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VOLUME II

A STABILITY AND CONTROL PREDICTION METHOD FOR HELICOPTERS AND STOPPABLE ROTOR AIRCRAFT

VOLUME II
USER'S MANUAL

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Bell Helicopter Company
A Textron Company

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AIR FORCE FLIGHT DYNAMICS LABORATORY
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FOREWORD

This report represents the results of the efforts expended in performance of Contract F33615-69-C-1121, "Development of Stability and Control Prediction Methods for Stoppable Rotor Aircraft." The work was performed by Bell Helicopter Company under Project No. 8219. It was sponsored by the Air Force Flight Dynamics Laboratory, Air Force Systems Command, from December 1968 through February 1970. Mr. Charles L. Livingston was the Bell Helicopter Company Project Engineer. Mr. Robert Nicholson was the Air Force Project Engineer.

This final report is presented in four volumes. The first describes the mathematical model and the methods used to calculate stability characteristics. They are of sufficient complexity that a digital computer is necessary for the solution of the equations. The second volume presents the results of sample computations and discusses input and output formats and good user techniques. The third volume describes the computer program while the fourth volume contains Appendices which are computer generated documentation of the program.

The authors gratefully acknowledge the assistance of Messrs. B. L. Blankenship and C. L. Livingston of the Bell Helicopter Company Flight Technology Section in the development of the mathematical model.

This technical report has been reviewed and is approved.

C. B. Westbrook
Chief, Control Criteria Branch
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ABSTRACT

This volume presents all documentation available to aid the user of the computer program developed in this work. The input format section provides an explanation of all of the quantities input to the computer program. Many of the inputs are defined by equations showing how they function in the program. This makes the use of the inputs as clear as possible. Four typical sets of input data are included as working examples.

The output guide gives a thorough discussion of all of the forms of computer output obtained by the user.

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SECTION I

INTRODUCTION

The purpose of this document is to inform the reader of the various capabilities of computer program ASAJ01 and to provide the information necessary for the assembling of data into the proper form and format for a successful execution of the program.

The first section, the Input Format, lists the input data in a sequence indicating the position of each parameter in the data deck. Where possible, a one line description, including units, is used. Some of the inputs cannot be so described. In these cases, a FORTRAN symbol or some other symbol is used. Where a FORTRAN symbol is used, the following conventions are observed:

1. If the first letter is I, J, K, L, M, or N, the number input should end in the rightmost column of the field specified and should not contain a decimal point; i.e., "I" format code.

2. If the first letter is not I, J, K, L, M, or N, the number input should begin in the leftmost column of the field specified and should contain a decimal point; i.e., "F" format code.

There are five aerodynamic surfaces to be defined by inputs: two rotors, wing, elevator and fin. Since these inputs have a uniform format and usage, only one item by item enumeration and explanation, under the title Aerodynamic Inputs, is necessary. The appropriate positions for these five sets of inputs are then indicated.

The first section, the Input Format, is designed to be the only documentation needed by the very experienced user. The less experienced the user, the more inadequate are some of the one line descriptions and symbols. The second section, arranged in the same order as the first, should be referred to in such cases for a more complete explanation.

In this document and in the output, there are references to the rotors by various names. Where practical, the names used are appropriate to the configuration. The following two groups of names are the ones used and the names within a group may be considered synonymous with context determining the appropriate word:

1. Main, forward, right, first

2. Tail, aft, left, second

Each general operation which the program can perform is illustrated in the flow charts in Figures 1 through 10, both alone, if possible, and in all permissible combinations with other operations. Each operation or combination of operations is controlled by data supplied by the user. Thus each flow chart begins with the operation "read data deck". Since the amount of data to be read depends on the operation or operations desired, a data deck in this context consists of a card ("NPART Card" or CARD 01 in the Input Format) telling the program which operation to perform followed by the additional data necessary to the performance of that operation. In some cases, the additional data are contained on 80 or more additional cards (trim, stability analysis, maneuver); in other cases, no additional data are required. Thus, a data deck consists of an "NPART Card" and all subsequent cards up to, but not including, the next "NPART Card". Obviously, a deck of cards to be used in one run on the computer may consist of any number of data decks. There are some restrictions on the order in which data decks may be used in a run; these will be pointed out in the appropriate places.

The second step on a number of the flow charts is "calculate problem constants". In each operation containing this step, a number of quantities, which must be defined by the input data, remain constant throughout the performance of the operation(s). This occurs because of the desirability of having a minimum amount of input data and at the same time having maximum flexibility in program capabilities.

In finding the trim point, the program manipulates the pilot's controls and fuselage and rotor attitude in space to reach desired values of the rotor flapping moments and the resultant forces and moments on the center of gravity.

Sometimes these desired values are all zero. In this case, the trim point is such that the rotorcraft would continue to fly indefinitely in a straight line in space. That is, maintaining an input rate of climb or descent as well as forward and lateral velocity.

Sometimes these desired values are not all zero. In this case, the use of the word "desired" rather than "predetermined" is significant because the desired values depend on the trim point. Two different results are possible in this case. In one, the rotorcraft is in a push-over or pull-up condition at a predetermined g-level. This condition cannot be maintained indefinitely and should not be attempted in conjunction with a maneuver. In the other, the rotorcraft is in a banked turn, either level or spiral, at a predetermined g-level, bank angle, or turn radius. This condition may be used as the starting point for a maneuver.

The stability operation uses a trim point as its initial condition. Calculated from this condition are the stability derivatives of the rotorcraft, both longitudinally and laterally in a free flight condition with no inputs and then with a step input from each of the controls. Transfer functions are also computed.

A parameter sweep may be used when either finding a trim point or doing a stability analysis. The most frequent uses are for sweeping speed or g-level, but any input or combination of inputs used in finding a trim point or doing a stability analysis may be swept. The assumption is made that each data point bears some relationship to the previous one, and further that the trim point of each one is a good starting point for finding the trim point of the next one. For example, in a speed sweep, a change of 20 or 30 knots is the most that should normally be used above 40 knots. Below 40 knots, the maximum change should not exceed 10 knots.

A maneuver also requires a trim point as a preliminary. Here the trim point is used to supply the initial conditions to a system of differential equations which describe the behavior of a rotorcraft in a maneuver under the specified conditions. Various external inputs, or forcing functions, may be applied. Examples are control movements, gusts, and throttle chops. The fuselage and rotor blades are, in general, assumed to be rigid.

A maneuver with stability analysis is a combination of two operations, maneuver and stability analysis. At times determined by input data, the maneuver is suspended while a stability analysis is performed. The maneuver is then resumed as if no interruption had occurred and continues until it reaches the next time point to do a stability analysis.

The value of a large number of variables is preserved at each time point in a maneuver. At the conclusion of the maneuver, the user may select any of these variables to be plotted on a scale of his choice.

At the conclusion of a maneuver all of the variables which have been preserved at each time point during the maneuver may then be transferred to a tape which can be stored in the tape library. Later the data may be recovered for any use desired.

At the conclusion of a maneuver, usually one in which one of the controls or the mast tilt angle has been varied sinusoidally, any of the variables which have been stored during the maneuver may be selected for analysis. The analysis consists of fitting, by least squares, a curve of the form

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

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

$$F_i(t) = C_i\ F_j(t) + D_i\ F_k(t) + E_i,$$

may be derived.

Some sample data setups are included to help the novice user get started and to give some insight into orders of magnitude for some of the inputs.

The output from the computer program can be separated into useful results for the user and messages resulting from an error condition. Each type of output has been explained in detail. Some error conditions cannot be diagnosed in the program. An example would be an unrealistic flight condition which cannot be trimmed. This type of problem depends on the knowledge and insight of the user for detection and correction. Some hints have been given to help the new user in these areas.

SECTION II

INPUT DATA

A. INPUT FORMAT

1. Identification and Flow Control Group

CARD 00 Message instructing computing control section about disposition of output and data deck. Columns 1-68, alphameric.

CARD 01

Col. 1 - 2	NPART (Permissible values are 1,2,3,7,8,10, and 11)
Col. 4 - 6	NPRINT
Col. 10	NSCALE
Col. 13 - 15	NVARA
Col. 21 - 25	AL(1)
Col. 26 - 30	AH(1)
Col. 33 - 35	NVARB
Col. 41 - 45	AL(2)
Col. 46 - 50	AH(2)
Col. 53 - 55	NVARC
Col. 61 - 65	AL(3)
Col. 66 - 70	AH(3)

CARD 02

Col. 3 - 10	IPSN
Col. 11 - 70	Identifying Comments

CARD 03

Col. 1 - 68	Identifying Comments

CARD 04

Col. 1 - 68	Identifying Comments

CARDS 11-201 have the format 7F10.0

2. Aerodynamic Inputs

CARD A

YXX* (1) Drag divergence Mach number for α=0

(2) Mach number for lower boundary of supersonic region

(3) Maximum C_L, normal flow, M (Mach number) = 0

(4)
(5)
(6) Coefficients of Mach number in maximum C_L equation, normal flow

(7) Maximum C_L, reversed flow, M=0

CARD B

(8)
(9)
(10) Coefficients of Mach number in maximum C_L equation, reversed flow

(11) Tail boom bending coefficient (/lb)

(12) C_D for α =0, M=0

(13)
(14) Coefficients of α in non-divergent drag equation (/deg) (/deg^2)

CARD C

(15) Coefficient in supersonic drag equation

(16) Maximum non-divergent C_D

(17) Two-dimensional lift curve slope (if zero, data tables are used) (/deg)

(18) Aspect ratio

(19)

(20)

(21)

*YXX stands for YMR, YTR, YWG, YEL, or YFN with context determining which one. Card numbers A, B, and C are used here only to indicate order. Actual numbers vary from group to group and are given in the proper place in each group.

3. Fuselage Group

Card	Item	Description	Group	Units
CARD 11 XFS	(1)	Gross weight		(lb)
	(2)	Station line	Location of fuselage aerodynamic center	(in)
	(3)	Buttline		(in)
	(4)	Waterline		(in)
	(5)	Station line	Location of center of gravity	(in)
	(6)	Buttline		(in)
	(7)	Waterline		(in)
CARD 12	(8)	Fuselage rolling inertia, I_x		($slug\text{-}ft^2$)
	(9)	Fuselage pitching inertia, I_y		($slug\text{-}ft^2$)
	(10)	Fuselage yawing inertia, I_z		($slug\text{-}ft^2$)
	(11)	Fuselage product of inertia, I_{xz}		($slug\text{-}ft^2$)
	(12)			
	(13)			
	(14)			
CARD 13	(15)		Coefficients in fuselage pitching moment equation	(ft^3)
	(16)			(ft^3/deg)
	(17)		Coefficients in fuselage yawing moment equation	(ft^3)
	(18)			(ft^3/deg)
	(19)			
	(20)		Coefficients in fuselage lift equation	(ft^2)
	(21)			(ft^2/deg)
CARD 14	(22)		Coefficients in fuselage drag equation	(ft^2)
	(23)			(ft^2/deg)
	(24)			(ft^2/deg^2)
	(25)			(ft^2/deg^2)
	(26)		Coefficients in fuselage side force equation	(ft^2)
	(27)			(ft^2/deg)
	(28)			(ft^2/deg^2)
CARD 15	(29)	Pylon weight		(lb)
	(30)	Station line	Location of pylon center of gravity	(in)
	(31)	Waterline		(in)
	(32)	Pylon differential flat plate drag area		(ft^2)
	(33)	Distance from mast pivot point to pylon aerodynamic center		(ft)
	(34)			
	(35)			

4. <u>Main Rotor Group</u>

CARD 21				
XMR	(1)	Number of blades		
	(2)	Number of radial aerodynamic stations		
	(3)			
	(4)	Radius		(ft)
	(5)	Chord		(in)
	(6)	Coning spring constant		(ft-lb/deg)
	(7)	Flapping stop		(deg)
CARD 22				
	(8)	Station	Location of shaft pivot point	(in)
	(9)	Buttline	Location of shaft pivot point	(in)
	(10)	Waterline	Location of shaft pivot point	(in)
	(11)	Mast tilt angle		(deg)
	(12)	Mast length		(ft)
	(13)	Rotor to engine gear ratio		
	(14)	Fold rotor C.G. shift switch		
CARD 23				
	(15)	Virtual hinge point		(ft)
	(16)	Flapping hinge offset		(ft)
	(17)	F/A flapping spring rate		(ft-lb/deg)
	(18)	Lateral flapping spring rate		(ft-lb/deg)
	(19)	Spring rate for focused pylon		(deg/lb)
	(20)			
	(21)	Hub extent		(ft)
CARD 24				
	(22)	Precone		(deg)
	(23)	Pitch-cone coupling ratio		
	(24)	Pitch-flap coupling ratio, δ_3		
	(25)	Drag coefficient for hub		
	(26)	Radial flow factor		(deg)
	(27)	Coefficient for tip vortex effect		
	(28)			
CARD 25, 26, 27		Twist		(deg)
CARD 28, 29, 2A		Blade weight distribution		(lbs/in)
CARD 2B, 2C, 2D		YMR(1) - YMR(21)		

5. Tail Rotor Group

CARD 31				
XTR	(1)	Number of blades		
	(2)	Number of radial aerodynamic stations		
	(3)			
	(4)	Radius		(ft)
	(5)	Chord		(in)
	(6)	Coning spring constant		(ft-lb/deg)
	(7)	Flapping stop		(deg)
CARD 32				
	(8)	Station	Location of shaft pivot point	(in)
	(9)	Buttline	Location of shaft pivot point	(in)
	(10)	Waterline	Location of shaft pivot point	(in)
	(11)	Mast tilt angle		(deg)
	(12)	Mast length		(ft)
	(13)	Rotor to engine gear ratio		
	(14)	Tail rotor indicator		
CARD 33				
	(15)	Virtual hinge point		(ft)
	(16)	Flapping hinge offset		(ft)
	(17)	F/A flapping spring rate		(ft-lb/deg)
	(18)	Lateral flapping spring rate		(ft-lb/deg)
	(19)	Spring rate for focused pylon		(deg/lb)
	(20)			
	(21)	Hub extent		(ft)
CARD 34				
	(22)	Precone		(deg)
	(23)	Pitch-cone coupling ratio		
	(24)	Pitch-flap coupling ratio, δ_3		
	(25)	Drag coefficient for hub		
	(26)	Radial flow factor		(deg)
	(27)	Coefficient for tip vortex effect		
	(28)	Sidewash coefficient		

CARD 35, 36, 37 — Twist

CARD 38, 39, 3A — Blade weight distribution (lbs/in)

CARD 3B, 3C, 3D — YTR(1) - YTR(21)

6. Wing Group

CARD 41

XWG	(1)	Wing area		(ft^2)
	(2)	Station line	Location of center of pressure of right wing	(in)
	(3)	Buttline		(in)
	(4)	Waterline		(in)
	(5)	Geometric angle of incidence relative to fuselage centerline		(deg)
	(6)			
	(7)			

CARD 42

(8) Main rotor induced velocity factor

(9) Coefficient in wing wake deflection equation (deg)

(10) Coefficient in η_q equation

(11)

(12) Coefficient of sideslip in roll moment equation

(13) Coefficient of sideslip and C_L in roll moment equation

(14) Coefficient of yaw rate and C_L in roll moment equation

CARD 43

(15) Coefficient of roll rate in roll moment equation

(16) Coefficient of sideslip in yaw moment equation

(17) Coefficient of sideslip and $C_L{}^2$ in yaw moment equation

(18) Coefficient of yaw rate and $C_L{}^2$ in yaw moment equation

(19) Coefficient of yaw rate and $dC_D/d\alpha$ in yaw moment equation

(20) Coefficient of roll rate and C_L in yaw moment equation

(21) Coefficient of roll rate and C_D in yaw moment equation

CARD 44, 45, 46 } YWG(1) - YWG(21)

7. Elevator Group

CARD 51

XEL	(1)	Area		(ft^2)
	(2)	Station line	Location of center of pressure	(in)
	(3)	Buttline		(in)
	(4)	Waterline		(in)
	(5)	Geometric angle of incidence relative to fuselage centerline		(deg)
	(6)			
	(7)			

CARD 52

(8)	Induced velocity factor	
(9)	Velocity at which elevator starts to enter main rotor wake	(kts)
(10)	Velocity at which elevator is completely into main rotor wake	(kts)
(11)	Coefficient for change of angle of attack due to wing wake	(deg)
(12)		
(13)		
(14)		

CARD 53, 54, 55 } YEL(1) - YEL(21)

8. <u>Fin/Rudder Group</u>

CARD 61

XFN	(1)	Area		(ft^2)
	(2)	Station line	Location of center of pressure	(in)
	(3)	Buttline		(in)
	(4)	Waterline		(in)
	(5)	Geometric angle of incidence relative to fuselage centerline		(deg)
	(6)	Induced velocity factor		
	(7)	Sidewash coefficient		

CARD 62, 63, 64 } YFN(1) - YFN(21)

9. Jet Group

CARD 71

XJET	(1)	Number of jets		(lb)
	(2)	Thrust of right jet		(lb)
	(3)	Thrust of left jet		(in)
	(4)	Station line	Location of right jet thrust	(in)
	(5)	Buttline		(in)
	(6)	Waterline		(in)
	(7)			

CARD 72

	(8)	Yaw angle, body to right jet	(deg)
	(9)	Pitch angle, body to right jet	(deg)
	(10)		
	(11)		
	(12)		
	(13)		
	(14)		

10. <u>Bobweight Group</u>

CARD 81

XBW	(1)	η	(deg/sec^2)
	(2)	K_X	(lb/in)
	(3)	C_X	(lb-sec/in)
	(4)	I_1	(lb-in^2)
	(5)	I_2	(lb-in^2)
	(6)	I_3	(lb-in^2)
	(7)	g preload	(g's)

CARD 82

(8)	M_1	(lb)
(9)	M_B	(lb)
(10)	M_3	(lb)
(11)	M_4	(lb)
(12)		
(13)		
(14)		

CARD 83

(15)	r_1	(in)
(16)	r_3	(in)
(17)	r_4	(in)
(18)	r_5	(in)
(19)	r_6	(in)
(20)	r_7	(in)
(21)	r_8	(in)

11. Controls Group

a. Collective

CARD 91

XCON	(1)	Range of collective stick	(in)
	(2)	Coefficients for lower limit of	
	(3)	collective pitch as a function	(/deg)
	(4)	of β_m	($/deg^2$)
	(5)	Coefficients for range of col-	(deg)
	(6)	lective pitch as a function of β_m	(deg)
	(7)	Collective lock indicator for rotor 1	

CARD 92

(8)	Root collective pitch of rotor 1 if XCON(7)≠0	(deg)
(9)	Coefficient for linking aft/left rotor collective pitch to forward/right rotor collective pitch	(deg/deg)
(10)	Coefficient for linking stick position to geometric angle of incidence of wing	(deg/in)
(11)	Coefficient for linking stick position to geometric angle of incidence of elevator	(deg/in)
(12)	Coefficient for linking change of stick position to change of auxiliary thrust	(lb/in)
(13)	Maximum rate for prop-rotor collective governor	(deg/sec)
(14)	RPM dead band for prop-rotor collective governor	(rpm/rpm)

b. F/A Cyclic

CARD 93

(15)	Range of F/A cyclic stick	(in)
(16)	F/A cyclic pitch on swashplate with stick full aft	(deg)
(17)	F/A range of swashplate	(deg)
(18)	F/A cyclic pitch lock indicator	
(19)	F/A cyclic pitch of rotor 1 if XCON(18)≠0	(deg)
(20)		
(21)		

CARD 94

(22)	Coefficient for linking forward rotor collective pitch to forward rotor F/A cyclic pitch	(deg/deg)

(23) Coefficient for linking aft rotor collective pitch to forward rotor F/A cyclic pitch (deg/deg)

(24) Coefficient for linking aft/left rotor F/A cyclic pitch to forward/right rotor F/A cyclic pitch (deg/deg)

(25) Coefficient for linking right rotor lateral cyclic pitch to right rotor F/A cyclic pitch (deg/deg)

(26) Coefficient for linking left rotor lateral cyclic pitch to right rotor F/A cyclic pitch (deg/deg)

(27) } Coefficients for linking geometric angle of incidence of elevator to stick position. (deg/in)

(28) (deg/in^2)

c. <u>Lateral Cyclic</u>

CARD 95

(29) Range of lateral cyclic stick (in)

(30) Lateral cyclic pitch on swashplate with stick full left (deg)

(31) Lateral range of swashplate (deg)

(32) Lateral cyclic pitch loc.. indicator

(33) Lateral cyclic pitch of rotor 1 if XCON(32)≠0 (deg)

(34)

(35)

CARD 96

(36) Coefficient for linking right rotor collective pitch to right rotor lateral cyclic pitch (deg/deg)

(37) Coefficient for linking left rotor collective pitch to right rotor lateral cyclic pitch (deg/deg)

(38) Coefficient for linking right rotor F/A cyclic pitch to right rotor lateral cyclic pitch (deg/deg)

(39) Coefficient for linking left rotor F/A cyclic pitch to right rotor lateral cyclic pitch (deg/deg)

(40) Coefficient for linking aft/left rotor lateral cyclic pitch to fwd/right rotor lateral cyclic pitch (deg/deg)

(41) Lateral cyclic stick - aileron coupling factor (deg/in)

(42)

d. Pedal and Mast Tilt

CARD 97

(43)	Range of pedal	(in)
(44)	Tail rotor collective or rudder angle with pedal full right	(deg)
(45)	Range of tail rotor collective or rudder	(deg)
(46)	Rotor 2 collective lock indicator	
(47)	Rotor 2 root collective pitch if XCON(46)≠0	(deg)
(48)	Rudder lock indicator	
(49)		

CARD 98

(50)	Coefficient for linking right rotor collective pitch to rudder position	(deg/deg)
(51)	Coefficient for linking left rotor collective pitch to rudder position	(deg/deg)
(52)	Coefficient for linking right rotor F/A cyclic pitch to rudder position	(deg/deg)
(53)	Coefficient for linking left rotor F/A cyclic pitch to rudder position	(deg/deg)
(54)	Coefficient for linking forward rotor lateral cyclic pitch to rudder position	(deg/deg)
(55)	Coefficient for linking aft rotor lateral cyclic pitch to rudder position	(deg/deg)
(56)		

CARD 99

(57) (58) (59)	Coefficients for tail rotor collective as a function of rudder angle if XCON(48)≠0	(deg) (/deg)
(60)	Coefficient for modifying XCON(36) and XCON(37) with β_m	
(61) (62)	Coefficients for modifying XCON(50) and XCON(51) with β_m	(deg)
(63)	Mast tilt - elevator incidence coupling factor	(deg/deg)

12. <u>Flight Constants Group</u>

Card		No.	Description	Units
CARD 101	XFC	(1)	Forward velocity	(kts)
		(2)	Lateral velocity	(kts)
		(3)	Rate of climb	(ft/sec)
		(4)	Altitude	(ft)
		(5)	Euler angle yaw	(deg)
		(6)	Euler angle pitch	(deg)
		(7)	Euler angle roll	(deg)
CARD 102		(8)	Collective stick position	(%)
		(9)	F/A cyclic stick position	(%)
		(10)	Lateral cyclic stick position	(%)
		(11)	Pedal position	(%)
		(12)	g level	
		(13)	Bank angle	(deg)
		(14)	Turn radius	(ft)
CARD 103		(15)	Main rotor F/A flapping angle	(deg)
		(16)	Main rotor lateral flapping angle	(deg)
		(17)	Tail rotor F/A flapping angle	(deg)
		(18)	Tail rotor lateral flapping angle	(deg)
		(19)	Main rotor thrust	(lbs)
		(20)	Tail rotor thrust	(lbs)
		(21)	Trim type indicator	
CARD 104		(22)	Initial approximation control	
		(23)	Fold indicator	
		(24)		
		(25)	Engine RPM	
		(26)	Maximum engine horsepower	
		(27)	Speed of sound	(ft/sec)
		(28)	Sigma-prime	

13. Weapons Group

CARD 105

XGN	(1)	Station line	Location of weapon	(in)
	(2)	Buttline	Location of weapon	(in)
	(3)	Waterline	Location of weapon	(in)
	(4)	Azimuth		(deg)
	(5)	Elevation		(deg)
	(6)			
	(7)			

14. Allowable Error Group

CARD 111

XER

(1)	Allowable error in F/A force balance	(lbs)
(2)	Allowable error in lateral force balance	(lbs)
(3)	Allowable error in vertical force balance	(lbs)
(4)	Allowable error in pitching and yawing moment balance	(ft-lb)
(5)	Allowable error in rolling moment balance	(ft-lb)
(6)	Allowable error in main rotor flapping moment balance	(ft-lb)
(7)	Allowable error in tail rotor flapping moment balance	(ft-lb)

15. Iteration Limits Group

CARD 121

XIT	(1)	Iteration limit for TRIM	
	(2)	Iteration limit for rotor flapping moment balance in rotor analysis	
	(3)	Partial derivative use indicator	
	(4)	Partial derivative increment for STAB	
	(5)	Trim output selector	
	(6)		
	(7)	Induced velocity change limiter	

CARD 122

	(8)	Minimum value for main rotor flapping angle correction limit	(deg)
	(9)	Minimum limit for tail rotor flapping angle correction limit	(deg)
	(10)	Maximum value for use of variable damper for main rotor	(ft-lb)
	(11)	Maximum value for use of variable damper for tail rotor	(ft-lb)
	(12)	Starting value for TRIM correction limit	(deg)
	(13)	Minimum value for TRIM correction limit	(deg)
	(14)	Maximum value for use of variable damper in TRIM	(lb or ft-lb)

CARD 123

	(15)	Euler angle iteration selector for TRIM	

16. Stability Times Group

CARDS 131-132

TSTAB(1) . . . TSTAB(14)	Maneuver times at which stability analysis is to be performed.	(sec)

17. Airload Printout Times Group

CARDS 133-134

TAIR(1)

.
.
.

TAIR(14)

Maneuver times at which blade element data is to be printed out. (sec)

18. Time Card

CARD 201

(1)	Start time of maneuver	(sec)
(2)	First time increment	(sec)
(3)	Time to stop using first increment	(sec)
(4)	Second time increment	(sec)
(5)	Time to stop using second increment	(sec)
(6)	Time to stop the maneuver	(sec)
(7)		

19. Variations from Stable Flight

CARD 211

Col. 1	Indicator for last card of this group
Col. 2 - 5	J, variation selector
Col. 11 - 20 Col. 21 - 30 Col. 31 - 40 Col. 41 - 50 Col. 51 - 60 Col. 61 - 70	Inputs which define the variations for each value of J in 6F10.0 format

B. USER'S GUIDE TO INPUT FORMAT

1. Identification and Flow Control Group

CARD 01

NPART is the primary variable on this card. Uses and meanings of the other variables on this card depend upon the value of NPART and are explained under each value of NPART. If a variable is not listed, it is not used for that value of NPART.

NPART < 1	Data error, job terminated.
NPART = 1	Obtain stabilized flight condition only. Card 134 is last data card. See Figure 1.
NPART = 2	Obtain stabilized flight condition, perform indicated time-variant maneuver. CARD 201 (time card) and at least one more card of the 200 series (J cards) must be included. See Figures 5 and 6.
NPRINT	Determines frequency of printout of maneuver data. Program prints data showing initial conditions for maneuver (maneuver time t=0) and every NPRINTth time point thereafter.
NVARB = 0	Wagner and Buettiker functions (non-steady aerodynamic effects) inactive.
NVARB = 1	Wagner and Buettiker functions active for first time increment only.
NVARB = 2	Wagner and Buettiker functions active for second time increment only.
NVARC = 0	Airload printout for main rotor only.
NVARC = 1	Airload printout for both rotors.

NVARC = 2	Airload printout for second rotor only.
NPART = 3	Plot time history of selected variables. (See Figure 7.)
NPRINT	Determines frequency of time points to be plotted. Used in same manner as under NPART=2.
NSCALE = 0	No effect.
NSCALE = 1	Multiplies scales for 1st variable by 1000.
NSCALE = 2	Multiplies scales for 2nd variable by 1000.
NSCALE = 3	Multiplies scales for 1st and 2nd variable by 1000.
NSCALE = 4	Multiplies scales for 3rd variable by 1000.
NSCALE = 5	Multiplies scales for 1st and 3rd variable by 1000.
NSCALE = 6	Multiplies scales for 2nd and 3rd variable by 1000.
NSCALE = 7	Multiplies scales for 1st, 2nd and 3rd variable by 1000.
NVARA	First variable, from Plot index, Table I.
NVARB	Second variable, from Plot index, Table I.
NVARC	Third variable, from Plot index, Table I.
AL(I), I=1,2,3	Lower scale limit for variable indicated by subscript.
AH(I), I=1,2,3	Upper scale limit for variable indicated by subscript.
NPART = 4	Not used at present.
NPART = 5	Not used at present.

NPART = 6	Not used at present.
NPART = 7	Stability analysis. See Figures 3 and 4.
NPART = 8	Time history tape file operation. See Figures 8 and 9.
NSCALE = 0	Transfer time history from plot disk to storage tape. This path allows subsequent time histories to be put on same storage tape if all the time histories are created under the same job card.
NSCALE = 1	Transfer time history from plot disk to storage tape. No more time histories may be stored on this particular tape.
NSCALE = 2	Transfer time history from file tape to plot disk.
NPART = 10	Parameter sweep (trim or stability derivatives only). See Figures 2 and 4.
NVARA = 0	Trim only.
NVARA = 1	Trim and stability derivatives.

The card or cards following have the new values of the sweep parameters in NAMELIST input. The first column of the first card must be blank. In Columns 2-8, put: &CHANGE column 9 is blank. Starting in column 10 and continuing on as many cards as necessary are the parameters to be changed and their values. After the last one, have either a comma or a blank followed by &END. Any variable on CARDS 11-123 except XFC(5) through XFC(11) and XFC(15) through XFC(20), may be changed by referring to it by its group symbol and word number. The excepted data are the trimmed values from the previous case.

Example:

```
&CHANGE XFS(1)=9500.,XMR(11)=5.,
XFC(3)=-50.,XER=5*1000.,100.,
50.,YEL(17)=.108,&END
```

The above information will cause a case to be run for which XFC(5) through XFC(11) and XFC(15) through XFC(20) will have the trim values of the preceding case, gross weight will be changed to 9500. lbs., main rotor mast tilt angle changed to 5. degrees, rate of climb changed to -50. ft/sec, the allowable force and moment unbalances on the fuselage changed to 1000 lbs. or ft-lbs, the allowable main rotor flapping moment unbalance changed to 100 ft-lb, the allowable tail rotor flapping moment unbalance changed to 50 ft-lb and the elevator lift curve slope for Mach number = 0 changed to .108/deg.

NPART = 11	Least squares curve fit of time history data. Variables which can be fit and their code numbers are found in Table I. See Figure 10.
NVARA	Number of curves to be fit.
AL(1)	Frequency in cps.
NVARB	Number of curves to be used as reference curves in computing amplitude ratios and phase angle differences.
AL(2)	Number of curves to be expressed as linear combinations of two other curves. (This number must have a decimal point punched.)

NVARC Number of maneuver time points to be skipped before curve fit begins.

All cards in an NPART=11 data deck, except the NPART card, have a 14I5 format.

Next Card(s) (110X series) Code numbers of curves to be fit (NVARA numbers)

Next Card(s) (111X series)

Column 1-5: NX

Column 6-10: Code number of reference variable for computing amplitude ratios and phase angle differences.

Column 11-15 16-20 etc.	NX code numbers of variables to be compared to the reference variable.

There are NVARB sets of cards of this type.

Next Card(s) (112X series) These cards select the variables to be expressed as a linear combination of two other selected variables.

A=KB*B+KC*C+D

Column 1-5: Code number for variable A.

Column 6-10: Code number for variable B.

Column 11-15: Code number for variable C.

The constants KB,KC, and D are then determined by the program.

There are AL(2) cards of this type.

Do not use any blank cards in the NPART = 11 group.

CARD 02

IPSN

Problem series number for identification purposes Printed in output headings.

CARD 02 CARD 03 CARD 04	Identifying Comments	Printed in output headings; used as problem identification.

2. Aerodynamic Inputs

The aerodynamic inputs are used by CLCD to compute the coefficients of lift, C_L, and drag, C_D, as a function of angle of attack, α, and Mach number, M. In the following discussion, YXX(I) refers to the Ith aerodynamic input for the appropriate aerodynamic surface. Except for sections specifically labeled otherwise, formulas and procedures apply to all aerodynamic surfaces, i.e., rotors, wings, elevators, or fins.

If the lift curve slope for zero Mach number, YXX(17), is input as a zero value, the program will compute C_L and C_D from data tables for a 64A210 airfoil. If YXX(17) has a non-zero value, C_L and C_D will be computed from the analytical/empirical equations described in Section III B, Volume I. The airfoil section characteristics included in the aerodynamic inputs are for a two-dimensional symmetric section at zero Mach number. These input values are corrected by the CLCD and YFIX subroutines to obtain the necessary three-dimensional characteristics. The C_L and C_D values computed from these three-dimensional characteristics are for an unswept symmetrical surface.

CARD A

Drag divergence Mach number locates the boundary between the subsonic and transonic regions. The program requires a value less than 1.

Mach number for lower boundary of supersonic region locates the boundary between the transonic and supersonic regions. The program requires a value greater than

$$\sqrt{1 + \left(1 - YXX(1)^2\right)\left(\frac{4}{YXX(17)}\right)^2} \quad .$$

CARDS A-B

$$C_L \text{ at the stall point} = \begin{cases} YXX(3)+YXX(4)M+YXX(5)M^2+YXX(6)M^3 \text{ for normal flow} \\ YXX(7)+YXX(8)M+YXX(9)M^2+YXX(10)M^3 \text{ for reversed flow} \end{cases}$$

CARD B

Tail boom bending coefficient reduces C_L, on the fin and elevator only, by the formula

$$C_L = C_L/(1 + YXX(11)q_t C_L/a)$$

where q_t is the dynamic pressure on the appropriate tail surface.

CARDS B-C

For non-divergent drag,

$$C_D = \text{minimum} \begin{cases} \dfrac{YXX(12)}{\sqrt{1-M^2}} + YXX(13)a + YXX(14)a^2 \\ YXX(16) \end{cases}$$

CARD C

In the supersonic region,

$$C_D = \frac{4(a^2+YXX(15)) + YXX(12)}{\sqrt{M^2-1}}$$

Below stall C_L is computed as a linear function of YXX(17) after YXX(17) and a have been modified by Mach number and aspect ratio corrections.

3. Fuselage Group

CARD 11

Gross weight includes pylons, rotors, fuel, etc.

Fuselage aerodynamic center defines the point of application of body lift, drag, and side force so that moments produced by them may be calculated.

C. G. location is for whole ship. If a conversion or fold maneuver is run and C.G. shift with mast tilt or fold is desired, these inputs should be for 0 degrees mast tilt and rotors unfolded. (See CARD 15, pylon weight and C.G.)

CARD 13-14

Let $q' = 1/2\,\rho V^2$

α = Fuselage pitch angle of attack

β = Fuselage sideslip

Pitch moment $= q'(XFS(15) + XFS(16)\alpha)$

Yaw moment $= q'(XFS(17) + XFS(18)\beta)$

Other contributions to fuselage moments will come from fuselage and pylon forces if the forces are not applied at the center of gravity.

Forces calculated below are in wind reference.

Lift $= q'(XFS(20) + XFS(21)\alpha)$

Drag $= q'(XFS(22) + XFS(23)\alpha + XFS(24)\alpha^2 + XFS(25)\beta^2)$ + pylon drag

Side Force $= q'(XFS(26) + XFS(27)\beta + XFS(28)\beta^2)$

CARD 15

Pylon weight is the total weight of both pylons, hubs, rotors, etc., which contribute to C.G. shift with mast tilt. If the mast tilt angle is to remain constant during the run and the C.G. inputs of CARD 11 are the locations of the ship C.G. for the input mast tilts, then pylon weight should be input as 0. Otherwise, a shift from the C.G. inputs will be calculated as explained below.

Pylon C.G. inputs are intended to locate the movable weight (pylons, etc.) for 0 degree mast tilt. Zero mast tilt means mast vertical for all but a side mount type tail rotor. For a tail rotor, zero mast tilt is directly to the pilot's left.

Pylon weight and C.G. location are necessary only in conversion maneuvers. However, they are used in all cases according to the following formulas.

The shift of the C.G. station, ΔSTA, and waterline, ΔWL, due to mast tilt are given by:

$$\Delta STA = Z \sin\beta_m + X(1 - \cos\beta_m)$$

$$\Delta WL = Z (1 - \cos\beta_m) - X \sin\beta_m$$

Where β_m is mast tilt angle,

$$X = \left[XFS(29)/XFS(1)\right] \quad \left[XMR(8)-XFS(30)\right]$$

$$Z = \left[XFS(29)/XFS(1)\right] \quad \left[XMR(10)-XFS(31)\right]$$

It is assumed here that the C.G. buttline does not change with mast tilt and that the mast tilt angles of both rotors are equal when this is used. Essentially, this means that use of this option assumes that a side-by-side configuration is being simulated.

Pylon differential flat plate drag area is defined as total ship flat plate drag area at 0 degrees mast tilt minus total ship flat plate drag area at 90 degrees mast tilt. The drag from this area is applied as a function of the cube of the cosine of the mast tilt angle. The drag from this area is applied at the pylon aerodynamic center which is assumed to be on the mast at some distance from the mast pivot point XFS(33), and thus causes a pitching moment on the fuselage.

4. Main Rotor Group

CARD 21

The blade chord is assumed to be constant over the radius.

The coning spring constant gives the amount of restoring moment generated by one degree of coning. A reasonable value for the coning spring constant, K_c, may be found from the following equation.

$$K_c = I_b(\omega^2 - \Omega^2) - e\Omega^2 \sum_{i=1}^{20} r_i m(r_i)\Delta r_i$$

where

I_b = Mass moment of inertia for one blade.

ω = Natural frequency of the first collective mode.

Ω = Rotor rotational speed.

e = Distance from the shaft to the flapping hinge.

r_i = Radius of ith radial station.

$m(r_i)$ = Mass per unit length at ith radial station.

Δr_i = Radius/20

Flapping stop is the maximum angle a blade can flap down relative to the mast. The normal input is negative. Aninput equal to the precone angle gives a rigid rotor.

CARD 22

Mast tilt angle is positive for forward tilt of the rotor.

Mast length is the distance from the shaft pivot point to the hub.

Fold rotor C.G. shift switch=0 gives no C.G. shift when the rotors are folded or unfolded. ≠0 does give shift in C.G.

CARD 23

The virtual hinge point, XMR(15), is used only in calculating the mass moments of inertia of the rotor. Only those rotor segments outboard of the virtual hinge point are included in the mass moments of inertia. If the real flapping hinge offset, XMR(16), is non-zero, then the virtual hinge point is set equal to the flapping hinge offset.

The focused pylon coefficient was included to control H-force and Y-force for a tilting prop-rotor. Changes are made in the swashplate angles proportional to the inplane forces. These may be expressed in equation form as

$$\Delta A_1 = \frac{L}{K} H$$

and

$$\Delta B_1 = -\frac{L}{K} Y$$

where

ΔA_1 is the change in the fore and aft swashplate angle;

ΔB_1 is the change in the lateral swashplate angle;

H is the H-force;

Y is the Y-force;

K is the torsional spring rate which couples the swashplate to the inplane forces; and

L is the moment arm through which the inplane forces are linked to the swashplate.

The ratio L/K is the program input XMR(19), focused pylon coefficient.

Flapping spring rates are the effective rates, per blade, for a rigid hub.

Hub extent is checked against the radius of each radial station. When the radius is less than the hub extent, C_L=0, C_D=Drag coefficient for hub, while area is that of the blade. That is, the blade starts at the center of the rotor (and center of the hub) but does not generate lift inboard of the outermost radial station which is in the hub.

CARD 24

Drag coefficient for hub is discussed with hub extent in CARD 23. Radial flow factor: <0 gives no radial flow; =0 gives radial drag but not radial lift; >0 gives both lift and drag radially. Normal input is 1/YMR(17).

The coefficient for tip vortex effect modifies the induced velocity distribution on the outboard 30% of the rotor blade to simulate the effect of shed tip vortices. The simulation gives improved air-load calculations in the low speed range. However, power and other performance values are not affected significantly. Rotor bending moments computed by another version of this program showed improved correlation with test data when a value of ten (10) was used for this coefficient. If the input is zero the effect is removed.

CARD 25 - 27

Blade twist at each radial station (up to 20) from tip to root, washout negative. The usual set of twist numbers is a sequence of negative numbers decreasing in magnitude.

Angle of attack at station j is computed by

$$\alpha_j = \theta_o + \phi_j + TWIST_j$$

where station 1 is the tip.

CARD 28 - 2A

Blade weight distribution is lbs/in for each of segments from root to tip with the 21st number t tip weight in pounds.

5. Tail Rotor Group

See Main Rotor Group for all except:

CARD 32

Tail rotor indicator = 0. means single rotor helicopter; = 1. means tandem or side-by-side ship.

CARD 34

Tail rotor sidewash coefficient, K, is used to simulate the effect of the fuselage on the wind vector as follows:

$$V_T = V_F (1. - K)$$

where V_F and V_T are the lateral components of the wind vector, in body reference, felt by the fuselage and the tail rotor, respectively.

6. Wing Group

CARD 41

Location of center of pressure of right wing is for the purpose of locating the point of applications of lift and drag to compute their moments. The wings are assumed to be symmetric.

CARD 42

Main rotor induced velocity factor is that fraction of main rotor induced velocity which hits the wing in the body vertical plane.

The deflection of the centerline of wing wake from downwind = $XWG(9)C_L$.

$$\eta_q = XWG(10)(C_D)^{1/2}\cos^2(\pi D/2h)/(\xi + .3)$$

where D is the distance from the trailing edge of the wing to the leading edge of the elevator in wing chords, h is the half width of the wing wake ξ wing chords down the wake centerline.

CARD 42 - 43

Coefficients for XWG(12) through XWG(21) are determined from Etkin, Reference 1, pp. 486-495, and used in the manner set forth below. These variables affect lateral stability and trim characteristics for non-zero sideslip.

Define:

B = Wing span

S = Wing area

β = Sideslip

α = Wing angle of attack

p = Roll rate of fuselage

r = Yaw rate of fuselage

L = Roll moment of wings

N = Yaw moment of wings

$$F = 1/2\ SV^2B$$

$$t^* = 1/2\ B/V$$

Then

$$L = F\left|\beta(XWG(12)+XWG(13)C_L)+t^*(XWG(14)rC_L+XWG(15)p)\right|$$

and

$$N = F\Big\{\beta(XWG(16)+XWG(17)C_L{}^2)$$

$$+\ t^*\Big|r(XWG(18)C_L{}^2+XWG(19)dC_D/d\alpha)$$

$$+\ p(XWG(20)C_L+XWG(21)(YWG(13)$$

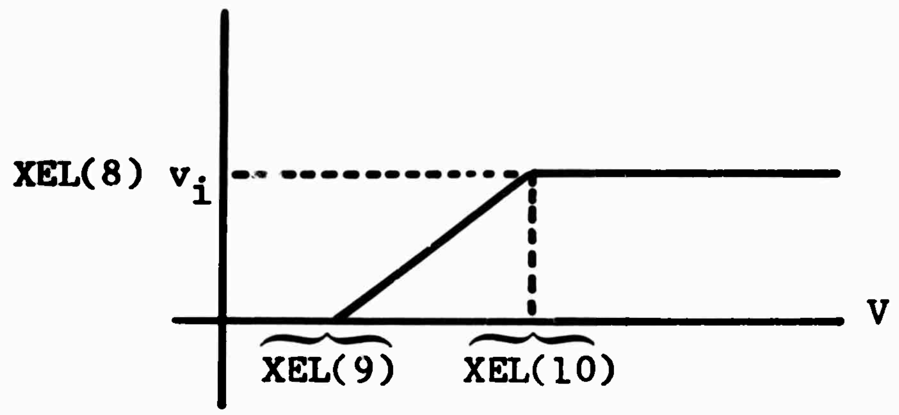
$$+\ 2\alpha YWG(14)YWG(18)/(3+YWG(18))))\Big|\Big\}$$

7. Elevator Group

CARD 51

Location of the center of pressure is the point of application of lift and drag to determine moments. XEL(5) is positive leading edge up.

CARD 52



v_i is the induced velocity of the main rotor

V is the airspeed

ϵ = XEL(11)C_L where ϵ is the change in elevator angle of attack, C_L is the average of the C_L on both wings

8. <u>Fin/Rudder Group</u>

CARD 61

Location of the center of pressure is the point of application of lift and drag to determine moments.

Geometric angle is considered positive if it tends to increase the lateral force which is positive to the pilot's right.

Induced velocity factor is for the portion of the tail rotor induced velocity which affects the fin.

Sidewash coefficient is used to simulate the effect of the fuselage on the wind vector

$$V_f = V_B(1. - XFN(7))$$

where V_f and V_B are the lateral components of the wind vector, in body reference, felt by the fin and fuselage, respectively.

9. Jet Group

CARD 71

Number of jets should be 0., 1., or 2. If number of jets = 1., left jet thrust is not changed from the input value by either movement of the collective stick (if XCON(12)≠0) or by maneuver inputs.

CARD 71 - 72

Location of right jet is the point of application of thrust with the angles defining the direction of thrust with respect to the fuselage.

A positive yaw angle gives the right jet a force component in body reference which is positive to the pilot's right. A positive pitch angle gives the right jet a force component in body reference which is positive up. The left jet is assumed to be symmetric in position and attitude with the right jet.

10. Bobweight Group

CARD 81 - 83

For no bobweight, set $\eta = 0$.

For a bobweight, set $\eta > 0$.

The parameters listed in the Input Format are for a special bobweight design and are defined in Reference 2. A value of $\eta = 4$ is assumed in that analysis.

The equation for the basic case is

$$\frac{I}{386}\ddot{\delta} + C_X\dot{\delta} + K_X\delta = \frac{\eta}{57.3}\,\frac{I}{386}\cdot \max\begin{cases} 0. \\ (g-g_p)\end{cases}$$

where

δ = change in collective pitch due to the bobweight (radians)

g = vertical acceleration of the fuselage

The remaining symbols are described in the input list below:

CARD 81
XBW

(1)	η	Effectivity coefficient	(deg/in)
(2)	K_X	Spring constant	(in-lb/rad)
(3)	C_X	Damping coefficient	(lb-in-sec)
(4)	0.		
(5)	0.		
(6)	0.		
(7)	g_p	Preload (bobweight not effective at $g<g_p$)	(g's)

CARD 82

(8)	0.		
(9)	I	Weight moment of inertia of bob-weight	(lb-in^2)
(10)	0.		
(11)	0.		
(12)			
(13)			
(14)			

CARD 83

(15) 1.
(16) 1.
(17) 1.
(18) 1.
(19) 1.
(20) 1.
(21) 1.

11. Controls Group

a. Collective

CARD 91

$$\text{Lower limit} = XCON(2)+XCON(3)\beta_m+XCON(4)\beta_m^2$$

$$\text{Range} = XCON(5)+\left|XCON(6)-XCON(5)\right|\beta_m/90$$

CARD 92

A collective stick movement such that the collective pitch of rotor 1 is increased by one degree results in a collective change on rotor 2 of XCON(9) degrees.

A stick movement of one inch results in a change of wing angle of attack of XCON(10) degrees, a change of elevator angle of attack of XCON(11) degrees, and a change in the thrust of each jet of XCON(12) pounds.

Maximum rate for PCG is the maximum rate which the PCG, when active, can change the root collective pitch.

RPM dead band is $\Delta RPM/RPM_{REF}$ where ΔRPM is the maximum change in RPM which does not activate the PCG and RPM_{REF} is the input RPM.

b. F/A Cyclic

CARD 93

A movement of the stick through 100% of its range is equivalent to movement of the stick through XCON(15) inches. During a stick movement from full aft to full forward, the swashplate F/A setting will move from XCON(16) degrees to XCON(16) + XCON(17) degrees.

CARD 94

A F/A cyclic stick movement such that the F/A cyclic pitch of the forward/right rotor is increased by one degree results in a collective pitch change on the forward rotor of XCON(22) degrees, a collective pitch change on the aft rotor of XCON(23) degrees, a F/A cyclic pitch change on the aft/left rotor of XCON(24) degrees, a lateral cyclic pitch change on the right rotor of XCON(25) degrees, and a lateral cyclic pitch change on the left rotor of XCON(26) degrees. However, XCON(25) and XCON(26) are used only when XCON(33)$\geq$2 and the result of their influence is added to XCON(32).

Δa_i = XCON(27)K + XCON(28)K^2 where Δa_i is the change in geometric angle of incidence of the elevator and K is the displacement, in inches, of the stick from neutral.

c. Lateral Cyclic

CARD 95

XCON(29), XCON(30), and XCON(31) are the lateral cyclic equivalents of XCON(15), XCON(16), XCON(17).

CARD 96

A lateral cyclic stick movement such that the lateral cyclic pitch of the forward/right rotor is increased by one degree results in a collective pitch change on the right rotor of XCON(36) degrees a collective pitch change on the left rotor of XCON (37) degrees, a F/A cyclic pitch change on the right rotor of XCON(38) degrees, a F/A cyclic pitch change on the left rotor of XCON(39) degrees, and a lateral cyclic pitch change on the aft/left rotor of XCON(40) degrees.

A lateral cyclic stick movement of one inch to the right results in an increase in the left wing angle of attack of XCON(41) degrees and an equal decrease in the right wing angle of attack.

d. Pedal and Mast Tilt

CARD 97

XCON(43), XCON(44), XCON(45) are the pedal equivalents of XCON(15), XCON(16), XCON(17) and apply to tail rotor collective if XCON(48)=0, or apply to the rudder if XCON(48)$\neq$0.

For a tandem or side-by-side configuration which does not have either a tail rotor or a rudder, it is necessary to input numbers for a fictitious rudder (i.e., XCON(48)=0) in XCON(43), XCON(44), and XCON(45) in order to define the inputs on CARD 98. It is best to construct this fictitious rudder so that at least one of the inputs on CARD 98 will be equal to 1.

Rudder lock indicator = 0. means fin is fixed and does not move.

Rudder lock indicator = 1. means the fin angle of attack is directly proportional to pedal deviation from neutral.

CARD 98

A pedal movement, to the left, such that the rudder angle or tail rotor collective is increased by one degree results in a collective pitch change on the right rotor of XCON(50) degrees, a collective pitch change on the left rotor of XCON(51) degrees, a F/A cyclic pitch change on the right rotor of XCON(52) degrees, a F/A cyclic pitch change on the left rotor of XCON(53) degrees, a lateral cyclic pitch change on the forward rotor of XCON(54) degrees, and a lateral cyclic pitch change on the aft rotor of XCON(55) degrees.

CARD 99

θ = XCON(57)+XCON(58)P+XCON(59)P^3 where θ is the collective pitch on the tail rotor of a single rotor helicopter and P is the deviation, in inches, of the pedal from neutral.

XCON(36) and XCON(37) are modified by cos(XCON(60) β_m).

XCON(50 and XCON(51) are modified by sin(XCON(61) β_m + XCON(62)).

An increase in mast tilt angle, β_m, of one degree results in an increase in elevator angle of attack of XCON(63) degrees.

The following inputs are modified by cos β_m: XCON(22), XCON(23), XCON(24), XCON(25), XCON(26), XCON(40), XCON(52), and XCON(53), while XCON(38) and XCON(39) are modified by sin β_m.

Inputs in the Controls Group are used only where appropriate as defined by the configuration control linkage tables, Table II and Table III.

If the following control inputs are zero, they are reset to the values indicated.

XCON(1)	-	100.
XCON(5)	-	100.
XCON(6)	-	100.
XCON(9)	-	1.
XCON(15)	-	100.
XCON(16)	-	-50.
XCON(17)	-	100.
XCON(24)	-	1.
XCON(29)	-	100.
XCON(30)	-	-50.
XCON(31)	-	100.
XCON(40)	-	1.
XCON(43)	-	100.
XCON(44)	-	-50.
XCON(45)	-	100.

Control deviation, in inches, from neutral is computed by

$$K = (K_1 K_2/100 + K_3)\ K_4/K_2$$

where

K_1 is the control position in percent

K_2 is the range of the control surface in degrees

K_3 is the lower limit of the control surface in degrees

K_4 is the range of the control in inches

12. Flight Constants Group

CARD 101

The input velocities are with respect to the ground.

The Euler Angles are the angles between the coordinate system attached to the body and the ground coordinate system. Yaw is positive nose right; pitch is positive nose up; roll is positive down right.

Altitude is the height above ground. It is used in the calculations for ground effect. If altitude is negative, the program stops.

CARD 102

The program checks g-level, bank angle, and turn radius, in that order, for a non-zero input. The first non-zero input completely specifies the turn and the program ignores the other inputs. During the TRIM process, instead of seeking zero force and moment values, the program seeks those force and moment values which, during an undisturbed maneuver, will cause the rotorcraft to fly in the circle determined by the input. A g-level input will produce a right turn. A left turn can be produced by a negative bank angle or a negative turn radius.

CARDS 102 - 103

Flapping angles on both rotors, control positions, and Euler angles of pitch and roll are changed in the TRIM subroutine as necessary in order to achieve stable flight conditions.

Trim type indicator: = 0. is for either a coordinated, banked turn, as explained above for CARD 102, or a Trim with no turn. =1. is for a pull-up or push-over at the g-level input in XFC(12).

CARD 104

Initial approximation control = 0. means the program is to make an initial approximation to the flapping angles and thrust on both rotors, ignoring the inputs.

Initial approximation control = 1. means the program is to use the inputs for flapping on both rotors and make an initial approximation for thrust on both rotors, ignoring the thrust inputs.

Initial approximation control = 2. means the program uses the inputs for the flapping angles and thrust on both rotors as the initial approximations.

Fold indicator = 0. if the rotors are unfolded and at the RPM specified; ≠0 if the rotors are stopped and folded. ≠0 is used to trim for an unfold and start maneuver. The data should be set up as if the rotors were unfolded and at normal RPM except for:

1. XFC(23)≠0
2. Controls are locked by XCON(7),XCON(18),XCON(32),XCON(46)≠0
3. Maneuver input cards for J=18 and J=27 have a start time of 0, i.e., for J = 18, $\Omega_B > 0$

Sigma-prime is the ratio of air density to standard day air density. $\rho = \sigma' \rho_O$ where ρ_O = .002378 slugs/ft^3. ρ is then used in the calculation of dynamic pressure.

13. Weapons Group

CARD 105

Stationline, buttline and waterline are used to locate the point of application of the recoil force of the weapon.

Azimuth and elevation define the orientation of the weapon with respect to the fuselage.

If both angles are input positive, the gun is pointing up and to the pilot's right.

14. Allowable Error Group

CARD 111

The forces and moments named are the ones which TRIM reduces to the range specified by the corresponding inputs.

15. Iteration Limits Group

CARD 121

If the program has not found a stable flight condition after XIT(1) iterations, it assumes there is no stable flight condition and terminates the problem.

If the iteration limit for the rotor flapping moment balance in the rotor analysis is input as a non-zero number, the TRIM equations are decoupled into one set of six equations in six unknowns and two sets of two equations in two unknowns. This should be done only on cases for which the coupled 10 x 10 system has defied solution because run time is increased by a factor of 3 to 5.

Partial derivative use indicator: = 0. means recompute partial derivative matrix for each iteration in TRIM. ≠ 0. means compute the partial derivative matrix on iterations 1, 6, 11, etc., in TRIM. During the other iterations, use the last computed matrix.

Partial derivative increment for STAB, XIT(4), is used in computing rate derivatives. The angular rate increment is 1/10 the input, in radians/sec, and the linear rate increment is 10 times the input, in ft/sec.

Trim output selector, XIT(5), = 0. prints the last set of partial derivatives and forces and moments in TRIM and a set of variables for each time point in MANU. = 1. prints each set of partial derivatives and forces and moments in TRIM and a set of variables for each time point in MANU.

The induced velocity change limiter is twice the maximum amount the induced velocity is allowed to change between time points during a maneuver.

CARD 122

XIT(12,13,14) are the inputs for a variable damping procedure in TRIM. At each iteration, a delta is computed for each of the 10 trim variables. These deltas are then compared to a correction limit. If any of the deltas are larger than the limit, they are ratioed down such that the largest one is equal to the limit. The starting value of the limit is input as XIT(12). If at the start of any iteration the force and moment errors are all less in absolute value than XIT(14), then the limit is halved with the restriction that the limit is never less than XIT(13). If XIT(12)<0.5 deg or >10 deg, the program resets it to 1 degree. If XIT(13)<.05 deg or >1.0 deg, the program resets it to .05 deg. If XIT(14)<40 XER(1), the program resets it to 40 XER(1).

The partial derivative increment for TRIM is computed from the correction limit. XIT(8,9,10,11) define variable dampers for balancing the rotor flapping moments in the rotor analysis. The starting value for the correction limit is computed from the minimum value input.

CARD 123

The Euler angle iteration selector for TRIM=1 for iterating on pitch and roll; =2 for iterating on pitch and yaw; ≠1 or 2 gives = 1.

16. Time Card

CARD 201

If a secondary time increment is not desired, only start time, first time increment, and time to stop using first time increment are necessary inputs.

If a secondary time increment is desired but a second use of the first time increment is not desired, the time to stop the maneuver should be either blank or equal to the time to stop using the second time increment.

This card and subsequent cards are to be put into the data deck only when running a maneuver, i.e., NPART=2 on CARD 01. The time increment is the Δt in the Runge-Kutta solution of the differential equations of motion. It may be desirable to chnage the value of Δt because of changes in rotor speed. Provisions have been made for such a change. See CARD 211, J=31 for an example of another use.

Unless specified otherwise, all times are relative to the scale established by the inputs on this card.

17. Variations from Stable Flight

CARD 211

NEXT = 0	This is the last card of the 211 type.
NEXT ≠ 0	Another card of the 211 type follows.
J	Type of variation, explained in list below.

It is possible to have as many as 20 cards similar to CARD 211. All have the same format. It is not necessary to have the J values in order, in fact, there may be several cards with the same value of J. It is necessary that NEXT ≠ 0 on all of these cards except the last one which must have NEXT = 0.

When the variations to be made during the maneuver have been decided, the list below may be used to find the proper values of J.

J = 1	is for movement of collective stick
J = 2	is for movement of F/A cyclic stick
J = 3	is for movement of lateral cyclic stick
J = 4	is for movement of pedal
J = 5	is for the prop-rotor collective governor
J = 6	is for folding rotors aft after tilting forward and stopping
J = 7	is for a change in rpm governor setting
J = 8	is for converting the tail rotor into a pusher prop., i.e., change the tail rotor mast tilt angle in the horizontal plane.
J = 9	is for a vertical ramp gust, ramp length may be 0.

J = 10	is for a vertical sine-squared gust
J = 11	is for a horizontal ramp gust, ramp length may be 0.
J = 12	is for a horizontal sine-squared gust
J = 13	is for a change in engine torque supplied
J = 14	is for a change in auxiliary thrust supplied
J = 15	is for activation of a "yaw pilot".
J = 16	is for weapon fire
J = 17	is for change of mast tilt angle on both rotors and rpm change
J = 18	is for rotor brake
J = 19	is for pitch A.S.E.
J = 20	is for sinusoidal movement of controls or mast
J = 21	is for a flat tracker for the main rotor
J = 22	is for a flat tracker for the tail rotor
J = 23	is for rpm dependent hubsprings
J = 24	not used
J = 25	not used
J = 26	not used
J = 27	is for folding rotors horizontally after stop
J = 28	is for rpm dependent flapping stops
J = 29	is for connecting and disconnecting helicopter controls
J = 30	is for rotor moment balancing mechanism
J = 31	is for changing NPRINT on CARD 01

After the values of J have been determined, the list below gives details for determining the rest of the inputs.

J = 1,2,3,4 (Control Movements)

Col.	11-20	Start time	(sec)
	21-30	Input rate 1	(in/sec)
	31-40	Stop time	(sec)
	41-50	Start time	(sec)
	51-60	Input rate 2	(in/sec)
	61-70	Stop time	(sec)

J = 5 (Proprotor Collective Governor)

Same as for J = 1, except rates are in hp/sec.

J = 6 (Folding Rotors Aft)

Col.	11-20	Start time (after Ω=0)	(sec)
	21-30	Rate (Positive to fold aft)	(deg/sec)
	31-40	Stop time (after Ω=0)	(sec)
	41-50	Start time (after Ω=0)	(sec)
	51-60	Rate (Positive to fold aft)	(deg/sec)
	61-70	Stop time (after Ω=0)	(sec)

J = 7 (Governor Rpm Setting)

Same format as for J = 1, except rates are in rpm/sec.

J = 8 (Tail Rotor to Pusher Prop)

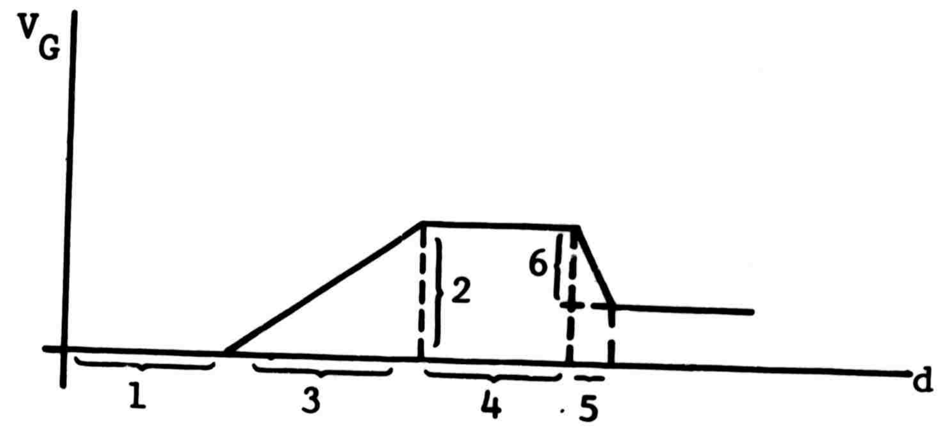
Same format as for J = 1, except rates are in deg/sec.

J = 9 (Vertical Ramp Gust)

See J = 11

J = 11 (Horizontal Ramp Gust)

Col.	11-20	(1)	Starting distance	(ft)
	21-30	(2)	1st max. velocity positive down or north	(ft/sec)
	31-40	(3)	1st ramp length	(ft)
	41-50	(4)	Distance gust is steady	(ft)
	51-60	(5)	2nd ramp length	(ft)
	61-70	(6)	2nd max. velocity (measured from first max velocity)	(ft/sec)



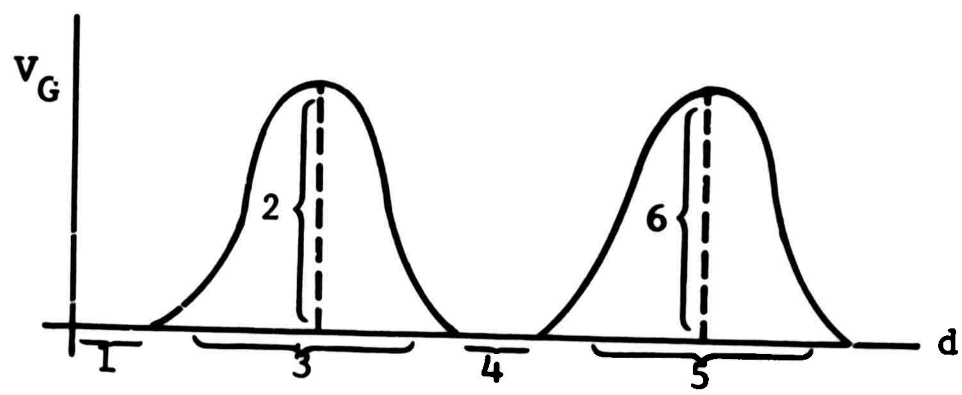
Ramp Gust

J = 10 (Vertical Sine-Squared Gust)

See J = 12

J = 12 (Horizontal Sine-Squared Gust)

Col. 11-20	(1)	Starting distance	(ft)
21-30	(2)	1st max value (positive down or north)	(ft/sec)
31-40	(3)	1st gust length	(ft)
41-50	(4)	Distance between gusts	(ft)
51-60	(5)	2nd gust length	(ft)
61-70	(6)	2nd max value	(ft/sec)



Sine-Squared Gust

J = 13 (Main Engine Torque)

Col.	11-20	Start time for rotor torque supplied variation	(sec)
	21-30	Ratio of torque desired to torque required at trim point	(ft-lb/ft-lb)
	31-40	Start time for rotor torque supplied recovery to torque required	(sec)
	41-50	(inactive)	
	51-60	Engine accel. lag, zero to full power	(sec)

J = 14 (Auxiliary Jet Thrust)

Col.	11-20	Start time for auxiliary thrust variation	(sec)
	21-30	=0 or 1 see below: =2 for setting col. 51-60 to trim thrust and resetting col. 21-30 to 1.	
	31-40	Rate	(lb/sec)
	41-50	Stop time if col. 21-30 = 0.	(sec)
	51-60	Final value of thrust if col. 21-30 = 1.	(lb)
	61-70	=1 for left jet; =2 for right jet	

J = 15 (Yaw Reactions by Pilot)

Col.	11-20	Start time	(sec)
	21-30	Acceptable sideslip, β, not requiring correction	(deg)
	31-40	T/R collective rate per sideslip, X_4	(deg/sec/deg)
	41-50	T/R collective rate per sideslip rate, X_5	(deg/sec/deg/sec)
	51-60	Ratio of acceptable yaw velocity to maximum yaw velocity	
	61-70	Stop time	

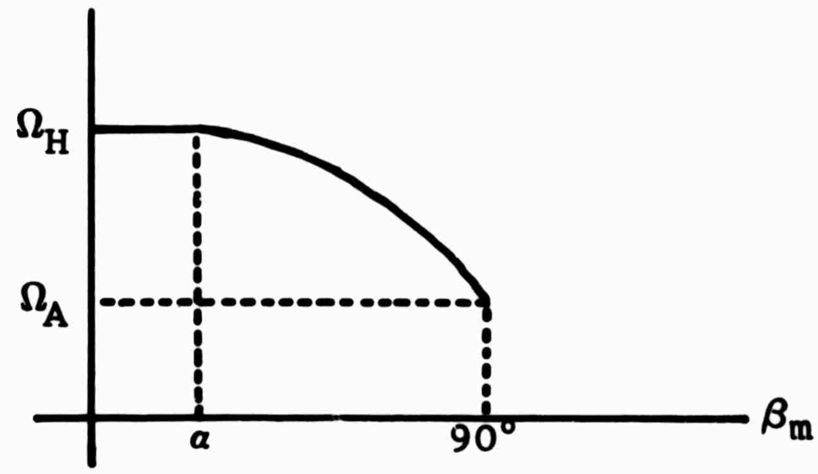
If T/R collective is to be changed,
rate = $\beta X_3 + \beta X_4$

J = 16 (Machine Gun Fire, Ramp Only)

Col.	11-20	Start time	(sec)
	21-30	Stop time	(sec)
	31-40	Max force	(lb)
	41-50	Ramp length	(sec)
	51-60	(inactive)	
	61-70	(inactive)	

J = 17 (Mast Tilt on Both Rotors)

Col.	11-20	Start time for mast tilt	(sec)
	21-30	Rate of mast tilt	(deg/sec)
	31-40	Stop time for mast tilt	(sec)
	41-50	(inactive)	
	51-60	a, mast tilt angle at which rpm change is activated	(deg)
	61-70	$\Omega_H - \Omega_A$, change in rpm in converting from airplane mode to helicopter mode	(rpm)



$$\Omega = \begin{cases} \Omega_A + (\Omega_H - \Omega_A)\cos\left[\left(\frac{\beta_m - a}{90 - a}\right) 90\right] & \text{if } \beta_m > a \\ \Omega_H & \text{if } \beta_m \leqslant a \end{cases}$$

where: β_m is mast tilt angle

Ω is current rotor rpm

Ω_H is rotor rpm in helicopter mode ($\beta_m = 0°$)

Ω_A is rotor rpm in airplane mode ($\beta_m = 90°$)

J = 18 (Rotor Brake)

Col.	11-20	Maximum brake torque	(ft-lb)
	21-30	RPM at which brake engages, Ω_B	(rpm)
	31-40	Target azimuth position for stop	(deg)
	41-50	Time to stop applying brake	(sec)

J = 19 (Pitch A.S.E.)

Col.	11-20	Start time (activate A.S.E.)	(sec)
	21-30	Cyclic displacement/pitch displacement from reference pitch angle, X_2	(deg/deg)
	31-40	Cyclic displacement/pitch velocity, X_3	(sec)
	41-50	Cyclic displacement/pitch acceleration, X_4	(sec^2)
	51-60	Reference pitch angle, X_5	(deg)
	61-70	Lag factor for mechanism, X_6	(sec)

Let δ = change in cyclic pitch for one time increment, Δt
δ_1 = value of δ for the previous time increment
α = fuselage Euler angle pitch
q = fuselage pitch rate

$$\delta = \left[X_2(X_5-\alpha) + X_3 q + X_4 \dot{q} + \frac{\delta_1 X_6}{\Delta t}\right]\left(\frac{1}{1 + \frac{X_6}{\Delta t}}\right)$$

J = 20 (Sinusoidal Movement of Controls or Mast)

Col.	11-20	Start time	(sec)
	21-30	Frequency	(cps)
	31-40	Amplitude	(inches for controls, deg. for mast)
	41-50	Stop time	(sec)
	51-60	Control to be moved 1. is for collective stick 2. is for F/A cyclic stick 3. is for lateral cyclic stick 4. is for pedal 5. is for mast	

J = 21 (Flat Tracker for Main Rotor)

See J = 22

J = 22 (Flat Tracker for Tail Rotor)

Col.	11-20	Start time	(sec)
	21-30	Acceptable deviation	(deg)
	31-40	Rate	(deg/sec)
	41-50	F/A reference angle	(deg)
	51-60	Lateral reference angle	(deg)
	61-70	Data selector 0. - use input values for reference angles; 1. = use TRIM values of flapping angles wrt mast as reference angles	

J = 23 (RPM Dependent Hubsprings)

Col.	11-20	Rotor number (1 or 2)	
	21-30	K_B hubspring value in lower rpm range	(ft-lb/deg)
	31-40	Ω_1 top of lower rpm range	(rpm)
	41-50	Ω_2 bottom of upper rpm range	(rpm)

Let Ω be the rpm of rotor 1, K_I be one of the following inputs, as appropriate; XMR(17), XMR(18), XTR(17) or XTR(18), and K_h be the rpm dependent value of the appropriate hubspring. Then

$$K_h = \begin{cases} K_I & \text{if } \Omega \geqslant \Omega_2 \\ \left(\dfrac{K_B - K_I}{\Omega_1 - \Omega_2}\right)\left(\Omega - \Omega_2\right) + K_I & \text{if } \Omega_1 < \Omega < \Omega_2 \\ K_B & \text{if } \Omega \leqslant \Omega_1 \end{cases}$$

In other words, the extreme values for the hub-springs are K_B, and the inputs in the rotor groups and linear interpolation is used in the transition region.

J = 27 (Horizontal Fold, for Main Rotor Only)

Col.	11-20	Start time	(sec after Ω=0)
	21-30	Rate	(deg/sec)
	31-40	Stop time	(sec after Ω=0)
	41-50	Blade number (each blade moves independently)	

J = 28 (Rpm Dependent Flapping Stops)

Same as for J=23 except that mechanism affected is flapping stops and K_B is in degrees.

J = 29 (Control Changer - to Lock or Unlock Swashplate)

Col.	11-20	Start time	(sec)
	21-30	Stop time	(sec)
	31-40	Indicator: =0 if start time is in maneuver sec., ≠0 if start time is in sec. after Ω=0	
	41-50	Indicator: =0 if stop time is in maneuver sec., ≠0 if stop time is in sec. after Ω=0	

Note: If this mechanism is off during a maneuver, swashplate settings will immediately assume the value dictated by the control positions. Care should be taken to set the controls so that there are no discontinuities.

51-60 Indicates which controls to lock or unlock: 1. is for rotor 1 collective; 2. is for F/A cyclic; 4. is for lat. cyclic; 8. is for rotor 2 collective; for any combination, add the indicators. 0. is equivalent to 15, which affects all controls.

J = 30 (Mechanism for Balancing Main Rotor Force and Moments During Horizontal Fold)

Col.	11-20	Start time	(sec after Ω=0)
	21-30	Stop time	(sec after Ω=0)
	31-40	∂Z-force/∂ collective	(lbs/deg)
	41-50	∂F/A flapping moment/∂ F/A cyclic	(ft-lb/deg)
	51-60	∂ Lat flapping moment/∂F/A cyclic	(ft-lb/deg)
	61-70	Maximum rate of change of controls (collective and cyclic)	(deg/sec)

J = 31 (Changing Printout Frequency)

Col.	11-20	Time to change NPRINT	(sec)
	21-30	New NPRINT	
	31-40	Time to change NPRINT	(sec)
	41-50	New NPRINT	
	51-60	Time to change NPRINT	(sec)
	61-70	New NPRINT	

NPRINT must be input as a floating number, i.e., punch a decimal point on the data card. The use of NPRINT is as described for CARD 01, NPART=2.

As an example of the use of this value of J, as well as an example of the use of the provision for different time increments on CARD 201, consider the following hypothetical situation.

A maneuver was run in which a pitch divergence occurred. Analysis of the output indicated that the divergence started between 3.5 and 3.75 seconds. The time increment used was .05 and NPRINT was 5 throughout the run which lasted 7.5 seconds.

A new maneuver was then set up, identical to the first except that the time card, CARD 201, now contained 0., .05, 3.5, .005, 3.75, 3.75 as the consecutive inputs instead of 0., .05, 7.5, blank, blank, blank which were used on the previous run. NPRINT on CARD 01 was changed from 5 to 70. An additional CARD 211 was input which had a J of 31. The number 3.5 was in Columns 11-20, the number 1.0 in Columns 21-30, and the rest of the card blank.

In the output (see Section III for a complete explanation of all outputs), the trim page was followed by the maneuver page for maneuver time of 0 second. The next time point for which output was given was 3.5 seconds and output was given at every .005 second until 3.75 seconds. The result was no output for time points of no interest, but complete coverage of the time interval of interest.

C. USER TECHNIQUES

Experience in using the program will increase the degree of success in obtaining trims, maneuvers, and stability calculations as desired. Difficulty encountered in running a case may be due to a number of things. Some of those related to engineering areas are discussed in Volume I. A check list of the most likely mechanical and numerical trouble spots, with suggested action, follows:

1. <u>Input Data</u>

If a data deck will not run, check for

- mispunched data: no decimal, extra decimal, wrong field
- misplaced card(s): card out of sequence, missing card, or extra card.

If a data deck runs but results are obviously wrong (at any output level), check for

- an extra card
- special inputs left in from a previous run
- wrong number

A missing card is very easy to detect since it usually leads to problems which generate error messages by the operating system of the computer. Cards out of sequence are usually very difficult to detect since interchanging any pair of cards in a data deck can generate unique symptoms. An extra card usually causes divisions by zero while or just after printing out the input data for the rotor groups.

2. <u>Difficulty in Trimming</u>

Failure to trim usually is due to the initial approximation of the trim vector being too far from the final solution trim vector. If a successful trim has been computed for a similar case, the new case can frequently be trimmed by using the variable incrementing feature to proceed in steps from the previous case to the new case. If a trimmed, similar case is not available, a hand calculation based on the partial derivative matrix output can aid in obtaining a closer initial approximation. Proceed as follows: determine the three largest force or moment errors. Next find the largest partial derivatives associated with some group of three elements of the trim vector in the three equations having the largest errors. Solve this 3x3 system for new values of the trim vector elements.

A trim failure may also be caused by one variable oscillating between two extremes as the computations go from one iteration to the next. This "bounce" phenomenon can usually be cured by using the average value in the initial approximation and/or reducing the correction limit and damping factor.

3. Maneuver Diverges

The first possibility to consider is bad maneuver inputs. If the data are good, a smaller time increment should be tried. A good rule of thumb is that the time increment should be such that a blade on any rotor does not move more than 45° around the azimuth during one time increment. It is also possible that the system may be inherently unstable and, therefore, the divergence may be real.

4. Stability Calculations

Erroneous values for stability characteristics may result from incorrect choice of the increment used in numerical approximation of the partial derivatives. If the increment is extremely small, the difference computed in the function may be only due to round off error or may be zero. If the increment is large, the curvature may have changed signs over the interval, causing large errors.

D. SAMPLE CASES

In Figures 11 through 14 are shown input data sets for the four common rotorcraft configurations for which the flight simulation program is used.

Figure 11 shows data for a single-rotor helicopter flying at 120 knots in a 1.25g coordinated turn. This data set causes the computer program to find a trim condition, run a stability analysis, and terminate the problem. The trim condition found is shown in Figure 20. The output of the stability analysis may be seen in Figures 24 through 28.

In Figure 12 is the input data set for a compound helicopter capable of flight with the rotors stopped. This particular data trims the craft with the rotors running at full speed but lightly loaded, as in preparation to stop and fold the rotors. A maneuver to stop the rotors and fold the main rotor was run using this data except that the fuselage inertias were made very large to simulate a wind tunnel test. No control motions were made to control the forces and moments. Some of the results of this case are shown in Figure 15.

The rotor rpm, thrust, and power required are plotted along with the torque applied by the rotor brake and the rotor blade positions after the rotor rpm is zero. The brake torque goes to zero when the rotor is stopped because the rotor is assumed to be locked in place at this time.

Figure 13 presents data for a tilting proprotor craft flying in helicopter mode. The trim condition for this data would make a good starting condition for a maneuver to convert from helicopter mode to airplane mode.

Figure 14 lists data for a tilting proprotor craft flying in airplane mode. Starting with this trim condition a maneuver may be run to reconvert to helicopter mode or to stop and fold the proprotors. Some results of the second case may be seen in Figure 16. The precone angle is plotted because this is the means by which the TFTA rotors are folded in the computer program.

SECTION III

OUTPUT GUIDE

All possible output of the computer program has been divided into eight groups for the purpose of explanation. The first three groups listed will always be printed. The appearance of the other items depends on the options exercised by the program user. A brief explanation of each output group is given below. The output is explained in detail on the following pages.

1. Input Data for Trim

The basic set of input data is printed as a record of the parameters used for each case.

2. Trim Iteration Page

If input XIT(5) is one, a trim iteration page is printed for each attempt to find a set of control and attitude variables corresponding to a trimmed ship. If a trim solution is achieved, most of this information is superfluous. However, if a trim condition cannot be found, this output can be very useful for analyzing the problem and finding a better set of initial values for control settings, fuselage angles, and flapping angles.

3. Final Trim Page

A final trim page is always printed indicating whether or not a trim condition was found and giving the general conditions for the final iteration in either case.

4. Input Data for Maneuver

If a maneuver is called for, the inputs controlling the maneuver are printed.

5. Typical Maneuver Page

At desired time points during a maneuver a number of variables such as positions, velocities, and accelerations are printed.

6. Time History Plots

Time history plots of variables selected by the user may be obtained at the end of a maneuver.

7. Output of Stability Analysis Routine

During the stability analysis much of the information obtained in computing the partial derivatives is printed out. At the completion of the stability analysis, the roots of the characteristic equations with controls fixed and a frequency response transfer function are printed.

8. Least Squares Curve Fit

Following a maneuver with a sinusoidal control motion the curve fit routine prints coefficients, phase angles,and correlation factors to indicate how well selected variables follow the control motion. This program option may also be used to find the mean and oscillatory values for rotor thrust, H-force,etc. See Figures 32 through 34.

A. SIGN CONVENTIONS

1. Cartesian Coordinates

Many of the forces, displacements, velocities, accelerations, moments, rotational velocities, and rotational accelerations computed in this program are expressed in cartesian coordinates in one of the three reference systems defined below. In all cases the sense of the moments and rotations is found by applying the right hand rule to the coordinate axes.

a. Ground Reference

In this reference system, X is positive due north, Y is positive to the east, and Z is positive downward.

b. Fuselage Reference

This coordinate system is attached to the rotorcraft at the center of gravity. The positive X axis is pointed forward; the positive Y axis points to the pilot's right; and the positive Z axis is pointed toward the bottom of the rotorcraft.

c. Rotor Shaft Reference

(1) Z Direction

The Z axis in shaft reference lies along the axis of the shaft. Rotor thrust is always expressed in shaft reference as the component of rotor force along the Z axis. The positive direction for rotor thrust may be found in Table IV. The positive Z direction is in the opposite direction of rotor thrust. Rotor induced velocity is positive in the direction of the positive Z axis.

(2) Y Direction

The positive Y axis in shaft reference is in the direction of positive Y-force. See Table IV. The Y-axis is perpendicular to the plane of the fuselage reference X and Z axes for all rotor reference systems except one. For the tail rotor of a single rotor helicopter, the Y axis is perpendicular to the fuselage reference X-Y plane.

(3) X-Direction

The X axis is parallel to the fuselage reference X-Z plane. The positive X direction is opposite the positive direction for H-force indicated in Table IV.

Table IV.

ROTOR DESIGNATIONS AND FORCE SIGN CONVENTIONS

	Single Rotor Helicopter	Tandem Rotor Helicopter	Prop-Rotor Aircraft (Helicopter Mode)	Prop-Rotor Aircraft (Airplane Mode)
Rotor 1				
Designation	MAIN	FORWARD	RIGHT	RIGHT
Thrust	Up	Up	Up	Forward
H-Force	Aft	Aft	Aft	Up
Y-Force	Right	Right	Right	Right
Rotor 2				
Designation	TAIL	AFT	LEFT	LEFT
Thrust	Right	Up	Up	Forward
H-Force	Aft	Aft	Aft	Up
Y-Force	Down	Right	Right	Right

Note: Right and left indicate the pilot's right and left respectively.

2. Euler Angles

The Euler angles used here give the angular orientation of the fuselage coordinate system with respect to ground reference. They are a set of three ordered angles as follows:

- Psi is a right handed rotation about the ground reference Z axis.

- Theta is a right handed rotation about the Y axis which has been rotated through psi previously

- Phi is a right handed rotation about the X axis resulting from the two prior rotations.

3. Flapping Angles and Moments

The flapping angles are a_{1s} and b_{1s} in shaft reference. Without coning, the flapping angle may be found in terms of a_{1s} and b_{1s} from the following expression:

$$\text{Flapping} = -a_{1s} \cos\psi \quad -b_{1s} \sin\psi$$

Where ψ is the aximuth location. Zero ψ is due aft and positive rotation is counterclockwise when viewed from above. Flapping angle in general is positive upward so fore and aft flapping, a_{1s} , is positive when a blade at $\psi = 0$ is down, that is,it makes an angle of less than ninety degrees with the rotor shaft. Lateral flapping, b_{1s} , is positive when a blade at $\psi = 90$ degrees is down.

A positive fore and aft flapping moment is one which follows the right hand rule about a line at $\psi = 270°$. A positive lateral flapping moment is a right hand moment about a line at $\psi = 0°$.

4. Control Positions

a. Percent or Inches

(1) Collective Stick

Zero percent collective is full down. Positive stick motion in percent or inches is upward.

(2) Fore and Aft Cyclic Stick

Zero percent fore and aft is full aft. Positive stick motion in percent or inches is forward.

(3) Lateral Cyclic Stick

Zero percent lateral cyclic is full left. Positive stick motion in percent or inches is to the right.

(4) Pedals

Zero percent pedal is full right. Positive pedal motion in percent or inches is to the left. That is, positive pedal tends to make the rotorcraft yaw nose left.

b. Radians or Degrees

When control positions are expressed in radians or degrees, these values apply to the pitch angles measured on the rotor itself. A neutral stick position is calculated based on the range of the stick, the range of the control, and the specified limit on the control with the stick at zero percent.

5. Miscellaneous Quantities

a. Mast Tilt Angle

Positive mast tilt angle for all rotor configurations is a right hand rotation about the negative Y axis in shaft reference.

b. Climb Angle

The climb angle is the angle of the flight path relative to the X-Y plane in ground reference. It is positive if the rotorcraft is climbing.

c. Heading Angle

This angle is the direction of the flight path on the compass. Zero heading is due north, along the ground reference X axis. A heading of ninety degrees is due east.

d. Rotor Rotation

Rotor number one always rotates in a right hand sense about a positive thrust vector. Rotor number two always rotates in the opposite direction.

e. Fuselage Angles of Attack

The fuselage angles of attack are based on the fuselage reference velocities, and gust velocities.

$$\text{Pitch angle of attack} = \tan^{-1}\left(\frac{\text{Z velocity}}{\text{X velocity}}\right)$$

$$\text{Yaw angle of attack} = \tan^{-1}\left(\frac{\text{-Y velocity}}{\text{X velocity}}\right)$$

Sideslip angle is the negative of yaw angle of attack.

f. Gust Velocities

(1) Forward Component

The forward component of gust velocity is positive if the gust is moving in the positive X direction relative to the fuselage.

(2) Lateral Component

The lateral component of gust velocity is positive if the gust is moving in the positive Y direction relative to the fuselage.

(3) Vertical Component

The vertical component of gust velocity is positive if the gust is moving in the positive Z direction relative to the fuselage.

g. Acceleration Levels in Gs

(1) Forward

Forward acceleration is positive in the positive X direction in fuselage reference.

(2) Lateral

Positive lateral g level is to the pilots left, in the negative fuselage Y direction.

(3) Vertical

Positive vertical g level is upward, in the negative fuselage Z direction. For straight and level flight the vertical g level is one (1.00).

B. INPUT DATA FOR TRIM

1. Disposition of Output (Figure 17)

Message on lead card for name and location of program user is printed on lead page repeatedly.

2. Problem Identification

The value of the primary control variable, NPART, the problem identification number, IPSN, and the three cards of comments appear at the beginning of each problem. See Figure 18.

3. Input Data (Figure 18)

The fourteen basic groups of data are printed exactly as they are input.

4. Check Aerodynamic Inputs

Several of the input aerodynamic inputs are changed if they do not have a reasonable value. An error message is printed explaining the action taken. See Figure 18 following input data.

5. Non-Standard Trim Conditions

If the rotorcraft is to be trimmed in a coordinated turn, a pull-up, or a push-over, information is printed concerning these conditions (Figure 18).

C. TRIM ITERATION PAGE (Figure 19)

1. VAR (I)

This row gives the current value of the ten variables which are changed in order to trim the rotorcraft.

VAR(1) = Collective Stick Position in Percent

VAR(2) = Fore and Aft Cyclic Stick Position in Percent

VAR(3) = Lateral Cyclic Stick Position in Percent

VAR(4) = Pedal Position in Percent

VAR(5) = Fuselage Pitch Angle in Degrees

VAR(6) = Fuselage Roll or Yaw Angle in Degrees [choice of roll or yaw is made by user, XIT(15)]

VAR(7) = Main, forward, or Right Rotor Fore and Aft Flapping Angle in Degrees (a_{1s})

VAR(8) = Main Forward, or Right Rotor Lateral Flapping Angle in Degrees (b_{1s})

VAR(9) = Tail Aft, or Left Rotor Fore and Aft Flapping Angle in Degrees (a_{1s})

VAR(10)= Tail, Aft, or Left Rotor Lateral Flapping Angle in Degrees (b_{1s})

2. Rotor Performance

These two rows give the following quantities for the two rotors:

- Thrust in shaft reference (lb);
- H-force in shaft reference (lb);
- Y-force in shaft reference (lb);
- Torque in shaft reference (ft-lb);
- Average Induced Velocity (ft/sec);
- Coning Angle (deg);
- Also thrust provided by the jets if present.

3. Force and Moment Summary

This block of output shows the contribution of each element of the rotorcraft to the total forces and moments. The X-force, Y-force, Z-force, Roll Moment, Pitch Moment, and Yaw Moment are in fuselage reference with the forces in pounds and the moments in foot-pounds. The rotor flapping moments are in shaft reference with the units being foot-pounds. The columns of forces and moments are presented as labeled in the following order:

- Total caused by all elements
- Right Wing
- Left Wing
- Elevator (Horizontal Stabilizer)
- Fuselage
- Right or Center Jet
- Left Jet
- Main, Forward, or Right Rotor
- Tail, Aft, or Left Rotor
- Gun (Non-zero for a Maneuver only)
- Fin (Fin/Rudder)
- Weight/Main or Right Rotor Torque (QMR)

  The forces in this column are caused by the weight; the moments are caused by main, forward, or right rotor torque.

- Tail, aft, or left rotor torque (QTR).

4. Partial Derivative Matrix

This matrix gives the partial derivative of each force and moment with respect to each of the iteration variables. The units on the force derivatives are pounds per radian, and on the moment derivatives foot-pounds per radian. For the controls the angles are measured on the rotor. If input XIT(3) = 0 this matrix is computed and printed at every iteration, otherwise it appears every fifth iteration.

5. Corrections

The line labeled "CORRECTIONS" gives the computed changes in the iteration variables in radians. They are in the same order as the VAR(I) and the partial derivative rows If any of these computed corrections are greater than the maximum allowed by the inputs in the iteration limits group, the entire row is multiplied by a ratio which will make all corrections within the allowable range and this ratio is printed along with the number of the iteration variable which determined it. The corrections are then added to the iteration variables to determine the values for the next iteration. It should be noted again that the "CORRECTIONS" are in radians and not the same units as the VAR(I) printed.

D. FINAL TRIM PAGE (Figure 20)

1. Problem Identification

This is the same as mentioned in B. "INPUT DATA FOR TRIM."

2. Trim Condition

A one-line message is printed indicating whether or not the rotorcraft is in a stable condition.

3. Rotor Conditions

At the upper left of this page are the basic rotor performance quantities. Most of this information is clearly marked and self-explanatory. The collective pitch is determined at the root of the blade. The flapping angles, thrust, H-force, and Y-force are in shaft reference.

4. Jet Thrust

Below the rotor data are the values of jet thrust. Jet thrust may be varied with the collective stick during the trim procedure, so it is necessary to have the output on this page.

5. Percent Control Used

Below the jet data the control positions are given in percent. For the collective stick, zero percent is full down. For the fore-and-aft cyclic stick, zero percent is full aft. For the lateral cyclic stick, zero percent is full left. For the pedals, zero percent is full right.

6. Aerodynamic Surfaces

The angles of attack and force components in fuselage reference, for the wing, elevator and fin are printed in the upper right portion of the trim page.

7. Fuselage Data

Below the data on the aerodynamic surfaces is given the basic information on the aircraft flight condition and attitude. The order of the Euler angle rotations from fixed reference to fuselage reference is yaw, pitch, and roll.

8. Iteration Count and Time

At the bottom of the page the number of iterations required to trim the rotorcraft and the elapsed computing time are printed.

E. INPUT DATA FOR MANEUVER (Figure 21)

The program prints the contents of the time card and all maneuver control cards as they are input before the start of the actual maneuver. This serves as a record of what type of maneuver has been run as well as a quick way to check the input data.

F. TYPICAL MANEUVER PAGE (Figure 22)

1. Time

At the top of the page for each maneuver time point is printed the current time in the maneuver and the total time used by the computer to this point.

2. Rotor Variables

Most of the rotor data of interest are printed for each rotor separately. The main, forward, or right rotor data are printed first followed by the tail, aft, or left rotor data. These data are broken up into six major groups.

a. Tip Path Plane Location and Velocity

The fore and aft flapping velocity, Q, and position, A1; and the lateral flapping velocity, P, and position, B1, are printed at the upper left. The units are degrees per second and degrees. All four quantities are in shaft reference.

b. Hub Velocities

To the right of group (1) are U, V, and W, which are the X, Y, and Z velocity components, respectively, of the hub in shaft reference. The units are feet per second.

c. Conditions for Rotor Blade Number One

To the right of group (2) is printed information on the location, velocity, and acceleration of blade number one for the rotor concerned. The column headed "PSI" gives the rotational acceleration, velocity, and location; the column headed "BETA" gives the flapping acceleration, velocity, and location relative to the shaft. The units are consistent in degrees and seconds.

d. Rotor Forces

To the right of group (3) the forces generated by the rotor are printed. The instantaneous values of thrust, H-force, and Y-force in pounds are in shaft reference.

e. Control Positions

Below group (1) are given the collective, fore and aft cyclic, and lateral cyclic pitch settings in degrees on the rotor. The row labeled "CONTROLS" is determined by the stick positions. The row labeled "OTHER" is control contributions caused by the equations representing optional devices. For collective pitch the "OTHER" control control contributions may be caused by pitch-cone coupling, a prop-rotor collective governor, or the pitch A.S.E. (Automatic Stabilization Equipment). For fore and aft or lateral cyclic "OTHER" control contributions may be caused by the focused pylon effect or the operation of a flat tracker. The "TOTAL" row gives the algebraic sum of the preceding two rows for convenience.

f. Miscellaneous Data

To the right of group (5) are several variables of interest which cannot be classified as a group. The rotor coning angle in degrees includes built-in precone as well as elastic effects. "IND.V" indicates the average induced velocity from modified momentum theory in feet per second. "M.TILT" indicates mast tilt angle in degrees. For a main rotor, or prop-rotor, or the aft rotor on a tandem, configuration, zero mast tilt is vertical. For the tail rotor on the usual helicopter configuration, zero mast tilt is to the pilot's right, that is, in the positive Y direction. "RPM" indicates the instantaneous rotor speed in revolutions per minute. This value will remain constant unless the power available is exceeded. The value of torque given beside "TORQ" is the airload torque on this rotor in foot-pounds. The horsepower required to drive this rotor at this instant is indicated by "HP." The present position of the flapping stops is given under "FLAP.LIM" in degrees. The stops are set so that when one blade hits the upper limit, a blade 180 degrees around the azimuth will hit the lower limit at the same time. The current values of the flapping springs, which may vary with rotor speed, are given under "HUB SPRINGS" in foot-pounds per degree.

3. Ground Reference Variables

The position and velocity of the rotorcraft relative to the ground is given in several ways.

a. Cartesian Coordinates

The X, Y, and Z components of velocity and location are printed on the left of the page. The units are feet per second and feet respectively.

b. Position

The position of the craft is partially defined again by the distance flown and present altitude. The units of these quantities are feet.

c. Speed

The total airspeed and net ground speed are also given in knots.

d. Flight Path Angles

The flight path heading relative to due north is given in degrees. The climb angle relative to the ground plane is given in degrees.

4. Fuselage Reference Variables

The accelerations and velocities of the rotorcraft are given in this group along with the Euler angle locations and velocities.

a. Translational Velocities and Accelerations

In fuselage reference U, V, and W are the X, Y, and Z components of velocity. The fuselage referenced velocities and accelerations are printed under these headings to distinguish them from ground reference quantities. The units are consistent in feet and seconds.

b. Rotational Velocities and Accelerations

In fuselage reference P, Q, and R are the roll rate, pitch rate, and yaw rate, respectively. Under the P, Q, and R headings are printed the angular accelerations and the angular velocities in degree and second units.

c. Bobweight Acceleration and Velocity

The differential equation for the bobweight is written in terms of degrees of collective pitch on the main rotor. The acceleration and velocity printed under "BOBWT" are in these same units.

d. Euler Angles from Ground

The Euler angles given are those to get from ground reference to fuselage reference. The order of the rotations is first yaw, "PSI," (positive nose right), then pitch, "THETA" (positive nose up), and then roll, "PHI" (positive left side up, right side down). The Euler angle velocities are not the same as the corresponding angular rates R, Q, and P in general. The units are degrees per second and degrees.

5. Aerodynamic Surfaces and Miscellaneous

Below the fuselage reference variables are several groups of unrelated data.

a. Control Stick Positions

The stick positions in percent are printed to show the operation of any maneuver control inputs

b. Aerodynamic Surfaces

The angle of attack in degrees, "ATK," and the lift, "CL," and drag, "CD," coefficients are printed for each of the aerodynamic surfaces, (left wing, right wing, elevator, and fin/rudder). A positive angle of attack for a wing or elevator will produce a lift force which is upward. A positive angle of attack for the fin/rudder will produce a force to the right.

c. Fuselage Angles of Attack

The "ATKY" label indicates the yaw angle of attack of the fuselage in degrees. This is the negative of the sideslip angle. The "ATKP" label indicates the pitch angle of attack of the fuselage in degrees.

d. Center of Gravity Location

The stationline, buttline, and waterline location of the rotorcraft center of gravity is given in inches. These values may change as the rotors are tilted or folded.

e. Gust Velocities

The forward, lateral, and vertical components of gust velocity in fuselage reference at the center of gravity are printed in feet per second.

f. Acceleration Levels

The acceleration level felt by a sensor at the center of gravity is printed in gs. The three components of acceleration are given in fuselage reference.

6. Power and Related Data

a. Jet Thrust

The thrust due to each jet engine is given in pounds.

b. Engine Data

Engine torque supplied and shaft horsepower output are printed together. This power is either the power required or the maximum power available whichever is lower. The torque is found directly from this power value. The units on torque are foot-pounds.

c. Total Horsepower and Rotor Brake

The rotor brake torque is given in foot-pounds. This value is computed so that one blade of the rotor will stop at the position specified on the maneuver input. A negative value may be computed in the last instant before the rotor stops but not for more than one time point. The total horsepower required is obtained from the total torque due to the rotors and the rotor brake. A difference between this quantity and the engine shaft horsepower indicates that available power has been exceeded.

7. Force and Moment Summary

This block of output is as described in C. TRIM ITERATION PAGE.

8. Instantaneous Rotor Flapping

For each blade on each rotor the azimuth location, the local flapping acceleration, the local flapping velocity, and the local flapping angle are printed in tabular form. See Figure 22. The units are consistent in degrees and seconds.

G. TIME HISTORY PLOTS (Figure 23)

1. Problem Identification

This printout is as described in B. INPUT DATA FOR TRIM.

2. Variable Ranges and Scales

The lower and upper limits on the plot scale are given for each of the three variables which may be plotted by each plot card. The scale in units per inch is also given.

3. Variables Plotted

The plot symbols used are the numbers 1, 2, and 4. The variable corresponding to each symbol and its units are printed as part of the plot heading.

4. General Comments

The plot symbols 1, 2, and 4 are used so that every plot point can be identified. If more than one symbol falls on the same print position, the symbol printed is the sum of these. An explanation of the print symbols 3, 5, 6, and 7 is included as part of each plot heading.

A good deal of judgment is required to select the best plot ranges. If the selected range is too large, small variations of the plotted variable will be hidden. If the selected range is too small, many points may be lost off-scale, and overall trends may be hidden. The range may also be shifted to the high or low side so that no points at all are plotted in extreme cases. Any points which do not fall within the ten-inch range allowed on the plot page are not printed.

The maneuver time is printed along the side of the plot so that the full maneuver output may be easily located for any given plot point. If the time increment is changed during a maneuver, there will be an apparent change in the time scale at this point.

Each plot card is independent of all other plot cards. Thus, if desired, one variable may be plotted on more than one plot. One example which has proved useful is rotor azimuth position.

The solitary number following the plot is the elapsed time in the computer to make this plot.

H. OUTPUT OF STABILITY ANALYSIS ROUTINE

The operation of the stability analysis depends on the numerical evaluation of a number of partial derivatives. The partial derivatives appear in the equations of motion for the rotorcraft. A frequency analysis is made on the equations of motion with controls fixed and following impulse inputs to the controls. "S" is the Laplace operator as used here as well as in the computer output.

1. Control and Attitude Partial Derivatives (Figure 24)

A 7 by 6 matrix similar to the partial derivative matrix printed during the trim procedure is printed. The first four rows give the partial derivatives of the six forces and moments (X-FORCE, Y-FORCE, Z-FORCE, YAW MOM, PITCH MOM, and ROLL MOM), in fuselage reference, with respect to each of the four control motions. These quantities are in pounds per inch of control and foot-pounds per inch of control. The fifth and sixth rows printed are the partial derivatives of the six forces and moments with respect to pitch angle and roll angle respectively. These quantities are in pounds per radian and foot-pounds per radian. The bottom row, labeled " - ERROR," is printed because of a programming simplification and should be disregarded.

2. Velocity Partial Derivatives (Figure 25)

The next six pages of output contain detailed information used for the calculation of the partial derivatives with respect to the six fuselage velocity components. The partial derivatives are taken in the same order as the variables (VAR(I) which are listed below.

a. VAR(I)

In the stability analysis output the VAR(I) are the six fuselage reference velocity components in the following order:

VAR(1) = U, velocity in the X direction (feet per second)

VAR(2) = W, velocity in the Z direction (feet per second)

VAR(3) = Q, pitch rate (degrees per second)

VAR(4) = V, velocity in the Y direction (feet per second)

VAR(5) = P, roll rate (degrees per second)

VAR(6) = R, yaw rate (degrees per second)

b. Rotor Performance

These two rows are as described in part 2 under section C. TRIM ITERATION PAGE.

c. Force and Moment Summary

This block of output is as described in part 3 under section C. TRIM ITERATION PAGE. The forces and moments printed here are computed after the small increment in the pertinent velocity component has been made. The rotor flapping angles have also been adjusted so that the flapping moments are the same as before the velocity increment.

d. Delta/Force and Moment Summary

This block of output presents the changes in the force and moment contributions in exactly the same format as the full FORCE AND MOMENT SUMMARY. Any number in this 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. If the stability analysis is called during a maneuver, the forces and moments are recomputed based on the quasi-static rotor analysis. Thus the base values for the partial derivatives of the rotor forces will probably not be the same as those printed on the maneuver page. The maneuver printout contains instantaneous values whereas the stability analysis is based on mean values. Note that the rotor flapping moments remain unchanged from the previous FORCE AND MOMENT SUMMARY printout. This is because the rotor flapping moments are allowed to return to the input values by adjusting the flapping angles following the small velocity change.

e. Normalized Delta/Force and Moment Summary

This block of data presents basically the same information as the block above. However, the values are all normalized so that the total changes in the forces and moments are one hundred. Thus the quantities printed represent a percent of the total changes. Again the rotor flapping moments are not changed.

3. Stability Partial Derivative Matrices (Figure 26)

On this page is printed a summary of the partial derivatives computed from the data on the six previous pages. Each row gives the partial derivatives of some force, moment, or flapping angle as labeled, with respect to the linear and angular velocities, U, W, Q, V, P, and R. The units are consistent in feet, pounds, radians, and seconds.

4. Longitudinal Mode (Figure 27)

The longitudinal mode deals with forward velocity, U, fuselage angle of attack, ALPHA, and fuselage pitch angle, THETA, as dependent variables. The variables which act as forcing functions are the fore-and-aft cyclic stick and the collective stick.

a. Equations of Motion

The coefficients for the linearized differential equations of motion for the summation of X-forces, the summation of Z-forces, and the summation of pitching moments are printed in both dimensional and nondimensional form. The column headings indicate the dependent variable and the order of the derivative. In the Laplace operator notation used, S indicates the first derivative and S**2 indicates the second derivative. The columns headed "F/A Cyclic" and "COLLEC." indicate the effectiveness of the controls, and the signs used assume they are on the right-hand side of the equations. That is, the "=" sign should be placed between the "THETA" column and the "F/A CYCLIC" column.

b. Controls Fixed Analysis

The characteristic equations are expanded into polynominal form and factored to give complex roots, S = a + ib. The values of a and b are printed under "REAL" and "IMAG." respectively. Only the positive imaginary part of complex roots is printed.

The "PERIOD" and "FREQUENCY" are non-zero only for roots with a non-zero imaginary part because they have no meaning otherwise. These quantities are given in seconds and cycles per second respectively.

The column headed "T * HALF - DBL" depends only 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 mode shape for each of the roots is presented under "FWD.VEL/THETA" and "ALPHA/THETA." The output lists a relative magnitude, "MAGN" and a phase angle difference, "PHASE."

The column labeled "LEAD COEF." presents the coefficient of the highest power of S in the polynominal expansion of the characteristic equations.

c. <u>Frequency Response Roots</u>

The frequency response roots for the six combinations of dependent variable and independent variable are found. The roots may be listed in the following form:

S = REAL1 + i IMAG1

S = REAL2 + i IMAG2

S = REAL3 + i IMAG3

If one of the imaginary parts is non-zero, the complex conjugate root will be printed.

The value printed under "GAIN" is the constant term in the frequency response polynominal.

d. <u>Numerators for Transfer Functions</u>

The numerator for the Laplace transfer function is printed for each of the six combinations of dependent variable and independent variable. The static gain and three quadratic factors may be printed. If both the "TAU" and the "DAMP" coefficients are zero for one factor, then that factor may be omitted from the numerator. The numerator of the Laplace transfer function, N(S), may be obtained from the output as follows:

$$N(S) = (\text{STATIC GAIN}) * (\text{TAU}\ S^2 + \text{DAMP}\ S + 1) * (\text{TAU}\ S^2 + \text{DAMP}\ S + 1) * (\text{TAU}\ S^2 + \text{DAMP}\ S + 1)$$

e. Denominator to be used for the six transfer functions is derived from the roots of the characteristic equations with the controls fixed. It is printed in the same format as the numerators. The value under "STATIC GAIN" in this case should be disregarded. The denominator of the Laplace transfer function, D(S), may be obtained from the output as follows:

$$D(S) = (\text{TAU}\ S^2 + \text{DAMP}\ S + 1) * (\text{TAU}\ S^2 + \text{DAMP}\ S + 1) * (\text{TAU}\ S^2 + \text{DAMP}\ S + 1)$$

A complete transfer function is formed by $\frac{N(S)}{D(S)}$.

f. General Information

At the bottom of the page are several notes concerning the units used in the output for quick reference. The "NATURAL UNITS" referred to are either feet per second or radians.

The last line gives a value of T*, the nondimensionalizing factor for time. For the longitudinal mode, T* equals the mean aerodynamic chord divided by twice the total velocity.

5. Lateral Mode (Figure 28)

The lateral mode deals with sideslip angle, BETA, roll angle, PHI, and yaw rate, R, as dependent variables. The variables which act as forcing functions are lateral cyclic stick and the pedals.

Note that yaw angle and yaw rate are positive nose right while sideslip angle is positive nose left.

The output for the lateral mode is in a form identical to that of the longitudinal mode. Only the differences will be mentioned below.

a. Equations of Motion

The equations of motion for the lateral mode are for the summation of Y-forces, the summation of rolling moments, and the summation of yawing moments in that order.

b. Static Gain

The units on the static gains are radians per inch of stick or radians-per-second per inch of stick.

c. T*

For the lateral mode, T* is the wing span divided by twice the total velocity.

I. VECTOR ANALYSIS DATA

This program option gives a harmonic analysis of selected variables following the completion of a maneuver.

1. Problem Identification

This output is as described in B. INPUT DATA FOR TRIM.

2. Curve Fit Heading (Figure 29)

The maneuver time at which the curve fit starts is given. All time points prior to this time are disregarded by the curve fit procedure. The frequency used in the curve fit, OMEGA, is given in cycles per second. The curve fit function, F(T), is expressed in general form:

F(T) = AMPLITUDE * SIN(OMEGA * T + PHASE ANGLE) + CONSTANT

(where T is time as measured during the maneuver).

3. Variable, Amplitude, Phase Angle, and Constant (Figures 29 and 32)

Below the general equation are five columns as follows:

a. Variable

In this column the variable being curve fit is identified, and its units are given.

b. Amplitude

This number may be substituted into the general equation for AMPLITUDE. The units are those given under VARIABLE.

c. Phase Angle

This number may be substituted into the general equation for PHASE ANGLE. The units are degrees as labeled.

d. Constant

This quantity may also be substituted directly into the general equation. The units are those given under VARIABLE.

e. Coef of Corr

This denotes coefficient of correlation and is a measure of how well the variable considered is fit by a sinusoidal variation at the frequency selected. A number greater than 0.95 in this column indicates a reasonably good fit. A number smaller is generally caused by other frequency content or transient conditions.

4. Problem Identification

At the top of the following page the problem identification is repeated.

5. Amplitude and Phase Angle Comparisons (Figures 30 and 33)

A comparison of the magnitudes and phase angles between variable vectors may be made for selected pairs of variables. The variables compared are labeled as variable A/variable B. The variable identifications used are the same as those used on the previous page and for the plot headings. The amplitude ratio printed is AMPLITUDE A divided by AMPLITUDE B. The phase angle difference is PHASE ANGLE A minus PHASE ANGLE B.

6. Problem Identification

Following the amplitude and phase angle comparisons, the program skips to the top of the next page and again prints the problem identification heading.

7. Variable "A" as a Linear Combination of Variables "B" and "C" (Figures 31 and 34)

If all the selected variables are viewed as vectors rotating at the same rotational speed, OMEGA, any one variable may be expressed as a linear combination of two other variables and a constant as long as the phase angle between the two variables is not 0 or 180 degrees. This relationship is given generally in the heading as "A = KB * B + KC * C + KD."

Here A, B, and C are the variables concerned. The variable identification phrase is printed for each in the output. KB, KC, and KD are constants determined by the program and printed in the column labeled COEFFICIENT. In this row for variable B, the coefficient is KB; in the row for variable C the coefficient is KC; and in the unlabeled row, which has CONSTANT, the coefficient is KD.

8. Time Used

At the completion of the vector analysis routine the time used in the vector analysis process is printed along with the total elapsed computing time.

J. ROTOR AIRLOAD DATA

At maneuver time points specified in the airload times group, the airload distribution on the rotors is printed. The option to print airloads for either or both rotors is determined by the input value of NVARC on data card 01. A set of airload data is printed for each blade on the rotor or rotors selected. See Figure 35.

1. Variables Which Are Independent of Radius

a. "AZIMUTH"

The azimuth position of the blade in question is given in degrees.

b. "U-SHAFT"

The shaft reference X component of the rotor hub velocity is given in feet per second.

c. "V-SHAFT"

The shaft reference Y component of the rotor hub velocity is given in feet per second.

d. "W-SHAFT"

The shaft reference Z component of the rotor hub velocity is given in feet per second.

e. "XK"

This quantity is a function of rotor advance ratio. It determines the variation of the induced velocity over the rotor disk.

f. "SIN(BETA)"

This is the sine of the local flapping angle.

g. "COS(BETA)"

This is the cosine of the local flapping angle.

h. "BETA DOT"

The local flapping velocity is printed in degrees per second.

2. Variables Which Change with Radius

a. "RAD. STA."

This column lists the radial station as a fraction of the rotor radius for each aerodynamic segment of the blade.

b. "PHI"

The local inflow angle is printed in degrees. If the geometric incidence is zero, this is the angle of attack.

c. "ALPHA"

This column gives the local angle of attack for each blade segment.

d. "CL"

The local lift coefficients are printed.

e. "CD"

The local drag coefficients are printed.

f. "MACH"

The local Mach number is given for each blade station.

g. "LOCAL VI"

The local values of induced velocity are printed in feet per second.

h. "LOC. LAMBDA"

The symbol lambda is usually used to denote the inflow ratio on the rotor. Lambda, then, is the ratio of the inflow velocity to the rotor tip speed. For a stopped rotor lambda is undefined, so the output in this column is the inflow velocity in feet per second. Positive inflow velocity is in the opposite sense of positive induced velocity.

i. "UT"

In this column is printed the velocity component, in feet per second, which is perpendicular to the radius and parallel to the local zero pitch line of the blade.

j. "UP"

In this column is printed the velocity component, in feet per second, which is perpendicular to the radius and perpendicular to the local zero pitch line of the blade.

SECTION IV

DIAGNOSTIC AND ERROR MESSAGES

All of the messages which may be printed out from the computer program and which are considered to be error messages are listed below. The messages are in alphabetical order with the following words ignored: M.R., T.R., WING, ELE, FIN, COLLECTIVE STICK, F/A CYCLIC STICK, LAT CYCLIC STICK, PEDAL, MAIN, TAIL, WING, ELEVATOR, FIN/RUDDER.

Two or more words or phrases are enclosed in brackets, one above the other, indicates that it is possible to have either word or phrase, but only one, in the message when it is printed out. An underline in the message indicates a place for a numerical value in the message.

After each message is the name of the subroutine which printed it out. The next statement is about the condition which caused the message to be printed. Next is an indication of the consequences of the condition followed by instructions to the user.

1. ALLEVIATION DEVICE FOR ROTORS BYPASSED FOR $\left|\begin{matrix}\text{MAIN}\\ \text{TAIL}\end{matrix}\right|$ ROTOR BECAUSE ROTOR DIAMETER IS TOO SMALL FOR THIS TIME INCREMENT AND VELOCITY.

From WAG

The analysis in WAG assumes a minimum number of data points will be sampled in a distance traveled which is calculated from the rotor diameter. This message indicates that the ratio, $V\Delta t$/rotor diameter, is too large.

WAG is bypassed for $\left|\begin{matrix}\text{main}\\ \text{tail}\end{matrix}\right|$ rotor.

Make Δt, ZDELT1 or ZDELT2 on data card 201, smaller.

2. ALLEVIATION DEVICE FOR WINGS BYPASSED BECAUSE WING CHORD IS TOO SMALL FOR THIS TIME INCREMENT AND VELOCITY.

From WAG

The analysis contained in WAG assumes a minimum number of data points will be sampled in a distance traveled which is calculated from the wing chord. This message indicates that the ratio, $V\Delta t$/wing chord, is too large.

WAG is bypassed for wing.

Make Δt, ZDELT1 or ZDELT2 on data card 201, smaller.

3. A (_,_) = ________

From COMSOL

Matrix of complex coefficients of linear equations in the stability analysis is singular.

Program continues.

4. CHECK INPUT FUSELAGE INERTIAS. THE NUMBERS INPUT ARE PHYSICALLY IMPOSSIBLE AND CANNOT BE HANDLED BY THIS PROGRAM.

From MNEM

This message indicates that $I_X I_Z - I_{XZ}^2 = 0$.

Problem step terminates.

Change the input data for I_X, I_Z or I_{XZ}.

5. CHECK PART 2 DATA CARD____ J CODE IS ____

From IVAR

A value for J on data card 211 has been input for which an operation is not defined.

Problem step terminates.

Change the card indicated by the message.

6. {M.R. / T.R. / WING / ELE / FIN} CLZ FOR |NORMAL / REVERSED| FLOW HAS BEEN RESET TO

________ALB = 40 DEGREES.

From YFIX

CLZ is YXX |3 / 7| in the Aerodynamic Inputs of Section II. ALB is α_B in Figure 11. This message indicates that the stall angle for Mach number = 0 is too large (CLZ is too large) and thus has been reduced.

7. DATA ERROR .. NPART = ___________

From C81

The control program, C81 read an illegal value of NPART on data card 01. This error most commonly occurs after another error has interrupted the normal sequence of events by terminating the problem step.

Program execution terminates.

8. {M.R. / T.R. / WING / ELE / FIN} DRAG DIVERGENCE MACH NUMBER HAS BEEN RESET

TO _________.

From YFIX

YXX(1) was input greater than or equal to 1. This is a warning message.

9. EXCESSIVE ANGLE OF ATTACK FOR N = {1 / 2 / 3 / 4 / 5}

From CLCD

Subroutine CLCD was entered with the angle of attack of the

{main rotor / tail rotor / wing / elevator / fin/rudder} greater than 20 radians.

Problem step terminates.

10. FLAPPING ANGLES CANNOT BE ESTIMATED FOR A STOPPED ROTOR.

From MNEM

The input data are contradictory. XFC (22) = 0 and either XFC (25) = 0 or XMR (13) = 0 or both.

Problem step terminates.

Change the input data to either XFC(22) = 0 or XFC(25) = 0 and XMR(13) = 0.

11. FUNCTION VALUE IS ZERO FOR ALL VALUES OF X.

From ROOA.

The determinant of one of the characteristic coefficient matrices in the stability analysis is identically zero.

Program continues.

Check coefficients for realistic values.

12. INDUCED VELOCITY SET TO 0. CALCULATIONS NON CONVERGENT.

From VIND

The iterative loop which calculates induced velocity for a constant velocity and rotor thrust has not converged in 100 iterations.

Warning message only.

13. IPSN INDICATED NOT ON LIBRARY.

From C81L

In an operation with NPART = 8, NSCALE = 2 on Card 01, the IPSN input on card 02 does not match any IPSN on the file tape.

Problem step terminates.

Check input IPSN and list of IPSN's on the file tape.

14. $\left\{\begin{matrix}\text{M.R.}\\ \text{T.R.}\\ \text{WING}\\ \text{ELE}\\ \text{FIN}\end{matrix}\right\}$ MACH NUMBER FOR LOWER BOUND OF SUPERSONIC REGION

HAS BEEN RESET TO ________.

From YFIX

YXX(2) was input less than or equal to 1.

This is a warning message.

15. NEXT ROOT GREATER THAN _____ RADIANS INCOMPLETE FUNCTION, RESIDUE F(S) REMAINING.

From ROOA

One of the characteristic coefficient matrices in the stability analysis is ill-conditioned.

Program continues.

Check coefficients for realistic values.

16. NSCALE HAS ILLEGAL VALUE.

From C81L

On data card 01 with NPART = 8, NSCALE has a value for which no operation is defined.

Problem step terminates.

17. THE PARTIAL DERIVATIVE MATRIX IS SINGULAR. THIS IS PROBABLY CAUSED BY ONE OF THE CONTROLS BEING UNCONNECTED.

From ITRIM

During the TRIM procedure, a singular partial derivative matrix occurred. The usual cause is an error in the input data for one of the controls. Previous matrices, if any, should be examined for a near-zero row or column to help locate the cause.

Problem step terminates.

18. THE PHASE ANGLE DIFFERENCE BETWEEN _______ AND _______ IS A MULTIPLE OF 180 DEGREES. THEREFORE NO VARIABLE CAN BE EXPRESSED AS A LINEAR FUNCTION OF THEM.

From CURVET

The Vector analysis section of the program where the coefficients in the expression A = K B * B + KC * C + D are derived has failed because of the linear dependency of B and C.

Program goes to next set of variables.

19. {COLLECTIVE STICK / F/A CYCLIC STICK / LAT CYCLIC STICK / PEDAL} POSITION EXCEEDS STOPS __________

PERCENT FULL THROW COMPUTED.

From TRIM

The program found a stable flight condition, but one of the control positions necessary is outside the allowable range.

Change flight conditions, configuration, or allowable control settings.

20. POWER REQUIRED FOR TRIM CONDITION EXCEEDS POWER AVAILABLE.

From PARA

The power required to maintain constant rpm at the trim condition is greater than the engine is capable of producing.

Check for rotor stall, practicality of flight conditions, or increase engine power.

21. {MAIN / TAIL} ROTOR BALANCE EXCEEDS ALLOWABLE ERROR.

From ITROT

The iteration loop in the rotor analysis which balances the rotor flapping moments was activated but could not balance the rotor in the number of iterations allowed.

Problem step terminates.

Check configuration, flight regime, and spatial orientation for compatibility.

22. {MAIN / TAIL} ROTOR FLAP CORRECTION EXCEEDS 90 DEGREES

From ITROT

The iteration loop in the rotor analysis which balances the rotor flapping moments was activated and computed a correction to a flapping angle which exceeded 90 degrees.

Problem step terminates.

Check configuration, flight regime, and spatial orientation for compatibility.

23. SHIP CONTACTS GROUND

From VIND

Altitude has become negative.

Problem stop terminates.

Find out why ship lost altitude and correct.

24. SOLUTION EXCEEDS MAXIMUM NUMBER OF ROOTS INCOMPLETE FUNCTION, RESIDUE F(S) REMAINING.

From ROOA

One of the characteristic coefficient matrices in the stability analysis is ill-conditioned.

Program continues.

Check coefficients for realistic values.

25. { WING / ELEVATOR / FIN/RUDDER } STALLED AT ______ DEGREES.

CL = __________ CD = __________

From CLCD

This is a warning that the surface is stalling out.

26. WARNING, THE PARTIAL DERIVATIVE MATRIX MAY BE IN ERROR.

From ITROT

In the rotor analysis the iteration loop which balances the rotor flapping moments and the thrust-induced velocity iteration loop are both activated. While each is able to converge separately, they have not been able to converge together.

Warning message.

Exercise care in use of the partial derivative matrix following this message.

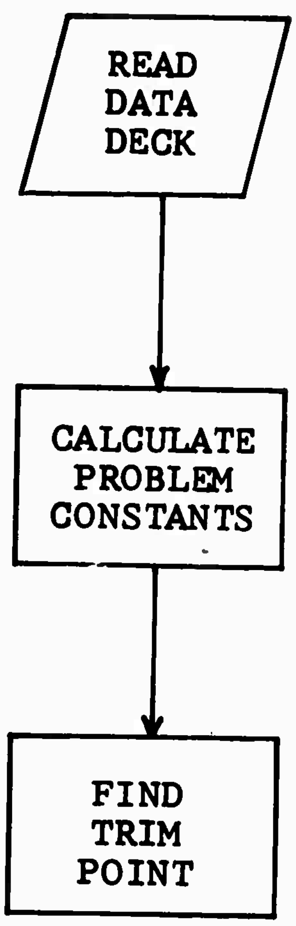


Figure 1. Trim Only

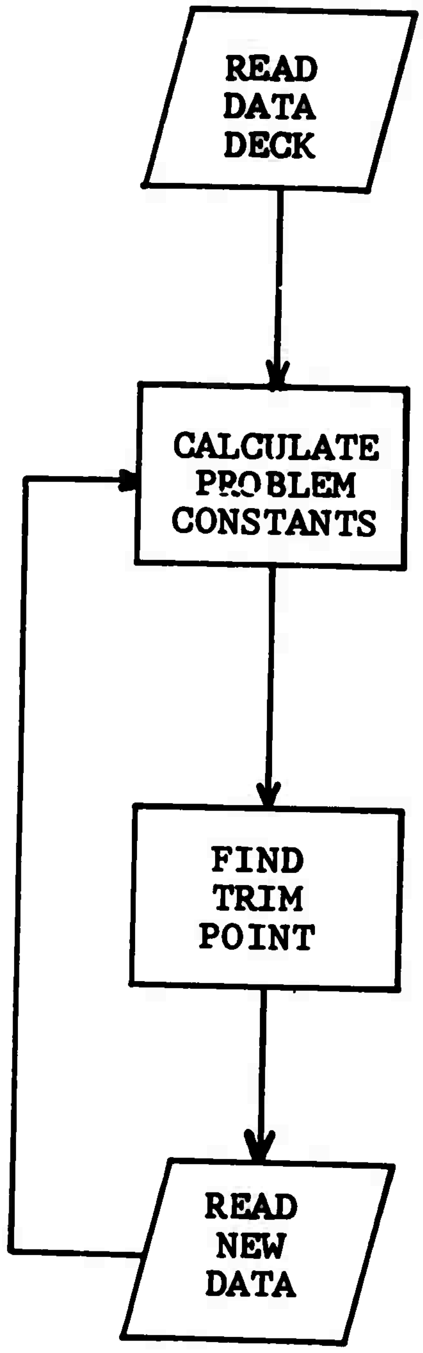


Figure 2. Parameter Sweep With Trim

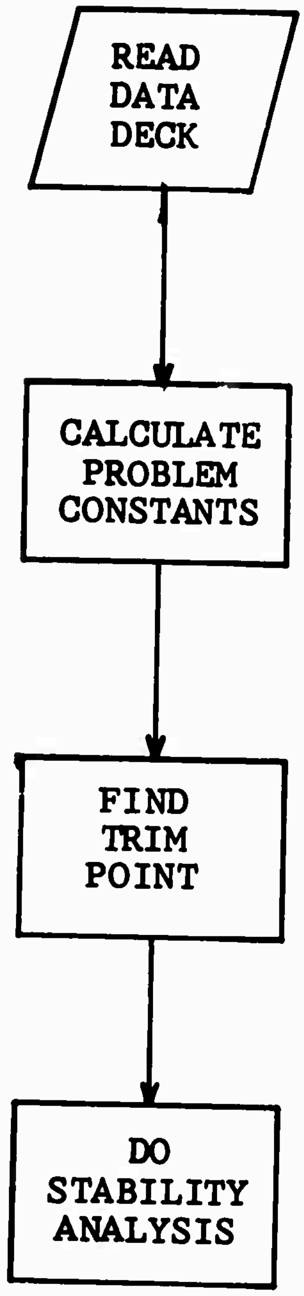


Figure 3. Stability Analysis

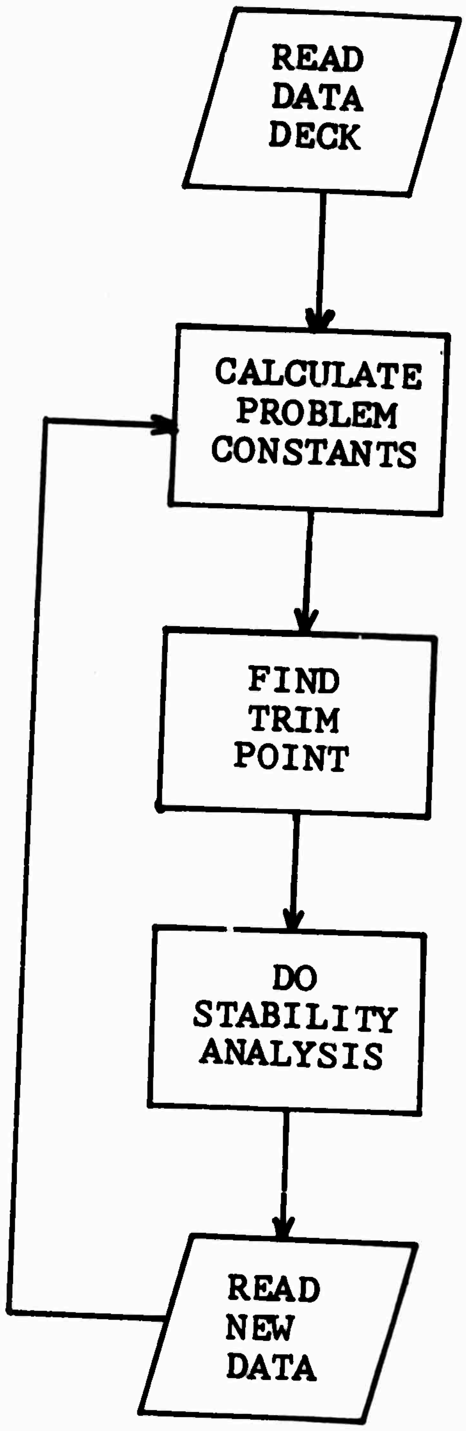


Figure 4. Parameter Sweep With Stability Analysis

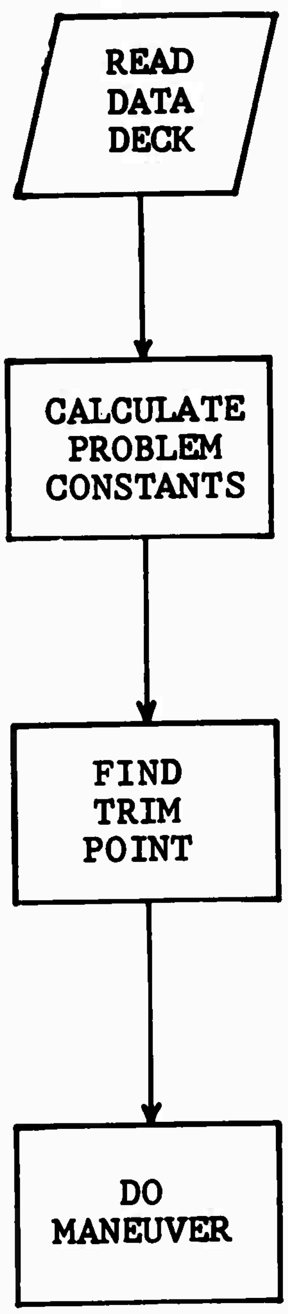


Figure 5. Maneuver

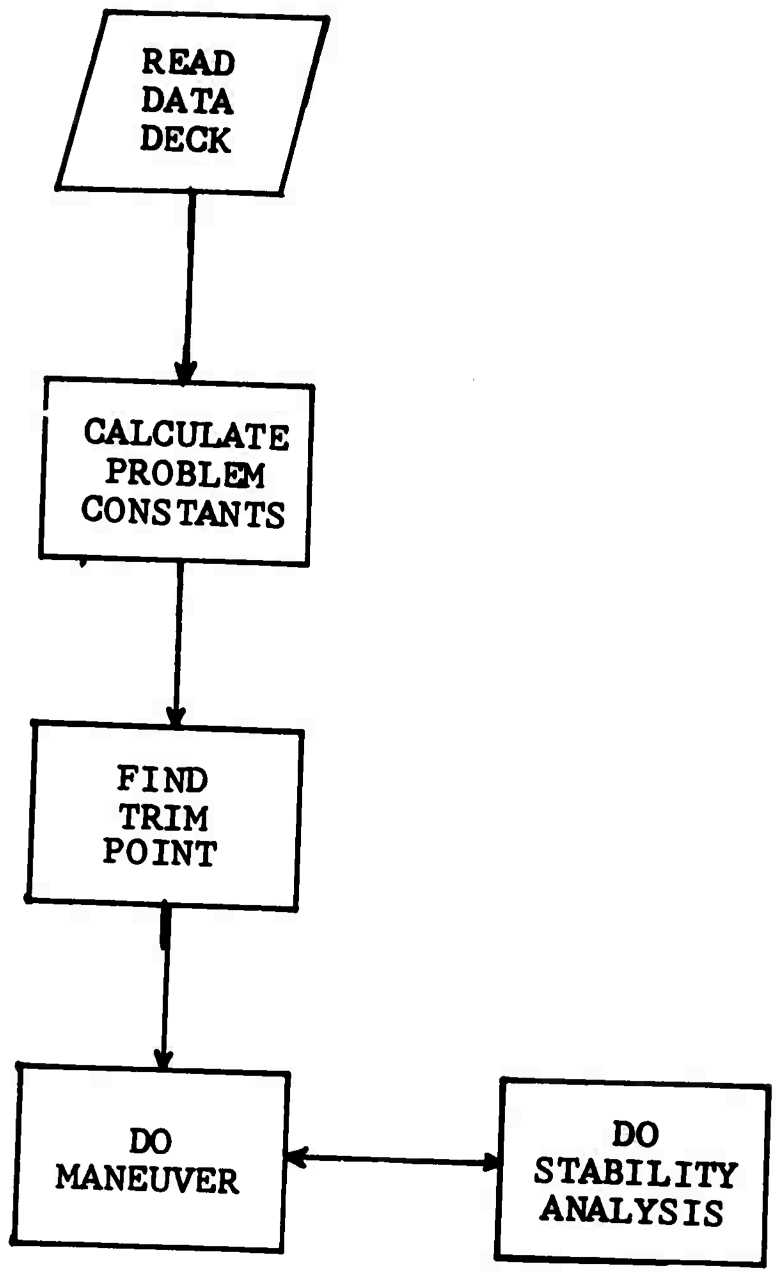


Figure 6. Maneuver With Stability Analysis

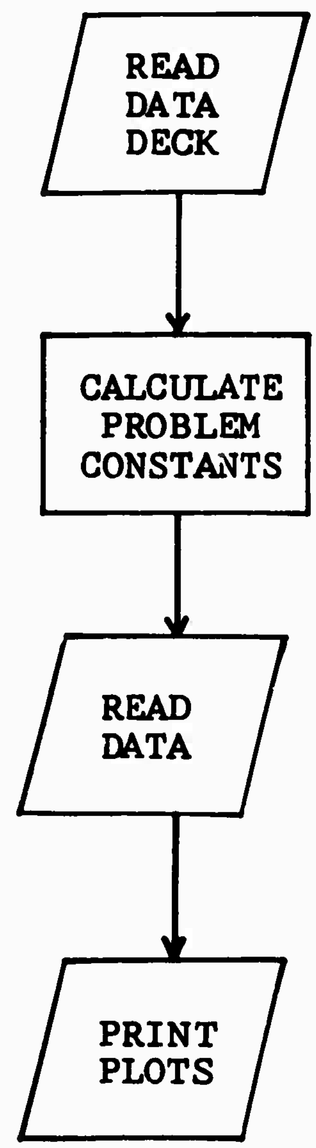


Figure 7. Printer Plots

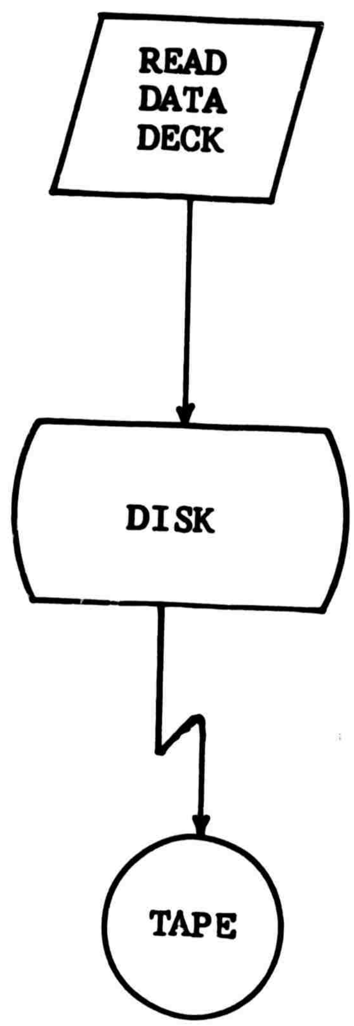


Figure 8. Storing Maneuver Data Permanently

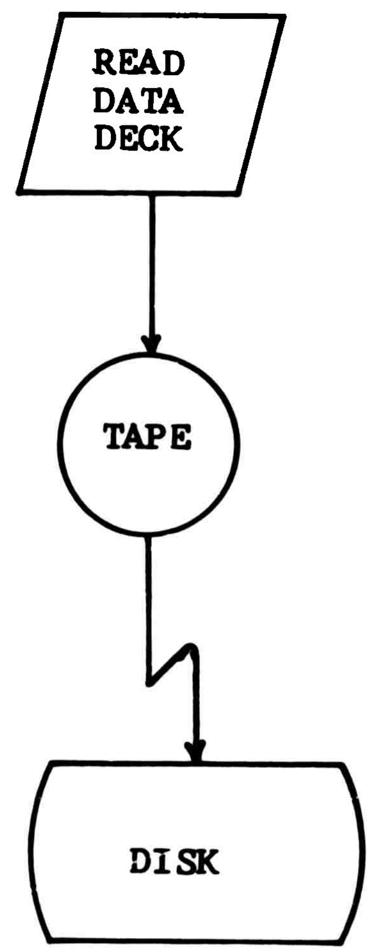


Figure 9. Retrieving Maneuver Data Stored Permanently

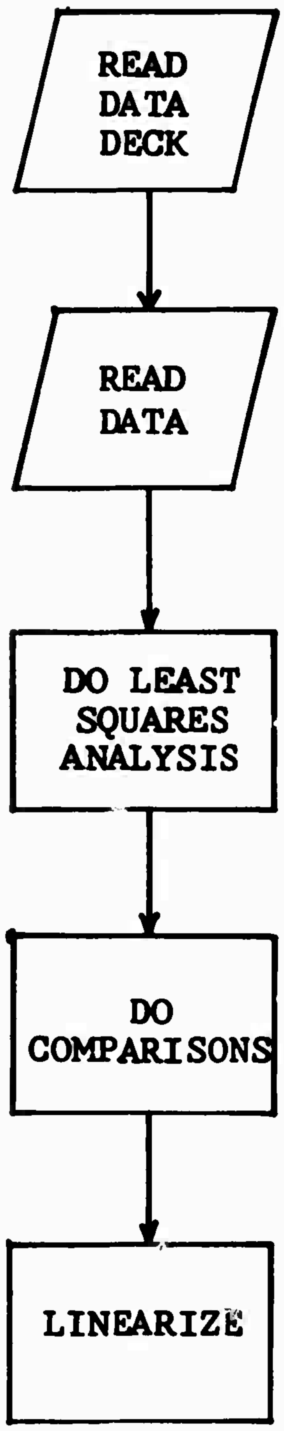


Figure 10. Vector Analysis and Data Reduction

7 10276900 SAMPLE DATA FOR SINGLE ROTOR HELICOPTER
OUTPUT FIGURES FOR FINAL REPORT
V= 120 KTS GW= 7900 CG= 192

INPUT DATA

			FUSELAGE GROUP			
7900.000	200.0000	0.0	54.00000	192.0000	0.0	75.96999
3573.100	11249.80	9933.598	-871.0000	0.0	0.0	0.0
-23.00000	2.000000	0.0	15.30000	0.0	-0.8699999	0.4250000
5.570000	0.9599996E-01	0.0	0.0	3.200000	2.639999	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			MAIN ROTOR GROUP			
2.000000	20.00000	12.00000	22.00000	27.00000	99999.00	24.00000
200.0000	0.0	152.6200	0.0	0.0	0.4910000E-01	0.0
0.6700000	0.0	0.0	0.0	0.0	0.0	2.000000
2.750000	-1.000000	0.0	0.0	-1.000000	0.0	0.0
10.00000	9.500000	9.000000	8.500000	8.000000	7.500000	7.000000
6.500000	6.000000	5.500000	5.000000	4.500000	4.000000	3.500000
3.000000	2.500000	2.000000	1.500000	1.000000	0.5000000	10.00000
3.237000	5.860000	6.040000	2.120000	0.9410000	0.7589999	0.6610000
0.6240000	0.5930000	0.5570000	0.5160000	0.6170000	1.115999	1.115999
0.6490000	0.5050000	0.5050000	0.5050000	1.660000	2.485999	0.0
0.8400000	1.270000	1.179999	0.2865196	-3.039829	1.746349	0.5300000
-0.1217860	0.2696422	-0.5178575	0.0	0.9000000E-02	0.0	0.1670000E-03
0.4000000E-01	0.3400000	0.1059999	10.60000	0.0	0.0	0.0
			TAIL ROTOR GROUP			
2.000000	20.00000	12.00000	4.250000	6.410000	99999.00	24.00000
520.7000	-14.85000	118.2700	0.0	0.0	0.2510000	0.0
1.061999	0.0	0.0	0.0	0.0	0.0	0.5000000
1.500000	0.0	30.00000	0.0	-1.000000	0.0	0.2000000
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.610000	1.476000	0.5940000	0.2200000	0.1490000	0.1220000	0.1070000
0.1030000	0.1100000	0.9799999E-01	0.9799999E-01	0.9799999E-01	0.9799999E-01	0.9799999E-01
0.5759999E-01	0.9799999E-01	0.9799999E-01	0.9799999E-01	0.9799999E-01	0.9799999E-01	0.7550000
0.8400000	1.270000	1.179999	0.2865196	-3.039829	1.746340	0.5300000
-0.1217860	0.2696422	-0.5178575	0.0	0.9399999E-02	0.0	0.1670000E-03
0.4000000E-01	0.3400000	0.1050000	5.160000	0.0	0.0	0.0
			WING GROUP			
27.75999	192.0000	39.00000	62.00000	14.00000	0.0	0.0
0.5000000	9.200000	2.419999	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5800000	1.099999	0.7200000	-0.1217860	0.2696422	-0.5178575	0.3500000
-0.1217860	0.2696422	-0.5178575	0.0	0.1600000E-01	0.0	0.1670000E-03
0.4000000E-01	0.5000000	0.6999999E-01	3.910000	0.0	0.0	0.0
			ELEVATOR GROUP			
14.70000	398.5000	0.0	56.00000	6.241300	0.0	0.0
1.500000	0.0	0.0	2.000000	0.0	0.0	0.0
0.7500000	1.099999	1.200000	0.2865196	-3.039829	1.746340	0.0
0.0	0.0	0.0	0.0	0.7999998E-02	0.0	0.3283999E-03
0.4000000E-01	0.2600000	0.8699989E-01	3.009998	0.0	0.0	0.0

Figure 11. Sample Data Set for Single Rotor Helicopter Case

			FIN/RUDDER GROUP			
18.59999	501.0000	C.0	84.00000	4.500000	0.4000000	0.2000000
0.7500000	1.099999	1.200000	0.2865196	-3.039829	1.746340	0.0
0.0	0.0	0.0	0.0	0.7999998E-02	0.0	0.1370000E-03
0.4000000E-01	0.2600000	0.9999996E-01	1.559999	0.0	0.0	0.0
			JFT GROUP			
0.0	0.0	0.0	75.50000	0.0	29.00000	0.0
90.00000	0.0	0.0	0.0	0.0	0.0	0.0
			BOMWEIGHT GROUP			
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			CONTROLS GROUP			
10.00000	8.625000	0.0	0.0	22.87500	15.00000	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.00000	-13.20000	27.00000	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.8273000	0.1339000
12.00000	-10.80000	17.79999	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.500000	-6.000000	25.50000	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			FLIGHT CONSTANTS GROUP			
120.0000	0.0	0.0	5000.000	0.0	-7.766000	-2.603999
30.00000	53.90900	52.42999	31.59200	1.250000	0.0	0.0
3.627999	1.480000	1.733000	0.3150000	8000.000	250.0000	0.0
2.000000	0.0	0.0	6600.000	100000.0	1117.000	1.000000
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			ALLOWABLE ERROR GROUP			
50.00000	50.00000	50.00000	50.00000	50.00000	50.00000	10.00000
			ITERATION GROUP			
40.00000	0.0	9.000000	0.5000000	1.000000	0.0	0.0
0.2000000	0.0	15000.00	3000.000	1.500000	0.2000000	3000.000
1.000000	0.0	0.0	0.0	0.0	0.0	0.0
			STAB TIMES GROUP			
99.00000	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			AIRLOAD TIMES GROUP			
0.5999996E-01	0.2000000	0.5000000	99.00000	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 11. Concluded

1 69103201 SAMPLE DATA FOR HORIZONTAL STOP AND FOLC HELICOPTER

WING AREA = 500.0 SQ. FT. WING CDO = 0.0005

CHECK DECK FUR HORRIZONTAL FOLD +RUDDER LINKED TO PEDAL

INPUT DATA

FUSELAGE GROUP

9500.000	200.0000	0.0	54.00000	192.0000	0.0	75.96999
3570.000	11250.00	9900.000	0.0	0.0	0.0	0.0
-23.00000	2.000000	0.0	15.30000	0.0	-0.8699999	0.4250000
5.570000	0.0	0.1670000E-02	0.0	3.200000	2.639999	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0

MAIN ROTOR GROUP

3.000000	20.00000	12.00000	22.00000	18.00000	12535.00	20.00000
200.0000	0.0	152.6200	0.0	0.0	0.4910000E-01	1.000000
0.6700000	0.0	1720.000	1720.000	0.0	0.0	7.000000
2.750000	0.0	0.0	0.0	9.349999	0.0	0.0
10.00000	9.500000	9.000000	8.500000	8.000000	7.500000	7.000000
6.500000	6.000000	5.500000	5.000000	4.500000	4.000000	3.500000
3.000000	2.500000	2.000000	1.500000	1.000000	0.5000000	10.00000
3.237000	5.860000	6.040000	2.120000	0.9410000	0.7589999	0.6610000
0.6240000	0.5930000	0.5570000	0.5160000	0.6170000	1.115999	1.115999
0.6490000	0.5050000	0.5050000	0.5050000	1.660000	2.485999	0.0
0.8000000	1.270000	1.299999	-0.7000000	0.0	0.0	0.7000000
-0.4000000	0.0	0.0	0.0	0.7999998E-02	0.0	0.0
0.4000000E-01	0.3400000	0.1070000	14.67000	0.0	0.0	0.0

TAIL ROTOR GROUP

2.000000	20.00000	12.00000	4.250000	8.410000	105.0000	20.00000
520.7000	-14.85000	118.2700	0.0	0.0	0.2510000	0.0
1.061999	0.0	0.0	0.0	0.0	0.0	0.5000000
1.500000	0.0	30.00000	0.0	9.349999	0.0	0.2000000
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.610000	1.476000	0.5940000	0.2200000	0.1490000	0.1220000	0.1070000
0.1030000	0.1100000	0.9799999E-01	0.9799999E-01	0.5799999E-01	0.9799999E-01	0.9799999E-01
0.5799999E-01	0.9799999E-01	0.5799999E-01	0.9799999E-01	0.5799999E-01	0.9799999E-01	0.7550000
0.7000000	1.270000	1.299999	-0.7000000	0.0	0.0	0.7000000
-0.4000000	0.0	0.0	0.0	0.9999998E-02	0.0	0.3000000E-04
0.4000000E-01	0.3400000	0.1070000	6.063999	0.0	0.0	0.0

WING GROUP

500.0000	192.0000	39.00000	62.00000	17.00000	0.0	0.0
0.5000000	9.200000	2.419999	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5899999	1.020000	1.200000	0.0	0.0	0.0	1.099999
0.0	0.0	0.0	0.0	0.4999998E-03	0.0	0.1667000E-03
0.0	0.2000000	0.6060000E-01	3.910000	0.0	0.0	0.0

ELEVATOR GROUP

14.70000	398.5000	0.0	56.00000	6.241300	0.0	0.0
1.500000	0.0	0.0	2.000000	0.0	0.0	0.0
0.5899999	1.009999	1.200000	0.0	0.0	0.0	1.200000
0.0	0.0	0.0	0.0	0.7999998E-02	0.0	0.3283999E-03
0.0	0.2000000	0.8699995E-01	3.009999	0.0	0.0	0.0

Figure 12. Sample Data Set for Horizontal Stop and Fold Helicopter Case

```
                                                  FIN/RUDDER GROUP
 18.59999        501.0000        0.0              84.00000        4.500000        0.4000000       0.2000000
0.5899999        1.009999        1.190000         0.0             0.0             0.0             1.200000
0.0              0.0             0.0              0.0             0.7999998E-02   0.0             0.1370000E-03
0.0              0.2000000       0.9999996E-01    1.559999        0.0             0.0             0.0

                                                       JET GROUP
 1.000000        1545.000        0.0              192.0000        0.0             75.96999        0.0
0.0              0.0             0.0              0.0             0.0             0.0             0.0

                                                  BOBWEIGHT GROUP
0.0              0.0             0.0              0.0             0.0             0.0             0.0
0.0              0.0             0.0              0.0             0.0             0.0             0.0
0.0              0.0             0.0              0.0             0.0             0.0             0.0

                                                   CONTROLS GROUP
 10.00000        0.0             0.0              0.0             40.00000        15.00000        0.0
0.0              0.0             0.0              0.0             0.0             0.0             0.0
 12.00000        -13.20000       27.00000         0.0             0.0             0.0             0.0
0.0              0.0             0.0              0.0             0.0             0.8273000       0.1339000
 12.00000        -10.80000       17.79999         0.0             0.0             0.0             0.0
0.0              0.0             0.0              0.0             0.0             0.0             0.0
 8.500000        -10.50000       30.00000         0.0             0.0             1.000000        0.0
0.0              0.0             0.0              0.0             0.0             0.0             0.0
0.0              0.0             0.0              0.0             0.0             0.0             0.0

                                           FLIGHT CONSTANTS GROUP
 140.0000        0.0             0.0              5000.000        0.0             -9.900000       -2.339999
 28.50000        53.09999        59.00000         35.00000        0.0             0.0             0.0
-0.7599958E-01   -0.2300000E-01  0.7530000        0.5120000       0.0             84.00000        0.0
 2.000000        0.0             0.0              6600.000        100000.0        1117.000        1.000000
0.0              0.0             0.0              0.0             0.0             0.0             0.0

                                            ALLOWABLE ERROR GROUP
 50.00000        50.00000        50.00000         50.00000        50.00000        50.00000        10.00000

                                                  ITERATION GROUP
 1.000000        0.0             9.000000         0.5000000       1.000000        0.0             0.0
0.2000000        0.0             0.0              0.0             1.500000        0.2000000       3000.000
 1.000000        0.0             0.0              0.0             0.0             0.0             0.0

                                                 STAB TIMES GROUP
0.0              2.500000        5.000000         7.500000        10.00000        12.50000        15.00000
 17.50000        20.00000        22.50000         25.00000        30.00000        35.00000        40.00000

                                               AIRLOAD TIMES GROUP
 59.00000        0.0             0.0              0.0             0.0             0.0             0.0
0.0              0.0             0.0              0.0             0.0             0.0             0.0
```

Figure 12. Concluded

1 69070902 SAMPLE DATA FOR TILTING PROP-ROTOR IN HELICOPTER MODE
ROTORS ON. FLAPS UP.AFT C.G..9000 LB GROSS WEIGHT
F/A STICK SHAKE AT 0.25 CPS VEL. = 140 KTS

INPUT DATA

FUSELAGE GROUP

9000.000	293.0000	0.0	84.00000	296.0000	0.0	80.00000
29500.00	9000.000	32900.00	-817.0000	0.0	0.0	0.0
-20.00000	10.00000	0.0	18.50000	0.0	0.0	1.250000
4.520000	-0.4000000E-01	0.6999999E-02	0.6999999E-02	0.0	1.549999	0.0
2696.000	296.3599	131.0000	10.25200	3.000000	0.0	0.0

MAIN ROTOR GROUP

3.000000	20.00000	12.00000	12.50000	14.00000	1000.000	70.00000
100.0000	193.0000	100.0000	10.00000	4.667000	1.000000	1.000000
0.0	0.0	133.3330	133.3330	0.0	2.000000	7.000000
3.000000	0.0	-15.00000	0.0	-1.000000	0.0	0.0
44.75000	43.50000	42.25000	41.00000	39.75000	38.50000	37.25000
36.00000	34.75000	33.50000	32.25000	31.00000	27.50000	24.00000
20.50000	17.00000	13.50000	10.00000	6.500000	3.000000	25.00000
3.209999	4.514999	1.400000	0.7750000	0.6500000	0.5800000	0.5000000
0.6350000	0.5599999	0.5300000	0.5100000	0.4850000	0.4600000	0.4349999
0.4119999	0.3900000	0.3649999	0.3400000	0.3000000	0.2700000	1.000000
0.8659999	1.270000	1.299999	-0.7000000	0.0	0.0	0.8000000
-0.3000000	0.0	0.0	0.0	0.7999998E-02	0.0	0.0
0.4000000E-01	0.2000000	0.0	0.0	0.0	0.0	0.0

TAIL ROTOR GROUP

3.000000	20.00000	12.00000	12.50000	14.00000	1000.000	20.00000
300.0000	-193.0000	100.0000	10.00000	4.667000	1.000000	1.000000
0.0	0.0	133.3330	133.3330	0.0	2.000000	2.000000
3.000000	0.0	-15.00000	0.0	-1.000000	0.0	0.0
44.75000	43.50000	42.25000	41.00000	39.75000	38.50000	37.25000
36.00000	34.75000	33.50000	32.25000	31.00000	27.50000	24.00000
20.50000	17.00000	13.50000	10.00000	6.500000	3.000000	25.00000
3.209999	4.514999	1.400000	0.7750000	0.6500000	0.5800000	0.5000000
0.6350000	0.5599999	0.5300000	0.5100000	[illegible]	0.4600000	0.4349999
0.4119999	0.3900000	0.3649999	0.3400000	0.3000000	0.2700000	1.000000
0.8699999	1.270000	1.299999	-0.7000000	0.0	0.0	0.8000000
-0.3000000	0.0	0.0	0.0	0.7999998E-02	0.0	0.0
0.4000000E-01	0.2000000	0.0	0.0	0.0	0.0	0.0

WING GROUP

176.0000	293.0000	97.20000	84.00000	11.00000	0.0	0.0
0.8000000	4.849999	2.419999	0.0	-0.4999999E-02	-0.1540000	0.2700000
-0.4500000	0.0	0.6999999E-02	-0.1600000E-01	-0.3200000	-0.6000000E-01	8.500000
0.8200000	1.000000	1.400000	0.0	0.0	0.0	1.700000
0.0	0.0	0.0	0.0	0.7349998E-02	0.0	0.0
0.0	0.8999997E-01	0.8849996E-01	6.629999	0.0	0.0	0.0

ELEVATOR GROUP

50.00000	547.0000	0.0	117.0000	5.500000	0.0	0.0
0.8000000	40.00000	80.00000	5.750000	0.0	0.0	0.0
0.8200000	1.000000	1.200000	0.0	0.0	0.0	1.200000
0.0	0.0	0.0	0.0	0.1082000E-01	0.0	0.0
0.0	0.2000000	0.9599996E-01	4.099999	0.0	0.0	0.0

Figure 13. Sample Data Set for Tilting Prop-Rotor In Helicopter Mode

			FIN/RUDDER GROUP			
57.84000	531.7000	0.0	127.8000	0.0	0.0	0.1939999
0.8200000	1.000000	1.000000	0.0	0.0	0.0	1.200000
0.0	0.0	0.0	0.0	0.8639999E-02	0.0	0.0
0.0	0.2000000	0.9649998E-01	[illegible]	0.0	0.0	0.0
			JET GROUP			
2.000000	800.0000	800.0000	300.0000	96.50000	76.00000	0.0
0.0	-6.599999	0.0	0.0	0.0	0.0	0.0
			BOBWEIGHT GROUP			
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.	0.0	0.0	0.0
			CONTROLS GROUP			
13.25000	34.92200	0.2130000	0.0	20.00000	37.00000	0.0
0.0	1.000000	0.0	0.0	0.0	0.0	0.0
12.00000	-9.000000	18.00000	0.0	0.0	0.0	0.0
0.0	0.0	1.000000	-0.2180000	0.2180000	0.0	0.8006999
12.00000	-6.000000	12.00000	2.000000	0.0	0.0	0.0
-0.5000000	0.5000000	0.0	0.0	1.000000	0.5750000	0.0
5.000000	-4.000000	8.000000	0.0	0.0	0.0	0.0
0.3750000	-0.3750000	1.250000	-1.250000	0.0	0.0	0.0
0.0	0.0	0.0	0.9360000	0.9999999E-04	9.599999	0.0
			FLIGHT CONSTANTS GROUP			
140.0000	0.0	0.0	20000.00	0.0	-5.775499	0.0
64.24022	75.00000	50.00000	50.00000	0.0	0.0	0.0
4.358809	1.145180	4.358809	-1.145180	3322.954	3372.954	0.0
2.000000	0.0	0.5000000	458.3999	20000.00	1117.000	1.000000
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			ALLOWABLE ERROR GROUP			
50.00000	50.00000	50.00000	50.00000	50.00000	50.00000	50.00000
			ITERATION GROUP			
40.00000	0.0	0.0	1.000000	1.000000	0.0	1.500000
0.5000000	0.5000000	750.0000	750.0000	1.500000	0.5000000	1000.000
1.000000	0.0	0.0	0.0	0.0	0.0	0.0
			STAB TIMES GROUP			
0.0	3.000000	6.000000	9.000000	11.50000	12.00000	15.00000
18.00000	20.00000	99.00000	0.0	0.0	0.0	0.0
			AIRLOAD TIMES GROUP			
59.00000	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 13. Concluded

1   69070902   SAMPLE DATA FOR TILTING PROP-ROTOR IN AIRPLANE MODE
FIRST ATTEMPT AT STOPPING AND FOLDING THE ROTORS
AUXILIARY THRUST = 500 LBS   V = 140 KNOT   100% RADIAL FLOW

INPUT DATA

FUSELAGE GROUP

9000.000	293.0000	0.0	84.00000	296.0000	0.0	80.00000
28500.00	9000.000	32800.00	-817.0000	0.0	0.0	0.0
-43.59999	18.29999	0.0	18.50000	0.0	0.0	1.250000
4.520000	-0.4000000E-01	0.6999999E-02	0.6999999E-02	0.0	1.549999	0.0
0.0	296.3599	131.0000	10.25200	3.000000	0.0	0.0

MAIN ROTOR GROUP

3.000000	20.00000	12.00000	12.50000	14.00000	1000.000	20.00000
300.0000	193.0000	100.0000	90.00000	4.667000	1.000000	1.000000
0.0	0.0	133.3330	133.3330	0.0	2.000000	2.000000
3.000000	0.0	-15.00000	0.0	1.426999	0.0	0.0
44.75000	43.50000	42.25000	41.00000	39.75000	38.50000	37.25000
36.00000	34.75000	33.50000	32.25000	31.00000	27.50000	24.00000
20.50000	17.00000	13.50000	10.00000	6.500000	3.000000	25.00000
3.209999	4.514999	1.400000	0.7750000	0.6500000	0.5800000	0.5000000
0.6350000	0.5599999	0.5300000	0.5100000	0.4850000	0.4600000	0.4349999
0.4119999	0.3900000	0.3649999	0.3400000	0.3000000	0.2700000	1.000000
0.8699999	1.270000	1.299999	-0.7000000	0.0	0.0	0.8000000
-0.3000000	0.0	0.0	0.0	0.7999998E-02	0.0	0.0
0.4000000E-01	0.2000000	0.0	0.0	0.0	0.0	0.0

TAIL ROTOR GROUP

3.000000	20.00000	12.00000	12.50000	14.00000	1000.000	20.00000
300.0000	-193.0000	100.0000	90.00000	4.667000	1.000000	1.000000
0.0	0.0	133.3330	133.3330	0.0	2.000000	7.000000
3.000000	0.0	-15.00000	0.0	1.426999	0.0	0.0
44.75000	43.50000	42.25000	41.00000	39.75000	38.50000	37.25000
36.00000	34.75000	33.50000	32.25000	31.00000	27.50000	24.00000
20.50000	17.00000	13.50000	10.00000	6.500000	3.000000	25.00000
3.209999	4.514999	1.400000	0.7750000	0.6500000	0.5800000	0.5000000
0.6350000	0.5599999	0.5300000	0.5100000	0.4850000	0.4600000	0.4349999
0.4119999	0.3900000	0.3649999	0.3400000	0.3000000	0.2700000	1.000000
0.8699999	1.270000	1.299999	-0.7000000	0.0	0.0	0.8000000
-0.3000000	0.0	0.0	0.0	0.7999998E-02	0.0	0.0
0.4000000E-01	0.2000000	0.0	0.0	0.0	0.0	0.0

WING GROUP

176.0000	293.0000	97.20000	84.00000	4.000000	0.0	0.0
0.8000000	4.849999	2.419999	0.0	-0.4999999E-02	-0.1540000	0.2700000
-0.4500000	0.0	0.6999999E-02	-0.1600000E-01	-0.3200000	-0.6000000E-01	8.500000
0.8200000	1.000000	1.400000	0.0	0.0	0.0	1.200000
0.0	0.0	0.0	0.0	0.7349998E-02	0.0	0.0
0.0	0.6999997E-01	0.6849996E-01	6.629999	0.0	0.0	0.0

ELEVATOR GROUP

50.00000	547.0000	0.0	117.0000	0.0	0.0	0.0
0.8000000	40.00000	80.00000	5.750000	0.0	0.0	0.0
0.8200000	1.000000	1.200000	0.0	0.0	0.0	1.200000
0.0	0.0	0.0	0.0	0.1082000E-01	0.0	0.0
0.0	0.2000000	0.9599996E-01	4.099999	0.0	0.0	0.0

Figure 14. Sample Data Set for Tilting Prop-Rotor In Airplane Mode

			FIN/RUDDER GROUP			
57.84000	5[illegible]1.7000	0.0	127.8000	0.0	0.0	0.1939999
0.8200000	1.000000	1.000000	0.0	0.0	0.0	1.200000
0.0	0.0	0.0	0.0	0.8639999E-02	0.0	0.0
0.0	0.2000000	0.9649998E-01	1.839999	0.0	0.0	0.0
			JET GROUP			
[illegible].000000	500.0000	500.0000	300.0000	96.50000	76.00000	0.0
0.0	-6.599999	0.0	0.0	0.0	0.0	0.0
			BOWWEIGHT GROUP			
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			CONTROLS GROUP			
200.0000	0.0	0.0	0.0	0.0	200.0000	0.0
0.0	0.0	0.0	0.0	0.0	10.00000	0.5000000E-01
12.00000	-9.000000	18.00000	0.0	0.0	0.0	0.0
0.0	0.0	0.0	-0.2180000	0.2180000	1.667000	0.0
12.00000	-6.000000	12.00000	1.000000	0.0	0.0	0.0
-0.5000000	0.5000000	0.0	0.0	0.0	0.5750000	0.0
5.000000	-5.000000	10.00000	0.0	0.0	1.000000	0.0
0.3750000	-0.3750000	1.250000	-1.250000	-0.2180000	0.2180000	0.0
0.0	0.0	0.0	0.9360000	0.0	0.0	0.0
			FLIGHT CONSTANTS GROUP			
140.0000	0.0	0.0	20000.00	0.0	6.638000	0.0
33.64400	48.06499	50.00000	50.00000	0.0	0.0	0.0
1.735000	0.7140000	1.735000	-0.7140000	8.099999	8.099999	0.0
2.000000	2.500000	0.5000000	458.3999	20000.00	1117.000	1.000000
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			ALLOWABLE ERROR GROUP			
50.00000	50.00000	50.00000	50.00000	50.00000	50.00000	50.00000
			ITERATION GROUP			
40.00000	0.0	9.000000	0.5000000	1.000000	0.0	1.500000
0.2000000	0.2000000	750.0000	750.0000	1.500000	0.2000000	3000.000
1.000000	0.0	0.0	0.0	0.0	0.0	0.0
			STAB TIMES GROUP			
1.000000	2.000000	3.000000	4.000000	5.000000	6.000000	7.000000
8.000000	9.000000	10.00000	99.00000	0.0	0.0	0.0
			AIRLOAD TIMES GROUP			
99.00000	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 14. Concluded

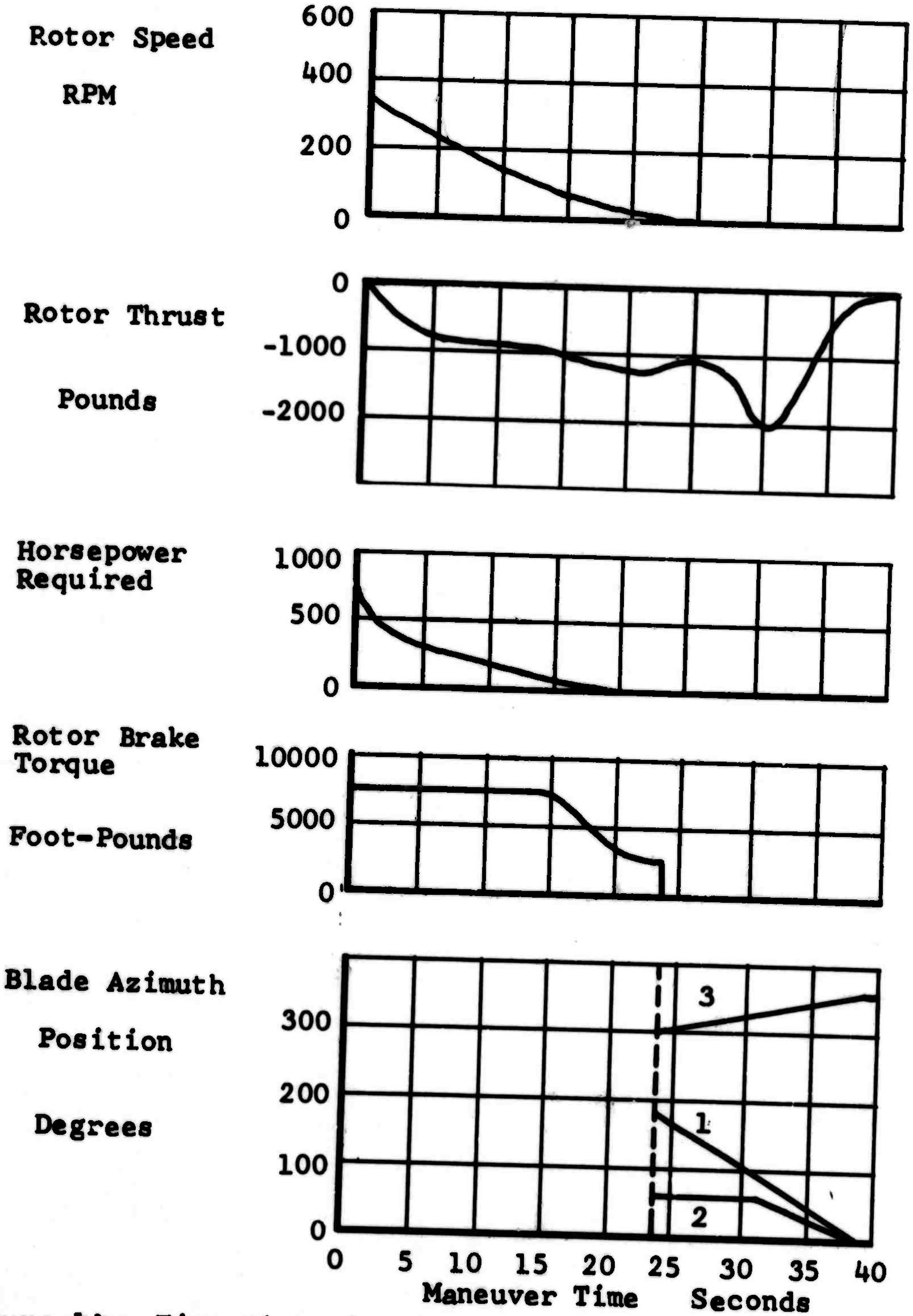


Figure 15. Time Histories for Horizontal Stop and Fold Case

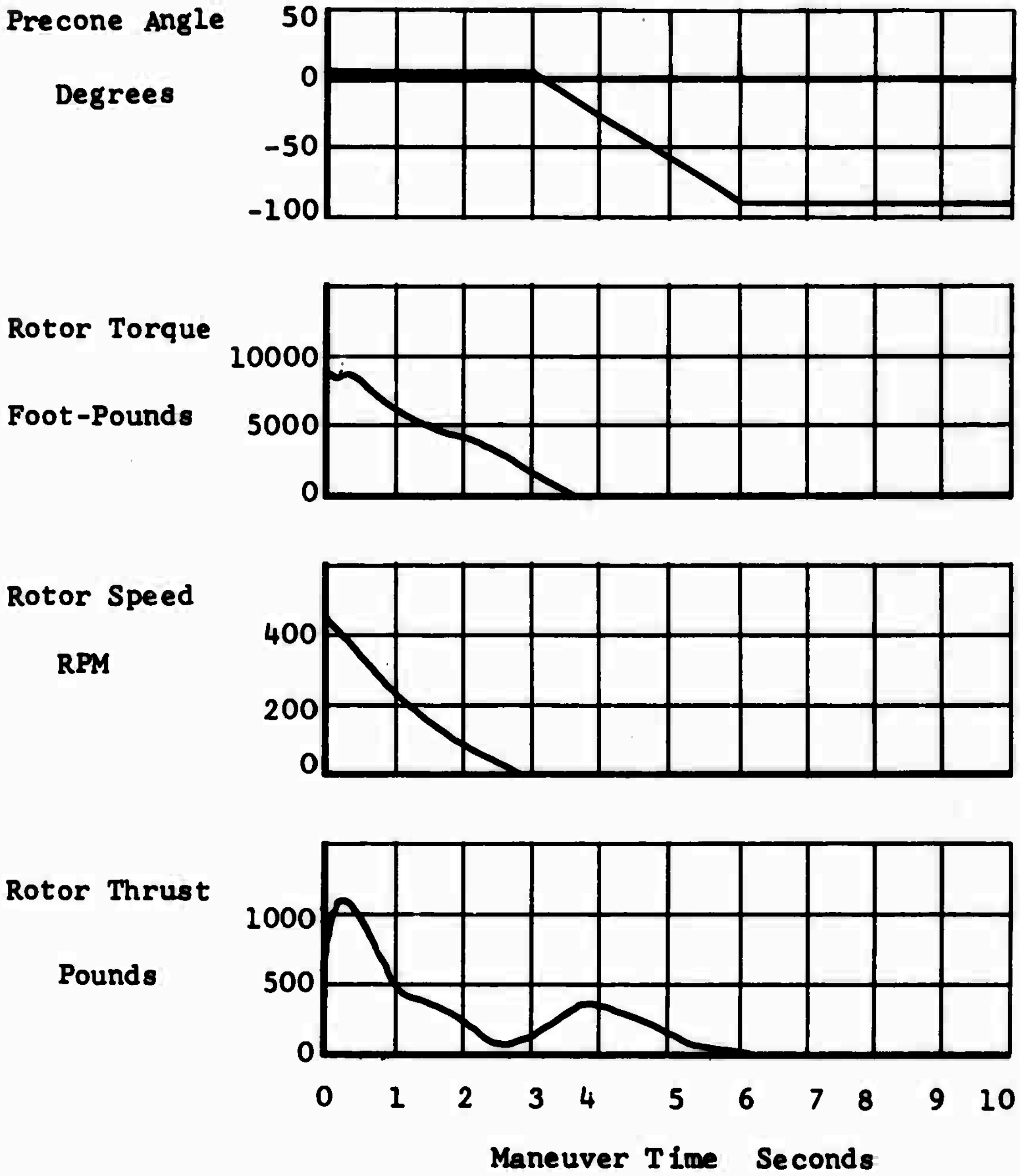


Figure 16. Time Histories for Tilt-Forward-Trail-Aft Case

```
RETURN THIS OUTPUT TO TYCE  AERONECHANICS  EXT.3280

RETURN THIS OUTPUT TO TYCE  AERONECHANICS  EXT.3280

RETURN THIS OUTPUT TO TYCE  AERONECHANICS  EXT.3280

RETURN THIS OUTPUT TO TYCE  AERONECHANICS  EXT.3280

RETURN THIS OUTPUT TO TYCE  AERONECHANICS  EXT.3280

RETURN THIS OUTPUT TO TYCE  AERONECHANICS  EXT.3280
```

Figure 17. Output Disposition Instructions

BELL HELICOPTER IBM 360/ PROGRAM ASAJ01
HELICOPTER RIGID BODY DYNAMICS ANALYSIS
COMPILED 10/30/69
COMPUTED 03/11/70

2 10276900

HUEY
OUTPUT FIGURES FOR FINAL REPORT
V= 140 KTS GW= 9500 CG= 200

INPUT DATA

FUSELAGE GROUP

9500.000	200.0000	0.0	54.00000	192.0000	0.0	75.96999
2539.800	11249.80	9933.598	0.0	0.0	0.0	0.0
-23.00000	2.000000	0.0	15.30000	0.0	-0.8699999	0.4250000
5.570000	0.0	0.1670000E-02	0.0	3.200000	2.639999	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0

MAIN ROTOR GROUP

3.000000	20.00000	12.00000	72.00000	18.00000	12535.00	-20.00000
200.0000	0.0	152.6200	0.0	0.0	0.4910000E-01	1.000000
0.6700000	0.0	1720.000	1720.000	0.0	0.0	2.000000
2.750000	0.0	0.0	0.0	9.349999	0.0	0.0
-10.00000	-9.500000	-9.000000	-8.500000	-8.000000	-7.500000	-7.000000
-6.500000	-6.000000	-5.500000	-5.000000	-4.500000	-4.000000	-3.500000
-3.000000	-2.500000	-2.000000	-1.500000	-1.000000	-0.5000000	-10.00000
3.237000	5.860000	6.040000	2.120000	0.9410000	0.7589999	0.6610000
0.6240000	0.5930000	0.5570000	0.5160000	0.6170000	1.115999	1.115999
0.6490000	0.5050000	0.5050000	0.5050000	1.660000	2.485999	0.0
0.8000000	1.270000	1.299999	-0.7000000	0.0	0.0	0.7000000
-0.4000000	0.0	0.0	0.0	0.7999998E-02	0.0	0.0
0.4000000E-01	0.3400000	0.1183000	19.00000	0.0	0.0	0.0

TAIL ROTOR GROUP

2.000000	20.00000	12.00000	4.250000	8.410000	105.0000	-20.00000
520.7000	-14.85000	118.2700	0.0	0.0	0.2510000	0.0
1.061999	0.0	0.0	0.0	0.0	0.0	0.5000000
1.500000	0.0	30.00000	0.0	9.349999	0.0	0.2000000
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.610000	1.476000	0.5943333	0.7200000	0.1490000	0.1220000	0.1070000
0.1030000	0.1100000	0.9799999E-01	0.9799999E-01	0.9799999E-01	0.9799999E-01	0.9799999E-01
0.9799999E-01	0.9799999E-01	0.9799999E-01	0.9799999E-01	0.9799999E-01	0.9799999E-01	0.7550000
0.7000000	1.270000	1.299999	-0.7000000	0.0	0.0	0.7000000
-0.4000000	0.0	0.0	0.0	0.9999998E-02	0.0	0.3000000E-34
0.4000000E-01	0.3400000	0.1335000	12.10000	0.0	0.0	0.0

WING GROUP

500.0000	192.0000	39.00000	62.00000	17.00000	0.0	0.0
0.5000000	9.200000	2.419999	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.9899999	1.020000	1.200000	0.0	0.0	0.0	1.099999
0.0	0.0	0.0	0.0	0.4999998E-03	0.0	0.1667000E-03
0.0	0.2000000	0.1070000	3.910000	0.0	0.0	0.0

ELEVATOR GROUP

14.70000	398.5000	0.0	56.00000	6.241300	0.0	0.0
1.570000	0.0	0.0	2.000000	0.0	0.0	0.0
0.9899999	1.009999	1.200000	0.0	0.0	0.0	1.200000
0.0	0.0	0.0	0.0	0.7999998E-02	0.0	0.3283999E-03
0.0	0.2000000	0.8699995E-01	3.009999	0.0	0.0	0.0

Figure 18. Input Data for Trim

			FIN/RUDDER GROUP			
10.59999	501.0000	0.0	84.00000	4.500000	0.4000000	0.2000000
0.9899999	1.009999	1.190000	0.0	0.0	0.0	1.200000
0.0	0.0	0.0	0.0	0.7999998E-02	0.0	0.1370000E-33
0.0	0.2000000	0.9999996E-01	1.559999	0.0	0.0	0.0
			JET GROUP			
1.000000	1545.000	0.0	192.0000	0.0	75.96999	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			BOBWEIGHT GROUP			
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			CONTROLS GROUP			
10.00000	0.0	0.0	0.0	40.00000	15.00000	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.00000	-13.20000	27.00000	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.8273000	0.1330000
12.00000	-10.80000	17.79999	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.500000	-6.000000	25.50000	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			FLIGHT CONSTANTS GROUP			
140.0000	0.0	0.0	5000.000	0.0	-9.900000	-2.330999
28.50000	53.09999	59.00000	28.20000	0.0	0.0	0.0
-0.7999998E-01	-0.2300000E-01	0.7530000	0.5120000	0.0	84.00000	0.0
2.000000	0.0	0.0	6600.000	100000.0	1117.000	1.000000
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			ALLOWABLE ERROR GROUP			
50.00000	50.00000	50.00000	50.00000	50.00000	50.00000	10.00000
			ITERATION GROUP			
40.00000	0.0	9.000000	0.5000000	1.000000	0.0	0.0
0.2000000	0.0	0.0	0.0	1.500000	0.2000000	3000.000
1.000000	0.0	0.0	0.0	0.0	0.0	0.0
			STAB TIMES GROUP			
0.0	99.00000	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
			AIRLOAD TIMES GROUP			
0.0	99.00000	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0

FIN CLZ FOR REVERSED FLOW HAS BEEN RESET TO 1.197 ALB = 40 DEGREES.

Figure 18. Concluded

***** START OF ITERATION 1 *****

VAR(I) 28.50000 53.09999 59.00330 28.20000 -9.90000 -2.34000 -0.04030 -0.02300 0.75300 0.51200

	THRUST	H-FORCE	Y-FORCE	TORQUE	IND. V.	CONING	JET THRUST	
MAIN ROTOR	-30.	405.	-15.	7227.	-0.014	0.421	RIGHT/CENTER	1945.
TAIL ROTOR	112.	36.	7.	169.	1.779	0.224	LEFT	0.

FORCE AND MOMENT SUMMARY

	TOTAL	R.WING	L.WING	ELE	FUS	R.JET	L.JET	M.R.	T.R.	GUN	FIN	W/OHR	OTR
X-FORCE	-1158.7	-1786.7	-1786.7	17.3	-318.1	1945.0	0.0	-405.1	-35.8	0.0	-21.8	1633.3	
Y-FORCE	25.7				136.7	0.0	0.0	-15.0	111.5	0.0	174.5	-382.1	
Z-FORCE	-4208.5	-7094.6	-7094.6	195.3	397.2	0.0	0.0	30.3	7.1	0.0		9350.7	
ROLL	95.9	-23057.4	23057.4	0.0	-250.3	0.0	0.0	-95.5	384.3	0.0	116.8	-59.3	0.3
PITCH	-1021.8	-2080.1	-2080.1	3390.2	-3157.6	0.0	0.0	2608.1	320.5	0.0	14.6	-206.4	160.9
YAW	-849.2	5806.9	-5806.9	-0.0	-493.6	-0.0	0.0	10.0	-3098.9	0.0	-4494.1	7227.4	-8.3
MR F/A MOM	-75.7												
MR LAT MOM	-129.5												
TR F/A MOM	-17.2												
TR LAT MOM	-13.0												

PARTIAL DERIVATIVE MATRIX

	X-FORCE	Y-FORCE	Z-FORCE	YAW MOM	PITCH MOM	ROLL MOM	MR F/A MOM	MR LAT MOM	TR F/A MOM	TR LAT MOM
COLLECTIVE	1273.	-1529.	-194481.	44891.	-111118.	-9745.	5933.	743214.	0.	0.
F/A CYCLIC	-168.	1392.	72726.	75900.	28474.	8633.	-1339.	-910007.	0.	0.
LAT CYCLIC	-957.	3344.	590.	-6335.	6504.	21362.	-730819.	-1272.	0.	0.
PEDAL	-766.	8691.	211.	-239004.	11747.	30373.	0.	0.	2003.	-11522.
PITCH	-32603.	927.	-119286.	1708.	-62517.	-696.	-991.	2261.	-199.	-3.
ROLL	120.	11486.	1065.	-349.	480.	-2346.	-2393.	-809.	-2.	-1.
MR F/A FLAP	1059.	891.	15741.	84696.	152243.	5434.	98585.	-693134.	0.	0.
MR LAT FLAP	740.	-2994.	-144.	-2583.	-4823.	128701.	661995.	90213.	0.	0.
TR F/A FLAP	-149.	-382.	32.	10287.	1222.	-1389.	0.	0.	7100.	13832.
TR LAT FLAP	-385.	2456.	136.	-67746.	7047.	8485.	0.	0.	11103.	-8322.
-ERROR	1159.	-26.	4208.	849.	1022.	-96.	79.	130.	17.	-13.

CORRECTIONS 0.0029966 0.0074530 -0.0009219 -0.3044720 -0.0355714 0.0021955 -0.0068695 0.0000507 -0.0031320 -0.0026925

RATIO APPLIED TO CORRECTION VECTOR IS 0.7359829 FROM COMPONENT 5

Figure 19. Trim Iteration Page

```
                              BELL HELICOPTER IBM 360/ PROGRAM ASAJ01
                              HELICOPTER RIGID BODY DYNAMICS ANALYSIS
                                         COMPILED  10/30/69
                                         COMPUTED  03/11/70

          2     10276900                          HUEY
                                     OUTPUT FIGURES FOR FINAL REPORT
                                  V= 140 KTS         GW= 9500         CG= 200

HELICOPTER IS IN STABLE CONDITION.

                                            MAIN       TAIL
     ROTOR COLLECTIVE PITCH   (DEGREES)    12.250     0.624     WING ANGLE OF ATTACK        (DEGREES)      5.185

           F/A CYCLIC PITCH   (DEGREES)     1.761     0.0            BODY Z-FORCE (+DOWN)      (LBS)  -10307.250

           LAT CYCLIC PITCH   (DEGREES)    -0.304     0.0            BODY X-FORCE (+FWD)       (LBS)   -2752.928

           F/A FLAPPING       (DEGREES)    -0.518     0.381     ELEVATOR ANGLE OF ATTACK    (DEGREES)     -5.447

           LAT FLAPPING       (DEGREES)     0.024     0.190          BODY Z-FORCE (+DOWN) (LBS)         260.497

           THRUST                (LBS)   -282.298    53.510          BODY X-FORCE (+FWD)  (LBS)          28.090

           H-FORCE               (LBS)    416.863    33.346     FIN ANGLE OF ATTACK         (DEGREES)      4.061

           Y-FORCE               (LBS)    -18.822     7.251          BODY Y-FORCE (+RIGHT)     (LBS)     174.903

           HORSEPOWER                     401.526    51.690          BODY R-FORCE (+FWD)       (LBS)     -21.685

           RPM                            324.060  1656.599     HELICOPTER EULER ANGLE YAW  (DEGREES)      0.0

           MAST TILT ANGLE    (DEGREES)     0.0       0.0                              PITCH(DEGREES)    -11.843

           BLADE INERTIA    (SLUG-FT-SQ)  1418.277    1.361                             ROLL (DEGREES)     -2.092

     JET THRUST, LEFT SIDE       (LBS)           0.0                     RATE OF CLIMB  (FT/SEC)           0.0

                 RIGHT SIDE      (LBS)        1545.000                   FORWARD SPEED  (KNOTS)          140.003

     PCT CONTROL USED  COLLECTIVE               30.625                   GROSS WEIGHT   (LBS)           9500.000

                       F/A CYCLIC               55.409                   ENGINE RPM                     6600.000

                       LAT CYCLIC               58.965                   C.G. STATION LINE  (IN)         192.000

                       PEDAL                    25.976                        WATER LINE    (IN)          75.970

  PART 1             6 ITERATIONS                       0.523    MINUTES ELAPSED COMPUTING TIME
```

Figure 20. Final Trim Page

WAGNER AND BUETTIKER FUNCTIONS INACTIVE

INPUT DATA FOR MANEUVER

START (SEC)	DELT1 (SEC)	MAX1 (SEC)	DELT2 (SEC)	MAX2 (SEC)	MAX3 (SEC)
0.0	0.005	10.000	0.005	0.0	0.0

J	XCIT(J,1)	(J,2)	(J,3)	(J,4)	(J,5)	(J,6)
20	0.0	0.500	2.000	10.000	2.000	0.0

Figure 21. Input Data for a Maneuver

```
1.000   SECONDS MANEUVER TIME          5.705   MINUTES ELAPSED COMPUTING TIME          LB.FT.DEG.SEC UNITS

                                          MAIN ROTOR SHAFT REFERENCE
               Q/R1      P/B1                                     PSI        BETR        FORCES
     VELOCITY  -4.871    1.549     U  227.240   ACCEL           33.170   1620.440      THRUST   -3242.877
     LOCATION  -1.237   -0.046     V   -1.489   VELOCITY      1944.890    -21.367      H-FORCE    414.521
                                   W  -61.932   LOCATION       144.574      1.769      Y-FORCE     -2.902
FROM       COLLEC F/R CYC LAT CYC
CONTROLS   12.250  1.830  -0.304   CONING   0.524   H.TILT     0.0   TORQ  -3544.76   FLAP. LIM.       HUB SPRINGS
OTHER       0.0    0.0     0.0     IND. V  -1.964   RPM    324.148   HP     -218.77   UPPER  25.500    F/A   1720.0
TOTAL      12.250  1.830  -0.304                                                      LOWER -20.000    LAT   1720.0

                                          TAIL ROTOR SHAFT REFERENCE
               Q/A1      P/B1                                     PSI        BETA        FORCES
     VELOCITY -49.342   69.548     U  226.527   ACCEL          169.566   2403.150      THRUST      35.391
     LOCATION  -0.200   -0.121     V  -67.362   VELOCITY      9942.305    -39.124      H-FORCE     34.046
                                   W   -1.655   LOCATION       220.705      1.427      V-FORCE     39.008
FROM       COLLEC F/A CYC LAT CYC
CONTROLS    0.624  0.0     0.0     CONING   0.262   H.TILT     0.0   TORQ    209.99   FLAP. LIM.       SPRINGS
OTHER       0.0    0.0     0.0     IND. V   0.949   RPM   1657.051   HP       [illegible]   UPPER  23.000    F/A      0.0
TOTAL       0.624  0.0     0.0                                                        LOWER -20.000    LAT      0.0

                                          GROUND REFERENCE
                      X          Y          Z                          SPEED (KTS)  FLT PATH ANGLES
     VELOCITY      233.648     1.419     16.620   DISTANCE    235.2   AIR  138.79  HEADING   0.348
     LOCATION      299.120     0.497  -4994.301   ALTITUDE   4994.3   GND  138.44  CLIMB    -4.069

                                          FUSELAGE REFERENCE
             U         V         W         P         Q         R       BODWT     EULER ANGLES FROM GROUND
ACCEL      -2.522    25.744   -13.960    -6.764    27.358   -35.766     0.0                PSI      THETA      PHI
VELOCITY  225.939    -1.483   -61.797    -0.688   -11.672    -6.032     0.0      VELOCITY  -6.264   -11.734    1.389
                                                                                 LOCATION   0.069   -19.361   -0.597

CONTROLS (PCT)
COLSTK       30.63        L. WING  R. WING    ELE    FIN/RUD  FUSELAGE         C.G. LOC (IN)      GUST (CG)    G-S
F/A CYCSTK   55.67  ATK    1.935    1.935   -8.722    4.019   ATKY    0.376    STA. LINE 192.00   FWD   0.0   FWD -0.02
LAT CYCSTK   58.96  CL     0.120    0.120   -0.426    0.147   ATKP  -15.297    B. LINE     0.00   LAT   0.0   LAT -0.05
PEDAL        25.98  CO     0.003    0.003    0.062    0.017                    W. LINE    75.97   VERT  0.0   VERT -0.05

                 JET THRUST              ENGINE
                 RIGHT/CENTER   1545.0   TORQUE      0.0   TOTAL HP ROD          -152.5
                 LEFT              0.0   SHAFT HP    0.0   ROTOR BRAKE TORQUE       0.0

                                          FORCE AND MOMENT SUMMARY

             TOTAL    R.WING    L.WING     ELE      FUS     R.JET   L.JET    M.R.     T.R.    GUN     FIN     W/OMR    OTR

X-FORCE     2926.6   -552.6    -552.6     53.1   -246.6   3545.0    0.0   -414.5    -34.0    0.0   -20.6   3149.5
Y-FORCE      359.1                                254.0     0.0     0.0     -2.9     35.4    0.0   165.5    -93.4
Z-FORCE     9475.2  -1872.0   -1872.0    408.7    566.4     0.0     0.0   3242.9     39.0    0.0            8962.3
ROLL        -416.7  -6084.1    6084.1      0.0   -465.9     0.0     0.0    -18.5     76.5    0.0   110.7   -119.5     0.0
PITCH       5303.5   -643.3    -643.3   7120.6  -3570.1     0.0     0.0   4009.6   1188.5    0.0    13.8  -3190.4   218.0
YAW        -6179.5   1796.0   -1796.0     -0.0    179.5    -0.0     0.0      1.9  -1011.5    0.0 -4261.1  -1088.3    -0.0
MR F/A MOM  1078.8
MR LAT MOM 22907.1
TR F/A MOM    30.0
TR LAT MOM    25.8
```

Figure 22. Typical Maneuver Page

MAIN ROTOR

	BLADE 1	BLADE 2	BLADE 3	BLADE 4	BLADE 5	BLADE 6	BLADE 7
AZIMUTH LOCATION	144.574	264.574	24.574	0.0	0.0	0.0	0.0
FLAPPING ACCEL WRT MAST	1620.440	-688.831	-931.608	0.0	0.0	0.0	0.0
FLAPPING VELOCITY WRT MAST	-21.367	44.520	-23.153	0.0	0.0	0.0	0.0
FLAPPING LOCATION WRT MAST	1.769	2.587	3.894	0.0	0.0	0.0	0.0

TAIL ROTOR

	BLADE 1	BLADE 2	BLADE 3	BLADE 4	BLADE 5	BLADE 6	BLADE 7
AZIMUTH LOCATION	220.705	40.705	0.0	0.0	0.0	0.0	0.0
FLAPPING ACCEL WRT MAST	2403.150	-2403.150	0.0	0.0	0.0	0.0	0.0
FLAPPING VELOCITY WRT MAST	-39.124	39.124	0.0	0.0	0.0	0.0	0.0
FLAPPING LOCATION WRT MAST	1.427	1.573	0.0	0.0	0.0	0.0	0.0

Figure 22. Concluded

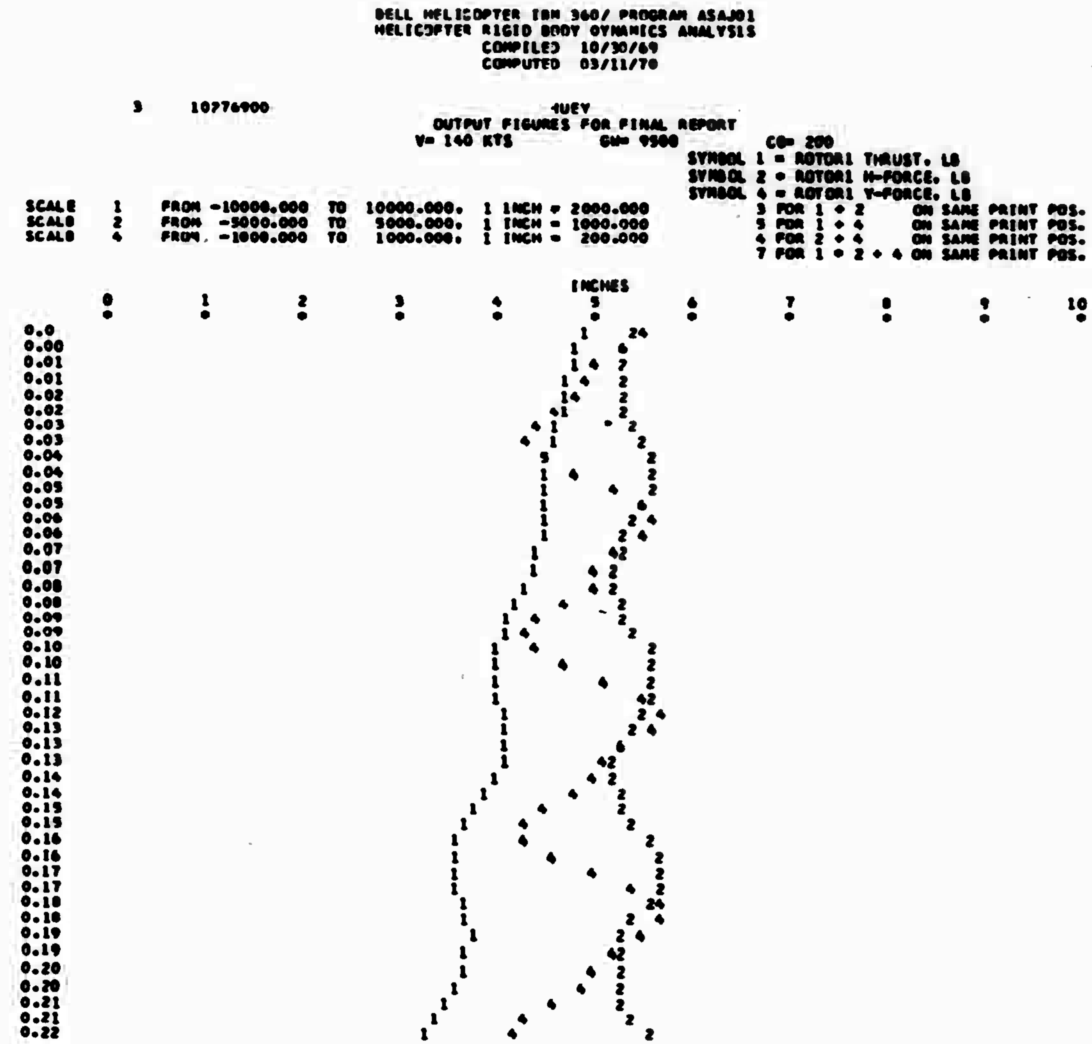


Figure 23. Computer Time History Plot

THE FIRST FOUR ROWS OF THIS MATRIX ARE LBS OR FT-LBS PER INCH OF CONTROL MOVEMENT

PARTIAL DERIVATIVE MATRIX

	X-FORCE	Y-FORCE	Z-FORCE	YAW MOM	PITCH MOM	ROLL MOM
COLLECTIVE	538.	2.	-7389.	9892.	4447.	1685.
F/A CYCLIC	-118.	-38.	1607.	-2181.	-6461.	2162.
LAT CYCLIC	6.	-4.	58.	462.	681.	4984.
PEDAL	-9.	398.	40.	-11190.	723.	3747.
PITCH	764.	14013.	6576.	-56025.	9593.	30451.
ROLL	-33308.	529.	-157328.	65821.	-55954.	27824.
-ERROR	-0.	1.	3.	3.	4.	7.

Figure 24. Control and Attitude Partial Derivatives for Stability Analysis

VAR(1) 236.26725 -48.46126 0.0 1.76998 0.0 0.0

	THRUST	H-FORCE	Y-FORCE	TORQUE	IND. V.	CONING	JET THRUST	
MAIN ROTOR	-226.	637.	-21.	6943.	-0.136	0.820	RIGHT/CENTER	1545.
TAIL ROTOR	54.	35.	7.	170.	0.875	0.209	LEFT	0.

FORCE AND MOMENT SUMMARY

	TOTAL	R.WING	L.WING	FLE	FUS	R.JET	L.JET	M.R.	T.R.	GUN	FIN	W/OMR	OTR
X-FORCE	-265.6	-1490.3	-1690.3	27.7	-313.1	1545.0	0.0	-436.6	-35.1	0.0	-22.7	1949.7	
Y-FORCE	14.0				137.2	0.0	0.0	-20.8	53.9	0.0	183.1	-339.4	
Z-FORCE	-980.5	-5620.1	-5620.1	261.5	673.2	0.0	0.0	225.9	7.4	0.0		9291.6	
ROLL	46.8	-18265.3	18265.3	0.0	-251.2	0.0	0.0	-132.7	180.7	0.0	122.5	127.4	0.0
PITCH	-177.5	-1734.9	-1734.9	4545.6	-3651.8	0.0	0.0	2939.7	327.6	0.0	15.2	-1254.2	170.6
YAW	195.0	4843.4	-4843.6	-3.0	-527.3	-0.0	0.0	13.8	-1519.1	0.0	-4715.3	6942.9	-0.5
MR F/A MOM	-16.9												
MR LAT MOM	-26.0												
TR F/A MOM	-7.1												
TR LAT MOM	0.6												

DELTA

FORCE AND MOMENT SUMMARY

	TOTAL	R.WING	L.WING	ELE	FUS	R.JET	L.JET	M.R.	T.R.	GUN	FIN	W/OMR	OTR
X-FORCE	-266.0	-113.8	-113.8	-0.6	-15.3	0.0	0.0	-20.1	-1.7	0.0	-1.0	-0.0	
Y-FORCE	15.0				7.3	0.0	0.0	-0.8	0.4	0.0	8.1	0.0	
Z-FORCE	-977.1	-464.5	-464.5	1.0	10.9	0.0	0.0	-56.4	0.2	0.0		0.0	
ROLL	54.2	-1516.0	1516.0	0.0	-13.4	0.0	0.0	-5.1	1.0	0.0	5.4	66.2	0.3
PITCH	-173.5	-132.5	-132.5	16.2	-116.8	0.0	0.0	90.8	12.6	0.0	0.7	81.5	6.6
YAW	197.7	349.9	-369.9	0.0	-14.1	0.0	0.0	0.5	-11.9	0.0	-209.5	432.6	-0.3
MR F/A MOM	-16.9												
MR LAT MOM	-26.0												
TR F/A MOM	-7.1												
TR LAT MOM	0.6												

NORMALIZED DELTA

FORCE AND MOMENT SUMMARY

	TOTAL	R.WING	L.WING	FLE	FUS	R.JET	L.JET	M.R.	T.R.	GUN	FIN	W/OMR	OTR
X-FORCE	100.0	42.8	42.8	0.1	5.8	0.0	0.0	7.6	0.6	0.0	0.4	0.0	
Y-FORCE	100.0				48.7	0.0	0.0	-5.3	2.4	0.0	54.2	0.0	
Z-FORCE	100.0	47.7	47.7	-0.1	-1.1	0.0	0.0	5.8	-0.0	0.0		0.0	
ROLL	100.0	-2799.0	2799.0	0.0	-24.7	0.0	0.0	-9.3	1.8	0.0	10.1	122.2	0.0
PITCH	100.0	76.4	76.4	-9.3	67.3	0.0	0.0	-52.4	-7.2	0.0	-0.4	-47.0	-3.8
YAW	100.0	107.1	-107.1	0.0	-7.1	0.0	0.0	0.3	-6.0	0.0	-106.0	218.9	-0.3
MR F/A MOM	-16.9												
MR LAT MOM	-26.0												
TR F/A MOM	-7.1												
TR LAT MOM	0.6												

Figure 25. Typical Velocity Partial Derivative Page For Stability Analysis

STABILITY PARTIAL DERIVATIVE MATRICES

	U	W	Q	V	P	R
X-FORCE	-53.20317	-89.52321	-303.2324	1.618554	-129.2969	-31.02539
Z-FORCE	-195.4297	-644.8608	-1996.016	-1.242969	-772.7344	40.78125
PITCH MOMENT	-34.69217	-249.7243	-23061.33	1.197983	2251.646	577.6270
Y-FORCE	3.001123	-0.2223633	-220.4443	-59.56978	402.6611	506.6895
ROLL MOMENT	10.93214	15.97816	-856.9001	26.07706	-17249.80	2570.390
YAW MOMENT	39.53281	236.6750	-15000.15	216.4062	-901.4058	-15780.46

MAIN ROTOR

	U	W	Q	V	P	R
THRUST	11.27058	195.8501	2098.018	1.858447	887.8390	-17.33390
H-FORCE	4.019581	-6.847071	342.3586	-0.1427852	156.2891	-3.154297
F/A FLAPPING	0.1102917E-03	0.1050416E-02	-0.1396950	0.2474496E-04	0.1202092E-01	0.1285374E-02
Y-FORCE.	-0.1583344	-0.1717529	-218.0951	-1.958212	556.9536	-0.367313
TORQUE	84.52579	235.1141	-16012.27	2.475000	-2566.172	123.4375
LAT FLAPPING	0.8953438E-04	0.1156811E-03	0.3645470E-02	-0.2120183E-04	-0.1390334	0.8544944E-02

TAIL ROTOR

	U	W	Q	V	P	R
THRUST	0.7202756E-01	-0.5667726E-01	-1.728821	-8.020807	-73.35999	339.9390
H-FORCE	0.3351594	-0.4115296E-01	-2.748718	-0.1949707	-2.125549	23.17963
F/A FLAPPING	0.0	0.0	0.0	-0.4915223E-03	-0.2475828E-01	-0.1073234E-01
Y-FORCE	0.4061088E-01	-0.1378082	-3.151665	-0.3298016E-01	-3.171177	6.601914
TORQUE	1.313599	-0.2373322	-10.69641	-0.5373200	-4.862061	96.79688
LAT FLAPPING	0.0	0.0	0.0	-0.3955555E-03	0.1431631E-01	-0.1472354E-01

Figure 26. Stability Partial Derivative Matrices

LONGITUDINAL MODE

DIMENSIONAL COEFFICIENTS OF CHARACTERISTIC EQUATIONS

U-S**2	U-S	U	ALPHA-S**2	ALPHA-S	ALPHA	THETA-S**2	THETA-S	THETA	F/A CYCLIC	COLLEC.
0.0	299.31	53.203	0.0	0.0	89.523	0.0	1.2033	39.322	-0.50017	2.2778
0.0	0.0	199.49	0.0	299.40	644.86	0.0	-204.86	-8.2511	6.7990	-31.272
0.0	0.0	34.692	0.0	1.4380	249.72	47.410	97.597	0.0	-27.344	18.819

NON-DIMENSIONAL COEFFICIENTS OF CHARACTERISTIC EQUATIONS

U-S**2	U-S	U	ALPHA-S**2	ALPHA-S	ALPHA	THETA-S**2	THETA-S	THETA	F/A CYCLIC	COLLEC.
0.0	87.053	0.37874	0.0	0.0	0.43729	0.0	0.30178	0.27992	-0.35605E-02	0.16215E-01
0.0	0.0	1.3912	0.0	87.881	4.5906	0.0	-85.339	-0.58737E-01	0.48400E-01	-0.22262
0.0	0.0	0.21839E-01	0.0	0.43091E-01	0.15720	52.344	2.5676	0.0	-0.17213E-01	0.11847E-01

CONTROLS FIXED

R O O T S					FWD.VEL/THETA		ALPHA/THETA		
REAL	IMAG.	PERIOD	FREQUENCY	T*HALF-DBL	MAGN.	PHASE	MAGN.	PHASE	LEAD COEF.
-0.53807E-01	0.15043	39.608	0.25247E-01	12.882	0.70828	111.01	0.17349	-68.212	0.41532R 07
-2.1494	2.2210	2.8289	0.35349	0.31951	0.14735	84.410	1.3147	45.940	0.41532E 07

FREQUENCY RESPONSE

DEPENT.VAR.	INDEP. VAR.	REAL1	IMAG1	REAL2	IMAG2	REAL3	IMAG3	GAIN
FWD. VEL.	F/A CYCLIC	-0.817404	0.0	8.98753	0.0	-15.0804	0.0	-0.400213
FWD. VEL.	COLLECTIVE	-1.61480	0.0	1.02214	0.0	-8.40749	0.0	1.82259
ANG. OF ATK.	F/A CYCLIC	-0.104593	-0.312704	-0.104593	0.312704	22.1666	0.0	0.230142E-01
ANG. OF ATK.	COLLECTIVE	-0.154253	-0.492554	-0.154253	0.492554	1.45999	0.0	-0.105063
PITCH ANGLE	F/A CYCLIC	-0.914613E-01	0.0	-2.47433	0.0	0.0	0.0	-0.575134
PITCH ANGLE	COLLECTIVE	-0.116353	0.0	-3.60522	0.0	0.0	0.0	0.398910

DEP. VAR.	INDEP. VAR.	TAU	DAMP	TAU	DAMP	TAU	DAMP	STATIC GAIN
FWD. VEL.	F/A CYCLIC	0.0	1.22330	0.0	-0.111245	0.0	0.463111E-01	143.923
FWD. VEL.	COLLECTIVE	0.0	0.610507	0.0	-0.548799	0.0	0.110939	-166.904
ANG. OF ATK.	F/A CYCLIC	9.16207	1.95322	0.0	0.0	0.0	-0.451129E-01	-0.205872
ANG. OF ATK.	COLLECTIVE	3.74498	1.17033	0.0	0.0	0.0	-0.602413	0.173484
PITCH ANGLE	F/A CYCLIC	0.0	10.9097	0.0	0.403824	0.0	0.0	-0.482430
PITCH ANGLE	COLLECTIVE	0.0	8.59453	0.0	0.277374	0.0	0.0	0.418647
D E N O M I N A T O R		35.4381	3.83518	0.103739	0.450114	0.0	0.0	0.270484

ALL ROOTS, FREQUENCIES, PERIODS, AND TIME TO HALF OR DOUBLE AMPLITUDE ARE IN REAL SECONDS
ALL MAGNITUDES AND PHASE ANGLES HAVE BEEN DETERMINED FROM ROOTS IN AIR SECONDS
GAINS ARE DETERMINED FROM ROOTS IN REAL SECONDS
ALL STATIC GAINS ARE IN NATURAL UNITS PER INCH OF STICK
T* = 0.23929E-01

Figure 27. Longitudinal Mode Results From Stability Analysis

LATERAL MODE

DIMENSIONAL COEFFICIENTS OF CHARACTERISTIC EQUATIONS

BETA-S**2	BETA-S	BETA	PHI-S**2	PHI-S	PHI	R-S**2	R-S	R	LAT CYCLIC	PEDAL
0.0	295.31	59.570	0.0	-2.3426	-99.327	0.0	0.0	292.82	-0.16338E-01	1.6861
0.0	0.0	-76.877	10.740	73.002	0.0	0.0	-0.0	-10.878	21.092	15.856
0.0	0.0	-216.41	-0.0	3.8148	0.0	0.0	42.040	66.784	1.9558	-47.356

NON-DIMENSIONAL COEFFICIENTS OF CHARACTERISTIC EQUATIONS

BETA-S**2	BETA-S	BETA	PHI-S**2	PHI-S	PHI	R-S**2	R-S	R	LAT CYCLIC	PEDAL
0.0	22.469	0.42406	0.0	-0.15542	-0.27992	0.0	0.0	22.280	-0.11630E-03	0.12003E-01
0.0	0.0	-0.43272E-02	0.19769	0.12562	0.0	0.0	0.0	-0.18719E-01	0.33958E-02	0.25528E-02
0.0	0.0	-0.34841E-01	0.0	0.85645E-02	0.0	0.0	0.77321	0.11492	0.31489E-03	-0.76243E-02

CONTROLS FIXED

ROOTS REAL	ROOTS IMAG.	PERIOD	FREQUENCY	T*HALF-DBL	SIDE SLIP/ROLL ANG. MAGN.	SIDE SLIP/ROLL ANG. PHASE	YAW ANG./ROLL ANG. MAGN.	YAW ANG./ROLL ANG. PHASE	LEAD COEF.
0.33191E-01	0.0	0.0	0.0	20.884	0.39981E-01	0.0	3.7675	0.0	0.13344E 06
-0.92349	2.1424	2.9328	0.34097	0.75049	3.7507	167.83	3.6660	-17.742	0.13344E 06
-6.7681	0.0	0.0	0.0	0.10241	0.27002E-01	180.01	0.13554E-01	0.0	0.13344E 06

FREQUENCY RESPONSE

DEPENT.VAR.	INDEP. VAR.	REAL1	IMAG1	REAL2	IMAG2	REAL3	IMAG3	GAIN
SDE.SLP.ANG.	LAT CYCLIC	-1.99302	0.0	6.35565	0.0	-401.268	0.0	-0.553241E-04
SDE.SLP.ANG.	PEDAL	-0.201251E-01	0.0	-7.01609	0.0	-198.759	0.0	0.570976E-02
ROLL ANGLE	LAT CYCLIC	-0.907120	-2.13255	-0.907120	2.13255	0.0	0.0	1.96228
ROLL ANGLE	PEDAL	-0.513588	-2.63327	-0.513588	2.63327	0.0	0.0	1.47515
YAW RATE	LAT CYCLIC	0.548641	-2.53213	0.548641	2.53213	-4.25733	0.0	0.465240E-01
YAW RATE	PEDAL	-0.530108	0.0	0.336784	0.0	-6.89293	0.0	-1.12646

DEP. VAR.	INDEP. VAR.	TAU	DAMP	TAU	DAMP	TAU	DAMP	STATIC GAIN
SDE.SLP.ANG.	LAT CYCLIC	0.0	0.501752	0.0	-0.157340	0.0	0.168319E-02	-0.344625
SDE.SLP.ANG.	PEDAL	0.0	49.8893	0.0	0.142530	0.0	0.503121E-02	-0.131060
ROLL ANGLE	LAT CYCLIC	0.188197	0.337807	0.0	0.0	0.0	0.0	-0.61950
ROLL ANGLE	PEDAL	0.138929	0.142705	0.0	0.0	0.0	0.0	-0.68435
YAW RATE	LAT CYCLIC	0.148971	-0.183464	0.0	0.0	0.0	0.234889	-1.00744
YAW RATE	PEDAL	0.0	1.88641	0.0	-2.96926	0.0	0.145076	-1.13370
D E N O M I N A T O R		0.0	-30.1287	0.183730	0.399387	0.0	0.147752	-1.22266

ALL ROOTS, FREQUENCIES, PERIODS, AND TIME TO HALF OR DOUBLE AMPLITUDE ARE IN REAL SECONDS
ALL MAGNITUDES AND PHASE ANGLES HAVE BEEN DETERMINED FROM ROOTS IN AIR SECONDS
GAINS ARE DETERMINED FROM ROOTS IN REAL SECONDS
ALL STATIC GAINS ARE IN NATURAL UNITS PER INCH OF STICK
T* = 0.93561E-01

1.349 MINUTES USED IN STAB   1.888 MINUTES TOTAL RUN TIME

Figure 28. Lateral Mode Results From Stability Analysis

BELL HELICOPTER IBM 360/ PROGRAM ASAJ01
HELICOPTER RIGID BODY DYNAMICS ANALYSIS
COMPILED 10/30/69
COMPUTED 03/11/70

11   10276900   HUEY
OUTPUT FIGURES FOR FINAL REPORT
V= 140 KTS   GW= 9500   CG= 200

LEAST SQUARES CURVE FIT STARTING AFTER 4.989 SECONDS MANEUVER TIME

FIT = AMPLITUDE*SIN(OMEGA*T + PHASE ANGLE) + CONSTANT   WITH OMEGA = 0.500 CPS

VARIABLE	AMPLITUDE	PHASE ANGLE (DEGREES)	CONSTANT	COEF OF CORR
Q VELOCITY, TPP1, DEG/SEC	12.835	158.01	0.46754	0.85955
P VELOCITY, TPP1, DEG/SEC	3.6727	3.9714	-0.10521	0.42097
ROTOR1 THRUST, LB	4512.0	132.66	-66.280	0.99830
F/A FLAPPING, MAST1/TPP1, DEG	2.8130	179.34	-0.99152	0.99923
LATERAL FLAPPING, MAST1/TPP1, DEG	0.24188	141.04	0.84479E-01	0.93274
ROTOR1 H-FORCE, LB	56.615	-122.13	501.34	0.23360
ROTOR1 Y-FORCE, LB	90.310	-28.391	-15.236	0.58328
ROTOR1 TORQUE, FT-LB	2978.9	77.676	7839.8	0.44575
Q VELOCITY, TPP2, DEG/SEC	8.9392	38.879	0.45523	0.10863
ROTOR2 THRUST, LB	103.29	-26.233	106.52	0.94579
F/A FLAPPING, MAST2/TPP2, DEG	0.90305E-03	-121.71	0.66301E-04	0.43045E-02
LATERAL FLAPPING, MAST2/TPP2, DEG	0.14002E-02	1.2000	-0.16411E-03	0.66694E-02
ROTOR2 H-FORCE, LB	5.4152	-6.7653	37.126	0.11247
ROTOR2 Y-FORCE, LB	4.3769	-68.035	7.8098	0.15366
P VELOCITY, TPP2, DEG/SEC	4.2135	-169.28	0.18098	0.57805E-01
ROTOR2 TORQUE, FT-LB	21.241	-7.4099	170.78	0.12266
Q-DOT ACCEL, BODY AXES, DEG/SEC/SEC	56.610	-139.51	-0.10736	0.98804
Q VELOCITY, BODY AXES, DEG/SEC	18.071	130.77	0.46337	0.99939
PITCH ANGLE, FIXED/BODY, DEG	5.7860	40.785	-12.070	0.98450
BODY PITCH WRT. FLIGHT PATH, DEG	4.1291	69.961	-11.614	0.99973

Figure 29. Harmonic Analysis Results for Low Frequency Case

BELL HELICOPTER IBM 360/ PROGRAM ASAJ01
HELICOPTER RIGID BODY DYNAMICS ANALYSIS
COMPILED 10/30/69
COMPUTED 03/11/70

I1 102T6900

HUEY
OUTPUT FIGURES FOR FINAL REPORT
V= 140 KTS GW= 9500. CG= 200

AMPLITUDE AND PHASE ANGLE COMPARISONS

VARIABLES		AMPLITUDE RATIO	PHASE ANGLE DIFFERENCE
Q VELOCITY, TPP1, DEG/SEC	/ BODY PITCH WRT. FLIGHT PATH, DEG	3.1884	80.054
ROTOR1 THRUST, LB	/ BODY PITCH WRT. FLIGHT PATH, DEG	1092.7	62.704
F/A FLAPPING, MAST1/TPP1, DEG	/ BODY PITCH WRT. FLIGHT PATH, DEG	0.68144	109.30
LATERAL FLAPPING, MAST1/TPP1, DEG	/ BODY PITCH WRT. FLIGHT PATH, DEG	0.58579E-01	71.875
ROTOR1 H-FORCE, LB	/ BODY PITCH WRT. FLIGHT PATH, DEG	13.711	-192.09
ROTOR1 Y-FORCE, LB	/ BODY PITCH WRT. FLIGHT PATH, DEG	21.071	-98.352
ROTOR1 TORQUE, FT-LB	/ BODY PITCH WRT. FLIGHT PATH, DEG	721.43	7.7140
W-DOT ACCEL, BODY AXES, DEG/SEC/SEC	/ BODY PITCH WRT. FLIGHT PATH, DEG	13.718	-209.48
PITCH ANGLE, FIXED/BODY, DEG	/ BODY PITCH WRT. FLIGHT PATH, DEG	1.4013	-29.176
Q VELOCITY, TPP1, DEG/SEC	/ Q VELOCITY, BODY AXES, DEG/SEC	0.71024	27.249
ROTOR1 THRUST, LB	/ Q VELOCITY, BODY AXES, DEG/SEC	249.60	1.0992
F/A FLAPPING, MAST1/TPP1, DEG	/ Q VELOCITY, BODY AXES, DEG/SEC	0.15570	48.571
LATERAL FLAPPING, MAST1/TPP1, DEG	/ Q VELOCITY, BODY AXES, DEG/SEC	0.13309E-01	10.266
ROTOR1 H-FORCE, LB	/ Q VELOCITY, BODY AXES, DEG/SEC	3.1320	-252.90
ROTOR1 Y-FORCE, LB	/ Q VELOCITY, BODY AXES, DEG/SEC	4.9974	-190.16
ROTOR1 TORQUE, FT-LB	/ Q VELOCITY, BODY AXES, DEG/SEC	164.84	-53.094

Figure 30. Amplitude and Phase Angle Comparison for Vector Analysis at Low Frequency

BELL HELICOPTER IBM 360/ PROGRAM ASAJ01
HELICOPTER RIGID BODY DYNAMICS ANALYSIS
COMPILED 10/30/69
COMPUTED 03/11/70

11 102T6900 HUEY
OUTPUT FIGURES FOR FINAL REPORT
V= 140 KTS GW= 9500 CG= 200

VARIABLE 'A' AS A LINEAR COMBINATION OF VARIABLES 'B' AND 'C'.

A = KB*B + KC*C + KD

VARIABLE	NAME	COEFFICIENT
A	F/A FLAPPING, MAST1/TPP1, DEG	
B	Q VELOCITY, BODY AXES, DEG/SEC	0.16825
C	BODY PITCH WRT. FLIGHT PATH, DEG	-0.58525
	CONSTANT	-7.4668
A	Q-DOT ACCEL, BODY AXES, DEG/SEC/SEC	
B	Q VELOCITY, BODY AXES, DEG/SEC	1.7636
C	BODY PITCH WRT. FLIGHT PATH, DEG	-15.704
	CONSTANT	-103.32
A	ROTOR1 H-FORCE, LB	
B	Q VELOCITY, BODY AXES, DEG/SEC	0.75192
C	BODY PITCH WRT. FLIGHT PATH, DEG	-15.012
	CONSTANT	326.64
A	ROTOR1 Y-FORCE, LB	
B	Q VELOCITY, BODY AXES, DEG/SEC	-5.6637
C	BODY PITCH WRT. FLIGHT PATH, DEG	0.9126
	CONSTANT	90.902

0.275 MINUTES USED IN CURVE FITTING 5.562 MINUTES TOTAL COMPUTING TIME

Figure 31. One Variable as a Function of Two Other Variables for Low Frequency Case

BELL HELICOPTER IBM 360/ PROGRAM ASAJ01
HELICOPTER RIGID BODY DYNAMICS ANALYSIS
COMPILED 10/30/69
COMPUTED 12/10/69

11 10276900 HUEY
OUTPUT FIGURES FOR FINAL REPORT
V= 120 KTS GW= 7900 CG= 192

LEAST SQUARES CURVE FIT STARTING AFTER 0.490 SECONDS MANEUVER TIME

F(T) = AMPLITUDE*SIN(OMEGA*T + PHASE ANGLE) + CONSTANT WITH OMEGA =10.800 CPS

VARIABLE	AMPLITUDE	PHASE ANGLE (DEGREES)	CONSTANT	COEF OF CORR
ROTOR1 THRUST, LB	863.64	153.46	8703.7	0.92978
ROTOR1 H-FORCE, LB	178.97	-140.74	727.25	0.98119
ROTOR1 V-FORCE, LB	141.86	147.45	-143.47	0.95786

Figure 32. Harmonic Analysis at Rotor Two Per Revolution Frequency

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                         BELL HELICOPTER IBM 360/ PROGRAM ASAJ01
                         HELICOPTER RIGID BODY DYNAMICS ANALYSIS
                                COMPILED  10/30/69
                                COMPUTED  12/10/69

  11     10276900                 HUEY
                    OUTPUT FIGURES FOR FINAL REPORT
                   V= 120 KTS          GW= 7900          CG= 192

                         AMPLITUDE AND PHASE ANGLE COMPARISONS
                   VARIABLES
                                                   AMPLITUDE RATIO   PHASE ANGLE DIFFERENCE
ROTOR1 H-FORCE, LB          / ROTOR1 THRUST, LB        0.20723            -294.20
ROTOR1 Y-FORCE, LB          / ROTOR1 THRUST, LB        0.16426            -6.0058
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Figure 33. Amplitude and Phase Angle Comparison for High Frequency Vector Analysis

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                      BELL HELICOPTER IBM 360/ PROGRAM ASAJ01
                      HELICOPTER RIGID BODY DYNAMICS ANALYSIS
                              COMPILED  10/30/69
                              COMPUTED  12/10/69

 11    10276900                   HUEY
                  OUTPUT FIGURES FOR FINAL REPORT
                V= 120 KTS        GW= 7900        CG= 192

           VARIABLE 'A' AS A LINEAR COMBINATION OF VARIABLES 'B' AND 'C'.

                             A = KB*B + KC*C + KD

   VARIABLE                      NAME                           COEFFICIENT

      A          ROTOR1 THRUST, LB
      B          ROTOR1 H-FORCE, LB                                0.93146
      C          ROTOR1 Y-FORCE, LB                                5.8490
                                          CONSTANT                 9195.8
0.016  MINUTES USED IN CURVE FITTING    1.003  MINUTES TOTAL COMPUTING TIME
```

Figure 34. Rotor Thrust as a Function of H-Force and Y-Force Determined by Vector Analysis

AZIMUTH	U-SHAFT	V-SHAFT	W-SHAFT	XK	SIN(BETA)	COS(BETA)	BETA DOT
119.99995	231.26228	1.76998	-48.46129	0.89554	0.00943	0.99996	-5.68759

RAD.STA.	PHI	ALPHA	CL	CD	MACH	LOCAL VI	LOC. LAMBDA	UT	UP
RADIAL FLOW	GAMMA	PHI	CL	CD	MACH	UR	UPR	UPT	
1.00000	-2.47643	-1.90324	-0.27924	0.11909	0.84118	-0.17004	-48.33719	965.93994	-41.54326
	82.91241	-0.30810	-0.00054	0.00000	0.01300	117.61429	-0.63246	-40.91080	
0.95000	-2.59274	-1.51954	-0.23144	0.07130	0.80753	-0.17004	-48.34344	908.61279	-41.83388
	82.62454	-0.33384	-0.00058	0.00000	0.01353	117.61433	-0.68942	-41.14445	
0.90000	-2.71849	-1.14530	-0.16859	0.02451	0.77390	-0.17004	-48.34970	871.28540	-42.12451
	82.31207	-0.36724	-0.00064	0.00000	0.01410	117.61441	-0.75387	-41.57064	
0.85000	-2.83487	-0.78168	-0.10973	0.01190	0.74023	-0.17004	-48.35597	833.95801	-42.41515
	81.97237	-0.40296	-0.00070	0.00000	0.01472	117.61447	-0.82719	-41.58795	
0.80000	-3.00323	-0.43004	-0.05794	0.01130	0.70653	-0.17004	-48.36223	796.63042	-42.70578
	81.60146	-0.44380	-0.00077	0.00000	0.01540	117.61433	-0.91103	-41.79474	
0.75000	-3.16319	-0.09200	-0.01196	0.01081	0.67281	-0.17004	-48.36848	759.30522	-42.99640
	81.19493	-0.49077	-0.00085	0.00000	0.01614	117.61439	-1.00766	-41.98892	
0.70000	-3.34264	0.23056	0.02903	0.01040	0.63906	-0.17004	-48.37476	721.97607	-43.28705
	80.74736	-0.54514	-0.00095	0.00000	0.01694	117.61463	-1.11909	-42.16795	
0.65000	-3.53782	0.53538	0.06334	0.01005	0.60527	-0.17004	-48.38101	684.64868	-43.57767
	80.23237	-0.60851	-0.00106	0.00000	0.01786	117.61470	-1.24917	-42.32849	
0.60000	-3.75340	0.81979	0.09786	0.00975	0.57145	-0.17004	-48.38727	647.32129	-43.86829
	79.70195	-0.68292	-0.00119	0.00000	0.01887	117.61476	-1.40194	-42.46634	
0.55000	-3.99263	1.08057	0.12612	0.00949	0.53758	-0.17004	-48.39354	609.99390	-44.15894
	79.08647	-0.77104	-0.00134	0.00000	0.01999	117.61482	-1.58206	-42.57607	
0.50000	-4.25933	1.31384	0.15028	0.00926	0.50365	-0.17004	-48.39980	572.66650	-44.44955
	78.39386	-0.87634	-0.00152	0.00000	0.02124	117.61488	-1.79907	-42.65047	
0.45000	-4.55828	1.51491	0.17016	0.00906	0.46966	-0.17004	-48.40605	535.33936	-44.74019
	77.60886	-1.00348	-0.00174	0.00000	0.02267	117.61494	-2.06011	-42.68007	
0.40000	-4.89519	1.67809	0.18545	0.00889	0.43559	-0.17004	-48.41232	498.01196	-45.03082
	76.71191	-1.15874	-0.00201	0.00000	0.02430	117.61501	-2.37896	-42.65186	
0.35000	-5.27678	1.79641	0.19363	0.00873	0.40142	-0.17004	-48.41858	460.68457	-45.32146
	75.67799	-1.33077	-0.00235	0.00000	0.02617	117.61507	-2.77332	-42.54815	
0.30000	-5.71169	1.86150	0.20311	0.00860	0.36714	-0.17004	-48.42484	423.35718	-45.61208
	74.47386	-1.59167	-0.00277	0.00000	0.02834	117.61511	-3.26817	-42.34390	
0.25000	-6.20986	1.96332	0.19799	0.00848	0.33272	-0.17004	-48.43111	386.03003	-45.90275
	73.03508	-1.89877	-0.00330	0.00000	0.03089	117.61517	-3.89916	-42.00356	
0.20000	-6.78292	1.79027	0.18828	0.00838	0.29813	-0.17004	-48.43736	348.70264	-46.19334
	71.36104	-2.29736	-0.00399	0.00000	0.03392	117.61525	-4.71848	-41.47485	
0.15000	-7.44328	1.62991	0.16988	0.00829	0.26331	-0.17004	-48.44362	311.37524	-46.48398
	69.50696	-2.82318	-0.00491	0.00001	0.03757	117.61530	-5.80417	-40.67979	
0.10000	-8.20167	1.37132	0.14185	0.00822	0.22821	-0.17004	-48.44989	274.04785	-46.77461
	66.77197	-3.53973	-0.00615	0.00001	0.04204	117.61536	-7.27553	-39.49987	
0.05000	-9.05996	0.0	0.0	0.0	0.19277	-0.17004	-48.45615	236.72070	-47.06522
	63.57933	-4.32992	0.0	0.0	0.04759	117.61542	-9.51854	-57.74687	

Figure 35. Rotor Airload Data Output

TABLE I. PLOT INDEX		
Group	Number	Description
FIRST ROTOR GROUP	1	Q VELOCITY, TPP1, DEG/SEC
	2	P VELOCITY, IPP1, DEG/SEC
	3	U VELOCITY, MAST1 AXES, FT/SEC
	4	OMEGA-DOT, ROTOR1, DEG/SEC/SEC
	5	BETA-2DOT,BLADE1,ROTOR1,DEG/SEC/SEC
	6	ROTOR1 THRUST, LB
	7	F/A FLAPPING, MAST1/TPP1, DEG
	8	LATERAL FLAPPING, MAST1/TPP1, DEG
	9	V VELOCITY, MAST1 AXES, FT/SEC
	10	OMEGA, ROTOR1,DEG/SEC
	11	BETA-DOT, BLADE1, ROTOR1, DEG/SEC
	12	ROTOR1 H-FORCE, LB
	13	W VELOCITY, MAST1 AXES, FT/SEC
	14	AZIMUTH LOC., BLADE1, ROTOR1, DEG
	15	BETA, BLADE1, ROTOR1, DEG
	16	ROTOR1 Y-FORCE, LB
	17	ROTOR1 COLLEC. FROM CONTROLS, DEG
	18	ROTOR1 F/A CYC. FROM CONTROLS, DEG
	19	ROTOR1 LAT CYC. FROM CONTROLS, DEG
	20	ROTOR1 CONING, DEG
	21	MAST1 TILT, DEG
	22	ROTOR1 TORQUE, FT-LB
	23	ROTOR1 OTHER COLLEC., DEG
	24	ROTOR1 OTHER F/A CYC., DEG
	25	ROTOR1 OTHER LAT CYC., DEG
	26	ROTOR1 INDUCED VELOCITY, FT/SEC
	27	ROTOR1 RPM
	28	ROTOR1 HORSEPOWER
	29	ROTOR1 UPPER FLAPPING LIMIT, DEG
	30	ROTOR1 F/A HUBSPRING, FT-LB/DEG
	31	ROTOR1 TOTAL COLLECTIVE, DEG
	32	ROTOR1 TOTAL F/A CYCLIC, DEG
	33	ROTOR1 TOTAL LAT CYCLIC, DEG
	34	ROTOR1 LOWER FLAPPING LIMIT, DEG
	35	ROTOR1 LAT HUBSPRING, FT-LB/DEG
SECOND ROTOR GROUP	36	Q VELOCITY, TPP2, DEG/SEC
	37	P VELOCITY, TPP2, DEG/SEC
	38	U VELOCITY, MAST2 AXES, FT/SEC
	39	OMEGA-DOT, ROTOR2, DEG/SEC/SEC
	40	BETA-2DOT,BLADE1,ROTOR2,DEG/SEC/SEC
	41	ROTOR2 THRUST, LB
	42	F/A FLAPPING, MAST2/TPP2, DEG
	43	LATERAL FLAPPING, MAST2/TPP2, DEG
	44	V VELOCITY, MAST2 AXES, FT/SEC
	45	OMEGA, ROTOR2, DEG/SEC
	46	BETA-DOT, BLADE1, ROTOR2, DEG/SEC

TABLE I. Continued		
Group	Number	Description
SECOND ROTOR GROUP (Cont'd)	47	ROTOR2 H-FORCE, LB
	48	W VELOCITY, MAST2 AXES, FT/SEC
	49	AZIMUTH LOC., BLADE1, ROTOR2, DEG
	50	BETA, BLADE1, ROTOR2, DEG
	51	ROTOR2 Y-FORCE, LB
	52	ROTOR2 COLLEC. FROM CONTROLS, DEG
	53	ROTOR2 F/A CYC. FROM CONTROLS, DEG
	54	ROTOR2 LAT CYC. FROM CONTROLS, DEG
	55	ROTOR2 CONING, DEG
	56	MAST2 TILT, DEG
	57	ROTOR2 TORQUE, FT-LB
	58	ROTOR2 OTHER COLLEC., DEG
	59	ROTOR2 OTHER F/A CYC., DEG
	60	ROTOR2 OTHER LAT CYC., DEG
	61	ROTOR2 INDUCED VELOCITY, FT/SEC
	62	ROTOR2 RPM
	63	ROTOR2 HORSEPOWER
	64	ROTOR2 UPPER FLAPPING LIMIT, DEG
	65	ROTOR2 F/A HUBSPIRNG, FT-LB/DEG
	66	ROTOR2 TOTAL COLLECTIVE, DEG
	67	ROTOR2 TOTAL F/A CYCLIC, DEG
	68	ROTOR2 TOTAL LAT CYCLIC, DEG
	69	ROTOR2 LOWER FLAPPING LIMIT, DEG
	70	ROTOR2 LAT HUBSPRING, FT-LB/DEG
FIXED REFERENCE GROUP	71	X-COMP VELOCITY, FIXED AXES, FT/SEC
	72	Y-COMP VELOCITY, FIXED AXES, FT/SEC
	73	Z-COMP VELOCITY, FIXED AXES, FT/SEC
	74	TOTAL DISTANCE FLOWN, FT
	75	AIR SPEED, KTS
	76	HEADING ANGLE, DEG
	77	X-COMP DISP., FIXED AXES, FT
	78	Y-COMP DISP., FIXED AXES, FT
	79	Z-COMP DISP., FIXED AXES, FT
	80	ALTITUDE, FT
	81	GROUND SPEED, KTS
	82	CLIMB ANGLE, DEG
FUSELAGE GROUP	83	U-DOT ACCEL., BODY AXES, FT/SEC/SEC
	84	V-DOT ACCEL., BODY AXES, FT/SEC/SEC
	85	W-DOT ACCEL., BODY AXES, FT/SEC/SEC
	86	P-DOT ACCEL, BODY AXES, DEG/SEC/SEC
	87	Q-DOT ACCEL, BODY AXES, DEG/SEC/SEC
	88	R-DOT ACCEL, BODY AXES, DEG/SEC/SEC
	89	COLLEC. BOBWT. ACCEL., DEG/SEC/SEC
	90	U VELOCITY, BODY AXES, FT/SEC
	91	V VELOCITY, BODY AXES, FT/SEC

TABLE I. Continued		
Group	Number	Description
FUSELAGE GROUP (Cont'd)	92	W VELOCITY, BODY AXES, FT/SEC
	93	P VELOCITY, BODY AXES, DEG/SEC
	94	Q VELOCITY, BODY AXES, DEG/SEC
	95	R VELOCITY, BODY AXES, DEG/SEC
	96	COLLEC. BOBWT. VELOCITY, DEG/SEC
	97	YAW VELOCITY, FIXED/BODY, DEG/SEC
	98	PITCH VELOCITY, FIXED/BODY, DEG/SEC
	99	ROLL VELOCITY, FIXED/BODY, DEG/SEC
	100	YAW ANGLE, FIXED/BODY, DEG
	101	PITCH ANGLE, FIXED/BODY, DEG
	102	ROLL ANGLE, FIXED/BODY, DEG
	103	COLLECTIVE STICK POSITION, PCT
	104	F/A CYCLIC STICK POSITION, PCT
	105	LEFT WING ANGLE OF ATTACK, DEG
	106	RIGHT WING ANGLE OF ATTACK, DEG
	107	ELEVATOR ANGLE OF ATTACK, DEG
	108	FIN ANGLE OF ATTACK, DEG
	109	BODY YAW WRT. FLIGHT PATH, DEG
	110	C.G. STATION LINE LOCATION, IN.
	111	X-COMP GUST VEL., BODY AXES, FT/SEC
	112	X-COMP G-S, BODY AXES
	113	LATERAL CYCLIC STICK POSITION, PCT
	114	LEFT WING COEFFICIENT OF LIFT
	115	RIGHT WING COEFFICIENT OF LIFT
	116	ELEVATOR COEFFICIENT OF LIFT
	117	FIN COEFFICIENT OF LIFT
	118	BODY PITCH WRT. FLIGHT PATH, DEG
	119	C.G. BUTT LINE LOCATION, IN.
	120	Y-COMP GUST VEL., BODY AXES, FT/SEC
	121	Y-COMP G-S, BODY AXES
	122	PEDAL POSITION, PCT
	123	LEFT WING COEFFICIENT OF DRAG
	124	RIGHT WING COEFFICIENT OF DRAG
	125	ELEVATOR COEFFICIENT OF DRAG
	126	FIN COEFFICIENT OF DRAG
	127	C.G. WATER LINE LOCATION, IN.
	128	Z-COMP GUST VEL., BODY AXES, FT/SEC
	129	Z-COMP G-S, BODY AXES
	130	RIGHT/CENTER JET THRUST, LB
	131	ENGINE TORQUE SUPPLIED, FT-LB
	132	TOTAL HORSEPOWER REQUIRED
	133	LEFT JET THRUST, LB
	134	SHAFT HORSEPOWER
	135	ROTOR BRAKE TORQUE APPLIED, FT-LB

TABLE I. Continued		
Group	Number	Description
AZIMUTH LOCATION AND FLAPPING GROUP	136	AZIMUTH LOC., BLADE1, ROTOR1, DEG
	137	AZIMUTH LOC., BLADE2, ROTOR1, DEG
	138	AZIMUTH LOC., BLADE3, ROTOR1, DEG
	139	AZIMUTH LOC., BLADE4, ROTOR1, DEG
	140	AZIMUTH LOC., BLADE5, ROTOR1, DEG
	141	AZIMUTH LOC., BLADE6, ROTOR1, DEG
	142	AZIMUTH LOC., BLADE7, ROTOR1, DEG
	143	BETA-2DOT,BLADE1,ROTOR1,DEG/SEC/SEC
	144	BETA-2DOT,BLADE2,ROTCR1,DEG/SEC/SEC
	145	BETA-2DOT,BLADE3,ROTOR1,DEG/SEC/SEC
	146	BETA-2DOT,BLADE4,ROTOR1,DEG/SEC/SEC
	147	BETA-2DOT,BLADE5,ROTOR1,DEG/SEC/SEC
	148	BETA-2DOT,BLADE6,ROTOR1,DEG/SEC/SEC
	149	BETA-2DOT,BLADE7,ROTOR1,DEG/SEC/SEC
	150	BETA-DOT, BLADE1, ROTOR1, DEG/SEC
	151	BETA-DOT, BLADE2, ROTOR1, DEG/SEC
	152	BETA-DOT, BLADE3, ROTOR1, DEG/SEC
	153	BETA-DOT, BLADE4, ROTOR1, DEG/SEc
	154	BETA-DOT, BLADE5, ROTOR1, DEG/SEC
	155	BETA-DOT, BLADE6, ROTOR1, DEG/SEC
	156	BETA-DOT, BLADE7, ROTOR1, DEG/SEc
	157	BETA, BLADE1, ROTOR1, DEG
	158	BETA, BLADE2, ROTOR1, DEG
	159	BETA, BLADE3, ROTOR1, DEG
	160	BETA, BLADE4, ROTOR1, DEG
	161	BETA, BLADE5, ROTOR1, DEG
	162	BETA, BLADE6, ROTOR1, DEG
	163	BETA, BLADE7, ROTOR1, DEG
	164	AZIMUTH LOC., BLADE1, ROTOR2, DEG
	165	AZIMUTH LOC., BLADE2, ROTOR2, DEG
	166	AZIMUTH LOC., BLADE3, ROTOR2, DEG
	167	AZIMUTH LOC., BLADE4, ROTOR2, DEG
	168	AZIMUTH LOC., BLADE5, ROTOR2, DEG
	169	AZIMUTH LOC., BLADE6, ROTOR2, DEG
	170	AZIMUTH LOC., BLADE7, ROTOR2, DEG
	171	BETA-2DOT,BLADE1,ROTOR2,DEG/SEC/SEC
	172	BETA-2DOT,BLADE2,ROTOR2,DEG/SEC/SEC
	173	BETA-2DOT,BLADE3,ROTOR2,DEG/SEC/SEC
	174	BETA-2DOT,BLADE4,ROTOR2,DEG/SEC/SEC
	175	BETA-2DOT,BLADE5,ROTOR2,DEG/SEC/SEC
	176	BETA-2DOT,BLADE6,ROTOR2,DEG/SEC/SEC
	177	BETA-2DOT,BLADE7,ROTOR2,DEG/SEC/SEC
	178	BETA-DOT, BLADE1, ROTOR2, DEG/SEC
	179	BETA-DOT, BLADE2, ROTOR2, DEG/SEC
	180	BETA-DOT, BLADE3, ROTOR2, DEG/SEC
	181	BETA-DOT, BLADE4, ROTOR2, DEG/SEC
	182	BETA-DOT, BLADE5, ROTOR2, DEG/SEC

TABLE I. Continued		
Group	Number	Description
AZIMUTH LOCATION AND FLAPPING GROUP (Cont'd)	183	BETA-DOT, BLADE6, ROTOR2, DEG/SEC
	184	BETA-DOT, BLADE7, ROTOR2, DEG/SEC
	185	BETA, BLADE1, ROTOR2, DEG
	186	BETA, BLADE2, ROTOR2, DEG
	187	BETA, BLADE3, ROTOR2, DEG
	188	BETA, BLADE4, ROTOR2, DEG
	189	BETA, BLADE5, ROTOR2, DEG
	190	BETA, BLADE6, ROTOR2, DEG
	191	BETA, BLADE7, ROTOR2, DEG
FORCE AND MOMENT GROUP	192	TOTAL X-FORCE ON C.G., LB
	193	X-FORCE FROM RIGHT WING, LB
	194	X-FORCE FROM LEFT WING, LB
	195	X-FORCE FROM ELEVATOR, LB
	196	X-FORCE FROM FUSELAGE, LB
	197	X-FORCE FROM RIGHT JET, LB
	198	X-FORCE FROM LEFT/CENTER JET, LB
	199	X-FORCE FROM ROTOR1, LB
	200	X-FORCE FROM ROTOR2, LB
	201	X-FORCE FROM WEAPON FIRE, LB
	202	X-FORCE FROM FIN, LB
	203	X-FORCE FROM WEIGHT, LB
	204	TOTAL Y-FORCE ON C.G., LB
	205	Y-FORCE FROM FUSELAGE, LB
	206	Y-FORCE FROM RIGHT JET, LB
	207	Y-FORCE FROM LEFT/CENTER JET, LB
	208	Y-FORCE FROM ROTOR1, LB
	209	Y-FORCE FROM ROTOR2, LB
	210	Y-FORCE FROM WEAPON FIRE, LB
	211	Y-FORCE FROM FIN, LB
	212	Y-FORCE FROM WEIGHT, LB
	213	TOTAL Z-FORCE ON C.G., LB
	214	Z-FORCE FROM RIGHT WING, LB
	215	Z-FORCE FROM LEFT WING, LB
	216	Z-FORCE FROM ELEVATOR, LB
	217	Z-FORCE FROM FUSELAGE, LB
	218	Z-FORCE FROM RIGHT JET, LB
	219	Z-FORCE FROM LEFT/CENTER JET, LB
	220	Z-FORCE FROM ROTOR1, LB
	221	Z-FORCE FROM ROTOR2, LB
	222	Z-FORCE FROM WEAPON FIRE, LB
	223	Z-FORCE FROM WEIGHT, LB
	224	TOTAL ROLL MOM ON C.G., FT-LB
	225	ROLL MOM FROM RIGHT WING, LB
	226	ROLL MOM FROM LEFT WING, FT-LB
	227	ROLL MOM FROM ELEVATOR, FT-LB
	228	ROLL MOM FROM FUSELAGE, FT-LB

TABLE I. Continued		
Group	Number	Description
FORCE AND MOMENT GROUP (Cont'd)	229	ROLL MOM FROM RIGHT JET, FT-LB
	230	ROLL MOM FROM LEFT/CENTR JET, FT-LB
	231	ROLL MOM FROM ROTOR1 FORCES, FT-LB
	232	ROLL MOM FROM ROTOR2 FORCES, FT-LB
	233	ROLL MOM FROM WEAPON FIRE, FT-LB
	234	ROLL MOM FROM FIN, FT-LB
	235	ROLL MOM FROM ROTOR1 TORQUE, FT-LB
	236	ROLL MOM FROM ROTOR2 TORQUE, FT-LB
	237	TOTAL PITCH MOM ON C.G., FT-LB
	238	PITCH MOM FROM RIGHT WING, FT-LB
	239	PITCH MOM FROM LEFT WING, FT-LB
	240	PITCH MOM FROM ELEVATOR, FT-LB
	241	PITCH MOM FROM FUSELAGE, FT-LB
	242	PITCH MOM FROM RIGHT JET, FT-LB
	243	PITCH MOM FROM LEFT/CENT JET, FT-LB
	244	PITCH MOM FROM ROTOR1 FORCES, FT-LB
	245	PITCH MOM FROM ROTOR2 FORCES, FT-LB
	246	PITCH MOM FROM WEAPON FIRE, FT-LB
	247	PITCH MOM FROM FIN, FT-LB
	248	PITCH MOM FROM ROTOR1 TORQUE, FT-LB
	249	PITCH MOM FROM ROTOR2 TORQUE, FT-LB
	250	TOTAL YAW MOM ON C.G., FT-LB
	251	YAW MOM FROM RIGHT WING, FT-LB
	252	YAW MOM FROM LEFT WING, FT-LB
	253	YAW MOM FROM ELEVATOR, FT-LB
	254	YAW MOM FROM FUSELAGE, FT-LB
	255	YAW MOM FROM RIGHT JET, FT-LB
	256	YAW MOM FROM LEFT/CENT JET, FT-LB
	257	YAW MOM FROM ROTOR1 FORCES, FT-LB
	258	YAW MOM FROM ROTOR2 FORCES, FT-LB
	259	YAW MOM FROM WEAPON FIRE, FT-LB
	260	YAW MOM FROM FIN, FT-LB
	261	YAW MOM FROM ROTOR1 TORQUE, FT-LB
	262	YAW MOM FROM ROTOR2 TORQUE, FT-LB
	263	ROTOR1 F/A FLAPPING MOMENT, FT-LB
	264	ROTOR1 LAT FLAPPING MOMENT, FT-LB
	265	ROTOR2 F/A FLAPPING MOMENT, FT-LB
	266	ROTOR2 LAT FLAPPING MOMENT, FT-LB

TABLE II. CONTROL TO SURFACES		
Configuration	Control	Surface
Single rotor	Collective stick	Main rotor collective Wing incidence Elevator incidence Jet thrust
	F/A cyclic stick	Main rotor F/A cyclic Elevator incidence
	Lateral cyclic stick	Main rotor lateral cyclic Aileron
	Pedal	Tail rotor collective Rudder incidence
Tandem	Collective stick	Fwd rotor collective Aft rotor collective Wing incidence Elevator incidence Jet thrust
	F/A cyclic stick	Fwd rotor F/A cyclic Aft rotor F/A cyclic Fwd rotor collective Aft rotor collective Elevator incidence
	Lateral cyclic stick	Fwd rotor lateral cyclic Aft rotor lateral cyclic Aileron
	Pedal	Rudder incidence Fwd rotor lateral cyclic Aft rotor lateral cyclic

TABLE II. Continued		
Configuration	**Control**	**Surface**
Composite	Collective stick	Rt rotor collective Left rotor collec-tive Wing incidence Elevator incidence Jet thrust
	F/A cyclic stick	Rt rotor F/A cyclic Left rotor F/A cyclic Rt rotor lateral cyclic Left rotor lateral cyclic Elevator incidence
	Lateral cyclic stick	Rt rotor lateral cyclic Left rotor lateral cyclic Right rotor collec-tive Left rotor collec-tive Rt rotor F/A cyclic Left rotor F/A cyclic Aileron
	Pedal	Rudder incidence Rt rotor collective Left rotor collec-tive Rt rotor F/A cyclic Left rotor F/A cyclic
	Mast tilt	Collective lower limit Collective-lateral cyclic ratio Collective-rudder ratio

TABLE III. SURFACE TO CONTROLS		
Configuration	Surface	Control
Single Rotor	Main rotor collective	Collective stick
	F/A cyclic	F/A stick
	Lateral cyclic	Lateral stick
	Tail rotor collective	Pedal
	Rudder incidence	Pedal
	Aileron	Lateral stick
	Elevator incidence	F/A stick Collective stick
	Wing incidence	Collective stick
	Jet thrust	Collective stick
Tandem	Fwd rotor collective	Collective stick F/A cyclic stick
	Aft rotor collective	Collective stick F/A cyclic stick
	Fwd rotor F/A cyclic	F/A cyclic stick
	Aft rotor F/A cyclic	F/A cyclic stick
	Fwd rotor lateral cyclic	Lateral cyclic stick pedal
	Aft rotor lateral cyclic	Lateral cyclic stick pedal
	Rudder incidence	Pedal
	Wing incidence	Collective stick
	Elevator incidence	Collective stick F/A cyclic stick
	Jet thrust	Collective stick
	Aileron	Lateral cyclic stick

TABLE III. Continued		
Configuration	Surface	Control
Composite	Rt rotor collective	Collective stick Lateral cyclic stick Pedal Mast tilt
	Left rotor collective	Collective stick Lateral cyclic stick Pedal Mast tilt
	Rt rotor F/A cyclic	F/A cyclic stick Lateral cyclic stick Pedal
	Left rotor F/A cyclic	F/A cyclic stick Lateral cyclic stick Pedal
	Rt rotor lateral cyclic	F/A cyclic stick Lateral cyclic stick
	Left rotor lateral cyclic	F/A cyclic stick Lateral cyclic stick
	Rudder incidence	Pedal
	Elevator incidence	Collective stick F/A cyclic stick
	Wing incidence	Collective stick
	Aileron	Lateral cyclic stick
	Jet thrust	Collective stick

REFERENCES

1. Etkin, Bernard, Dynamics of Flight, New York, John Wiley and Sons, Inc., 1959.

2. McCorkle, Roger, "HPH Collective Bobweight Dynamic Definition," BHC IOM 81:RM:jt-81, December 21, 1967.

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13. ABSTRACT

This report describes a mathematical model of rotorcraft that may be used to determine characteristics of performance, stability, response, and rotor blade loads. The complexity of the equations used requires the use of a digital computer for efficient solution. This four volume report describes the computer program in detail and illustrates the method of computing rotorcraft characteristics by specific example.

This volume presents all documentation available to aid the user of the computer program developed in this work. The input format section provides an explanation of all of the quantities input to the computer program. Many of the inputs are defined by equations showing how they function in the program. Four typical sets of input data are included as working examples. The output guide gives a thorough discussion of all of the forms of computer output obtained by the user.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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ERRATA

The following corrections are applicable to AFFDL TR 69-123, A Stability and Control Prediction Method for Helicopters and Stoppable Rotor Aircraft, Volume II (User's Manual), February 1970.

The numbers in Figures 11 through 14 which are associated with the main and tail rotor blade twist and flapping stop should be negative. The correct sign convention is illustrated in Figure 18, page 123. To correct the figures, place a negative sign in front of the "words" as indicated below:

Figure	Page	Group	Line	Word
11	112	Main Rotor	1	7
11	112	Main Rotor	5, 6, 7	1 through 7
11	112	Tail Rotor	1	7
12	114	Main Rotor	1	7
12	114	Main Rotor	5, 6, 7	1 through 7
12	114	Tail Rotor	1	7
13	116	Main Rotor	1	7
13	116	Main Rotor	5, 6, 7	1 through 7
13	116	Tail Rotor	1	7
13	116	Tail Rotor	5, 6, 7	1 through 7
14	118	Main Rotor	1	7
14	118	Main Rotor	5, 6, 7	1 through 7
14	118	Tail Rotor	1	7
14	118	Tail Rotor	5, 6, 7	1 through 7

The computer program in Volume IV of AFFDL TR 69-123 is correct as printed.

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