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COMPUTER PROGRAM FOR PREDICTION OF CAPTURE MANEUVER PROBABILITY FOR AN ON-OFF REACTION CONTROLLED UPPER STAGE

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Computer Program for Prediction of Capture Maneuver Probability for an On-Off Reaction Controlled Upper Stage

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SUMMARY

This report describes a FORTRAN coded computer program and method to analyze the statistics of a transient 'capture' manuever for a single axis on-off controlled upper stage of a rocket powered vehicle. It uses a simple integration of the equations of motion to compute the time history of the transient maneuver. The Monte Carlo technique is employed to determine the statistics of maximum attitude error overshoot, time to maximum overshoot and total impulse expended. Booster induced disturbances, initial conditions, and aerodynamic disturbances are the main sources of excitement. These are treated as random variables. Certain vehicle and control system characteristics are also treated statistically.

Control logic assumes a simple on-off attitude control system with a deadband. An optional limited integral of attitude error term is included in the control logic.

Pitch, yaw and roll axis transient maneuvers can be evaluated by appropriate selection of input data.

Running time for a Monte Carlo analysis of 199 samples is 3 seconds on a CDC Cyber 175 computer system.

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LIST OF ILLUSTRATIONS

LIST OF SYMBOLS

Symbol	Description	Units
a_3	aerodynamic coefficient cubic term	(ft^2/deg^3)
C_N	aerodynamic normal force coefficient	—
C_l	aerodynamic rolling moment coefficient	—
d	deadband halfwidth	degrees
d_{ref}	aerodynamic reference length	inches
e	control error signal	degrees
F	control motor thrust	lb_f
f	frequency	hertz
G	integral gain error signal function	degrees
H	control motor switching hysteresis $(1-d_{on}/d_{off})$	—
I	moment of inertia	$slug\text{-}ft^2$
K_α	previous stage sensitivity to angle of attack (θ_e/α)	—
K_I	control gain on integral of attitude error	1/sec
L	booster motor roll torque	ft-lbs
N	integer number of samples	—
P	probability	—
q	dynamic pressure	lbs/ft^2
Q	random number (uniform 0 to 1)	
RND	random normal deviate	
S	aerodynamic reference area	ft^2
t	time	seconds
t_b	effective time delay due to bending	seconds

t_G	control electronics time delay	seconds
t_{RG}	rate gyro time delay	seconds
T	booster motor thrust	lbs
V	velocity	ft/sec
X_c	control motor location body station	inches
X_{cg}	center of gravity body station (aft position)	inches
X_{cp}	aerodynamic center body station	inches
X_r	booster nozzle throat body station	inches
y	arbitrary variable	—
Z_c	radial location of control motors	inches

Greek Letters

α	angle of attack	degrees
γ	flight path angle	degrees
δ	partial differential	degrees
Δ	increment	—
ϵ	booster thrust misalignment angle	angle
ζ	rate gyro damping factor	—
η	phase angle	radians
θ	pitch attitude	degrees
Ω	commanded guidance pitch attitude	degrees
λ	control motor cant angle	degrees
μ	mean value	—
π	ratio of circular perimeter to diameter	—
ϕ	roll attitude	degrees
σ	standard deviation	—

Subscripts

aero	aerodynamic
amp	amplitude
b	bending
B	bottom motor
c	control
e	error
i	"i"th sample
I	integral gain
l	roll
m	control motor
on	control motor turn-on
off	control motor turn-off
p	pitch
RG	rate gyro
T	top motor
w	wind
x	roll axis
y	transverse axis
o	initial value
α	angle of attack
r	booster thrust

Special Notation

•	dots over parameter denote time derivative (caution, flies have been known to perform unwanted differentiations, Reference 2)

1.0 INTRODUCTION

Evaluation of reaction control system performance includes transient responses to events such as stage separation transients, rocket booster motor ignition, or handoff from a previously operating control system. Peak attitude error, time, and impulse experienced during these transients are a measure of the control system performance. A vehicle experiencing a rocket motor ignition while aerodynamic moments are still appreciable can diverge and lose control. Figure 1 presents a phase plane trajectory of a capture maneuver for the Scout launch vehicle. A successful and a divergent case is shown. The divergence results from aerodynamic disturbances. Probability of successfully capturing during these events is usually required in design analyses or for definition of permissable staging criteria.

Designing to worst case criteria is sometimes used but can result in severe penalties in the system performance. A statistical approach is usually preferred to gain a sound basis for control system design with qualitative results. Non-linearities in the disturbances and control system behavior result in a difficult statistical prediction unless a Monte Carlo analysis is used. The Monte Carlo technique is employed in the 'capture' transient computer analysis routine described herein. This method has been used for 15 years on the NASA SCOUT launch vehicle upper stage control systems.

The accuracy of this method is only as good as the validity of the assumptions as applied to the particular case and the accuracy of the input data statistics. It is suggested that sensitivities to variation in the random variables be evaluated for a given system. Occassionally a modified Murphy's Law prevails, i.e. the most significant random variable is the one for which the least accurate information exists.

2.0 METHODOLOGY

Prediction of the staging capture maneuver statistics presented herein makes assumptions which may or may not apply to a particular control system. The method is for a single degree-of-freedom (pitch, yaw, or roll) time response of a launch vehicle upper stage using an on-off type reaction control system. Assumptions and equations for the control system, vehicle, and forcing functions are described in this Section. Statistical analysis methodology is also presented.

2.1 Assumptions

A block diagram of the general control system logic is presented in Figure 2. Some of the assumptions made in this method are:

- single axis control unaffected by other axes motion or control,
- mass properties do not vary during capture maneuver,
- velocity and wind velocity can be defined by a linear variation with time (two point curve),
- control motor thrust is constant level and it responds to 'on' and 'off' commands with separate time delays,
- gyro and other guidance system component responses can be represented by a time delay,
- aerodynamic normal force coefficient can be expressed as an odd function of angle of attack including linear and cubic terms,
- aerodynamic center longitudinal location is an even function of angle of attack and can be expressed as a constant with linear variation with the absolute value of angle of attack,
- vehicle bending effects are represented as a simple control motor switching delay time based on a random phase of one bending cycle,
- initial attitude error includes (1) a bias value, (2) a function of initial angle of attack, and (3) a random sinusoidal component with an amplitude having a Log-Normal Distribution Function,
- the vehicle is statically balanced and is aerodynamically symmetric.

2.2 Pitch Plane Equations of Motion

2.2.1 Angular Accelerations

Angular equations of motion written in terms of the accelerations are presented below. See Figure 3 for sign convention. The total angular acceleration includes control, aerodynamic and booster thrust misalignment disturbances.

(2-1) $$\ddot{\theta} = \ddot{\theta}_c + \ddot{\theta}_{aero} + \ddot{\theta}_\tau \quad (\text{deg/sec}^2)$$

where $\ddot{\theta}_c$ is the control angular acceleration

(2-2) $$\ddot{\theta}_c = 57.3(F_T - F_B)[(X_c - X_{cg})\cos\lambda_c + Z_c \sin\lambda_c] / 12\ I_y \quad (\text{deg/sec}^2)$$

$\ddot{\theta}_{aero}$ is the aerodynamic disturbing acceleration

(2-3) $$\ddot{\theta}_{aero} = 57.3\ C_N S q(X_{cg} - X_{cp}) / 12\ I_y \quad (\text{deg/sec}^2)$$

$\ddot{\theta}_\tau$ is the rocket booster motor disturbing acceleration

(2-4) $$\ddot{\theta}_\tau = T\epsilon_\tau (X_\tau - X_{cg}) / 12\ I_y \quad (\text{deg/sec}^2)$$

2.2.2 Aerodynamic Coefficients

Aerodynamic coefficients are assumed to be the following function of angle of attack

(2-5) $$C_N S = (C_{N\alpha} S)_{\alpha=0}\alpha + a_3\alpha^3 \qquad (\text{ft}^2)$$

(2-6) $$X_{cp} = X_{cp_{\alpha=0}} + \frac{\delta X_{cp}}{\delta\alpha}\left|\alpha\right| \qquad (\text{inches})$$

This provides an approximate form to the supersonic aerodynamic coefficients of a symmetric missile type body at angles of attack over a plus or minus 10 degree range. Typical aerodynamic coefficient variation with angle of attack are shown in Figure 4. If it is not available the non-linear coefficients can be approximated by the method of Reference 1.

2.2.3 Angle of Attack

Angle of attack is computed from the trajectory flight path deviation, attitude error, wind, velocity, and path angle by the following relationship

(2-7) $\alpha = \theta_e - \gamma_e + \alpha_{wp}$ (degrees)

Pitch attitude error is obtained from the attitude minus the commanded pitch program,

(2-8) $\theta_e = \theta - \dot{\theta}_c t$ (degrees)

Wind and trajectory parameters are assumed to be linear functions of time following ignition, i.e.

(2-9) $\gamma = \gamma_o + \dot{\theta}_c t$ nominal flight path angle (deg)

(2-10) $V = V_o + \dot{V}t$ velocity (ft/sec)

(2-11) $V_{wp} = V_{wp_o} + \dot{V}_{wp} t$ wind velocity (ft/sec)

(2-12) $\alpha_{wp} = \alpha_{wp_o} + \dot{\alpha}_{wp} t$ angle of attack due to wind (deg)

Angle of attack due to a horizontal wind component in the pitch plane (V_{wp}) is,

(2-13) $\alpha_{wp} = 57.3 \left(\frac{V_{wp} \sin \gamma}{V + V_{wp} \cos \gamma} \right)$ (degrees)

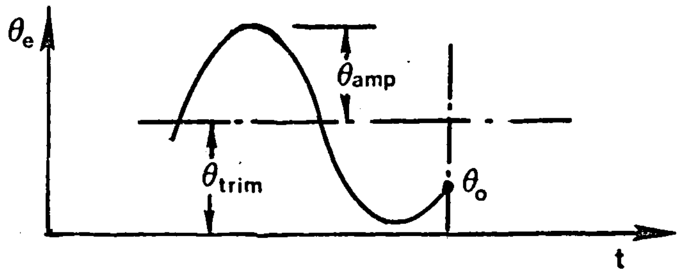
Angle of attack can be expressed as

(2-14) $\alpha = \theta + \alpha_{wp_o} - \gamma_e + (\dot{\alpha}_{wp} - \dot{\theta}_c)t$. (degrees)

2.2.4 Initial Conditions

Initial conditions for a vehicle at an upper stage ignition will depend upon (1) the behavior of the previous stage and (2) the 'tip off' or change in characteristics due to an impulsive type ignition or separation disturbance.

If the previous stage has a proportional control system and aerodynamic disturbances are significant, as in the case of the Scout second stage, the initial conditions will be correlated with the trajectory deviations and wind velocity. It is assumed that the initial attitude error can be expressed as a combination of static trim and an oscillatory motion as shown in the sketch



(2-15) $\theta_{e_o} = \theta_{trim} + \theta_{amp} \sin \eta$ (degrees)

where η is a random phase angle for the oscillatory motion

Trim conditions of the prior stage include a nominal bias and a bias due to the steady state angle of attack due to wind and trajectory errors.

(2-16) $\theta_{trim} = \theta_{e_{bias}} + K_\alpha \alpha_o$ (degrees)

where $\theta_{e\,bias}$ is the previous stage trim attitude error due to vehicle asymmetries (degrees)

K_α is the sensitivity of previous stage attitude error to angle of attack

Initial angular rate must include the total from previous stage motion and tipoff disturbances.

2.2.5 Control Logic

Control logic is according to the block diagram of Figure 2. The error signal is given by

(2-17) $e_p = \theta_e + K_R/K_D\dot{\theta} + G\left\{K_I\int\theta_e dt\right\}$ (degrees)

where K_R/K_D is a constant rate to displacement gain ratio. The integral gain term can be delayed and limited. Integration of the attitude error starts at ignition, or time zero. The integral gain (K_I) is a constant but can be set to zero for an initial time period (t_{KI}) following ignition. This helps to alleviate the initial transient capture. Limiting of the total integral gain term can also be used. This usually is desirable to make the control system dynamically stable. The integral gain function can be expressed by the following equations

(2-18) $$\int \theta_e dt = \int_0^t (\theta - \theta_o - \dot{\Omega}\, t)dt \qquad t \geq 0$$

$$G\left\{ \quad \right\} = 0 \qquad t < t_{KI}$$

For, $t \geq t_{KI}$,

$$G\left\{ \quad \right\} = K_I \int \theta_e dt \qquad ; \left|K_I \int \theta_e dt\right| \leq G_{LIMIT}$$

(2-19) $$G\left\{ \quad \right\} = G_{LIMIT}\ \mathrm{SIGN}(K_I \int \theta_e dt) \qquad ; \left|K_I \int \theta_e dt\right| > G_{LIMIT}$$

The integral gain term can be deleted completely by input option selection.

Control motor firing logic based on the error signal generated by equation (2-17) and the deadband halfwidth (d) is as follows:

(2-20)

	F_B	F_T
$e_p > d$	ON,	OFF
$-d < e_p < d$	OFF,	OFF
$e_p < -d$	OFF,	ON

Equation (2-20) defines the nominal switch points (also see Figure 1). Hysteresis in the switching is treated by narrowing the switch off deadband once a motor is fired, i.e.

(2-21) $$d_{off} = d(1-H) \qquad \text{(degrees)}$$

Phase lags and delays in the system are treated as simple time delays. They include control electronics or computer lags, gyro lag, control motor thrust response and decay times and an incremental effect due to bending cycles. These time delays are applied to the control motor thrust turn-on and turn-off after sensing the crossing of a switching point defined by equations (2-20) and (2-21). Rate terms have the most significant effect on the error signal dynamics. The rate gyros are assumed to have a time delay based on a second order response.

(2-22) $$t_{RG} = \zeta_{RG}/\pi f_{RG}$$

where, ζ_{RG} is the gyro damping factor

f_{RG} is the natural frequency (hertz)

An effective time delay induced by large amplitude bending mode oscillations following ignition is,

(2-23) $$t_b = \frac{\sin\eta}{2f_b} \qquad \text{(seconds)}$$

where, η is an arbitrary phase angle at the switching point
f_b is the bending frequency (hertz)

Bending can increase or decrease the time delay. However, in the routine if the bending effect reduces the total system delay to a time advance, the time delay is set to zero. Total control motor thrust turn-on and turn-off delay time is,

$$t_{on} = t_G + t_{RG} + t_b + t_{on_m} \qquad \text{(seconds)} \tag{2-24}$$
$$t_{off} = t_G + t_{RG} + t_b + t_{off_m} \qquad \text{(seconds)}$$

where, t_G is the guidance electronics delay (sec)
t_{on_m} is the control motor effective turn-on delay (sec)
t_{off_m} is the control motor effective turn-off delay (sec)

2.3 Yaw Axis Equations

When analyzing capture maneuvers in the yaw plane the equations used are basically the same as for pitch. However, horizontal winds from the side are not reduced by the sine of the flight path angle as in pitch. By entering the flight path angle as 90 degrees in input the correct aerodynamic moments will be generated for a sidewind. Equation (2-13) degenerates to,

$$\alpha_w = 57.3 \, V / V_w \qquad \text{(degrees)} \tag{2-25}$$

where, α_w, is angle of attack in yaw and V_w is sidewind velocity.

Flight path error becomes a flight path error measured in the yaw plane.

Control motor designations become,

(2-26) F_T right yaw motor
F_B left yaw motor

Sign convention trades the pitch-nose-up positive direction for a yaw nose-right positive direction.

2.4 Roll Axis Equations

Roll axis equations of motion can be simulated by appropriate choice of input variables. Sign convention is shown in Figure 3. Roll accelerations are,

$$\ddot{\phi} = \ddot{\phi}_c + \ddot{\phi}_{aero} + \ddot{\phi}_r \qquad (\text{deg/sec}^2) \tag{2-27}$$

Roll control acceleration is,

$$\ddot{\phi}_c = 57.3(F_T - F_B)Z_c/12\, I_x \qquad (\text{deg/sec}^2) \tag{2-28}$$

where, F_T is roll right control motor thrust (lbs)
F_B is roll left control motor thrust (lbs)
Z_c is moment arm about centerline (inches)
I_x is roll moment of inertia (slug-ft^2)

This is similar to Equation (2-2) if the control motor cant angle (λ_c) is input as 90 degrees.

Aerodynamic disturbances due to a nonlinear rolling moment coefficient is,

(2-29) $\ddot{\phi}_{aero} = 57.3\ C_lSd_{ref}q/12\ I_x$ (deg/sec^2)

where,

(2-30) $C_lS = \left(\frac{\delta C_lS}{\delta \phi}\right)_{\phi=0} + a_3\phi^3$ (ft^2/deg)

which is of the form of equations (2-3) and (2-5). The following input data must correspond to pitch channel variables as follows,

(2-31)

Pitch	Roll equivalent input
$(C_{N_\alpha}S)_{\alpha=0}$	$\left(\frac{\delta C_lS}{\delta\phi}\right)_{\phi=0}$
X_{cg}	0
X_{cp}	$-d_{ref}$
γ	0.
V_w	0.
V	1.

Booster induced roll torque accelerations are,

(2-32) $\ddot{\phi}_r = 57.3\ L\ /\ I_x$ (deg/sec^2)

where L is the roll torque in (ft-lbs). This is similar to equation (2-4) with the following input changes,

Pitch	Roll
T	1.
ϵ_r	L (ft-lbs)
X	687.6
X_{cg}	0.

The changes in input data for the roll axis are defined in paragraph 3.5.

2.5 Statistical Analysis

Treatment of the random variables for input and output is discussed in the following paragraphs.

2.5.1 Input Random Variables

Random variables used in the analysis include mass properties, trajectory deviations, control system characteristics, thrust misalignment and wind. Most of these variables are treated as Gaussian (Normal Distribution Function) and are entered as a mean and standard deviation. These include:

- moment of inertia
- center of gravity station
- booster thrust
- dynamic pressure
- control system switching hysteresis
- control motor turn-on and turn-off delay times
- rate to displacement gain ratio
- control motor thrust level
- guidance electronics delay time
- rate gyro natural frequency and damping
- initial rate
- wind speed
- flight path angle
- booster thrust misalignment

Random samples of normally distributed parameters are computed as:

$$y_i = \mu + \text{RND}\ \sigma \tag{2-33}$$

where (RND) is the Random Normal Deviate.

Initial attitude error is computed based on the previous stage sensitivities to angle of attack and aerodynamic dissymmetries with respect to angle of attack. An independent contribution to initial attitude error is input as a Log-Normal Distribution of an oscillation amplitude. From Equation 2-15,

$$\Delta\theta_e = \theta_{amp} \sin \eta$$

The amplitude of the sine wave is a positive number having a minimum value of zero. Several distribution functions can be used to describe the amplitude (i.e., Log-Normal, Rayleigh, Poisson). The Log-Normal was assumed since it is easily handled in the computer program by the Normal Distribution pseudo-random number generator. To accomplish this a new variable, 'y', is defined in input,

$$y = \ln \theta_{amp}$$

The mean and standard deviation of (y) the natural logarithm of amplitude is input. In the routine (y) is treated as Gaussian. The amplitude is then computed by

(2-34) $$\theta_{amp} = e^{\ln(\mu + RND\,\sigma)}$$

where, μ is the mean of y
σ is the standard deviation of y
RND is the Random Normal Deviate

The incremental attitude error at ignition includes a random phase angle (η). Internally this phase is assumed to be a Uniform Distribution function ranging from $-\pi/2$ to $+\pi/2$ radians. It is computed as

(2-35) $$\eta = \pi(Q - 0.5) \qquad ; \quad 0 \leq Q \leq 1$$

where, Q, is a pseudo-random number ranging from zero to one.

2.5.2 Output Statistical Analysis

Individual capture transient information is stored in arrays. These include maximum overshoot attitude error, time to reach this maximum, and the total impulse expended by the control motors. These arrays are arranged in ascending order. Discrete probability levels are computed by Equation (2-36) and output with each sample.

(2-36) $$P\left\{y \leq y_i\right\} = \frac{N_i}{N+1}$$

where y_i is the value of the parameter
N_i is the location in the array of y
N is the total number of samples computed

Histogram data are also output in terms of the number of values falling in each cell specified in the input. Cell location algorithms used are:

(2-37) HIST (ICELL) = HIST(ICELL) + 1

where, HIST (ICELL) contains the cumulative number of values in the 'i'th cell

and,

(2-38) $$ICELL = (y_i - y_{min})/\Delta y + 1$$

y_i is the value of the parameter being tested
y_{min} is the lowest range of the histogram specified in input (usually zero)
Δy is the cell width computed from the input histogram range and number of cells.

Capture parameters computed are always positive numbers. Therefore the minimum expected value (y_{min}) is zero. If a value greater than the maximum specified histogram is computed it is put into the last cell.

A divergent case will not be included in the discrete probability tables. The number of such cases are printed out following the discrete probability tables. If there are any divergent cases the probability of successful capture can be computed externally.

(2-39) $$P(\text{SUCCESS}) = 1\text{-}P(\text{FAILURE})$$

(2-40) $$P(\text{FAILURE}) = N_F/N_{TOT}$$

where N_F is the number of failures
N_{TOT} is the total number of samples

If there are capture manuevers which are considered failures due to high overshoot angles the probability of failure is calculated from Equation (2-40) where

(2-41) $$N_F = N_{F/C} + N_D$$

(2-42) $$N_{TOT} = N + N_D$$

where $N_{F/C}$ are the number of cases which captured but are considered failures
N_D is the number of divergent cases calculated
N is the sample size requested (note this does not include divergent cases or other error modes encountered)

Generally a finite sample size computed by Monte Carlo techniques makes application of Equation (2-40) somewhat inaccurate. Therefore it is desireable to attach a confidence level to the probability. This can be done by using the Binomial Failure Rate Tables. These are based on the solution of the following equation for confidence coefficient:

(2-43) $$\beta = 1 - \sum_{j=0}^{N_F} \frac{N_{TOT}!}{j!\,(N_{TOT}-j)!}\,\hat{P}^{\,j}\left(1-\hat{P}\right)^{N_{TOT}-j}$$

where β is the confidence coefficient
N_F is the total number of failures
N_{TOT} is the total number of trials
$\hat{P}$ is the upper confidence limit on the true probability of failure

A table of the upper confidence limit of the true probabilty of failure is presented in Figure 5 for sample sizes of 200, 500 and 1000.

3.0 PROGRAM DESCRIPTION

3.1 General

This computer program is coded in FORTRAN IV for a CDC CYBER 175 system. Code is compatible with ANSI standards. It is arranged to operate with standard card input and line printer output.

A main routine and four subroutines require approximately 8K words of computer memory. Program flow and user instructions are presented in the following paragraphs. Input and output of sample problems are illustrated along with the detailed descriptions. These can be used to checkout the program on another machine.

3.2 Program Flow

Program flow is straight forward in five basic parts,

- input data
- initilize constants
- compute Monte Carlo capture samples
- compute statistical distribution
- output Monte Carlo results

All four subroutines are single level. Blank common is used to pass information between MAIN and subroutines RNDX, and PAGEHD.

A flow chart showing the general flow of the MAIN Program is presented in Figure 6. More detailed charts of specific branches of the routine are presented in Figure 7. A complete list of the FORTRAN source program is presented in the Appendix.

A description of the subroutines is presented in the following paragraphs.

3.3 Subroutine Description

Four subroutines are used to support the MAIN program; ASCEND, PAGEHD, RNDX, and TBLU. A brief description of each is presented below.

ASCEND

This subroutine rearranges an array of numbers in monotonically increasing or decreasing order. The call to this subroutine is:

CALL ASCEND (L, VAL, M)

L - is the number of values in array VAL (input)
VAL - is the array to be rearranged (input and output)
M - is input option
M = 0 for ascending order
M = 1 for descending order

PAGEHD

This subroutine ejects a page, prints run number page number and title information at the top of the page.

The call statement is

CALL PAGEHD

Page number, line number, run number and title information are transferred by blank common from the MAIN routine.

RNDX

This is a pseudo random number generator for a Uniform or a Normal distribution function. It uses a seed integer 'K' to compute a uniformly distributed number 'Q' which ranges from zero to one. If the Normal Distribution is required the Uniform Distribution U(0,1) is transformed to the Normal Distribution N(0, 1). A random normal deviate, 'RXD', is obtained from the value of 'Q'. The call to this subroutine is,

CALL RNDX(L)

L = 0 gives random normal deviate N(0, 1)
L = 1 gives uniform U(0, 1)

The values of 'Q', 'RXD' and the changed random number seed value 'K' are located in blank common.

TBLU

This is a single table lookup subroutine. It is based on linear interpolation between points from a single array having alternating values of abscissas and ordinates. Abscissas must be in ascending order. If the abscissa given is out of the range, either the first or the last table ordinate is returned depending on the direction of the abscissa.

The call statement is

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

NT - number of values in table 'T' including abscissas and ordinates (input)
Y - is the ordinate found (output)
X - is the given abscissa (input)
T - is the table of alternating abscissas and ordinates (input)
M - is the table locator index. 'M' must be greater than zero and less than 'NT'. 'M' returns the index for the current location found for the abscissa and should be used for the next table lookup of the same table to minimize search time.

3.4 Error Modes

There are several error modes which can be encountered during the numerical integration of a capture manuever. These result in cases which cannot be completed within the input limitations or the computational procedure. A description, of each of these is given below along with the test equations. Printout of some key random variables is made when an error mode is encountered.

3.4.1 Deadband Overshoot (Error Mode 1)

This error occurs when the error signal over a single integration step crosses a turn-on and turn-off point without turning off a control motor (see Figure 8). This is a result of either a poorly designed control system or too coarse of an integration step size. If this is encountered it is suggested that integration step size be reduced significantly. If this does not affect the results, recheck all input data. Improper input data is usually the cause. As an example if the bending frequency is arbitrarily set to zero or some other low value the effective time delay will become very large. Incorrect units on input data is another common error.

If no errors can be found, the control system, disturbing accelerations, control gains, and deadbands should be reviewed along with the specified system time delays. Reduction of control force, widening deadbands or reducing gains should reduce the number of deadband overshoot cases.

3.4.2 Divergence

Divergence is the loss of attitude control due to excessive disturbance (see Figure 1). It occurs when the attitude error reaches the limiting value determined by input data. These cases are not included in the end statistical results and must be treated as described in paragraph 2.5.2.

3.4.3 Time Limit

In order to restrict computer run time the user must input a time limit for the capture maneuver. If this were not done certain conditions could lead to an endless or excessively long capture maneuver which in most cases would be trivial. As an example if there were very low disturbances and rate it would take a relatively long time to reach a deadband to fire a control motor. By inputing a realistic time limit such as 5 or 10 seconds, these trivial cases would be terminated and an Error mode would be encountered. Review of output data generally would reveal the seriousness of the error. If an excessive number of these errors are encountered either the input data is in error or the time limit specified is too short for the control system.

3.5 Input Data Description

Input data descriptions for pitch, yaw, or roll analyses are described in the following paragraphs. Pitch, yaw and roll options use the same routine. Only the input data is redefined. Sample problem input listings are presented in Figures 9 through 11 to aid in the descriptions. Input data occurs in eight (8) basic groups:

(1) card of integers which includes option designations, sample size and run number,
(2) two cards of arbitrary hollerith data which is printed out for identification,
(3) a card containing an integer initial random number generator seed,
(4) nineteen (19) cards containing the floating point values of the mean and standard deviation of random constants,
(5) nineteen (19) cards containing constants which include limits, integration data and non-random constants,
(6) three cards for integral gain option if used,
(7) four (4) tables of time histories,
(8) optional histogram output information.

Groups (1), (2), (3), (6), and (8) are the same for pitch, yaw, or roll axes. Groups (4), (5), and (7) are generally the same for a pitch or yaw axis analysis with minor differences in definition. Roll axis analysis results in many definition changes which are described in paragraph 3.5.9.

3.5.1 First Card (Group 1)

The first input card contains eight fixed point numbers entered in fields of five. These must be entered right justified. Definitions of each of these constants is given below.

Card Column	FORTRAN Variable	Description
1 - 5	NRUN	An arbitrary run number
10	NPRINT	Output print option 0 print out summary data 1 also print values at each overshoot on each case 2 Same as (1) with addition of thrust on and off switching points 3 print out data at each integration step of each case
11 - 15	NTRUN	Number of random samples to be computed by the Monte Carlo technique. (Current dimensions limit this to 1000 samples)

Card Column	FORTRAN Variable	Description
16 - 20	INC	Incremental number of samples for computing the running mean and standard deviation of the capture results
25	NSTAGE	Desired control system state at start of the capture 2 Control system activation occurs simultaneously with ignition or separation event. Control motors are off initially even if error is outside of deadband 3 Control system activated prior to ignition. If initial conditions are outside of deadband control motor thrust is applied immediately
26 - 30	N	Number of overshoots desired before the capture maneuver is assumed to be completed. If an integral gain is used (NKI=1), overshoots are counted only after the integral gain is switched into the loop
35	NHIST	Option to obtain histogram data for capture parameters 0 No histogram data, capture parameters are printed out in unarranged order of computation 1 Histogram data is output, (Group 8 input is required)
40	NKI	Option for integral of attitude error gain function in control logic 0 No integral gain term 1 Integral gain used (Group 6 data must be input)

3.5.2 Arbitrary Identification (Group 2)

The second and third cards contain user defined arbitrary labeling information. The alphanumeric information is contained on the first seventy-eight (78) columns of each card. It is output at the top of the page in two lines the same as input. Internally the information is stored in array NTITLE which contains 26 words each containing 6 characters.

3.5.3 Initial Random Number Seed (Group 3)

The fourth card contains the initial value of the random number seed integer (K). This should be limited to a seven (7) digit integer located in columns 1 through 10 right justified.

3.5.4 Random Constants (Group 4)

Cards (5) through (23) contain the mean (XM) and standard deviations (XSD) of nineteen random constants. These are read in two fields of fifteen (FORMAT 2E15.8). These are:

Card No.	FORTRAN Variable	Symbol	Units	Description
5	XM(1), XSD(1)	I_y	slug-ft^2	Moment of inertia, mean and standard deviation
6	XM(2), XSD(2)	X_{cg}	inches	Center of mass body station location, mean and standard deviation
7	XM(3), XSD(3)	T/T_{nom}	—	ratio of booster motor thrust to nominal value, mean and standard deviation
8	XM(4), XSD(4)	q/q_{nom}	—	ratio of dynamic pressure to nominal value, mean and standard deviation
9	XM(5), XSD(5)	d	degrees	deadband halfwidth, mean and standard deviation
10	XM(6), XSD(6)	H	—	switching hysteresis $(1-d_{off}/d_{on})$
11	XM(7), XSD(7)	t_{on_m}	seconds	control motor turn-on delay time
12	XM(8), XSD(8)	t_{off_m}	seconds	control motor turn-off delay time

Card No.	FORTRAN Variable	Symbol	Units	Description
13	XM(9), XSD(9)	K_R/K_D	seconds	rate to displacement gain ratio
14	XM(10), XSD(10)	F_T	lbs	upper control motor thrust (right control motor for yaw)
15	XM(11), XSD(11)	F_B	lbs	lower control motor thrust (left control motor for yaw)
16	XM(12), XSD(12)	t_G	seconds	control electronics time delay
17	XM(13), XSD(13)	ζ_{RG}	—	rate gyro damping factor
18	XM(14), XSD(14)	f_{RG}	hertz	rate gyro natural frequency
19	XM(15), XSD(15)	$\ln \theta_{e_{amp}}$	degree	natural log of attitude error oscillation amplitude prior to ignition
20	XM(16), XSD(16)	θ_o	deg/sec	attitude rate initial condition
21	XM(17), XSD(17)	V_w	ft/sec	headwind velocity at ignition (right sidewind for yaw) from wind profile at ignition altitude
22	XM(18), XSD(18)	V_w	ft/sec	headwind velocity at second time point, card 35 in Group 5 (right sidewind for yaw) from wind profile at appropriate altitude
23	XM(19), XSD(19)	γ_o	degrees	flight path angle at ignition measured from local horizontal (yaw path angle usually 90 degrees mean)

3.5.5 Constants (Group 5)

This group of data includes non-random constants for the integration, control system characteristics, vehicle and trajectory characteristics. The first two cards in this group contain aerodynamic coefficients, two to a card with Format (2E15.8). These are followed by seventeen (17) cards each having a single value read in with Format (E15.8). They are:

Card No.	FORTRAN Variable	Symbol	Units	Description
24	CNAS	$(C_{N_\alpha}S)_{\alpha=0}$	ft^2/deg	aerodynamic normal force coefficient slope at $\alpha=0$;
	A3	a_3	ft^2/deg^3	cubic term in aerodynamic normal force coefficient
25	XCPO	X_{cpo}	inches	body station of aerodynamic center at $\alpha=0$
	DCPDA	$\delta X_{cp}/\delta\alpha$	in/deg	rate of change in aerodynamic center with angle of attack
26	XF	X_c	inches	body station of control force
27	ZC	Z_c	inches	control motor location off centerline
28	XLAM	λ_c	degrees	forward cant angle of control motor thrusts
29	XN	X_r	inches	body station of booster nozzle throat
30	WB	f_b	hertz	bending frequency (use very large number if rigid body, e.g., 100000)
31	TI	t_o	seconds	start time (usually zero)
32	TMAX	—	seconds	present cutoff timer for capture integration. If this time is reached an error mode is indicated and data for this case is printed out
33	DELTO	—	seconds	coarse integration step size
34	DELTMN	—	seconds	minimum integration step size used when isolating switching points

Card No.	FORTRAN Variable	Symbol	Units	Description
35	AT	--	seconds	second table time used for velocity and wind velocity input
36	VO	V_o	ft/sec	vehicle velocity at ignition
37	V1	V_1	ft/sec	vehicle velocity at second time point (card 35)
38	GDOT	$\dot{\Omega}$	deg/sec	pitch torqueing rate or flight path angle rate (usually zero for yaw)
39	ASEN	$K\alpha$	--	sensitivity of attitude error to angle of attack for previous stage trim conditions
40	THCMO	θ_e bias	degrees	attitude error bias of previous stage at zero angle of attack
41	TLIMIT	θ_e limit	degrees	maximum allowable capture overshoot angle. If this limit is reached the case is terminated and a divergence error is indicated
42	ADES	α_{nom}	degrees	predicted angle of attack on an undisturbed trajectory

3.5.6 Integral Gain Values (Group 6)

Three (3) cards of constants are needed when an integral of attitude error control logic is used. These are input only if NKI on the first card is one or greater. One value per card is input with a FORMAT (E15.8) as follows:

Card No.	FORTRAN Variable	Symbol	Units	Description
43	GINT	K_I	1/sec	integral of attitude error gain
44	XLIM	G_{limit}	degrees	integral gain term limiting
45	TKI	t_{KI}	seconds	time after ignition at which integral gain term enters control logic

3.5.7 Time History Tables (Group 7)

Four (4) tables of parameter time histories are input. These include dynamic pressure, booster thrust, the mean and standard deviation of booster thrust misalignment angle. Each of these tables is input with FORMAT (I5/(6E10.3)). The first card of each table contains the integer number of values in the array; it must be located in columns one (1) through five (5) and be right justified. Succeeding cards contain alternating values of time and ordinate with six (6) numbers per card in fields of ten (10). Each of these tables are dimensioned to carry up to fifty values or twenty-five (25) time points each.

FORTRAN Table Name	Ordinate Symbol	Units	Absciaas Symbol	Units	Description
TABQ	q_{nom}	lbs/ft^2	t	sec	nominal dynamic pressure
TABT	T	lbs	t	sec	booster thrust
ETMEAN	ϵ_T	degrees	t	sec	mean value of booster thrust misalignment
ETSIG	ϵ_T	degrees	t	sec	standard deviation of booster thrust misalignment

3.5.8 Histogram Information (Group 8)

This last group of input is used only when NHIST is one (1) or greater on the first card. This results in histogram cell counts for the overshoot angle, time to overshoot, and impulse expended output parameters. Input includes two cards of data. The first card contains the integer number of cells for the histogram (NCEL). This is entered in the first five (5) columns and is right justified. A maximum of 150 cells is included in the dimension statement.

The second and last card contains the minimum and maximum values which specify the ranges of each histogram. These are entered with format (6E10.3) and are:

Card Column	FORTRAN Variable	Units	Description
1 - 10	CMINH	degrees	attitude error overshoot angle lower range (usually zero)
11 - 20	CMAXH	degrees	attitude error overshoot upper end of range
21 - 30	TMINH	seconds	capture time lower end of range (usually zero)
31 - 40	TMAXH	seconds	capture time upper end of range
41 - 50	PMINH	lb-sec	capture impulse lower end of range (usually zero)
51 - 60	PMAXH	lb-sec	capture impulse upper end of range

In output if any data is out of the range specified they will be included in the first and last cells.

3.5.9 Roll Axis Input Data Differences

When using the routine for roll axes analyses the definition of some terms is different. A sample problem input is presented in Figure 11. The changes from a pitch axis run are reflected in groups 4, 5, and 7. Since wind and angle of attack are not included in the roll axis equations certain parameters associated with these must be entered as a specified constant. These are denoted by asterisks in the description column in Figure 11. Group 4 and 5 data are the same as presented in paragraphs 3.5.4 and 3.5.5 with the following exceptions. Asterisks indicate specified numbers must be entered.

Card No.	FORTRAN Variable	Symbol	Units	Description or Specified Numbers
6	XM(2), XSD(2)	***	***	0., 0.
7	XM(3), XSD(3)	***	***	1., 0.
14	XM(10), XSD(10)	F_T	lbs	roll right control motor thrust. If a couple this must reflect both motors
15	XM(11), XSD(11)	F_B	lbs	roll left control motor thrust
21	XM(17), XSD(17)	***	***	0., 0.
22	XM(18), XSD(18)	***	***	0., 0.
23	XM(19), XSD(19)	***	***	0., 0.

Card No.	FORTRAN Variable	Symbol	Units	Description or Specified Numbers
24	CNAS	$(C_{\ell\phi}\ S)_{\phi_e=o}$	ft^2/deg	aerodynamic rolling moment coefficient slope at roll error of zero
	A3	a_3	ft^2/deg^3	cubic term in rolling moment coefficient
25	XCPO,	$-d_{ref}$	inches	negative of the aerodynamic reference length
26	XF	***	***	0.
27	ZC	Z_c	inches	roll control motor location from vehicle centerline
28	XLAM	***	***	90.
29	XN	***	***	687.6
30	WB	f_b	hertz	torsional mode frequency
35	AT	***	***	1.
36	VO	***	***	1.
37	V1	***	***	1.
38	GDOT	$\dot{\Omega}$	deg/sec	commanded roll attitude rate
39	ASEN	***	***	0.
40	THCMO	$\phi_{e\ bias}$	deg	initial roll attitude error bias
42	ADES	***	***	0.

Group 7 tables are redefined from those presented in paragraph 3.5.7. The dynamic pressure is the same. The inputs are,

FORTRAN Table Name	Ordinate Symbol	Units	Absciaas Symbol	Units	Description
TABQ	q_{nom}	lbs/ft^2	t	sec	nominal dynamic pressure
TABT	***	1.	t	sec	unity multiplier

FORTRAN Table Name	Ordinate Symbol	Units	Absciaas Symbol	Units	Description
ETMEAN	L	ft-lbs	t	sec	mean value of booster induced roll torque
ETSIG	L	ft-lbs	t	sec	standard deviation of booster roll torque

3.6 Output Data Description

All output for this program is printed on output tape unit six (6). The amount of output is controlled by options selected in the first card of input (paragraph 3.5.1). Output is made in groups, i. e.,

1) running mean and standard deviation and individual sample data

2) unarranged capture overshoot, time and impulse for all cases (NHIST=0 only)

3) histogram cell data for capture overshoot, time and impulse (NHIST =1)

4) discrete probability versus overshoot, time and impulse arranged in ascending order

5) summary of divergent cases, abnormal terminations and final pseudo random number seed

Detailed descriptions of the output with sample problems are presented in the following paragraphs.

3.6.1 Running Mean, Standard Deviation and Sample Data (Group 1)

The amount of data output in this first section depends upon the selected options. The amount of information output is determined by the parameter NPRINT on the first card of input described in paragraph 3.5.1.

NPRINT = 0

When NPRINT = 0 the running mean and standard deviation is printed after the specified increment (INC) or random captures. The sample output for this option is shown in Figure 12 for a 199 sample run with INC = 50. The following nomenclature applies,

ITER NO	is the current sample at which all previous normally computed cases are included in the mean (MEAN) and standard deviation (SIGMA) calculations,
THETA	is the absolute value of the maximum attitude error overshoot in degrees,
TIME	is the time to reach the maximum overshoot angle (seconds),
IMPULSE	is the control motor total impulse expended during capture in pound-seconds

Also interspersed within these output lines will be four lines indicating abnormal terminations as described in section 3.4. The sample problem presented in Figure 12 had one divergent case between sample 150 and 199. Output for the abnormal case is always as shown in Figure 12 with the following difinitions; all values occurred at time of termination.

TIME (SEC)	is the time from stage ignition at which the error occurred
RATE (DEG/SEC)	is the attitude angular rate
ATT ERROR (DEG)	is the attitude error
Q (PSF)	is the dynamic pressure
ALPHA (DEGREE)	is the angle of attack or roll attitude error for a roll capture
THRUST MIS (DEG)	is the booster thrust misalignment in degrees or the roll torque in ft-lbs
F TOP (LB)	is the upper pitch, right yaw, or roll right control motor thrust
F LOWER (LB)	is the lower pitch, left yaw, or roll left control motor thrust
LAST OVERSHOOT	is the maximum overshoot angle (zero rate crossing) prior to the termination

Above information is output for any printout option and is interspersed with other outputs in Group 1.

NPRINT = 1

This selection of output includes all overshoots which occurred during the capture maneuver. A sample output is shown in Figure 13. Three overshoots were selected for this run (N parameter on first card of input). Definitions of terms include,

THETA	is attitude error in degrees
THETADOT	is attitude rate in degrees per second

TIME is time from stage ignition in seconds

IMPULSE is control motor impulse expended in pound-seconds

NPRINT = 2

With this option the Group 1 output includes all items discussed above plus points in each capture at control deadband crossing and thrust-on and thrust-off points. A sample output is shown in Figure 14.

NPRINT = 3

This option increases the amount of output for each sample to include all integration steps. A sample output is presented in Figure 15. It is helpful for individual capture maneuvers. As shown on the second and third page of Figure 15 one sample ended in divergence.

3.6.2 Unarranged Parameters (Group 2 - NHIST = 0)

In certain circumstances, the order in which attitude error overshoot, capture time, and impulse are desired as well as the relationship of these three parameters. This can be obtained by setting NHIST = 0 on the first card of input. It prevents the histogram output from being generated and output also. A sample output is shown in Figure 16.

3.6.3 Histogram Cell Data (Group 3 - NHIST = 1)

Capture overshoot angle, time, and impulse are counted and located in histogram cells if NHIST = 1 on the first card of input. The number of cells and ranges for the histogram are user selected in the Group (8) input described in paragraph 3.5.8. A sample output is presented in Figure 17. The following is output for each cell,

CAPTURE ANGLE the attitude error overshoot angle range of the cell in degrees

NO the number of cases which had values in this cell range

TIME the time to maximum overshoot cell range in seconds

IMPULSE the control motor impulse expended in pound-seconds

3.6.4 Discrete Probability (Group 4)

All options include this output. It includes the maximum overshoot angle, capture time, and impulse expended versus probability level as defined by Equation 3-1,

(3-1) $$P = N_i / (NTRUN + 1)$$

where, P is the probability of not exceeding the given value

N_i is the sample number after being arranged in ascending order for the particular variable

NTRUN is the number of normally completed cases, specified on the first card

A sample problem output is presented in Figure 18. It should be noted that the probability of successful capture must include these results plus the abnormally terminated cases as discussed in paragraph 2.5.2.

3.6.5 Summary of Abnormal Cases (Group 5)

This page of output occurs with all options. A sample is presented in Figure 19. It includes the total number of divergent maneuvers, as well as those which encountered a "deadband overshoot" or a time limit as discussed in Section 3.4. The final integer value of the pseudo-random number generator seed is also output on this page. This number can be used as an input to a successive run to increase the sample size based on a pseudo-random number set which is "uncorrelated" from the previous run.

4.0 References

(1) Jorgensen, L. H., "Prediction of Static Aerodynamic Characteristics for Slender Bodies Alone and With Lifting Surfaces to Very High Angles of Attack" NASA TMX-73.123, Ames Research Center, July 1976.

(2) Rainville, Earl D., "A Short Course in Differential Equations", page 113, the MacMillan Company, New York, Seventh Printing 1956.

Figure 1
Phase Plane Trajectories of Capture Maneuver

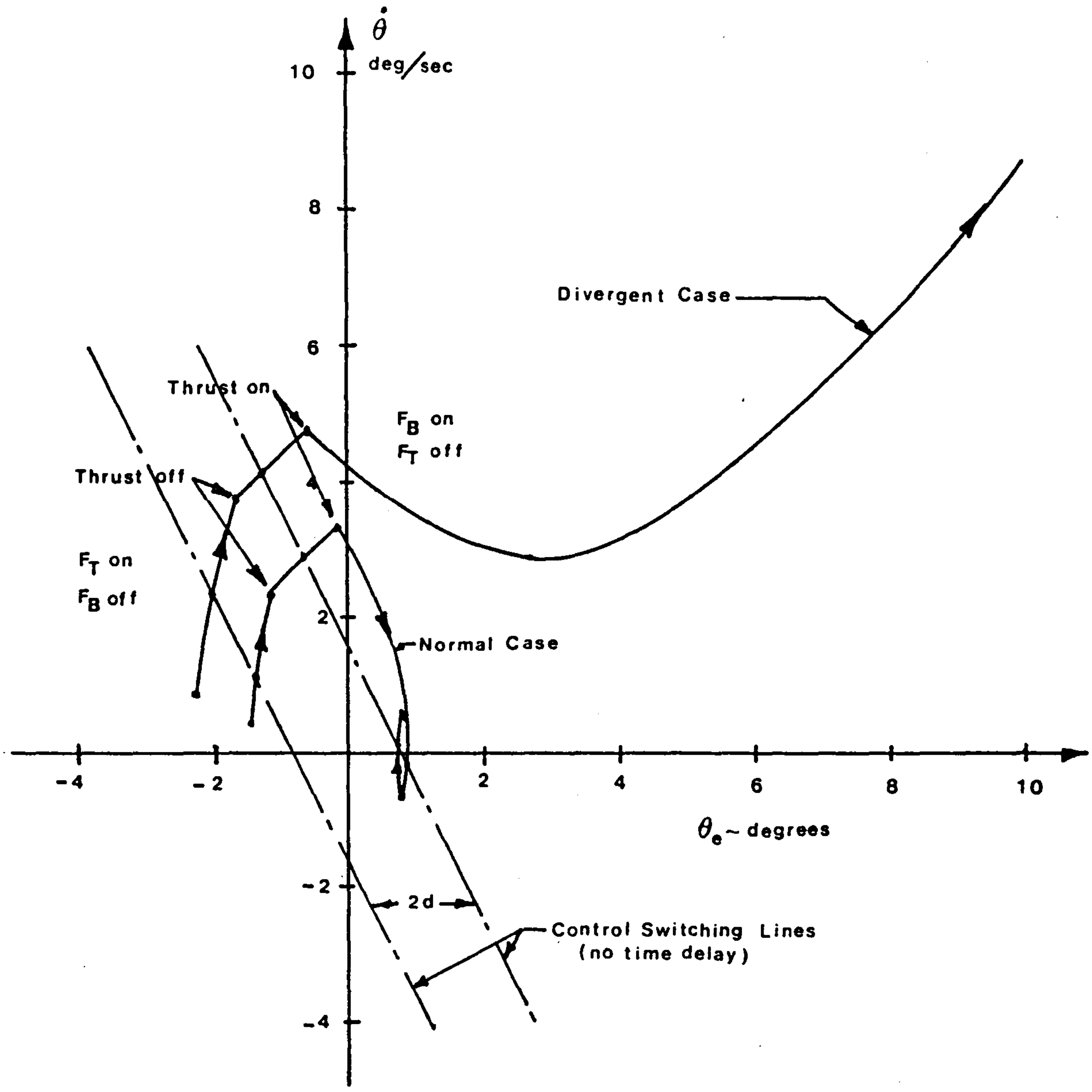


Figure 2
Control System Block Diagram

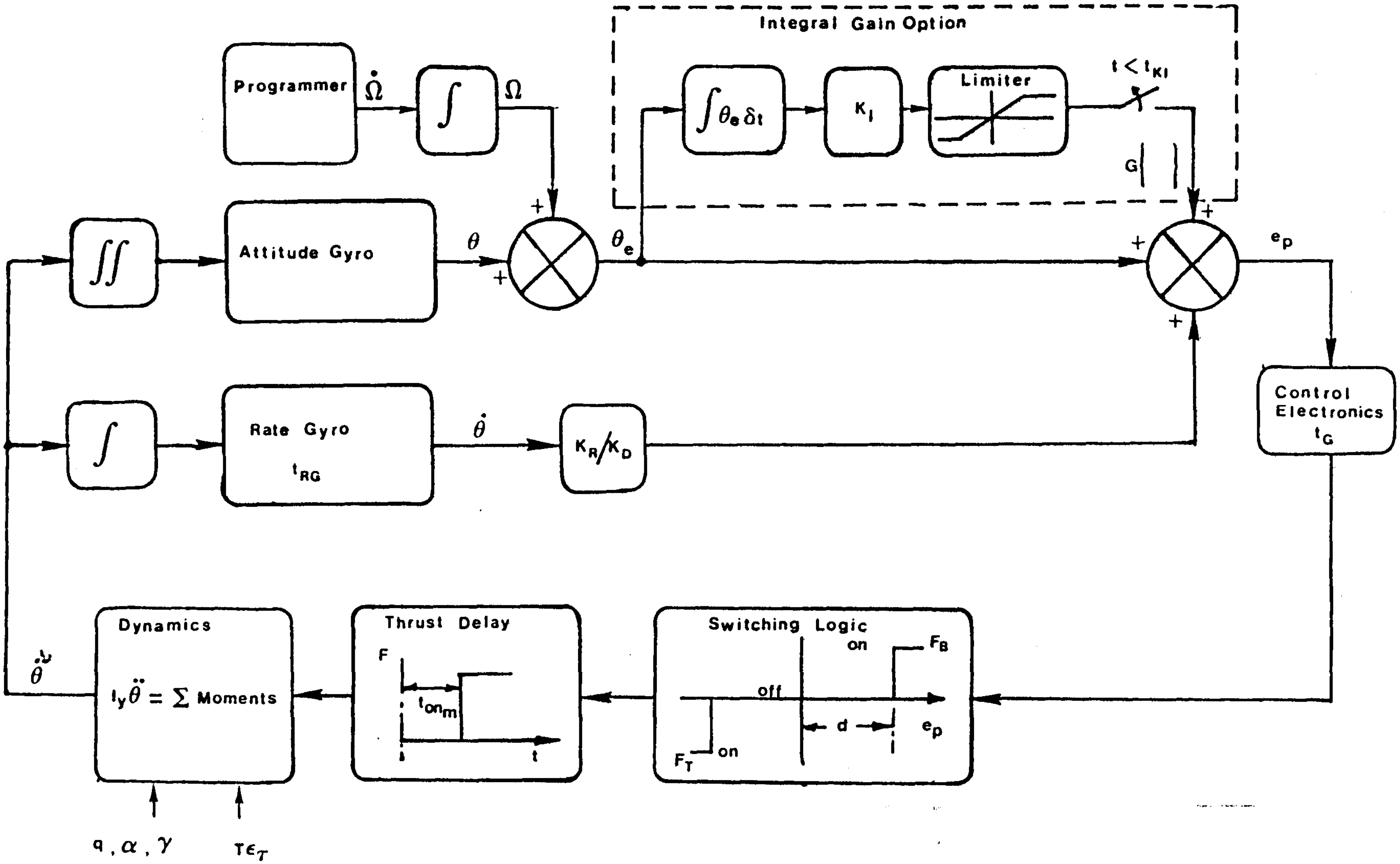
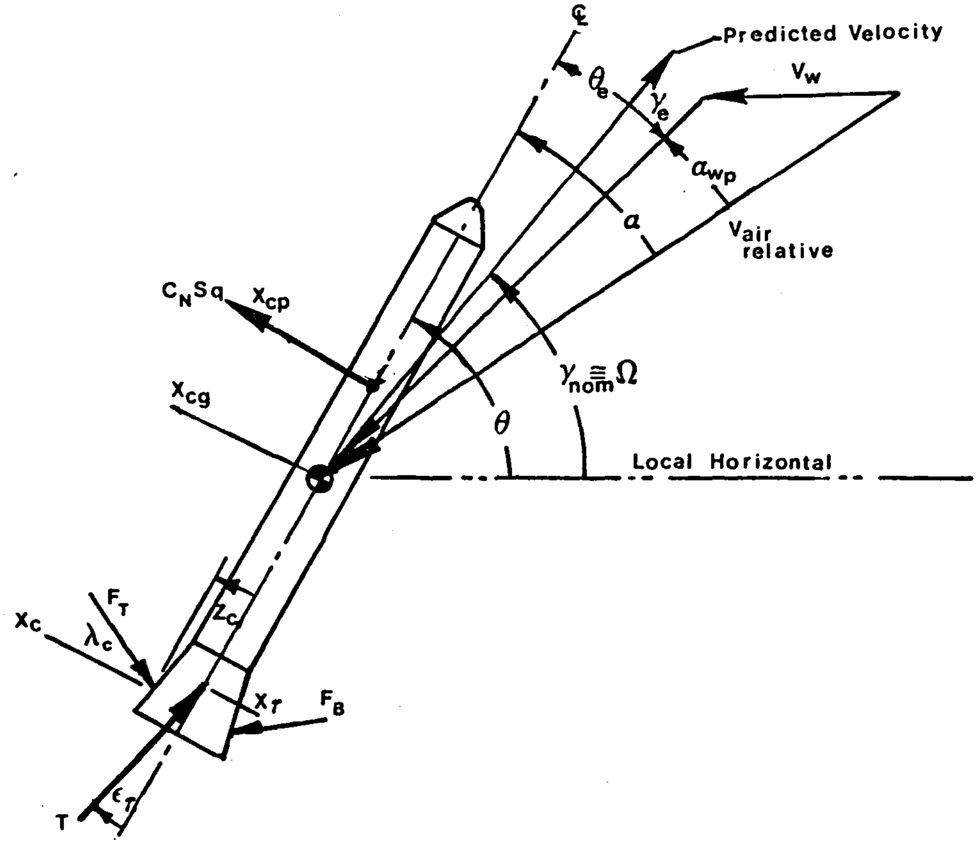


Figure 3
Sign Convention

PITCH AXIS



ROLL AXIS

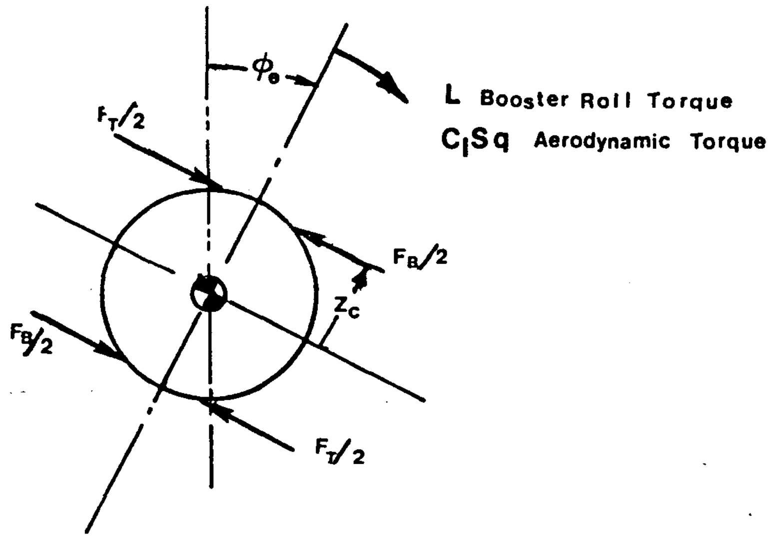
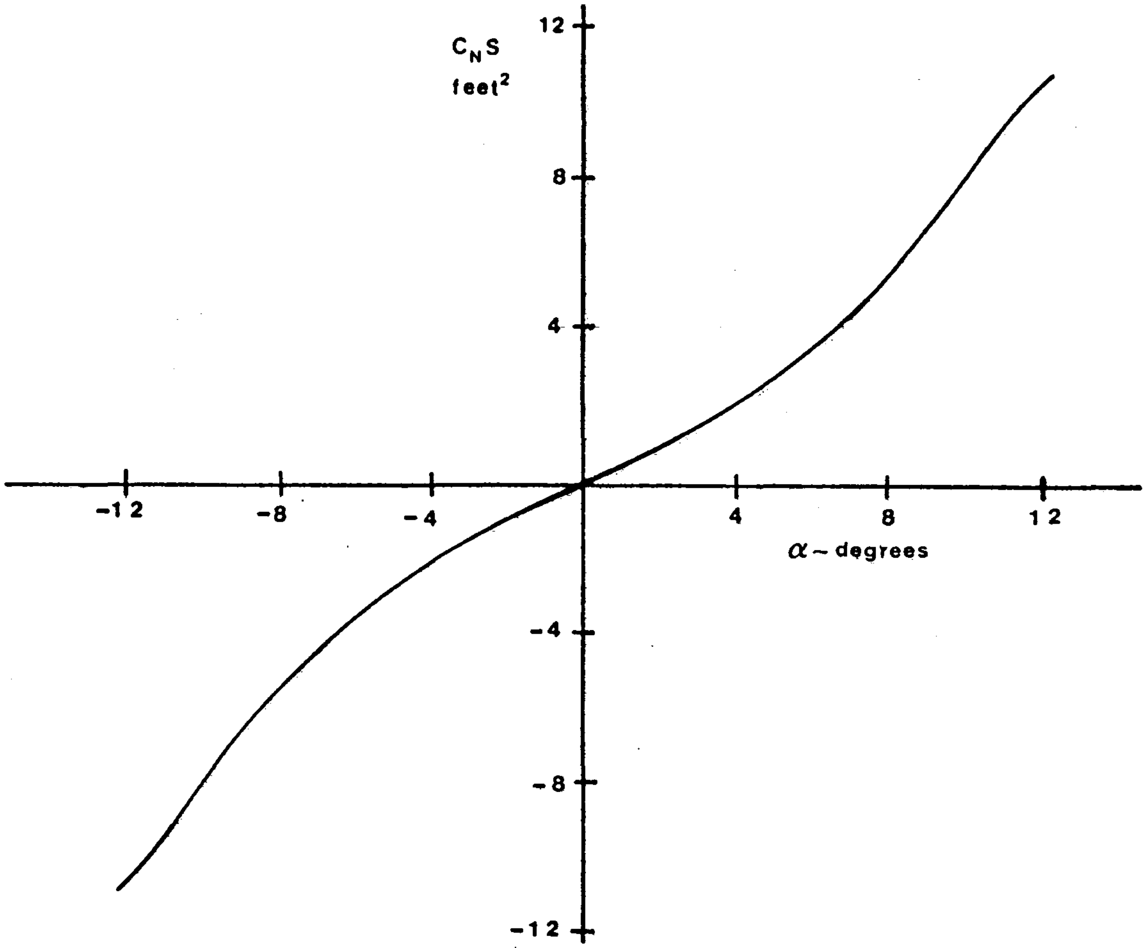


Figure 4
Typical Aerodynamic Coefficients
SCOUT Second Stage — Mach 4



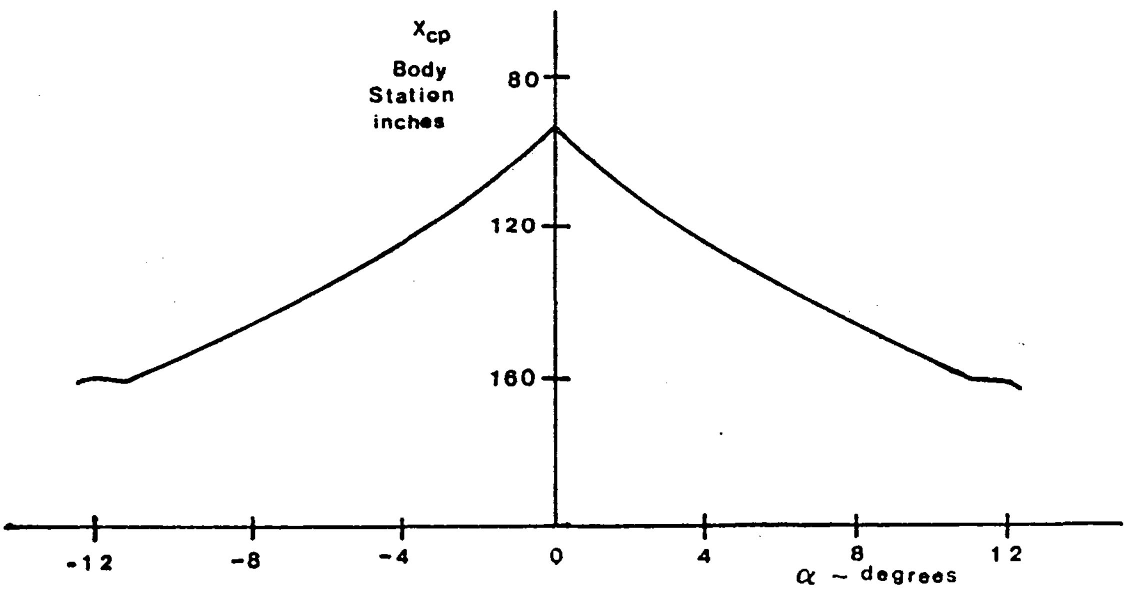


Figure 5
Tables of Binomial Upper Confidence Limits
Probability of Failure - 200 Samples

Confidence Coefficient / No. of failures	.500	.800	.900	.950	.990	.995
0	0.003460	0.008015	0.011447	0.014867	0.022763	0.026144
1	0.008377	0.014897	0.019309	0.023498	0.032728	0.036559
2	0.013348	0.021274	0.026391	0.031143	0.041362	0.045534
3	0.018330	0.027402	0.033098	0.038310	0.049348	0.053803
4	0.023315	0.033377	0.039570	0.045180	0.056929	0.061631
5	0.028303	0.039243	0.045879	0.051843	0.064224	0.069146
6	0.033292	0.045028	0.052064	0.058350	0.071304	0.076425
7	0.038282	0.050749	0.058153	0.064733	0.078212	0.083516
8	0.043272	0.056417	0.064162	0.071014	0.084981	0.090455
9	0.048263	0.062041	0.070104	0.077211	0.091632	0.097264
10	0.053254	0.067628	0.075990	0.083335	0.098182	0.103960
11	0.058245	0.073182	0.081826	0.089396	0.104640	0.110560
12	0.063235	0.078707	0.087618	0.095401	0.111030	0.117080
13	0.068227	0.084207	0.093371	0.101360	0.117340	0.123520
14	0.073218	0.089683	0.099089	0.107270	0.123600	0.129890
15	0.078209	0.095139	0.104780	0.113140	0.129800	0.136200
16	0.083200	0.100580	0.110430	0.118970	0.135940	0.142460
17	0.088192	0.105990	0.116060	0.124770	0.142040	0.148660
18	0.093183	0.111400	0.121670	0.130540	0.148090	0.154810
19	0.098174	0.116780	0.127250	0.136280	0.154110	0.160920
20	0.103170	0.122160	0.132820	0.141990	0.160080	0.166980
21	0.108160	0.127520	0.138360	0.147680	0.166020	0.173010
22	0.113150	0.132870	0.143880	0.153340	0.171930	0.179000
23	0.118140	0.138200	0.149390	0.158980	0.177800	0.184950
24	0.123130	0.143530	0.154880	0.164590	0.183640	0.190880
25	0.128120	0.148840	0.160350	0.170190	0.189460	0.196770
26	0.133110	0.154150	0.165810	0.175770	0.195250	0.202630
27	0.138110	0.159440	0.171250	0.181330	0.201010	0.208460
28	0.143100	0.164730	0.176680	0.186870	0.206750	0.214270
29	0.148090	0.170010	0.182100	0.192400	0.212470	0.220050
30	0.153080	0.175280	0.187500	0.197910	0.218160	0.225800
31	0.158070	0.180540	0.192900	0.203410	0.223830	0.231530
32	0.163060	0.185790	0.198280	0.208890	0.229480	0.237240
33	0.168060	0.191040	0.203650	0.214350	0.235110	0.242930
34	0.173050	0.196280	0.209010	0.219800	0.240730	0.248590
35	0.178040	0.201510	0.214350	0.225240	0.246320	0.254240
36	0.183030	0.206740	0.219690	0.230670	0.251890	0.259860
37	0.188020	0.211960	0.225020	0.236080	0.257450	0.265470
38	0.193010	0.217170	0.230340	0.241480	0.262990	0.271060
39	0.198010	0.222380	0.235650	0.246870	0.268520	0.276620
40	0.203000	0.227580	0.240950	0.252250	0.274020	0.282180
41	0.207990	0.232780	0.246250	0.257620	0.279520	0.287710
42	0.212980	0.237970	0.251530	0.262970	0.285000	0.293230
43	0.217970	0.243150	0.256810	0.268320	0.290460	0.298730
44	0.222960	0.248330	0.262070	0.273650	0.295910	0.304210
45	0.227960	0.253510	0.267330	0.278980	0.301340	0.309680
46	0.232950	0.258680	0.272590	0.284300	0.306760	0.315140
47	0.237940	0.263840	0.277830	0.289600	0.312170	0.320580
48	0.242930	0.269000	0.283070	0.294900	0.317570	0.326000
49	0.247920	0.274160	0.288300	0.300190	0.322950	0.331420
50	0.252910	0.279310	0.293530	0.305470	0.328320	0.336810

Figure 5 (cont'd)
Tables of Binomial Upper Confidence Limits
Probability of Failure - 500 Samples

Confidence Coefficient / No. of failures	.500	.800	.900	.950	.990	.995
0	0.001385	0.003214	0.004595	0.005974	0.009168	0.010541
1	0.003354	0.005977	0.007757	0.009452	0.013202	0.014765
2	0.005344	0.008539	0.010609	0.012538	0.016705	0.018413
3	0.007339	0.011002	0.013312	0.015434	0.019949	0.021781
4	0.009336	0.013405	0.015923	0.018213	0.023033	0.024973
5	0.011333	0.015766	0.018470	0.020910	0.026005	0.028042
6	0.013330	0.018095	0.020969	0.023547	0.028892	0.031018
7	0.015328	0.020399	0.023430	0.026135	0.031713	0.033921
8	0.017326	0.022683	0.025860	0.028684	0.034479	0.036765
9	0.019325	0.024949	0.028264	0.031200	0.037200	0.039558
10	0.021323	0.027202	0.030647	0.033688	0.039882	0.042309
11	0.023321	0.029442	0.033010	0.036153	0.042530	0.045023
12	0.025320	0.031670	0.035357	0.038596	0.045149	0.047705
13	0.027318	0.033890	0.037690	0.041020	0.047741	0.050358
14	0.029317	0.036100	0.040009	0.043427	0.050310	0.052984
15	0.031315	0.038303	0.042316	0.045820	0.052858	0.055588
16	0.033314	0.040499	0.044613	0.048198	0.055387	0.058170
17	0.035312	0.042688	0.046899	0.050564	0.057898	0.060733
18	0.037311	0.044871	0.049177	0.052918	0.060392	0.063278
19	0.039309	0.047048	0.051446	0.055262	0.062872	0.065806
20	0.041308	0.049221	0.053707	0.057596	0.065338	0.068319
21	0.043306	0.051389	0.055962	0.059920	0.067791	0.070818
22	0.045305	0.053552	0.058209	0.062236	0.070232	0.073303
23	0.047303	0.055711	0.060450	0.064543	0.072661	0.075776
24	0.049302	0.057866	0.062685	0.066843	0.075080	0.078237
25	0.051301	0.060018	0.064915	0.069136	0.077488	0.080687
26	0.053299	0.062166	0.067139	0.071422	0.079887	0.083126
27	0.055298	0.064310	0.069358	0.073702	0.082277	0.085556
28	0.057297	0.066452	0.071572	0.075975	0.084658	0.087975
29	0.059295	0.068590	0.073782	0.078243	0.087032	0.090386
30	0.061294	0.070726	0.075988	0.080505	0.089397	0.092789
31	0.063292	0.072859	0.078189	0.082762	0.091755	0.095183
32	0.065291	0.074989	0.080386	0.085013	0.094106	0.097569
33	0.067290	0.077117	0.082580	0.087260	0.096450	0.099948
34	0.069288	0.079242	0.084770	0.089502	0.098788	0.102320
35	0.071287	0.081365	0.086956	0.091740	0.101120	0.104680
36	0.073286	0.083486	0.089139	0.093974	0.103440	0.107040
37	0.075284	0.085605	0.091319	0.096203	0.105760	0.109390
38	0.077283	0.087722	0.093496	0.098428	0.108080	0.111740
39	0.079281	0.089837	0.095670	0.100650	0.110390	0.114080
40	0.081280	0.091950	0.097841	0.102870	0.112690	0.116410
41	0.083279	0.094061	0.100010	0.105080	0.114990	0.118740
42	0.085277	0.096170	0.102170	0.107290	0.117280	0.121060
43	0.087276	0.098278	0.104340	0.109500	0.119570	0.123380
44	0.089275	0.100380	0.106500	0.111700	0.121850	0.125690
45	0.091273	0.102490	0.108660	0.113900	0.124130	0.128000
46	0.093272	0.104590	0.110810	0.116100	0.126410	0.130300
47	0.095271	0.106690	0.112960	0.118300	0.128680	0.132600
48	0.097269	0.108790	0.115110	0.120490	0.130950	0.134890
49	0.099268	0.110890	0.117260	0.122680	0.133210	0.137180
50	0.101270	0.112990	0.119410	0.124870	0.135470	0.139470
51	0.103270	0.115080	0.121550	0.127050	0.137720	0.141750
52	0.105260	0.117180	0.123700	0.129230	0.139980	0.144030
53	0.107260	0.119270	0.125840	0.131410	0.142220	0.146300

Figure 5 (concluded)
Tables of Binomial Upper Confidence Limits
Probability of Failure - 1000 Samples

Confidence Coefficient / No. of failures	.500	.800	.900	.950	.990	.995
0	0.000693	0.001608	0.002300	0.002991	0.004595	0.005284
1	0.001678	0.002991	0.003884	0.004735	0.006620	0.007406
2	0.002673	0.004274	0.005313	0.006282	0.008379	0.009240
3	0.003671	0.005508	0.006668	0.007735	0.010010	0.010934
4	0.004669	0.006712	0.007978	0.009130	0.011561	0.012540
5	0.005668	0.007894	0.009255	0.010484	0.013055	0.014085
6	0.006667	0.009061	0.010508	0.011808	0.014508	0.015584
7	0.007667	0.010216	0.011743	0.013108	0.015928	0.017047
8	0.008666	0.011361	0.012962	0.014388	0.017321	0.018480
9	0.009665	0.012497	0.014169	0.015653	0.018691	0.019889
10	0.010665	0.013626	0.015365	0.016903	0.020043	0.021276
11	0.011665	0.014749	0.016552	0.018142	0.021377	0.022645
12	0.012664	0.015866	0.017730	0.019370	0.022697	0.023999
13	0.013664	0.016979	0.018901	0.020589	0.024005	0.025338
14	0.014663	0.018088	0.020066	0.021800	0.025301	0.026664
15	0.015663	0.019192	0.021225	0.023004	0.026586	0.027979
16	0.016662	0.020294	0.022379	0.024200	0.027862	0.029283
17	0.017662	0.021392	0.023528	0.025391	0.029129	0.030578
18	0.018662	0.022487	0.024673	0.026576	0.030389	0.031865
19	0.019661	0.023579	0.025813	0.027755	0.031641	0.033143
20	0.020661	0.024669	0.026950	0.028930	0.032886	0.034414
21	0.021660	0.025757	0.028083	0.030101	0.034125	0.035678
22	0.022660	0.026843	0.029213	0.031267	0.035358	0.036935
23	0.023660	0.027926	0.030340	0.032429	0.036586	0.038186
24	0.024659	0.029008	0.031463	0.033587	0.037809	0.039432
25	0.025659	0.030088	0.032585	0.034743	0.039026	0.040672
26	0.026659	0.031166	0.033703	0.035894	0.040239	0.041907
27	0.027658	0.032242	0.034820	0.037043	0.041448	0.043138
28	0.028658	0.033317	0.035934	0.038189	0.042653	0.044364
29	0.029658	0.034391	0.037045	0.039332	0.043854	0.045585
30	0.030657	0.035463	0.038155	0.040472	0.045050	0.046803
31	0.031657	0.036534	0.039263	0.041610	0.046244	0.048016
32	0.032657	0.037604	0.040369	0.042746	0.047434	0.049226
33	0.033656	0.038673	0.041473	0.043879	0.048621	0.050432
34	0.034656	0.039740	0.042575	0.045010	0.049804	0.051635
35	0.035655	0.040806	0.043676	0.046138	0.050985	0.052834
36	0.036655	0.041872	0.044775	0.047265	0.052163	0.054030
37	0.037655	0.042936	0.045873	0.048390	0.053338	0.055224
38	0.038654	0.043999	0.046969	0.049513	0.054511	0.056414
39	0.039654	0.045062	0.048064	0.050634	0.055681	0.057602
40	0.040654	0.046123	0.049157	0.051753	0.056848	0.058786
41	0.041653	0.047184	0.050249	0.052871	0.058013	0.059969
42	0.042653	0.048244	0.051340	0.053987	0.059176	0.061148
43	0.043653	0.049303	0.052429	0.055102	0.060337	0.062326
44	0.044652	0.050361	0.053518	0.056215	0.061495	0.063501
45	0.045652	0.051418	0.054605	0.057326	0.062652	0.064673
46	0.046652	0.052475	0.055691	0.058436	0.063806	0.065844
47	0.047651	0.053531	0.056776	0.059545	0.064959	0.067012
48	0.048651	0.054586	0.057860	0.060653	0.066109	0.068178
49	0.049651	0.055641	0.058943	0.061759	0.067258	0.069342
50	0.050650	0.056695	0.060025	0.062863	0.068405	0.070504

Figure 6
MAIN Program Basic Flow Chart

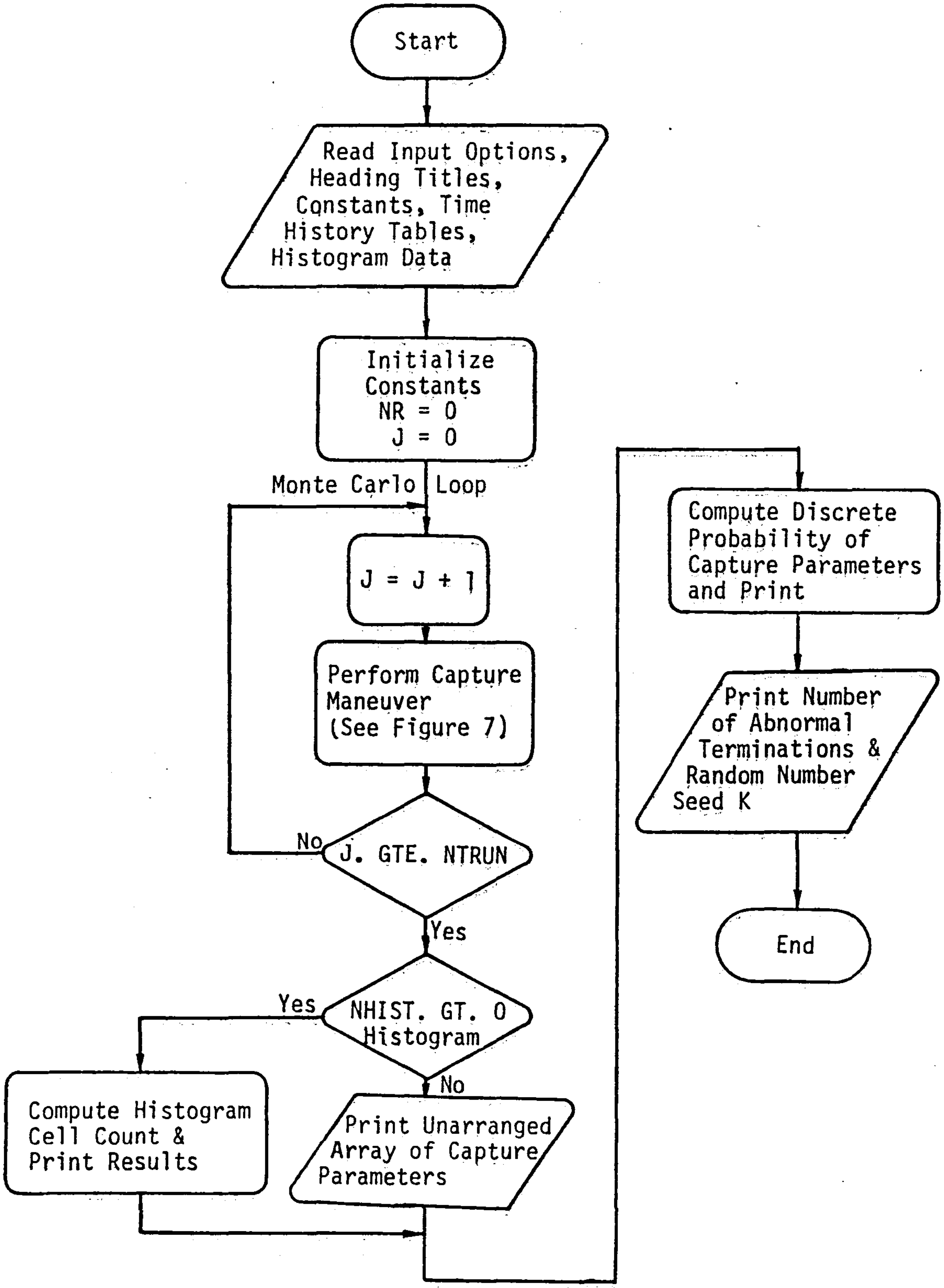
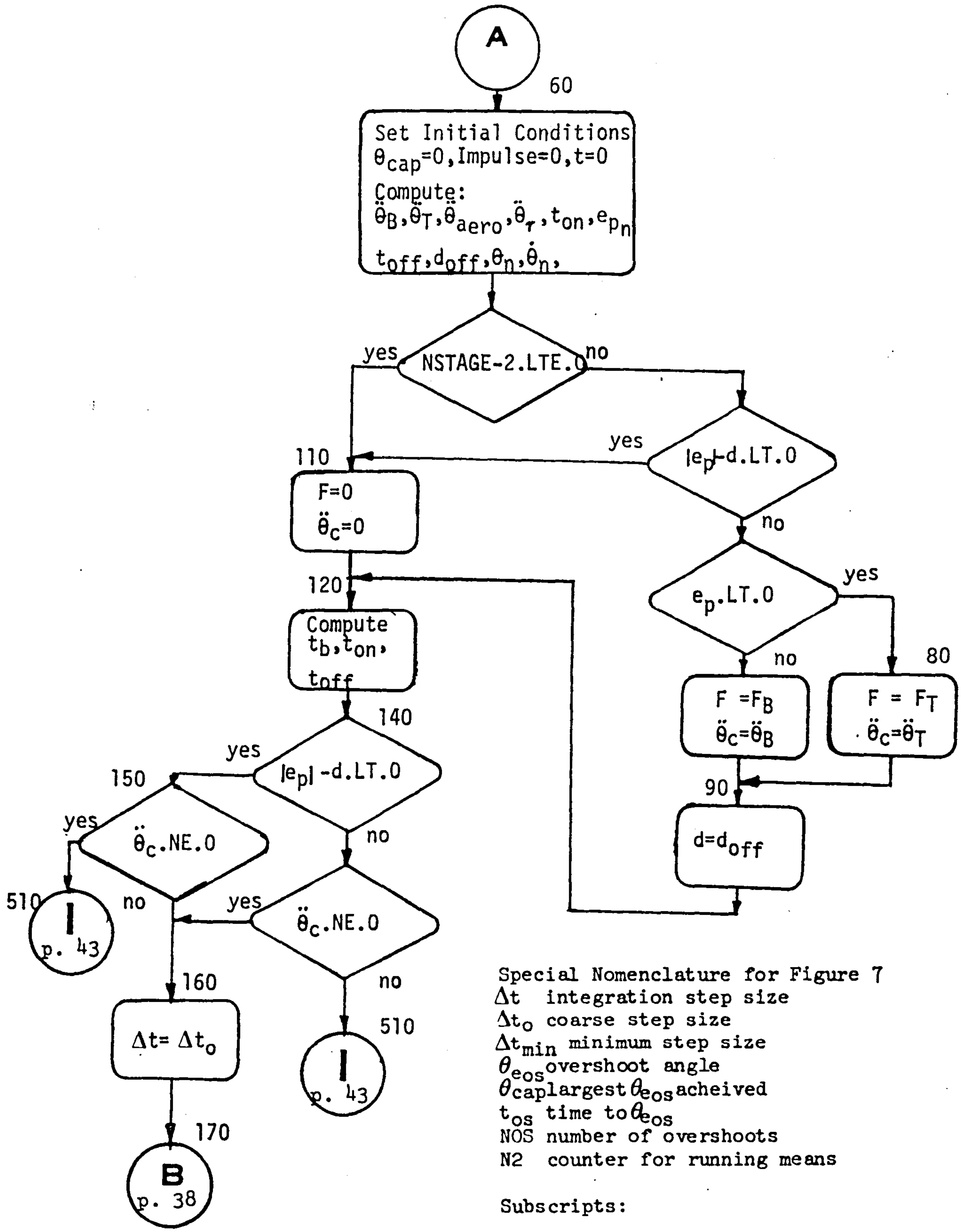


Figure 7
Detailed Flow Chart of Capture Maneuver Logic



Special Nomenclature for Figure 7

Δt integration step size
Δt_o coarse step size
Δt_{min} minimum step size
θ_{eos} overshoot angle
θ_{cap} largest θ_{eos} acheived
t_{os} time to θ_{eos}
NOS number of overshoots
N2 counter for running means

Subscripts:

n denotes start of integration step
n+1 denotes end of integration step

Figure 7 (Continued)
Detailed Flow Chart of Capture Maneuver Logic

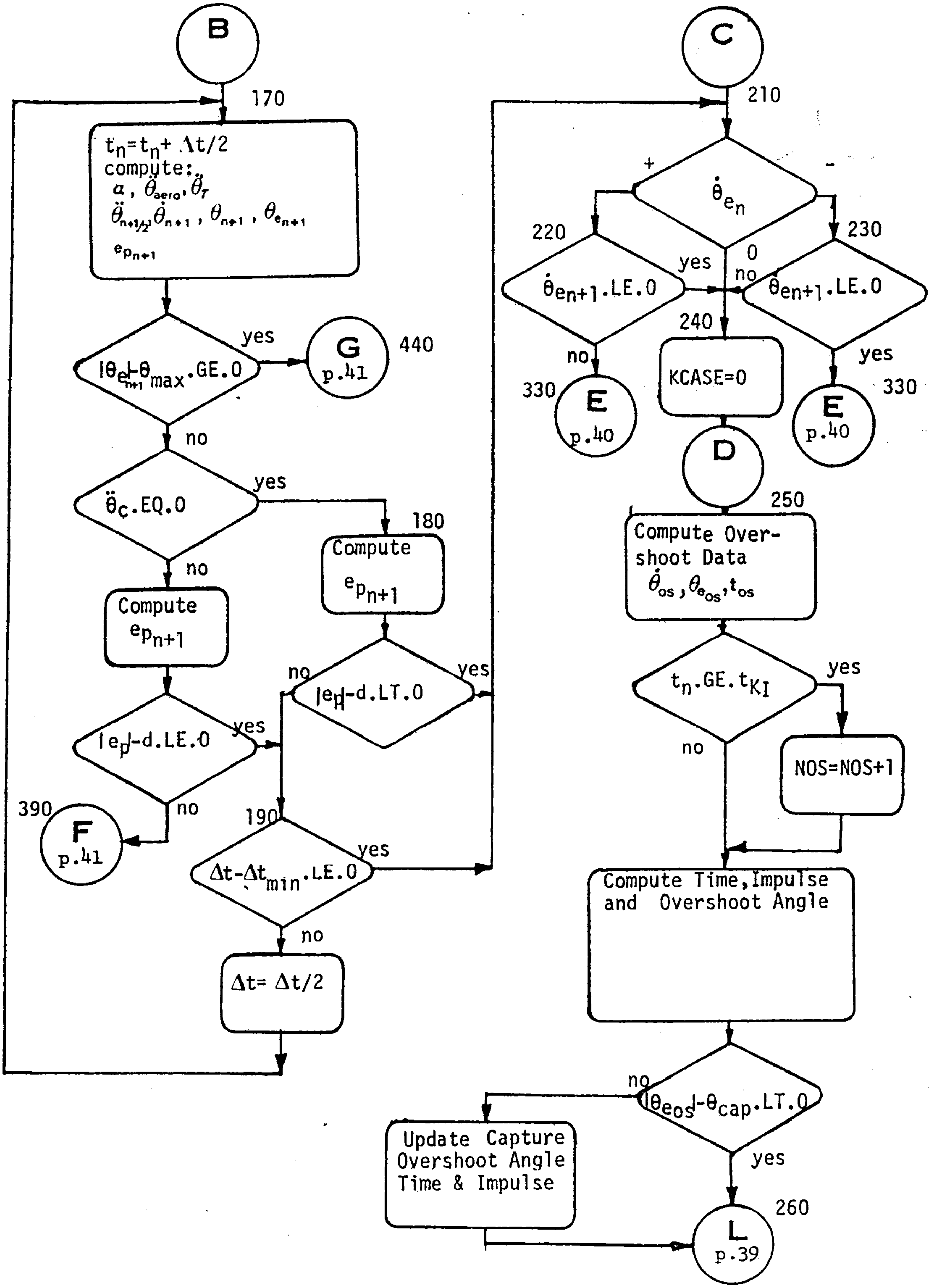


Figure 7 (Continued)
Detailed Flow Chart of Capture Maneuver Logic

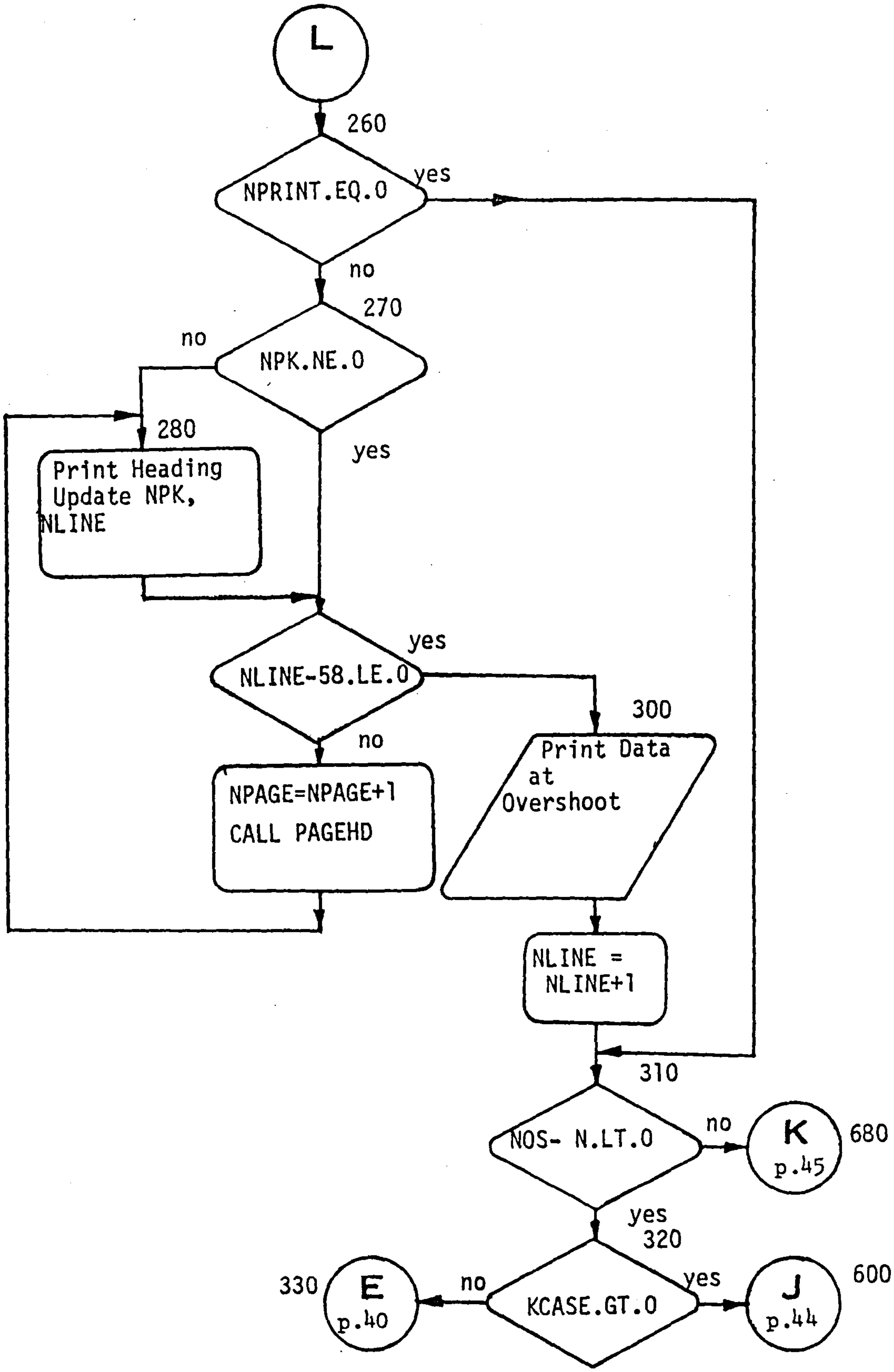


Figure 7 (Continued)
Detailed Flow Chart of Capture Maneuver Logic

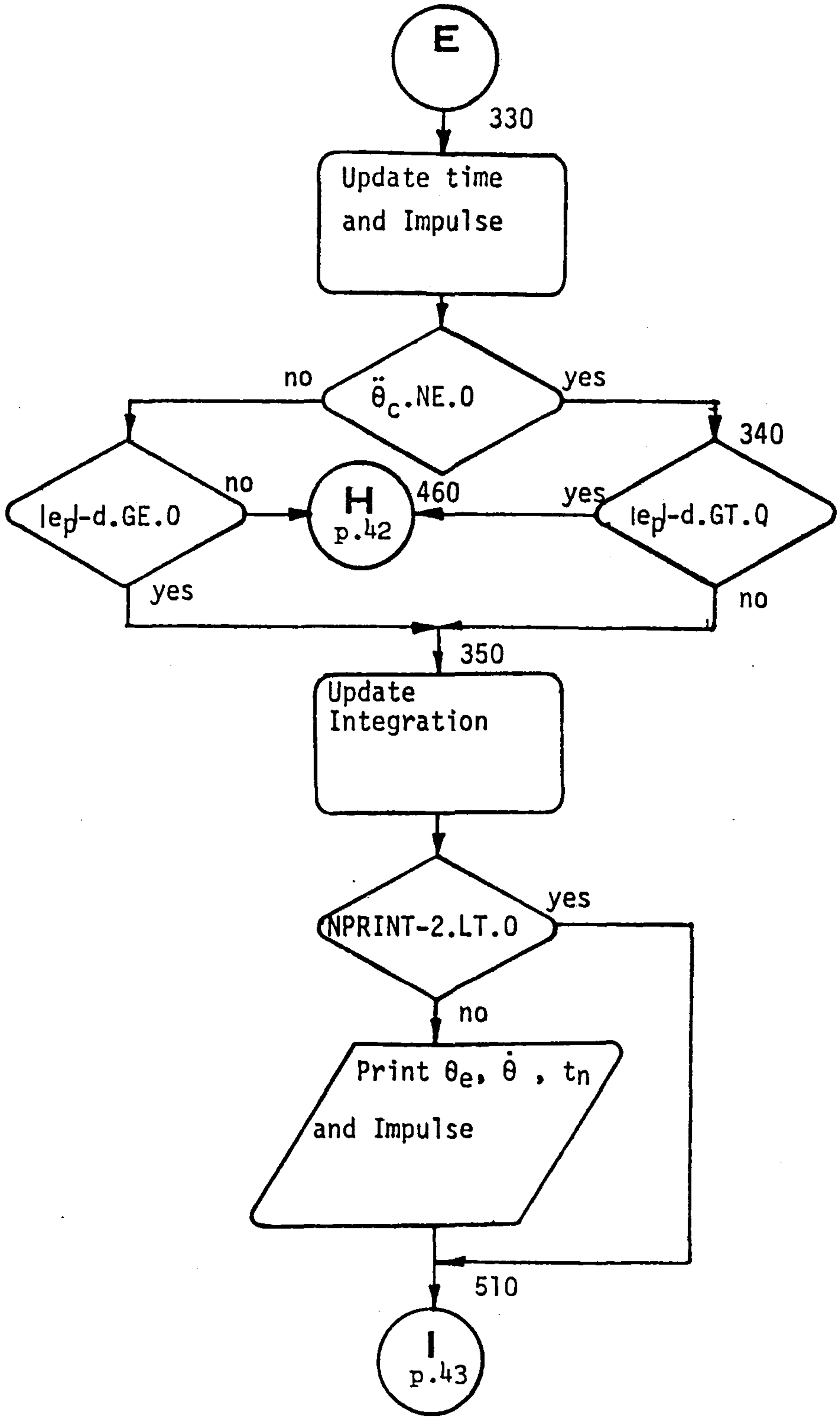


Figure 7 (Continued)
Detailed Flow Chart of Capture Maneuver Logic

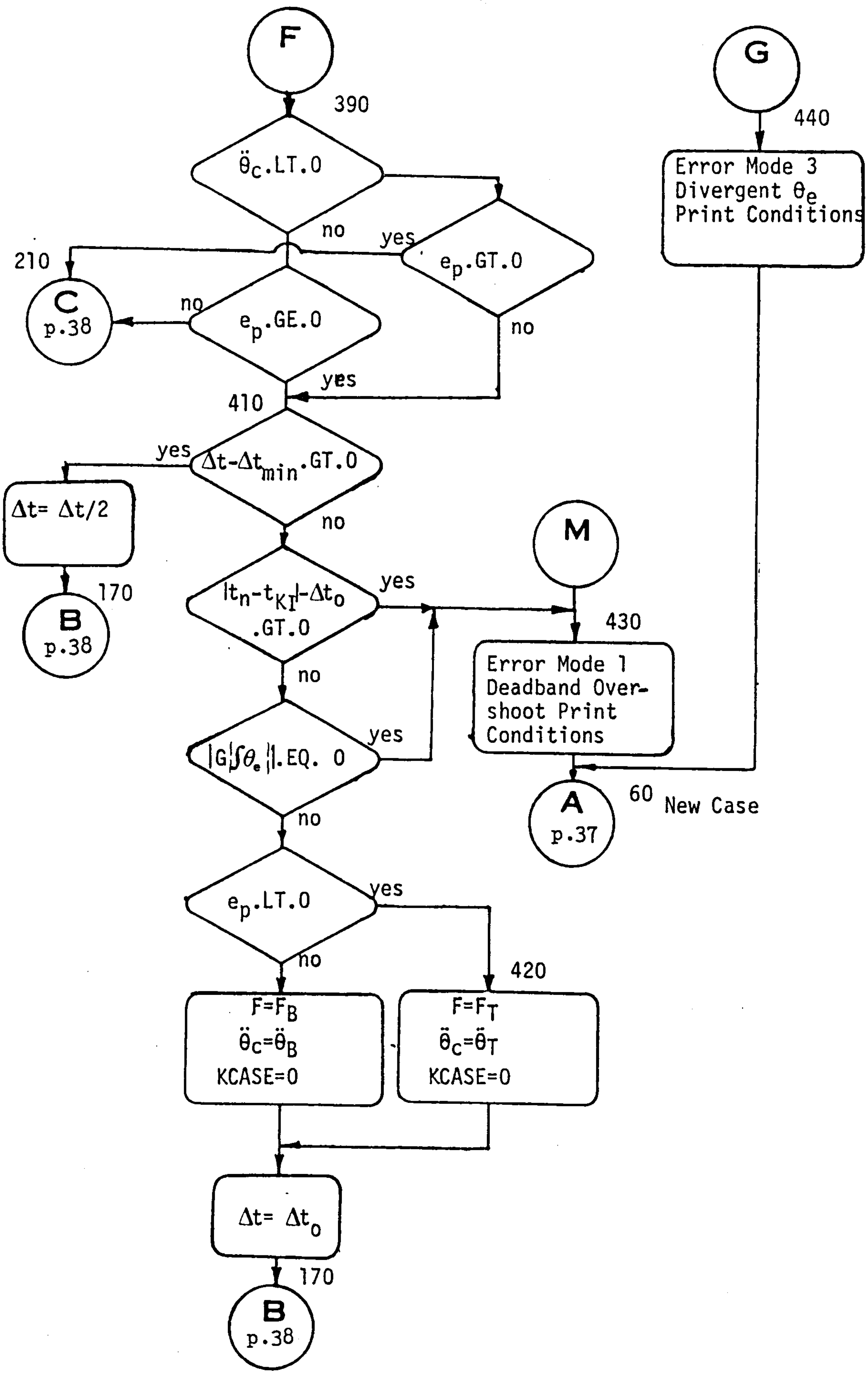


Figure 7 (Continued)
Detailed Flow Chart of Capture Maneuver Logic

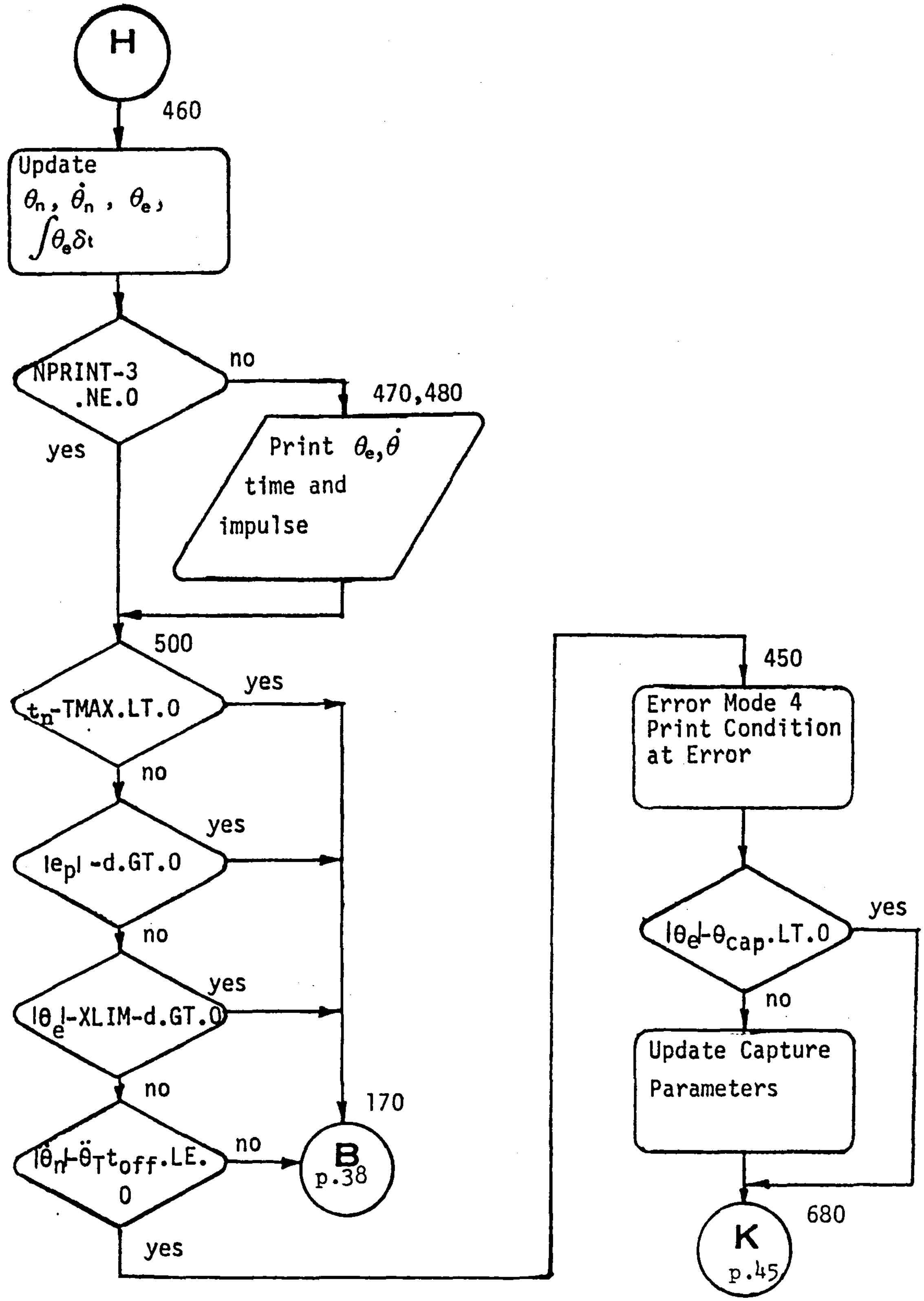


Figure 7 (Continued)
Detailed Flow Chart of Capture Maneuver Logic

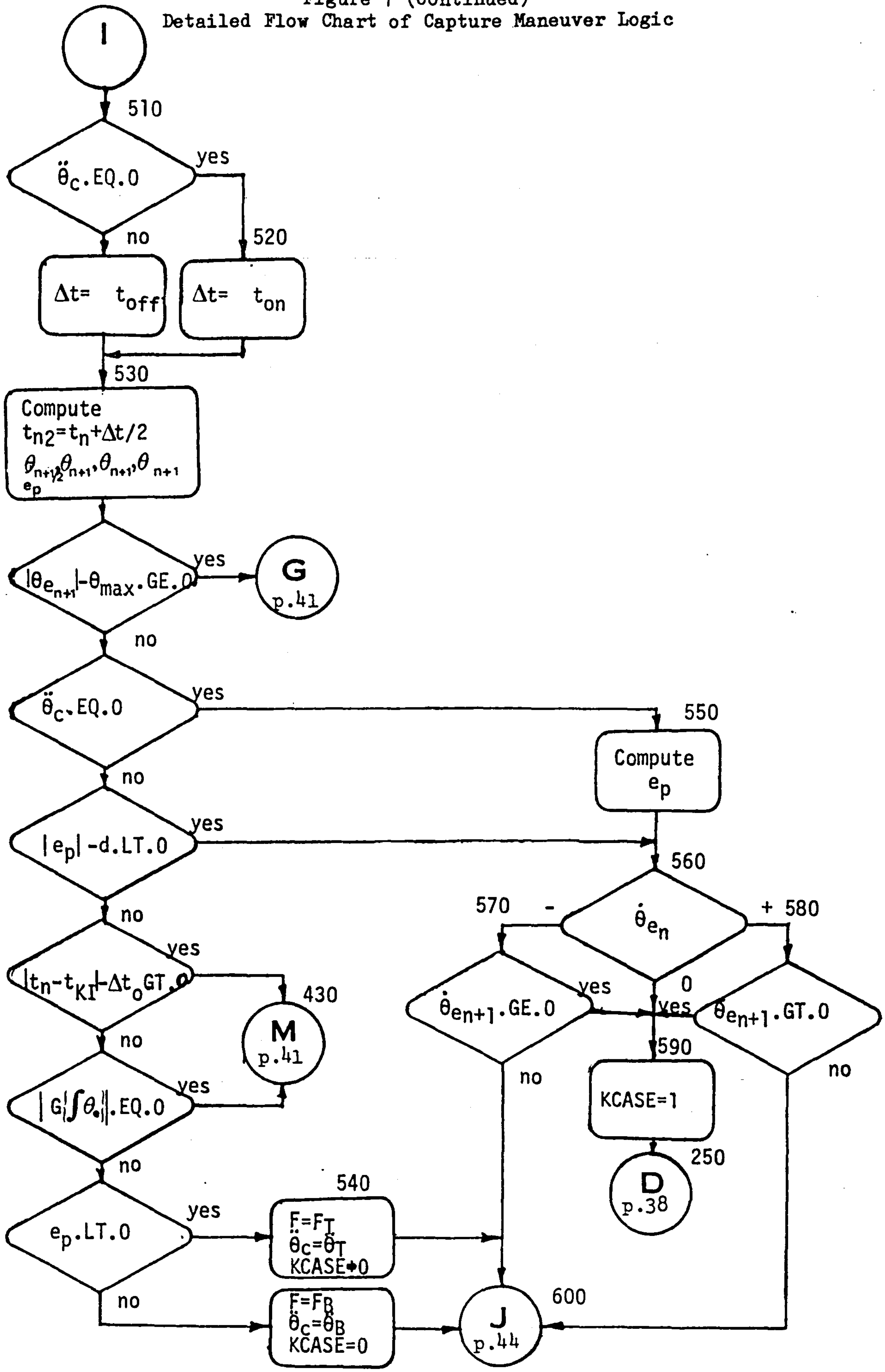


Figure 7 (Continued)
Detailed Flow Chart of Capture Maneuver Logic

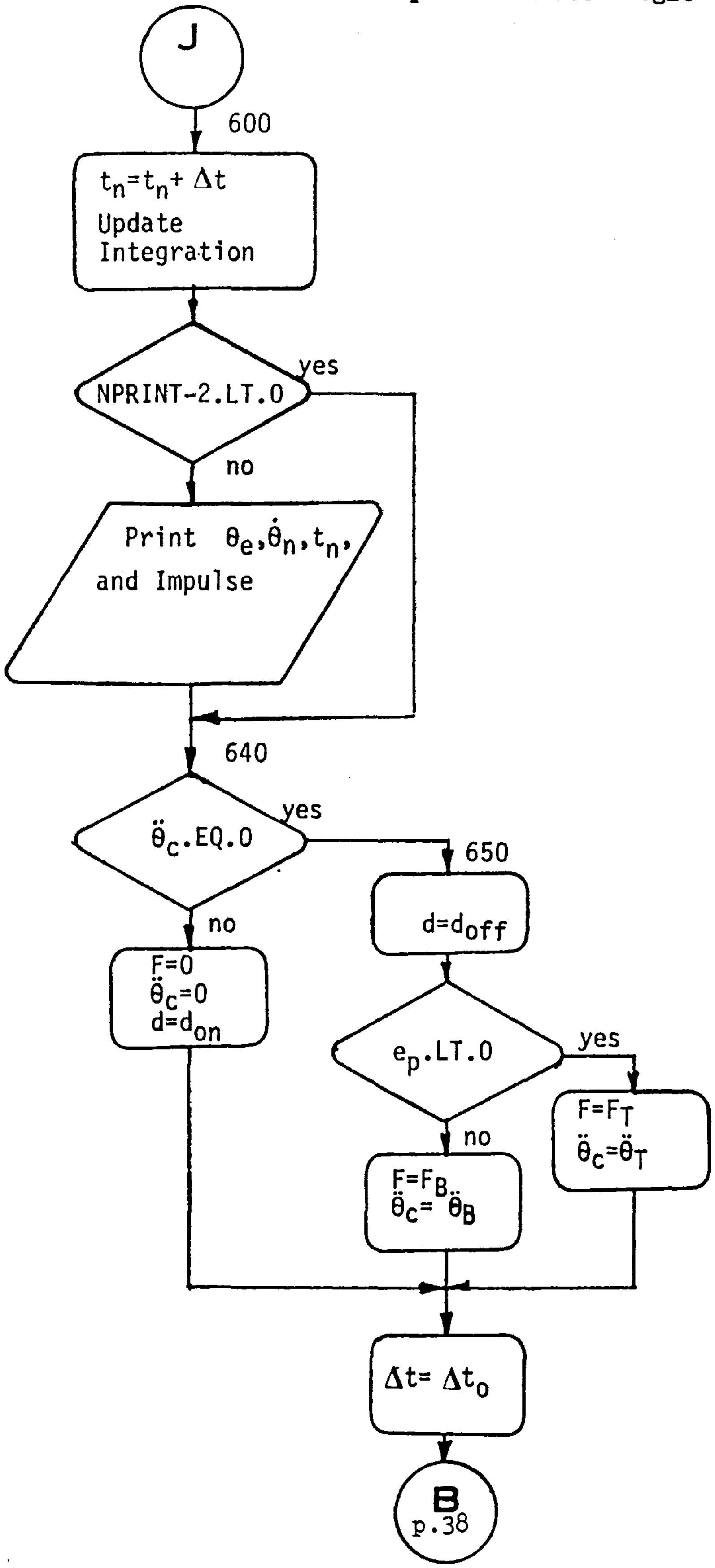


Figure 7 (Concluded)
Detailed Flow Chart of Capture Maneuver Logic

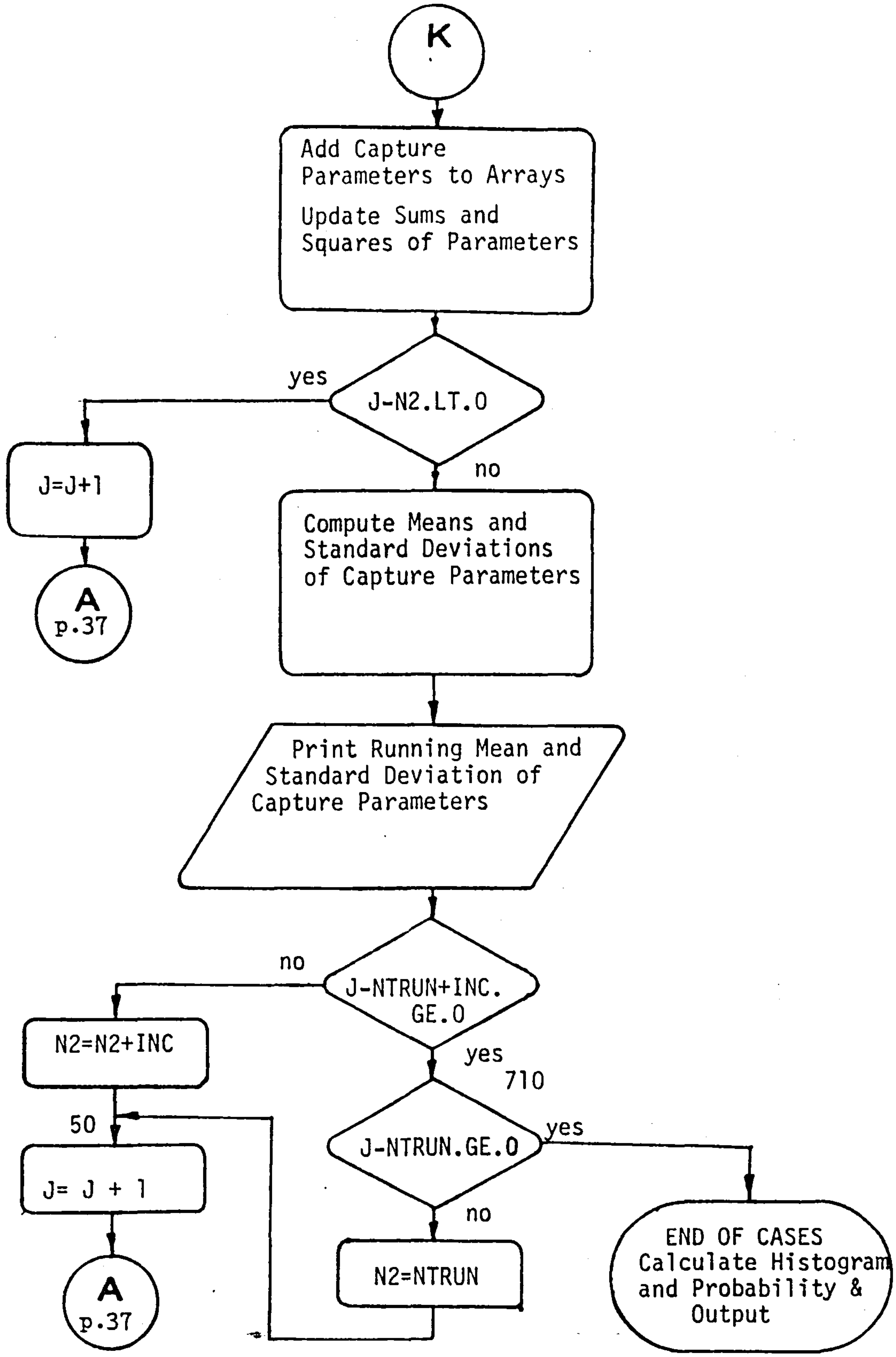
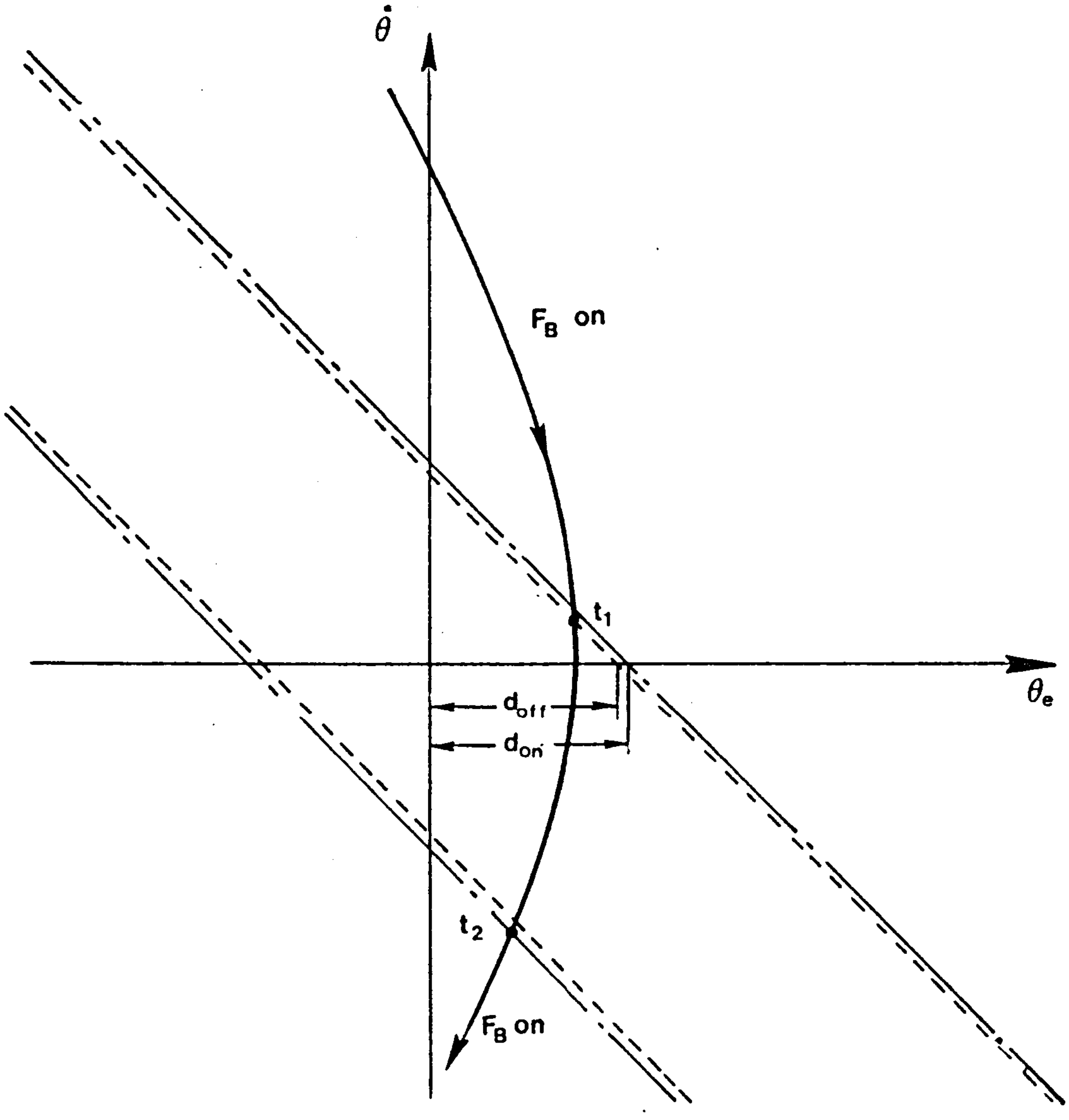


Figure 8
Deadband Overshoot Phase Plane



$t_2 - t_1 < t_{min}$ or $t_{off} \longrightarrow$ Deadband Overshoot

Figure 9
Sample Problem Input Data - Pitch Axis

```
  1    0  199   50    2    3    1    1                                      1
SAMPLE PROBLEM  SCOUT SECOND STAGE PITCH  WITH INTEGRAL GAIN 42 IN H/S       2
199 SAMPLES, NPRINT=0, INC=50, 3 OVERSHOOTS, 12 SEC TIME LIMIT,NHIST=1       3
 1234567                    INITIAL RANDOM NUMBER SEED (K)                   4
       52000.          500. MOMENT OF INERTIA (SLUG-FT2)       MEAN,SIG      5
        278.8            1. CENTER OF GRAVITY STATION (IN.)    MEAN,SIG      6
           1.        0.0158 BOOSTER THRUST RATIO TO NOM.       MEAN,SIG      7
           1.          0.12 Q RATIO TO NOMINAL                 MEAN,SIG      8
        0.802        0.0267 DEADBAND HALFWIDTH (DEG)           MEAN,SIG      9
        0.035        0.0167 HYSTERESIS RATIO                   MEAN,SIG     10
        0.072        0.0088 CONTROL MOTOR TURN-ON DELAY(SEC)   MEAN,SIG     11
        0.035        0.0052 CONTROL MOTOR TURN-OFF DELAY(SEC)  MEAN,SIG     12
         0.50        0.0167 RATE GAIN RATIO KR/KD(SEC)         MEAN,SIG     13
        494.1          17.2 UPPER CONTROL MOTOR THRUST(LBS)    MEAN,SIG     14
        494.1          17.2 LOWER CONTROL MOTOR THRUST(LBS)    MEAN,SIG     15
        0.046        0.0034 CONTROL ELECTRONICS DELAY(SEC)     MEAN,SIG     16
        0.650        0.0667 RATE GYRO DAMPING FACTOR           MEAN,SIG     17
         22.5          1.17 RATE GYRO FREQUENCY (HZ)           MEAN,SIG     18
        -2.22         0.817 LOG OF ATT. OSCILLATION AMP.(DEG)  MEAN,SIG     19
       -0.097         0.326 INITIAL RATE (DEG/SEC)             MEAN,SIG     20
         125.          124. WIND VEL. AT IGNITION (FT/SEC)     MEAN,SIG     21
         148.          152. WIND VEL. AT 2ND TIME (FT/SEC)     MEAN,SIG     22
          35.          0.73 FLIGHT PATH ANGLE AT IGNITION(DEG)MEAN,SIG      23
       0.4725        0.0037 CNAS(FT2/DEG), A3(FT2/DEG3)                     24
          95.           6.6 XCP0(IN.), DXCP/DA(IN/DEG)                      25
       467.68               CONTROL MOTOR STATION (IN)                      26
          17.               CONTROL MOTOR RADIAL LOCATION(IN.)              27
           5.               CONTROL MOTOR CANT ANGLE (DEG)                  28
       448.51               BOOSTER NOZZLE THROAT LOCATION (IN.)            29
       1000.0               BENDING FREQ.(HZ) (LARGE VALUE - SMALL DT)      30
           0.               INITIAL TIME (SEC)                              31
          12.               TIME LIMIT FOR CAPTURE(SEC)                     32
          0.1               COARSE INTEGRATION STEP SIZE(SEC)               33
        0.001               MINIMUM INTEGRATION STEP SIZE (SEC)             34
```

Figure 9 (Concluded)
Sample Problem Input Data - Pitch Axis

```
         8.                    2ND TABLE TIME FOR WIND AND VELOCITY(SEC)    35
      4315.                    VELOCITY AT IGNITION (FT/SEC)                36
      4995.                    VELOCITY AT 2ND TABLE TIME(FT/SEC)           37
      -0.5                     COMMANDED PITCH PROGRAM RATE(DEG/SEC)        38
    -0.416                     THETA ERROR/ALPHA SENSITIVITY 1ST STAGE      39
       0.5                     INITIAL ATTITUDE ERROR BIAS (DEG)            40
       10.                     ATT. ERROR TEST LIMIT FOR DIVERGENCE(DEG)    41
      -0.5                     NOMINAL ANGLE OF ATTACK BIAS (DEG)           42
      0.75 (ONLY IF NKI=1) INTEGRAL GAIN KI (1/SEC)                         43
       2.0 (ONLY IF NKI=1) LIMIT VALUE OF INTEGRAL GAIN FUNCTION(DEG)       44
       3.0 (ONLY IF NKI=1) INTEGRAL GAIN START TIME (SEC)                   45
   8    NOMINAL DYNAMIC PRESSURE(PSF) VS. TIME (SEC)                        46
     0.      120.        4.       99.        8.       82.                   47
    12.       67.                                                           48
   8    NOMINAL BOOSTER THRUST (LBS) VS. TIME (SEC)                         49
     0.    41000.        4.3   47155.        9.3   55936.                   50
   12.5    61620.                                                           51
  10    MEAN VALUE OF THRUST MISALIGNMENT(DEG) VS. TIME(SEC)                52
     0.     0.090        2.     0.094        5.     0.089                   53
    10.     0.082       15.     0.080                                       54
  10    STANDARD DEVIATION OF THRUST MISALIGNMENT(DEG) VS. TIME(SEC)        55
     0.     0.060        1.     0.060        2.     0.034                   56
     5.     0.025       15.     0.025                                       57
  20   NO. HISTOGRAM CELLS,MIN AND MAX THETA ERROR,TIME,IMPULSE(NHIST=1)    58
     0.       10.        0.       10.        0.     2000.                   59
*EOR
```

Figure 10
Sample Problem Input Data - Yaw Axis

```
  2    0  199   50    2    3    1    0                                       1
SAMPLE PROBLEM  SCOUT SECOND STAGE YAW CAPTURE  NO INTEGRAL GAIN              2
199 SAMPLES, NPRINT=0, INC=50, 3 OVERSHOOTS, 12 SEC. TIME LIMIT               3
  1234567                     INITIAL RANDOM NUMBER SEED (K)                  4
        52000.          500.  MOMENT OF INERTIA (SLUG-FT2)       MEAN,SIG     5
         278.8            1.  CENTER OF GRAVITY STATION (IN.)    MEAN,SIG     6
            1.        0.0158  BOOSTER THRUST RATIO TO NOM.       MEAN,SIG     7
            1.          0.12  Q RATIO TO NOMINAL                 MEAN,SIG     8
         0.802        0.0267  DEADBAND HALFWIDTH (DEG)           MEAN,SIG     9
         0.035        0.0167  HYSTERESIS RATIO                   MEAN,SIG    10
         0.072        0.0088  CONTROL MOTOR TURN-ON DELAY(SEC)   MEAN,SIG    11
         0.035        0.0052  CONTROL MOTOR TURN-OFF DELAY(SEC)  MEAN,SIG    12
          0.50        0.0167  RATE GAIN RATIO KR/KD(SEC)         MEAN,SIG    13
         494.1          17.2  RIGHT CONTROL MOTOR THRUST(LBS)    MEAN,SIG    14
         494.1          17.2  LEFT  CONTROL MOTOR THRUST(LBS)    MEAN,SIG    15
         0.046        0.0034  CONTROL ELECTRONICS DELAY(SEC)     MEAN,SIG    16
         0.650        0.0667  RATE GYRO DAMPING FACTOR           MEAN,SIG    17
          22.5          1.17  RATE GYRO FREQUENCY (HZ)           MEAN,SIG    18
         -2.28         0.897  LOG OF ATT. OSCILLATION AMP.(DEG)  MEAN,SIG    19
         0.085         0.196  INITIAL RATE (DEG/SEC)             MEAN,SIG    20
          125.          124.  WIND VEL. AT IGNITION (FT/SEC)     MEAN,SIG    21
          148.          152.  WIND VEL. AT 2ND TIME (FT/SEC)     MEAN,SIG    22
           90.          0.73  YAW    PATH ANGLE AT IGNITION(DEG)MEAN,SIG     23
        0.4725        0.0037  CNAS(FT2/DEG), A3(FT2/DEG3)                    24
           95.           6.6  XCP0(IN.), DXCP/DA(IN/DEG)                     25
        467.68                CONTROL MOTOR STATION (IN)                     26
           17.                CONTROL MOTOR RADIAL LOCATION(IN.)             27
            5.                CONTROL MOTOR CANT ANGLE (DEG)                 28
        448.51                BOOSTER NOZZLE THROAT LOCATION (IN.)           29
        1000.0                BENDING FREQ.(HZ) (LARGE VALUE - SMALL DT)     30
            0.                INITIAL TIME (SEC)                             31
           12.                TIME LIMIT FOR CAPTURE(SEC)                    32
           0.1                COARSE INTEGRATION STEP SIZE(SEC)              33
         0.001                MINIMUM INTEGRATION STEP SIZE (SEC)            34
```

Figure 10 (Concluded)
Sample Problem Input Data - Yaw Axis

```
          8.                 2ND TABLE TIME FOR WIND AND VELOCITY(SEC)    35
       4315.                 VELOCITY AT IGNITION (FT/SEC)                36
       4995.                 VELOCITY AT 2ND TABLE TIME(FT/SEC)           37
          0.                 COMMANDED  YAW  PROGRAM RATE(DEG/SEC)        38
     -0.416                  THETA ERROR/ALPHA SENSITIVITY 1ST STAGE      39
          0.                 INITIAL ATTITUDE ERROR BIAS (DEG)            40
         10.                 ATT. ERROR TEST LIMIT FOR DIVERGENCE(DEG)    41
          0.                 NOMINAL ANGLE OF ATTACK BIAS (DEG)           42
   8     NOMINAL DYNAMIC PRESSURE(PSF) VS. TIME (SEC)                     43
       0.       120.       4.       99.        8.       82.               44
      12.        67.                                                      45
   8     NOMINAL BOOSTER THRUST (LBS) VS. TIME (SEC)                      46
       0.     41000.       4.3    47155.       9.3    55936.              47
     12.5     61620.                                                      48
   6     MEAN VALUE OF THRUST MISALIGNMENT(DEG) VS. TIME(SEC)             49
       0.     0.010        5.     0.003       10.     0.006               50
   6     STANDARD DEVIATION OF THRUST MISALIGNMENT(DEG) VS. TIME(SEC)     51
       0.     0.048        5.     0.023       10.     0.020               52
  20    NO. HISTOGRAM CELLS,MIN AND MAX THETA ERROR,TIME,IMPULSE(NHIST=1) 53
       0.       10.        0.       10.        0.     2000.               54
*EOR
```

Figure 11
Sample Problem Input Data - Roll Axis

```
   3    0  199   50    2    3    1    0                                           1
SAMPLE PROBLEM  SCOUT SECOND STAGE ROLL CAPTURE   CASTOR I MOTOR                   2
199 SAMPLES, NPRINT=3, INC=50, 3 OVERSHOOTS, 12 SEC. TIME LIMIT                    3
  1234567                  INITIAL RANDOM NUMBER SEED (K)                          4
         425.1        7.07 MOMENT OF INERTIA (SLUG-FT2)        MEAN,SIG            5
            0.          0. ***CARDS WITH ASTERISKS MUST BE AS SHOWN                6
            1.          0. ***                                                     7
            1.        0.12 Q RATIO TO NOMINAL                  MEAN,SIG            8
         1.432      0.0476 DEADBAND HALFWIDTH (DEG)            MEAN,SIG            9
         0.035      0.0167 HYSTERESIS RATIO                    MEAN,SIG           10
         0.025      0.0048 CONTROL MOTOR TURN-ON DELAY(SEC)    MEAN,SIG           11
         0.016      0.0030 CONTROL MOTOR TURN-OFF DELAY(SEC)   MEAN,SIG           12
          0.45       0.015 RATE GAIN RATIO KR/KD(SEC)          MEAN,SIG           13
         90.90         1.7 RIGHT CONTROL MOTOR THRUST(LBS)     MEAN,SIG           14
         90.90         1.7 LEFT  CONTROL MOTOR THRUST(LBS)     MEAN,SIG           15
         0.016      0.0034 CONTROL ELECTRONICS DELAY(SEC)      MEAN,SIG           16
         0.650      0.0667 RATE GYRO DAMPING FACTOR            MEAN,SIG           17
          36.5        1.17 RATE GYRO FREQUENCY (HZ)            MEAN,SIG           18
         -2.63        0.66 LOG OF ATT. OSCILLATION AMP.(DEG)   MEAN,SIG           19
         -0.04       0.168 INITIAL RATE (DEG/SEC)              MEAN,SIG           20
            0.          0. ***                                                    21
            0.          0. ***                                                    22
            0.          0. ***                                                    23
            0.          0. CLPHI*S(FT2/DEG), A3(FT**2/DEG**3)                     24
          -31.          0. -D REF (IN.) AERO REF. LENGTH                          25
            0.             ***                                                    26
           17.             ROLL MOTOR ARM (INCHES)                                27
           90.             ***                                                    28
         687.6             ***                                                    29
       100000.             TORSIONAL FREQUENCY(HERTZ)                             30
            0.             INITIAL TIME (SEC)                                     31
           12.             TIME LIMIT FOR CAPTURE(SEC)                            32
           0.1             COARSE INTEGRATION STEP SIZE(SEC)                      33
         0.001             MINIMUM INTEGRATION STEP SIZE (SEC)                    34
```

Figure 11 (Concluded)
Sample Problem Input Data - Roll Axis

```
          1.               ***
          1.               ***
          1.               ***
          0.               COMMANDED  ROLL  PROGRAM RATE(DEG/SEC)
          0.               ***
          0.               INITIAL ATTITUDE ERROR BIAS (DEG)
         10.               ATT. ERROR TEST LIMIT FOR DIVERGENCE(DEG)
          0.               ***
    8    NOMINAL DYNAMIC PRESSURE(PSF) VS. TIME (SEC)
      0.       120.      4.       99.       8.       82.
     12.        67.
    4                      ***   TABLE NECESSARY FOR ROLL TORQUE
      0.         1.   1000.        1.
   16    MEAN VALUE OF BOOSTER ROLL TORQUE(FT-LBS) VS. TIME (SEC)
      0.         0.     0.2      -45.       0.4     -55.
     0.6       -50.     1.0      -25.       1.5     -15.
     4.0       -10.    15.0      -5.0
   16    STANDARD DEVIATION OF BOOSTER ROLL TORQUE(FT-LBS) VS. TIME (SEC)
      0.         2.     0.2       20.       0.4      25.
     0.6        19.     1.0       10.       1.5       8.
     4.0         5.    15.0        4.
   40   NO. CELL FOR HISTOGRAM,MIN AND MAX THETA ERROR,TIME,IMPULSE
      0.        10.      0.       10.        0.    2000.
 *EOR
```

Figure 12
Group 1 - NPRINT = 0

RUN NO. 1 PAGE NO. 2

SAMPLE PROBLEM SCOUT SECOND STAGE PITCH WITH INTEGRAL GAIN 42 IN H/S
199 SAMPLES, NPRINT=0, INC=50, 3 OVERSHOOTS, 12 SEC TIME LIMIT,NHIST=1

ITER NO	MEAN THETA	SIGMA THETA	MEAN TIME	SIGMA TIME	MEAN IMPULSE	SIGMA IMPULSE
50	1.92199	.24179	4.26861	1.21442	756.96489	256.15586
100	1.89088	.27689	4.14423	1.39258	736.03906	287.62953
150	1.88824	.25828	4.24425	1.27771	771.09885	281.06229

ERROR MODE 3ENCOUNTERED - DIVERGENT ATTITUDE WITH FOLLOWING DATA:
TIME (SEC)= 3.9 RATE(DEG/SEC)= 6.68 ATT. ERROR(DEG)= 10.309

Q (PSF) = 113.2 ALPHA(DEGREE)= 13.22 THRUST MIS(DEG)= .117

F TOP(LB) = 459.2 F LOWER (LB) = 470.81 LAST OVERSHOOT = 1.093

199	1.89772	.25663	4.29096	1.20281	782.31230	266.33504

Figure 13
Group 1 - NPRINT = 1

RUN NO. 2 PAGE NO. 2

SAMPLE PROBLEM SCOUT SECOND STAGE YAW CAPTURE NO INTEGRAL GAIN
199 SAMPLES, NPRINT=1, INC= 5, 3 OVERSHOOTS, 12 SEC. TIME LIMIT

ITER NO	MEAN THETA	SIGMA THETA	MEAN TIME	SIGMA TIME	MEAN IMPULSE	SIGMA IMPULSE
5	.72590	.11674	1.38240	.77183	147.99451	164.80215

THETA (DEG)	THETADOT (DEG/SEC)	TIME (SEC)	IMPULSE (LB-SEC)/	
.5445	0.0000	.4457	0.0000	
-.7093	0.0000	2.6655	145.2359	(Case 6 - Overshoot Data)
-.6621	0.0000	2.9367	170.5716	

THETA (DEG)	THETADOT (DEG/SEC)	TIME (SEC)	IMPULSE (LB-SEC)/	
.4733	0.0000	1.1606	95.1301	
.4673	0.0000	1.2619	103.3494	(Case 7)
.6446	0.0000	1.8062	149.1225	

THETA (DEG)	THETADOT (DEG/SEC)	TIME (SEC)	IMPULSE (LB-SEC)/	
.6849	0.0000	1.4954	302.9446	(Case 8)
.6445	0.0000	1.7040	334.9332	
.7504	0.0000	2.0416	386.7701	

THETA (DEG)	THETADOT (DEG/SEC)	TIME (SEC)	IMPULSE (LB-SEC)/

Figure 14
Group 1 - NPRINT = 2

RUN NO. 2 PAGE NO. 2

SAMPLE PROBLEM SCOUT SECOND STAGE YAW CAPTURE NO INTEGRAL GAIN
25 SAMPLES, NPRINT=2, INC= 5, 3 OVERSHOOTS, 12 SEC. TIME LIMIT

ITER NO	MEAN THETA	SIGMA THETA	MEAN TIME	SIGMA TIME	MEAN IMPULSE	SIGMA IMPULSE
5	.72590	.11674	1.38240	.77183	147.99451	164.80215

THETA (DEG)	THETADOT (DEG/SEC)	TIME (SEC)	IMPULSE (LB-SEC)/
.5445	0.0000	.4457	0.0000
-.2402	-1.2546	1.8594	0.0000
-.4014	-1.4209	1.9799	0.0000
-.5239	-.6164	2.1002	57.4454
-.5524	-.0355	2.1874	99.0876
-.6140	-.4400	2.4483	99.0876
-.6787	-.6340	2.5688	99.0876
-.7055	-.2241	2.6313	128.9294
-.7093	0.0000	2.6655	145.2359
-.7001	.3482	2.7186	170.5716
-.6621	0.0000	2.9367	170.5716

(Case 6 - Critical Points
Deadband Crossing,
Thrust-on & off,
Overshoot points.)

THETA (DEG)	THETADOT (DEG/SEC)	TIME (SEC)	IMPULSE (LB-SEC)/
.1847	1.2144	.8531	0.0000
.3485	1.3782	.9795	0.0000
.4529	.5576	1.0873	56.6175
.4733	0.0000	1.1606	95.1301
.4724	-.1190	1.1763	103.3494
.4673	0.0000	1.2619	103.3494

(Case 7)

Figure 15
Group 1 - NPRINT = 3

SAMPLE PROBLEM SCOUT SECOND STAGE YAW CAPTURE NO INTEGRAL GAIN
25 SAMPLES, NPRINT=3, INC= 5, 3 OVERSHOOTS, 12 SEC. TIME LIMIT

ITER NO	MEAN THETA	SIGMA THETA	MEAN TIME	SIGMA TIME	MEAN IMPULSE	SIGMA IMPULSE
10	.71774	.08504	1.67518	.66616	195.37197	156.82787

THETA (DEG)	THETADOT (DEG/SEC)	TIME (SEC)	IMPULSE (LB-SEC)/
.4928	0.0000	.0307	0.0000
.4915	-.0380	.1000	0.0000
.4849	-.0934	.2000	0.0000
.4728	-.1497	.3000	0.0000
.4550	-.2072	.4000	0.0000
.4313	-.2664	.5000	0.0000
.4016	-.3279	.6000	0.0000
.3656	-.3922	.7000	0.0000
.3230	-.4597	.8000	0.0000
.2734	-.5311	.9000	0.0000
.2165	-.6068	1.0000	0.0000
.1518	-.6875	1.1000	0.0000
.0787	-.7737	1.2000	0.0000
-.0033	-.8662	1.3000	0.0000
-.0948	-.9656	1.4000	0.0000
-.1968	-1.0726	1.5000	0.0000
-.2239	-1.1006	1.5250	0.0000
-.2378	-1.1147	1.5375	0.0000
-.2448	-1.1219	1.5438	0.0000
-.2483	-1.1255	1.5469	0.0000
-.2491	-1.1264	1.5477	0.0000
-.3917	-1.2701	1.6667	0.0000

(Case 11 - all integration steps)

Figure 15 (Continued)
Group 1 - NPRINT = 3

-.4464	-.9146	1.7167	24.1102
-.4670	-.7376	1.7417	36.1653
-.4757	-.6493	1.7542	42.1928
-.4796	-.6051	1.7604	45.2066
-.4805	-.5941	1.7620	45.9600
-.4810	-.5886	1.7628	46.3367
-.4815	-.5831	1.7635	46.7135
-.5055	0.0000	1.8461	86.5209
-.5053	.0538	1.8537	90.1907
-.5042	0.0000	1.8947	90.1907

(Case 12)

THETA (DEG)	THETADOT (DEG/SEC)	TIME (SEC)	IMPULSE (LB-SEC)
-2.2569	.8738	.1284	0.0000
-2.1106	2.0518	.2284	48.4547
-2.0556	2.3490	.2534	60.5683
-2.0407	2.4235	.2596	63.5967
-2.0330	2.4607	.2628	65.1110
-2.0311	2.4701	.2635	65.4895
-1.7096	3.7277	.3673	115.7545
-1.3169	4.1279	.4673	115.7545
-1.2649	4.1801	.4798	115.7545
-1.2617	4.1833	.4806	115.7545
-.6874	4.7622	.6089	115.7545
-.2298	4.3906	.7089	165.8308
.1928	4.0610	.8089	215.9071
.5846	3.7755	.9089	265.9835
.9500	3.5317	1.0089	316.0598
1.2929	3.3276	1.1089	366.1361
1.6174	3.1615	1.2089	416.2124
1.9271	3.0318	1.3089	466.2887
2.2255	2.9374	1.4089	516.3650
2.5163	2.8776	1.5089	566.4413
2.8027	2.8520	1.6089	616.5176

Figure 15 (Concluded)
Group 1 - NPRINT = 3

3.0884	2.8606	1.7089	666.5939	
3.3766	2.9038	1.8089	716.6702	
3.6709	2.9827	1.9089	766.7465	
3.9750	3.0984	2.0089	816.8229	
4.2925	3.2530	2.1089	866.8992	
4.6276	3.4488	2.2089	916.9755	
4.9845	3.6888	2.3089	967.0518	
5.3678	3.9768	2.4089	1017.1281	
5.7825	4.3170	2.5089	1067.2044	
6.2340	4.7143	2.6089	1117.2807	
6.7285	5.1745	2.7089	1167.3570	
7.2724	5.7037	2.8089	1217.4333	(Case 12 - Divergent)
7.8730	6.3086	2.9089	1267.5096	
8.5382	6.9960	3.0089	1317.5860	
9.2766	7.7722	3.1089	1367.6623	

ERROR MODE 3 ENCOUNTERED - DIVERGENT ATTITUDE WITH FOLLOWING DATA:

TIME (SEC)= 3.1 RATE(DEG/SEC)= 7.77 ATT. ERROR(DEG)= 10.097

Q (PSF) = 112.6 ALPHA(DEGREE)= 15.09 THRUST MIS(DEG)= .011

F TOP(LB) = 500.8 F LOWER (LB) = 484.55 LAST OVERSHOOT = 0.000

THETA (DEG)	THETADOT (DEG/SEC)	TIME (SEC)	IMPULSE (LB-SEC)/	
-1.2350	.2441	.1305	0.0000	
-1.2127	.6508	.1805	24.5905	
-1.2039	.7526	.1930	30.7381	
-1.1990	.8035	.1992	33.8120	
-1.1978	.8163	.2008	34.5804	(Case 13)
-1.1971	.8226	.2016	34.9646	
-1.0917	1.5524	.2903	78.6147	
-.9378	1.5257	.3903	78.6147	

Figure 16
Group 2 Output - Unarranged Results - NHIST = 0

RUN NO. 2 PAGE NO. 3

SAMPLE PROBLEM SCOUT SECOND STAGE YAW CAPTURE NO INTEGRAL GAIN
25 SAMPLES, NPRINT=0, INC= 5, 3 OVERSHOOTS, 12 SEC. TIME LIMIT

CAP. ANGLE (DEGREES)	CAP. TIME (SECONDS)	IMPULSE (LB-SEC)
.85282	1.32139	406.56157
.75069	2.15986	11.77130
.70802	1.35056	209.85397
.53957	1.91740	90.77326
.77838	.16278	21.01247
.70933	2.66549	145.23594
.64459	1.80620	149.12251
.75038	2.04156	386.77013
.76496	1.50510	424.64849
.67867	1.82151	107.97003
.50552	1.84609	86.52092
.74647	2.94102	297.10001
.67147	2.28236	317.82994
.87586	.01637	0.00000
1.43315	.06736	0.00000
.71359	1.94375	157.96780
.75209	2.40397	289.30930
.65715	1.89176	41.18371
.73182	2.91294	178.54109
1.30457	.02874	0.00000
.68130	1.81563	126.37307
.98769	.01882	0.00000
.70236	3.21081	113.31923
.70297	3.98907	161.24542
.78631	2.11634	306.76177

Figure 17
Group 3 Output - Histogram Data - NHIST = 1

RUN NO. 1 PAGE NO. 3

SAMPLE PROBLEM SCOUT SECOND STAGE PITCH WITH INTEGRAL GAIN 42 IN H/S
199 SAMPLES, NPRINT=0, INC=50, 3 OVERSHOOTS, 12 SEC TIME LIMIT,NHIST=1

CAPTURE ANGLE	NO	TIME	NO	IMPULSE	NO
0.00 TO .50,	0	0.00 TO .50,	15	0.00 TO 100.00,	15
.50 TO 1.00,	2	.50 TO 1.00,	0	100.00 TO 200.00,	0
1.00 TO 1.50,	15	1.00 TO 1.50,	0	200.00 TO 300.00,	1
1.50 TO 2.00,	108	1.50 TO 2.00,	1	300.00 TO 400.00,	1
2.00 TO 2.50,	73	2.00 TO 2.50,	0	400.00 TO 500.00,	2
2.50 TO 3.00,	1	2.50 TO 3.00,	1	500.00 TO 600.00,	7
3.00 TO 3.50,	0	3.00 TO 3.50,	0	600.00 TO 700.00,	19
3.50 TO 4.00,	0	3.50 TO 4.00,	0	700.00 TO 800.00,	45
4.00 TO 4.50,	0	4.00 TO 4.50,	43	800.00 TO 900.00,	45
4.50 TO 5.00,	0	4.50 TO 5.00,	136	900.00 TO 1000.00,	32
5.00 TO 5.50,	0	5.00 TO 5.50,	3	1000.00 TO 1100.00,	21
5.50 TO 6.00,	0	5.50 TO 6.00,	0	1100.00 TO 1200.00,	10
6.00 TO 6.50,	0	6.00 TO 6.50,	0	1200.00 TO 1300.00,	0
6.50 TO 7.00,	0	6.50 TO 7.00,	0	1300.00 TO 1400.00,	1
7.00 TO 7.50,	0	7.00 TO 7.50,	0	1400.00 TO 1500.00,	0
7.50 TO 8.00,	0	7.50 TO 8.00,	0	1500.00 TO 1600.00,	0
8.00 TO 8.50,	0	8.00 TO 8.50,	0	1600.00 TO 1700.00,	0
8.50 TO 9.00,	0	8.50 TO 9.00,	0	1700.00 TO 1800.00,	0
9.00 TO 9.50,	0	9.00 TO 9.50,	0	1800.00 TO 1900.00,	0
9.50 TO 10.00,	0	9.50 TO 10.00,	0	1900.00 TO 2000.00,	0

Figure 18
Group 4 Output - Discrete Probability

RUN NO. 1 PAGE NO. 4

SAMPLE PROBLEM SCOUT SECOND STAGE PITCH WITH INTEGRAL GAIN 42 IN H/S
199 SAMPLES, NPRINT=0, INC=50, 3 OVERSHOOTS, 12 SEC TIME LIMIT,NHIST=1

PROB	CAP. ANGLE (DEGREES)	CAP. TIME (SECONDS)	IMPULSE (LB-SEC)
.005	.95327	.16011	6.12147
.010	.99407	.16515	21.19936
.015	1.03178	.17519	21.21522
.020	1.17653	.18857	22.60156
.025	1.19216	.19801	30.90811
.030	1.20856	.20157	33.40953
.035	1.21071	.21497	40.21509
.040	1.28335	.21898	43.22989
.045	1.28845	.22300	46.15758
.050	1.29451	.22487	46.72905
.055	1.29831	.22870	50.65938
.060	1.36888	.23016	51.53070
.065	1.37766	.23849	53.32380
.070	1.38274	.26741	57.59848
.075	1.44232	.41766	71.45598
.080	1.47849	1.63489	287.20122
.085	1.49196	2.83012	321.79292
.090	1.50558	4.25585	432.70692
.095	1.51309	4.31106	460.44663
.100	1.54064	4.31527	501.71154
.105	1.54156	4.34524	534.59690
.110	1.56323	4.35449	538.11011
.115	1.57396	4.36009	542.53905
.120	1.60986	4.37472	544.26847
.125	1.61019	4.37772	559.79617

Figure 18 (Continued)
Group 4 Output - Discrete Probability

RUN NO. 1 PAGE NO. 5

SAMPLE PROBLEM SCOUT SECOND STAGE PITCH WITH INTEGRAL GAIN 42 IN H/S
199 SAMPLES, NPRINT=0, INC=50, 3 OVERSHOOTS, 12 SEC TIME LIMIT,NHIST=1

PROB	CAP. ANGLE (DEGREES)	CAP. TIME (SECONDS)	IMPULSE (LB-SEC)
.240	1.81497	4.46498	706.62076
.245	1.81838	4.47001	707.17155
.250	1.82636	4.47665	707.97991
.255	1.82671	4.48028	709.46333
.260	1.82762	4.48157	712.70609
.265	1.83541	4.48232	714.90028
.270	1.83822	4.48477	717.69771
.275	1.84410	4.48700	720.03541
.280	1.84778	4.48779	720.04334
.285	1.86167	4.49045	720.36123
.290	1.86681	4.49172	722.20390
.295	1.86695	4.49416	732.08493
.300	1.87215	4.49798	732.33217
.305	1.87320	4.50073	738.46872
.310	1.87714	4.50289	739.32199
.315	1.87875	4.50618	740.14204
.320	1.87891	4.51013	743.81406
.325	1.88198	4.51105	748.82072
.330	1.88405	4.51246	749.38205
.335	1.88504	4.51436	753.44694
.340	1.88680	4.51582	753.62911
.345	1.88733	4.51816	753.68218
.350	1.89251	4.52320	755.55886
.355	1.90160	4.52447	761.80032
.360	1.90191	4.52605	762.06797

Figure 18 (Continued)
Group 4 Output - Discrete Probability

RUN NO. 1 PAGE NO. 6

SAMPLE PROBLEM SCOUT SECOND STAGE PITCH WITH INTEGRAL GAIN 42 IN H/S
199 SAMPLES, NPRINT=0, INC=50, 3 OVERSHOOTS, 12 SEC TIME LIMIT,NHIST=1

PROB	CAP. ANGLE (DEGREES)	CAP. TIME (SECONDS)	IMPULSE (LB-SEC)
.475	1.95174	4.58402	810.93177
.480	1.95221	4.58636	812.69659
.485	1.95290	4.59932	813.58912
.490	1.95531	4.60059	821.43338
.495	1.95575	4.60277	822.82932
.500	1.95631	4.60284	825.57772
.505	1.96469	4.60431	827.10577
.510	1.96863	4.60683	827.82367
.515	1.96939	4.60745	831.13156
.520	1.96993	4.61147	833.88485
.525	1.96994	4.61934	834.68096
.530	1.97147	4.61989	834.83876
.535	1.97244	4.62936	835.63925
.540	1.97382	4.63885	835.70028
.545	1.97389	4.64553	836.04854
.550	1.97422	4.64800	839.10901
.555	1.97658	4.65331	849.78964
.560	1.97784	4.66428	854.47960
.565	1.97985	4.66806	857.70405
.570	1.98042	4.68428	860.35022
.575	1.98166	4.68637	860.61986
.580	1.98216	4.68754	861.84803
.585	1.98532	4.68755	863.57420
.590	1.98836	4.68908	866.05315
.595	1.98855	4.68933	868.64973

Figure 18 (Continued)
Group 4 Output - Discrete Probability

RUN NO. 1 PAGE NO. 7

SAMPLE PROBLEM SCOUT SECOND STAGE PITCH WITH INTEGRAL GAIN 42 IN H/S
199 SAMPLES, NPRINT=0, INC=50, 3 OVERSHOOTS, 12 SEC TIME LIMIT,NHIST=1

PROB	CAP. ANGLE (DEGREES)	CAP. TIME (SECONDS)	IMPULSE (LB-SEC)
.710	2.03294	4.74556	913.58711
.715	2.03445	4.74678	922.74508
.720	2.03485	4.74798	937.21875
.725	2.03714	4.75103	937.89049
.730	2.03778	4.75399	940.05228
.735	2.03796	4.75694	940.67391
.740	2.03922	4.75706	942.93587
.745	2.04340	4.75896	943.66154
.750	2.04885	4.76122	943.94283
.755	2.04980	4.76178	944.01645
.760	2.05269	4.76312	945.61506
.765	2.05364	4.77626	948.36702
.770	2.05498	4.77960	950.55707
.775	2.05756	4.78221	951.84329
.780	2.05957	4.78350	957.14790
.785	2.05993	4.78373	957.17877
.790	2.06014	4.78783	958.42992
.795	2.06079	4.78855	961.62725
.800	2.06932	4.78918	963.07453
.805	2.07095	4.79054	965.45803
.810	2.07112	4.79587	978.05693
.815	2.07318	4.80019	980.20018
.820	2.07324	4.80125	984.11719
.825	2.07732	4.80130	985.17226
.830	2.08161	4.80621	986.93587
.835	2.08195	4.80734	997.68271

Figure 18 (Concluded)
Group 4 Output - Discrete Probability

SAMPLE PROBLEM SCOUT SECOND STAGE PITCH WITH INTEGRAL GAIN 42 IN H/S
199 SAMPLES, NPRINT=0, INC=50, 3 OVERSHOOTS, 12 SEC TIME LIMIT,NHIST=1

PROB	CAP. ANGLE (DEGREES)	CAP. TIME (SECONDS)	IMPULSE (LB-SEC)
.945	2.13970	4.93210	1106.88744
.950	2.14761	4.93312	1109.64838
.955	2.15164	4.94324	1114.15247
.960	2.17061	4.94561	1114.80366
.965	2.18225	4.96196	1120.27628
.970	2.18749	4.96437	1126.23876
.975	2.18941	4.97130	1180.31498
.980	2.23244	4.97289	1182.40544
.985	2.27390	5.00607	1183.19656
.990	2.33126	5.11458	1196.01366
.995	2.99827	5.19169	1338.36315

Figure 19
Group 5 Output - Abnormal Termination Summary

```
   RUN NO.    1                                                        PAGE NO

 SAMPLE PROBLEM  SCOUT SECOND STAGE PITCH  WITH INTEGRAL GAIN 42 IN H/S
 199 SAMPLES, NPRINT=0, INC=50, 3 OVERSHOOTS, 12 SEC TIME LIMIT,NHIST=1


TOTAL NUMBER OF DIVERGENT CAPTURES =     1



TOTAL NUMBER OF ABNORMAL CASES DELETED:

    DEADBAND OVERSHOOT                          =    0
    TIME LIMIT WITHOUT DIVERGENCE OR CAPTURE =    0



      FINAL VALUE OF RANDOM SEQUENCE INTEGER  =                      5585969
```

APPENDIX

FORTRAN PROGRAM LISTING

A complete FORTRAN source program listing is presented in the following pages. It starts with the MAIN routine and is followed by the four (4) subroutines arranged in alphabetical order. There are a total of 627 cards in the MAIN routine. The total program including subroutines contains 723 cards.

```
*DECK MAIN
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C     THIS IS A MONTE CARLO ANALYSIS OF THE STAGING CAPTURE MANUEVER
C     FOR A REACTION JET ATTITUDE CONTROL WITH A SIMPLE DEADBAND.  IT
C     INCLUDES THE EFFECTS OF SEPARATION DISTURBANCES, NON-LINEAR
C     AERODYNAMIC MOMENTS, THRUST MISALIGNMENTS, AND OFF-NOMINAL
C     TRAJECTORY, VEHICLE, AND CONTROL SYSTEM CHARACTERISTICS.
C
      INTEGER CAHIST(150),THIST(150),HISTIP(150)
      DIMENSION ETMEAN(50),ETSIG(50), TABQ(50),TABT(50),V(20),XM(19),
     1  XSD(19),THES(1000),TTCAP(1000),TIMP(1000),MD1(3),MD3(3),MD4(3)
      COMMON RXD,Q,K,NPAGE,NLINE,NRUN,NTITLE(26)
      DATA ME1/1/,ME3/3/,ME4/4/,MD1(1)/6HDEADBA/,MD1(2)/6HND OVE/,
     1 MD1(3)/6HRSHOOT/,MD3(1)/6HDIVERG/,MD3(2)/6HENT AT/,MD3(3)
     2 /6HTITUDE/,MD4(1)/6HTIME L/,MD4(2)/6HIMIT B/,MD4(3)/6HENIGN /
C     READ IN INTEGER CONSTANTS AND RUN OPTIONS
   10 READ( 5,1020) NRUN,NPRINT,NTRUN,INC,NSTAGE,N,NHIST,NKI
C     TEST INPUT FILE FOR END OF FILE, IF NO MORE DATA STOP.
      IF (EOF(5).NE.0) STOP
C     READ TWO CARDS OF HOLLERITH IDENTIFICATION OF RUN FOR OUTPUT
      READ( 5,1030) (NTITLE(J),J=1,26)
      IF(EOF(5).NE.0) STOP
C     INITIALIZE CONSTANTS AND SUMS
      STS=0.
      SSTS=0.
      STT=0.
      SSTT=0.
      STI=0.
      SSTI=0.
      GINT=0.
      TKI=0.
      MQ=1
      MT=1
```

```
      MEM=1
      MES=1
      NPAGE=1
      NLINE=0
      NERR1=0
      NERR3=0
      NERR4=0
C     READ INITIAL RANDOM NUMBER GENERATOR SEED
      READ( 5,1040) K
C     WARMUP PSEUDO-RANDOM NUMBER GENERATOR WITH 10 PASSES
      DO 20 J=1,10
   20 CALL RNDX(1)
C     READ IN MEANS AND STANDARD DEVIATIONS OF RANDOM VARIABLES
      READ( 5,1050) (XM(I),XSD(I),I=1,19)
C     READ IN AERODYNAMIC COEFFICIENTS
      READ( 5,1050) CNAS,A3,XCP0,DCPDA
C     READ IN SINGLE VALUED CONSTANTS
      READ( 5,1060) XF,ZC,XLAM,XN,WB,TI,TMAX,DELT0,DELTMN,AT,VO,V1,
     1       GDOT,ASEN,THCMO,TLIMIT,ADES
      SL=SIN(XLAM/57.3)
      CL=COS(XLAM/57.3)
C     TEST TO SEE IF INTEGRAL GAIN CONTROL IS USED. NKI=1 YES.
      IF (NKI .LE. 0 ) GO TO 30
C     IF INTEGRAL GAIN USED, READ IN GAIN (KI), LIMITER VALUE XLIM,
C     TIME AT WHICH INTEGRAL GAIN IS STARTED (TKI)
      READ( 5,1060) GINT,XLIM,TKI
C     READ IN TABLES OF DYNAMIC PRESSURE, THRUST, MEAN AND SIGMA THRUST
C     MISALIGNMENT
   30 READ(5,1070) NT1,(TABQ(J),J=1,NT1)
      READ(5,1070) NT2,(TABT(J),J=1,NT2)
      READ(5,1070) NT3,(ETMEAN(J),J=1,NT3)
      READ(5,1070) NT4,(ETSIG(J),J=1,NT4)
      N2=INC
      NPH=0
```

```
      J=0
C     TEST FOR HISTOGRAM DATA, NHIST=1 IS YES
      IF (NHIST .EQ. 0 ) GO TO 50
C     READ IN HISTOGRAM CELL INFORMATION
      READ( 5,1070) NCEL,CMINH,CMAXH,TMINH,TMAXH,PMINH,PMAXH
C     SET UP HISTOGRAM CELL INFORMATION
      XNCEL=NCEL
      DO 40 LCEL=1,NCEL
      CAHIST(LCEL)=0
      THIST(LCEL)=0
   40 HISTIP(LCEL)=0
      DIFC=(CMAXH-CMINH)/XNCEL
      DIFT=(TMAXH-TMINH)/XNCEL
      DIFP=(PMAXH-PMINH)/XNCEL
C
C     THIS IS THE START OF THE MONTE CARLO LOOP, J IS THE SAMPLE NUMBER
C
   50 J=J+1
C     COMPUTE VALUE FOR EACH OF THE NORMALLY DISTRIBUTED VARIABLES
   60 DO 70 I=1,16
      CALL RNDX(0)
      V(I)=XM(I)+RXD*XSD(I)
   70 CONTINUE
      RINT=V(1)
      CG=V(2)
      TDELTA=V(3)
      THEDD=0.
      QDELTA=V(4)
      DB=V(5)
      H=V(6)
      T1=V(7)
      T2=V(8)
      GAIN=V(9)
      FT=V(10)
```

```
      FB=V(11)
      FTAU=V(12)
      GTAU=V(13)/(3.14159*V(14))
      THEDTO=V(16)
      THED=0.
      CALL RNDX(1)
      ANGX=3.14159*Q-1.57079
      CALL RNDX(0)
      GME=RXD*XSD(19)-ADES
      CALL RNDX(0)
      RXDET=RXD
C     COMPUTE RANDOM WIND AT TWO POINTS
      CALL RNDX(0)
      VWO=XM(17)+RXD*XSD(17)
      VW1=XM(18)+RXD*XSD(18)
      GM1=XM(19)+GDOT*AT
C     COMPUTE ANGLE OF ATTACK DUE TO WIND AT IGNITION AND RATE OF CHANGE
      AWPO=(57.3*VWO*SIN(XM(19)/57.3))/(VO+VWO*COS(XM(19)/57.3))
      AWPR=AWPO-GME
      AWPD=((57.3*VW1*SIN(GM1/57.3))/(V1+VW1*COS(GM1/57.3))-AWPO)/AT
      AWD=AWPD-GDOT
      CALL RNDX(1)
      ANGY=3.14159*Q-1.57079
C     COMPUTE THE INITIAL ATTITUDE ERROR
      THE=EXP(V(15))*SIN(ANGY)+AWPR*ASEN+THCMO
C     BEGIN THE CAPTURE ANALYSIS
C     SET ALL INITIAL CONDITIONS AND COMPUTE CONSTANTS
      NPK=0
      THETN=THE
      XINN=0.
      TIMPN=0.0
      TN=TI
      THEROR=THETN-GDOT*TN
      D=DB
```

```
      RATIO1=(XN-CG)/(12.*RINT)
      THEDN=THED+THEDTO
      DBOFF=DB*(1.-H)
      THECAP=0.0
C     COMPUT TURN-ON AND TURN-OFF TIME DELAYS
      TY=T1+FTAU+GTAU
      TZ=T2+FTAU+GTAU
C     COMPUTE CONTROL ACCELERATIONS FOR TOP AND BOTTOM MOTORS
      TDDCT=4.775*FT*((XF-CG)*CL+ZC*SL)/RINT
      TDDCB=-4.775*FB*((XF-CG)*CL+ZC*SL)/RINT
C     SET NO. OF OVERSHOOTS TO ZERO
      NOS=0
C      TEST NSTAGE. NSTAGE=2  CONTROL SYSTEM IS ACTIVATED AT IGNITION
C                   NSTAGE=3 CONTROL SYSTEM IS ALREADY ACTIVATED
      IF (NSTAGE-2 .LE. 0 ) GO TO 110
C     CONTROLS ALREADY ACTIVATED, FIRE MOTOR IF OUTSIDE DEADBAND
      THETS0=THEROR+GAIN*THEDN
      IF (ABS(THETS0)-D .LT. 0 ) GO TO 110
C     OUT OF DEADBAND
      IF (THETS0 .LT. 0 ) GO TO 80
C     OUT OF + DEADBAND, TURN ON BOTTOM MOTOR
      THEDDC=TDDCB
      FC=FB
      GO TO 90
C     OUT OF - DEADBAND, TURN ON TOP MOTOR
   80 THEDDC=TDDCT
      FC=FT
C     CHANGE DEADBAND TO TURN OFF LEVEL(LESS HYSTERESIS)
   90 D=DBOFF
      GO TO 120
C     CONTROL ACTIVATED AT IGNITION, SET CONTROL FORCE TO ZERO
  110 THEDDC=0.0
      FC=0.0
C     COMPUTE EFFECTIVE DELAY TIME DUE TO BENDING, USE IF NON-NEGATIVE
```

```
  120 TB=SIN(ANGX)/(2.*WB)
C     COMPUTE TOTAL TURN ON AND TURN OFF DELAY INCLUDING BENDING
C     IF LESS THAN ZERO, SET DELAY TO ZERO
      TAU1=TB+TY
      IF (TAU1 .GE. 0 ) GO TO 130
      TAU1=0.
  130 TAU2=TB+TZ
      IF (TAU2 .GE. 0 ) GO TO 140
      TAU2=0.
C     COMPUTE INITIAL ERROR SIGNAL
  140 THETS0=THEROR+GAIN*THEDN
      IF (ABS(THETS0)-D .LT. 0 ) GO TO 150
C     OUT OF DEADBAND
      IF (THEDDC .NE. 0 ) GO TO 160
C     OUT OF DEADBAND CONTROL MOTOR OFF
      GO TO 510
  150 IF (THEDDC .NE. 0 ) GO TO 510
C     IN DEADBAND- CONTROL MOTOR OFF OR OUT OF DEADBAND CONTROL MOTOR ON
C     SET INTEGRATION STEP SIZE BACK TO COARSE LEVEL
  160 DELTAT=DELT0
C     COMPUTE AVERAGE TIME FOR INTEGRATION AND COMPUTE ACCELERATIONS
  170 TN2=TN+DELTAT/2.
      CALL TBLU(NT1,ORD,TN2,TABQ,MQ)
      DYNP=ORD*QDELTA
      CALL TBLU(NT2,ORD,TN2,TABT,MT)
      THRUST=ORD*TDELTA
      CALL TBLU (NT3,ETM,TN2,ETMEAN,MEM)
      CALL TBLU (NT4,ETS,TN2,ETSIG,MES)
      ET=ETM+RXDET*ETS
C     COMPUTE ANGLE OF ATTACK AND TOTAL ACCELERATION
      AL=AWPR+THETN+AWD*TN2+THEDN*DELTAT/2.+THEDD*0.5*DELTAT**2
      TDDN2=THEDDC+RATIO1*ET*THRUST+4.775*DYNP*(CNAS*AL+A3*AL*AL*AL)
     1*(CG-XCP0-DCPDA*ABS(AL))/RINT
C     SET TOTAL ACCELERATION
```

```
      THEDD=TDDN2
C     COMPUTE RATE AT END OF INTEGRATION STEP
      THEDN1=TDDN2*DELTAT+THEDN
C     COMPUTE ATTITUDE AT END OF INTEGRATION STEP
      THETN1=(THEDN1+THEDN)*DELTAT/2.+THETN
C     COMPUTE ATTITUDE ERROR AT END OF INTEGRATION STEP
      THERO1=THETN1-GDOT*(TN+DELTAT)
C     COMPUTE INTEGRAL OF ATTITUDE ERROR AT END OF INTEGRATION STEP
      XINN1=XINN+THEROR*DELTAT
C     COMPUTE INTEGRAL GAIN TERM AND LIMITED INTEGRAL GAIN FUNCTION
      EPIT1=GINT*XINN1
      EPIN1=SIGN(AMIN1(ABS(EPIT1),XLIM),EPIT1)
C     TEST TO SEE IF TIME TO START INTEGRAL GAIN LOGIC
      IF(TN.LE.TKI)EPIN1=0.
C     TEST FOR DIVERGENCE LIMIT ON ATTITUDE ERROR
      IF (ABS(THERO1)-TLIMIT .GE. 0 ) GO TO 440
C     STILL WITHIN ATTITUDE ERROR LIMITS- NO DIVERGENCE
      IF (THEDDC .EQ. 0 ) GO TO 180
C     CONTROL MOTOR ON, COMPUTE ERROR SIGNAL AT END OF STEP
      THETS=THERO1+GAIN*THEDN1+EPIN1
      IF (ABS(THETS)-D .LE. 0 ) GO TO 190
C     OUT OF DEADBAND
      GO TO 390
  180 THETS=THERO1+GAIN*THEDN1+EPIN1
      IF (ABS(THETS)-D .LT. 0 ) GO TO 210
C      IN DEADBAND, TEST FOR MINIMUM INTEGRATION STEP SIZE
  190 IF (DELTAT-DELTMN .LE. 0 ) GO TO 210
C     CUT STEP SIZE IN HALF AND TRY AGAIN
  200 DELTAT=DELTAT/2.
      GO TO 170
C     TEST FOR ATTITUDE ERROR OVERSHOOT
  210 IF (THEDN-GDOT) 230,240,220
  220 IF (THEDN1-GDOT .LE. 0 ) GO TO 240
C     NO OVERSHOOT ENCOUNTERED ON THIS STEP
```

```
      GO TO 330
  230 IF (THEDN1-GDOT .LT. 0 ) GO TO 330
C     POSITIVE RATE
  240 KCASE=0
C     COMPUTE OVERSHOOT ATTITUDE,RATE,ATTITUDE ERROR
  250 THETOS=(GDOT**2-THEDN**2)/(2.*TDDN2)+THETN
      THEDOS=GDOT
      THEEOS=THETOS-GDOT*(TN+(GDOT-THEDN)/THEDD)
C     UPDATE NO. OF OVERSHOOTS, IF INTEGRAL GAIN USED,ONLY AFTER START
      IF(TN.GE.TKI)NOS=NOS+1
C     COMPUTE TIME AND IMPULSE TO OVERSHOOT
      TX=(GDOT-THEDN)/TDDN2
      TOS=TN+TX
      TIMPOS=TIMPN+FC*TX
C     TEST OVERSHOOT VERSUS LAST OVERSHOOT FOR A MAXIMUM
      IF (ABS(THEEOS)-THECAP .LT. 0 ) GO TO 260
      THECAP=ABS(THEEOS)
      TIMPCP=TIMPOS
      TCAP=TOS
  260 IF(NPRINT.EQ.0) GO TO 310
C     TEST FOR PAGE CHANGE ON OUTPUT
  270 IF (NPK .NE. 0 ) GO TO 290
  280 WRITE( 6,870)
      NLINE=NLINE+2
      WRITE( 6,880)
      NLINE=NLINE+2
      NPK=NPK+1
  290 IF (NLINE+1-59 .LE. 0 ) GO TO 300
      NPAGE=NPAGE+1
      CALL PAGEHD
      GO TO 280
C     PRINT ATTITUDE ERROR,  RATE, TIME, AND IMPULSE AT OVERSHOOT
  300 WRITE( 6,890) THEEOS,THEDOS,TOS,TIMPOS
      NLINE=NLINE+1
```

```
C     TEST TO SEE IF MAXIMUM NUMBER OF OVERSHOOTS HAS BEEN REACHED
  310 IF (NOS-N .LT. 0 ) GO TO 320
C     THIS INDIVIDUAL CAPTURE RUN IS FINISHED
      GO TO 680
C      NOT ENOUGH OVERSHOOTS, CONTINUE
  320 IF (KCASE .GT. 0 ) GO TO 600
C     UPDATE IMPULSE AND TIME
  330 TIMPN=FC*DELTAT+TIMPN
      TN=TN+DELTAT
      IF (THEDDC .NE. 0 ) GO TO 340
C     MOTOR OFF, TEST FOR DEADBAND
      IF (ABS(THETS)-D .GE. 0 ) GO TO 350
      GO TO 460
  340 IF (ABS(THETS)-D .GT. 0 ) GO TO 460
C     MOTOR OFF AND OUT OF DEADBAND, OR MOTOR ON AND IN DEADBAND
  350 THEDN=THEDN1
      THETN=THETN1
      THEROR=THERO1
      XINN=XINN1
C     TEST PRINT OPTION
      IF (NPRINT-2 .LT. 0 ) GO TO 510
      IF (NPK .NE. 0 ) GO TO 370
  360 WRITE( 6,870)
      WRITE( 6,880)
      NLINE=NLINE+4
      NPK=NPK+1
  370 IF (NLINE+1-59 .LE. 0 ) GO TO 380
      NPAGE=NPAGE+1
      CALL PAGEHD
      GO TO 360
C     PRINT EACH POINT OF ATTITUDE ERROR,RATE,TIME,AND IMPULSE
  380 WRITE( 6,890) THEROR,THEDN,TN,TIMPN
      GO TO 510
  390 IF (THEDDC .LT. 0 ) GO TO 400
```

```
      IF (THETS .GE. 0 ) GO TO 410
      GO TO 210
  400 IF (THETS .GT. 0 ) GO TO 210
  410 IF (DELTAT-DELTMN .GT. 0 ) GO TO 200
      IF (ABS(TN-TKI)-DELT0 .GT. 0 ) GO TO 430
      IF (ABS(EPIN1) .EQ. 0 ) GO TO 430
      IF (THETS .LT. 0 ) GO TO 420
      FC=FB
      THEDDC=TDDCB
      KCASE=0
      GO TO 160
C     TOP MOTOR FIRING
  420 FC=FT
      THEDDC=TDDCT
      KCASE=0
      GO TO 160
C     DETECT ERROR MODE 1 - DEADBAND OVERSHOOT
  430 NERR1=NERR1+1
      NLINE=NLINE+5
      WRITE(6,1100) ME1,MD1(1),MD1(2),MD1(3),TN,THEDN,THERO1,DYNP,AL,ET,
     1   FB,FT,THECAP
      GO TO 60
C     DIVERGENT TO LIMITING ATTITUDE ERROR , ERROR MODE 3
  440 NERR3=NERR3+1
      NLINE=NLINE+5
      WRITE(6,1100) ME3,MD3(1),MD3(2),MD3(3),TN,THEDN,THERO1,DYNP,AL,ET,
     1   FB,FT,THECAP
      GO TO 60
C     ERROR MODE 4 REACHED LIMITING TIME BEFORE ATTITUDE OVERSHOOT
  450 NERR4=NERR4+1
      NLINE=NLINE+5
      WRITE(6,1100) ME4,MD4(1),MD4(2),MD4(3),TN,THEDN,THERO1,DYNP,AL,ET,
     1   FB,FT,THECAP
      IF (ABS(THERO1)-THECAP .LT. 0 ) GO TO 680
```

```
C       UPDATE CAPTURE  DATA
        THECAP=ABS(THERO1)
        TCAP=TN
        TIMPCP=TIMPN
        GO TO 680
C       UPDATE INTEGRATION VARIABLES
  460   THEDN=THEDN1
        THETN=THETN1
        THEROR=THERO1
        XINN=XINN1
C       TEST PRINT OPTION
        IF (NPRINT-3 .NE. 0 ) GO TO 500
        IF (NPK .GT. 0 ) GO TO 480
  470   WRITE( 6,870)
        WRITE( 6,880)
        NLINE=NLINE+4
        NPK=NPK+1
  480   IF (NLINE+1-59 .LE. 0 ) GO TO 490
        NPAGE=NPAGE+1
        CALL PAGEHD
        GO TO 470
C       PRINT ATTITUDE ERROR, RATE, TIME, AND TOTAL IMPULSE
  490   WRITE( 6,890) THEROR,THEDN,TN,TIMPN
C       TEST FOR CASE TERMINATION DUE TO TIME LIMIT
  500   IF (TN-TMAX .LT. 0 ) GO TO 170
C       REACHED TIME LIMIT. IF OUT OF DEADBAND CONTINUE UNTIL OVERSHOOT OR
C       DIVERGENCE IS REACHED
        IF (ABS(THETS)-DB .GT. 0 ) GO TO 170
C       IN DEADBAND. IF ERROR IS NEAR LIMITING ERROR CONTINUE TO DIVERGENC
        IF (ABS(THEROR)-XLIM-DB .GT. 0 ) GO TO 170
C       IN DEADBAND. IF RATE IS LESS THAN MINIMUM MOTOR FIRING,TERMINATE
        IF (ABS(THEDN)-TDDCT*TAU2 .LE. 0 ) GO TO 450
C       CONTINUE INTEGRATION
        GO TO 170
```

```
C     TEST FOR MOTOR ON OR OFF. AT SWITCHING LINE, SET INTEGRATION STEP
C     TO ON OR OFF DELAY TIME. THIS LOGIC GOES TO STATEMENT 600
  510 IF (THEDDC .EQ. 0 ) GO TO 520
C     CONTROL MOTOR ON, SET INTEGRATION STEP TO TURN OFF DELAY(TAU2)
      DELTAT=TAU2
      GO TO 530
C     CONTROL MOTOR OFF, SET INTEGRATION STEP TO TURN ON DELAY(TAU1)
  520 DELTAT=TAU1
C     PERFORM INTEGRATION
  530 TN2=TN+DELTAT/2.
      CALL TBLU(NT1,ORD,TN2,TABQ,MQ)
      DYNP=ORD*QDELTA
      CALL TBLU(NT2,ORD,TN2,TABT,MT)
      THRUST=ORD*TDELTA
      CALL TBLU (NT3,ETM,TN2,ETMEAN,MEM)
      CALL TBLU (NT4,ETS,TN2,ETSIG,MES)
      ET=ETM+RXDET*ETS
      AL=AWPR+THETN+AWD*TN2+THEDN*DELTAT/2.+THEDD*0.5*DELTAT**2
      TDDN2=THEDDC+RATIO1*ET*THRUST+4.775*DYNP*(CNAS*AL+A3*AL*AL*AL)
     1*(CG-XCP0-DCPDA*ABS(AL))/RINT
      THEDD=TDDN2
      THEDN1=TDDN2*DELTAT+THEDN
      THETN1=(THEDN1+THEDN)*DELTAT/2.+THETN
      THERO1=THETN1-GDOT*(TN+DELTAT)
      XINN1=XINN+THEROR*DELTAT
      EPIT1=GINT*XINN1
      EPIN1=SIGN(AMIN1(ABS(EPIT1),XLIM),EPIT1)
C     TEST FOR START TIME FOR INTEGRAL GAIN CONTROL TERM
      IF(TN.LE.TKI)EPIN1=0.
C     TEST FOR DIVERGENT OVERSHOOT, THETA MAX., ERROR MODE 3
      IF (ABS(THERO1)-TLIMIT .GE. 0 ) GO TO 440
      IF (THEDDC .EQ. 0 ) GO TO 550
C     CONTROL MOTOR ON
      THETS=THERO1+GAIN*THEDN1+EPIN1
```

```
      IF (ABS(THETS)-D .LT. 0 ) GO TO 560
C     OUT OF DEADBAND. TEST FOR ONE INTEGRATION STEP WITHIN INTEGRAL
C     GAIN START TIME
      IF (ABS(TN-TKI)-DELT0 .GT. 0 ) GO TO 430
C     WITHIN  ONE STEP OF TKI. CHECK FOR INTEGRAL GAIN VALUE
      IF (ABS(EPIN1) .EQ. 0 ) GO TO 430
      IF (THETS .LT. 0 ) GO TO 540
      FC=FB
      THEDDC=TDDCB
      KCASE=0
      GO TO 600
C     TOP MOTOR FIRING
  540 FC=FT
      THEDDC=TDDCT
      KCASE=0
      GO TO 600
C     COMPUTE CONTROL ERROR SIGNAL
C     CONTROL MOTOR OFF BUT COMING ON
  550 THETS=THERO1+GAIN*THEDN1+EPIN1
C     TEST FOR OVERSHOOT
  560 IF (THEDN-GDOT) 570,590,580
  570 IF (THEDN1-GDOT .GE. 0 ) GO TO 590
      GO TO 600
  580 IF (THEDN1-GDOT .GT. 0 ) GO TO 600
  590 KCASE=1
      GO TO 250
C     INCREMENT TIME
  600 TN=TN+DELTAT
      TIMPN=TIMPN+FC*DELTAT
      THEDN=THEDN1
      THETN=THETN1
      THEROR=THERO1
      XINN=XINN1
C     TEST PRINT OPTION
```

```
      IF (NPRINT-2 .LT. 0 ) GO TO 640
      IF (NPK .NE. 0 ) GO TO 620
  610 WRITE( 6,870)
      WRITE( 6,880)
      NLINE=NLINE+4
      NPK=NPK+1
  620 IF (NLINE+1-59 .LE. 0 ) GO TO 630
      NPAGE=NPAGE+1
      CALL PAGEHD
      GO TO 610
C     PRINT ATTITUDE ERROR, RATE, TIME AND IMPULSE
  630 WRITE( 6,890) THEROR,THEDN,TN,TIMPN
      NLINE=NLINE+1
  640 IF (THEDDC .EQ. 0 ) GO TO 650
      FC=0.0
      THEDDC=0.0
      D=DB
      GO TO 160
C      SET DEADBAND FOR SWITCHING OFF
  650 D=DBOFF
      IF (THETS .LT. 0 ) GO TO 660
      FC=FB
      THEDDC=TDDCB
      GO TO 160
C      TOP MOTOR FIRING
  660 FC=FT
      THEDDC=TDDCT
      GO TO 160
C     RECORD FINAL VALUES FOR THIS CASE AND UPDATE SUMS
  680 THES(J)=THECAP
      TTCAP(J)=TCAP
      TIMP(J)=TIMPCP
      STS=STS+THECAP
      SSTS=SSTS+THECAP*THECAP
```

```
      STT=STT+TCAP
      SSTT=SSTT+TCAP*TCAP
      STI=STI+TIMPCP
      SSTI=SSTI+TIMPCP*TIMPCP
      IF (J-N2 .LT. 0 ) GO TO 50
C     COMPUTE THE MEAN AND STANDARD DEVIATION FOR SPECIFIED NUMBER(INC)
C     OF CAPTURE ANGLES, TIMES AND IMPULSES
      AM=N2
      BM=AM*(AM-1.0)
      XMTS=STS/AM
      XMTT=STT/AM
      XMTI=STI/AM
      SDTS=SQRT((AM*SSTS-STS*STS)/BM)
      SDTT=SQRT((AM*SSTT-STT*STT)/BM)
      SDTI=SQRT((AM*SSTI-STI*STI)/BM)
C     PRINT THE MEAN AND STANDARD DEVIATION AT SPECIFIED INTERVALS
      IF (NPRINT .NE. 0 ) GO TO 690
      IF (NPH .GT. 0 ) GO TO 700
  690 NPAGE=NPAGE+1
      CALL PAGEHD
      WRITE( 6,900)
      WRITE( 6,910)
      NLINE=NLINE+4
      NPH=NPH+1
  700 IF (NLINE+1-59 .GT. 0 ) GO TO 690
C     PRINT RUNNING MEANS AND STANDARD DEVIATIONS
      WRITE( 6,920) N2,XMTS,SDTS,XMTT,SDTT,XMTI,SDTI
      NLINE=NLINE+1
C     CHECK FOR TOTAL NUMBER OF RUNS
      IF (J-NTRUN+INC .GE. 0 ) GO TO 710
      N2=N2+INC
      GO TO 50
  710 IF (J-NTRUN .GE. 0 ) GO TO 720
      N2=NTRUN
```

```
      GO TO 50
  720 I=0
C      PRINT HISTOGRAM RESULTS
      IF (NHIST .EQ. 0 ) GO TO 750
C     FILL HISTOGRAM CELLS  WITH DATA
      DO 730 L=1,N2
      ICELL=(THES(L)-CMINH)/DIFC+1
      IF(ICELL.GT.NCEL)ICELL=NCEL
      CAHIST(ICELL)=CAHIST(ICELL)+1
      ICELL=(TTCAP(L)-TMINH)/DIFT+1
      IF(ICELL.GT.NCEL)ICELL=NCEL
      THIST(ICELL)=THIST(ICELL)+1
      ICELL=(TIMP(L)-PMINH)/DIFP+1
      IF(ICELL.GT.NCEL)ICELL=NCEL
  730 HISTIP(ICELL)=HISTIP(ICELL)+1
      NPAGE=NPAGE+1
      CALL PAGEHD
      WRITE( 6,1140)
      DO 740 L=1,NCEL
      CMINH1=CMINH
      TMINH1=TMINH
      PMINH1=PMINH
      CMINH=CMINH+DIFC
      TMINH=TMINH+DIFT
      PMINH=PMINH+DIFP
C     PRINT OUT THE HISTOGRAM CELL DATA
      WRITE( 6,1150) CMINH1,CMINH,CAHIST(L),TMINH1,TMINH,THIST(L),PMINH1
     1,PMINH,HISTIP(L)
  740 CONTINUE
      GO TO 770
  750 NPAGE=NPAGE+1
      CALL PAGEHD
      WRITE( 6,930)
      WRITE( 6,940)
```

```
      NLINE=NLINE+4
  760 I=I+1
C     PRINT THE UNARRANGED ARRAYS OF CAPTURE ANGLE,TIME AND IMPULSE
C     ONLY IF HISTOGRAM DATA IS NOT OUTPUT
      WRITE( 6,950) THES(I),TTCAP(I),TIMP(I)
      NLINE=NLINE+1
      IF (N2-I .LE. 0 ) GO TO 770
      IF (NLINE+1-59 .LE. 0 ) GO TO 760
      GO TO 750
  770 CONTINUE
C     REARRANGE TOTAL IMPULSE, CAPTURE TIME AND ANGLE IN ASCENDING ORDER
      CALL ASCEND(N2,TIMP,0)
      CALL ASCEND(N2,TTCAP,0)
      CALL ASCEND(N2,THES,0)
C     PRINT THE REARRANGED ARRAYS IN ASCENDING ORDER
      I=0
  840 NPAGE=NPAGE+1
      CALL PAGEHD
      WRITE( 6,960)
      WRITE( 6,970)
      NLINE=NLINE+4
  850 I=I+1
C     COMPUTE DISCRETE PROBABILITY CC AND OUTPUT
      AA=N2+1
      BB=I
      CC=BB/AA
      WRITE( 6,980) CC,THES(I),TTCAP(I),TIMP(I)
      NLINE=NLINE+1
      IF (N2-I .LE. 0 ) GO TO 860
      IF (NLINE+1-59 .LE. 0 ) GO TO 850
      GO TO 840
  860 CONTINUE
C     PRINT THE TOTAL NUMBER OF DIVERGENT CASES ENCOUNTERED
      NPAGE=NPAGE+1
```

```
      CALL PAGEHD
      WRITE( 6,990) NERR3
      WRITE( 6,1000) NERR1,NERR4
      WRITE( 6,1010) K
      GO TO 10
C
  870 FORMAT (//59H          THETA        THETADOT        TIME        IMP
     1ULSE   )
  880 FORMAT (59H           (DEG)        (DEG/SEC)        (SEC)       (LB-SE
     1C)/ )
  890 FORMAT (5X,F10.4,3(F14.4))
  900 FORMAT (//79H         ITER      MEAN       SIGMA        MEAN      SIG
     1MA         MEAN       SIGMA   )
  910 FORMAT (79H           NO       THETA       THETA        TIME      TIME
     1      IMPULSE    IMPULSE /)
  920 FORMAT (5X,I6,F13.5,5(F11.5))
  930 FORMAT (//47H        CAP. ANGLE      CAP. TIME       IMPULSE )
  940 FORMAT (47H         (DEGREES)      (SECONDS)       (LB-SEC)/)
  950 FORMAT (5X,F11.5,F15.5,F16.5)
  960 FORMAT (//58H        PROB       CAP. ANGLE      CAP. TIME       IMPU
     1LSE   )
  970 FORMAT (57H                        (DEGREES)      (SECONDS)     (LB-SEC
     1) /)
  980 FORMAT (F11.3,F15.5,F15.5,F16.5)
  990 FORMAT (//,1X,37HTOTAL NUMBER OF DIVERGENT CAPTURES = ,
     1        I5)
 1000 FORMAT (///,1X,41HTOTAL NUMBER OF ABNORMAL CASES DELETED: ,//,5X,
     1  42HDEADBAND OVERSHOOT                         = ,I5,/,5X,
     2  42HTIME LIMIT WITHOUT DIVERGENCE OR CAPTURE = ,I5,/)
 1010 FORMAT (//52H       FINAL VALUE OF RANDOM SEQUENCE INTEGER  =    ,
     15X,I15)
 1020 FORMAT (14(I5))
 1030 FORMAT (13A6)
C
```

```
1040 FORMAT (I10)
1050 FORMAT (2(E15.8))
1060 FORMAT (E15.8)
1070 FORMAT (I5/,(6E10.3))
1100 FORMAT (/,10X,10HERROR MODE ,I2,14HENCOUNTERED - ,3A6,1X,
    1   20HWITH FOLLOWING DATA: ,/,12X,11HTIME (SEC)=,F7.1,3X,
    2   14HRATE(DEG/SEC)= ,F7.2,3X,16HATT. ERROR(DEG)=,F8.3,/,
    3   12X,11HQ (PSF)   = ,F7.1,3X,14HALPHA(DEGREE)= ,F7.2,3X,
    4   16HTHRUST MIS(DEG)=,F8.3,/,12X,11HF TOP(LB) = ,F7.1,3X,
    5   14HF LOWER (LB) = ,F7.2,3X,16HLAST OVERSHOOT =,F8.3,/)
1140 FORMAT (1H1,4X,20HCAPTURE ANGLE     NO ,8X,4HTIME,7X,2HNO,7X,
    1  7HIMPULSE,10X,2HNO,/)
1150 FORMAT (1X,F7.2,3H TO,F10.2,1H,,I4,F7.2,3H TO,F6.2,1H,,I4,F9.2,
    1 3H TO,F9.2,1H,,I4)
     END
```

```
*DECK ASCEND
      SUBROUTINE ASCEND (L,VAL,M)
C     SUBROUTINE FOR REARRANGING ARRAY IN ASCENDING ORDER
C     OR DESCENDING ORDER IF M=1
      DIMENSION VAL(1)
      K=L-1
      DO 40 J=1,K
      KB=J+1
      DO 40 JL=KB,L
      IF(M) 10,10,20
   10 IF (VAL(J)-VAL(JL) .LE. 0 ) GO TO 40
      GO TO 30
   20 IF(VAL(JL)-VAL(J).LE.0) GO TO 40
   30 TEMP=VAL(J)
      VAL(J)=VAL(JL)
      VAL(JL)=TEMP
   40 CONTINUE
      RETURN
      END
```

```
*DECK PAGEHD
      SUBROUTINE PAGEHD
C     THIS SUBROUTINE PRINTS HEADING AT THE TOP OF EACH PAGE
      COMMON RXD,Q,K,NPAGE,NLINE,NRUN,NTITLE(26)
      NLINE=8
      WRITE( 6,10)
      WRITE( 6,20) NRUN,NPAGE
      WRITE(6,5) (NTITLE(J),J=1,26)
      RETURN
    5 FORMAT(/,(1X,13A6))
   10 FORMAT (1H1)
   20 FORMAT (5X,7HRUN NO.,I5,49X,8HPAGE NO.,I5)
      END
```

```
*DECK RNDX
      SUBROUTINE RNDX(L)
C     THIS SUBROUTINE COMPUTES THE PSEUDO-RANDOM NUMBER
C          L=0 GIVES RANDOM NORMAL DEVIATE RXD FROM N(0,1)
C          L=1 GIVES RANDOM UNIFORM NUMBER Q 0 TO 1 U(0,1)
      COMMON RXD,Q,K,NPAGE,NLINE,NRUN,NTITLE(26)
      DATA A/1.0E07/,JJ/10000000/
      KA=K*23
      N=KA/JJ
      M=N*JJ
      K=KA-M-N
      AK=K
C     COMPUTE RANDOM NUMBER Q UNIFORM FRON ZERO TO ONE
      Q=AK/A
      IF ( L . GT . 0 )  RETURN
C     CHANGE Q TO PLUS AND MINUS O TO 0.5 RANGE
      IF (Q-.5 .LE. 0 ) GO TO 10
      Q=1.-Q
      AB=-1.0
      GO TO 20
C
   10 AB=1.0
C     TRANSFORM Q TO GAUSSIAN RANDOM NORMAL DEVIATE RXD
   20 Y=SQRT(-ALOG(Q*Q))
      D=2.515517+0.802853*Y+0.010328*Y*Y
      E=1.0+1.432788*Y+0.189269*Y*Y+0.001308*Y*Y*Y
      RXD=AB*(Y-(D/E))
      RETURN
      END
```

```
      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 coded computer program which computes the 'capture' transient of a launch vehicle upper stage at the ignition and/or separation event. It is for a single degree-of-freedom on-off reaction jet attitude control system. The Monte Carlo method is used to determine the statistical value of key parameters at the outcome of the event. Aerodynamic and booster induced disturbances, vehicle and control system characteristics, and initial conditions are treated as random variables. By appropriate selection of input data pitch, yaw and roll axes can be analyzed. Transient response of a single deterministic case can be computed. The program is currently set up on a CDC CYBER 175 computer system but is compatible with ANSI FORTRAN computer language. This routine has been used over the past fifteen (15) years for the SCOUT Launch Vehicle and has been run on RECOMP III, IBM 7090, IBM 360/370, CDC6600 and CDC CYBER 175 computers with little modification.

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