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COMPUTER PROGRAM FOR POST-FLIGHT EVALUATION OF A LAUNCH VEHICLE UPPER-STAGE ON-OFF REACTION CONTROL SYSTEM

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COMPUTER PROGRAM FOR POST-FLIGHT EVALUATION OF A LAUNCH VEHICLE UPPER STAGE ON-OFF REACTION CONTROL SYSTEM

SUMMARY

This report describes a FORTRAN IV coded computer program for post-flight evaluation of a launch vehicle upper stage ON-OFF reaction control system. Aerodynamic and thrust misalignment disturbances are computed as well as the total disturbing moments in pitch, yaw, and roll. Effective thrust misalignment angle time histories of the rocket booster motor are calculated. Disturbing moments are integrated and used to estimate the required control system total impulse. Effective control system specific impulse is computed for the boost and coast phases using measured control fuel useage. This method has been used for more than fifteen years for analyzing the NASA Scout Launch Vehicle second and third stage reaction control system performance.

The computer program is set up in FORTRAN IV for a CDC CYBER 175 system. With slight modification it can be used on other machines having a FORTRAN compiler. The program has optional CALCOMP plotting output. With this option the program requires 19K words of memory and has 786 cards. Running time on a CDC CYBER 175 system is less than three (3) seconds for a typical problem.

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LIST OF ILLUSTRATIONS

LIST OF SYMBOLS

Symbol	Description	Units
a_3	cubic coefficient in aerodynamic normal force coefficient versus angle of attack expression	$1/deg^3$
C_N	aerodynamic normal force coefficient	——
$C_{N\alpha}$	aerodynamic normal force coefficient slope at zero angle of attack	1/deg
C_{reg}	control fuel system regulated gas pressurization compressibility factor	——
C_g	control fuel system unregulated gas pressurization compressibility factor	——
F_c	control motor force	lbs
I_{sp}	control fuel specific impulse	lb -sec/lb_m
I_T	control system total impulse	lb_f-sec
I_x	roll moment of inertia	slug-ft^2
I_y	pitch or yaw moment of inertia	slug-ft^2
K_t	rate trace paper speed	in/sec
K_p	rate trace scale factor	deg/sec/in
L	roll moment	ft-lbs
l_c	pitch or yaw control moment arm	ft
l_r	effective thrust misalignment moment arm	ft
M	pitching moment	ft-lbs
N	yawing moment	ft-lbs
P	pressure	psia
Q	dynamic pressure	lbs/ft^2
R_c	roll control moment arm	ft
S	aerodynamic reference area	ft^2
T	booster thrust	lbs

T_g	temperature of pressurizing gas..............°R
V_g	unregulated pressurizing gas volume..........in^3
W_c	control fuel weight.........................lbs
W_p	rocket booster propellant remaining..........lbs
x	body station..................................inches
z_c	location of pitch or yaw control motors from centerline..............................inches

Greek Letters

α	angle of attack.............................deg
β	angle of sideslip...........................deg
η	total aerodynamic angle.....................deg
θ	pitch attitude..............................deg
ϵ_τ	effective booster thrust misalignment........deg
λ_c	pitch and yaw control motor cant angle.......deg
λ_τ	orientation angle of thrust misalignment.....deg
$\lambda_\theta, \lambda_\psi, \lambda_\phi$	rate trace slopes...........................deg
ρ_L	weight density of control liquid fuel........lbs/in^3
ϕ	roll attitude...............................deg
ψ	yaw attitude................................deg

Prefix

∂	derivative or differential
Δ	incremental value
Σ	prefix summation sign

Subscripts

aero	aerodynamic
c	control

Subscripts (continued)

cg	center of mass
cons	consumed
cp	aerodynamic center
d	disturbance
g	gas
L	liquid
N	normal force
o	initial value
p	pitch
R	roll
reg	regulated gas
rem	remaining
T	total
y	yaw
r	booster thrust

Special Notation

$\int dt$	integral with respect to time
•	dots above a variable denote derivative with respect to time

1.0 INTRODUCTION

Post-flight analysis of a reaction controlled launch vehicle upper stage should include computation of the disturbing pitch, yaw, and roll moments, control fuel consumption, estimated control fuel specific impulse, as well as other performance measures. The method presented herein, provides a useful tool to aid in these tasks for an ON-OFF reaction controlled vehicle. It is a straightforward deterministic approach based on uncoupled rigid body equations of motion. Impulse and control fuel useage is based on integration of the absolute value of average duty cycles required to balance disturbing moments and optional inputs for additional impulse such as used during limit cycle operation. Being straightforward and simple this important evaluation method is sometimes overlooked in post-flight evaluation of reaction-control systems.

The method has been used for more than fifteen years for evaluating the ON-OFF hydrogen peroxide reaction control systems on the second and third stages of the NASA SCOUT (SCientific Orbital Utility Test) Vehicle. Use of this method has led to an accurate data bank on the booster rocket motors thrust misalignment and roll torque characteristics and control system specific impulse deviations. It has also been useful in helping diagnose rocket motor failures.

Input data required includes dynamic pressure, angles of attack and sideslip, angular accelerations or angular rate trace slopes, booster thrust and weight time histories, mass properties, control fuel or pressurization variables, and vehicle control moment arms. Optional input includes incremental rates at control motor firings and/or incremental impulse.

Methodology and a detailed computer program description is presented herein. Details of the computer program including a sample problem and detailed input and output descriptions are presented in Section 3. A complete FORTRAN listing is presented in Appendix A.

2.0 METHODOLOGY

This section presents the methodology and equations which can be used to compute pitch, yaw and roll disturbing moments, effective thrust misalignment, total impulse expended by the control system, control fuel consumption and effective overall control system specific impusle. Knowledge of vehicle angular rate time histories and control motor firings from telemetry data is required. Booster thrust, dynamic pressure, angles of attack and sideslip, are also required. If the ON-OFF control system is a regulated pressure system an option of computing fuel useage is included based on measured pressure and temperature of the unregulated pressure supply.

2.1 Assumptions

Major assumptions and approximations made in the method are:

- non-spinning three-axes stabilized vehicle,
- ON-OFF reaction control motors which are off sufficiently long to define angular accelerations about each axis,
- aerodynamic and mass properties symmetry in pitch and yaw,
- no gyroscopic cross-coupling terms,
- aerodynamic coefficients are non-linear with angle of attack and can be described by a cubic for normal force coefficient and a linear variation of aerodynamic center with absolute value of angle of attack,
- control impulse expended assumes balance of disturbing moments plus an additional impulse supplied as input,
- control impulse calculations assume independence of pitch, yaw, and roll control motors (no mixing of pitch-roll or yaw-roll, etc.),
- optional calculation of control fuel useage from unregulated pressure and temperature assumes nitrogen pressure regulated system without venting and non-varying temperature on regulated side,
- no rocket motor jet damping in pitch, yaw, and roll,
- no aerodynamic damping

2.2 Equations

2.2.1 Disturbing Moments and Thrust Misalignment

The angular equations of motion in pitch, yaw and roll based on the previously mentioned assumptions are (see Figure 1 for sign conventions):

(2-1) $$I_y \ddot{\theta} = 57.3 \sum M = 57.3 \left[M_c + M_\tau + M_{aero} \right]$$

(2-2) $$I_y \ddot{\psi} = 57.3 \sum N = 57.3 \left[N_c + N_\tau + N_{aero} \right]$$

(2-3) $$I_x \ddot{\phi} = 57.3 \sum L = 57.3 \left[L_c + L_D \right]$$

Control moments are:

(2-4) $$M_c = -F_{c_p} \, l_c$$ (ft-lbs)

(2-5) $$N_c = -F_{c_y} \, l_c$$ (ft-lbs)

(2-6) $$L_c = -2 \, F_{cR} \, R_c$$ (ft-lbs)

where the control moment arm is,

(2-7) $$l_c = \left[(x_c - x_{cg}) \cos \lambda_c + z_c \sin \lambda_c \right] / 12$$ (ft)

Booster induced moments which are produced by all sources (i.e., angular, offset, swirl, jet damping, etc.) are all lumped into an effective thrust misalignment angle in the pitch and yaw planes.

(2-8) $$M_\tau = T \, \epsilon_{\tau_p} \, l_\tau / 57.3$$ (ft-lbs)

(2-9) $$N_\tau = T \, \epsilon_{\tau_y} \, l_\tau / 57.3$$ (ft-lbs)

where the thrust side force is assumed to act at the nozzle throat,

(2-10) $$l_\tau = (x_\tau - x_{cg}) / 12$$ (ft)

aerodynamic moments are,

(2-11) $$M_{aero} = C_N \, S \, Q \, (x_{cg} - x_{cp}) \tan \alpha / 12 \tan \eta$$ (ft-lbs)

(2-12) $$N_{aero} = -C_N \, S \, Q \, (x_{cg} - x_{cp}) \tan \beta / 12 \tan \eta$$ (ft-lbs) total aerodynamic angle (η) is,

$$\eta = \tan^{-1}\sqrt{\tan^2\alpha + \tan^2\beta} \qquad (2\text{-}13)$$

aerodynamic normal force coefficient is a cubic function of 'η',

$$C_N = C_{N_\alpha}\eta + a_3\eta^3 \qquad (2\text{-}14)$$

and aerodynamic center is,

$$x_{cp} = x_{cp_o} + \frac{\partial x_{cp}}{\partial \alpha}|\eta| \quad \text{inches} \qquad (2\text{-}15)$$

Total disturbing moments are computed from equations 2-1, 2-2, and 2-3 when the control motors are off, i.e.,

$$M_D = I_y\ddot{\theta} / 57.3 \quad \text{(ft-lbs)} \qquad (2\text{-}16)$$

$$N_D = I_y\ddot{\psi} / 57.3 \quad \text{(ft-lbs)} \qquad (2\text{-}17)$$

$$L_D = I_x\ddot{\phi} / 57.3 \quad \text{(ft-lbs)} \qquad (2\text{-}18)$$

An effective moment due to the rocket booster is,

$$M_r = M_D - M_{aero} \quad \text{(ft-lbs)} \qquad (2\text{-}19)$$

$$N_r = N_D - N_{aero} \quad \text{(ft-lbs)} \qquad (2\text{-}20)$$

An effective thrust misalignment can then be computed from equations (2-8), (2-9), and (2-16) through (2-20) for periods when the control motors are off. Pitch, yaw and total effective thrust misalignment is,

$$\epsilon_{r_p} = \left[I_y\ddot{\theta} - 57.3\,M_{aero}\right] / T\,l_r \quad \text{(degrees)} \qquad (2\text{-}21)$$

$$\epsilon_{r_y} = \left[I_y\ddot{\psi} - 57.3\,N_{aero}\right] / T\,l_r \quad \text{(degrees)} \qquad (2\text{-}22)$$

$$\epsilon_r = \sqrt{\epsilon_{r_p}^2 + \epsilon_{r_y}^2} \quad \text{(degrees)} \qquad (2\text{-}23)$$

Total thrust misalignment angle and orientation angle (λ_r) is shown in Figure 1.

$$\lambda_r = \tan^{-1}(\epsilon_{r_y} / \epsilon_{r_p}) \qquad (2\text{-}24)$$

2.2.2 Total Impulse Expended

Total impulse expended by the control system is the integral of the absolute value of thrust-time histories of each control motor.

(2-25) $$I_T = \sum \int |F_i| dt \qquad ; \qquad i = 1,2,3,\ldots\ldots.n \quad \text{motors}$$

This information is not usually available. Estimation of this from motor commands and preflight measured thrust levels is often inaccurate when short pulse widths are commanded. During a boost phase the disturbing torques are generally large enough for the control system to operate on one side of the deadband resulting in a long period of single direction control motor pulsing (Figure 2). When this occurs the average angular impulse expended by the pitch yaw and roll control motors balances that produced by the disturbances. The linear impulse is,

(2-26) $$I_T = \int \left[|M_D/l_c| + |N_D/l_c| + |L_D/R_c| \right] dt + \Delta I_T$$

where ΔI_T is an additional impulse,

When the control system deadband is crossed opposite motors fire (Figure 2). If this occurs the impulse expended includes the balance of disturbances plus the balancing of the opposite motor plus the impulse expended by the opposite motor. For this reason the program includes an input table of an "additional" impulse (ΔI) time history which can be estimated by other means such as angular rate changes and measured motor pulse widths.

An option for computing the impulse from supplied changes in pitch, yaw and roll rates is available to cover periods of no disturbance such a limit cycle operation during a coast period. A typical rate trace is presented in Figure 3. The linear impulse required to produce the motion is,

(2-27) $$\Delta I_T = \sum \left[|I_y \Delta\dot{\theta}/57.3\ l_c| + |I_y \Delta\dot{\psi}/57.3\ l_c| + |I_x \Delta\dot{\phi}/57.3 R_c| \right]$$

With this option the absolute values of incremental pitch, yaw and roll rates must be supplied as a time history as described in the input data description (paragraph 3.4).

2.2.3 Control Fuel Useage

Measured control fuel useage can be input directly to the program to be used to compute an effective specific impulse.

(2-28) $$I_{sp} = I_T / W_c \qquad (lb_f\text{-sec}/lb_m)$$

This is computed as a running time history during the boost and coast phases.

If a closed pressure regulated liquid monopropellant control system is used there is an option to compute the liquid expelled from measured unregulated pressure and temperature. The following assumptions are made:

- total mass of pressurizing gas does not change
- regulated side gas pressurant is the same temperature as the unregulated side
- liquid monopropellant density is constant
- the compressibility factor of the gas on the regulated side does not change

The amount of propellant expended is:

$$\Delta W_c = \frac{\rho_L C_{reg} V_g}{P_{reg}} \left\{ \frac{P_{g_0} T_g}{C_{g_0} T_{g_0}} - \frac{P_g}{C_g} \right\} + \rho_L \Delta V_g \left\{ \frac{T_g}{T_{g_0}} - 1 \right\} \qquad (2\text{-}29)$$

where,

ρ_L	-	weight density of the liquid fuel (lbs/in^3)
C_{reg}	-	compressibility factor of the regulated side gas pressure
V_g	-	unregulated side pressurizing gas volume (in^3)
P_{reg}	-	regulated side gas pressure (psia)
P_g	-	unregulated side gas pressure (psia)
C_g	-	unregulated gas compressibility factor
T_g	-	unregulated gas temperature (^{o}R)
ΔV_g	-	initial volume of gas on the regulated side (in^3)

The zero subscript denotes values at the start of operation when a known quantity of fuel is in the tanks such as at initial operation.

The computer program includes a short subroutine (C) which computes the compressibility factor for dry diatomic nitrogen based on a curve fit. The curve fit is accurate for pressures in the range of 400 to 3000 psia and temperatures between 50 and 100 degrees Fahrenheit. The curve fit is,

$$C_g = 0.9977 + 1.657738 \times 10^{-5}(P_g - 1400) + 1.264881 \times 10^{-8}(P_g - 1400)^2 + 4.5833 \times 10^{-4}(T_g - 522)^2 \qquad (2\text{-}30)$$

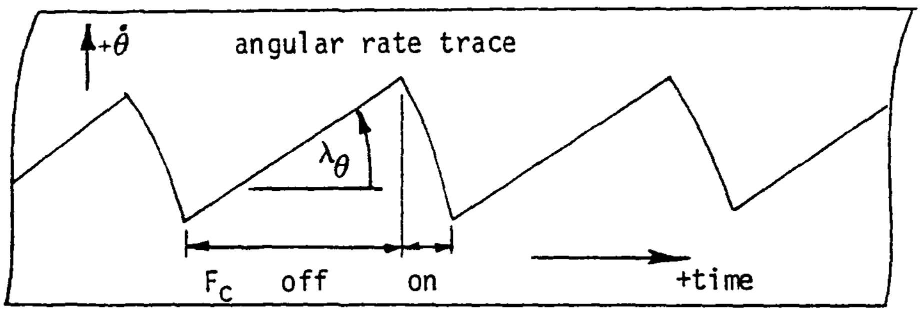
Control fuel remaining is the initial value minus that consumed,

$$W_{c_{rem}} = W_{c_0} - \Delta W_c \qquad \text{(lbs)} \qquad (2\text{-}31)$$

A time history comparison of the control fuel useage computed from measurements with that based on calculated total impulse and effective average specific impulse is output by the program.

2.2.4 Angular Accelerations

Angular accelerations between control motor firings are used to compute the disturbing moments (equations 2-16 through 2-18). An optional input includes the slope and scale factors from a plotted time history or oscillograph record as shown in the sketch below.



The angular acceleration is computed as,

(2-32) $$\ddot{\theta} = K_t \, K_p \, \tan \lambda_\theta \qquad \text{(deg/sec)}$$

where,

K_t is the paper speed in length units per second.

K_p is the rate scale factor in degrees per second per length unit.

λ_θ is the slope of the rate trace in degrees.

3.0 PROGRAM DESCRIPTION

3.1 General

This computer program is programmed in FORTRAN IV for a CDC CYBER 175 system. The coding is compatible with ANSI standards. It is arranged to operate with standard card input and line printer output. Optional CALCOMP plotting is based on standard CALCOMP plotters and software.

A main routine (UPSTAG) and four subroutines require approximately 19K words of computer memory. All output is stored in array variables to facilitate a well formatted print and CALCOMP plot output format.

Program flow and user instructions are presented in the following paragraphs. Input and output of a sample problem is illustrated along with the detailed descriptions.

3.2 Program Flow

Program flow is straightforward in five basic parts:

- input data
- calculation of boost phase disturbances and impulse
- calculation of coast phase variables
- output data on line printer
- optional CALCOMP plots

A flow chart of the main routine (UPSTAG) is presented in Figure 4. A complete listing of the FORTRAN program and subroutines other than the standard CALCOMP library subroutines are presented in Appendix A.

Descriptions of the four subroutines are presented in the following paragraphs.

3.3 Subroutine Description

Four subroutines are used to support the UPSTAG main program; C, CURVE, DASH, and TBLU. A brief description of each is presented below.

C

This short subroutine computes the compressibility factor for dry diatomic nitrogen by a curve fit over the pressure range of 400 to 3000 psia and a temperature range of 50 to 100 degrees Fahrenheit. The call statement is,

CALL C(P, T, CR)

where,

P	is the input nitrogen pressure (psia)
T	is the input nitrogen temperature (degrees Rankine)
CR	is the output compressibility factor

CURVE

This subroutine is used to set up the sequence of CALCOMP plots for pitch, yaw, and roll disturbing moments and the effective thrust misalignments. Plots are set up for a 20 x 20 divisions per inch graph paper having a grid size of 10 x 7 1/2 inches (see the output data description in this section for a sample plot output). The data to be plotted is passed to this subroutine via common in arrays PVAR, YVAR, RVAR, and TVAR. Solid dashed and dash-dot line plots are accomplished by the subroutine DASH. The call statement is,

CALL CURVE (NP, NQ, IROLL, NTITLE, DYP, DYR, DYET, DX)

where,

NP	input number of time points in the arrays to be plotted
NQ	input controls NQ = 0 if aerodynamic moments are zero only the total disturbing moments are plotted NQ = 1 total disturbing moments in addition to aerodynamic and thrust misalignment moments are plotted
IROLL	input control integer IROLL = 0 roll disturbing moment not plotted IROLL = 1 roll disturbing moment is plotted
NTITLE	input title description of 80 characters with eight (8) 'ten-letter' words
DYP	input ordinate scale factor for the pitch and yaw moments (ft-lbs per inch).
DYR	input ordinate scale factor for the roll moment (ft-lbs per inch)
DYET	input ordinate scale factor for thrust misalignment (degrees per inch)
DT	input abscissa scale factor for time (seconds per inch)

Note that care must be taken in selecting scale factors so that plotted data falls on grid. Limiting of the plotted data is automatically invoked in CURVE through the call statements to DASH.

DASH

This subroutine plots a curve on a CALCOMP plotter for a set of ordinates and abscissas. The style and type of line drawn is selected by the user. Note that the CALCOMP plot is specified in inches; plotting on metric paper requires appropriate scaling change before entering this subroutine.

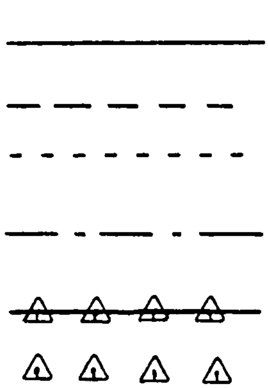
The call statement is,

CALL DASH (X, Y, NP, Z1, Z2, SPACE, XSCALE, YSCALE, LSYMB, XLIM, YLIM)

where,

- X - input array of abscissa values
- Y - input array of ordinate values
- NP - number of points in X and Y to be plotted
- Z1 - for dashed-dot lines this is length of long line measured in inches (see sketch below)
- Z2 - for dashed-dot lines this is length of short line measured in inches (see sketch)
- SPACE - for dashed style lines this is the length of the space between lines measured in inches.
  SPACE = 0 gives a solid line plot
  SPACE = negative gives special CALCOMP symbols at each point
- XSCALE - abscissa plot scale factor (units per inch)
- YSCALE - ordinate plot scale factor (units per inch)
- LSYMB - special CALCOMP symbol code number used if SPACE is negative (see code below)
  - (+) LSYMB gives straight solid lines between symbol points
  - (-) LSYMB gives only symbols at each point without lines
- XLIM - plot limiting of the abscissa (inches) points out of range, range will appear at this limit
- YLIM - plot range of ordinate (inches)

For ease in use, the following styles are typically possible,



LINE	TYPE	Z1	Z2	SPACE	LSYMB
	Solid	--	--	0.	0.
	Dashed	0.25	0.25	0.10	0.
	Dashed	0.07	0.07	0.07	0.
	Dashed Dot	0.5	0.03	0.07	0.
	Symbols	--	--	-0.1	+2
	Symbols (no line)	--	--	-0.1	-2

TBLU

This is a single table lookup subroutine. It is based on linear interpolation between points for a single array having alternating values of abscissas and ordinates. The abscissas must be in ascending order.

The call to this subroutine is:

CALL TBLU (NT, Y, X, T, M)

NT -	number of values in table 'T' including abscissas and ordinates.
Y -	is the ordinate to be found.
X -	is the given abscissa.
T -	is the table of alternating abscissas and ordinates.
M -	is the table locator to begin the table search. M must be an integer value from 1 to NT. This index is changed by the subroutine to the location found in the lookup.

3.4 Input Data Description

Input data descriptions are presented in the following subparagraphs. A sample problem input data listing is presented in Figure 5 for reference. The input data can be separated into the following groups:

1) option control card and title
2) constants
3) trajectory and vehicle characteristics tables
4) angular accelerations (not shown in Figure 5)
5) rate trace scale factors and slopes
6) additional impulse table and incremental rates
7) control fuel
8) coast phase only constants (not shown in Figure 5)
9) CALCOMP plot variables

3.4.1 Options and Title

The first card of input contains six integer control constants for the run. These are input in fields of five (5) columns. The number must be right justified. The input format is (10I5).

FORTRAN NAME	COLUMN	DESCRIPTION
IOPT1	5	option for input of pitch, yaw, and roll disturbing accelerations IOPT1 = 0 input angular acceleration tables IOPT1 = 1 input angular rate trace slopes and scale factors
IOPT2	10	option for input of control fuel useage IOPT2 = 0 read in table of fuel remaining time history IOPT1 = 1 read constants, pressure and temperature time histories and compute control fuel useage

FORTRAN NAME	COLUMN	DESCRIPTION
IOPT3	15	coast input impulse option IOPT3 = 0 no incremental rates input IOPT3 = 1 input pitch yaw and roll incremental rates versus time during coast to compute impulse
IOPT4	20	CALCOMP plot option IOPT4 = 0 no plot IOPT4 = 1 CALCOMP plot output
IOPT5	25	boost and coast phase calculations IOPT5 = 0 boost phase only IOPT5 = +1 boost and coast phases IOPT5 = -1 coast phase only
IOPT6	30	boost phase impulse option IOPT6 = 0 boost phase impulse computed from disturbing moments and additional impulse IOPT6 = 1 boost phase impulse computed from incremental rates

The second and third card of input contains two lines of an arbitrary title which is output at the top of the printed page. Each card contains 80 columns of hollerith data. It is read with a format of (8A10).

3.4.2 Constants

Constants are input with fields of 10 columns. The fourth card contains five (5) time parameters as described below.

FORTRAN NAME	COLUMN	DESCRIPTION
TP	sec	time of stage ignition (flight time)
TBO	sec	end of boost phase for stage being studied (flight time)
TSTEP	sec	output step size desired during the boost phase (this is also the integration step size for impulse expended)
TCOAST	sec	time of coast phase termination (flight time)
TSTEPC	sec	output step size for the coast phase

The next two cards of boost phase constants are input only if IOPT5 is zero or positive. The constants are read with format (6E10.3).

FORTRAN NAME	SYMBOL	UNITS	DESCRIPTION
XT	x_T	inches	body station of booster nozzle throat
XC	x_c	inches	body station of pitch and yaw control motors
ZC	z_c	inches	location of pitch and yaw control motors away from centerline
RC	$12R_c$	inches	roll control motor moment arm
WH2O2I	W_c	lbs	weight of control fuel onboard at stage ignition
CNAS	$C_{N_\alpha}S$	ft^2/deg	aerodynamic normal force coefficient slope at zero angle of attack times reference area
XCP	x_{cp}	inches	body station of aerodynamic center at zero angle of attack
ETA	λ_c	degrees	pitch and yaw control motor forward cant angle
CN3	a_3S	ft^2/deg^3	cubic coefficient in aerodynamic normal force times reference area
DCP	$\partial x_{cp}/\partial\alpha$	inch/deg	incremental change in aerodynamic center per degree angle of attack

3.4.3 Boost Phase Tables (IOPT5 = 0, +1)

When the boost phase disturbances are analyzed (IOPT5 = 0 or +1) the following eight (8) tables are input: dynamic pressure, angle of attack, angle of sideslip, booster thrust, weight of booster propellant remaining versus time, and roll moment of inertia, pitch or yaw moment of inertia, and center of mass versus percent propellant consumed. The first three tables of aerodynamic parameters are input with format (I5/(7E10.3)). The first card of each table is an integer number of values to be read into the table. This number is input in columns 1 through 5 and must be right justified. The table is entered with alternating values of abscissa and ordinate with seven (7) numbers per card. These three tables are dimensioned for 300 numbers. See Figure 5 for the sample problem input. The descriptions follow.

FORTRAN NAME	NO. OF VALUES	ABSCISSA	UNITS	ORDINATE	UNITS	DESCRIPTION
NQ	1	--	--	--	--	number of values in table Q
Q	NQ	t_f	sec	Q	lbs/ft^2	dynamic pressure versus flight time
NALPH	1	--	--	--	-	number of values in table ALPH
ALPH	NALPH	t_f	sec	α	deg	angle of attack versus flight time
NBETA	1	--	--	--	-	number of values in table BETA
BETA	NBETA	t_f	sec	β	deg	angle of sideslip versus flight time

The remaining input tables are dimensioned for 200 numbers each. These are read with format (I5/(6F10.3)). The first card of each table contains an integer number (right justified in columns 1 through 5) indicating the number of numbers included in the table. The table is read in with alternating abscissas and ordinates in fields of ten (10) with six (6) numbers per card. The descriptions of these tables follow .

FORTRAN NAME	NO. OF VALUES	ABSCISSA	UNITS	ORDINATE	UNITS	DESCRIPTION
NTT	1	--	--	--	--	number of values in table TT
TT	NTT	t_s	sec	T	lbs	booster thrust versus time after stage ignition
NNWP	1	--	--	--	-	number of values in table WP
WP	NNWP	t_s	sec	$W_{P_{rem}}$	lbs	booster propellant weight remaining versus time after booster ignition
NWX	1	--	--	--	-	number of values in table AIXX
AIXX	NWX	$\%W_{cons}$	--	I_x	$slug\text{-}ft^2$	roll moment of inertia versus percent of booster propellant consumed
NWY	1	--	--	--	-	number of values in table AIYY

FORTRAN NAME	NO. OF VALUES	ABSCISSA	UNITS	ORDINATE	UNITS	DESCRIPTION
AIYY	NWY	$\%W_{cons}$	--	I_y	slug-ft^2	pitch or yaw moment of inertia versus percent of booster propellant consumed
NXCG	1	--	--	--	-	number of values in table XCG
XCG	NXCG	$\%W_{cons}$	--	x_{cg}	inches	center of mass body station versus percent of booster propellant consumed

3.4.4 Boost Phase Angular Accelerations (IOPT1 = 0)

Angular acceleration tables are input only when the boost phase is analyzed (IOPT5 - 0 or +1) and the acceleration input option IOPT1 = 0. These are read in with format (I5/(6E10.3)).

FORTRAN NAME	NO. OF VALUES	ABSCISSA	UNITS	ORDINATE	UNITS	DESCRIPTION
NTHE	1	--	--	--	-	number of values in table THEDD
THEDD	NTHE	t_f	sec	$\ddot{\theta}$	deg/sec^2	pitch angular acceleration versus flight time when control motors are off
NPSI	1	--	--	--	-	number of values in table PSIDD
PSIDD	NPSI	t_f	sec	$\ddot{\psi}$	deg/sec^2	yaw angular acceleration versus flight time when control motors are off
NPHI	1	--	--	--	-	number of values in table PHIDD
PHIDD	NPHI	t_f	sec	$\ddot{\phi}$	deg/sec^2	roll angular acceleration versus flight time when control motors are off

3.4.5 Boost Phase Rate Slopes (IOPT1 = 1)

When IOPT1 = 1 and IOPT5 = 0 or +1 the angular accelerations are computed fom the slopes of the rate traces and their scale factors (see paragraph 2.2.4 and equation 2-32). A single card containing the six (6) rate trace scale factors is input before the slope table. These are input with format (6E10.3) and have the following definitions:

FORTRAN NAME	UNITS	COLUMNS	DESCRIPTION
XKTHE	deg/sec/inch	1-10	pitch rate trace scale factor
XKPSI	deg/sec/inch	11-20	yaw rate trace scale factor
XKPHI	deg/sec/inch	21-30	roll rate trace scale factor
XKTP	inches/sec	31-40	pitch rate trace paper speed (inverse of time scale factor)
XKTY	inches/sec	41-50	yaw rate trace paper speed (inverse of time scale factor)
XKTR	inches/sec	51-60	roll rate trace paper speed (inverse of time scale factor)

Three tables of the pitch, yaw and roll rate trace slopes are entered next with format (I5/(6E10.3)).

FORTRAN NAME	NO. OF VALUES	ABSCISSA	UNITS	ORDINATE	UNITS	DESCRIPTION
NTHE	1	--	--	--	-	number of values in THEDD
THEDD	NTHE	t_f	sec	λ_θ	deg	pitch rate trace slope versus flight time when control motors are off
NPSI	1	--	--	--	-	number of values in table PSIDD
PSIDD	NPSI	t_f	sec	λ_ψ	deg	yaw rate trace slope versus flight time when control motors are off
NPHI	1	--	--	--	-	number of values in table PHIDD
PHIDD	NPHI	t_f	sec	λ_ϕ	deg	roll rate trace slope versus flight time when control motors are off

3.4.6 Incremental Impulse

Total impulse calculations include allowance for an incremental impulse which is precalculated. This allows for impulse not covered by moment balance during boost in any of three axes of control. It is up to the user to define entries into this table. This table is input with format (I5/6E10.3). The impulse is cumulative or a continuous sum.

FORTRAN NAME	NO. OF VALUES	ABSCISSA	UNITS	ORDINATE	UNITS	DESCRIPTION
NRI	1	--	--	--	-	number of values in table RI
RI	NRI	t_f	sec	I_T	lb-sec	sum of incremental impulse versus flight time

When (IOPT3 = 1) incremental rates are also used to compute impulse, such as, during limit cycle motion. Additional tables are required. These are input as an incremental absolute value of rate changes between time points (not cumulative). These incremental rates are summed in the program to estimate total impulse.

FORTRAN NAME	NO. OF VALUES	ABSCISSA	UNITS	ORDINATE	UNITS	DESCRIPTION
NDPR	1	--	--	--	-	number of values in table DPR
DPR	NDPR	t_f	sec	$\Delta\dot{\theta}$	deg/sec	incremental pitch rate between time points versus flight time (absolute values)
NDYR	1	--	--	--	-	number of values in table DYR
DYR	NDYR	t_f	sec	$\Delta\dot{\psi}$	deg/sec	incremental yaw rate between time points versus flight time (absolute values)
NDRR	1	--	--	--	-	number of values in table DRR
DRR	NDRR	t_f	sec	$\Delta\dot{\phi}$	deg/sec	incremental roll rate between time points versus flight time (absolute values)

3.4.7 Control Fuel

When IOPT2 = 0 the control fuel remaining versus flight time is input with format (I5/(6E10.3)).

FORTRAN NAME	NO. OF VALUES	ABSCISSA	UNITS	ORDINATE	UNITS	DESCRIPTION
NW	1	--	--	--	-	number of values in table W
W	NW	t_f	sec	W_c	lbs	control fuel weight remaining versus flight time

When IOPT2 = 1 the control fuel remaining is computed from the unregulated pressure and temperature of the pressurizing gas. The alternate input includes a card containing five (5) constants followed by two tables. These are,

FORTRAN NAME	COLUMN	SYMBOL	UNITS	DESCRIPTION
DENS	1-10	ρ_L	lbs/in^3	density of liquid control fuel
COMFAC	11-20	C_{reg}	--	compressibility factor of gas on regulated side
PREREG	21-30	P_{reg}	psia	regulated pressure of system
DVOL	31-40	ΔV_{reg}	in^3	initial volume of gas on regulated side of system
VOLN2	41-50	V_g	in^3	volume of unregulated side of pressurization system

The following tables are then entered with format (I5/6E10.3)).

FORTRAN NAME	NO. OF VALUES	ABSCISSA	UNITS	ORDINATE	UNITS	DESCRIPTION
NNP	1	--	--	--	-	number of values in table P
P	NNP	t_f	sec	P_g	psia	unregulated gas pressure versus flight time
NNT	1	--	--	--	-	number of values in table T
T	NNT	t_f	sec	T_g	^oF	unregulated gas temperature versus flight time

3.4.8 Coast Phase Constants (IOPT5 = -1)

When no boost phase is analyzed (IOPT5 = -1) nine (9) constants are input with format (6E10.3). These are,

FORTRAN NAME	COLUMN	SYMBOL	UNITS	DESCRIPTION
RC	1-10	$12R_c$	inches	roll control motor moment arm
WH202I	11-20	W_{co}	lbs	value of control fuel onboard at stage ignition
YMA	21-30	$12 \cdot l_c$	inches	pitch or yaw control motor moment arm
RIXX	31-40	I_x	slug-ft^2	roll moment of inertia
YIYY	41-50	I_y	slug-ft^2	pitch or yaw moment of inertia
WH202M	51-60	W_c	lbs	control fuel onboard at stage burnout
(next card)				
WH202C	1-10		lbs	calculated control fuel at stage burnout
BOIMP	11-20	I_T	lb-sec	total impulse expended during boost phase
RIC	21-30	I_T	lb-sec	incremental impulse expended during the boost phase

3.4.9 CALCOMP Plot Variables (IOPT4 = 1)

This group of input data is required if the optional CALCOMP plots are desired (IOPT4 = 1). It includes scale factors, plot options and a title. The first card in this group is the title card containing 80 columns of alphanumeric information to be included at the top of each plot. It is read into array NTITLE with format (8A10). The next card contains the variable IROLL in column 5. This is an integer control constant;

IROLL = 0 no roll moment plotted
IROLL = 1 roll moment time history is plotted

The third card contains four scale factor constants. These are read with format (4E10.3) and are,

FORTRAN NAME	COLUMNS	UNITS	DESCRIPTION
SFT	1-10	sec/in	abscissa time scale factor of plots (note plot is limited to 7 inches along abscissa axis)
SFPYM	11-20	ft-lbs/in	pitch and yaw moment scale factor (plot is limited to ± 3 inches)
SFET	21-30	deg/in	thrust misalignment scale factor (plot is limited to ± 3 inches)
SFRM	31-40	ft-lbs/in	roll moment scale factor (plot is limited to ± 5 inches)

Note that there is no plotted information if the boost phase is deleted (IOPT5 = -1).

3.5 Output Data Description

Output includes printed data and optional CALCOMP plots (if IOPT4 = 1). A detailed description of the output is presented in the following paragraphs with a sample problem output of Figures 6 and 7 for reference. The printed output occurs in five basic pages,

- pitch boost phase variables
- yaw boost phase variables
- roll boost phase variables
- boost phase system summary data
- coast phase data

3.5.1 Boost Phase - Pitch (IOPT5 = 0, +1)

This page of output includes the time histories of pitch variables during the boost phase. Both stage time (measured from ignition) and flight time (measured from liftoff) are included. Refer to Figure 6 for the output layout. The definitions of the printed names follow,

LABEL	SYMBOL	UNITS	DESCRIPTION
FLIGHT TIME	t_f	sec	flight time
STAGE TIME	t_s	sec	stage time (measured from booster ignition)
ANGULAR ACCEL	$\ddot{\theta}$	deg/sec^2	pitch angular acceleration
MOMENT OF INER	I_y	slug-ft^2	pitch moment of inertia
AERO MOMENT	M_{aero}	ft-lbs	aerodynamic pitching moment (Equation 2-11)
MISALIGN MOMENT	M_τ	ft-lbs	pitching moment due to booster (Equation 2-19)
TOTAL MOMENT	M_D	ft-lbs	total pitch disturbing moment (Equation 2-16)
THRUST MISALN	ϵ_{τ_p}	deg	pitch component of effective thrust misalignment (Equation 2-21)
IMPULSE	I_T	lb-sec	total impulse due to pitch control motors during boost phase

3.5.2 Boost Phase - Yaw (IOPT5 = 0, +1)

This page format contains the following variables.

LABEL	SYMBOL	UNITS	DESCRIPTION
FLIGHT TIME	t_f	sec	flight time
STAGE TIME	t_s	sec	stage time measured from booster ignition
ANGULAR ACCEL	$\ddot{\psi}$	deg/sec^2	yaw angular acceleration
MOMENT OF INER	I_y	slug-ft^2	pitch or yaw moment of inertia
AERO MOMENT	N_{aero}	ft-lbs	yaw component of aerodynamic moment (Equation 2-12)
MISALIGN MOMENT	N_τ	ft-lbs	yaw moment due to booster (Equation 2-20)

LABEL	SYMBOL	UNITS	DESCRIPTION
TOTAL MOMENT	N_D	ft-lbs	total yaw disturbing moment (Equation 2-17)
THRUST MISALN	ϵ_{T_y}	deg	yaw component of effective thrust misalignment (Equation 2-22)
IMPULSE	I_T	lb-sec	yaw contribution to total impulse during boost phase

3.5.3 Boost Phase - Roll (IOPT5 = 0, +1)

This page format includes the following variables,

LABEL	SYMBOL	UNITS	DESCRIPTION
FLIGHT TIME	t_f	sec	flight time
STAGE TIME	t_s	sec	stage time measured from booster ignition
ANGULAR ACCEL	$\ddot{\phi}$	deg/sec^2	roll angular acceleration
MOMENT OF INER	I_x	$slug\text{-}ft^2$	roll moment of inertia
TOTAL MOMENT	L_D	ft-lbs	total roll disturbing moment (Equation 2-18)
IMPULSE	I_T	lb-sec	yaw contribution to total impulse during boost phase
C.G. POINT	x_{cg}	inches	body station of center of mass
CALCULATED CONSUM	W_c	lbs	calculated control fuel consumed based on total pitch yaw and roll inpulse and average specific impulse (Equations 2-26)
CALCULATED REMAIN	$W_{c\ rem}$	lbs	calculated control fuel remaining based on total impulse computed and average specific impulse

3.5.4 Boost Phase System Variables (IOPT5 = 0, +1)

This page format includes the following summary data,

LABEL	SYMBOL	UNITS	DESCRIPTION
FLIGHT TIME	t_f	sec	flight time
STAGE TIME	t_s	sec	stage time measured from booster ignition
THRUST	T	lbs	booster thrust
TOTAL MISALIGN	ϵ_T	deg	total effective booster thrust misalignment
LAMDA	λ_T	deg	roll orientation of thrust misalignment (Equation 2-24)
SPECIFIC IMPULSE	I_{sp}	sec	effective specific impulse during the boost phase (Equation 2-28)
TOTAL IMPULSE	I_T	lb-sec	total pitch yaw and roll impulse expended (Equation 2-26)
FUEL CONSUM	W_c	lbs	control fuel consumed measured or computed by Equation 2-29
FUEL REMAIN	W_{rem}	lbs	control fuel remaining based on measured or Equation 2-29

3.5.5 Coast Phase (IOPT5 = $\pm$ 1)

This page of output includes the coast phase performance and total flight results on total impulse.

LABEL	SYMBOL	UNITS	DESCRIPTION
FLIGHT TIME	t_f	sec	flight time
STAGE TIME	t_s	sec	stage time measured from booster ignition
COAST IMPULSE	I_T	lb-sec	total impulse expended during coast

LABEL	SYMBOL	UNITS	DESCRIPTION
TOTAL IMPULSE	I_T	lb-sec	total impulse including boost and coast phases
COAST ISP	I_{sp}	lb_f-sec/lb_m	effective specific impulse during the coast phase
TOTAL ISP	I_{sp}	lb_f-sec/lb_m	effective specific impulse including boost and coast phases
COAST FUEL	W_c	lbs	control fuel consumed during the coast phase only
TOTAL FUEL	W_c	lbs	control fuel consumed including the boost and coast phases
FUEL REM MEAS	W_{rem}	lbs	control fuel remaining based on measured data or Equation (2-29)
FUEL REM CALC	W_{rem}	lbs	calculated control fuel remaining based on effective average specific impulse and impulse expended

3.5.6 CALCOMP Plots (IOPT4 = 1)

The optional CALCOMP plots include the pitch, yaw and roll disturbing moments and the effective thrust misalignment versus flight time. Plots from the sample problem are presented in Figure 7.

Figure 1
Sign Convention

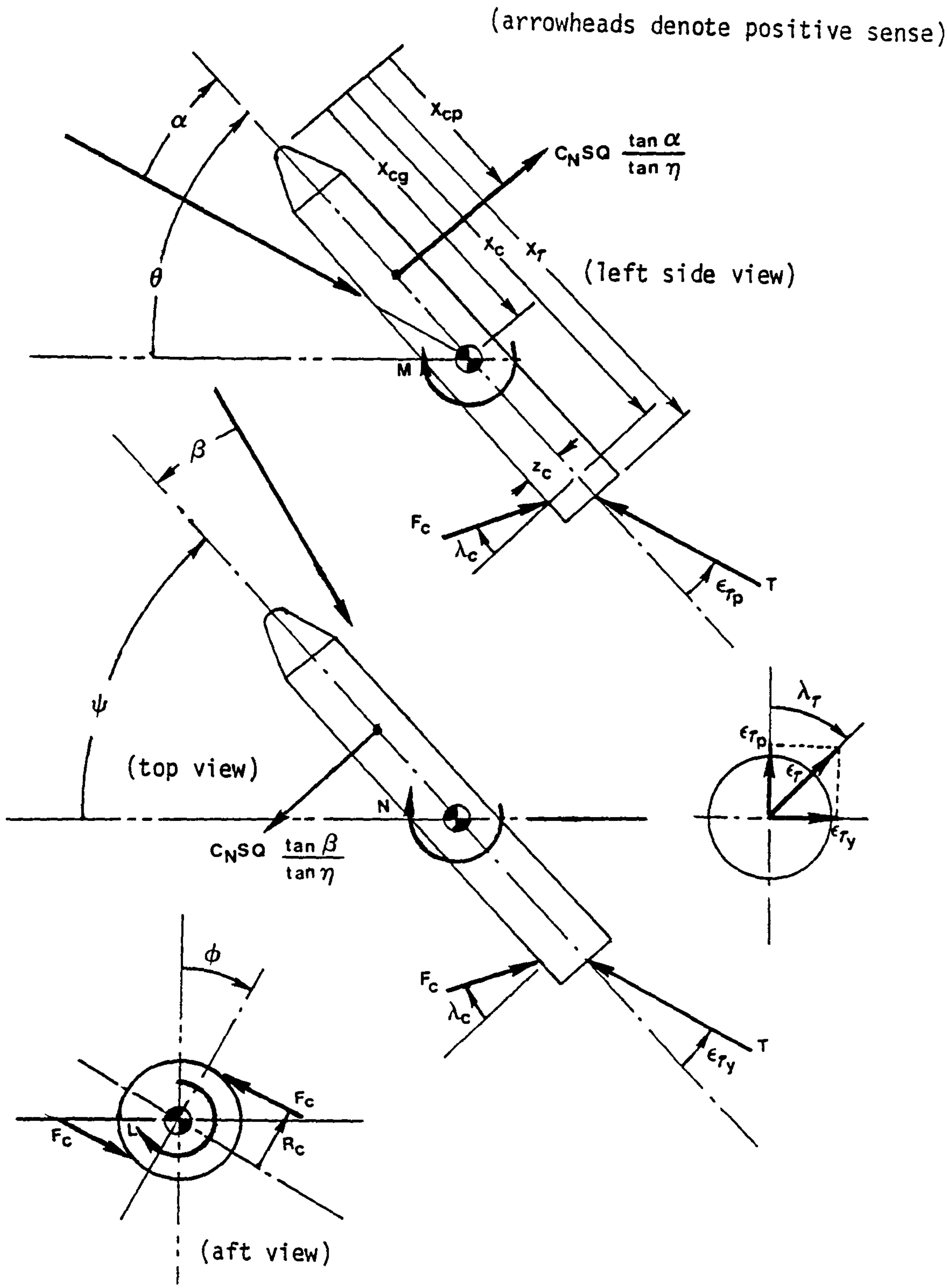
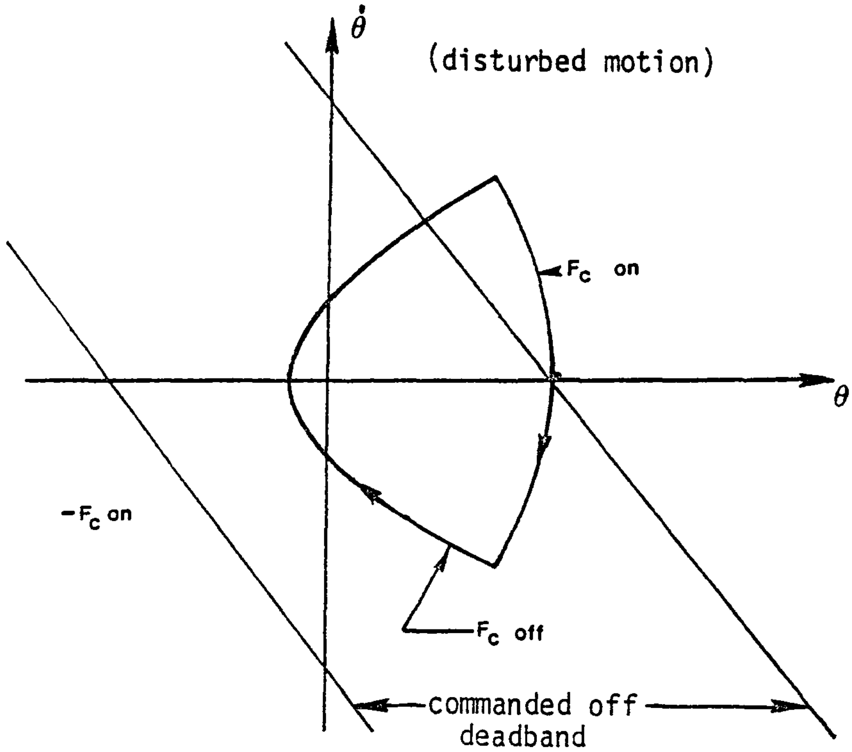


Figure 2
Disturbed and Undisturbed Motion



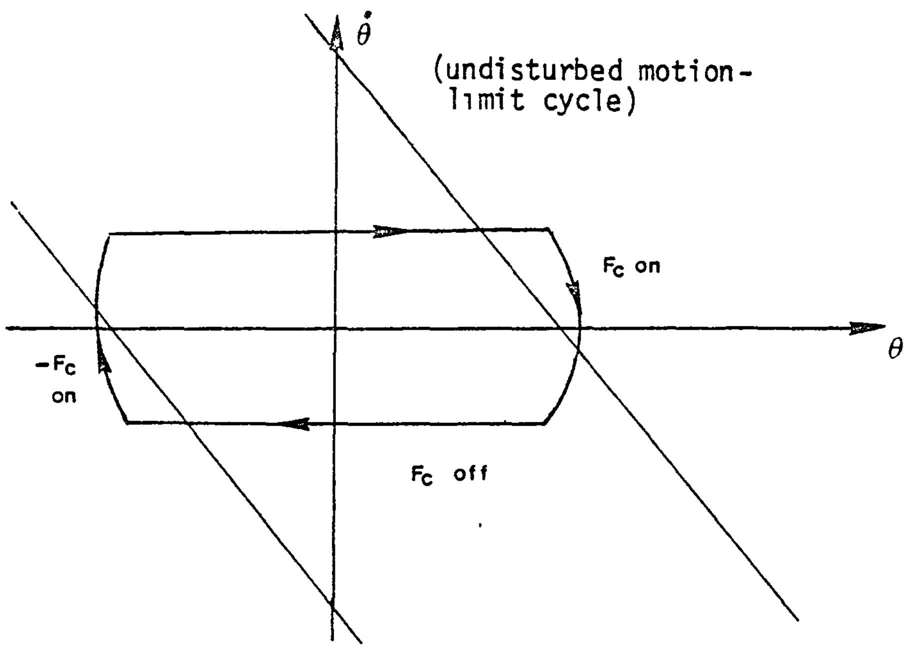


Figure 3
Typical Rate Time Histories

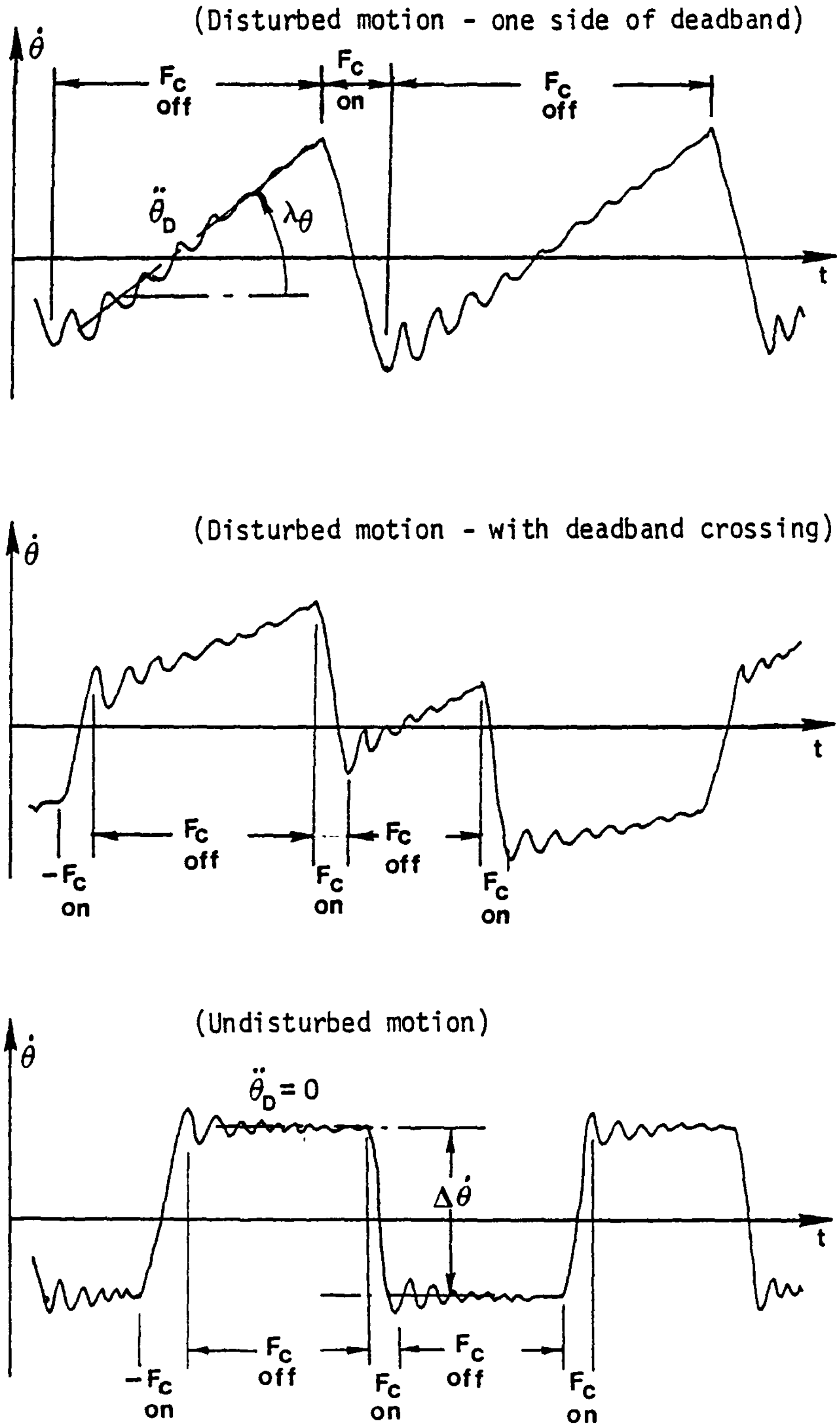


Figure 4
Flow Chart of UPSTAG

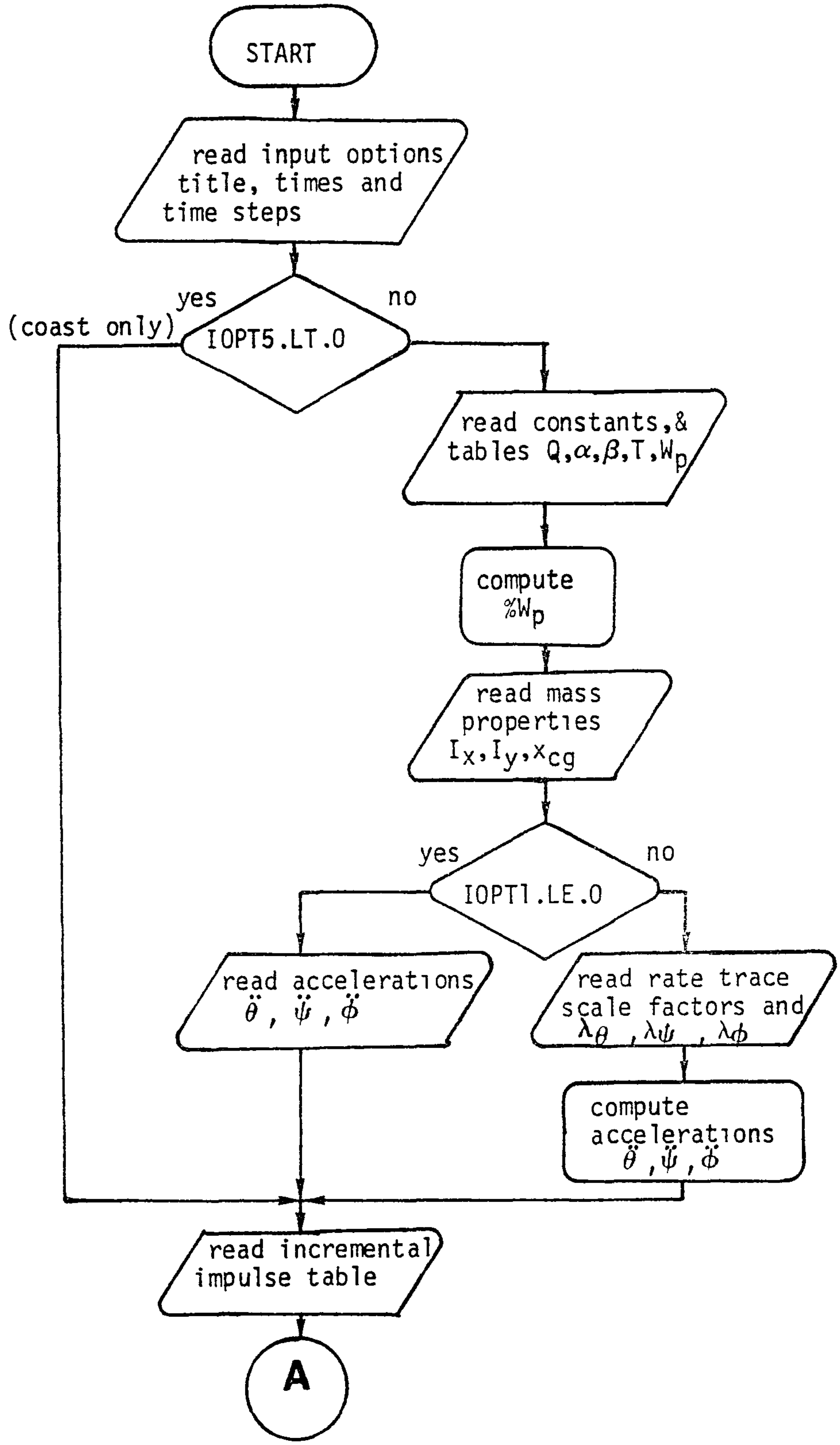


Figure 4 (continued)
Flow Chart of UPSTAG

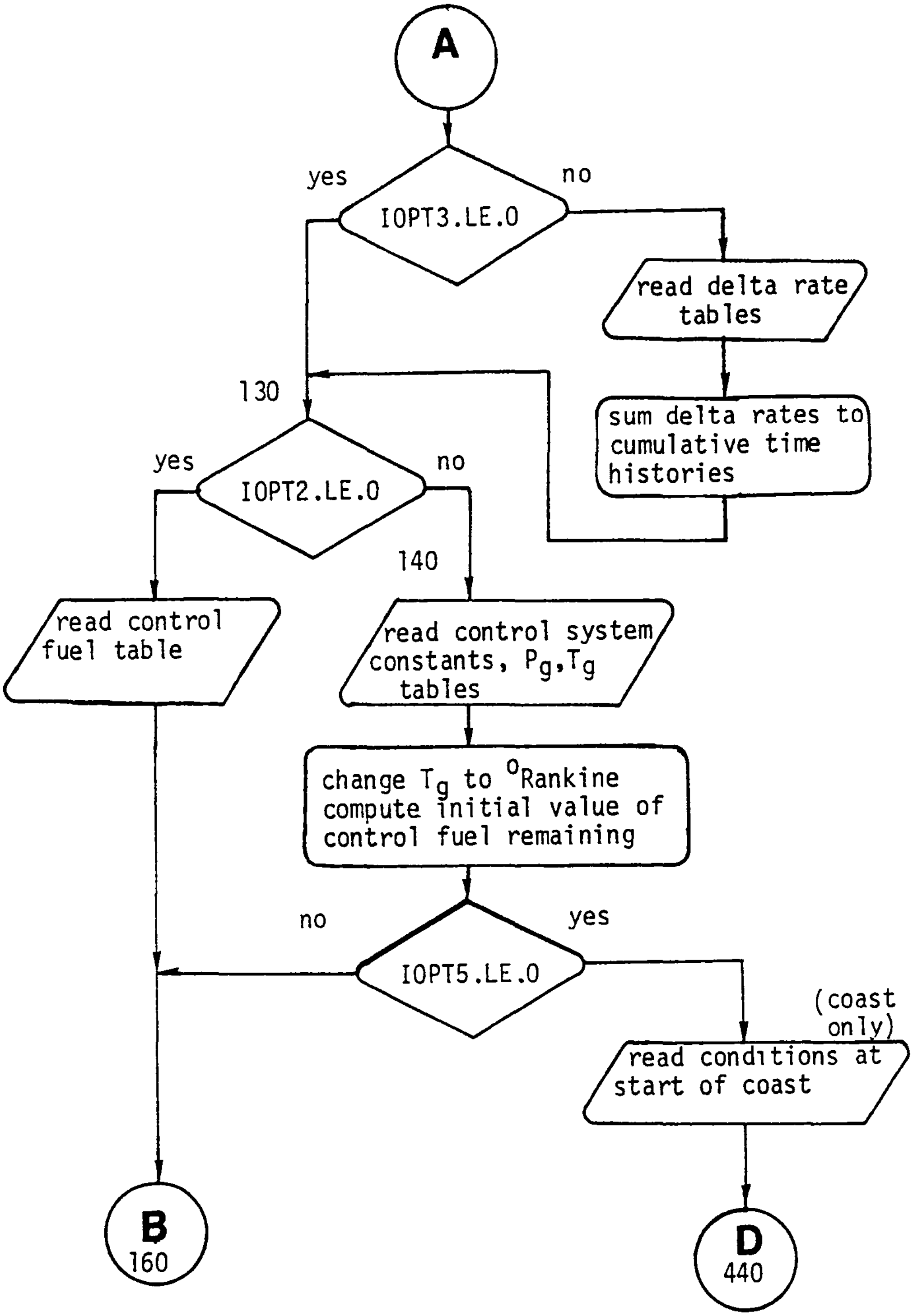


Figure 4 (continued)
Flow Chart of UPSTAG

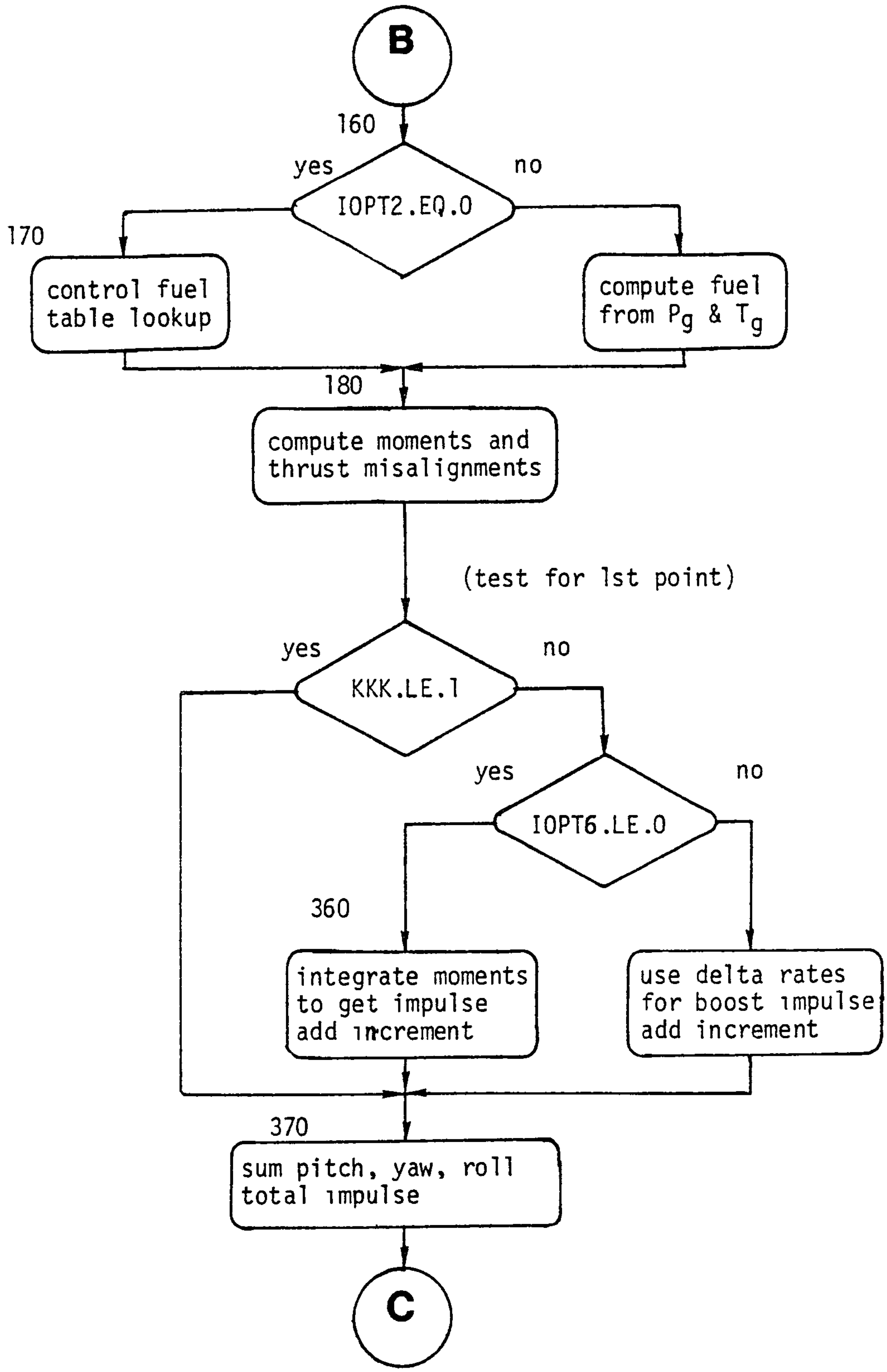


Figure 4 (continued)
Flow Chart of UPSTAG

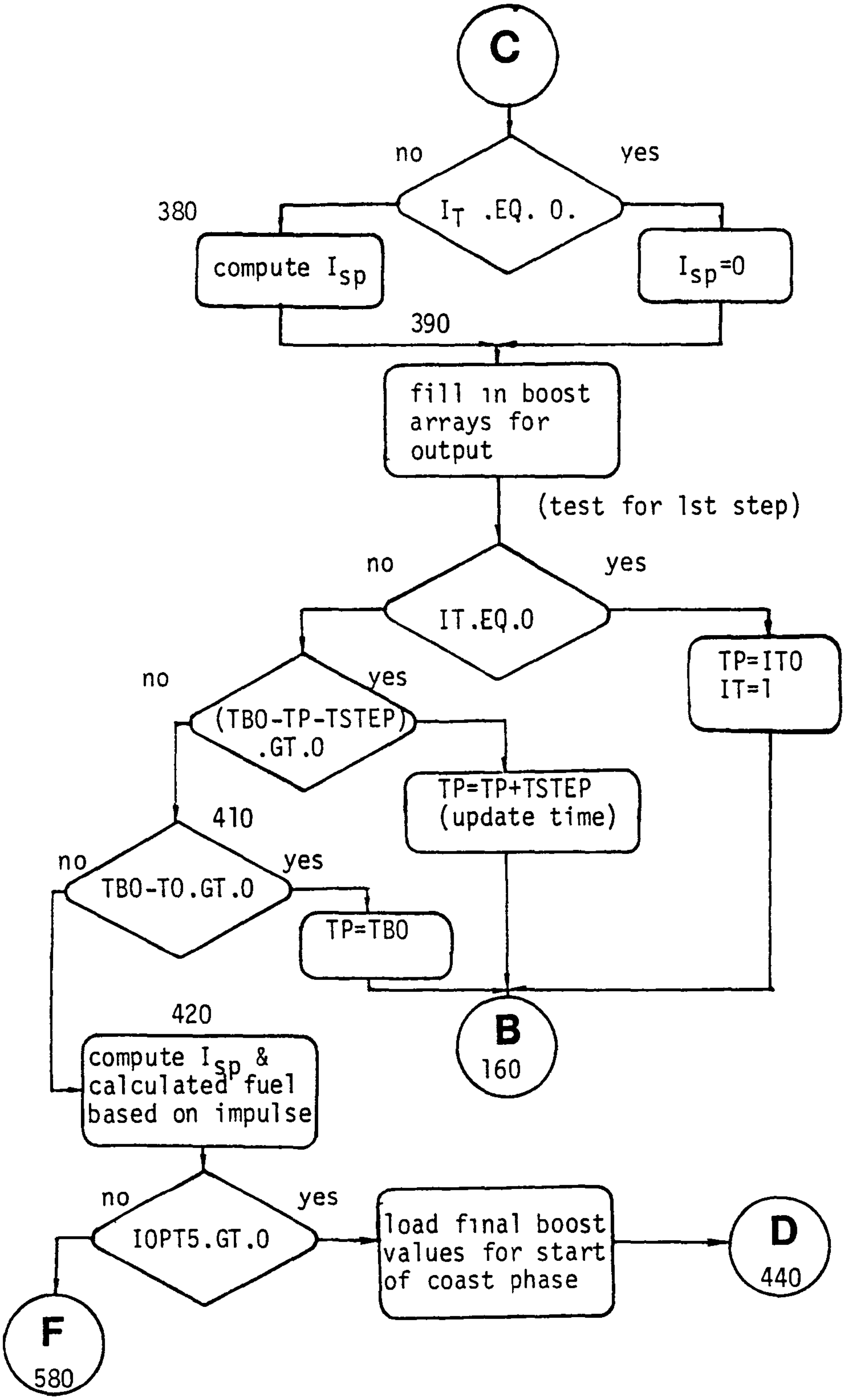


Figure 4 (continued)
Flow Chart of UPSTAG

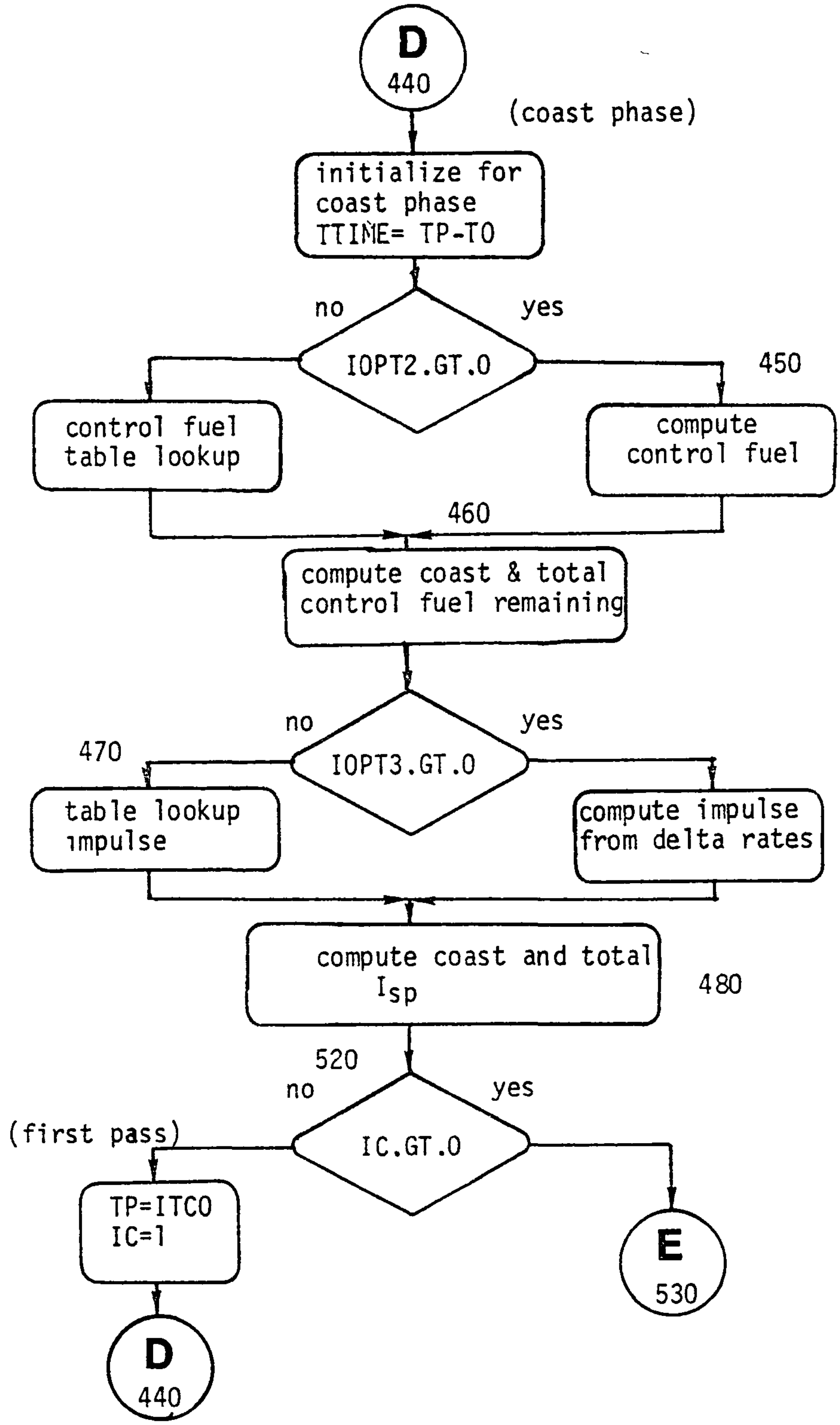


Figure 4 (continued)
Flow Chart of UPSTAG

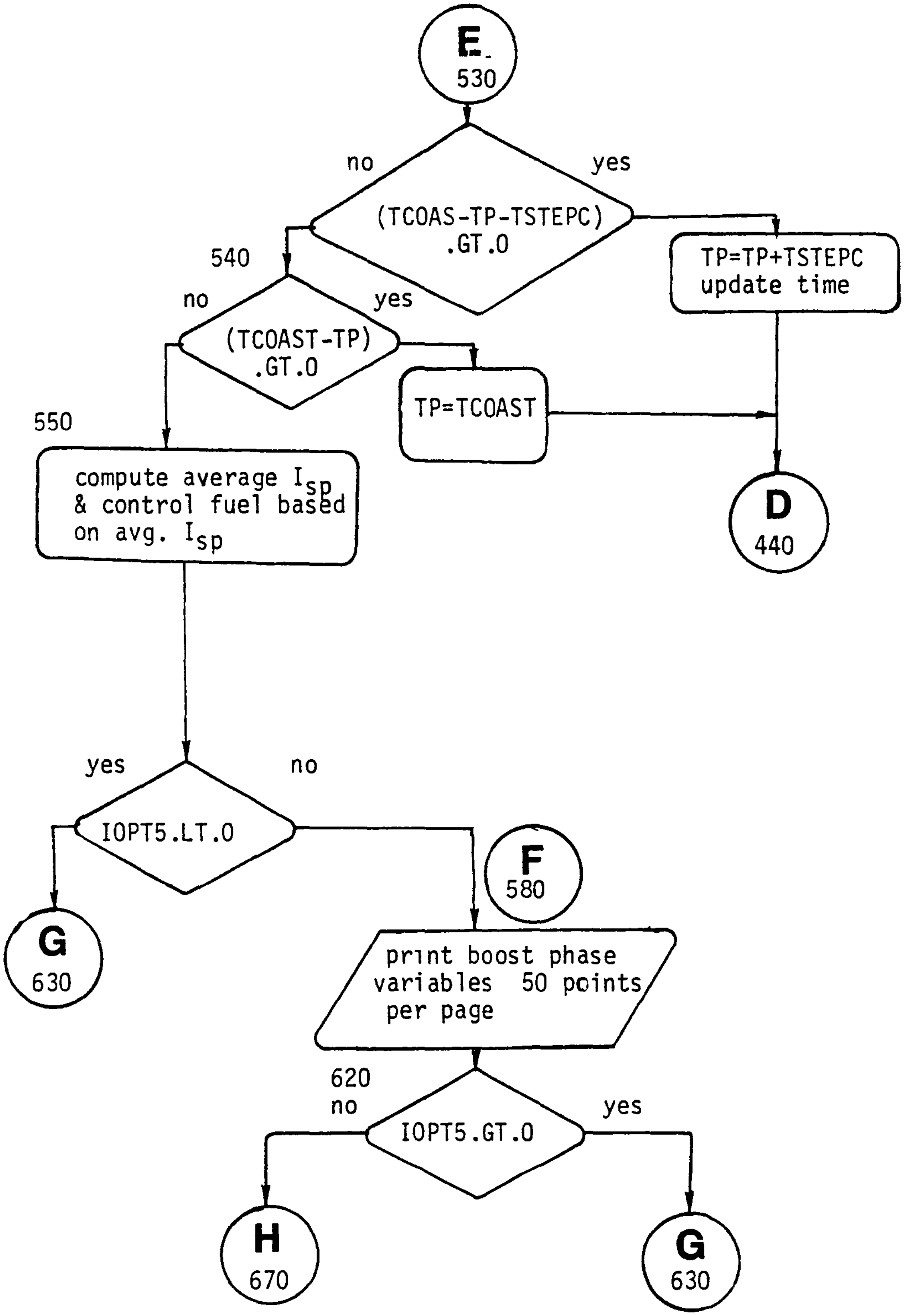


Figure 4 (concluded)
Flow Chart of UPSTAG

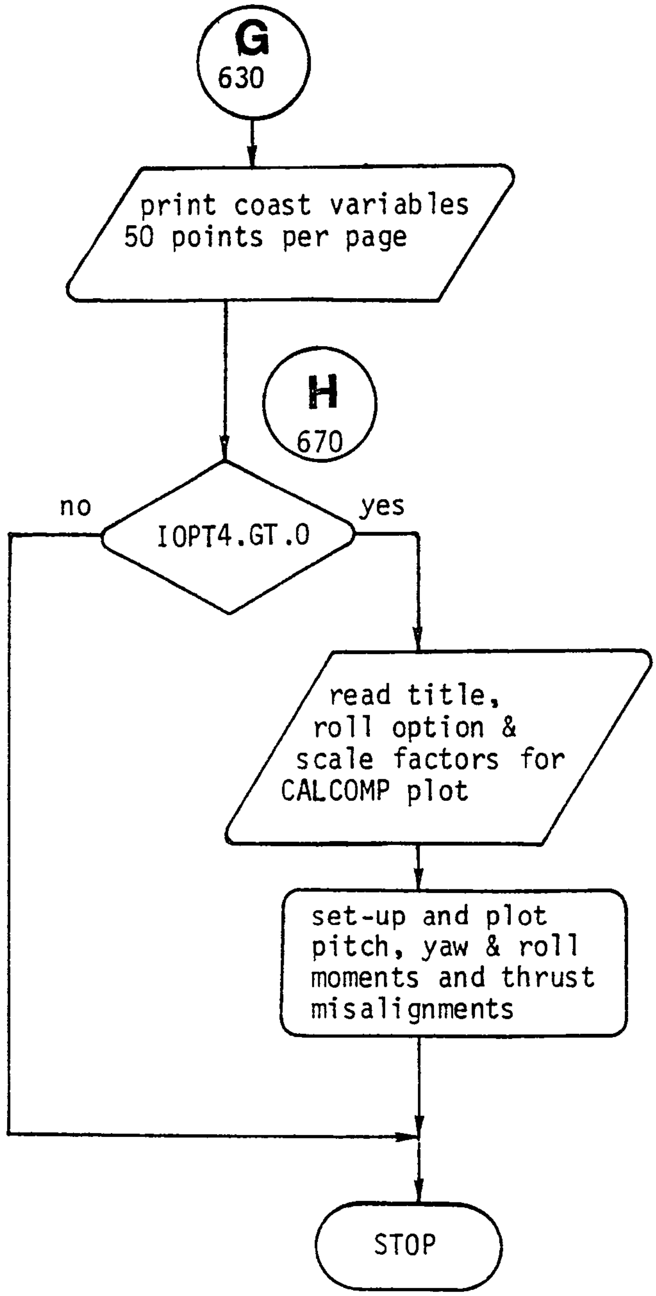


Figure 5
Sample Problem Input Data

```
  1    0    1    1    1    0
SAMPLE PROBLEM FOR UPSTAG PROGRAM
SCOUT VEHICLE S-192C SECOND STAGE DISTURBING MOMENTS
    86.16     126.44       0.25      160.4        1.0
   448.51     467.76      14.93      16.89      119.3      0.472
    109.0        5.0    0.00358        6.3
 222                            Q DYNAMIC PRESSURE
   84.000    138.680     84.500    131.201     85.000    124.079     85.500
  118.106     86.000    112.148     86.500    106.786     87.000    101.354
   87.500     95.946     88.000     90.751     88.500     86.363     89.000
   84.740     89.500     82.326     90.000     79.853     90.500     77.682
   91.000     75.215     91.500     72.610     92.000     69.868     92.500
   67.020     93.000     64.742     93.500     63.296     94.000     61.789
   94.500     60.204     95.000     58.548     95.500     56.802     96.000
   54.926     96.500     52.932     97.000     51.202     97.500     50.740
   98.000     50.252     98.500     49.688     99.000     48.966     99.500
   48.175    100.000     47.271    100.500     46.257    101.000     45.146
  101.500     43.869    102.000     42.476    102.500     41.000    103.000
   39.436    103.500     37.732    104.000     35.870    104.500     34.135
  105.000     33.763    105.500     33.372    106.000     32.956    106.500
   32.511    107.000     31.957    107.500     31.278    108.000     30.516
  108.500     29.649    109.000     28.698    109.500     27.650    110.000
   26.515    110.500     25.259    111.000     23.909    111.500     22.088
  112.000     20.100    112.500     17.952    113.000     15.659    113.500
   13.171    114.000     10.499    114.500     10.009    115.000      9.824
  115.500      9.585    116.000      9.311    116.500      9.003    117.000
    8.664    117.500      8.285    118.000      7.894    118.500      7.476
  119.000      7.023    119.500      6.524    120.000      6.320    120.500
    6.120    121.000      5.900    121.500      5.601    122.000      5.336
  122.500      4.992    123.000      4.632    123.500      4.223    124.000
    3.807    124.500      3.368    125.000      3.158    125.500      2.948
  126.000      2.739    126.500      2.532    127.000      2.325    127.500
    2.121    128.000      1.918    128.500      1.716    129.000      1.515
  129.500      1.324    130.000      1.235    130.500      1.146    131.000
    1.058    131.500       .971    132.000       .883    132.500       .797
  133.000       .710    133.500       .625    134.000       .540    134.500
     .455    135.000       .414    135.500       .386    136.000       .357
  136.500       .329    137.000       .301    137.500       .273    138.000
     .245    138.500       .218    139.000       .190
 222                            ALPHA
   84.000       .087     84.500       .136     85.000       .134     85.500
     .123     86.000       .100     86.500       .231     87.000       .167
   87.500       .258     88.000       .252     88.500       .245     89.000
     .212     89.500       .291     90.000       .197     90.500       .306
   91.000       .181     91.500       .217     92.000       .149     92.500
     .085     93.000       .163     93.500       .097     94.000       .246
   94.500       .154     95.000       .215     95.500       .292     96.000
     .217     96.500       .312     97.000       .333     97.500       .323
   98.000       .462     98.500       .494     99.000       .449     99.500
     .539    100.000       .588    100.500       .504    101.000       .531
  101.500       .535    102.000       .428    102.500       .397    103.000
     .509    103.500       .373    104.000       .273    104.500       .264
  105.000       .213    105.500       .164    106.000       .210    106.500
     .274    107.000       .215    107.500       .339    108.000       .335
  108.500       .231    109.000       .303    109.500       .205    110.000
     .140    110.500       .183    111.000       .024    111.500       .002
  112.000       .050    112.500      -.003    113.000       .224    113.500
     .050    114.000       .176    114.500       .159    115.000       .091
  115.500       .211    116.000       .097    116.500       .153    117.000
     .246    117.500       .046    118.000       .210    118.500       .061
  119.000       .101    119.500       .272    120.000       .174    120.500
     .371    121.000       .297    121.500       .182    122.000       .447
  122.500       .011    123.000       .092    123.500       .077    124.000
    -.632    124.500      -.465    125.000       .032    125.500      -.588
  126.000      -.295    126.500      -.065    127.000      -.691    127.500
    -.167    128.000      -.280    128.500      -.445    129.000      -.004
  129.500      -.235    130.000      -.480    130.500      -.753    131.000
    -.518    131.500      -.077    132.000      -.215    132.500      -.411
  133.000      -.636    133.500      -.854    134.000      -.397    134.500
    -.074    135.000      -.246    135.500      -.418    136.000      -.597
  136.500      -.774    137.000      -.929    137.500      -.291    138.000
    -.136    138.500      -.316    139.000      -.437
```

```
222                               BETA
  84.000       -.440     84.500       -.417     85.000       -.359     85.500
   -.400      86.000      -.386      86.500      -.351      87.000      -.136
  87.500        .052     88.000       -.023     88.500        .021     89.000
    .248      89.500       .147      90.000       .081      90.500       .185
  91.000        .276     91.500        .013     92.000       -.161     92.500
   -.279      93.000      -.273      93.500      -.216      94.000      -.083
  94.500       -.107     95.000       -.284     95.500       -.341     96.000
   -.315      96.500      -.262      97.000      -.140      97.500      -.161
  98.000       -.318     98.500       -.335     99.000       -.306     99.500
   -.138     100.000       .141     100.500       .075     101.000      -.048
 101.500       -.067    102.000       -.011    102.500        .127    103.000
   -.112     103.500      -.333     104.000      -.492     104.500      -.592
 105.000       -.580    105.500       -.400    106.000       -.140    106.500
   -.389     107.000      -.477     107.500      -.472     108.000      -.303
 108.500       -.180    109.000       -.013    109.500        .137    110.000
    .337     110.500       .288     111.000      -.107     111.500      -.557
 112.000       -.831    112.500       -.587    113.000       -.398    113.500
   -.224     114.000       .044     114.500       .163     115.000       .219
 115.500       -.429    116.000      -1.006    116.500       -.818    117.000
   -.406     117.500       .022     118.000      -.013     118.500      -.440
 119.000       -.590    119.500       -.055    120.000        .505    120.500
    .304     121.000      -.083     121.500       .109     122.000       .886
 122.500        .151    123.000       -.090    123.500        .094    124.000
   -.643     124.500      -.292     125.000      -.158     125.500      -.521
 126.000        .069    126.500        .092    127.000       -.322    127.500
    .292     128.000       .135     128.500      -.310     129.000      -.088
 129.500        .284    130.000        .459    130.500        .065    131.000
   -.348     131.500       .014     132.000       .450     132.500       .389
 133.000        .062    133.500       -.339    134.000       -.013    134.500
    .400     135.000       .227     135.500      -.094     136.000      -.433
 136.500       -.081    137.000        .437    137.500        .100    138.000
   -.206     138.500      -.133     139.000       .404
 66             BOOSTER THRUST VERSUS TIME (CASTOR II)
    0.00         0.0        .21     42713.6        .46     40156.7
    1.86     44017.7       3.36     46204.6       6.36     51153.7
    8.36     54410.5      10.36     57460.7      12.36     60198.0
   14.36     62885.3      16.36     65194.0      18.36     67299.6
   20.36     68908.8      22.36     70342.4      23.86     71204.5
   25.86     71801.8      27.86     71612.4      29.36     71214.3
   30.86     70392.3      31.86     69206.1      34.96     69507.8
   35.56     67122.7      35.86     66835.9      35.96     65433.8
   36.46     27492.7      36.66     15760.3      36.86     10049.3
   37.26      5339.6      37.86      1697.8      38.36       440.0
   39.41        21.0      40.00         0.0     100.00         0.0
 66             BOOSTER WEIGHT OF PROPELLANT REMAINING TIME HISTORY
    0.00     8274.34        .21     8253.70        .46     8213.68
    1.86     7984.04       3.36     7733.81       6.36     7197.29
    8.36     6805.81      10.36     6396.28      12,36     5967.30
   14.36     5511.28      16.36     5041.14      18.36     4557.46
   20.36     4056.87      22.36     3547.13      23.86     3159.52
   25.86     2643.79      27.86     2130.12      29.36     1746.67
   30.86     1372.14      31.86     1126.46      34.96      372.10
   35.56      227.09      35.86      157.85      35.96      133.41
   36.46       47.56      36.66       31.58      36.86       22.04
   37.26       10.67      37.86        2.87      38.36         .89
   39.41        0.00      40.00        0.00     100.00        0.00
 10             IXX ROLL INERTIA VS. % PROPELLANT CONSUMED
      0.      427.80        25.      410.55        50.      367.84
     75.      299.68       100.      206.10
 10               IYY PITCH/YAW INERTIA VS. % PROPELLANT CONSUMED
      0.    49263.29        25.    45824.92        50.    41600.69
     75.    36058.32       100.    28031.35
 10               XCG VS. % PROPELLANT  CONSUMED
      0.      282.03        25.      272.09        50.      258.44
     75.      238.53       100.      206.76
```

Figure 5 (concluded)
Sample Problem Inout Data

```
    2.825       2.841       2.318       3.96        3.96        3.96
108                              PITCH SLOPES
    86.36        5.90       86.76       5.00       87.26        9.40
    87.86        7.60       88.86       6.20       89.86        6.90
    90.66        7.50       91.16       8.40       91.76        8.90
    92.76        8.90       93.56       9.50       94.46        9.50
    95.26       10.50       95.96      11.10       96.86       11.50
    97.56       11.50       98.36      11.50       99.06       12.50
    99.86       12.20      100.46      12.50      101.26       13.00
   101.96       12.70      102.76      13.00      103.36       12.80
   104.16       12.90      104.96      13.00      105.66       13.10
   106.46       13.00      107.16      13.70      107.86       14.20
   108.66       13.20      109.36      14.30      110.16       14.50
   110.96       12.60      111.86      12.50      112.66       13.40
   113.46       13.60      114.36      14.20      115.16       15.00
   116.46       15.10      117.06      15.80      117.56       15.90
   118.46       16.90      119.26      17.20      120.06       18.00
   120.96       19.00      121.46      20.00      121.76       21.30
   122.36       16.00      122.66      11.10      123.06        3.20
   123.66         .80      124.76       0.00      186.16        0.00
 98                              YAW SLOPES
    86.26       -2.50       87.16      -4.90       87.96       -2.80
    88.96       -4.90       89.46      -3.90       90.16       -1.90
    90.66       -2.50       91.46      -3.00       92.06       -1.20
    93.16       -1.00       94.06      -2.40       94.66       -2.60
    95.66       -1.90       96.36      -2.10       97.06       -3.00
    97.46       -2.10       98.66      -2.40       99.66       -2.10
   100.46       -3.80      101.16      -2.50      102.16       -2.20
   102.96       -2.30      103.96      -2.00      105.16       -1.80
   105.76       -2.20      106.56      -3.00      107.16       -2.40
   108.16       -1.00      109.16       -.30      110.16        -.80
   111.16        0.00      112.16        .80      113.16        1.00
   114.16         .30      115.66        .20      116.66         .20
   117.36         .10      119.36        .50      120.66         .60
   121.66        -.30      122.26       3.50      122.41        0.00
   122.66       -1.00      123.06      -2.70      123.26         .70
   123.86        1.00      124.46       -.20      125.16        0.00
   186.16        0.00
 58                              ROLL SLOPES
    86.96        3.50       87.96       1.20       88.76         .10
    89.96        1.10       91.66       1.00       93.56        1.00
    95.16        1.50       96.76       1.10       98.36        1.00
    99.06        1.50       99.76       1.20      101.16        1.00
   103.36        1.20      104.86        .90      105.46        0.00
   107.06        -.60      107.76      -1.00      108.56       -1.40
   109.16       -1.40      110.86       -.60      111.76       -2.00
   112.76        -.60      113.46       -.40      114.16        0.00
   118.16        0.00      121.66       0.00      122.36        2.00
   123.16        0.00      186.16       0.00
 22             INCREMENTAL IMPULSE VS. FLIGHT TIME
      86.         0.0         98.        0.0       102.          2.8
     106.         3.9        110.        7.3       114.         63.0
     118.       209.3        122.      419.0       124.        530.0
     126.       981.0        160.      981.0
 22             PITCH DELTA RATES DURING COAST
       0.        0.00        126.       0.00       130.         8.94
     134.        5.44        138.       3.48       142.         3.56
     146.        0.00        150.       3.87       154.         0.00
     156.        5.09        160.       1.92
 22             YAW DELTA RATES DURING COAST
       0.        0.00        126.       0.00       130.        10.62
     134.        5.11        138.       5.22       142.         7.27
     146.        6.99        150.       5.22       154.         7.44
     156.        5.34        160.       3.58
  4             ROLL DELTA RATES DURING COAST
       0.          0.        160.         0.
 32             CONTROL FUEL REMAINING VS. FLIGHT TIME
      80.       119.4         90.     119.35        95.        114.7
     100.       109.7        105.      104.2       110.         99.8
     115.        95.8        120.       90.3       125.         84.6
     130.        78.2        135.       75.8       140.         73.3
     145.        70.1        150.       68.5       155.         67.6
     160.        66.0
SAMPLE PROBLEM - SCOUT S-192C SECOND STAGE DISTURBANCES
  1             CALCOMP PLOT OPTION WITH ROLL PLOT
      10.       2000.         0.1         2.
%EOR
```

Figure 6
Sample Problem Printed Output Data

UPPER STAGE MOMENT ROUTINE PAGE = 1 A
PITCH VARIABLES TIME HISTORIES
SAMPLE PROBLEM FOR UPSTAG PROGRAM
SCOUT VEHICLE S-192C SECOND STAGE DISTURBING MOMENTS

FLIGHT TIME SEC	STAGE TIME SEC	ANGULAR ACCEL DEG/S/S	MOMENT OF INER. SLUG-FT2	AERO MOMENT FT-LB	MISALIGN MOMENT FT-LB	TOTAL MOMENT FT-LB	THRUST MISALN DEG	IMPULSE LB-SEC
86.16	0.00	1.16	49263.3	105.23	888.61	993.84	0.0000	0.00
87.00	.84	1.40	49058.9	113.94	1082.82	1196.76	.1082	59.07
88.00	1.84	1.45	48786.2	153.04	1084.68	1237.73	.1011	136.89
89.00	2.84	1.23	48509.0	119.37	925.81	1045.18	.0831	209.56
90.00	3.84	1.37	48222.1	104.41	1052.34	1156.74	.0908	279.34
91.00	4.84	1.59	47924.9	89.54	1244.08	1333.62	.1032	357.91
92.00	5.84	1.75	47627.6	68.37	1387.64	1456.01	.1108	445.52
93.00	6.84	1.79	47316.9	68.71	1407.59	1476.30	.1083	537.19
94.00	7.84	1.87	46991.5	98.60	1436.56	1535.16	.1066	630.88
95.00	8.84	2.01	46659.0	80.91	1554.03	1634.94	.1114	729.01
96.00	9.84	2.20	46318.6	76.08	1700.88	1776.96	.1179	834.10
97.00	10.84	2.28	45970.5	108.24	1717.62	1825.86	.1155	944.50
98.00	11.84	2.28	45565.7	145.28	1664.50	1809.79	.1085	1055.19
99.00	12.84	2.46	45114.5	136.39	1802.36	1938.76	.1140	1168.49
100.00	13.84	2.43	44648.9	170.46	1725.25	1895.71	.1058	1283.52
101.00	14.84	2.55	44176.3	145.90	1819.42	1965.33	.1085	1398.47
102.00	15.84	2.52	43696.3	109.93	1814.84	1924.76	.1054	1513.40
103.00	16.84	2.57	43209.6	119.75	1815.33	1935.07	.1028	1626.57
104.00	17.84	2.56	42715.8	57.72	1849.10	1906.82	.1021	1738.34
105.00	18.84	2.58	42213.6	41.85	1861.59	1903.44	.1005	1848.33
106.00	19.84	2.59	41702.5	40.36	1847.79	1888.15	.0978	1956.92
107.00	20.84	2.69	41057.8	39.05	1891.23	1930.28	.0978	2065.11
108.00	21.84	2.79	40374.9	57.26	1911.69	1968.95	.0966	2174.32
109.00	22.84	2.73	39687.5	48.14	1845.67	1893.81	.0912	2281.29
110.00	23.84	2.88	38995.1	20.14	1942.96	1963.10	.0941	2386.89
111.00	24.84	2.50	38304.2	3.09	1667.78	1670.87	.0794	2485.27
112.00	25.84	2.51	37613.3	5.16	1643.97	1649.13	.0770	2574.16
113.00	26.84	2.68	36925.1	17.93	1710.70	1728.63	.0793	2663.62
114.00	27.84	2.78	36237.0	9.38	1749.22	1758.60	.0802	2754.98
115.00	28.84	2.96	35325.0	4.40	1822.85	1827.26	.0825	2847.49
116.00	29.84	3.01	34344.1	4.17	1800.45	1804.62	.0805	2939.67
117.00	30.84	3.15	33375.2	9.73	1825.40	1835.14	.0808	3030.57
118.00	31.84	3.29	32421.6	7.42	1854.23	1861.65	.0821	3121.48
119.00	32.84	3.44	31477.1	3.01	1887.73	1890.75	.0821	3212.36
120.00	33.84	3.62	30532.8	4.52	1925.33	1929.85	.0823	3303.53
121.00	34.84	3.87	29588.6	7.03	1990.98	1998.01	.0836	3395.89
122.00	35.84	3.90	28661.8	8.88	1941.81	1950.70	.0835	3487.43
123.00	36.84	.86	28120.6	1.63	420.81	422.44	.1129	3541.99
124.00	37.84	.11	28043.5	-8.77	61.59	52.82	.0963	3552.91
125.00	38.84	0.00	28033.2	.38	-.38	0.00	-.0044	3554.12
126.00	39.84	0.00	28031.4	-3.05	3.05	0.00	1.5225	3554.12
126.44	40.28	0.00	28031.4	-.90	.90	0.00	0.0000	3554.12

Figure 6 (continued)
Sample Problem Printed Output Data

UPPER STAGE MOMENT ROUTINE PAGE - 1 B
YAW VARIABLES TIME HISTORIES
SAMPLE PROBLEM FOR UPSTAG PROGRAM
SCOUT VEHICLE S-192C SECOND STAGE DISTURBING MOMENTS

FLIGHT TIME SEC	STAGE TIME SEC	ANGULAR ACCEL DEG/S/S	MOMENT OF INER. SLUG-FT2	AERO MOMENT FT-LB	MISALIGN MOMENT FT-LB	TOTAL MOMENT FT-LB	THRUST MISALN DEG	IMPULSE LB-SEC
86.16	0.00	-.49	49263.3	277.92	-700.20	-422.28	0.0000	0.00
87.00	.84	-.88	49058.9	92.79	-846.47	-753.68	-.0845	31.71
88.00	1.84	-.57	48786.2	13.97	-496.52	-482.55	-.0463	71.23
89.00	2.84	-.95	48509.0	-139.64	-663.45	-803.09	-.0595	112.15
90.00	3.84	-.46	48222.1	-42.93	-346.87	-389.80	-.0299	149.95
91.00	4.84	-.53	47924.9	-136.54	-309.24	-445.78	-.0257	176.32
92.00	5.84	-.27	47627.6	73.88	-299.16	-225.28	-.0239	197.39
93.00	6.84	-.20	47316.9	115.07	-281.94	-166.87	-.0217	209.65
94.00	7.84	-.45	46991.5	33.27	-404.89	-371.63	-.0300	226.40
95.00	8.84	-.46	46659.0	106.88	-484.74	-377.86	-.0347	249.61
96.00	9.84	-.39	46318.6	110.44	-427.54	-317.10	-.0296	271.01
97.00	10.84	-.57	45970.5	45.51	-506.32	-460.82	-.0340	294.85
98.00	11.84	-.44	45565.7	100.00	-449.14	-349.14	-.0293	319.51
99.00	12.84	-.45	45114.5	92.95	-448.39	-355.43	-.0284	340.80
100.00	13.84	-.55	44648.9	-40.87	-391.39	-432.26	-.0240	364.43
101.00	14.84	-.55	44176.3	13.19	-436.98	-423.79	-.0261	389.92
102.00	15.84	-.44	43696.3	2.83	-339.59	-336.76	-.0197	412.39
103.00	16.84	-.45	43209.6	26.35	-365.29	-338.94	-.0207	432.20
104.00	17.84	-.39	42715.8	104.02	-395.90	-291.88	-.0219	450.55
105.00	18.84	-.36	42213.6	113.96	-378.27	-264.31	-.0204	466.61
106.00	19.84	-.48	41702.5	26.90	-375.80	-348.89	-.0199	484.17
107.00	20.84	-.50	41057.8	86.63	-447.04	-360.41	-.0231	504.27
108.00	21.84	-.24	40374.9	51.79	-221.17	-169.38	-.0112	519.11
109.00	22.84	-.08	39687.5	2.07	-58.10	-56.03	-.0029	525.35
110.00	23.84	-.14	38995.1	-48.47	-47.74	-96.21	-.0023	529.52
111.00	24.84	-.03	38304.2	13.78	-30.58	-16.80	-.0015	532.58
112.00	25.84	.13	37613.3	85.77	.84	86.62	.0000	534.45
113.00	26.84	.19	36925.1	31.86	90.63	122.49	.0042	539.98
114.00	27.84	.08	36237.0	-2.35	53.50	51.16	.0025	544.53
115.00	28.84	.05	35325.0	-10.59	40.13	29.53	.0018	546.62
116.00	29.84	.04	34344.1	43.21	-19.67	23.54	-.0009	547.96
117.00	30.84	.03	33375.2	16.07	1.25	17.32	.0001	548.98
118.00	31.84	.04	32421.6	.46	24.87	25.33	.0011	550.03
119.00	32.84	.08	31477.1	17.59	28.58	46.16	.0012	551.76
120.00	33.84	.11	30532.8	-13.12	70.58	57.46	.0030	554.24
121.00	34.84	.06	29588.6	1.97	27.84	29.81	.0012	556.29
122.00	35.84	.36	28661.8	-17.61	199.87	182.26	.0086	561.20
123.00	36.84	-.48	28120.6	1.60	-237.35	-235.76	-.0637	562.43
124.00	37.84	.14	28043.5	8.92	60.27	69.19	.0942	566.26
125.00	38.84	-.01	28033.2	1.90	-6.29	-4.39	-.0720	567.75
126.00	39.84	0.00	28031.4	-.71	.71	0.00	.3561	567.85
126.44	40.28	0.00	28031.4	-.87	.87	0.00	0.0000	567.85

Figure 6 (continued)
Sample Problem Printed Output Data

UPPER STAGE MOMENT ROUTINE PAGE - 1 C
ROLL VARIABLES TIME HISTORIES
SAMPLE PROBLEM FOR UPSTAG PROGRAM
SCOUT VEHICLE S-192C SECOND STAGE DISTURBING MOMENTS

FLIGHT TIME SEC	STAGE TIME SEC	ANGULAR ACCEL DEG/S/S	MOMENT OF INER SLUG-FT2	TOTAL MOMENT FT-LB	IMPULSE LB-SEC	C.G. POINT INCH	CALCULATED FUEL CONSUM LB	CALCULATED FUEL REMAIN LB
86.16	0.00	.56	427.8	4.19	0.00	282.030	0.000	119.369
87.00	.84	.55	426.8	4.07	2.47	281.439	.669	118.700
88.00	1.84	.18	425.4	1.36	1.93	280.651	1.507	117.862
89.00	2.84	.05	424.0	.36	.61	279.849	2.313	117.057
90.00	3.84	.18	422.6	1.30	.59	279.020	3.084	116.285
91.00	4.84	.17	421.1	1.22	.90	278.161	3.839	115.530
92.00	5.84	.16	419.6	1.17	.85	277.301	4.619	114.750
93.00	6.84	.16	418.0	1.17	.83	276.403	5.364	114.005
94.00	7.84	.18	416.4	1.32	.89	275.462	6.157	113.212
95.00	8.84	.23	414.7	1.68	1.07	274.501	7.029	112.340
96.00	9.84	.21	413.0	1.49	1.13	273.517	7.937	111.432
97.00	10.84	.17	411.3	1.25	.97	272.511	8.899	110.470
98.00	11.84	.16	407.9	1.17	.86	271.252	9.869	109.500
99.00	12.84	.23	403.4	1.64	1.70	269.794	10.841	108.528
100.00	13.84	.19	398.7	1.30	2.45	268.290	11.841	107.528
101.00	14.84	.16	393.9	1.13	2.96	266.763	12.852	106.517
102.00	15.84	.17	389.0	1.17	3.62	265.212	13.843	105.526
103.00	16.84	.19	384.1	1.25	3.94	263.639	14.799	104.570
104.00	17.84	.17	379.1	1.14	4.20	262.043	15.735	103.634
105.00	18.84	.11	374.0	.72	4.29	260.421	16.640	102.729
106.00	19.84	-.03	368.9	-.21	4.08	258.769	17.543	101.826
107.00	20.84	-.09	361.2	-.58	5.03	256.490	18.471	100.899
108.00	21.84	-.18	352.8	-1.10	6.20	254.037	19.369	100.000
109.00	22.84	-.22	344.3	-1.35	7.32	251.567	20.189	99.180
110.00	23.84	-.16	335.8	-.94	8.11	249.080	20.983	98.387
111.00	24.84	-.13	327.3	-.75	21.83	246.598	21.809	97.560
112.00	25.84	-.27	318.8	-1.48	35.94	244.116	22.561	96.808
113.00	26.84	-.09	310.3	-.46	49.77	241.644	23.342	96.027
114.00	27.84	-.01	301.9	-.08	63.19	239.172	24.126	95.243
115.00	28.84	0.00	291.1	0.00	99.60	235.627	25.066	94.303
116.00	29.84	0.00	279.7	0.00	136.15	231.745	26.000	93.370
117.00	30.84	0.00	268.4	0.00	172.73	227.910	26.922	92.448
118.00	31.84	0.00	257.3	0.00	209.30	224.136	27.844	91.525
119.00	32.84	0.00	246.3	0.00	261.73	220.398	28.884	90.485
120.00	33.84	0.00	235.3	0.00	314.15	216.661	29.932	89.437
121.00	34.84	0.00	224.3	0.00	366.58	212.923	30.986	88.383
122.00	35.84	.16	213.4	.58	419.21	209.255	32.056	87.314
123.00	36.84	.06	207.1	.23	474.79	207.113	32.855	86.515
124.00	37.84	0.00	206.2	0.00	530.08	206.808	33.357	86.012
125.00	38.84	0.00	206.1	0.00	755.50	206.767	34.994	84.375
126.00	39.84	0.00	206.1	0.00	981.00	206.760	36.612	82.757
126.44	40.28	0.00	206.1	0.00	981.00	206.760	36.612	82.757

Figure 6 (continued)
Sample Problem Printed Output Data

UPPER STAGE MOMENT ROUTINE PAGE • 1 D
TIME HISTORIES OF SYSTEM
SAMPLE PROBLEM FOR UPSTAG PROGRAM
SCOUT VEHICLE S-192C SECOND STAGE DISTURBING MOMENTS

FLIGHT TIME SEC	STAGE TIME SEC	THRUST LB	TOTAL MISALGN DEG	LAMDA DEG	SPECIFIC IMPULSE SEC	TOTAL IMPULSE LB-SEC	FUEL CONSUM LB	FUEL REMAIN LB
86.16	0.00	0.	0.0000	0.00	0.00	0.00	0.00	119.37
87.00	.84	41205.	.1373	321.98	*******	93.24	.00	119.37
88.00	1.84	43963.	.1112	335.40	*******	210.05	.01	119.36
89.00	2.84	45446.	.1022	324.37	*******	322.32	.01	119.36
90.00	3.84	46996.	.0956	341.76	*******	429.88	.02	119.35
91.00	4.84	48646.	.1064	346.04	563.76	535.12	.95	118.42
92.00	5.84	50296.	.1133	347.83	342.58	643.77	1.88	117.49
93.00	6.84	51935.	.1104	348.67	266.15	747.68	2.81	116.56
94.00	7.84	53564.	.1107	344.26	229.51	858.17	3.74	115.63
95.00	8.84	55143.	.1167	342.67	209.82	979.68	4.67	114.70
96.00	9.84	56668.	.1216	345.89	195.13	1106.23	5.67	113.70
97.00	10.84	58118.	.1204	343.57	185.98	1240.32	6.67	112.70
98.00	11.84	59486.	.1124	344.90	179.36	1375.56	7.67	111.70
99.00	12.84	60843.	.1174	346.03	174.29	1510.99	8.67	110.70
100.00	13.84	62187.	.1085	347.22	170.69	1650.40	9.67	109.70
101.00	14.84	63439.	.1116	346.49	166.34	1791.35	10.77	108.60
102.00	15.84	64594.	.1072	349.40	162.56	1929.41	11.87	107.50
103.00	16.84	65699.	.1048	348.62	159.05	2062.70	12.97	106.40
104.00	17.84	66752.	.1045	347.91	155.88	2193.09	14.07	105.30
105.00	18.84	67686.	.1026	348.51	152.89	2319.22	15.17	104.20
106.00	19.84	68490.	.0998	348.50	152.35	2445.17	16.05	103.32
107.00	20.84	69253.	.1005	346.70	152.07	2574.41	16.93	102.44
108.00	21.84	69970.	.0972	353.40	151.59	2699.63	17.81	101.56
109.00	22.84	70618.	.0913	358.20	150.57	2813.96	18.69	100.68
110.00	23.84	71193.	.0941	358.59	149.44	2924.52	19.57	99.80
111.00	24.84	71497.	.0795	358.95	149.23	3039.67	20.37	99.00
112.00	25.84	71796.	.0770	.03	148.54	3144.55	21.17	98.20
113.00	26.84	71709.	.0794	3.03	148.09	3253.37	21.97	97.40
114.00	27.84	71614.	.0803	1.75	147.69	3362.70	22.77	96.60
115.00	28.84	71352.	.0825	1.26	148.23	3493.71	23.57	95.80
116.00	29.84	70951.	.0805	359.37	146.89	3623.78	24.67	94.70
117.00	30.84	70403.	.0808	.04	145.61	3752.28	25.77	93.60
118.00	31.84	69230.	.0821	.77	144.43	3880.81	26.87	92.50
119.00	32.84	69301.	.0821	.87	143.94	4025.85	27.97	91.40
120.00	33.84	69399.	.0823	2.10	143.52	4171.91	29.07	90.30
121.00	34.84	69496.	.0836	.80	142.96	4318.75	30.21	89.16
122.00	35.84	66855.	.0839	5.88	142.52	4467.84	31.35	88.02
123.00	36.84	10620.	.1296	330.57	140.95	4579.21	32.49	86.88
124.00	37.84	1819.	.1348	44.38	138.25	4649.25	33.63	85.74
125.00	38.84	248.	.0721	266.51	140.28	4877.37	34.77	84.60
126.00	39.84	6.	1.5636	13.17	141.56	5102.97	36.05	83.32
126.44	40.28	0.	0.0000	0.00	139.38	5102.97	36.61	82.76

(Note: ******* results when the computed number overflows the available output field width)

Figure 6 (concluded)
Sample Problem Printed Output Data

UPPER STAGE MOMENT ROUTINE   PAGE = 1 E
COAST VARIABLES TIME HISTORIES
SAMPLE PROBLEM FOR UPSTAG PROGRAM
SCOUT VEHICLE S-192C SECOND STAGE DISTURBING MOMENTS

FLIGHT TIME SEC	STAGE TIME SEC	COAST IMPULSE LB-SEC	TOTAL IMPULSE LB-SEC	COAST ISP SEC	TOTAL ISP SEC	COAST FUEL LB	TOTAL FUEL LB	FUEL REMAINING MEAS LB	FUEL REMAINING CALC LB
126.44	40.28	48.3	5151.3	0.00	140.96	0.00	36.54	82.76	82.35
127.00	40.84	109.9	5212.8	153.26	139.90	.72	37.26	82.04	81.84
129.00	42.84	329.6	5432.5	100.58	136.43	3.28	39.82	79.48	80.00
131.00	44.84	498.7	5601.6	99.01	134.72	5.04	41.58	77.72	78.58
133.00	46.84	617.2	5720.2	102.92	134.47	6.00	42.54	76.76	77.59
135.00	48.84	725.3	5828.3	104.26	133.98	6.96	43.50	75.80	76.68
137.00	50.84	823.0	5926.0	103.44	133.17	7.96	44.50	74.80	75.87
139.00	52.84	932.7	6035.7	104.13	132.65	8.96	45.50	73.80	74.95
141.00	54.84	1054.4	6157.3	104.43	132.02	10.10	46.64	72.66	73.93
143.00	56.84	1154.5	6257.4	101.47	130.58	11.38	47.92	71.38	73.09
145.00	58.84	1233.0	6335.9	97.42	128.78	12.66	49.20	70.10	72.43
147.00	60.84	1323.3	6426.2	99.52	128.94	13.30	49.84	69.46	71.68
149.00	62.84	1425.4	6528.4	102.27	129.33	13.94	50.48	68.82	70.82
151.00	64.84	1518.2	6621.2	105.16	129.88	14.44	50.98	68.32	70.05
153.00	66.84	1601.8	6704.8	108.25	130.60	14.80	51.34	67.96	69.35
155.00	68.84	1760.7	6863.7	116.17	132.76	15.16	51.70	67.60	68.02
157.00	70.84	1908.8	7011.8	120.83	133.97	15.80	52.34	66.96	66.78
159.00	72.84	1970.6	7073.5	119.89	133.51	16.44	52.98	66.32	66.26
160.40	74.24	2001.5	7104.4	119.44	133.29	16.76	53.30	66.00	66.00

*EOR

Figure 7

Sample Problem CALCOMP Plots

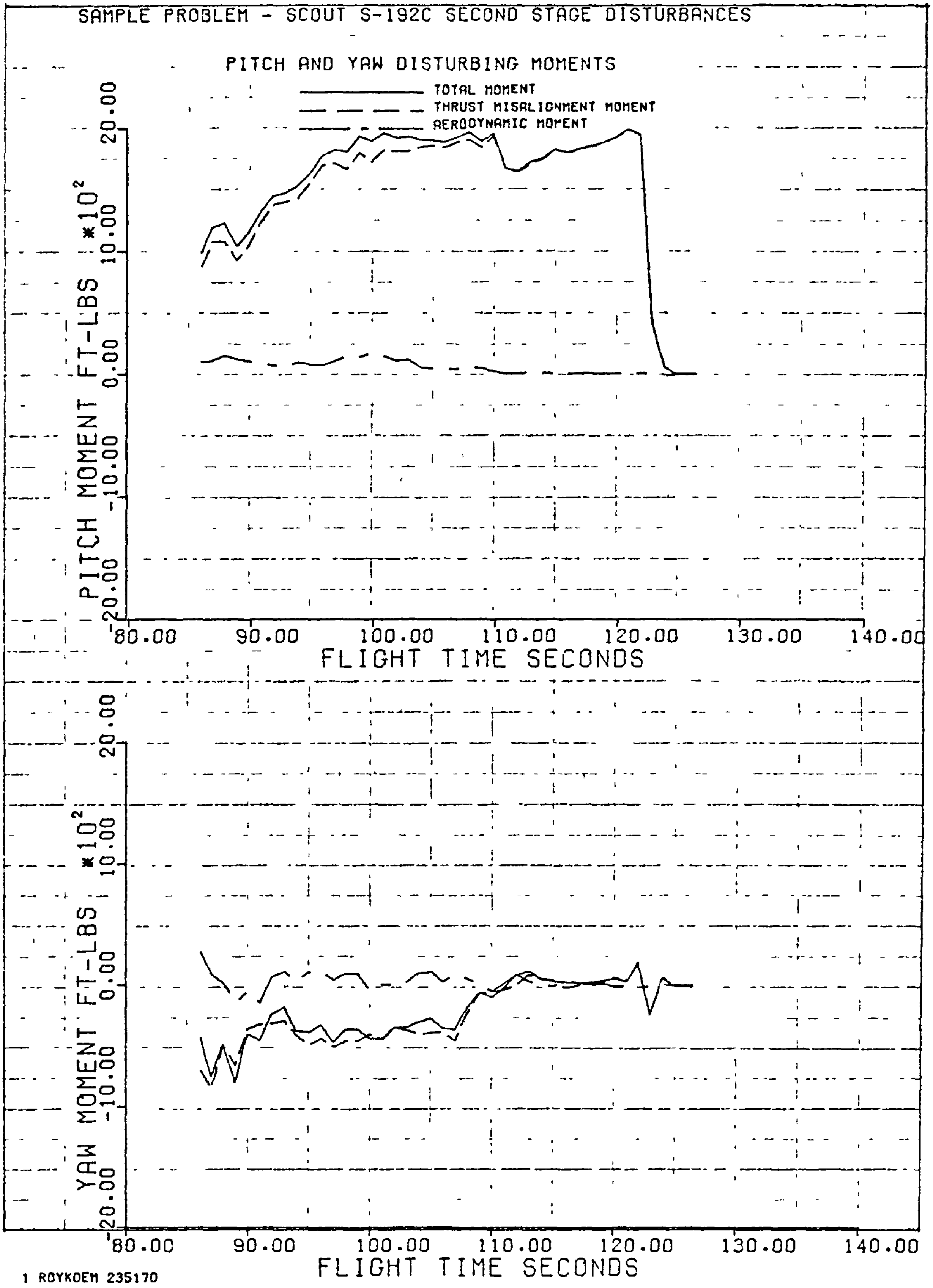
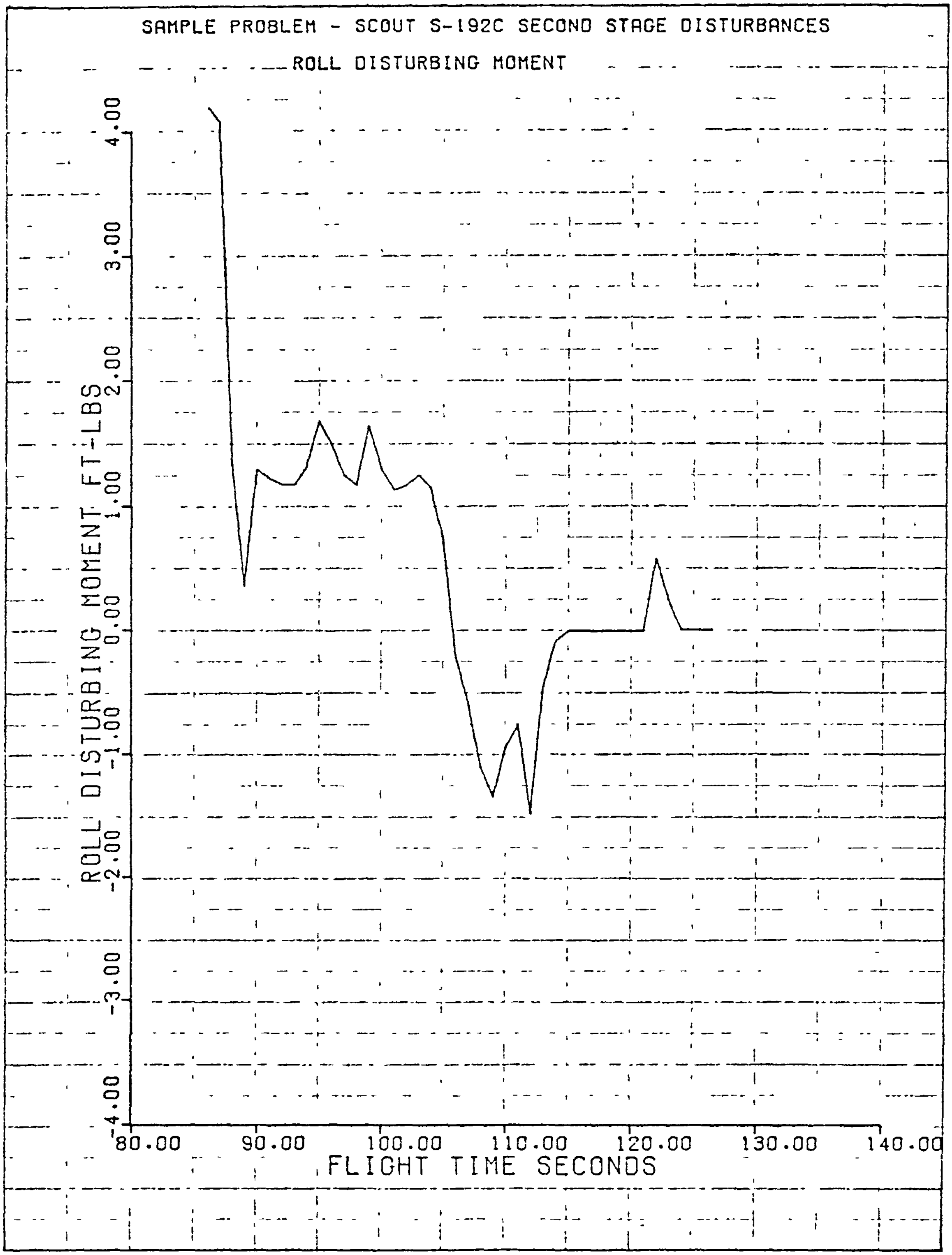
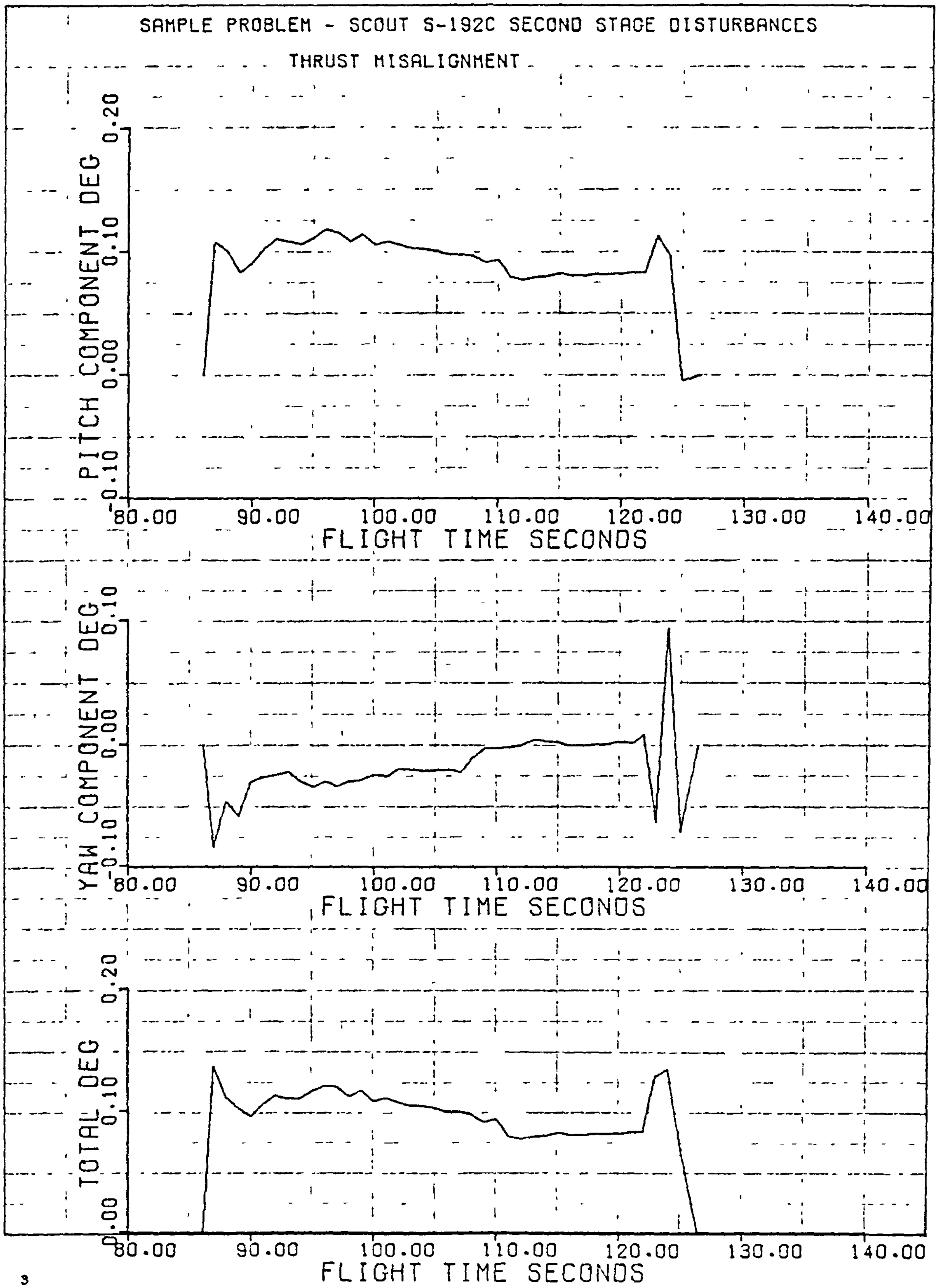


Figure 7 (continued)
Sample Problem CALCOMP Plots



2

Figure 7 (concluded)
Sample Problem CALCOMP Plots



3

APPENDIX A

FORTRAN PROGRAM LISTING

A complete FORTRAN source program listing is presented in the following pages. It starts with the main routine (UPSTAG) and is followed by the subroutines arranged in alphabetical order. There are a total of 481 cards in UPSTAG. The total program including subroutines contains 805 cards.

```
*DECK UPSTAG
      PROGRAM UPSTAG(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     UPSTAG IS A PROGRAM FOR POST-FLIGHT ANALYSIS OF THE PITCH, YAW
C     AND ROLL DISTURBANCES AND CONTROL FUEL CONSUMPTION FOR AN ON-OFF
C     REACTION CONTROLLED UPPER STAGE ROCKET VEHICLE.
      COMMON PVAR(200,9),YVAR(200,9),RVAR(200,9),TVAR(200,9)
      DIMENSION  NTITLE(8),LTITL(16),P(200),T(200),W(200),DPR(200),
     1          DYR(200),DRR(200),THEDD(200),PHIDD(200),PSIDD(200),
     2          TT(200),WP(200),XCG(200),AIXX(200),AIYY(200),RI(200),
     3          Q(300),ALPH(300),BETA(300),CVAR(200,10),BRACK(200)
C     READ OPTIONS
      READ( 5,830) IOPT1,IOPT2,IOPT3,IOPT4,IOPT5,IOPT6
C     READ TWO CARDS OF ARBITRARY LABELING
      READ( 5,860) (LTITL(J),J=1,16)
C     READ TIME PARAMETERS
      READ( 5,850) TO,TBO,TSTEP,TCOAST,TSTEPC
C     INITIALIZE ALL COUNTERS, INDICES, AND SUMS
      AINT=0.0
      BINT=0.0
      CINT=0.0
      KKK=0
      LLL=0
      IC=0
      IT=0
      TP=TO
      ITO=TO+1.
      ITCO=TBO+1.
      MPHD=1
      MTT=1
      MQ=1
      MA=1
      MB=1
      MDP=1
      MDY=1
      MDR=1
```

```
      MR=1
      MP=1
      MT=1
      MW=1
      MWP=1
      MIX=1
      MIY=1
      MCG=1
      MTD=1
      MPSD=1
      IF (IOPT5 .LT. 0 ) GO TO 90
C     READ IN CONSTANTS
      READ( 5,850) XT,XC,ZC,RC,WFUELI,CNAS,XCP,ETA,CN3,DCP
      ETA=ETA/57.3
C     READ AERODYNAMIC PARAMETER TABLES Q, ALPHA, BETA
      READ( 5,880) NQ,(Q(I),I=1,NQ)
      READ( 5,880) NALPH,(ALPH(I),I=1,NALPH)
      READ( 5,880) NBETA,(BETA(I),I=1,NBETA)
C     READ IN BOOSTER THRUST AND PROPELLANT REMAINING TIME HISTORIES
      READ( 5,840) NTT,(TT(I),I=1,NTT)
      READ( 5,840) NNWP,(WP(I),I=1,NNWP)
C     CONVERT PROPELLANT REMAINING TO PER-CENT WEIGHT REMAINING
      WTIGN=WP(2)
      DO 10 I=2,NNWP,2
   10 WP(I)=(WTIGN-WP(I))*100.0/WTIGN
C     READ IN MASS PROPERTIES VERSUS PERCENT BOOSTER PROPELLANT CONSUMED
      READ( 5,840) NWX,(AIXX(I),I=1,NWX)
      READ( 5,840) NWY,(AIYY(I),I=1,NWY)
      READ( 5,840) NXCG,(XCG(I),I=1,NXCG)
C     TEST FOR INPUT OF ANGULAR ACCELERATION VALUES
      IF (IOPT1 .GT. 0 ) GO TO 20
C     READ IN ANGULAR ACCELERATIONS
      READ( 5,840) NTHE,(THEDD(J),J=1,NTHE)
      READ( 5,840) NPSI,(PSIDD(J),J=1,NPSI)
      READ( 5,840) NPHI,(PHIDD(J),J=1,NPHI)
```

```
      GO TO 90
C
C     READ RATE TRACE SLOPE FACTORS
   20 READ( 5,850) XKTHE,XKPSI,XKPHI,XKTP,XKTY,XKTR
C     READ IN SLOPE ANGLES
      READ( 5,840) NTHE,(THEDD(I),I=1,NTHE)
      READ( 5,840) NPSI,(PSIDD(I),I=1,NPSI)
      READ( 5,840) NPHI,(PHIDD(I),I=1,NPHI)
      DO 30 I=2,NTHE,2
   30 THEDD(I)=THEDD(I)/57.3
      DO 40 I=2,NPSI,2
   40 PSIDD(I)=PSIDD(I)/57.3
      DO 50 I=2,NPHI,2
   50 PHIDD(I)=PHIDD(I)/57.3
C     CALCULATE ANGULAR ACCELERATIONS
      DO 60 I=2,NTHE,2
   60 THEDD(I)=XKTHE*XKTP*TAN(THEDD(I))
      DO 70 I=2,NPSI,2
   70 PSIDD(I)=XKPSI*XKTY*TAN(PSIDD(I))
      DO 80 I=2,NPHI,2
   80 PHIDD(I)=XKPHI*XKTR*TAN(PHIDD(I))
C     TEST FOR INPUT OF ROLL IMPULSE TABLE
   90 READ( 5,840) NRI,(RI(I),I=1,NRI)
C     TEST FOR INPUT OF DELTA RATES
      IF (IOPT3 .LE. 0 ) GO TO 130
      READ( 5,840) NDPR,(DPR(I),I=1,NDPR)
      READ( 5,840) NDYR,(DYR(I),I=1,NDYR)
      READ( 5,840) NDRR,(DRR(I),I=1,NDRR)
      DPRATE=0.0
      DYRATE=0.0
      DRRATE=0.0
      DO 100 I=2,NDPR,2
      DPR(I)=DPRATE+DPR(I)
  100 DPRATE=DPR(I)
      DO 110 I=2,NDYR,2
```

```
      DYR(I)=DYRATE+DYR(I)
  110 DYRATE=DYR(I)
      DO 120 I=2,NDRR,2
      DRR(I)=DRRATE+DRR(I)
  120 DRRATE=DRR(I)
C     TEST FOR     FUEL   WEIGHT INPUT/CALCULATION
  130 IF (IOPT2 .GT. 0 ) GO TO 140
C     READ IN FUEL WEIGHT DATA
      READ( 5,840) NW,(W(I),I=1,NW)
      GO TO 160
C
C     FUEL WEIGHT CALCULATION
  140 READ( 5,850) DENS,COMFAC,PREREG,DVOL,VOLN2
      READ( 5,840) NNP,(P(I),I=1,NNP)
      READ( 5,840) NNT,(T(I),I=1,NNT)
      DO 150 I=2,NNT,2
  150 T(I)=T(I)+460.0
      CONST1=DENS*COMFAC*VOLN2/PREREG
      CONST2=DENS*DVOL
      CALL C (P(2),T(2),CI)
      IF (IOPT5 .GE. 0 ) GO TO 160
      READ( 5,850) RC,WFUELI,YMA,RIXX,YIYY,WFUELM,WFUELC,BOIMP,RIC
      GO TO 440
C
  160 CONTINUE
      TTIME=TP-TO
      KKK=KKK+1
C     GET FUEL FUEL REMAINING ARRAY
      IF (IOPT2 .EQ. 0 ) GO TO 170
      CALL TBLU (NNP,PRES,TP,P,MP)
      CALL TBLU (NNT,TEMP,TP,T,MT)
      CALL C (PRES,TEMP,CF)
      DW=CONST1*((P(2)*TEMP)/(CI*T(2))-PRES/CF)+CONST2*((TEMP/T(2))-1.0)
      TVAR(KKK,9)=WFUELI-DW
      GO TO 180
```

```
C
 170 CALL TBLU (NW,WWT,TP,W,MW)
     TVAR(KKK,9)=WWT
C    OBTAIN IXX,IYY,CP IN TERMS OF TIME
 180 CALL TBLU (NNWP,WWP,TTIME,WP,MWP)
     CALL TBLU (NWX,AAIXX,WWP,AIXX,MIX)
     CALL TBLU (NWY,AAIYY,WWP,AIYY,MIY)
     CALL TBLU (NXCG,XXCG,WWP,XCG,MCG)
C    COMPUTE THE SUM OF THE MOMENT DISTURBANCES
C    OBTAIN THE ANGULAR ACCELERATIONS FROM TABLE LOOKUP ROUTINE
     CALL TBLU (NTHE,TTHEDD,TP,THEDD,MTD)
     CALL TBLU (NPSI,PPSIDD,TP,PSIDD,MPSD)
     CALL TBLU (NPHI,PPHIDD,TP,PHIDD,MPHD)
C    COMPUTE THE SUM OF MOMENTS
     PVAR(KKK,7)=AAIYY*TTHEDD/57.3
     YVAR(KKK,7)=AAIYY*PPSIDD/57.3
     RVAR(KKK,5)=AAIXX*PPHIDD/57.3
C    DEFINE X1 AND X2
     X2=(XT-XXCG)/12.
C    COMPUTE THRUST MISALIGNMENT COMPONENTS
     CALL TBLU (NTT,TTT,TTIME,TT,MTT)
     CALL TBLU (NQ,QQ,TP,Q,MQ)
     CALL TBLU (NALPH,AALPH,TP,ALPH,MA)
     CALL TBLU (NBETA,BBETA,TP,BETA,MB)
     IF (AALPH.NE.0.) GO TO 190
     IF (BBETA.NE.0.) GO TO 190
     AERO=0.
     AB=0.
     PVAR(KKK,5)=0.
     YVAR(KKK,5)=0.
     GO TO 200
C
C    COMPUTE TOTAL AERODYNAMIC ANGLE AND AERODYNAMIC MOMENTS
 190 TNA=TAN(AALPH/57.3)
     TNB=TAN(BBETA/57.3)
```

```
      TANETA=SQRT(TNA*TNA+TNB*TNB)
      AB=57.3*ATAN(TANETA)
      AERO=(CNAS*AB+CN3*AB**3)*QQ*(XXCG-XCP-DCP*ABS(AB))/12.
      PVAR(KKK,5)=AERO*TNA/TANETA
      YVAR(KKK,5)=-AERO*TNB/TANETA
  200 PVAR(KKK,6)=PVAR(KKK,7)-PVAR(KKK,5)
      YVAR(KKK,6)=YVAR(KKK,7)-YVAR(KKK,5)
      IF (TTT .GT. 0.) GO TO 210
      ETP=0.0
      ETY=0.0
      GO TO 220
C
  210 ETP=(PVAR(KKK,7)-PVAR(KKK,5))/(TTT*X2)
      ETY=(YVAR(KKK,7)-YVAR(KKK,5))/(TTT*X2)
C     COMPUTE TOTAL THRUST MISALIGNMENT
  220 ETOT=SQRT(ETP**2+ETY**2)
      PVAR(KKK,8)=ETP*57.3
      YVAR(KKK,8)=ETY*57.3
      TVAR(KKK,4)=ETOT*57.3
      IF (ETP) 230,270,310
  230 IF (ETY) 240,250,260
  240 ETOR=ATAN(ETY/ETP)*57.3+180.0
      GO TO 350
C
  250 ETOR=180.0
      GO TO 350
C
  260 ETOR=ATAN(ETY/ETP)*57.3+180.0
      GO TO 350
C
  270 IF (ETY) 280,290,300
  280 ETOR=270.0
      GO TO 350
C
  290 ETOR=0.0
```

```
      GO TO 350
C
  300 ETOR=90.0
      GO TO 350
C
  310 IF (ETY) 320,330,340
  320 ETOR=ATAN(ETY/ETP)*57.3+360.0
      GO TO 350
C
  330 ETOR=0.0
      GO TO 350
C
  340 ETOR=ATAN(ETY/ETP)*57.3
  350 TVAR(KKK,5)=ETOR
C     GET TIME ARRAY
      PVAR(KKK,1)=TP
      YVAR(KKK,1)=TP
      RVAR(KKK,1)=TP
      TVAR(KKK,1)=TP
      PVAR(KKK,2)=TTIME
      YVAR(KKK,2)=TTIME
      RVAR(KKK,2)=TTIME
      TVAR(KKK,2)=TTIME
C     GET BRACK ARRAY
      BRACK(KKK)=(XC-XXCG)*COS(ETA)/12.+(ZC*SIN(ETA))/12.
C     COMPUTE HYDROGEN PEROXIDE FUEL USED
      TVAR(KKK,8)=TVAR(1,9)-TVAR(KKK,9)
C     INTEGRATE MOMENTS IN PITCH AND YAW
      IF (KKK-1 .LE. 0 ) GO TO 370
      IF (IOPT6 .LE. 0 ) GO TO 360
      CALL TBLU (NDPR,DP,TP,DPR,MDP)
      CALL TBLU (NDYR,DY,TP,DYR,MDY)
      CALL TBLU (NDRR,DR,TP,DRR,MDR)
      AINT=AAIYY*DP/(57.3*BRACK(KKK))
      BINT=AAIYY*DY/(57.3*BRACK(KKK))
```

```
      CALL TBLU (NRI,CINT,TP,RI,MR)
      CINT=CINT+AAIXX*DR/(57.3*(RC/12.0))
      GO TO 370
C
  360 AINT=AINT+ABS((PVAR(KKK,7)+PVAR(KKK-1,7))*(TVAR(KKK,1)-TVAR(KKK-1,
     11))/(2.0*BRACK(KKK)))
      BINT=BINT+ABS((YVAR(KKK,7)+YVAR(KKK-1,7))*(TVAR(KKK,1)-TVAR(KKK-1,
     11))/(2.0*BRACK(KKK)))
      CALL TBLU (NRI,CINT,TP,RI,MR)
      CINT=CINT+ABS(6.0*(RVAR(KKK,5)+RVAR(KKK-1,5))*(TVAR(KKK,1)-
     1 -TVAR(KKK-1,1))/RC)
C     FIND TOTAL IMPULSE
  370 TVAR(KKK,7)=AINT+BINT+CINT
C     COMPUTE THE SPECIFIC IMPULSE
      IF (TVAR(KKK,8) .NE. 0 ) GO TO 380
      TVAR(KKK,6)=0.0
      GO TO 390
C
  380 TVAR(KKK,6)=TVAR(KKK,7)/TVAR(KKK,8)
  390 CONTINUE
      PVAR(KKK,3)=TTHEDD
      PVAR(KKK,4)=AAIYY
      PVAR(KKK,9)=AINT
      YVAR(KKK,3)=PPSIDD
      YVAR(KKK,4)=AAIYY
      YVAR(KKK,9)=BINT
      RVAR(KKK,3)=PPHIDD
      RVAR(KKK,4)=AAIXX
      RVAR(KKK,6)=CINT
      RVAR(KKK,7)=XXCG
      TVAR(KKK,3)=TTT
      IF (IT .NE. 0 ) GO TO 400
      TP=ITO
      IT=1
      GO TO 160
```

```
C
  400 IF (TBO-(TP+TSTEP) .LE. 0 ) GO TO 410
      TP=TP+TSTEP
      GO TO 160
C
  410 IF (TBO-TP .LE. 0 ) GO TO 420
      TP=TBO
      GO TO 160
C
  420 AVGISP=TVAR(KKK,6)
      DO 430 I=1,KKK
      RVAR(I,8)=TVAR(I,7)/AVGISP
  430 RVAR(I,9)=TVAR(1,9)-RVAR(I,8)
      IF (IOPT5 .LE. 0 ) GO TO 580
      BOIMP=TVAR(KKK,7)
      WFUELM=TVAR(KKK,9)
      WFUELC=RVAR(KKK,9)
      RIC=RVAR(KKK,6)
      YMA=BRACK(KKK)
      RIXX=AAIXX
      YIYY=AAIYY
  440 CONTINUE
      TTIME=TP-TO
      LLL=LLL+1
      CVAR(LLL,1)=TP
      CVAR(LLL,2)=TTIME
      IF (IOPT2 .GT. 0 ) GO TO 450
      CALL TBLU (NW,WWT,TP,W,MW)
      CVAR(LLL,9)=WWT
      GO TO 460
C
  450 CALL TBLU (NNP,PRES,TP,P,MP)
      CALL TBLU (NNT,TEMP,TP,T,MT)
      CALL C (PRES,TEMP,CF)
      DW=CONST1*((P(2)*TEMP)/(CI*T(2))-PRES/CF)+CONST2*((TEMP/T(2))-1.0)
```

```
      CVAR(LLL,9)=WFUELI-DW
  460 CVAR(LLL,8)=WFUELI-CVAR(LLL,9)
      CVAR(LLL,7)=WFUELM-CVAR(LLL,9)
      IF (IOPT3 .LE. 0 ) GO TO 470
      CALL TBLU (NDPR,DP,TP,DPR,MDP)
      CALL TBLU (NDYR,DY,TP,DYR,MDY)
      CALL TBLU (NDRR,DR,TP,DRR,MDR)
      PIMP=YIYY*DP/(57.3*YMA)
      YIMP=YIYY*DY/(57.3*YMA)
      RIMP=RIXX*DR/(57.3*(RC/12.0))
      CVAR(LLL,3)=PIMP+YIMP+RIMP
      CVAR(LLL,4)=CVAR(LLL,3)+BOIMP
      GO TO 480
C
  470 CALL TBLU (NRI,TIMP,TP,RI,MR)
      CVAR(LLL,4)=BOIMP+TIMP-RIC
      CVAR(LLL,3)=CVAR(LLL,4)-BOIMP
  480 IF (CVAR(LLL,7) .NE. 0.) GO TO 490
      CVAR(LLL,5)=0.0
      GO TO 500
C
  490 CVAR(LLL,5)=CVAR(LLL,3)/CVAR(LLL,7)
  500 IF (CVAR(LLL,8) .NE. 0.) GO TO 510
      CVAR(LLL,6)=0.0
      GO TO 520
C
  510 CVAR(LLL,6)=CVAR(LLL,4)/CVAR(LLL,8)
  520 IF (IC .GT. 0 ) GO TO 530
      TP=ITCO
      IC=1
      GO TO 440
C
  530 IF (TCOAST-(TP+TSTEPC) .LE. 0.) GO TO 540
      TP=TP+TSTEPC
      GO TO 440
```

```
C
  540 IF (TCOAST-TP .LE. 0.) GO TO 550
      TP=TCOAST
      GO TO 440
C
  550 AVGISP=CVAR(LLL,5)
      DO 570 I=1,LLL
      IF (AVGISP .NE. 0.) GO TO 560
      CFUELC=0.0
      GO TO 570
C
  560 CFUELC=CVAR(I,3)/AVGISP
  570 CVAR(I,10)=WFUELM-CFUELC
      IF (IOPT5 .LT. 0 ) GO TO 630
  580 XKKK=KKK
      XP=XKKK/50.
      NP=KKK/50
      XNP=NP
      IF(XP.GT.XNP)NP=NP+1
      NLL=0
      NPP=1
  590 IF (NP-NPP .GT. 0 ) GO TO 600
      NFL=NLL+1
      NLL=KKK
      GO TO 610
C
  600 NFL=NLL+1
      NLL=NLL+50
  610 WRITE( 6,690) NPP
      WRITE( 6,870) (LTITL(J),J=1,16)
      WRITE( 6,700)
      WRITE( 6,710) ((PVAR(I,J),J=1,9),I=NFL,NLL)
      WRITE( 6,720) NPP
      WRITE( 6,870) (LTITL(J),J=1,16)
      WRITE( 6,730)
```

```
      WRITE( 6,710) ((YVAR(I,J),J=1,9),I=NFL,NLL)
      WRITE( 6,740) NPP
      WRITE( 6,870) (LTITL(J),J=1,16)
      WRITE( 6,750)
      WRITE( 6,760) ((RVAR(I,J),J=1,9),I=NFL,NLL)
      WRITE( 6,770) NPP
      WRITE( 6,870) (LTITL(J),J=1,16)
      WRITE( 6,780)
      WRITE( 6,820) ((TVAR(I,J),J=1,9),I=NFL,NLL)
      IF (NP-NPP .LE. 0 ) GO TO 620
      NPP=NPP+1
      GO TO 590
C
  620 CONTINUE
      IF (IOPT5 .LE. 0 ) GO TO 670
  630 XLLL=LLL
      XC=XLLL/50.
      NC=LLL/50
      XNC=NC
      IF(XC.GT.XNC)NC=NC+1
      NCLL=0
      NCPP=1
  640 IF (NC-NCPP .GT. 0 ) GO TO 650
      NCFL=NCLL+1
      NCLL=LLL
      GO TO 660
C
  650 NCFL=NCLL+1
      NCLL=NCLL+50
  660 WRITE( 6,790) NCPP
      WRITE( 6,870) (LTITL(J),J=1,16)
      WRITE( 6,800)
      WRITE( 6,810) ((CVAR(I,J),J=1,10),I=NCFL,NCLL)
      IF (NC-NCPP .LE. 0 ) GO TO 670
      NCPP=NCPP+1
```

```
      GO TO 640
C
  670 CONTINUE
      IF (IOPT4 .LE. 0 ) GO TO 680
      READ( 5,860) (NTITLE(J),J=1,8)
      NQPL=0
      IF(Q(2).GT.0.)NQPL=1
      READ( 5,840) IROLL,SFT,SFPYM,SFET,SFRM
      CALL CURVE (KKK,NQPL,IROLL,NTITLE,SFPYM,SFRM,SFET,SFT)
  680 CONTINUE
      STOP
C     THIS ENDS THE UPSTAG EXECUTION. ONLY FORMAT STATEMENTS REMAIN.
  690 FORMAT (1H1,25X,26HUPPER STAGE MOMENT ROUTINE,14X,6HPAGE =,I2,2H A
     1/25X,31H PITCH VARIABLES TIME HISTORIES)
  700 FORMAT (//4X,6HFLIGHT,2X,5HSTAGE,2X,7HANGULAR,2X,6HMOMENT,4X,4HAER
     10,3X,8HMISALIGN,3X,5HTOTAL,3X,6HTHRUST/2(4X,4HTIME),4X,5HACCEL,2X,
     28HOF INER.,2X,3(6HMOMENT,3X),6HMISALN,1X,7HIMPULSE/5X,3HSEC,5X,3HS
     3EC,3X,7HDEG/S/S,1X,8HSLUG-FT2,3X,3(5HFT-LB,4X),3HDEG,4X,6HLB-SEC//
     4)
  710 FORMAT (3X,F7.2,1X,F6.2,2X,F6.2,2X,F8.1,1X,F8.2,1X,F8.2,1X,F8.2,1X
     1,F7.4,1X,F7.2)
  720 FORMAT (1H1,25X,26HUPPER STAGE MOMENT ROUTINE,14X,6HPAGE =,I2,2H B
     1/25X,31H   YAW VARIABLES TIME HISTORIES)
  730 FORMAT (//4X,6HFLIGHT,2X,5HSTAGE,2X,7HANGULAR,2X,6HMOMENT,4X,4HAER
     10,3X,8HMISALIGN,3X,5HTOTAL,3X,6HTHRUST/2(4X,4HTIME),4X,5HACCEL,2X,
     28HOF INER.,2X,3(6HMOMENT,3X),6HMISALN,1X,7HIMPULSE/5X,3HSEC,5X,3HS
     3EC,3X,7HDEG/S/S,1X,8HSLUG-FT2,3X,3(5HFT-LB,4X),3HDEG,4X,6HLB-SEC//
     4)
  740 FORMAT (1H1,25X,26HUPPER STAGE MOMENT ROUTINE,14X,6HPAGE =,I2,2H C
     1/25X,31H  ROLL VARIABLES TIME HISTORIES)
  750 FORMAT (//4X,6HFLIGHT,2X,5HSTAGE,2X,7HANGULAR,1X,6HMOMENT,4X,5HTOT
     1AL,13X,4HC.G.,4X,18H  CALCULATED FUEL /2(4X,4HTIME),4X,5HACCEL,2X,
     27HOF INER,3X,6HMOMENT,2X,7HIMPULSE,3X,5HPOINT,3X,7H CONSUM,3X,7HRE
     3MAIN /5X,3HSEC,5X,3HSEC,3X,7HDEG/S/S,1X,8HSLUG-FT2,2X,5HFT-LB,3X,6
     4HLB-SEC,4X,4HINCH,7X,2HLB,7X,2HLB//)
```

```
760 FORMAT (3X,F7.2,1X,F6.2,2X,F6.2,2X,F8.1,1X,F8.2,1X,F7.2,1X,F8.3,1X
   1,F8.3,1X,F8.3)
770 FORMAT (1H1,25X,26HUPPER STAGE MOMENT ROUTINE,14X,6HPAGE =,I2,2H D
   1/25X,31H   TIME HISTORIES OF SYSTEM     )
780 FORMAT (//4X,6HFLIGHT,2X,5HSTAGE,11X,5HTOTAL,10X,8HSPECIFIC,2X,5HT
   1OTAL,2(4X,4HFUEL)/2(4X,4HTIME),3X,6HTHRUST,2X,7HMISALGN,2X,5HLAMDA
   2,2X,2(7HIMPULSE,2X),6HCONSUM,2X,6HREMAIN/5X,3HSEC,5X,3HSEC,5X,2HLB
   3,6X,3HDEG,5X,3HDEG,5X,3HSEC,4X,6HLB-SEC,4X,2HLB,6X,2HLB//)
790 FORMAT (1H1,25X,26HUPPER STAGE MOMENT ROUTINE,14X,6HPAGE =,I2,2H E
   1/25X,31H COAST VARIABLES TIME HISTORIES)
800 FORMAT (//,4X,6HFLIGHT,2X,5HSTAGE,3X,5HCOAST,3X,5HTOTAL,2X,5HCOAST
   1,,2X,5HTOTAL,3X,5HCOAST,3X,5HTOTAL,2X,14HFUEL REMAINING,/5X,4HTIME
   2,3X,4HTIME,3X,2(7HIMPULSE,1X),1X,2(3HISP,4X),4HFUEL,4X,4HFUEL,3X,1
   34H MEAS    CALC /5X,3HSEC,5X,3HSEC,3X,2(6HLB-SEC,2X),1X,2(3HSEC,4X
   4),2HLB,7X,2HLB,6X,2HLB,6X,2HLB//)
810 FORMAT (3X,F7.2,1X,F6.2,1X,F7.1,1X,F7.1,1X,F6.2,1X,F6.2,1X,F7.2,1X
   1,F7.2,1X,F7.2,1X,F7.2)
820 FORMAT (3X,F7.2,1X,F6.2,2X,F7.0,1X,F7.4,1X,F7.2,1X,F7.2,1X,F8.2,1X
   1,F6.2,2X,F7.2)
830 FORMAT (10I5)
840 FORMAT (I5/(6E10.3))
850 FORMAT (6E10.3)
860 FORMAT (8A10)
870 FORMAT (1X,8A10)
880 FORMAT (I5/(7E10.3))
    END
```

```
*DECK C
      SUBROUTINE C (PAT,TAT,CAT)
C     THIS SUBROUTINE COMPUTES THE COMPRESSIBILITY FACTOR FOR DRY
C     NITROGEN FOR 50-100 DEG F. AND 400-3000 PSIA
      PP=PAT-1400.
      CAT=.9977+1.657738E-5*PP+1.264881E-8*PP*PP+4.5833E-4*(TAT-522.)
      RETURN
      END
```

```
*DECK CURVE
      SUBROUTINE CURVE (NP,NQ,IROLL,NTITLE,DY,DYR,DYET,DX)
C     THIS SUBROUTINE PERFORMS THE CALCOMP PLOT SETUP FOR PITCH, YAW
C     AND ROLL MOMENTS AND THRUST MISALIGNMENT.
      DIMENSION  NTITLE(8),X(400),Y(400)
      COMMON PVAR(200,9),YVAR(200,9),RVAR(200,9),TVAR(200,9)
      DATA Z1,Z2,Z3/0.42,0.07,0.14/
C      SET UP INITIAL AXIS VARIABLES
C
      YF=-2.*DY
      NDX=DX
      CALL PLOTS (5HCAL19,0,4HPLOT)
      DO 10 J=1,NP
   10 X(J)=PVAR(J,1)
C  PLOT PITCH MOMENTS
      CALL SYMBOL (0.5,9.9,0.10,NTITLE,0.,80)
      CALL SYMBOL (0.5,9.5,0.10,45H             PITCH AND YAW DISTURBING
     1 MOMENTS,0.,45)
      CALL SYMBOL(3.5,9.3,0.07,12HTOTAL MOMENT,0.,12)
      CALL PLOT(3.4,9.3,3)
      CALL PLOT(2.4,9.3,2)
      CALL PLOT(2.4,9.15,3)
      CALL PLOT(2.6,9.15,2)
      CALL PLOT(2.7,9.15,3)
      CALL PLOT(2.9,9.15,2)
```

```
      CALL PLOT(3.0,9.15,3)
      CALL PLOT(3.2,9.15,2)
      CALL PLOT(3.3,9.15,3)
      CALL PLOT(3.4,9.15,2)
      CALL SYMBOL(3.5,9.15,0.07,26HTHRUST MISALIGNMENT MOMENT ,0.,26)
      CALL PLOT(2.4,9.0,3)
      CALL PLOT(2.8,9.0,2)
      CALL PLOT(2.90,9.0,3)
      CALL PLOT(2.95,9.0,2)
      CALL PLOT(3.05,9.0,3)
      CALL PLOT(3.4,9.0,2)
      CALL SYMBOL(3.5,9.0,0.07,18HAERODYNAMIC MOMENT ,0.,18)
      NTI=X(1)/DX
      XF=NTI*NDX
      CALL PLOT (1.,7.,-3)
      CALL AXIS (0.,-2.,20HFLIGHT TIME SECONDS ,-20,6.,0.,XF,DX)
      DO 20 J=1,NP
      X(J)=(X(J)-XF)/DX
   20 Y(J)=PVAR(J,7)
      CALL AXIS (0.,-2.,19HPITCH MOMENT FT-LBS,19,4.,90.,YF,DY)
      CALL DASH (X,Y,NP,Z1,Z1,0.,1.,DY,0,7.,3.)
      IF (NQ.EQ.0) GO TO 50
      DO 30 J=1,NP
   30 Y(J)=PVAR(J,6)
      CALL DASH (X,Y,NP,Z3,Z3,Z2,1.,DY,0,7.,3.)
      DO 40 J=1,NP
   40 Y(J)=PVAR(J,5)
      CALL DASH (X,Y,NP,Z1,Z2,Z3,1.,DY,0,7.,3.)
C PLOT YAW MOMENTS
   50 CALL PLOT (0.,-5.,-3)
      CALL AXIS (0.,-2.,20HFLIGHT TIME SECONDS ,-20,6.,0.,XF,DX)
      CALL AXIS (0.,-2.,17HYAW MOMENT FT-LBS,17,4.,90.,YF,DY)
      DO 60 J=1,NP
   60 Y(J)=YVAR(J,7)
      CALL DASH (X,Y,NP,Z1,Z1,0.,1.,DY,0,7.,3.)
```

```
      IF (NQ.EQ.0) GO TO 90
      DO 70 J=1,NP
   70 Y(J)=YVAR(J,6)
      CALL DASH (X,Y,NP,Z3,Z3,Z2,1.,DY,0,7.,3.)
      DO 80 J=1,NP
   80 Y(J)=YVAR(J,5)
      CALL DASH (X,Y,NP,Z1,Z2,Z3,1.,DY,0,7.,3.)
   90 CALL PLOT (-1.,-2.,-3)
      CALL PLOT (12.,0.,-3)
      CALL PLOT (0.,0.,999)
C CHECK AND PLOT ROLL MOMENTS
      IF (IROLL.EQ.0) GO TO 110
      YFR=-4.*DYR
      CALL PLOTS (5HCAL19,0,4HPLOT)
      CALL SYMBOL (1.,9.8,0.10,NTITLE,0.,80)
      CALL SYMBOL (1.,9.5,0.10,35H             ROLL DISTURBING MOMENT,0.
     1,35)
      CALL PLOT (1.,5.,-3)
      CALL AXIS (0.,-4.,20HFLIGHT TIME SECONDS ,-20,6.,0.,XF,DX)
      CALL AXIS (0.,-4.,29HROLL DISTURBING MOMENT FT-LBS,29,8.,90.,YFR,D
     1YR)
      DO 100 J=1,NP
  100 Y(J)=RVAR(J,5)
      CALL DASH (X,Y,NP,Z1,Z1,0.,1.,DYR,0,7.,5.)
      CALL PLOT (11.,-5.,-3)
      CALL PLOT (0.,0.,999)
C PLOT THRUST MISALIGNMENTS
  110 CALL PLOTS (5HCAL19,0,4HPLOT)
      YFET=-DYET
      CALL SYMBOL (1.,9.8,0.10,NTITLE,0.,80)
      CALL SYMBOL (1.,9.5,0.10,32H             THRUST MISALIGNMENT,0.,32
     1)
      CALL PLOT (1.,7.,-3)
      CALL AXIS (0.,-1.,20HFLIGHT TIME SECONDS ,-20,6.,0.,XF,DX)
      CALL AXIS (0.,-1.,19HPITCH COMPONENT DEG,19,3.,90.,YFET,DYET)
```

```
      DO 120 J=1,NP
  120 Y(J)=PVAR(J,8)
      CALL DASH (X,Y,NP,Z1,Z1,0.,1.,DYET,0,7.,3.)
      CALL PLOT (0.,-3.,-3)
      CALL AXIS (0.,-1.,20HFLIGHT TIME SECONDS ,-20,6.,0.,XF,DX)
      CALL AXIS (0.,-1.,17HYAW COMPONENT DEG,17,2.,90.,YFET,DYET)
      DO 130 J=1,NP
  130 Y(J)=YVAR(J,8)
      CALL DASH (X,Y,NP,Z1,Z1,0.,1.,DYET,0,7.,3.)
      CALL PLOT (0.,-4.,-3)
      CALL AXIS (0.,0.,20HFLIGHT TIME SECONDS ,-20,6.,0.,XF,DX)
      CALL AXIS (0.,0.,9HTOTAL DEG,9,2.,90.,0.,DYET)
      DO 140 J=1,NP
  140 Y(J)=TVAR(J,4)
      CALL DASH (X,Y,NP,Z1,Z1,0.,1.,DYET,0,7.,3.)
      CALL PLOT (11.,0.,-3)
      CALL PLOT (0.,0.,999)
      RETURN
      END
```

```
*DECK DASH
      SUBROUTINE DASH (X,Y,NP,Z1,Z2,SPACE,XSCALE,YSCALE,LSYMB,XLIM,YLIM)
C     SYMBOLS,DASHED,DASHED-DOT LINES OR SOLID LINES WITH OR WITHOUT
C     SYMBOLS BASED ON A SET OF SEQUENTIAL POINTS GIVEN IN
C     THE INPUT 'X' ABSCISSA ARRAY AND THE 'Y' ORDINATE ARRAY
      DIMENSION X(1),Y(1)
      DO 10 I=1,NP
      XA=X(I)/XSCALE
      YA=Y(I)/YSCALE
      IF (ABS(XA).GT.XLIM) GO TO 10
      IF (ABS(YA).GT.YLIM) GO TO 10
      CALL PLOT (XA,YA,3)
      GO TO 20
   10 CONTINUE
   20 IF (SPACE) 330,310,30
C     THIS SUBROUTINE PLOTS A CALCOMP PLOT WITH A WIDE VARIETY OF
   30 K=0
      PI2=1.5708
      Z=Z1
      ZB=Z2
      IF (Z2 .GT. 0.) GO TO 40
      ZB=Z1
   40 ZD=Z
      LZ=0
      SL=0.
      NF=NP-1
      DO 300 J=1,NF
      XA=X(J)/XSCALE
      IF (ABS(XA)-XLIM .GT. 0.) GO TO 300
      XB=X(J+1)/XSCALE
      IF (ABS(XB)-XLIM .GT. 0.) GO TO 300
      YA=Y(J)/YSCALE
      IF (ABS(YA)-YLIM .GT. 0.) GO TO 300
      YB=Y(J+1)/YSCALE
      IF (ABS(YB)-YLIM .GT. 0.) GO TO 300
```

```
      DY=YB-YA
      DX=XB-XA
      IF (DX .NE. 0.) GO TO 80
      IF (DY) 50,60,70
   50 TH=-PI2
      GO TO 90
   60 TH=0.
      GO TO 90
   70 TH=PI2
      GO TO 90
   80 TH=ATAN(DY/DX)
   90 DX=XB-XA
      DY=YB-YA
      DZ=SQRT(DX*DX+DY*DY)
C     TEST TO SEE WHAT IS GOING ON
      IF (K) 100,180,220
  100 K=1
      SL=SPACE
      IF (DZ-SPACE) 110,120,150
C     SPACE IS LARGER THAN DZ
  110 SL=SL-DZ
      CALL PLOT (XB,YB,3)
      GO TO 300
C     NEXT POINT IS EXACTLY ONE SPACE
  120 K=0
      IF (LZ .NE. 0 ) GO TO 130
      ZD=ZB
      LZ=1
      GO TO 140
  130 ZD=Z
      LZ=0
  140 SL=0.
      CALL PLOT (XB,YB,3)
      GO TO 300
C     NEXT POINT MORE THAN ONE SPACE AWAY
```

```
  150 XA=XA+SPACE*COS(TH)
      YA=YA+SPACE*SIN(TH)
      IF (ABS(XA)-XLIM .GE. 0.) GO TO 300
      IF (ABS(YA)-YLIM .GE. 0.) GO TO 300
      K=0
      IF (LZ .NE. 0 ) GO TO 160
      ZD=ZB
      LZ=1
      GO TO 170
  160 ZD=Z
      LZ=0
  170 SL=0.
      CALL PLOT (XA,YA,3)
      GO TO 90
C  K=0 LINE BEING DRAWN ZD LENGTH NOT DRAWN RESUME AS IS LINE STARTING
  180 IF (DZ-ZD) 190,200,210
C    LINE GOES AT LEAST TO NEXT POINT
  190 K=0
      ZD=ZD-DZ
      CALL PLOT (XB,YB,2)
      GO TO 300
C    LINE ENDS AT NEXT POINT
  200 K=-1
      SL=SPACE
      ZD=0.
      CALL PLOT (XB,YB,2)
      GO TO 300
C    LINE ENDS BEFORE NEXT POINT
  210 K=1
      SL=SPACE
      XA=XA+ZD*COS(TH)
      YA=YA+ZD*SIN(TH)
      IF (ABS(XA)-XLIM .GE. 0.) GO TO 300
      IF (ABS(YA)-YLIM .GE. 0.) GO TO 300
      CALL PLOT (XA,YA,2)
```

```
      ZD=0.
      GO TO 90
C   K=1 IS IN SPACE
  220 ZD=0.
      IF (DZ-SL) 230,240,270
  230 K=1
      SL=SL-DZ
      CALL PLOT (XB,YB,3)
      GO TO 300
C  SL=DZ
  240 K=0
      IF (LZ .NE. 0 ) GO TO 250
      ZD=ZB
      LZ=1
      GO TO 260
  250 ZD=Z
      LZ=0
  260 CALL PLOT (XB,YB,3)
      GO TO 300
C   SL IS LESS THAN DZ
  270 K=0
      IF (LZ .NE. 0 ) GO TO 280
      ZD=ZB
      LZ=1
      GO TO 290
  280 ZD=Z
      LZ=0
  290 XA=XA+SL*COS(TH)
      YA=YA+SL*SIN(TH)
      IF (ABS(XA)-XLIM .GE. 0.) GO TO 300
      IF (ABS(YA)-YLIM .GE. 0.) GO TO 300
      SL=0.
      CALL PLOT (XA,YA,3)
      GO TO 90
  300 CONTINUE
```

```
      GO TO 370
C  STRAIGHT LINE PLOT OPTION
  310 DO 320 J=I,NP
      XA=X(J)/XSCALE
      YA=Y(J)/YSCALE
      IF (ABS(XA)-XLIM .GT. 0.) GO TO 320
      IF (ABS(YA)-YLIM .GT. 0.) GO TO 320
      CALL PLOT (XA,YA,2)
  320 CONTINUE
      GO TO 370
C  PLOT SYMBOLS ON LINE  NO LINE IF LYSMB IS NEGATIVE
  330 NSM=IABS(LSYMB)
      IF (LSYMB .LT. 0 ) GO TO 340
      K=-2
      GO TO 350
  340 K=-1
  350 DO 360 J=1,NP
      XA=X(J)/XSCALE
      YA=Y(J)/YSCALE
      IF (ABS(XA)-XLIM .GT. 0.) GO TO 360
      IF (ABS(YA)-YLIM .GT. 0.) GO TO 360
      CALL SYMBOL (XA,YA,0.07,NSM,0.0,K)
  360 CONTINUE
  370 CALL PLOT (0.,0.,3)
      RETURN
      END
```

```
*DECK TBLU
      SUBROUTINE TBLU (NT,Y,X,T,M)
C     SINGLE TABLE LOOKUP SUBROUTINE
C        NT = NUMBER OF VALUES IN ARRAY
C        Y  = RETURNED ORDINATE
C        X  = ABSCISSA VALUE CALLED
C        T  = INPUT TABLE OF ALTERNATING ABSCISSAS AND ORDINATES
C             ORDINATES MUST BE MONOTONICALLY INCREASING
C        M  = PREVIOUS INDEX USED IN THIS TABLE LOOKUP
C             THIS INDEX GETS CHANGED TO CURRENT VALUE
      DIMENSION T(1)
   10 IF (T(M)-X) 50,20,30
   20 Y=T(M+1)
      RETURN
   30 IF (T(1)-X.LT.0.) GO TO 40
      M=1
      GO TO 20
   40 M=M-2
      GO TO 10
   50 MM=M+2
      IF (MM-NT-1.LE.0) GO TO 60
      M=NT-1
      GO TO 20
   60 IF (T(MM)-X.GT.0.) GO TO 70
      M=MM
      GO TO 50
   70 M=MM-2
      DT=T(MM)-T(M)
      IF (DT.NE.0.) GO TO 80
      Y=T(M+1)
      RETURN
   80 DY=T(MM+1)-T(M+1)
      DDT=X-T(M)
      Y=T(M+1)+DY*DDT/DT
      RETURN
      END
```

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16. Abstract

This report describes a FORTRAN IV coded computer program for post-flight evaluation of a launch vehicle upper stage ON-OFF reaction control system. Aerodynamic and thrust misalignment disturbances are computed as well as the total disturbing moments in pitch, yaw, and roll. Effective thrust misalignment angle time histories of the rocket booster motor are calculated. Disturbing moments are integrated and used to estimate the required control system total inpulse. Effective control system specific inpulse is computed for the boost and coast phases using measured control fuel useage. This method has been used for more than fifteen years for analyzing the NASA Scout Launch Vehicle second and third-stage reaction control system performance.

The computer program is set up in FORTRAN IV for a CDC CYBER 175 system. With slight modification it can be used on other machines having a FORTRAN compiler. The program has optional CALCOMP plotting output. With this option the program requires 19K words of memory and has 786 cards. Running time on a CDC CYBER 175 system is less than three (3) seconds for a typical problem.

17. Key Words (Suggested by Author(s)): COMPUTER PROGRAM, POST-FLIGHT ANALYSIS, ON-OFF REACTION CONTROLS, RIGID BODY MOMENTS

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