Quasi-Static trim rotor variables for tabulation and contour plots. Data are stored in one Postprocessing Data Block for each rotor during Quasi-Static trim whenever $IPL(79) \neq 0$.

Since the data in any one PDB is generally completely independant of the data in any other PDB, the postprocessing instructions for a particular PDB are input to GDAP80 in a unique set. Each such set can contain instructions to perform any of the following operations, with certain restrictions:

- 1) Plot time histories of selected data ($NPART = 3$)
- 2) Perform a stability analysis of time-history data using the Moving Block Fast Fourier Transform procedure ($NPART = 6$)
- 3) Store maneuver time-history data on magnetic tape for future postprocessing ($NPART = 8$)
- 4) Perform an harmonic analysis of time-history data ($NPART = 9$)
- 5) Perform a vector analysis of time-history data ($NPART = 11$)
- 6) Tabulate or contour plot rotor aerodynamic data ($NPART = 12$)
- 7) Perform a stability analysis of time-history data using Prony's Method ($NPART = 13$)
- 8) Create a Data Transfer File ($NPART = 15$)

The $NPART = 14$ card is used to terminate the list of postprocessing instructions pertaining to a particular PDB. Upon reading an $NPART = 14$ card, GDAP80 indexes the AGAP80-generated file of data to the beginning of the next PDB and prepares to execute the next set of postprocessing instructions.

As mentioned earlier, only two of these eight postprocessing operations, time-history plots and storing time-history data on tape, are planned at present to be utilized by this group. The input format and output for these two operations is discussed in the following two sections.

PLOTTING OF TIME-HISTORY DATA

The input format for plotting of time-history data is illustrated below.

Card 11

Col 1 - 2 NPART (must equal 14 to move to the next Postprocessing Data Block)

Card 21

Col 2 NPART (must equal 3 for plotting)
Col 4 - 6 NPRINT print control

Cards 22A, 22B... (One for each set of plots desired - 10 maximum)

Col 1 KEYS (Blank except for the last 22-type card)
Col 2 - 5 KV1, Code for variable 1
Col 7 - 10 KV2, Code for variable 2
Col 12 - 15 KV3, Code for variable 3
Col 20 KEY (1 = Plot on printer only)
Col 31 - 40 SC1, Minimum scale for KV1
Col 41 - 50 SC2, Minimum scale for KV2
Col 51 - 60 SC3, Minimum scale for KV3

Section 9 of reference 1 provides a table of the code numbers to be used for KV1, KV2, and KV3.

Whenever time-history data are available, the 20-series cards may be used to plot the data. This procedure is an option. If it is not to be used, simply omit the 20-series cards. The data may be plotted on the computer printer or put on tape for plotting by the CALCOMP plotter. The local programmer should be consulted for the proper setup for jobs that write a tape for CALCOMP plotting.

Time-history data are stored after all time-variant trim cases and for maneuvers and may be plotted by inserting 20-type cards in the data deck. If a maneuver simulation is being performed, a 21-type card and up to 10 22-type cards are placed immediately after the maneuver specification cards. See figure 37, cards labeled with sequence numbers 1111 through 1117, for illustration.

Card 21

Column 2 must contain the integer 3 to call the plotting routine. NPRINT specifies that the first and every NPRINTth data point following are to be plotted. If NPRINT = 0, it is reset to unity.

Cards 22A, 22B, etc.

The first column of all but the last 22-type card must be blank. The first column of the last 22-type card must contain a character (a slash is recommended).

One 22-type card is required for each plot. A maximum of 10 of these cards is permitted after each CARD 21. Each plot may contain one to three variables. The first three inputs (KV1, KV2, KV3) on a 22-type card are the code numbers for the variable(s) to be plotted. The code numbers must be integers. If only one variable is to be plotted. The code numbers must be in columns 2 - 5; if only two are to be plotted, only columns 2 - 5 and 7 - 10 are to be used.

KEY (column 20) controls where the plotting is done.

Plotting of Time-History Data

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KEY = 0 for CALCOMP only
 KEY = 1 for printer only
 KEY = 2 for both

The program internally computes its own scales for plotting each variable based on the maximum and minimum values of the variables during the time-history and internally specified minimum scales. The internal minimum scale may be overridden for each variable with the last three inputs on the 22-type card. The minimum scale inputs (SC1, SC2, SC3) are in units of the appropriate variable per inch for printer plots and units per centimeter for CALCOMP plots.

If the user wishes to plot more variables than permitted on the 22-type cards, then another 21-type card should be inserted in the instruction set, followed by up to 10 more 22-type cards.

A sample time-history printer plot that was generated after maneuver simulation is provided in figure 38. The plot symbols used are the numbers 1, 2, and 4. The variables corresponding to each symbol and its units are printed as part of the plot heading. If two or all three of the curves intersect at a single point, the symbol printed is the sum of the individual symbols. For example, the symbol 7 ($=1+2+4$) means that all three curves pass through the point where the 7 is printed.

The lower and upper limits on the plot scale are given for each variable plotted. The scale in units per inch is also given.

The user is cautioned that the automatic plot scaling procedure may expand small variations completely out of proportion to their true importance. Be certain to check the scales on all plots.

Time is the independent variable, and is printed along the left edge of the plot, defining the time axis. Maneuver plots will always start at $t = 0.0$. If the time increment is changed at some point during a maneuver, there will be a change in the time scale at this point. The resulting compression or expansion of the time scale may cause apparent discontinuities that are not actually in the data. The user should check the time scale carefully.

Each plot card, CARD 22, is independent of all other plot cards. Thus, if desired, one variable may be plotted on more than one plot.

The dots printed down the page are spaced at 1-inch intervals to make it easier to read the plot values by eye. They also provide reference lines to help see slower variations on long time histories.

The plot routine can store the values of all plot variables for a maximum of 2000 time points. Should the user specify $NPRINT = 1$ on CARD 21 for a particularly long maneuver, the program will keep internally doubling $NPRINT$ until the total number of points to be plotted is less than or equal to 2000.

For CALCOMP plots, the names of the variables plotted appear at the top of each CALCOMP page along with their respective plot symbols. The vertical scales and the plots themselves are identified by the plot symbols.

It is recommended that the user avoid plotting periodic variables of approximately the same magnitude, with near-zero phase shifts, on the same plot, as it will be difficult to differentiate between the traces. This applies to printer plots as well. A maximum of 2500 time points may be plotted on CALCOMP PLOTS.

STORING TIME-HISTORY DATA ON TAPE

The input format for this postprocessing option is given below.

Card 41

Note that this card may be included only for the Postprocessing Data Block resulting from a maneuver.

Col 2 NPART (must equal 8 for tape file operations)

Col 11- 15 NVARA (must be blank or all zeros to store data)

Note also that time-history data which has been stored on tape can be retrieved with an AGAP80 deck with NPART = 8.

Following a maneuver (NPART = 2, 4, or 5), it may be desirable to store the time-history on tape so that the data can be recalled later for additional analysis or plotting. Inputs of 8 and 0 in columns 2 and 15 respectively will store the data. However, the local programmer should be consulted for the proper setup of the job before attempting to use this option. This instruction should only be used for the PDB resulting from the maneuver portion of a run.

PRESENT OPERATIONAL PROBLEMS

Two program operation problems were identified while running test cases to check out each of the program operational capabilities. The two problems encountered were 1) the inability to perform any of the postprocessing operations of GDAP80, and 2) the inability to compute the correct eigenvalues in the rotorcraft stability analysis. Both of these problems are associated with the copy of the AGAP80 version that is installed on the CDC CYBER 175/CDC 6600 computer system at NAVAIRDEVCEEN and are not considered universal problems with the C81 program.

POSTPROCESSING OPERATIONS

After running a test case to perform a maneuver simulation, it was decided to check out the postprocessing capabilities available in GDAP80, namely, the plotting of time-history data. Upon submitting the test case with all the proper required inputs to plot the time-history of the selected parameters (as indicated in figure 37), the program calculated and printed out all the maneuver-time-point digital data but did not print the printer plots as directed. After investigating the problem it was determined that the CDC conversion copy of the AGAP80 version of C81 as delivered to NAVAIRDEVCEEN did not have the postprocessing program (GDAP80) subroutines. Further checking with the Army Structures Laboratory revealed that the postprocessing program portion of C81 had not been converted as yet for usage on CDC CYBER computer systems. The conversion of this part of the program is presently underway. As soon as the conversion is complete and validated by the Army Structures Laboratory, the NAVAIRDEVCEEN will receive a new copy of AGAP80 program source on magnetic tape which will include the postprocessing program GDAP80. It is anticipated that this work will be completed by March 1982.

EIGENVALUE CALCULATION

Several test cases were run in an attempt to check out the rotorcraft stability analysis capability of the program. Throughout all attempts the program would successfully calculate and print out the stability derivatives for both the total aircraft and the rotors. The program would then develop and print out the mass matrix, the damping matrix, and the stiffness matrix. Up to this point all output data correlated with the sample rotorcraft stability analysis case in section 6.8 of reference 1. But, when the controls-fixed roots and transfer function denominator were printed out, it was noted that that output data had to be incorrect. For example, the printout would one time show the following 12 complex roots of the rotorcraft characteristic equation:

<u>Root #</u>	<u>Real</u>	<u>Imag</u>
1	.10000E+13	0.
2	.10000E+13	0.
3	.10000E+13	65536.
4	.10000E+13	65536.
5	.10000E+13	65536.
6	.10000E+13	65536.
7	.10000E+13	65536.
8	.10000E+13	65536.
9	.10000E+13	65536.
10	.10000E+13	65536.
11	.10000E+13	65536.
12	.10000E+13	65536.

and the program would stop printing at that point. That is, it would not go on to print out the remaining parts of the stability analysis, namely, the controls-fixed mode shapes, transfer function data, and frequency response data.

Another run of the same case would produce different results. An example of different results is the following 4 complex roots of the rotorcraft characteristic equation:

<u>Root #</u>	<u>Real</u>	<u>Imag.</u>
1	.10000E+13	0.
2	.10000E+13	0.
3	.10000E+13	.15749E-03
4	.10000E+13	518.96

and then the program would continue printing out extraneous controls-fixed mode shape data, transfer function data, and frequency response data to correspond with these 4 strange roots.

There have been several discussions about this problem with personnel at the Army Structures Laboratory and the Applied Technology Laboratory, Ft. Eustis, VA. This problem is still under investigation and is believed to be associated with the conversion of the code for usage on CDC CYBER computer systems. The two subroutines, ALLMAT and ALLVEC, which the stability analysis uses to compute eigenvalues and eigenvectors have had some cards changed as a result of the conversion. It is expected that, with the second conversion of AGAP80 that is currently underway by the Army Structures Laboratory to include the postprocessing program GDAP80, this problem will be resolved.

COST OF PROGRAM OPERATION

The cost of running this program on the CDC CYBER 175/CDC 6600 computer system at NAVAIRDEVCEEN has been of interest. With the limited number of cases that have been run thus far throughout this checkout and validation stage, a cost breakdown for trim analysis, stability analysis, and maneuver simulation is presented in the following sections.

TRIMMED FLIGHT ANALYSIS

The cost of running a trimmed flight analysis is directly related to the number of iterations required to converge to a trimmed flight condition. Two factors determine this number of iterations. The program is set up to accept inputs of allowable errors in the force and moment summations (XIT(15) through XIT(21) of the Iteration Logic Group). Normally, the smaller the allowable errors, the larger the number of iterations required for trim.

Also, the initial settings of the control positions, the Euler angles, the rotor flapping angles and rotor thrust inputs have a direct bearing on how many iterations are required to converge to a trim. These are all inputs in the Flight Constants Group (XFC(5) through XFC(20)). The closer these values are to the final trim value, the faster the analysis will converge on trim. In a parameter sweep, the previous trim point is the starting condition for finding the next trim point. So, for example, in a speed sweep, a change of 20 or 30 knots is the most that should normally be used between 40 and 150 knots. Outside of this range, the maximum change should not exceed 10 knots.

A typical trimmed flight analysis cost about \$25 to \$30 and used about 20 to 25 cp seconds execution time. Whereas, a parameter sweep of five airspeeds for trim cost about \$95 to \$100 and used about 75 to 80 cp seconds of execution time.

The program includes the option for two basic types of rotor analyses for trim: Quasi-Static (QS) and Time-Variant (TV). The cost data discussed above is for a QS rotor analysis trim. A Time-Variant (TV) trim is much more expensive and is generally used to simulate an aeroelastic rotor when blade load data are desired. The Quasi-Static (QS) rotor analysis is best suited to rotor systems where the dominant blade motions are at 1/rev and where, for most performance and flying qualities investigations, other flapping frequencies can be neglected. The major limitation of the Quasi-Static analysis is that only the static and 1/rev component of the blades response are calculated. Consequently, accurate computation of blade loads is not possible. For a more detailed explanation of the two types of rotor analyses, the reader is referred to Volume I, section 2.2 of reference 3.

Two identical trimmed flight analyses were run with the only difference being the requirement for one to be a QS trim followed by a TV trim of the main rotor. The data below gives an indication of the difference in cost to perform these two analyses.

<u>Case #</u>	<u>Type of Trim</u>	<u>Execution Time ~ CP Seconds</u>	<u>Cost</u>
10	QS + TV	68.427	\$86.10
11	QS only	21.555	\$27.72

The Time-Variant portion of a Quasi-Static trim followed by a Time-Variant trim is in essence a time-history of XIT(6) rotor revolutions with the fuselage and control positions locked. (In this case XIT(6) = 7 rotor revolutions). For each rotor which is Time-Variant, the additional run time for the Time-Variant trim after the Quasi-Static trim will be about the same as the time for a maneuver of XIT(6) rotor revolutions.

ROTORCRAFT STABILITY ANALYSIS

A rotorcraft stability analysis can be performed following a Quasi-Static trim. With the eigenvalue calculation problem that was discussed in an earlier section, only preliminary cost data for this operation can be discussed. At least five cases were run in an attempt to checkout this analysis operation. In all cases the program stopped short of computing the correct eigenvalues. Some cases computed incorrect eigenvalues and used those in further computations, while other cases caused the program to terminate after calculating and printing out the extraneous roots.

Even with these problems in the rotorcraft stability analysis, all indications lead to the assumption that, if the analysis were completed with correct computations of the eigenvalues, the cost of operations would be approximately the same. The following data gives an indication of anticipated cost of operation of the trim followed by rotorcraft stability analysis.

Case#	Type Of Analysis	Execution Time	Cost	Comments
		CP Seconds		
6	TRIM+STAB.ANAL.(1)	42.067	\$52.77	Program terminated before analysis completed
7	TRIM+STAB.ANAL.(1)	41.951	\$52.58	Program terminated before analysis completed
8	TRIM+STAB.ANAL.(1)	43.363	\$54.34	Analysis completed with incorrect eigenvalues
9	TRIM+STAB.ANAL.(2)	23.203	\$29.94	Analysis completed with incorrect eigenvalues
12	TRIM+STAB.ANAL.(2)	26.585	\$33.93	Program terminated before analysis completed
15	TRIM+STAB.ANAL.(2) (3 Case Parameter Sweep)	59.487	\$74.04	Program terminated before last analysis completed
(1)	Coupled fuselage (one 6x6 matrix) in stability analysis matrix; no rotor flapping degrees of freedom			
(2)	Uncoupled fuselage (two 3x3 matrices) in stability analysis matrix; both rotor flapping degrees of freedom			

MANEUVER SIMULATION

The amount of computer execution time required to perform a maneuver simulation is dependent on two factors: 1) the time increment (Δt) between the calculation of maneuver time points; and 2) the total length of maneuver time. These two factors can be lumped into one by the simple fact that:

$$\text{number of maneuver time points} = \frac{\text{total length of maneuver time}}{(\Delta t) \text{ time increment between maneuver time points}}$$

Therefore, the cost of running a maneuver simulation is directly related to the number of maneuver time points.

Section 4.28 of reference 1 discusses some of the constraints placed on the size of Δt . These requirements generally apply to Time-Variant maneuvers.

The sample maneuver simulation case discussed earlier was a trim followed by maneuver, both of which used a Quasi-Static rotor analysis. The maneuver begins at time $t = 0.0$, ends at time $t = 7.5$ seconds, and the time increment (Δt) between the calculation of maneuver time points is .02 seconds.

A Δt equal to .02 seconds was found to be both adequate and necessary for this aircraft with this rotor system with a rotational speed of 324.1 RPM, using the Quasi-Static rotor analysis for maneuver. A Δt of .02 seconds corresponds with a maneuver time point calculation every 38.9 degrees of main rotor azimuth. It was found that when Δt was input as .05 seconds (every 97.2 degrees of rotor azimuth) the numerical integration technique went unstable. A Δt of .02 seconds or less (approximately 30 degrees or rotor azimuth or less) is recommended for Quasi-Static maneuvers. To insure stability of the numerical technique during a Time-Variant maneuver, the azimuth increment should always be less than or equal to 15 degrees.

The following data illustrates the cost of performing maneuver simulations with this program. It must be mentioned that the cost figures are for a digital listing of the maneuver time point data and do not represent any postprocessing of maneuver data, such as time history plots, harmonic analysis, etc.

Case#	Type of Analysis	Maneuver Time Lgth.	Δt	No. of Maneuver	Execution Time ~	Total	Cost
		~Seconds	Seconds	Points	CP Sec	Cost	Time Pt
1	TV TRIM+MAN.SIM.	.201	.00386	52	73.742	\$ 93.82	\$1.80
2	QS TRIM+MAN.SIM.	8.224	.01543	533	455.266	\$552.60	\$1.04
3	QS TRIM+MAN.SIM.	.300	.05	6	27.068	\$ 34.72	\$5.79
4	QS TRIM+MAN.SIM.	2.500	.02	125	125.954	\$154.28	\$1.23
5	QS TRIM+MAN.SIM.	6.900	.02	345	320.090	\$389.15	\$1.13
16	QS TRIM+MAN.SIM.	7.500	.02	375	383.842	\$479.49	\$1.28

The cost/time point for case 3 is ambiguous since it cost \$27.89 of the \$34.72 total cost to perform the trimmed flight analysis. Therefore, it cost \$6.83 for 6 maneuver time points, \$1.14/time point. It must be kept in mind that in each of the above cases, the total cost includes the cost to perform the trimmed flight analysis.

From the data presented it can be seen that it costs approximately \$1.15/time point to perform a maneuver simulation. Therefore, a maneuver of 5 to 10 seconds in length consisting of 250 to 500 time points is going to cost between \$275 and \$575 to run.

CONCLUSIONS AND RECOMMENDATIONS

1. The Rotorcraft Flight Simulation Program C81 provides the NAVAIRDEVCCEN with an analytical tool necessary to evaluate the flying qualities, performance and aircraft loads of existing and future helicopters.

2. The program in its present form here at NAVAIRDEVCCEN (with the eigenvalue calculation problem and inability to perform postprocessing operations) has a limited usability. Trims and maneuvers can be calculated; total aircraft and rotor partial derivatives can be calculated. The limitations are that characteristic equation roots and transfer functions have to be computed in another program and time-history plots of the maneuver data must be hand plotted.

3. The parameter sweep operation works as advertised.

4. Due to the method of billing for computer execution time here at NAVAIRDEVCCEN, the cost of running this program is higher than that which most other user facilities experience. Maneuver simulation is an operational capability that is an important asset to this program. It also is expensive to run. It was shown that a typical maneuver cost approximately \$1.15/time point and, at this rate, it is not unusual for a single maneuver simulation to cost about \$500.

5. It is recommended that the second CDC conversion of the AGAP80 version of C81 (with postprocessing capabilities included) be installed, checked out and validated here at NAVAIRDEVCCEN as soon as the conversion is completed.

6. The time-history plotting operation is a highly desirable and valuable asset of C81 that can be used extensively in conjunction with maneuver simulation.

7. The eigenvalue calculation portion of the rotorcraft stability analysis must be made operational. The problem is still under investigation.

8. After the second CDC conversion is implemented on the CDC CYBER 175/CDC 6600 computer system at NAVAIRDEVCCEN, the program can be made available for center-wide usage by other helicopter technology disciplines, i.e., structural loads analysts, performance analysts, and control system analysts.

9. Future Navy helicopter designs can be modeled and their flying qualities, flight loads, and performance can be analytically studied with this program when its full capabilities are brought to fruition at this center.

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3. McLarty, T. T., et al., ROTORCRAFT FLIGHT SIMULATION WITH COUPLED ROTOR AEROELASTIC STABILITY ANALYSIS, Volumes I - III, Bell Helicopter Textron, USAAMRDL Technical Reports 76-41A, 76-41B, and 76-41C, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, May 1977, AD A042464 (TR 76-41A only).
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NADC-81290-60

APPENDIX A

SAMPLE INPUT DATA DECK FOR AH-1G HELICOPTER

PLEASE RETURN TO D. J. GAJKOWSKI, FLIGHT DYNAMICS, CODE 6053, EXT. 8221												
040201 AN-10 ULS ROTOR SIMULATION 040201 NAMEFLUW -- LONG, LAT + PEDAL DOUBULETS AT UH (DAT3) 040201 LEVEL FLIGHT AT 2000' HP, 87 DEG C 8319 LB APT CG												
OLS PROGRAM LOGIC GROUP												
0	2	0	-20	5	0	0	0	0	0	2	1	0
-1	-1	1	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	5	1	2	0	0	0	0	0	3	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	1	1	1	0	0	0	0	0	0	0	0
0	0	3	0	0	0	0	0	0	0	0	0	0
MODEL 809 M/R AIRFOIL DATA TABLE												
SUPER 540 EXTENDED 540 EXTENDED 1301175 947												
0.0	0.3000	0.5000	0.6000	0.6500	0.7000	0.7500	0.8000	0.8500	0.8500	0.8500	0.8500	0.8500
0.0000	1.0000	0.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-180.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-172.00	0.7800	0.7800	0.7800	0.7800	0.7800	0.7800	0.7800	0.7800	0.7800	0.7800	0.7800	0.7800
-161.00	0.6200	0.6200	0.6200	0.6200	0.6200	0.6200	0.6200	0.6200	0.6200	0.6200	0.6200	0.6200
-147.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
-129.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
-49.00	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800
-39.00	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800	-1.1800
-21.00	-0.8400	-0.8100	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500
-18.00	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500	-0.8500
-14.00	-1.1700	-1.1700	-0.8280	-0.8710	-0.8720	-0.8530	-0.8410	-0.8010	-0.7670	-0.7670	-0.7670	-0.7670
-12.00	-1.2200	-1.2200	-0.9350	-0.8670	-0.8670	-0.8390	-0.8400	-0.8180	-0.7780	-0.7780	-0.7780	-0.7780
-11.00	-1.1800	-1.1800	-0.9340	-0.8620	-0.8600	-0.8290	-0.8320	-0.8120	-0.7770	-0.7770	-0.7770	-0.7770
-10.00	-1.0700	-1.0700	-0.9300	-0.8530	-0.8540	-0.8150	-0.8200	-0.8030	-0.7760	-0.7760	-0.7760	-0.7760
-9.00	-0.9800	-0.9800	-0.8200	-0.8380	-0.8400	-0.8050	-0.8010	-0.7810	-0.7530	-0.7530	-0.7530	-0.7530
-8.00	-0.8500	-0.8600	-0.8000	-0.8130	-0.8190	-0.7780	-0.7800	-0.7530	-0.7300	-0.7300	-0.7300	-0.7300
-7.00	-0.7630	-0.7630	-0.8300	-0.7640	-0.7650	-0.7540	-0.7420	-0.7200	-0.7040	-0.7040	-0.7040	-0.7040
-6.00	-0.6450	-0.6450	-0.7100	-0.7450	-0.7280	-0.7210	-0.6700	-0.6720	-0.6580	-0.6580	-0.6580	-0.6580
-4.00	-0.4300	-0.4300	-0.4740	-0.5840								

[illegible]

1	842001	84200	00012100
-50.001	662001	66200	00012200
1	662001	66200	00012300
-50.001	302001	302001	00012400
1	302001	30200	00012500
-30.000	600000	600000	00012600
0	600000	60000	00012700
-28.000	540000	540000	00012800
0	540000	54000	00012900
-26.000	480000	480000	00013000
0	480000	48000	00013100
-24.000	420000	420000	00013200
0	420000	42000	00013300
-22.000	360000	360000	00013400
0	360000	36000	00013500
-20.000	300000	300000	00013600
0	300000	30000	00013700
-18.000	240000	240000	00013800
0	240000	24000	00013900
-16.000	180000	180000	00014000
0	180000	18000	00014100
-15.000	167000	167000	00014200
0	167000	16700	00014300
-13.500	135000	135000	00014400
0	135000	13500	00014500
-12.500	106500	106500	00014600
0	106500	10650	00014700
-11.500	046500	046500	00014800
0	319000	31900	00014900
-10.500	026500	026500	00015000
0	302000	30200	00015100
-9.500	017500	017500	00015200
0	287000	28700	00015300
-8.500	012500	012500	00015400
0	269000	26900	00015500
-7.500	010200	010200	00015600
0	250000	25000	00015700
-6.500	009200	009200	00015800
0	239000	23900	00015900
-5.500	008500	008500	00016000
0	211000	21100	00016100
-4.500	008000	008000	00016200
0	190000	19000	00016300
-3.500	007000	007000	00016400
0	165000	16500	00016500
-2.500	007400	007400	00016600
0	140000	14000	00016700
-1.500	007100	007100	00016800
0	105000	10500	00016900
-0.500	006500	006500	00017000
0	072000	07200	00017100
0	065000	06500	00017200
0	069000	06900	00017300
0	063000	06300	00017400
1.500	007100	007100	00017500
2.500	007400	007400	00017600
3.500	007000	007000	00017700
			00017800
			00017900
			00018000
			00018100
			00018200
			00018300
			00018400
			00018500
			00018600
			00018700
			00018800
			00018900
			00019000
			00019100
			00019200
			00019300
			00019400
			00019500
			00019600
			00019700
			00019800
			00019900
			00020000

0.165000.17500
 4.500.000000.000000.000000.013400.020000.043000.070000.100000.16500
 0.190000.19800
 5.500.000500.000500.010000.022300.041500.071500.095500.120000.18700
 0.211000.22000
 6.500.000000.000000.012400.030000.071000.103000.127000.148000.21000
 0.230000.23000
 7.500.010000.010000.027400.066000.103000.132000.155000.171000.23000
 0.250000.25700
 8.500.010000.010000.040000.066000.103000.132000.155000.171000.23000
 0.250000.27300
 9.500.017500.017500.070000.127000.164000.189000.204000.218000.28000
 0.287000.29100
 10.500.020000.020000.110000.150000.185000.210000.220000.240000.28700
 0.303000.30500
 11.500.040000.040000.140000.180000.220000.230000.251000.261000.30300
 0.310000.32100
 12.500.100000.100000.175000.220000.240000.261000.274000.285000.32100
 0.335000.33500
 13.500.135000.135000.200000.244000.271000.283000.290000.300000.33900
 0.350000.35100
 15.000.167000.167000.230000.275000.303000.318000.333000.342000.38500
 0.370000.37200
 16.000.191000.191000.253000.300000.328000.341000.350000.367000.38100
 0.380000.38000
 18.000.240000.240000.300000.345000.370000.385000.407000.414000.41900
 0.410000.41000
 20.000.280000.280000.351000.395000.414000.431000.451000.453000.45300
 0.453000.45300
 22.000.350000.350000.400000.448000.461000.472000.480000.491000.49100
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1.0	0.06000	100000	10000	0.011500	0.11500	0.11500	0.11500	0.11500	0.11500	0.11500	0.15000	0.03000	00042200
2.0	0.082500	117000	11700	0.012000	0.12000	0.12000	0.12000	0.12000	0.12000	0.12000	0.13000	0.04500	00042300
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8.0	0.180000	217000	21700	0.018000	0.18000	0.18000	0.18000	0.18000	0.18000	0.18000	0.22000	0.15000	00042900
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13.0	0.277000	300000	30000	0.030000	0.30000	0.30000	0.30000	0.30000	0.30000	0.30000	0.32000	0.20000	00043400
14.0	0.312000	334000	33400	0.034000	0.34000	0.34000	0.34000	0.34000	0.34000	0.34000	0.36000	0.21000	00043500
15.0	0.349700	361300	36130	0.035000	0.35000	0.35000	0.35000	0.35000	0.35000	0.35000	0.37000	0.22000	00043600
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17.0	0.365100	380000	38000	0.037000	0.37000	0.37000	0.37000	0.37000	0.37000	0.37000	0.39000	0.24000	00043800
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166.0	0.360000	360000	36000	0.360000	3.60000	3.60000	3.60000	3.60000	3.60000	3.60000	3.60000	3.60000	00044700
167.0	0.350000	350000	35000	0.350000	3.50000	3.50000	3.50000	3.50000	3.50000	3.50000	3.50000	3.50000	00044800
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0.60058	0.36546	0.42816	-0.01999	-0.03776	0.23021	-0.06771
0.44874	0.08085	0.52982	-0.20171	0.03289	-0.04507	-0.03868
0.35822	0.41317	0.65324	-0.16479	-0.05957	0.16889	-0.20020
0.38155	0.05324	0.43893	-0.08690	-0.03181	-0.04487	-0.04235
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0.32385	0.10416	0.08085	-0.01999	-0.03776	0.23021	-0.06771
0.28084	0.06324	0.16479	0.03530	0.03289	-0.04507	-0.03868
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0.44874	0.08085	0.52982	-0.20171	0.03289	-0.04507	-0.03868
0.35822	0.41317	0.65324	-0.16479	-0.05957	0.16889	-0.20020
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0.32385	0.10416	0.08085	-0.01999	-0.03776	0.23021	-0.06771
0.28084	0.06324	0.16479	0.03530	0.03289	-0.04507	-0.03868
0.33570	0.45798	0.43893	-0.08690	-0.03181	-0.04487	-0.04235
0.42492	0.13948	0.16148	-0.08182	-0.10033	-0.06378	-0.05315
0.53004	0.34066	0.41899	0.12340	-0.08341	-0.08190	-0.25709
0.68228	0.25735	0.08757	-0.02492	0.15927	-0.06095	-0.04849
0.72359	0.02880	0.02050	-0.05752	-0.19838	-0.11327	-0.10193
0.89626	0.07423	0.47934	0.17828	0.08348	-0.21107	-0.06543
1.15493	-0.08395	-0.05780	-0.03729	-0.23714	-0.07923	-0.14641
1.34511	-0.01705	0.54439	0.33162	-0.11311	-0.24751	-0.00928
1.81312	-0.16993	-0.04817	-0.05298	-0.17191	-0.03083	-0.11738
1.63294	-0.34287	0.75912	0.16622	0.48339	-0.18631	-0.03716
3.19446	-0.43076	0.07300	-0.18942	0.05314	-0.05031	-0.06358
0.77379	-0.34546	0.76784	-0.14459	0.44433	-0.23219	-0.00981
0.61389	-0.41559	-0.00537	0.15129	0.09435	-0.06584	-0.03498
0.60058	-0.44141	0.82885	0.04284	0.48158	-0.31628	0.05640
0.44874	-0.33400	0.00285	-0.04284	0.09456	-0.18875	-0.16468
0.35822	-0.61906	0.71831	0.05109	-0.49720	-0.02050	-0.10630
0.38155	-0.26103	0.06343	-0.03308	0.07860	0.11499	-0.05144
0.77379	-1.01754	0.63626	-0.00233	0.48811	-0.03132	-0.00454
0.61389	-0.77442	2.33877	-0.01703	0.43330	-0.03265	-0.40817
0.60058	-0.07470	-0.11049	-0.16347	0.17125	-0.10258	-0.00125
0.44874	-1.07569	5.07106	-1.17876	1.26794	-0.64296	-0.77055
0.35822	0.05105	-1.20574				

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USER'S GUIDE FOR THE ROTORCRAFT FLIGHT SIMULATION COMPUTER PROG--ETC(U)
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UNCLASSIFIED NADC-81290-60 NL

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0.28974	0.12338	-0.15073	-0.03139	-0.03181	-0.04457	-0.09325	00084100
0.32385	0.42222	-0.44311	-0.06053	-0.03881	-0.18358	-0.19142	00084200
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0.33576	0.34005	-0.41829	-0.12340	-0.06341	-0.08100	-0.55709	00084400
0.42402	0.55725	-0.02757	-0.02402	-0.15227	-0.02055	-0.65948	00084500
0.53004	0.23382	-0.22129	-0.01205	-0.02779	-0.10210	-0.17482	00084600
0.66226	0.18639	-0.04859	-0.01045	-0.18122	-0.02272	-0.05535	00084700
0.72350	0.16558	-0.46385	-0.32000	-0.00941	-0.06901	-0.05517	00084800
0.80626	0.04448	-0.01893	-0.06874	-0.18304	-0.14377	-0.06976	00084900
1.15483	0.12305	-0.44694	-0.25823	-0.01043	-0.12488	-0.01703	00085000
1.34511	-0.02280	-0.03950	-0.06752	-0.19838	-0.11327	-0.01003	00085100
0.51028	-0.07423	-0.47934	-0.17022	-0.02348	-0.21107	-0.06543	00085200
0.70675	-0.04305	-0.05720	-0.03728	-0.02714	-0.07003	-0.14641	00085300
0.60427	-0.01785	-0.54129	-0.12102	-0.11311	-0.24751	-0.00922	00085400
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0.49081	-0.34076	-0.76912	-0.18628	-0.45339	-0.18331	-0.03716	00085600
0.50767	-0.43076	-0.07300	-0.06314	-0.06031	-0.06031	-0.06368	00085700
0.52812	-0.34546	-0.76704	-0.14450	-0.44433	-0.23210	-0.06081	00085800
0.55290	-0.41650	-0.06537	-0.09435	-0.03408	-0.03408	-0.03408	00085900
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	-1.07689	-0.07106	-0.17876	-1.08784	-0.04256	-0.77855	00086900
	-0.05105	-1.20574	-0.37712	-0.29513	-0.21339	-0.59568	00087000
	-0.04946	-0.07595	-0.78383	-0.47443	-0.08515	-0.18748	00087100
	-0.19102	-0.38547	-0.07407	-0.02844	-0.06041	-0.25137	00087200
	-0.18364	-0.35617	-0.52300	-0.84218	-0.12879	-0.34894	00087300
	-0.03313	-0.18613	-0.00541	-0.03243	-0.02589	-0.05540	00087400
	-0.14384	-0.51139	-0.43934	-0.03251	-0.12827	-0.38910	00087500
	-0.06335	-0.01096	-0.07617	-0.08550	-0.06537	-0.04106	00087600
	-0.15417	-0.09228	-0.34884	-0.04343	-0.06560	-0.38836	00087700
	-0.10126	-0.06023	-0.01745	-0.03405	-0.02964	-0.02681	00087800
	-0.15968	-0.43377	-0.20135	-0.07235	-0.02380	-0.38743	00087900
	-0.17144	-0.04403	-0.01827	-0.03150	-0.03180	-0.06573	00088000
	-0.00466	-0.51093	-0.15457	-0.15581	-0.02347	-0.45537	00088100
	-0.37263	-0.03744	-0.05081	-0.11739	-0.06568	-0.05068	00088200
	-0.22389	-0.43136	-0.14791	-0.13689	-0.03211	-0.43621	00088300
	-0.35984	-0.03189	-0.06107	-0.14429	-0.02823	-0.05378	00088400
	-0.14905	-0.42236	-0.03770	-0.10078	-0.04654	-0.30834	00088500
	-0.26444	-0.05139	-0.05045	-0.11511	-0.02380	-0.04551	00088600
	-0.03544	-0.54784	-0.22843	-0.02481	-0.02453	-0.49044	00088700
	-0.16447	-0.06061	-0.09481	-0.15318	-0.07117	-0.02233	00088800
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	-0.11192	-0.00261	-0.10822	-0.07959	-0.02013	-0.08162	00089000
	-0.14687	-0.39266	-0.31405	-0.03664	-0.00448	-0.03559	00089100
	-0.08468	-0.13569	-0.10170	-0.01823	-0.00016	-0.14006	00089200
	-0.14829	-0.32070	-0.21055	-0.02365	-0.00433	-0.03204	00089300
	-0.01048	-0.11684	-0.14458	-0.02382	-0.01708	-0.22000	00089400
	-0.17043	-0.02845	-0.20369	-0.02228	-0.00099	-0.33825	00089500
	-0.02900	-0.06847	-0.10329	-0.02230	-0.06189	-0.11128	00089600
	-0.30789	-0.30227	-0.31948	-0.11769	-0.04752	-0.08780	00089700
	-0.14315	-0.00952	-0.01767	-0.09281	-0.12752	-0.08305	00089800
	-0.33081	-0.34186	-0.27140	-0.11146	-0.02280	-0.05050	00089900
	-0.20450	-0.03378	-0.00681	-0.04929	-0.10165	-0.12075	00090000
	-0.43208	-0.45287	-0.24090	-0.20657	-0.09459	-0.02294	00090100

1.28637	-0.23465	-0.02269	-0.08413	-0.08438	-0.01160	-0.14691	0.0000100
	-0.76415	-0.46186	-0.18077	-0.48718	-0.03108	-0.10628	0.0000300
1.81061	-0.18330	-0.18518	-0.18693	-0.13319	-0.10123	-0.17155	0.0000500
	-1.16396	-0.16723	-0.18335	-0.57741	-0.01332	-0.17082	0.0000700
1.87146	-0.10666	-0.16728	-0.25117	-0.17067	-0.14987	-0.04106	0.0000900
	-0.87123	-0.16728	-0.25117	-0.17067	-0.14987	-0.04106	0.0001100
1.87146	-0.87123	-0.16728	-0.25117	-0.17067	-0.14987	-0.04106	0.0001300
3.28061	-0.87123	-0.16728	-0.25117	-0.17067	-0.14987	-0.04106	0.0001500
	-1.30600	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0001700
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	-0.44330	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0002100
0.60487	-0.44330	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0002300
	-0.18182	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0002500
0.51808	-0.18182	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0002700
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0.48081	-0.00313	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0003100
	-0.18182	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0003300
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	-0.11144	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0003700
0.53818	-0.11144	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0003900
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0.55200	-0.37853	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0004300
	-0.22300	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0004500
0.52050	-0.22300	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0004700
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0.43044	-0.14005	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0005100
	-0.35444	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0005300
0.43407	-0.35444	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0005500
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	-0.04482	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0006100
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	-0.14020	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0006500
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	-0.17603	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0006900
0.60143	-0.17603	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0007100
	-0.30000	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0007300
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	-0.14316	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0007700
1.06023	-0.14316	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0007900
	-0.30681	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0008100
1.28637	-0.30681	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0008300
	-0.76415	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0008500
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	-0.18330	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0008900
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	-0.87123	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0009300
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	-1.30600	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0009700
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	-0.44330	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0010100
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	-0.21831	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0010900
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	-0.05823	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0011300
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	-0.01045	-0.18176	-0.25117	-0.17067	-0.14987	-0.04106	0.0011700
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0.58556	0.20833	0.26932	0.14125	-0.07372	0.00889	0.02762	0.0056100
0.51271	0.19457	0.56744	0.01756	-0.07490	-0.20044	0.22431	0.0056200
0.47343	0.14783	0.55975	0.15830	-0.07038	0.00491	-0.00676	0.0056300
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0.60402	0.27511	0.54481	0.26684	0.07088	-0.07088	0.00123	0.0056600
0.61733	0.00441	0.19782	0.19231	0.03056	-0.03056	-0.16836	0.0056700
0.65762	0.25103	0.49403	0.22255	0.05312	0.03952	-0.00654	0.0056800
0.77171	0.00769	0.15804	0.18600	0.03155	-0.04812	-0.10488	0.0056900
0.95514	0.23604	0.44552	0.23744	0.04804	-0.01599	-0.01769	0.0057000
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1.74500	0.23129	0.30046	0.23095	0.03117	-0.01445	-0.01556	0.0057200
1.57376	0.00854	0.11823	0.13147	0.03300	0.05112	-0.00161	0.0057300
3.22056	0.35446	0.25788	0.22452	0.02746	0.07918	-0.00185	0.0057400
0.66733	0.00430	0.03341	0.06674	0.12011	0.14322	-0.04184	0.0057500
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0.56189	-0.03015	-0.02305	0.00864	0.04890	0.06315	-0.00795	0.0057700
0.57623	0.00405	0.02313	0.07613	0.12475	0.12828	-0.01477	0.0057800
0.49834	0.01406	0.02322	0.00078	0.03206	0.04845	-0.00805	0.0057900
0.52556	0.50326	0.18022	0.28839	0.11083	0.11108	-0.00304	0.0058000
0.51271	0.00406	0.02538	0.01633	0.01814	0.02508	-0.01047	0.0058100
0.47343	0.00828	0.13215	0.31105	0.11991	0.09050	-0.01793	0.0058200
0.51714	-0.78334	0.13215	0.04176	0.00036	0.06333	-0.01208	0.0058300
0.60402	-1.18903	0.03488	0.34617	0.21226	0.15438	-0.04537	0.0058400
0.61733	0.00800	0.11795	0.14993	-0.01160	0.10911	-0.00591	0.0058500
0.65762	0.07081	0.05489	0.53954	0.13358	0.19722	-0.57775	0.0058600
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1.74500	0.02002	0.00820	0.05235	-0.09137	0.02487	-0.15788	0.0059000
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0.64857	0.21831	0.07600	0.07082	-0.21065	-0.02229	-0.00976	0.0059300
0.56189	0.01826	0.50162	0.46704	-0.13167	-0.17885	0.44110	0.0059400
0.57623	0.06383	0.82998	0.18806	0.12043	0.06757	0.09598	0.0059500
0.49834	0.01045	0.54200	-0.33224	-0.13000	-0.17096	0.46948	0.0059600
0.52556	0.20326	0.06351	0.07098	0.04586	0.10350	0.11092	0.0059700
0.51271	0.04849	0.51133	-0.07098	0.15138	-0.14750	-0.46689	0.0059800
0.47343	0.25189	0.08784	0.03114	-0.00111	0.10556	0.19598	0.0059900
0.51714	0.13099	0.82291	0.00662	-0.07223	-0.23394	0.24542	0.0060000
0.60402	0.20833	0.25032	0.14125	-0.07372	0.00889	0.02762	0.0060100
0.61733	0.10483	0.56744	0.01756	-0.07490	-0.20044	-0.00676	0.0060200
0.65762	0.19457	0.55975	0.15830	-0.07038	0.00491	-0.00676	0.0060300
0.77171	0.14783	0.55308	0.19559	-0.05650	0.20305	0.13365	0.0060400
0.95514	0.14822	0.59385	0.23859	-0.04530	0.01433	0.14523	0.0060500
1.22405	0.27511	0.54481	0.26684	0.07088	-0.07088	0.00123	0.0060600
1.74500	0.00441	0.19782	0.19231	0.03056	-0.03056	-0.16836	0.0060700
3.22056	0.25103	0.49403	0.22255	0.05312	0.03952	-0.00654	0.0060800
0.66733	0.00769	0.15804	0.18600	0.03155	-0.04812	-0.10488	0.0060900
0.64857	0.23604	0.44552	0.23744	0.04804	-0.01599	-0.01769	0.0061000
0.56189	0.00486	0.12510	0.14141	0.02781	0.04921	-0.00785	0.0061100
0.57623	0.23129	0.30046	0.23095	0.03117	-0.01445	-0.01556	0.0061200
0.49834	0.00854	0.11823	0.13147	0.03300	0.05112	-0.00161	0.0061300
0.52556	0.35446	0.25788	0.22452	0.02746	0.07918	-0.00185	0.0061400
0.51271	0.00430	0.03341	0.06674	0.12011	0.14322	-0.04184	0.0061500
0.47343	0.45778	0.28638	0.26813	0.14897	0.03077	-0.00746	0.0061600
0.51714	-0.03015	-0.02305	0.00864	0.04890	0.06315	-0.00795	0.0061700
0.60402	0.00405	0.02313	0.07613	0.12475	0.12828	-0.01477	0.0061800
0.61733	0.00406	0.02538	0.01633	0.01814	0.02508	-0.01047	0.0061900
0.65762	0.50326	0.18022	0.28839	0.11083	0.11108	-0.00304	0.0062000
0.77171	0.00406	0.02538	0.01633	0.01814	0.02508	-0.01047	0.0062100
0.95514	1.37892	4.56900	-1.43642	1.07064	-0.64878	-0.91338	0.0062200
1.22405	0.18178	1.32230	0.41546	-0.19598	0.06218	-0.72437	0.0062300
1.74500	0.02002	0.00820	0.05235	-0.09137	0.02487	-0.15788	0.0062400
3.22056	0.20200	0.07700	0.04315	0.15326	-0.15322	-0.04747	0.0062500
0.66733	0.04575	0.25108	0.23084	-0.04584	-0.01739	-0.34076	0.0062600
0.64857	0.21831	0.07600	0.07082	-0.21065	-0.02229	-0.00976	0.0062700
0.56189	0.01826	0.50162	0.46704	-0.13167	-0.17885	0.44110	0.0062800
0.57623	0.06383	0.82998	0.18806	0.12043	0.06757	0.09598	0.0062900
0.49834	0.01045	0.54200	-0.33224	-0.13000	-0.17096	0.46948	0.0063000
0.52556	0.20326	0.06351	0.07098	0.04586	0.10350	0.11092	0.0063100
0.51271	0.04849	0.51133	-0.07098	0.15138	-0.14750	-0.46689	0.0063200
0.47343	0.25189	0.08784	0.03114	-0.00111	0.10556	0.19598	0.0063300
0.51714	0.13099	0.82291	0.00662	-0.07223	-0.23394	0.24542	0.0063400
0.60402	0.20833	0.25032	0.14125	-0.07372	0.00889	0.02762	0.0063500
0.61733	0.10483	0.56744	0.01756	-0.07490	-0.20044	-0.00676	0.0063600
0.65762	0.19457	0.55975	0.15830	-0.07038	0.00491	-0.00676	0.0063700
0.77171	0.14783	0.55308	0.19559	-0.05650	0.20305	0.13365	0.0063800
0.95514	0.14822	0.59385	0.23859	-0.04530	0.01433	0.14523	0.0063900
1.22405	0.27511	0.54481	0.26684	0.07088	-0.07088	0.00123	0.0064000
1.74500	0.00441	0.19782	0.19231	0.03056	-0.03056	-0.16836	0.0064100
3.22056	0.25103	0.49403	0.22255	0.05312	0.03952	-0.00654	0.0064200
0.66733	0.00769	0.15804	0.18600	0.03155	-0.04812	-0.10488	0.0064300
0.64857	0.23604	0.44552	0.23744	0.04804	-0.01599	-0.01769	0.0064400
0.56189	0.00486	0.12510	0.14141	0.02781	0.04921	-0.00785	0.0064500
0.57623	0.23129	0.30046	0.23095	0.03117	-0.01445	-0.01556	0.0064600
0.49834	0.00854	0.11823	0.13147	0.03300	0.05112	-0.00161	0.0064700
0.52556	0.35446	0.25788	0.22452	0.02746	0.07918	-0.00185	0.0064800
0.51271	0.00430	0.03341	0.06674	0.12011	0.14322	-0.04184	0.0064900
0.47343	0.45778	0.28638	0.26813	0.14897	0.03077	-0.00746	0.0065000
0.51714	-0.03015	-0.02305	0.00864	0.04890	0.06315	-0.00795	0.0065100
0.60402	0.00405	0.02313	0.07613	0.12475	0.12828	-0.01477	0.0065200
0.61733	0.00406	0.02538	0.01633	0.01814	0.02508	-0.01047	0.0065300
0.65762	0.50326	0.18022	0.28839	0.11083	0.11108	-0.00304	0.0065400
0.77171	0.00406	0.02538	0.01633	0.01814	0.02508	-0.01047	0.0065500
0.95514	1.37892	4.56900	-1.43642	1.07064	-0.64878	-0.91338	0.0065600
1.22405	0.18178	1.32230	0.41546	-0.19598	0.06218	-0.72437	0.0065700
1.74500	0.02002	0.00820	0.05235	-0.09137	0.02487	-0.15788	0.0065800
3.22056	0.20200	0.07700	0.04315	0.15326	-0.15322	-0.04747	0.0065900
0.66733	0.04575	0.25108	0.23084	-0.04584	-0.01739	-0.34076	0.0066000
0.64857	0.21831	0.07600	0.07082	-0.21065	-0.02229	-0.00976	0.0066100
0.56189	0.01826	0.50162	0.46704	-0.13167	-0.17885	0.44110	0.0066200
0.57623	0.06383	0.82998	0.18806	0.12043	0.06757	0.09598	0.0066300
0.49834	0.01045	0.54200	-0.33224	-0.13000	-0.17096	0.46948	0.0066400
0.52556	0.20326	0.06351	0.07098	0.04586	0.10350	0.11092	0.0066500
0.51271	0.04849	0.51133	-0.07098	0.15138	-0.14750	-0.46689	0.0066600
0.47343	0.25189	0.08784	0.03114	-0.00111	0.10556	0.19598	0.0066700
0.51714	0.13099	0.82291	0.00662	-0.07223	-0.23394	0.24542	0.0066800
0.60402	0.20833	0.25032	0.14125	-0.07372	0.00889	0.02762	0.0066900
0.61733	0.10483	0.56744	0.01756	-0.07490	-0.20044	-0.00676	0.0067000
0.65762	0.19457	0.55975	0.15830	-0.07038	0.00491	-0.00676	0.0067100
0.77171	0.14783	0.55308	0.19559	-0.05650	0.20305	0.13365	0.0067200
0.95514	0.14822	0.59385	0.23859	-0.04530	0.01433	0.14523	0.0067300
1.22405	0.27511	0.54481	0.26684	0.07088	-0.07088	0.00123	0.0067400
1.74500	0.00441	0.19782	0.19231	0.03056	-0.03056	-0.16836	0.0067500
3.22056	0.25103	0.49403	0.22255	0.05312	0.03952	-0.00654	0.0067600
0.66733	0.00769	0.15804	0.18600	0.03155	-0.04812	-0.10488	0.0067700
0.64857	0.23604	0.44552	0.23744	0.04804	-0.01599	-0.01769	0.0067800
0.56189	0.00486	0.12510	0.14141	0.02781	0.04921	-0.00785	0.0067900
0.57623	0.23129	0.30046	0.23095				

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END OF INFORMATION
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