BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

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SUBJECT: POGO2 - A Computer Program for Longitudinal Stability Analysis of Large Launch Vehicles - Case 320

DATE: May 22, 1969

FROM: C. F. Banick

ABSTRACT

A computer program, POGO2, is available to aid in evaluating the longitudinal stability of a large launch vehicle modeled as a coupled system comprised of a mass-spring structure, a distributed propellant feed system, and engines. For a given time into the flight, a Nyquist plot representing the open loop gain of the system is generated to permit subsequent evaluation of system stability by means of the Nyquist criterion.

This memorandum contains a description of POGO2, a guide to its use, and a sample run. A copy of the program can be obtained from the Bellcomm Applications Program Library.

(NASA-CR-106693) POGO-2 - A COMPUTER PROGRAM FOR LONGITUDINAL STABILITY ANALYSIS OF LARGE LAUNCH VEHICLES (Bellcomm, Inc.) 65 p

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POGO 00002

SUBJECT: POGO2 - A Computer Program for Longitudinal Stability Analysis of Large Launch Vehicles - Case 320

DATE: May 22, 1969

FROM: C. F. Banick

MEMORANDUM FOR FILE

Identification

TITLE: POGO2

AUTHOR: C. F. Banick

SPONSOR: G. C. Reis

DATE: January 28, 1969

LANGUAGE: FORTRAN V

KEY WORDS: POGO, Nyquist, Stability

Purpose

To evaluate the longitudinal stability of a large launch vehicle modeled as a coupled system comprised of a mass-spring structure, a distributed propellant feed system, and engines. Longitudinal stability or instability is a consequence of the interaction between the launch vehicle structure and the propulsion system. Instability (POGO) is most likely to occur when there is a coincidence of the resonant frequencies of the structure and of the propulsion system.

Method

The interaction between the propulsion system and the vehicle structure is described by a nonlinear system of time dependent differential equations.* For the purpose of obtaining numerical solutions of the system, the equations are linearized and LaPlace transformed. The resulting system of simultaneous complex linear equations is a function of the LaPlace transform variable s. For a given time into the flight, entries of the coefficient matrix representing the linear system are calculated as functions of the frequency

*For a description of these equations see R. L. Goldman and G. C. Reis, "A Method For Determining The POGO Stability Of Large Launch Vehicles", in preparation.

ω where $j\omega=s$,** and a Gauss-Jordan reduction scheme is used to obtain numerical results. At each time point, a Nyquist plot is generated representing the open loop gain of the system and the Nyquist stability criterion is used to evaluate the stability.

Input

All input to POGO2 is accomplished by means of the namelists RUNS and INPUT which are read in that order. Below is a description of all the variables in these namelists.

NAMELIST 'RUNS'

NRUNS	number of different sets of input data for which the program will be run during a single execution.

This namelist is placed immediately behind the XQT card and before the namelist 'INPUT'.

NAMELIST 'INPUT'...

NFRQNC	number of frequency intervals of interest. The maximum value of NFRQNC is determined by the parameter variable NN which can be changed at will.
OMGAMN(I), OMGAMX(I)	minimum and maximum values of the frequency in the Ith interval (hz).
TMIN,TMAX	minimum and maximum values of the flight times to be considered. For a single set of input data, the same frequencies are considered for each flight time (sec).
DT	increment for the flight time (sec).
TCECO	time for center engine cut-off (sec).
MU(1)	viscosity of the oxygen (lbs/(sec*in)).
MU(2)	viscosity of the fuel (lbs/(sec*in)).
D,E,TH, SL,C1,T	each of these arrays is dimensioned 6x2. The first subscript determines suction line segment, the first five being oxygen

**For a description of these calculations see A. T. Ackerman and H. E. Stephens, "AS-503 S-IC Stability Analysis", in preparation.

and the sixth being fuel. The second subscript is 1 for inboard engine and 2 for outboard engines.

D Diameter of the segment (in).

E Modulus of elasticity of line material (lb/in**2).

TH Line material thickness (in).

SL Length (in).

C1 Orifice loss coefficient (lbs*sec**2/in**4).

T O..LE.T(I,K).LE.1. gives wall velocity as linear combination of tank and pump velocities.

SKA,SLA,TA each of these is dimensioned 2x2. The first subscript is 1 for inboard and 2 for outboard.

SKA Dimensionless isentropic exponent.

SLA Height of fluid in the accumulator (in).

TA O..LE.TA(I,K).LE.1. gives wall velocity in the accumulator as linear combination of tank and pump velocities.

ASO(K), ASF(K) pump inlet area for each oxidizer and fuel line. Each engine has two fuel lines. K=1,2 for inboard, outboard (in**2).

CI a 6x3x2x2 array of constants used to compute the coefficients of the Rocketdyne transfer functions. These coefficients are represented by a 3x2 matrix. Six constants are used in the calculation of each entry of this 3x2 matrix. These six constants are represented by the first subscript. The last subscript is 1 for inboard and 2 for outboard engines. Thus, C(5,3,2,1) would stand for the fifth constant to be used in calculating the third row-second column entry of the matrix representing the inboard engine transfer functions.

SKI a 3x2x2 array of gain constants of the Rocketdyne engine transfer functions. There is one gain constant corresponding

to each entry of the 3x2 matrix described above. The last subscript is 1 for inboard and 2 for outboard engines.

MP — total pump mass (lbs*sec**2/in).

PVCD, PVCE, PVCTH, PVCSL — each of these arrays is dimensioned 2x2x2. The first subscript refers to the sections of the PVC and is 1 for the smaller and 2 for the larger. The second subscript is 1 for oxidizer PVC and 2 for fuel PVC. The third subscript is 1 for inboard and 2 for outboard.

- PVCD — Diameter of the section (in).
- PVCE — Modulus of elasticity of the PVC material (lb/in**2).
- PVCTH — Material thickness of the PVC (in).
- PVCSL — Length (in).

PVCKS, PVCT — each of these arrays is dimensioned 2x2. The first subscript is for oxidizer, fuel and the second for inboard, outboard.

- PVCKS — Spring constant of the PVC (in/lb).
- PVCT — 0..LE.PVCT(I,J).LE.1. gives the wall velocity in the PVC relative to the ends of the PVC.

PVCSKG — longitudinal acceleration in G's=thrust/weight. On ground, PVCSKG=1.

ALPHA, BETA — each of these is dimensioned 2x2. The first subscript is for oxidizer, fuel and the second for inboard, outboard.

- ALPHA — Adds a constant phase shift to the transfer functions which represent suction line pressure to thrust ratios (degrees).
- BETA — BETA*OMEGA, where OMEGA is the frequency, adds a phase shift to the transfer functions which represent suction line pressure to thrust ratios. This phase shift varies as a linear function of frequency (sec).

KBCTF — if KBCTF=0, the gain constants of the engine transfer functions and the constants used to compute the coefficients of these functions are given by the input arrays SKI and CI. If KBCTF=1, these

constants are given by the arrays BCMSK and BCMC in a data statement in the main program (Bellcomm transfer functions).

KBC2A — if KBC2A=0, the last section of each suction line is replaced by a PVC (Pressure Volume Compensator). If KBC2A=1, no PVC's are included, and the last section of each line serves to convert absolute flow rates to rates which are relative to the walls.

KIEOL — the program incorporates five engines and associated suction lines by modeling the inboard engine separately from the four identical outboard engines. The indicator KIEOL permits the use of two different methods of combining these inboard and outboard lines.

KIEOL=1 ... the inboard engine operates 'open loop' and is connected 'in parallel' with the outboard engine. Only 4/5 of the input signal is applied to the outboard lines, the remaining 1/5 being applied to the inboard line. The thrust output from the inboard engine is not fed back to the input of the inboard lines, but is added to the thrust output of the outboard lines to produce the total thrust output.

KIEOL=0 ... the inboard engine operates 'closed loop'. The entire input signal is fed to the outboard lines, and the total thrust output is that due to the outboard lines only. The inboard thrust output is fed back to the input of the inboard lines.

KCENP — if the center engine is operating closed loop, the Nyquist stability criterion requires that this loop be investigated for stability. The indicator KCENP was defined to allow such center engine Nyquist plots to be made. If KCENP=1 (N.B. it is necessary that KIEOL=1 in this case), the center engine loop is opened, and the total thrust output printed by the program is the net force returned to the center engine due to a unity thrust input to the center engine. Otherwise, set KCENP=0.

KSLNL, KSLCO — important parameters in the POGO problem are the frequency responses of the various suction lines and their sensitivity to variations in cavitation compliance and other 'downstream' impedance. A commonly accepted definition of the suction line transfer function is the ratio of output pressure (pressure at the pump) to pump acceleration. To determine these parameters the indicators KSLNL and KSLCO were defined.

When KSLNL=0, the downstream impedance is removed from all suction lines, except for the cavitation compliance. When KSLNL=1, the suction lines are connected to their downstream impedance.

KSLCO isolates the suction lines and their terminating impedances from the rest of the system. When KSLCO=0, the input to the suction lines from tank bottom pressures is set equal to zero as is the POS-AOS feedback. When KSLCO=1, the system is in its normal state.

INDPNT — 2 for printout of all variables representing solutions of the linear system.

1 for printout of only those variables representing suction line transfer functions and the thrust output.

INDPLT — 1 for Nyquist plots of the thrust output represented by the variable TOPRNT. A plot of imaginary vs real part of TOPRNT is generated for each time point with frequency varying.

0 for no plots.

MPRNT — 1 for printout of the entire matrix of coefficients of the simultaneous equations representing the linear system.

0 for no printout of coefficient matrix.

Output

For each set of input data, all of the variables in the input namelist 'INPUT' are printed along with the variables in the output namelist 'CSK'.

At each time point, a Nyquist plot of imaginary vs real part of TOPRNT is generated with frequency varying (if INDPLT=1) and the following are printed out

... the variables in the output namelist 'OUTPUT',

... amplitudes (db) of zero phase crossings and the frequencies (hz) at which they occur (except when KSLCO=0),

... variables which represent solutions of the linear system as functions of frequency (dependent upon the indicator INDPNT).

At each frequency, the coefficient matrix of the linear system may be printed out (MPRNT=1).

Namelist 'CSK' ...

C,SK	the C and SK arrays represent the actual transfer functions used by the program. If KBCTF=1, these will be Bellcomm. If KBCTF=0, these will be Rocketdyne.

Namelist 'OUTPUT' ...

in what follows, the subscript K refers to the engines and is 1 for the inboard engine and 2 for the outboard engines.

MO(K),MF(K)	propellant weight per unit length (lbs/in).
MTO(K), MTF(K)	pressure per unit acceleration at tank bottoms (lb*sec**2/in**2).
PAOS(K), PAFS(K)	static LOX pump inlet pressure (psia). static fuel pump inlet pressure (psia).
RHO(I,K)	weight density of the fluids. I is 1 for oxygen and 2 for fuel (lbs/in**3).
CBO(K), CBF(K)	bubble compliance of the fluids (in**2).
CF,V,SA	each of these is dimensioned 6x2. The first subscript determines suction line segment, the first five being oxygen and the sixth being fuel. The second subscript is 1 for inboard and 2 for outboard engines.

CF	Frictional coefficient of the segment.
V	Velocity of fluid in the segment (in/sec).

SA Wave speed of fluid in the segment (in/sec).

OMGA(I) I=1,9 the natural resonant frequency of the structure in the Ith mode (rad/sec).

ZETA(I) I=1,9 damping ratio of the structure in the Ith mode.

HP(I,K), HTO(I,K), HTF(I,K) I=1,10 the coefficient of the Ith term in the generalized coordinate expansion of the displacement of the pump, oxidizer tank bottom, and fuel tank bottom, respectively.

HGOMEQ(I) I=1,10 converts the force at the gimbal to the generalized force in the Ith mode.

LA(J,K) the product of the acceleration of gravity and the inertance of fluid in the accumulator. J is 1 for oxidizer and 2 for fuel (1./in).

VAO(J,K) volume of gas in the accumulator. J is 1 for oxidizer and 2 for fuel (in**3).

KA(J,K) elastance or stiffness of the gas in the accumulator. J is 1 for oxidizer and 2 for fuel (1./in**2).

PVCA(I,J,K), PVCSA(I,J,K) the subscript I refers to the sections of the PVC and is 1 for the smaller and 2 for the larger. J is 1 for the oxidizer PVC and 2 for the fuel PVC.

PVCA Cross-section area of the PVC section (in**2).

PVCSA Wave speed of the fluid in the section (in/sec).

Printout of solutions of the linear system ...

P10I, DW10I inboard engine oxidizer line inlet pressure and flow rate.

P80I, DW80I inboard engine oxidizer line outlet pressure and flow rate.

P10O, DW10O outboard engine oxidizer line inlet pressure and flow rate.

P80O, DW80O outboard engine oxidizer line outlet pressure and flow rate.

P1FI, DW1FI	inboard engine fuel line inlet pressure and flow rate.
P2FI, DW2FI	inlet pressure and flow rate of the second segment of the inboard engine fuel lines.
P3FI, DW3FI	inboard engine fuel line outlet pressure and flow rate.
P1FO, DW1FO	outboard engine fuel line inlet pressure and flow rate.
P2FO, DW2FO	inlet pressure and flow rate of the second segment of the outboard engine fuel lines.
P3FO, DW3FO	outboard engine fuel line outlet pressure and flow rate.
	All of the above pressures are lbs/in**2 and the flow rates are lbs/sec.
XTOI,XPI, XTFI	oxidizer tank bottom, pump, and fuel tank bottom displacements of the inboard engine (in).
XTOO,XPO, XTFO	oxidizer tank bottom, pump, and fuel tank bottom displacements of the outboard engine (in).
XI0 THRU XI9	the ten generalized coordinates (in).
TI	thrust output of the inboard engine (lbs).
TOPRNT	if KIEOL=0 and KCENP=0, TOPRNT is the thrust output of the outboard engines.
	If KIEOL=0 and KCENP=1, TOPRNT is TI+OMEGA**2*MP-ASO(1)*P8OI-2.*ASF(1) *P3FI where OMEGA is the frequency in radians/sec.
	If KIEOL=1, TOPRNT is the sum of the thrusts from inboard and outboard engines.
TFOI,TFFI	ratios of output pressures of the oxidizer and fuel suction lines to OMEGA**2*XPI (inboard engine).
TFOO,TFFO	ratios of output pressures of oxidizer and fuel lines to OMEGA**2*XPO (outboard engines).

Subprograms Used

ACCUM2	supplies accumulator variables LA and VAO which are independent of flight time and frequency.
DATA	supplies values of the suction line, pump, and tank data for a given flight time.
PMTRX2	calculates the entries of the coefficient matrix of the linear system for a given flight time and frequency.
PVC	a routine called by PMTRX2 to define the matrices used to model the pressure-volume compensators.
SOLVEQ	supplies solutions of the linear system in the form of amplitude and phase angle for a given flight time and frequency.
STRCT2	supplies values of the structural data for a given flight time.
TABLEB	performs linear interpolations using a binary search.
POGPLT	used to obtain Nyquist plots. These plots are generated by the Stromberg Carlson 4020 plotter. POGPLT is an adaptation of ORPLOT and uses routines belonging to the SC-4020 plot package. This package is at present maintained on the Bellcomm system library.

A FORTRAN deck of each of the above routines can be obtained from the Bellcomm Applications Program Library.

CGJR	a routine in the UNIVAC MATH-PACK which performs a complex Gauss-Jordan reduction on the matrix supplied to it by SOLVEQ. The MATH-PACK is at present maintained on the Bellcomm system library.
CLOCK	a Bellcomm system library routine which prints the program execution time required for obtaining and printing solutions of the system over one flight time.

Program Limitations

The maximum number of frequencies that may be considered for one flight time is determined by the parameter variable NOMEGA and is at present 125. The maximum number of frequency intervals that may be considered for one flight time is determined by the parameter variable NN which is at present 20. NOMEGA and NN may be changed by the user and are restricted only by the size of core.

Program Usage

At present, POGO2 is running on the UNIVAC EXEC 8 system. Assuming that the user has not already established a FASTRAND file or tape on which the program is stored, a typical run deck would be set up as follows:

```
@RUN        CFB,POGCFB,POGO2,20,50

@HDG        C F BANICK   SAMPLE POGO2 RUN

@ASG,M      10,T,PLOT  (A plotting tape must be assigned
                       whenever Nyquist plots are to be
                       generated.)

@FOR,IS     POGO2,POGO2
            (FORTRAN cards)

@FOR,IS     ACCUM2,ACCUM2
            (FORTRAN cards)

                    etc.

       FORTRAN decks of POGO2, ACCUM2, DATA, PMTRX2,
       PVC, SOLVEQ, STRCT2, TABLEB, and POGPLT.

@XQT

 $RUNS
  NRUNS=____
 $END

 $INPUT
  (data)
 $END

 $INPUT
  (data)
 $END
```

Program listings and a sample run of the program are reproduced below. Included is the Nyquist plot generated by the run.

NOTE: The values of input variables are not changed by the program. Therefore, it is unnecessary to reset values of variables in the namelist INPUT between successive readings during one execution of the program.

Carl F. Banick

1032-CFB-mfa C. F. Banick

PROGRAM LISTINGS

```
@FOR.SI          POGSIC.PDG02,.POGO2
C
C TITLE          POGO2
C
C AUTHOR         CAROL F. BANICK
C
C SPONSOR        GEORGE C. REIS
C
C DATE           11-15-68
C
C PURPOSE        SOLVE A SYSTEM OF SIMULTANEOUS LINEAR EQUATIONS WHICH
C                MODEL THE SATURN V SELF-SUSTAINING LONGITUDINAL
C                OSCILLATIONS (POGO). THRUST VARIATIONS ARE DUE TO
C                OSCILLATIONS IN THE STRUCTURE WHICH ARE FED BACK TO THE
C                THRUST THROUGH THE PROPELLANT LINES.
C
C METHOD         DEFINE THE MATRIX USED TO DESCRIBE THE SYSTEM AND USE
C                A GAUSS-JORDAN REDUCTION SCHEME TO OBTAIN NUMERICAL
C                RESULTS.
C
C INPUT          THROUGH NAMELISTS
C
C                NAMELIST 'RUNS' ...
C                   NRUNS          NUMBER OF DIFFERENT SETS OF INPUT DATA
C                                  FOR WHICH THE PROGRAM WILL BE RUN DURING
C                                  A SINGLE EXECUTION.
C                   THIS NAMELIST IS PLACED IMMEDIATELY BEHIND THE XQT
C                   CARD AND BEFORE THE NAMELIST 'INPUT'.
C
C                NAMELIST 'INPUT'...
C                   NFRONC         NUMBER OF FREQUENCY INTERVALS OF INTEREST.
C                                  THE MAXIMUM VALUE OF NFRONC IS DETERMINED
C                                  BY THE PARAMETER VARIABLE NN WHICH CAN
C                                  BE CHANGED AT WILL.
C
C                   OMGAMN(I),     MINIMUM AND MAXIMUM VALUES OF THE
C                   OMGAMX(I)      FREQUENCY IN THE ITH INTERVAL (HZ).
C
C                   DOMGA(I)       BASIC STEP SIZE OF THE FREQUENCY IN THE
C                                  ITH INTERVAL (HZ).
C
C                   TMIN,TMAX      MINIMUM AND MAXIMUM VALUES OF THE FLIGHT
C                                  TIMES TO BE CONSIDERED. FOR ONE EXECUTION
C                                  OF THE PROGRAM, THE SAME FREQUENCIES
C                                  ARE CONSIDERED FOR EACH FLIGHT TIME (SEC).
C
C                   DT             INCREMENT FOR THE FLIGHT TIME (SEC).
C
C                   TCECO          TIME FOR CENTER ENGINE CUT-OFF (SEC).
C
C                   MU(1)          VISCOSITY OF THE OXYGEN (LBS/(SEC*IN)).
C                   MU(2)          VISCOSITY OF THE FUEL (LBS/(SEC*IN)).
C
C                   D,E,TH,        EACH OF THESE ARRAYS IS DIMENSIONED 6X2.
C                   SL,C1,T        THE FIRST SUBSCRIPT DETERMINES SUCTION
C                                  LINE SEGMENT. THE FIRST FIVE BEING OXYGEN
C                                  AND THE SIXTH BEING FUEL. THE SECOND
C                                  SUBSCRIPT IS 1 FOR INBOARD ENGINE AND 2
```

```
C                2 FOR OUTBOARD.
C                PVCD     DIAMETER OF THE SECTION (IN).
C                PVCE     MODULUS OF ELASTICITY OF THE
C                         PVC MATERIAL (LB/IN**2).
C                PVCTH    MATERIAL THICKNESS OF THE PVC (IN)
C                PVCSL    LENGTH (IN).
C
C       PVCKS,   EACH OF THESE ARRAYS IS DIMENSIONED 2X2.
C       PVCT     THE FIRST SUBSCRIPT IS FOR OXIDIZER, FUEL
C                AND THE SECOND FOR INBOARD, OUTBOARD.
C                PVCKS    SPRING CONSTANT OF THE PVC (IN/LB)
C                PVCT     D..LE. PVCT(I,J).LE.1. GIVES
C                         THE WALL VELOCITY IN THE PVC
C                         RELATIVE TO THE ENDS OF THE PVC.
C
C       PVCSKG   LONGITUDINAL ACCELERATION IN G'S = THRUST/
C                WEIGHT. ON GROUND, PVCSKG=1.
C
C       ALPHA,   EACH OF THESE IS DIMENSIONED 2X2. THE
C       BETA     FIRST SUBSCRIPT IS FOR OXIDIZER, FUEL
C                AND THE SECOND FOR INBOARD, OUTBOARD.
C                ALPHA    ADDS A CONSTANT PHASE SHIFT TO
C                         THE TRANSFER FUNCTIONS WHICH
C                         REPRESENT SUCTION LINE PRESSURE
C                         TO THRUST RATIOS(DEGREES).
C                BETA     ADDS A PHASE SHIFT TO THE TRANSFER
C                         FUNCTIONS WHICH REPRESENT SUCTION
C                         LINE PRESSURE TO THRUST RATIOS.
C                         THIS PHASE SHIFT VARIES AS A
C                         LINEAR FUNCTION OF FREQUENCY.
C
C
C       KBCTF    IF KBCTF=0, THE GAIN CONSTANTS OF THE
C                ENGINE TRANSFER FUNCTIONS AND THE
C                CONSTANTS USED TO COMPUTE THE COEFFICIENTS
C                OF THESE FUNCTIONS ARE GIVEN BY THE INPUT
C                ARRAYS SKI AND CI. IF KBCTF=1, THESE
C                CONSTANTS ARE GIVEN BY THE ARRAYS BCHSK
C                AND BCHC IN A DATA STATEMENT IN THE MAIN
C                PROGRAM (BELLCOMM TRANSFER FUNCTIONS).
C
C       KBC2A    IF KBC2A=0, THE LAST SECTION OF EACH
C                SUCTION LINE IS REPLACED BY A PVC
C                (PRESSURE VOLUME COMPENSATOR). IF
C                KBC2A=1, NO PVC'S ARE INCLUDED, AND THE
C                LAST SECTION OF EACH LINE SERVES TO
C                CONVERT ABSOLUTE FLOW RATES TO RATES WHICH
C                ARE RELATIVE TO THE WALLS.
C
C       KIEOL    THE PROGRAM INCORPORATES FIVE ENGINES
C                AND ASSOCIATED SUCTION LINES BY MODELING
C                THE INBOARD ENGINE SEPARATELY FROM THE
C                FOUR IDENTICAL OUTBOARD ENGINES. THE
C                INDICATOR KIEOL PERMITS THE USE OF TWO
C                DIFFERENT METHODS OF COMBINING THESE
C                INBOARD AND OUTBOARD LINES.
C             KIEOL=1 ... THE INBOARD ENGINE OPERATES
C                'OPEN LOOP' AND IS CONNECTED 'IN PARALLEL'
```

```
C                    FOR OUTBOARD ENGINES.
C                    D     DIAMETER OF THE SEGMENT (IN).
C                    E     MODULUS OF ELASTICITY OF LINE
C                          MATERIAL (LB/IN.*2).
C                    TH    LINE MATERIAL THICKNESS (IN).
C                    SL    LENGTH (IN).
C                    C1    ORIFICE LOSS COEFFICIENT (LBS.SEC.*2/
C                          IN.*4).
C                    T     0.*LE.T(I,K).LE.1. GIVES WALL
C                          VELOCITY AS LINEAR COMBINATION OF
C                          TANK AND PUMP VELOCITIES.
C
C         SKA,SLA,TA EACH OF THESE IS DIMENSIONED 2X2. THE
C                    FIRST SUBSCRIPT IS 1 FOR OXIDIZER AND 2
C                    FOR FUEL, THE SECOND IS 1 FOR INBOARD AND
C                    2 FOR OUTBOARD.
C                    SKA   DIMENSIONLESS ISENTROPIC EXPONENT.
C                    SLA   HEIGHT OF FLUID IN THE ACCUMULATOR
C                          (IN).
C                    TA    0.*LE.TA(I,K).LE.1. GIVES WALL
C                          VELOCITY IN THE ACCUMULATOR AS LINEAR
C                          COMBINATION OF TANK AND PUMP
C                          VELOCITIES.
C
C         ASO(K),    PUMP INLET AREA FOR EACH OXIDIZER AND
C         ASF(K)     FUEL LINE. EACH ENGINE HAS TWO FUEL LINES.
C                    K=1,2 FOR INBOARD, OUTBOARD (IN.*2).
C
C         CI         A 6X3X2X2 ARRAY OF CONSTANTS USED TO
C                    COMPUTE THE COEFFICIENTS OF THE
C                    ROCKETDYNE TRANSFER FUNCTIONS. THESE
C                    COEFFICIENTS ARE REPRESENTED BY A 3X2
C                    MATRIX. SIX CONSTANTS ARE USED IN THE
C                    CALCULATION OF EACH ENTRY OF THIS 3X2
C                    MATRIX. THESE SIX CONSTANTS ARE
C                    REPRESENTED BY THE FIRST SUBSCRIPT. THE
C                    LAST SUBSCRIPT IS 1 FOR INBOARD AND 2 FOR
C                    OUTBOARD ENGINES. THUS, C(5,3,2,1) WOULD
C                    STAND FOR THE FIFTH CONSTANT TO BE USED
C                    IN CALCULATING THE THIRD ROW.SECOND COLUMN
C                    ENTRY OF THE MATRIX REPRESENTING THE
C                    INBOARD ENGINE TRANSFER FUNCTIONS.
C
C         SKI        A 3X2X2 ARRAY OF GAIN CONSTANTS OF THE
C                    ROCKETDYNE ENGINE TRANSFER FUNCTIONS.
C                    THERE IS ONE GAIN CONSTANT CORRESPONDING
C                    TO EACH ENTRY OF THE 3X2 MATRIX DESCRIBED
C                    ABOVE. THE LAST SUBSCRIPT IS 1 FOR
C                    INBOARD AND 2 FOR OUTBOARD ENGINES.
C
C         MP         TOTAL PUMP MASS (LBS.SEC.*2/IN)
C
C         PVCD,PVCE, EACH OF THESE ARRAYS IS DIMENSIONED 2X2X2.
C         PVCTH,     THE FIRST SUBSCRIPT REFERS TO THE SECTIONS
C         PVCSL      OF THE PVC AND IS 1 FOR THE SMALLER AND
C                    2 FOR THE LARGER. THE SECOND SUBSCRIPT
C                    IS 1 FOR OXIDIZER PVC AND 2 FOR FUEL PVC.
C                    THE THIRD SUBSCRIPT IS 1 FOR INBOARD AND
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```
C                 WITH THE OUTBOARD ENGINE. ONLY 4/5 OF
C                 THE INPUT SIGNAL IS APPLIED TO THE
C                 OUTBOARD LINES, THE REMAINING 1/5 BEING
C                 APPLIED TO THE INBOARD LINE. THE THRUST
C                 OUTPUT FROM THE INBOARD ENGINE IS NOT FED
C                 BACK TO THE INPUT OF THE INBOARD LINES,
C                 BUT IS ADDED TO THE THRUST OUTPUT OF THE
C                 OUTBOARD LINES TO PRODUCE THE TOTAL THRUST
C                 OUTPUT.
C            KIEOL=0 ... THE INBOARD ENGINE OPERATES
C                 'CLOSED LOOP'. THE ENTIRE INPUT SIGNAL
C                 IS FED TO THE OUTBOARD LINES, AND
C                 THE TOTAL THRUST OUTPUT IS THAT DUE TO
C                 THE OUTBOARD LINES ONLY. THE INBOARD
C                 THRUST OUTPUT IS FED BACK TO THE INPUT OF
C                 THE INBOARD LINES.
C
C      KCENP      IF THE CENTER ENGINE IS OPERATING CLOSED
C                 LOOP, THE NYQUIST STABILITY CRITERION
C                 REQUIRES THAT THIS LOOP BE INVESTIGATED
C                 FOR STABILITY. THE INDICATOR KCENP WAS
C                 DEFINED TO ALLOW SUCH CENTER ENGINE
C                 NYQUIST PLOTS TO BE MADE. IF KCENP=1
C                 (N.B. IT IS NECESSARY THAT KIEOL=1 IN
C                 THIS CASE), THE CENTER ENGINE LOOP IS
C                 OPENED, AND THE TOTAL THRUST OUTPUT
C                 PRINTED BY THE PROGRAM IS THE NET FORCE
C                 RETURNED TO THE CENTER ENGINE DUE TO A
C                 UNITY THRUST INPUT TO THE CENTER ENGINE.
C                 OTHERWISE, SET KCENP=0.
C
C      KSLNL,     IMPORTANT PARAMETERS IN THE POGO PROBLEM
C      KSLCO      ARE THE FREQUENCY RESPONSES OF THE
C                 VARIOUS SUCTION LINES AND THEIR
C                 SENSITIVITY TO VARIATIONS IN CAVITATION
C                 COMPLIANCE AND OTHER 'DOWNSTREAM'
C                 IMPEDANCE. A COMMONLY ACCEPTED DEFINITION
C                 OF THE SUCTION LINE TRANSFER FUNCTION IS
C                 THE RATIO OF OUTPUT PRESSURE (PRESSURE AT
C                 THE PUMP) TO PUMP ACCELERATION. TO
C                 DETERMINE THESE PARAMETERS THE INDICATORS
C                 KSLNL AND KSLCO WERE DEFINED.
C                      WHEN KSLNL=0, THE DOWNSTREAM
C                 IMPEDANCE IS REMOVED FROM ALL SUCTION
C                 LINES, EXCEPT FOR THE CAVITATION
C                 COMPLIANCE. WHEN KSLNL=1, THE SUCTION
C                 LINES ARE CONNECTED TO THEIR DOWNSTREAM
C                 IMPEDANCE.
C                      KSLCO ISOLATES THE SUCTION LINES AND
C                 THEIR TERMINATING IMPEDANCES FROM THE REST
C                 OF THE SYSTEM. WHEN KSLCO=0, THE INPUT TO
C                 THE SUCTION LINES FROM TANK BOTTOM
C                 PRESSURES IS SET EQUAL TO ZERO AS IS THE
C                 POS-AOS FEEDBACK. WHEN KSLCO=1, THE
C                 SYSTEM IS IN ITS NORMAL STATE.
C
C      INDPNT     2 FOR PRINTOUT OF ALL VARIABLES
C                   REPRESENTING SOLUTIONS OF THE LINEAR
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C                                SYSTEM.
C                              1 FOR PRINTOUT OF ONLY THOSE VARIABLES
C                                REPRESENTING SUCTION LINE TRANSFER
C                                FUNCTIONS AND THE THRUST OUTPUT.
C
C                 INDPLT       1 FOR NYQUIST PLOTS OF THE THRUST OUTPUT
C                                REPRESENTED BY THE VARIABLE TOPRNT. A
C                                PLOT OF IMAGINARY VS REAL PART OF TOPRNT
C                                IS GENERATED FOR EACH TIME POINT WITH
C                                FREQUENCY VARYING.
C                              0 FOR NO PLOTS.
C
C                 MPRNT        1 FOR PRINTOUT OF THE ENTIRE MATRIX OF
C                                COEFFICIENTS OF THE SIMULTANEOUS
C                                EQUATIONS REPRESENTING THE LINEAR SYSTEM.
C                              0 FOR NO PRINTOUT OF COEFFICIENT MATRIX.
C
C
C OUTPUT          FOR EACH SET OF INPUT DATA, ALL OF THE VARIABLES IN THE
C                 INPUT NAMELIST 'INPUT' ARE PRINTED OUT ALONG WITH THE
C                 VARIABLES IN THE OUTPUT NAMELIST 'CSK'.
C                      AT EACH TIME POINT, A NYQUIST PLOT OF IMAGINARY VS
C                 REAL PART OF TOPRNT IS GENERATED WITH FREQUENCY VARYING
C                 (IF INDPLT=1) AND THE FOLLOWING ARE PRINTED OUT
C                 ... THE VARIABLES IN THE OUTPUT NAMELIST 'OUTPUT'.
C                 ... AMPLITUDES (DB) OF ZERO PHASE CROSSINGS AND THE
C                 FREQUENCIES (HZ) AT WHICH THEY OCCUR (EXCEPT WHEN
C                 KSLCO=0).
C                 ... VARIABLES WHICH REPRESENT SOLUTIONS OF THE LINEAR
C                 SYSTEM AS FUNCTIONS OF FREQUENCY (DEPENDENT UPON THE
C                 INDICATOR INDPNT).
C                      AT EACH FREQUENCY, THE COEFFICIENT MATRIX OF THE
C                 LINEAR SYSTEM MAY BE PRINTED OUT (MPRNT=1).
C
C                 NAMELIST 'CSK'...
C                    C,SK          THE C AND SK ARRAYS REPRESENT THE ACTUAL
C                                  TRANSFER FUNCTIONS USED BY THE PROGRAM.
C                                  IF KBCTF=1, THESE WILL BE BELLCOMM. IF
C                                  KBCTF=0, THESE WILL BE ROCKETDYNE.
C
C                 NAMELIST 'OUTPUT' ...
C                                  IN WHAT FOLLOWS, THE SUBSCRIPT K REFERS
C                                  TO THE ENGINES AND IS 1 FOR THE INBOARD
C                                  ENGINE AND 2 FOR THE OUTBOARD ENGINES.
C
C                    MO(K),MF(K)   PROPELLANT WEIGHT PER UNIT LENGTH (LBS/IN).
C
C                    MTO(K),       PRESSURE PER UNIT ACCELERATION AT TANK
C                    MTF(K)        BOTTOMS (LB*SEC**2/IN**2).
C
C                    PAOS(K)       STATIC LOX PUMP INLET PRESSURE (PSIA).
C                    PAFS(K)       STATIC FUEL PUMP INLET PRESSURE (PSIA).
C
C                    RHO(I,K)      WEIGHT DENSITY OF THE FLUIDS. I IS 1 FOR
C                                  OXYGEN AND 2 FOR FUEL (LBS/IN**3).
C
C                    CBO(K),       BUBBLE COMPLIANCE OF THE FLUIDS (IN**2).
C                    CBF(K)
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```
C
C          CF,V,SA      EACH OF THESE IS DIMENSIONED 6X2. THE
C                       FIRST SUBSCRIPT DETERMINES SUCTION LINE
C                       SEGMENT, THE FIRST FIVE BEING OXYGEN AND
C                       THE SIXTH BEING FUEL. THE SECOND
C                       SUBSCRIPT IS 1 FOR INBOARD AND 2 FOR
C                       OUTBOARD ENGINES.
C                       CF    FRICTIONAL COEFFICIENT OF THE SEGMENT.
C                       V     VELOCITY OF FLUID IN THE SEGMENT
C                             (IN/SEC).
C                       SA    WAVE SPEED OF FLUID IN THE SEGMENT
C                             (IN/SEC).
C
C          OMGA(I)      I=1,9  THE NATURAL RESONANT FREQUENCY OF
C                       THE STRUCTURE IN THE ITH MODE (RAD/SEC).
C
C          ZETA(I)      I=1,9  DAMPING RATIO OF THE STRUCTURE IN
C                       THE ITH MODE.
C
C          HP(I,K),     I=1,10  THE COEFFICIENT OF THE ITH TERM
C          HTO(I,K),    IN THE GENERALIZED COORDINATE EXPANSION
C          HTF(I,K)     OF THE DISPLACEMENT OF THE PUMP, OXIDIZER
C                       TANK BOTTOM, AND FUEL TANK BOTTOM,
C                       RESPECTIVELY.
C
C          HGOMEO(I)    I=1,10  CONVERTS THE FORCE AT THE GIMBAL
C                       TO THE GENERALIZED FORCE IN THE ITH MODE.
C
C          LA(J,K)      THE PRODUCT OF THE ACCELERATION OF
C                       GRAVITY AND THE INERTANCE OF FLUID IN
C                       THE ACCUMULATOR.  J IS 1 FOR OXIDIZER AND
C                       2 FOR FUEL (1./IN).
C
C          VAO(J,K)     VOLUME OF GAS IN THE ACCUMULATOR.  J IS
C                       1 FOR OXIDIZER AND 2 FOR FUEL (IN**3).
C
C          KA(J,K)      ELASTANCE OR STIFFNESS OF THE GAS IN THE
C                       ACCUMULATOR.  J IS 1 FOR OXIDIZER AND 2
C                       FOR FUEL (1./IN**2).
C
C          PVCA(I,J,K),          THE SUBSCRIPT I REFERS TO THE
C          PVCSA(I,J,K)          SECTIONS OF THE PVC AND IS 1
C                                FOR THE SMALLER AND 2 FOR THE
C                                LARGER. J IS 1 FOR THE OXIDIZER
C                                PVC AND 2 FOR THE FUEL PVC.
C                       PVCA     CROSS-SECTIONAL AREA OF THE
C                                PVC SECTION (IN**2).
C                       PVCSA    WAVE SPEED OF THE FLUID IN THE
C                                SECTION (IN/SEC).
C
C
C
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C
C
C
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C
C                    TFOO,TFFO    RATIOS OF OUTPUT PRESSURES OF OXIDIZER
C                                 AND FUEL LINES TO OMEGA**2*XPO
C                                 (OUTBOARD ENGINES).
C
C SUBROUTINES   DATA        SUPPLIES VALUES OF THE SUCTION LINE, PUMP, AND
C USED                      TANK DATA AS A FUNCTION OF TIME.
C
C               STRCT2      SUPPLIES VALUES OF THE STRUCTURAL DATA AS A
C                           FUNCTION OF TIME.
C
C               ACCUM2      SUPPLIES ACCUMULATOR VARIABLES INDEPENDENT OF
C                           TIME AND FREQUENCY.
C
C               MATRX2      DEFINES THE COEFFICIENT MATRIX OF THE LINEAR
C                           SYSTEM AS A FUNCTION OF TIME AND FREQUENCY.
C
C               SOLVEQ      SUPPLIES SOLUTIONS OF THE SYSTEM DEFINED BY
C                           'MATRX2'.
C
C               CGJR        A ROUTINE IN THE UNIVAC MATH PACK WHICH
C                           PERFORMS A COMPLEX GAUSS-JORDAN REDUCTION ON
C                           THE MATRIX SUPPLIED TO IT BY 'SOLVEQ'.
C
C               PVC         A ROUTINE CALLED BY 'MATRX2' WHICH DEFINES THE
C                           MATRICES USED TO MODEL THE PVC'S.
C
C               TABLED      PERFORMS A LINEAR INTERPOLATION.
C
C               CLOCK       A BELLCOMM LIBRARY ROUTINE WHICH PRINTS THE
C                           PROGRAM EXECUTION TIME REQUIRED FOR OBTAINING
C                           AND PRINTING SOLUTIONS OF THE SYSTEM OVER ONE
C                           FLIGHT TIME.
C
C               POGPLT      USED TO OBTAIN NYQUIST PLOTS.  THESE PLOTS ARE
C                           GENERATED BY THE SC-4020 PLOTTER. POGPLT USES
C                           ROUTINES FOUND ON THE FASTRAND FILE 'SSCPLT'.
C
C                           SUBROUTINES 'SUB1', 'SUB3', AND 'SUB4' ARE
C                           INTERNAL TO 'POGOR'.
C
C       NOTES ...
C                           IF INPUT DATA IS SUCH THAT THE CGJR ROUTINE HAS
C               DIFFICULTY WHILE TRYING TO INVERT THE COEFFICIENT MATRIX,
C               THE MESSAGE 'JG.I' IS PRINTED, WHERE I IS AN INTEGER.
C               SEE THE MATH PACK WRITE-UP OF CGJR FOR AN EXPLANATION OF
C               ERROR RETURNS.
C                           THE CENTER ENGINE OXIDIZER LINE EXTENDS INTO
C               THE OXIDIZER TANK FORMING A STANDPIPE.  ONCE THE HEIGHT
C               OF FLUID IN THE TANK FALLS BELOW THE HEIGHT OF THE
C               STANDPIPE, IT IS IMPOSSIBLE TO OPERATE THE CENTER ENGINE.
C               IF THE INPUT DATA ATTEMPTS TO SET CENTER ENGINE SHUTDOWN
C               AT A TIME SUCH THAT AUTOMATIC SHUTDOWN WOULD HAVE
C               ALREADY OCCURRED, A MESSAGE IS PRINTED.
C
C
C
C
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```
C       THE COEFFICIENT MATRIX P IS DIMENSIONED NRP X NCP.
C       NOMEGA IS THE MAXIMUM NUMBER OF FREQUENCIES THAT MAY BE
C       CONSIDERED FOR ONE FLIGHT TIME.     NN IS THE MAXIMUM NUMBER OF
C       FREQUENCY INTERVALS THAT MAY BE CONSIDERED FOR ONE FLIGHT TIME.
C       NOMEGA AND NN MAY BE CHANGED BY THE USER AND ARE RESTRICTED ONLY
C       BY THE SIZE OF CORE.
C
              PARAMETER NRP=38,NCP=39,NOMEGA=125,NN=20
C
              REAL LA,MU(2),MTO,MTF,MO,MF,MP,KA
C
              COMPLEX P(NRP,NCP),TOUT,TOUTKP,TOPRNT,TIOUT
C
C       PH2 IS SHARED BY POGO2 AND PHTRX2.
C
              COMMON /PH2/G,CF(6,2),V(6,2),SA(6,2),A(6,2),SL(6,2),
     .        CI(6,2),RHO(2,2),T(6,2),LA(2,2),KA(2,2),ALPHA(2,3),
     .        BETA(2,2),SLA(2,2),TA(2),KSLCO,KCECO,ASO(2),ASF(2),
     .        ZETA(9),OMGA(9),
     .        MP(10,2),MTO(10,2),MTF(10,2),MGOMEO(10),MTO(2),MTF(2),
     .        C(6,3,2,2),SK(3,2,2),KSLNL,CBO(2),CBF(2),MO(2),MF(2),
     .        MP,PVCSL(2,2,2),PVCKS(2,2),PVCSKG,PVCT(2,2),PVCA(2,2,2),
     .        PVCSA(2,2,2),KBC2A,KIEOL,KCENP
C
              DIMENSION OMGANN(NN),OMGANX(NN),DOMGA(NN),P(6,2),TH(6,2),
     .        E(6,2),PVCD(2,2,2),PVCE(2,2,2),PVCTH(2,2,2),
     .        OMEGA(NOMEGA),ATOUTO(NOMEGA),PTOUTO(NOMEGA),
     .        RTOUTO(NOMEGA),CTOUTO(NOMEGA),TITLE(42),
     .        ASOLKP(NOMEGA,42),PSOLKP(NOMEGA,42),ANP(NRP),PHSANG(NRP),
     .        NCHAR(26),OMGCRS(NOMEGA),ATCRS(NOMEGA),SKA(2,2),PAOS(2),
     .        PAFS(2),VAO(2,2),ATOUTI(NOMEGA),PTOUTI(NOMEGA),
     .        SKI(3,2,2),CI(6,3,2,2)
C
              EQUIVALENCE (P(38,39),TOUT),(P(37,39),TIOUT),
     .        (ATOUTO,ASOLKP(1,38)),(PTOUTO,PSOLKP(1,38)),
     .        (ATOUTI,ASOLKP(1,37)),(PTOUTI,PSOLKP(1,37))
C
              NAMELIST/RUNS/NRUNS
C
              NAMELIST /INPUT/NFRONC,OMGANN,OMGANX,DOMGA,THMIN,THMAX,DT,
     .        TCECO,MU,D,E,TH,SL,CI,T,SKA,SLA,TA,ASO,ASF,CI,SKI,MP,
     .        PVCD,PVCE,PVCTH,PVCSL,PVCKS,PVCT,PVCSKG,ALPHA,BETA,
     .        KBCTF,KBC2A,KIEOL,KCENP,KSLNL,KSLCO,INDPRT,INDPLT,MPRNT
C
              NAMELIST /CSK/ C,SK
C
              NAMELIST /OUTPUT/MO,MF,MTO,MTF,PAOS,PAFS,
     .        RHO,CBO,CBF,V,CF,SA,
     .        OMGA,ZETA,MP,MTO,MTF,MGOMEO,LA,VAO,KA,PVCA,PVCSA
C
C       GAIN CONSTANTS OF THE BELLCOMM TRANSFER FUNCTIONS ...
C
              DIMENSION BCMSK(3,2,2)/.460E3,2.3000315,-.25626542,
     .        .23761E3,-.36589693,.84347324,
     .                                .460E3,2.3000315,-.25626542,
     .        .23761E3,-.36589693,.84347324/
C
C       CONSTANTS USED TO COMPUTE BELLCOMM TRANSFER FUNCTION
```

```
C       COEFFICIENTS ...
C
              DIMENSION BCHC(6,3,2,2)/.76124560E-2,0.,11.991125E-3,
              75.392103E-6,.156367E-6,0.,.10708612E-1,.34448399E-4,
     .        11.991125E-3,75.392103E-6,.156367E-6,0.,0.,0.,
     .        11.991125E-3,75.392103E-6,.156367E-6,0.,.59330143E-2,0.,
     .        11.991125E-3,75.392103E-6,.156367E-6,0.,0.,0.,
     .        11.991125E-3,75.392103E-6,.156367E-6,0.,.03257038E-2,
     .        .2376306E-4,11.991125E-3,75.392103E-6,.156367E-6,0.,
     .                                  .76124560E-2,0.,11.991125E-3,
     .        75.392103E-6,.156367E-6,0.,.10708612E-1,.34448399E-4,
     .        11.991125E-3,75.392103E-6,.156367E-6,0.,0.,0.,
     .        11.991125E-3,75.392103E-6,.156367E-6,0.,.59330143E-2,0.,
     .        11.991125E-3,75.392103E-6,.156367E-6,0.,0.,0.,
     .        11.991125E-3,75.392103E-6,.156367E-6,0.,.03257038E-2,
     .        .2376306E-4,11.991125E-3,75.392103E-6,.156367E-6,0./
C
              DATA NCHAR/1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,1HI,1HJ,1HK,
     .        1HL,1HM,1HN,1HO,1HP,1HQ,1HR,1HS,1HT,1HU,1HV,1HW,1HX,
     .        1HY,1HZ/
C
              DATA TITLE/'P1OI','DW1OI','P0OI','DW0OI','P1OO','DW1OO',
     .                    'P0OO','DW0OO','P1FI','DW1FI','P2FI','DW2FI',
     .                    'P3FI','DW3FI','P1FO','DW1FO','P2FO','DW2FO',
     .                    'P3FO','DW3FO','XTOI','XPI','XTPI','XTOO',
     .                    'XPO','XTPO','X10','X11','X12','X13','X14',
     .                    'X15','X16','X17','X18','X19','TI','TOPHNT',
     .                    'TFOI','TFFI','TFOO','TFFO'/
C
C       THIS CALL TO CHAINV PREVENTS A REWINDING OF THE PLOT TAPE
C       BETWEEN SUCCESSIVE EXECUTIONS OF THE PROGRAM.
C
              CALL CHAINV(1,0)
              CALL CANRAV(935)
C
C       GRAVITATIONAL CONSTANT ...
C
              G=386.4                    @  IN/SEC**2
C
              RDTODG=180./3.1415927
              TWOPI=2.*3.1415927
C
              READ(5,RUNS)
C
              DO 25 IRUN=1,NRUNS
              READ(5,INPUT)
              IF(TCECO.GT.125.6)GO TO 255
C
C       DETERMINE WHICH TRANSFER FUNCTIONS ARE TO BE USED.
C
              IF(KBCTF.EQ.0)GO TO 4
              DO 3 J=1,3
              DO 3 I=1,2
              DO 3 K=1,2
              SK(J,I,K)=BCHSK(J,I,K)
              DO 3 L=1,6
    3         C(L,J,I,K)=BCHC(L,J,I,K)
              GO TO 34
```

```
C
 4          DO 44 J=1,3
            DO 44 I=1,2
            DO 44 K=1,2
            SK(J,I,K)=SKI(J,I,K)
            DO 44 L=1,6
 44         C(L,J,I,K)=CI(L,J,I,K)
C
 34         WRITE(6,10)
            WRITE(6,INPUT)
            WRITE(6,CSK)
C
            CALL ACCUM2(SLA,LA,VAO)
C
C       DETERMINE THE NUMBER OF TIME POINTS FOR WHICH SOLUTIONS ARE
C       DESIRED.
C
            NT=(TMAX-TMIN)/DT+1.
            CALL CLOCK
            DO 25 INT=1,NT          B LOOPS THROUGH TIME
            TFLGHT=DT*(INT-1)+TMIN
C
C       IF KCECO=0, THE CENTER ENGINE IS CUT OFF.
C
            KCECO=0
            IF(TFLGHT.LE.TCECO)KCECO=1
C
C       OBTAIN SUCTION LINE, PUMP, AND TANK DATA FOR CURRENT FLIGHT TIME.
C
            CALL DATA(TFLGHT,ASO,ASF,MU,D,TN,E,PVCD,PVCTH,PVCE,
     .      KCECO,A,PVCA,MO,MF,MTO,MTF,PAOS,PAFS,RHO,CDO,CDF,V,CF,
     .      SA,PVCSA)
C
C       KA IS THE ELASTANCE OR STIFFNESS OF GAS IN THE ACCUMULATOR.
C
            DO 1 K=1,2
            KA(1,K)=SKA(1,K)*PAOS(K)/(VAO(1,K)*RHO(1,K))
 1          KA(2,K)=SKA(2,K)*PAFS(K)/(VAO(2,K)*RHO(2,K))
C
C
C       OBTAIN STRUCTURAL DATA FOR THIS FLIGHT TIME.
C
            CALL STRCT2(TFLGHT,TCECO,OMGA,ZETA,MP,MTO,MTF,MCOMBO)
C
C       I COUNTS THE FREQUENCIES FOR WHICH SOLUTIONS ARE OBTAINED
C       FOR THIS FLIGHT TIME.
C       ICRS COUNTS THE FREQUENCIES CORRESPONDING TO ZERO PHASE GAINS.
C
            I=1
            ICRS=0
C
            DO 17 NO=1,NFRQNC       B LOOPS THROUGH FREQUENCIES
            DDOMGA=DOMGA(NO)
            OMEGA(I)=OMGAMN(NO)
C
C       SUB1 DEFINES THE COEFFICIENT MATRIX AND RETURNS NUMERICAL SOLUTIONS.
C
            CALL SUB1
```

```
C
                IF(OMGAMX(NO)-OMGAMN(NO).LT.1.E.35)IND=1
C
C       SUB3 AND SUB4 STORE SOLUTIONS FOR PRINTING AND PLOTTING.
C
 2              CALL SUB4
                IF(INDPNT.EQ.2)CALL SUB3
C
C       IF IND=1, ALL SOLUTIONS HAVE BEEN OBTAINED FOR THIS TIME.
C
 5              IF(IND.EQ.1)GO TO 17
C
C       RETAIN THE VALUE OF THE THRUST OUTPUT AND ITS AMPLITUDE.
C
                TOUTKP=TOPRNT
                AMPKP=ABS(TOUTKP)
C
C       DOES THE NUMBER OF FREQUENCIES EXCEED THE MAXIMUM?
C
                IF(I.GE.NOMEGA)GO TO 16
C
                I=I+1
 6              OMEGA(I)=OMEGA(I-1)+DDOMGA-INDOM*OMFIX
                INDOM=0
C
C       HAVE ALL FREQUENCIES BEEN CONSIDERED?
C
                IF(OMEGA(I).LT.OMGAMX(NO)-1.E-5 )GO TO 7
                OMEGA(I)=OMGAMX(NO)
                IND=1
C
 7              CALL SUB1
C
C       IF KSLCO=1, FIND OUT IF THERE HAS BEEN A ZERO PHASE CROSSING.  IF
C       SO, CHANGE THE FREQUENCY STEP SIZE AND DETERMINE THE FREQUENCY
C       AT WHICH IT OCCURS.
C
                IF(KSLCO.EQ.0)GO TO 2
                AIMKP=AIMAG(TOUTKP)
                IF(AIM*AIMKP)8,2,2
C
 8              RLTKP=REAL(TOUTKP)
                IF(RLT.LT.0..AND.RLTKP.LT.0.)GO TO 155
                IF(AMPKP.LT.1.E.3)GO TO 82
                IF(ABS(ATOPRT/AMPKP-1.).LT.1.E-3)GO TO 83
C
 81             DDOMGA=.5*DDOMGA
                IND=0
                GO TO 6
 82             IF(ATOPRT.LT.1.E-3)GO TO 9
                IF(ABS(AMPKP/ATOPRT-1.).GT.1.E-3)GO TO 81
C
C
 83             IF(ABS(RLT).LT.1.E-36.OR.ABS(RLTKP).LT.1.E-36)GO TO 81
                IF(ABS(AIM/RLT).GT..05.OR.ABS(AIMKP/RLTKP).GT..05)GO TO
                81
C
 9              ICRS=ICRS+1
```

```
      IF(AIN-AINKP)91,92,92
C
C     STORE THE AMPLITUDE (DB) OF THE ZERO PHASE GAIN AND THE FREQUENCY.
C
 91   OMGCRS(ICRS)=OMEGA(I)
      ATCRS(ICRS)=20.0*ALOG10(ATOPRT)
      GO TO 93
C
 92   OMGCRS(ICRS)=OMEGA(I-1)
      ATCRS(ICRS)=20.0*ALOG10(AMPKP)
C
 93   CALL SUB4
      IF(INDPNT.EQ.2)CALL SUB3
C
 13   IF(IND.EQ.1)GO TO 17
C
      I=I+1
      OMEGA(I)=OMEGA(I-1)+DDOMGA
      IF(OMEGA(I).LT.OMGAMX(NO)-1.E-10)GO TO 14
      OMEGA(I)=OMGAMX(NO)
      IND=1
C
 14   CALL SUB1
C
C     RESET THE FREQUENCY STEP SIZE TO ITS INITIAL VALUE.
C
 150  DDOMGA=DOMGA(NO)
C
C     OMFIX IS USED TO OBTAIN THE NEXT LARGEST FREQUENCY CONGRUENT TO
C     THE ORIGINAL STEP SIZE.
C
      OMFIX=AMOD(OMEGA(I),DDOMGA)
      INDOM=1
      GO TO 2
C
 16   WRITE(6,20)
 17   IND=0
C
C
C
      WRITE(6,30)TFLGHT
      WRITE(6,OUTPUT)
      WRITE(6,40)
C
      IF(ICRS.EQ.0)GO TO (19,22),INDPNT
C
C     PRINT ZERO PHASE CROSSINGS.
C
      IF(ICRS.EQ.1)GO TO 109
      ICRS02=ICRS/2
      DO 18 J=1,ICRS02
      JPI=J+ICRS02
 18   WRITE(6,50)((OMGCRS(JJ),ATCRS(JJ)),JJ=J,JPI,ICRS02)
      IF(ICRS02*2.EQ.ICRS)GO TO (19,22),INDPNT
 109  WRITE(6,110)OMGCRS(ICRS),ATCRS(ICRS)
C
      GO TO (19,22),INDPNT
C
```

```
C       PRINT THRUST OUTPUTS.
C
 19             WRITE(6,60)
                JX=I/2
                JXX=JX*2+1
                DO 21 II=1,JX
 21             WRITE(6,70)((OMEGA(II+JX*J),ATOUTI(II+JX*J),
     .          PTOUTI(II+JX*J),ATOUTO(II+JX*J),PTOUTO(II+JX*J)),J=0,1)
     .          IF(JXX.LE.I)WRITE(6,60)((OMEGA(J),ATOUTI(J),PTOUTI(J),
     .          ATOUTO(J),PTOUTO(J)),J=JXX,I)
                GO TO 233
C
C       PRINT ALL SOLUTIONS OF THE SYSTEM.
C
 22             DO 23 JQ=1,10
                JX=(JQ-1)*4+1
                JXX=MINO(JX+3,39)
                WRITE(6,90)(TITLE(J),J=JX,JXX)
                DO 23 II=1,I
 23             WRITE(6,100)OMEGA(II),((ASOLKP(II,J),PSOLKP(II,J)),
     .                      J=JX,JXX)
C
C       PRINT TRANSFER FUNCTION VALUES.
C
 233            WRITE(6,90)(TITLE(J),J=39,42)
                DO 234 II=1,I
 234            WRITE(6,100)OMEGA(II),((ASOLKP(II,J),PSOLKP(II,J)),
     .          J=39,42)
C
C       MAKE NYQUIST PLOTS.
C
 24             IF(INDPLT.EQ.0)GO TO 25
                CALL POGPLT(TFLGHT,RTOUTO,CTOUTO,1,1,5,26,NCHAR,
     .          1,2,-2,2,2,2,-2,2,
     .                 'BELLCOMM POGO 2A ... THRUST OUTPUT                  ',
     .                 'IMAGINARY PART OF TOUT                              ',
     .                 'REAL PART OF TOUT                                   ')
C
 25             CALL CLOCK
                CALL EOFTV
                GO TO 256
 255            WRITE(6,120)TCPCO
 256            CALL EXIT
C
C
 10             FORMAT(1H1)
 20             FORMAT(1H ,'NUMBER OF FREQUENCIES EXCEEDED')
 30             FORMAT(1H1,'TIME OF FLIGHT ... ',F9.3,' SECONDS')
 40             FORMAT(1H0,1X,2('FREQUENCY',9X,'ZERO PHASE GAIN',15X)/
     .          1H ,3X,'(HZ)',10X,'(DB)',22X,'(HZ)',10X,'(DB)')
 50             FORMAT(1H ,F11.5,7X,E16.8,19X,F11.5,7X,E16.8)
 60             FORMAT(1H0,2(1X,'FREQUENCY',15X,'TI',19X,'TOPRNT',
     .          ,10X)/1H ,2(3X,'(HZ)',8X,
     .          'AMPLITUDE  PHASE ANGLE   AMPLITUDE  PHASE ANGLE',2X))
 70             FORMAT(1H ,0PF11.5,3X,1P2E11.4,3X,1P2E11.4,3X,
     .                     0PF11.5,3X,1P2E11.4,3X,1P2E11.4)
 80             FORMAT(1H ,64X,0PF11.5,3X,1P2E11.4,3X,1P2E11.4)
 90             FORMAT(1H0,3X,'FREQUENCY',15X,A6,3(23X,A6)/1H ,6X,'(HZ)',
```

```
     .          7X,4('AMPLITUDE PHASE ANGLE',9X))
 100            FORMAT(1H ,F11.5,4X,4(1P2E11.4,0X))
 110            FORMAT(1H ,48X,F11.5,7X,E16.8)
 120            FORMAT(1H ,'TCECO=',F11.3,
     .          ' IS NOT CONSISTENT WITH CURRENT STANDPIPE HEIGHT')
C
C       SUBROUTINES ...
C
C       DEFINE THE COEFFICIENT MATRIX AND SOLVE THE SYSTEM ...
C
                SUBROUTINE SUB1
                OMEG=OMEGA(I)*TWOPI
                CALL PHTRX2(OMEG,P,NRP,NCP)
                IF(HPRNT.EQ.0)GO TO 104
                WRITE(6,102)
                DO 101 J=1,NRP
 101            WRITE(6,103)J,(P(J,JJ),JJ=1,NCP)
 102            FORMAT(1H1,36X,'BASIC LINEARIZED POGO MODEL 2 COEFFICIENT
     . MATRIX'/1H ,'ROW')
 103            FORMAT(//1H ,I2,2X,4(1P2E11.4,'J',3X),1P2E11.4,'J'/
     .          (1H ,4X,1P2E11.4,'J',3X,1P2E11.4,'J',3X,1P2E11.4,'J',
     .          3X,1P2E11.4,'J',3X,1P2E11.4,'J'))
 104            CALL SOLVEQ(P,NRP,NCP,AMP,PHSANG)
                TOPRNT=TOUT*KIEOL*TIOUT
                IF(KCRNT.EQ.1)TOPRNT=-5.*(ASP(1)*P(3,NCP)+2.*ASP(1)
     .          *P(13,NCP)+AMP(22,NCP)*OMEG**2)*5.*TIOUT
                ATOPRT=ABS(TOPRNT)
                RLT=REAL(TOPRNT)
                AIM=AIMAG(TOPRNT)
                RETURN
C
C
C       SAVE VALUES OF THE AMPLITUDES AND PHASE ANGLES OF SOLUTIONS OF
C       THE SYSTEM ...
C
                SUBROUTINE SUB3
                DO 301 J=1,36
                ASOLKP(I,J)=AMP(J)
 301            PSOLKP(I,J)=PHSANG(J)*RDTODG
                RETURN
C
C
C       SAVE VALUES OF THE THRUST OUTPUTS AND THE ENGINE TRANSFER FUNCTIONS ...
C
                SUBROUTINE SUB4
                ASOLKP(I,37)=AMP(37)
                PSOLKP(I,37)=PHSANG(37)*RDTODG
                ASOLKP(I,38)=ATOPRT
                PSOLKP(I,38)=0.
                IF(ASOLKP(I,38).GT.1.E-37)PSOLKP(I,38)=ATAN2(
     .          AIM,RLT)*RDTODG
                COT=(OMEGA(I)*TWOPI)**2
                DENOM1=AMP(22)*COT
                DENOM2=AMP(25)*COT
                ASOLKP(I,39)=AMP(3 )/DENOM1
                ASOLKP(I,40)=AMP(7 )/DENOM2
                ASOLKP(I,41)=AMP(13)/DENOM1
                ASOLKP(I,42)=AMP(19)/DENOM2
```

```
      PSOLKP(I,39)=(PHSANG(3 )-PHSANG(22))*RDTODG
      PSOLKP(I,40)=(PHSANG(7 )-PHSANG(25))*RDTODG
      PSOLKP(I,41)=(PHSANG(13)-PHSANG(32))*RDTODG
      PSOLKP(I,42)=(PHSANG(19)-PHSANG(25))*RDTODG
C
C     SAVE FOR NYQUIST PLOTS ...
C
      RTOUTO(I)=RLT
      CTOUTO(I)=AIM
      RETURN
      END
```

```
@FOR,SI          POGS1C.ACCUM2,.ACCUM2
C
C TITLE          ACCUM2
C
C AUTHOR         C.F. BANICK
C
C DATE           9-9-68
C
C PURPOSE        SUPPLY THE MAIN PROGRAM 'POGS02' WITH THE VALUES OF
C                VARIABLES PERTAINING TO THE ACCUMULATORS IN THE LOX
C                AND FUEL SUCTION LINES.
C
C CALL           CALL ACCUM2(HFA,L,VA)
C
C INPUT          THROUGH CALL LIST ...
C                HFA        HEIGHT OF FLUID IN THE ACCUMULATOR (IN).
C
C OUTPUT         THROUGH CALL LIST ...
C                L          THE PRODUCT OF THE ACCELERATION OF GRAVITY
C                            AND THE INERTANCE OF FLUID IN THE ACCUMULATOR
C                            (1./IN).
C                VA         VOLUME OF GAS IN THE ACCUMULATOR (IN**3).
C
C                            EACH OF THE THREE ARRAYS ABOVE IS DIMENSIONED
C                            2X2.  THE FIRST SUBSCRIPT IS FOR OXIDIZER, FUEL
C                            AND THE SECOND FOR INBOARD, OUTBOARD.
C
C
C
                 SUBROUTINE ACCUM2(HFA,L,VA)
C
                 REAL L(2,2)
C
                 DIMENSION HFA(2,2),VA(2,2),AH(2,2),H(9),A(9),B(9)
C
C       HEIGHT OF FLUID IN THE ACCUMULATOR (IN)
                 DATA H/0.,1.7,3.92,6.13,8.85,12.95,14.48,18.22,19.77/
C
C       CROSS-SECTIONAL AREA OF ACCUMULATOR AS A FUNCTION OF HEIGHT
C       (IN**2)
                 DATA A/18.5,100.,184.,235.,289.,284.,208.,126.,49.5/
C
                 G=386.4          @ IN/SEC**2
C
C       L IS THE INTEGRAL OF THE RECIPROCAL OF THE CROSS-SECTIONAL AREA
C       FROM 0. TO HFA.
C
C       VA IS THE INTEGRAL OF THE CROSS-SECTIONAL AREA FROM HFA TO THE
C       TOTAL ACCUMULATOR HEIGHT.
C
C       METHOD ... SIMPLE SUMMATION OF TRAPEZOIDAL AREAS
C
                 DO 1 I=1,9
  1              B(I)=1./A(I)
C
                 DO 8 K=1,2
                 DO 8 IOF=1,2
                 DO 2 II=2,9
                 I=II
```

```
      IF(HFA(IOF,K).LE.H(II))GO TO 3
 2    CONTINUE
C
 3    SLP=(A(I)-A(I-1))/(H(I)-H(I-1))
      AH(IOF,K)=SLP*(HFA(IOF,K)-H(I-1))+A(I-1)
      VA(IOF,K)=.5*(H(I)-HFA(IOF,K))*(A(I)+AH(IOF,K))
      IF(I.EQ.9)GO TO 5
C
      DO 4 II=I,8
 4    VA(IOF,K)=VA(IOF,K)+.5*(H(II+1)-H(II))*(A(II)+A(II+1))
C
 5    SLP=(B(I)-B(I-1))/(H(I)-H(I-1))
      Y=SLP*(HFA(IOF,K)-H(I-1))+B(I-1)
C
      L(IOF,K)=.5*(HFA(IOF,K)-H(I-1))*(B(I-1)+Y)
      IF(I.EQ.2)GO TO 8
C
      IM2=I-2
      DO 6 II=1,IM2
 6    L(IOF,K)=L(IOF,K)+.5*(H(II+1)-H(II))*(B(II)+B(II+1))
 8    CONTINUE
C
      RETURN
    END
```

```
@FOR,SI          POGSIC.DATA..DATA
C
C TITLE          DATA
C
C AUTHOR         C.F. DANICK
C
C SPONSOR        A. T. ACKERMAN
C
C DATE           9-6-68
C
C PURPOSE        CALCULATES SATURN V SUCTION LINE, PUMP, AND TANK DATA
C                AS A FUNCTION OF TIME.
C
C METHOD         EVALUATION OF ANALYTICAL EXPRESSIONS AND LINEAR
C                INTERPOLATIONS ON EXISTING DATA.
C
C CALL           CALL DATA(TIME,AO,AF,MU,D,TH,E,PVCD,PVCTH,PVCE,KCECO,
C                A,PVCA,MO,MF,MTO,MTF,PAOS,PAFS,RHO,CBO,CDF,V,CF,SA,PVCSA)
C
C INPUT          ALL INPUT IS THROUGH THE CALL LIST ...
C                TIME        FLIGHT TIME FOR WHICH THE DATA WILL BE COMPUTED
C                            (SEC).
C                AO,AF       PUMP INLET AREA FOR EACH OXIDIZER AND FUEL
C                            LINE (IN**2).  THESE ARE CALLED ASO AND ASF
C                            IN THE MAIN PROGRAM 'POGOO'.
C                KCECO       IF KCECO=0, THE CENTER ENGINE IS CUT OFF.
C                            OTHERWISE, KCECO=1.  THE VALUE OF KCECO IS
C                            DETERMINED IN 'POGO2'.
C                            FOR A DESCRIPTION OF ALL OTHER INPUT VARIABLES,
C                            SEE 'POGO2'.
C
C OUTPUT         ALL OUTPUT IS THROUGH THE CALL LIST. SEE 'POGO2' FOR
C                A DESCRIPTION OF ALL OUTPUT VARIABLES.
C
C SUBROUTINE     TABLEB      PERFORMS A LINEAR INTERPOLATION.
C USED
                 SUBROUTINE DATA(TIME,AO,AF,MU,D,TH,E,PVCD,PVCTH,PVCE,
     .           KCECO,A,PVCA,MO,MF,MTO,MTF,PAOS,PAFS,RHO,CBO,CDF,V,
     .           CF,SA,PVCSA)
C
                 REAL MO(2),MF(2),MTO(2),MTF(2),LXMSVT,MU(2),KK
C
                 DIMENSION AO(2),AF(2),A(6,2),D(6,2),TH(6,2),E(6,2),C(2),
     .           RHO(2,2),PAOS(2),PAOT(2),PAFS(2),PAFT(2),CDO(2),CDF(2),
     .           V(6,2),CF(6,2),SA(6,2),TPDNS(6),DNSVTP(6),THASS(3),
     .           LXMSVT(3),FLMSVT(3),
     .           MTOVVL(17),VOLOMT(17),MTFVVL(15),VOLFMT(15),QT(2),
     .           OPOSVT(24),TOPOS(24),FPOSVT(24),TFPOS(24),CDOVPS(10),
     .           POSCBO(10),CDFIVP(5),CDFOVP(5),F1(16),F2(16),F3(16),
     .           POSCDF(5),
     .           ARE(16),SOSVTP(6),THPSOS(6),OXTPVT(10),TTEMP(10),
     .           TAVTMP(10),AVTPVT(10),PVCE(2,2,2),PVCTH(2,2,2),
     .           PVCA(2,2,2),PVCSA(2,2,2),PVCD(2,2,2)
C
                 EQUIVALENCE (THPSOS(1),TPDNS(1))
C
C       TEMPERAYURE USED TO COMPUTE LOX DENSITY (DEGREES RANKINE)
                 DATA TPDNS/5..163.5,164..164.5,165..165.5/
```

```
C
C       LOX DENSITY VS TEMPERATURE (LB/FT**3)
                DATA DNSVTP/5.,71.22,71.15,71.07,70.99,70.91/
C
C       TIME USED TO COMPUTE MASS (SEC)
                DATA TMASS/0.,125.5,151./
C
C       LOX MASS VS TIME (LBS)
                DATA LXMSVT/3060.E3,470.E3,0.E3/
C
C       FUEL MASS VS TIME (LBS)
                DATA FLMSVT/1325.E3,215.E3,91.E3/
C
C       TIME USED TO COMPUTE AVERAGE TEMPERATURE OF THE LOX (SEC)
                DATA TAVYMP/17.,0.,10.,20.,30.,40.,50.,60.,70.,80.,90.,
     .          100.,110.,120.,130.,140.,150.,151./
C
C       LOX AVERAGE TEMPERATURE VS TIME (DEGREES FAHRENHEIT)
                DATA AVTPVT/17.,-295.96,-295.99,-295.90,-295.07,-295.02,
     .          -295.70,-295.72,-295.65,-295.58,-295.49,-295.39,-295.27,
     .          -295.13,-294.98,-294.82,-294.64,-294.6/
C
C       LOX HEIGHT VS VOLUME (IN)
                DATA HTOVVL/16.,0.,10.,20.,40.,60.,80.,100.,150.,200.,
     .          300.,400.,450.,500.,730.,740.,760./     DIN
C
C       VOLUME TO COMPUTE LOX HEIGHT (IN**3)
                DATA VOLHT/16.,0.,60328.,318298.,1227807.,2445204.,
     .          4462603.,6583113.,12530366.,16627598.,30712619.,
     .          67263113.,73337407.,78648343.,80220419.,81318986.,
     .          81650504./    DIN**3
C
C       FUEL HEIGHT VS VOLUME (IN)
                DATA HTFVVL/14.,0.,10.,20.,40.,60.,80.,100.,150.,200.,
     .          350.,400.,450.,500.,510./      DIN
C
C       VOLUME TO COMPUTE FUEL HEIGHT (IN**3)
                DATA VOLFHT/14.,0.,4.,119673.,1017098.,2405565.,4195790.,
     .          6279666.,12198929.,18179952.,36272040.,42275068.,
     .          47499079.,50433735.,50606236./     DIN**3
C
C       TOTAL LOX PUMP INLET PRESSURE VS TIME (PSIA)
                DATA OPOSVT/23.,77.,86.5,91.,94.5,96.,92.,93.,93.5,
     .          94.5,97.,103.,109.,115.,129.5,134.5,109.5,111.,117.,
     .          120.,121.5,120.5,90./
C
C       TIME TO COMPUTE LOX PUMP INLET PRESSURE (SEC)
                DATA TOPOS/23.,0.,2.,10.,20.,30.,40.,50.,55.,60.,65.,
     .          70.,80.,90.,100.,120.,125.5,126.,130.,140.,145.,148.,
     .          150.,151./
C
C       TOTAL FUEL PUMP INLET PRESSURE VS TIME (PSIA)
                DATA FPOSVT/23.,41.8,43.2,42.25,42.1,42.75,42.70,42.50,
     .          42.25,43.3,43.7,44.2,44.7,44.9,45.5,46.4,46.6,46.7,
     .          41.6,41.7,41.9,41.6,40.6,40./
C
C       TIME TO COMPUTE FUEL PUMP INLET PRESSURE (SEC)
                DATA TFPOS/23.,0.,2.,5.,10.,20.,30.,40.,50.,60.,70.,80.,
```

```
     .        90.,96.,100.,110.,120.,125.5,126.,130.,140.,145.,150.,
     .        151./
C
C       TOTAL PRESSURE TO COMPUTE BUBBLE COMPLIANCE (PSIA)
              DATA POSCBO/9.,70.,80.,90.,100.,110.,120.,130.,140.,150./
              DATA POSCBF/4.,36.,43.,49.,53./
C
C       BUBBLE COMPLIANCE VS PRESSURE (IN**2)
              DATA CBOVPS/9.,.16,.14,.1,.08,.07,.06,.05,.043,
     .        .034/
              DATA CBFIVP/4.,.05,.048,.046,.044/
              DATA CBFOVP/4.,.0635,.060,.059,.0565/
C
C       REYNOLDS NUMBERS USED TO COMPUTE FRICTION FACTORS
              DATA ARE/15.,2.E4,4.E4,6.E4,8.E4,1.E5,2.E5,4.E5,6.E5,
     .        8.E5,1.E6,2.E6,4.E6,6.E6,8.E6,1.E7/
C
C       FRICTION FACTORS FOR 20 INCH DIAMETER
              DATA F1/15.,.0260,.0225,.0205,.0195,.0190,.0170,.0150,
     .        .0140,.0135,.013,.0120,.0118,.0116,.0114,.0110/
C
C       FRICTION FACTORS FOR 17 INCH DIAMETER
              DATA F2/15.,.0260,.0225,.0206,.0196,.0194,.0175,.0150,
     .        .0145,.0140,.0135,.0125,.0123,.0121,.0119,.0115/
C
C       FRICTION FACTORS FOR 12 INCH DIAMETER
              DATA F3/15.,.037,.034,.0305,.0215,.0205,.0185,.0171,
     .        .0172,.0169,.0170,.0166,.0163,3*.016/
C
C       LOX SPEED OF SOUND VS TEMPERATURE (FT/SEC)
              DATA SOSVTP/5.,2944.,2932.,2920.,2907.,2893./
C
C       LOX TEMPERATURE VS TIME (DEGREES FAHRENHEIT)
              DATA OXTPVT/9.,-296.4,-296.35,-296.3,-296.25,-296.2,
     .        -296.,-295.6,-295.,-294.6/
C
C       TIME FOR LOX TEMPERATURE (SEC)
              DATA TTEMP/9.,0.,50.,60.,70.,80.,100.,120.,140.,151./
C
              PI=3.1415927
              G=386.4          @ IN/SEC**2
C
C
C       CALCULATE THE CROSS-SECTIONAL AREA OF EACH SEGMENT OF THE
C       SUCTION LINES AND THE PVC'S (IN**2)
C
              DO 4 K=1,2
              DO 5 I=1,6
 5            A(I,K)=.25*PI*D(I,K)**2
              DO 4 I=1,2
              DO 4 J=1,2
 4            PVCA(I,J,K)=.25*PI*PVCD(I,J,K)**2
C
C
C       FUEL PUMP INLET TEMPERATURE (DEGREES RANKINE)
              FTEMP=534.
C
C       CALCULATE THE WEIGHT DENSITY OF THE FUEL (LBS/IN**3)
```

```
C
            RHO(2,1)=(52.30-.0239*(FTEMP-460.))/1728.
            RHO(2,2)=RHO(2,1)
C
C       LOX AVERAGE TEMPERATURE (DEGREES RANKINE)
            OXAVTP=TABLED(AVTPVT,TAVTMP,TIME)+460.
C
C       LOX AVERAGE DENSITY (LB/IN**3)
            RHOOAV=TABLED(DNSVTP,TPDNS,OXAVTP)/1728.
C
C       CALCULATE THE PROPELLANT WEIGHT PER UNIT LENGTH (LBS/IN)
C
            DO 1 I=1,2
            MO(I)=RHOOAV*AO(I)
 1          MF(I)=RHO(2,I)*AF(I)
C
            IF(TIME.LT.THASS(1).OR.TIME.GT.THASS( 3))GO TO 15
            DO 2 I=2,3
            II=I
            IF(TIME.LE.THASS(I))GO TO 3
 2          CONTINUE
C
C       LINEAR INTERPOLATE FOR LOX AND FUEL MASSES (LBS)
C
 3          DT=THASS(II)-THASS(II-1)
            CON=(TIME-THASS(II-1))/DT
C
            OXM=CON*(LXMSVT(II)-LXMSVT(II-1))+LXMSVT(II-1)
            FLM=CON*(FLMSVT(II)-FLMSVT(II-1))+FLMSVT(II-1)
C
C       DETERMINE LOX AND FUEL VOLUMES (IN**3)
C
            VO=(OXM-40911.)/RHOOAV
            VF=(FLM-20509.)/RHO(2,1)
C
C       DETERMINE LOX HEIGHT.
C
            HTOX=TABLED(HTOVVL,VOLOHT,VO)
C
C       DETERMINE PRESSURE PER UNIT ACCELERATION AT TANK BOTTOMS (LBS*
C       SEC**2/IN**2)
C
            HTO(2)=HTOX*RHOOAV/G
            HTOX=HTOX-61.6
            IF(HTOX.LT.0.)HTOX=0.
            HTO(1)=HTOX*RHOOAV/G
C
            HTF(1)=TABLED(HTFVVL,VOLFHT,VF)*RHO(2,1)/G
            HTF(2)=HTF(1)
C
C       DETERMINE THE FLOW RATES (LBS/SEC)
C
            DENOM=4.*KCECO
            QT(1)=.5*(LXMSVT(II-1)-LXMSVT(II))/(DT*DENOM)
            QT(2)=.5*(FLMSVT(II-1)-FLMSVT(II))/(DT*DENOM)
C
C       CALCULATE THE TOTAL PUMP INLET PRESSURE (PSIA)
C
```

```
      PAOT(1)=TABLEB(OPOSVT,TOPOS,TIME)
      PAOT(2)=PAOT(1)*2.
      PAFT(1)=TABLEB(FPOSVT,TFPOS,TIME)
      PAFT(2)=PAFT(1)*2.5
C
C     CALCULATE THE BUBBLE COMPLIANCE OF THE FLUIDS (IN**2)
C
      CBO(1)=TABLEB(CBOVPS,POSCBO,PAOT(1))
      CBO(2)=TABLEB(CBOVPS,POSCBO,PAOT(2))
      CBF(1)=TABLEB(CBFIVP,POSCBF,PAFT(1))
      CBF(2)=TABLEB(CBFOVP,POSCBF,PAFT(2))
C
C     DETERMINE STATIC PRESSURE FROM TOTAL PRESSURE
C
      PAOS(1)=PAOT(1)*10.
      PAOS(2)=PAOT(2)*10.
      PAFS(1)=PAFT(1)*3.
      PAFS(2)=PAFT(2)*3.
C
C     DETERMINE LOX TEMPERATURE AND DENSITY (DEGREES RANKINE, LBS/
C     IN**3)
      OXTEMP=TABLEB(OXTPVT,TTEMP,TIME)*460.
      RHO(1,1)=TABLEB(DNSVTP,TPDNS,OXTEMP)/1728.
      RHO(1,2)=RHO(1,1)
C
C     CALCULATE THE VELOCITY OF FLUID IN THE SEGMENTS (IN/SEC)
C
      DO 7 K=1,2
      DO 6 I=1,5
6     V(I,K)=QT(1)/(RHO(1,K)*A(I,K))
7     V(6,K)=QT(2)/(RHO(2,K)*A(6,K))
C
C     DETERMINE THE FRICTIONAL COEFFICIENT OF EACH SEGMENT
C
      DO 11 I=1,6
      IJ=I/6+1
      DO 11 K=1,2
      J=D(I,K)*17.
C
C     ... CALCULATE THE REYNOLDS NUMBER CORRESPONDING TO THIS SEGMENT
C
      RE=4.*QT(IJ)/(MU(IJ)*PI*D(I,K))
      IF(J)10,9,8
C
C     ... DETERMINE THE FRICTION FACTOR OF THE SEGMENT
C
8     F=TABLEB(F1,ARE,RE)
      GO TO 11
C
9     F=TABLEB(F2,ARE,RE)
      GO TO 11
C
10    F=TABLEB(F3,ARE,RE)
C
C     ... FRICTION COEFFICIENT
C
11    CF(I,K)=F/(D(I,K)*G)
      CF(3,1)=CF(3,1)**DS/386.4
```

```
            CF(3,2)=CF(3,2)+.05/386.4
C
C       DETERMINE THE SPEED OF SOUND IN THE LOX AND FUEL (IN/SEC)
C
            C(1)=12.*TABLED(SOSVTP,TMPSOS,OXTEMP)
            C(2)=-62.*FTEMP+96180.
C
C       DETERMINE THE WAVE SPEEDS IN EACH SECTION OF THE LOX AND FUEL
C       LINES AND IN THE PVC'S (IN/SEC)
C
            DO 14 K=1,2
            DO 14 I=1,2
            KK=C(I)**2*RHO(I,K)/G
            JJ=I*4*(I-1)          @JJ=1,6
            JJJ=I*4               @JJJ=5,6
C
            DO 13 J=JJ,JJJ
 13         SA(J,K)=C(I)/SQRT(1.+D(J,K)*KK/(TH(J,K)*E(J,K)))
C
            DO 14 J=1,2
            PVCSA(J,I,K)=C(I)/SQRT(1.+PVCD(J,I,K)*KK/(PVCTH(J,I,K)*
            PVCE(J,I,K)))
 14         CONTINUE
            RETURN
C
 15         WRITE(6,20)TIME
C
            RETURN
 20         FORMAT(1H ,'TIME=',F8.3,' IS OUTSIDE THE RANGE')
      END
```

```
@FOR,SI          POGS1C.POGPLT,.POGPLT
C
C       TO USE--
C
C       CALL POGPLT(TFLGHT,X,Y,NP,ND,NDD,NCHARN,NCHAR,NOVER,NX,XL,XR,
C                NY,YL,YU,TOPTTL,SIDTTL,BOTTTL)
C
C          WHERE-
C
C               TFLGHT = FLIGHT TIME WHICH WILL APPEAR ON THE PLOT
C               X = THE X-ARRAY OF VALUES (ORDERED)
C
C               Y = THE Y-ARRAY OF VALUES
C
C               NP - NUMBER OF (X,Y) VALUES
C
C               ND - DENSITY OF POINTS TO BE PLOTTED WITH DOTS
C                    IF ND=3, EVERY THIRD POINT WILL BE PLOTTED
C
C               NDD - DENSITY OF POINTS TO BE PLOTTED WITH CHARACTERS
C                     IN THE NCHAR ARRAY
C                     NDD MUST BE A MULTIPLE OF ND
C
C               NCHARN - NUMBER OF ELEMENTS IN THE ARRAY NCHAR
C
C               NCHAR -   ARRAY OF CHARACTERS TO BE PLOTTED
C
C               NOVER - IF NOVER=1, A NEW FRAME IS PLOTTED
C                     - IF NOVER=2, AN OVERLAY OF THE PREVIOUS FRAME IS
C                         PRODUCED (IF NOVER IS 2, THAN NONE OF THE
C                         FOLLOWING ARGUMENTS NEED BE INCLUDED)
C
C               NX - IF NX=1, THE PROGRAM WILL USE XMIN AND XMAX TO
C                            SCALE THE ABSCISSA
C                    IF NX=2, THE PROGRAM WILL SEARCH THE X-ARRAY FOR
C                            THE MINIMUM AND MAXIMUM VALUES
C
C               XL   - VALUE TO BE ASSIGNED TO THE LEFT-HAND SIDE OF THE
C                      GRID(ABSCISSA)(IF NX=2, THIS IS A DUMMY)
C
C               XR   - VALUE TO BE ASSIGNED TO THE RIGHT-HAND SIDE OF THE
C                      GRID(ABSCISSA)(IF NX=2, THIS IS A DUMMY)
C
C               NY - IF NY=1, PROGRAM WILL USE YMIN AND YMAX TO SCALE THE
C                            ABSCISSA.
C                    IF NY=2, PROGRAM WILL SEARCH THE Y-ARRAY FOR THE
C                            MINIMUM AND MAXIMUM VALUES.
C
C               YL   - VALUE TO BE ASSIGNED TO LOWER BOUND OF GRID
C                      (ORDINATE) (IF NY=2, THIS IS A DUMMY)
C
C               YU   - VALUE TO BE ASSIGNED TO THE UPPER BOUND OF THE
C                      GRID (ORDINATE) (IF NY=2, THIS IS A DUMMY)
C
C               TOPTTL - A 48 CHARACTER LABEL TO BE DISPLAYED AT THE TOP
C                        THE GRAPH.
C
C               SIDTTL - A 48-CHARACTER LABEL TO BE DISPLAYED ALONG THE
```

```
C                    ORDINATE AXIS
C
C          BOTTTL - A 48-CHARACTER LABEL TO BE DISPLAYED ALONG THE
C                   ABSCISSA.
C
C     IT IS ALSO NECESSARY THAT A CALL TO 'CAMRAV' WITH A DUMMY
C     ARGUMENT          ( CALL CAMRAV(935) )
C          BE MADE PRIOR TO PLOTTING A SERIES OF GRAPHS, AND A
C          CALL TO 'EOPTV' BE MADE AFTER THE PLOTTING HAS BEEN
C          COMPLETED.
C
C   THE PROGRAM USES A SUBROUTINE (RETURN) THAT ALLOWS THE USER TO
C   SHORTEN HIS CALLING SEQUENCE ON OVERLAYS.  THIS ROUTINE IS
C   AVAILABLE ON $WMK.. (UNDER THE NAME FOR5AL/CODE)
C
C     TAPE REQUIREMENTS (FOR UNIVAC EXEC II.)
C
C          (1) $SCPLT MUST BE BROUGHT ONTO THE 'PCF'
C
C          (2) A MESSAGE SHOULD BE DISPLAYED OF THE ORDER
C               'I (NAME) NEED A SCRATCH TAPE, THIS TAPE WILL BE
C                    A PLOT TAPE, AND I SHALL PLOT ON IT'
C
C          (3) ASSIGN A TAPE TO 'J'
C                ('7-8'T       ASG       J)
C
C          (4) FILL OUT A PLOT REQUEST FORM (ESTIMATE NUMBER OF
C                    PLOTS)
C
C   ***********************************************************************
C
          SUBROUTINE POGPLT(IFLGHT,X,Y,NP,ND,NDO,NCHARN,NCHAR,
          NOVER,NX,XL,XR,NY,YL,YU,TOPTTL,SIDTTL,BOTTTL)
C
          DIMENSION X(1),Y(1),TOPTTL(8),SIDTTL(8),BOTTTL(8),
          NCHAR(1)
C
          IF(NOVER.EQ.2)GO TO 100
C
          IF(NX.EQ.1)GO TO 40
C
C   FIND MINIMUM AND MAXIMUM OF X-ARRAY
C
          XMIN=X(1)
          XMAX=X(1)
          NI=ND+1
          DO 10 J=NI,NP,ND
          XMAX=AMAX1(XMAX,X(J))
 10       XMIN=AMIN1(XMIN,X(J))
C
C
          GO TO 41
C
 40       CONTINUE
C
          XMAX=XR
          XMIN=XL
C
```

```
 41          CONTINUE
C
             IF(NY.EQ.1)GO TO 60
C
C       FIND MINIMUM AND MAXIMUM OF Y-ARRAY
C
             YMIN=Y(1)
             YMAX=Y(1)
             NI=ND+1
             DO 50 J=N1,NP,ND
             YMIN=AMIN1(YMIN,Y(J))
 50          YMAX=AMAX1(YMAX,Y(J))
C
C
             GO TO 61
C
 60          CONTINUE
C
             YMAX=YU
             YMIN=YL
C
 61          CONTINUE
C
C       SET UP SCALE FACTORS FOR ABSCISSA AND ORDINATE
C
             XMIN=AMIN1(XMIN,YMIN)
             XMAX=AMAX1(XMAX,YMAX)
             IF(ABS(XMAX)-ABS(XMIN))2,1,1
 1           XMAX=AMAX1(.1,XMAX)
             GO TO 3
 2           XMIN=AMIN1(-.1,XMIN)
 3           YMIN=XMIN
             YMAX=XMAX
             WRITE(6,901)XMIN,XMAX,YMIN,YMAX
 901         FORMAT(5X,4E16.3)
C
C       FORCE LABELS TO BE IN SCIENTIFIC NOTATION AND LIMIT TO FOUR (4)
C       SIGNIFICANT FIGURES
C
             NXX=-4
             NYY=-4
             DX=.1
             DY=.1
C
C       SET UP GRID
C
             CALL GRID1V(NOVER,XMIN,XMAX,YMIN,YMAX,DX,DY,-0,-0,-1,-1,
             NXX,NYY)
C
C       WRITE LABELS
C
             CALL RITE2V(90,1010,1023,90,1,48,1,TOPTTL,NLAST1)
             CALL RITE2V(10,30,1023,180,1,48,1,SIDTTL,NLAST2)
             CALL RITE2V(90,10,1023,90,1,48,1,BOTTTL,NLAST3)
C
             CALL PRINTV(-12,12HFLIGHT TIME=,510,0)
             CALL LABLV(TFLGHT,600,0,5,1,3)
 100         CONTINUE
```

```
C
C       PLOT POINTS
C
              CALL APLOTV(NP,X,Y,ND,ND,1,44,IERR3)
              CALL APROTV(NP,X,Y,NDD,NDD,NCHARN,NCHAR,3,3,IERR3)
C
C       DRAW LINES BETWEEN THE POINTS
C
              IX1=NXV(X(1))
              IY1=NYV(Y(1))
              NDP1=ND+1
              DO 200 J=NDP1,NP,ND
              IX2=NXV(X(J))
              IY2=NYV(Y(J))
              CALL LINEV(IX1,IY1,IX2,IY2)
              CALL LINEV(IX1,IY1,IX2,IY2)
              IX1=IX2
 200          IY1=IY2
C
C       WRITE OUT ERROR VALUES
C
              WRITE(6,900)IERR3,NLAST1,NLAST2,NLAST3
 900          FORMAT(' ',T10,'IERR3= ',I3,5X
             'NLAST1=',I3,5X,'NLAST2=',I3,5X,'NLAST3=',I3//)
C
              RETURN
C
        END
```

```
@FOR.SI          POGS1C.PHTRX2,.PHTRX2
C
C TITLE          BELLCOMM II POGO MODEL COEFFICIENT MATRIX
C
C AUTHOR         C.F. BANICK
C
C DATE           9-4-68
C
C PURPOSE        DEFINE THE COEFFICIENT MATRIX OF THE LINEAR SYSTEM WHICH
C                MODELS THE SATURN V 'POGO' PHENOMENON.
C
C CALL           CALL PHTRX2(OMEGA,P,NRP,NCP)
C
C INPUT          THROUGH CALL LIST ...
C                OMEGA      FREQUENCY FOR WHICH THE MATRIX WILL BE DEFINED
C                           (RADIANS).
C                NRP,NCP    THE COEFFICIENT MATRIX IS DIMENSIONED NRP X NCP.
C                           ALL OF THE REMAINING VARIABLES ARE SUPPLIED
C                THROUGH THE COMMON BLOCK 'PH2'.  A DESCRIPTION OF ALL OF
C                THESE CAN BE FOUND IN THE MAIN PROGRAM 'POGO2'.
C
C OUTPUT         THROUGH CALL LIST ...
C                P          THE MATRIX OF COEFFICIENTS DEFINED FOR ONE
C                           FLIGHT TIME AND ONE FREQUENCY.
C
C SUBROUTINES    PVC        DEFINES THE MATRICES USED TO MODEL THE PVC'S.
C USED
C                           SUBHH AND SUBRA ARE INTERNAL ROUTINES USED TO
C                           MULTIPLY AND ADD TWO COMPLEX 2X2 MATRICES.
C
                 SUBROUTINE PHTRX2(OMEGA,P,NRP,NCP)
C
                 COMPLEX P(NRP,NCP),S,GAMMA,Z,CSL,SKP,CKP,B1,B2,SUM1,SUM2,
     .           CON(2),ONEOVZ,KS(3,2,2),YK,CE(2,2),Y(2,2,9),YW(2,2,9),
     .           Y710(2,2,2,2),YW710(2,2,2,2),YWOW(2,2),TEMPH(2,2),
     .           TEMP(2,2),Y71(2,2),CCON,COERC
C
                 REAL KA,HTO,HTF,LA,HP,HO,HF
C
C       PH2 IS SHARED BY PHTRX2 AND POGO2.
C
                 COMMON /PH2/G,CP(6,2),V(6,2),SA(6,2),A(6,2),SL(6,2),
     .           C1(6,2),RHO(2,3),T(6,2),LA(2,2),KA(2,2),ALPHA(2,2),
     .           BETA(2,2),SLA(2,2),TA(2),KSLCO,KCECO,ASO(2),ASF(2),
     .           ZETA(9),OMGA(9),
     .           HP(10,2),HTO(10,2),HTF(10,2),HGOHGO(10),HTO(2),HTF(2),
     .           C(6,3,2,2),SK(3,2,2),KSLNL,CBO(2),CBF(2),HO(2),HF(2),
     .           HP,PVCSL(2,2,2),PVCKS(2,2),PVCSKG,PVCT(2,2),PVCA(2,2,2),
     .           PVCSA(2,2,2),KDC2A,KIEOL,KCENP
C
                 S=CMPLX(0.,OMEGA)
                 DGTORD=3.1415927/180.
C
                 DO 1 I=1,NRP
                 DO 1 J=1,NCP
  1              P(I,J)=0.
C
C       FILL THE FIRST 12 ROWS (THRU STATEMENT 80).
```

```
C
C         PVC MATRICES ...
C
              CALL PVC(OMEGA,PVCSL,PVCA,PVCSA,PVCT,PVCKS,PVCSKG,RHO,MO,
     .        MF,KBC2A,Y710,YW710)
C
C         ACCUMULATOR MATRICES ...
C
              DO 3 K=1,2                    @ LOOPS THROUGH INBOARD, OUTBOARD
C
              DO 12 IK=1,2                  @ LOOPS THROUGH OXIDIZER, FUEL
              IJ=4*IK+1
              YK=1./(KA(IK,K)/S+S*LA(IK,K)/G)
              CON(IK)=-RHO(IK,K)*SLA(IK,K)*YK*S**2/G
              Y(1,1,IJ)=-1.
              Y(2,1,IJ)=YK
 12           Y(2,2,IJ)=-1.
C
C         ACCUMULATOR WALL MOTION MATRICES ...
C
              YW(2,1,5)=CON(1)*TA(K)
              YW(2,2,5)=CON(1)*(1.-TA(K))
              YW(2,1,9)=CON(2)
C
C       OXIDIZER AND FUEL SUCTION LINE MATRICES ...
C
              DO 2 I=1,6
              NY=I+(I/5)*(I-4)        @ NY=1,2,3,4,6,8
C
              CFV=CF(I,K)*V(I,K)
              GAMMA=S/SA(I,K)*SQRT(1.+G*CFV/S)
              Z=GAMMA*SA(I,K)**2/(G*A(I,K)*S)
C
              GSL=GAMMA*SL(I,K)
              SKP=SINH(GSL)
              CKP=COSH(GSL)
C
              J=I/6+1
              COEFC=2.*V(I,K)/(RHO(J,K)*A(I,K)*Z)
              Y(1,1,NY)=-CKP*C1(I,K)*SKP*COEFC
              Y(1,2,NY)=Z*(SKP*C1(I,K)+CKP*COEFC)
              Y(2,1,NY)=SKP/Z
              Y(2,2,NY)=-CKP
C
C       OXIDIZER AND FUEL SUCTION LINE WALL MOTION MATRICES ...
C
              CFV=-CFV*RHO(I,K)/(S*CFV*G)*G*A(I,K)*S
              B2=CFV*(1.-CKP)
              B1=CFV*Z*SKP-2.*C1(I,K)*V(I,K)*(1.+B2/(RHO(J,K)*A(I,K)))
     .        *S
C
              YW(1,1,NY)=-T(I,K)*B1
              YW(1,2,NY)=(T(I,K)+1.)*B1
              YW(2,1,NY)=-T(I,K)*B2
              YW(2,2,NY)=(T(I,K)+1.)*B2
 2            CONTINUE
C
C       COLLAPSE OXIDIZER LINES.
```

```
C
            DO 33 II=1,2
            DO 33 JJ=1,2
            YWOW(II,JJ)=YW710(II,JJ,1,K)
            Y(II,JJ,7)=Y710(II,JJ,1,K)
 33         TEMPM(II,JJ)=0.
C
            TEMPM(1,1)=1.
            TEMPM(2,2)=1.
C
            DO 55 JJ=7,2,-1
            CALL SUBMM(TEMPM,Y(1,1,JJ),TEMP)
            DO 44 II=1,2
            DO 44 KK=1,2
 44         TEMPM(II,KK)=-TEMP(II,KK)
            CALL SUBMM(TEMPM,YW(1,1,JJ-1),TEMP)
C
C       Y71 RELATES OUTPUTS OF OXIDIZER PVC TO INPUTS OF THE FIRST
C       SECTION OF THE OXIDIZER LINE. YWOW ACCOUNTS FOR TOTAL ENERGY
C       LOSSES DUE TO SUCTION LINE WALL MOTION.
C
 55         CALL SUBMA(YWOW,TEMP,YWOW)
C
            CALL SUBMM(TEMPM,Y(1,1,1),Y71)
            CALL SUBMM(Y(1,1,9),Y710(1,1,3,K),TEMP)
            CALL SUBMM(Y(1,1,9),Y710(1,1,2,K),TEMPM)
C
            DO 66 NR=1,2
            DO 66 NC=1,2
            IR=2*K+2+NR              @ IR=1,3
            IC=4*K+4+NC              @ IC=1,5
            P(IR,IC)=Y71(NR,NC)
            P(IR,IC+21-K)=YWOW(NR,NC)
C
            IR=4*K+NR                @ IR=5,9
            IC=6*K+2+NC              @ IC=9,15
            JC=18+3*K+NC             @ JC=22,25
C
C
C       FUEL SUCTION LINE MATRICES ...
C
            P(IR,IC)=Y(NR,NC,8)
            P(IR,JC)=YW(NR,NC,8)
C
C       FUEL PVC AND ACCUMULATOR MATRICES ...
C
            P(IR+2,IC+2)=-TEMPM(NR,NC)
 66         P(IR+2,JC)=YW(NR,NC,9)-TEMP(NR,NC)
 3          CONTINUE
C
            DO 77 I=1,4
            J=I+2+(I/3)*2            @ J=3,4,7,8
 77         P(I,J)=1.
            DO 88 I=5,12
            J=I+6+2*(I/9)            @ J=11,12,13,14,17,18,19,20
 88         P(I,J)=1.
C
C       FILL ROWS 13 THRU 20 (THRU STATEMENT 5).
```

```
C
C         STRUCTURAL EQUATIONS ...
C
              CCON=0.
              DO 4 I=1,10
              IR=I+12
              IC=I+26
C
              KKSLCO=KSLCO
              IF(KIEOL.EQ.1)KKSLCO=1
              CCC=HP(I,1)/HP(I,2)
              CC=CCC*(1-KCENP)
C
              P(IR,3 )=CC*ASO(1)*KSLCO
              P(IR,7 )=4.*KSLCO*ASO(2)
              P(IR,13)=2.*CC*ASF(1)*KSLCO
              P(IR,19)=0.*KSLCO*ASF(2)
              P(IR,22)=CC*HP*S**2*KSLCO
              P(IR,25)=4.*HP*KSLCO*S**2
C
              IF(I.NE.1)CCON=2.*ZETA(I-1)*OMGA(I-1)*S*OMGA(I-1)**2
              ONEOVZ=HGONEQ(I)/(S**2+CCON)
              Z=1.E10
              IF(ABS(ONEOVZ).GT.1.E-34)Z=1./ONEOVZ
C
              P(IR,IC)=Z
              P(IR,37)=-CC*(1.-KIEOL)*KKSLCO
              P(IR,NCP)=.8*(1.-KCENP)-.2*(KIEOL-1)*.2*CCC*KKSLCO*KIEOL
C
              DO 4 K=1,2
              IR=20+3*K
              P(IR,IC)=-HTO(I,K)
              P(IR+1,IC)=-HP(I,K)
 4            P(IR+2,IC)=-HTF(I,K)
C
              DO 5 I=23,28
 5            P(I,I-2)=1.
C
C
C       FILL ROWS 29 THRU 32
C
C          TANK BOTTOM PRESSURE EQUATIONS ...
C
              DO 6 I=1,2
              IR=28+I
              IC=16+I+3
              P(IR,IC)=-KSLCO*S**2*HTO(I)
 6            P(IR+2,IC+2)=-KSLCO*S**2*HTF(I)
              P(29,1 )=1.
              P(30,5 )=1.
              P(31,9 )=1.
              P(32,15)=1.
C
C       FILL ROWS 33 THRU 38
C
C          ENGINE TRANSFER FUNCTIONS ...
C
              DO 9 I=1,3
```

```
      DO 9 J=1,2
      DO 9 K=1,2
      SUM1=1.
      DO 7 L=1,2
7     SUM1=SUM1+C(L,I,J,K)*S**L
      SUM2=1.
      DO 8 L=3,6
8     SUM2=SUM2+C(L,I,J,K)*S**(L-2)
9     KS(I,J,K)=SK(I,J,K)*SUM1/SUM2
C
      DO 11 J=1,2
      DO 11 K=1,2
11    CE(J,K)=CMPLX(0.,ALPHA(J,K)*DGTORD+OMEGA*BETA(J,K)*DGTORD
     )
      P(33,3 )=(-KS(2,1,1)*KSLNL*S*CBO(1))*KCECO
      P(34,3 )=-KS(3,1,1)*KSLNL/2.*KCECO
      P(37,3 )=-KS(1,1,1)*EXP(CE(1,1))*KCECO
C
      P(33,13)=-KS(2,2,1)*KSLNL*KCECO
      P(34,13)=-(KS(3,2,1)*KSLNL+2.*S*CBF(1))/2.*KCECO
      P(37,13)=-KS(1,2,1)*EXP(CE(2,1))*KCECO
C
      P(35,7 )=-KS(2,1,2)*KSLNL*S*CBO(2)
      P(36,7 )=-KS(3,1,2)*KSLNL/2.
      P(38,7 )=-KS(1,1,2)*4.*EXP(CE(1,2))
C
      P(35,19)=-KS(2,2,2)*KSLNL
      P(36,19)=-(KS(3,2,2)*KSLNL+2.*S*CBF(2))/2.
      P(38,19)=-KS(1,2,2)*4.*EXP(CE(2,2))
C
      P(33,4 )=1.
      P(34,14)=1.
      P(35,8 )=1.
      P(36,20)=1.
      P(37,37)=1.
      P(38,38)=1.
C
      RETURN
C
C
      SUBROUTINE SUBMM(A,B,C)
      COMPLEX A(2,2),B(2,2),C(2,2)
      DO 111 MI=1,2
      DO 111 MJ=1,2
      C(MJ,MI)=0.
      DO 111 MK=1,2
111   C(MJ,MI)=C(MJ,MI)+A(MJ,MK)*B(MK,MI)
      RETURN
C
      SUBROUTINE SUBMA(A,B,C)
      COMPLEX A(2,2),B(2,2),C(2,2)
      DO 222 MI=1,2
      DO 222 MJ=1,2
222   C(MI,MJ)=A(MI,MJ)+B(MI,MJ)
      RETURN
      END
```

```
@FOR,SI          POGS1C,PVC,,PVC
C
C TITLE          PVC
C
C AUTHOR         C.F. BANICK
C
C DATE           10-15-68
C
C PURPOSE        THIS ROUTINE IS CALLED BY 'PNTRX2' TO DEFINE THE
C                MATRICES USED TO MODEL THE PVC'S.
C
C CALL           CALL PVC(OMEGA,PVCSL,PVCA,PVCSA,PVCT,PVCKS,PVCSKG,RHO,
C                MO,MF,KBC2A,YPVC,YWPVC)
C
C INPUT          ALL INPUT IS THROUGH THE CALL LIST. OMEGA IS THE
C                FREQUENCY FOR WHICH THE MATRICES WILL BE DEFINED (RADIANS).
C                A DESCRIPTION OF ALL OTHER VARIABLES IN THE LIST UP TO
C                AND INCLUDING KBC2A CAN BE FOUND IN THE MAIN PROGRAM
C                'POGO2'.
C
C OUTPUT         YPVC,      EACH OF THESE IS DIMENSIONED 2X2X2X2. THE
C                YWPVC      LAST SUBSCRIPT IS FOR INBOARD, OUTBOARD. THE
C                           SECOND LAST IS FOR OXYGEN, FUEL. THE 2X2
C                           MATRICES DETERMINED BY THE FIRST TWO SUBSCRIPTS
C                           RELATE PVC OUTPUT PRESSURES AND FLOWS TO THE
C                           CORRESPONDING INPUTS. THE YWPVC MATRICES
C                           ACCOUNT FOR GIMBAL MOTION EFFECTS.
C
C SUBROUTINES    SUBMM AND SUBMV ARE INTERNAL TO 'PVC' AND ARE USED
C USED           TO MULTIPLY TWO COMPLEX 2X2 MATRICES OR MULTIPLY A 2X2
C                COMPLEX MATRIX BY A TWO-DIMENSIONAL COMPLEX VECTOR.
C
C
                 SUBROUTINE PVC(OMEGA,PVCSL,PVCA,PVCSA,PVCT,PVCKS,PVCSKG,
     .           RHO,MO,MF,KBC2A,YPVC,YWPVC)
C
                 REAL MO(2),MF(2)
C
                 COMPLEX YPVC(2,2,2,2),YWPVC(2,2,2,2),S,GL,GC,SC,
     .           D,E,TP(2,2,5),T54(2,2),
     .           TEMPM(2,2),T5432(2,2),T54321(2,2),TEMPV1(2),TEMPV2(2),
     .           TEMPV3(2),SAVEM(2,2),ST(2,5)
C
                 DIMENSION PVCSL(2,2,2),PVCA(2,2,2),PVCSA(2,2,2),PVCT(2,2)
     .           ,RHO(2,2),PVCKS(2,2)
C
                 S=CMPLX(0.,OMEGA)
                 G=386.4          @ IN/SEC**2
C
C       IF KBC2A=1, NO PVC'S ARE INCLUDED IN THE LINES
C
                 IF(KBC2A.EQ.1)GO TO 7
                 IR=-1
                 IC=-3
C
C
                 DO 6 I=1,2            @OX,FUEL
                 IJ=4*(2-I)+1D
```

```
      JIC=4I+I
C
      DO 6 K=1,2            ØINBOARD,OUTBOARD
      RKSP=PVCKS(I,K)/(PVCA(2,I,K)-PVCA(1,I,K))
C
      INDS=1
      DO 1 J=1,2
      INDS=-INDS
C
      GL=S*PVCSL(J,I,K)/PVCSA(J,I,K)
      CC=COSH(GL)
      SC=SINH(GL)
      Z=PVCSA(J,I,K)/(PVCA(J,I,K)*G)
C
      D=-RHO(I,K)*(PVCSKG*CC+S*PVCA(J,I,K)*Z*SC)
      E=RHO(I,K)*(PVCSKG*SC/Z+S*PVCA(J,I,K)*CC)
C
      JJ=7-2*J              ØJJ=5,3
      TP(1,1,JJ)=-CC+(D/RKSP)*INDS
      TP(2,1,JJ)=SC/Z+(E/RKSP)*INDS
      TP(1,2,JJ)=SC*Z
      TP(2,2,JJ)=-CC
C
      JJJ=2*J
      TP(1,1,JJJ)=RKSP/(RKSP*RHO(I,K)*PVCSKG*INDS)
      TP(2,1,JJJ)=S*RHO(I,K)*PVCA(J,I,K)/(-RKSP*INDS
     +RHO(I,K)*PVCSKG)
      TP(1,2,JJJ)=0.
      TP(2,2,JJJ)=1.
C
      ST(1,J)=RHO(I,K)*PVCSKG
      ST(2,J)=-S*RHO(I,K)*PVCA(J,I,K)
      ST(1,J+2)=D
      ST(2,J+2)=E
C
      IF(J.EQ.2)GO TO 1
      TP(1,1,1)=-CC
      TP(2,1,1)=SC/Z
      TP(1,2,1)=SC*Z
      TP(2,2,1)=-CC
C
 1    CONTINUE
C
      ST(1,5)=0.
      ST(2,5)=-ST(2,1)
C
      CALL SUBMM(TP(1,1,5),TP(1,1,4),T54)
      CALL SUBMM(T54,TP(1,1,3),TEMPM)
      CALL SUBMM(TEMPM,TP(1,1,2),T5432)
      CALL SUBMM(T5432,TP(1,1,1),T54321)
C
      T5432(1,1)=T5432(1,1)+1.
      T5432(2,2)=T5432(2,2)+1.
C
      CALL SUBMV(T54321,ST(1,5),TEMPV1)
      CALL SUBMV(T5432,ST(1,3),TEMPV2)
      CALL SUBMV(T54,ST(1,2),TEMPV3)
      DO 2 II=1,2
```

```
 2          TEMPV1(II)=TEMPV1(II)+TEMPV2(II)-TEMPV3(II)
C
            CALL SUBMV(T5432,ST(1,1),TEMPV2)
            CALL SUBMV(T54,ST(1,4),TEMPV3)
            DO 3 II=1,2
 3          TEMPV2(II)=TEMPV2(II)-TEMPV3(II)
C
            DO 4 IM=1,2
            SAVEM(IM,I)=TEMPV1(IM)*PVCT(I,K)
            MMI=3-I
 4          SAVEM(IM,MMI)=TEMPV1(IM)*(1.-PVCT(I,K))+TEMPV2(IM)
C
C
            DO 5 NR=1,2
            DO 5 NC=1,2
            YPVC(NR,NC,1,K)=T54321(NR,NC)
 5          YWPVC(NR,NC,I,K)=SAVEM(NR,NC)
 6          CONTINUE
            RETURN
C
C
C
C     RELATES ABSOLUTE FLOW RATES TO RATES WHICH ARE RELATIVE TO THE WALLS
C     WALLS
C
 7          DO 8 K=1,2
            YWPVC(2,2,1,K)=-SCRO(K)
            YWPVC(2,1,2,K)=-SCRP(K)
            DO 8 I=1,2
            YPVC(1,1,I,K)=-1.
 8          YPVC(2,2,I,K)=-1.
            RETURN
C
C     SUBROUTINES ...
C
            SUBROUTINE SUBMM(A,B,C)
            COMPLEX A(2,2),B(2,2),C(2,2)
            DO 11 MI=1,2
            DO 11 MJ=1,2
            C(MJ,MI)=0.
            DO 11 MK=1,2
 11         C(MJ,MI)=C(MJ,MI)+A(MJ,MK)*B(MK,MI)
            RETURN
C
C
            SUBROUTINE SUBMV(A,B,C)
            COMPLEX A(2,2),C(2),B(2)
            DO 12 MI=1,2
            C(MI)=0.
            DO 12 MK=1,2
 12         C(MI)=C(MI)+A(MI,MK)*B(MK)
            RETURN
C
      END
```

```
@FOR.IS         POGSIC.SOLVEQ..SOLVEQ
C
C TITLE         SOLVEQ
C
C AUTHOR        C. F. BANICK
C
C DATE          7-2-68
C
C PURPOSE       'SOLVEQ' IS CALLED BY THE MAIN PROGRAM 'POGO2' TO
C               SUPPLY SOLUTIONS OF THE LINEAR SYSTEM DEFINED BY 'PMTRX2'.
C
C METHOD        OBTAIN COMPLEX VALUED SOLUTIONS BY USING A GAUSS-JORDAN
C               REDUCTION.  RETURN THESE SOLUTIONS TO 'POGO2' IN THE
C               FORM OF AMPLITUDE AND PHASE ANGLE.
C
C CALL          CALL SOLVEQ(P,NRP,NCP,AMP,PHSANG)
C
C INPUT         THROUGH CALL LIST ...
C               P           COEFFICIENT MATRIX OF THE LINEAR SYSTEM.
C               NRP,NCP     P IS DIMENSIONED NRP X NCP.
C
C OUTPUT        THROUGH CALL LIST ...
C               AMP         ARRAY OF AMPLITUDES OF SOLUTIONS OF THE SYSTEM.
C               PHSANG      ARRAY OF PHASE ANGLES OF SOLUTIONS OF THE
C               SYSTEM.
C
C SUBROUTINE    CGJR        A ROUTINE IN THE UNIVAC MATH PACK WHICH
C USED                      PERFORMS THE GAUSS-JORDAN REDUCTION.
C
C
                SUBROUTINE SOLVEQ(P,NRP,NCP,AMP,PHSANG)
                COMPLEX P(NRP,NCP),V,PP
                DIMENSION AMP(1),PHSANG(1)
C
                V=(4.,0.)
                CALL CGJR(P,NCP,NRP,NRP,NCP,S1,JC,V)
                GO TO 2
 1              WRITE(6,10)JC
C
 2              DO 3 I=1,NRP
                PP=P(I,NCP)
                AMP(I)=ABS(PP)
                PHSANG(I)=0.
                IF(AMP(I).GT.1.E-37)PHSANG(I)=ATAN2(AIMAG(PP),REAL(PP))
 3              CONTINUE
                RETURN
 10             FORMAT(1H ,'JC=',I2)
        END
```

```
@FOR,SI          POGSIC,STRCT2,,STRCT2
C
C TITLE          STRCT2 -- C PRIME BOEING  9-23-68
C
C AUTHOR         C.F. BANICK
C
C DATE           9-9-68
C
C SPONSOR        H. E. STEPHENS
C
C PURPOSE        CALLED BY THE MAIN PROGRAM 'POGO2' TO SUPPLY VALUES OF
C                THE STRUCTURAL DATA AS FUNCTIONS OF TIME.
C
C METHOD         LINEAR INTERPOLATIONS ON EXISTING DATA.
C
C CALL           CALL STRCT2(T,TCECO,OMGA,ZETA,HP,HTO,HTF,MGOMEQ)
C
C INPUT          THROUGH CALL LIST ...
C                T          FLIGHT TIME FOR WHICH THE DATA WILL BE
C                           DETERMINED (SEC).
C                TCECO      TIME FOR THE CENTER ENGINE CUT-OFF (SEC).
C
C OUTPUT         THROUGH CALL LIST ...
C                           A DESCRIPTION OF ALL OUTPUT VARIABLES CAN BE
C                FOUND IN THE MAIN PROGRAM 'POGO2'.
C
C NOTE           THE STRUCTURAL MODE SHAPES DEPEND ON THE MASS OF FUEL
C                AND OXIDIZER PRESENT.  THE MODE SHAPE DATA IS STORED
C                NUMERICALLY FOR DISCRETE VALUES OF FLIGHT TIME.  THESE
C                VALUES PRESUPPOSE A PARTICULAR CENTER ENGINE CUT-OFF
C                TIME.  HENCE, A CHANGE IN CUT-OFF TIME VARIES THE TIME
C                AT WHICH A PARTICULAR MODE SHAPE (FROM THE DATA) IS A
C                VALID REPRESENTATION FOR THE VEHICLE.
C
C
                 SUBROUTINE STRCT2(T,TCECO,OMGA,ZETA,HP,HTO,HTF,MGOMEQ)
C
                 DIMENSION OMGA(9),ZETA(9),HP(10,2),HTO(10,2),HTF(10,2),
     .           MGOMEQ(10),TH(6),AOMGA(6,9),AMEQ(6,9),RGOMEQ(6),
     .           RGMOVM(2),AHP(6,2,9),AHTO(6,9),AHTF(6,9),C(2,2),C1(2,2),
     .           C2(2),C3(2),ZZETA(8),AHP623(73),ZETA1(6)
C
                 EQUIVALENCE(AHP623,AHP(6,2,3))
C
                 DATA TH/0.,10.,60.,100.,125.,155./
                 DATA ZZETA/.009,.01,.02,.3,.014,.2,.02/
                 DATA ZETA1/2.009,2.01,.014,.02/
                 DATA RGOMEQ/1.59E4,1.51E4,1.35E4,8.24E3,6.33E3,4.55E3/
                 DATA AOMGA/3.77,4.04,6.27,8.59,10.92,22.99,4.59,4.67,
     .           4.9,5.25,5.74,6.10,6.43,6.52,6.71,6.03,7.17,9.12,10.39,
     .           10.50,2.18,11.10.3,19.40,2.9,21.11.46,12.36,12.4,
     .           12.45,10.50,
     .           10.93,12.37,3.14.47,11.33,11.56,14.40,3.14.05,
     .           6.16.76,2.17.20,17.02,17.72,18.02,
     .           18.07/
C
                 DATA AMEQ/.298E4,.6E3,.275E0,.189E4,.127E4,.709E2,
     .           .139E4,.135E4,.321E2,.420E2,.469E3,.344E3,
```

```
     .151E3,.5E3,.5133,.629E3,.117E4,.779E3,
     .305E3,.234E3,.175E3,.150E3,.236E3,.55E1,
     2*,.212E3,.249E3,.214E3,.214E3,.211E3,
     .410E4,.483E4,.217E3,.607E2,2*,.607E2,
     .441E4,.302E4,.607E2,3*,.101E2,
     2*,.262E3,.209E3,.193E3,.195E3,.195E3,
     2*,.106E4,.295E3,.355E3,.155E3,.135E3/
C
      DATA ANP/.292,.119,.176,.524,.470,
     1*,.284,.115,.162,.445,
     .362,-.685E-1,.233,.265,.336E-1,
     .620E-1,.253,.171,.223,.253,
     .321E-1,.059,.235,.150,.605E-2,
     .021,.0160,.167,.452,1*,
     .554E-2,.191E-1,.152E-1,.151,.405,73*0,/
      DATA ANP623/.831,
     1*,.841,.345,.218,1*,
     .323E-2,.314,.258,.115,.0732,
     .321,.746E-3,.34E-3,.221E-3,.133,
     .153E-2,.391E-2,.101,.201E-3,.183E-3,
     .976E-1,.106E-2,.269E-2,.124,1*,
     .92,.391E-3,.931E-3,.202E-3,.034E-2,
     .772,.696,.263E-3,.535E-3,.162E-3,
     .479E-2,.5,.616,.146E-2,.223E-2,
     .925E-2,.1E1E-1,.269,.445,.[illegible]E-3,
     .123E-2,.511E-3,.033E-2,.153,.152,
     .154,.144,.105,.209,.0455,
     .0650,.0664,.0709,.0455,.0699,
     .754,.933,1*,1*,.365,
     .0755,.301,.366,.354,.363,
     .125,.0255/
C
      DATA ANTO/-.391,-.189,-.150,-.696,-.077,
     -.124,.0199,.412E-2,.0239,.0472,
     .199,.13,-.0256,-.0259,.0826,
     .09,.314,.504,-.0243,-.0235,
     -.552E-2,-.397E-2,-.0912,-.0036,-.255E-3,
     -.284E-3,.219,-.0304,-.094,.0304,
     .0243,.0772,-.0269,-.00151,-.00339,
     -.230E-3,-.17,-.133,-.094E-2,-.273E-2,
     -.6E-2,-.945E-3,-.024,-.0257,-.0336,
     -.0422,-.055,-.0443,-.0191,-.0265,
     -.0443,-.0792,-.062,-.0212/
C
      DATA ANTF/.427,.177,.297,.944,1*,
     -.212,.402,.437,.0393,.0411,
     .286,.161,.0473,.115,.0301,
     .226,.557,.059,-.066,-.056,
     -.0451,-.0470,-.362,.091E-3,-.159E-3,
     -.17E-3,-.232,-.0127,.0144,.132,
     .0217,-.0467,-.428E-3,-.107E-2,-.119E-2,
     .527E-2,.206,.166,-.653E-3,-.211E-2,
     -.257E-2,.922E-2,-.0251,-.0264,-.035,
     -.0663,-.083,.103,-.137,-.161,
     -.148,-.264,-.153,.03/
C
      TWOPI=2.*3.1415927
C
```

```
      DO 13 IZ=2,9
13    ZETA(IZ)=ZZETA(IZ-1)
      TIME=T
C
C     DETERMINE THE RELATIONSHIP BETWEEN THE CURRENT TIME AND THE
C     NOMINAL TIME FOR CENTER ENGINE CUT-OFF.
C
      IF(T-125.)1,1,111
C
C     DETERMINE THE TABLE LOOK-UP TIME.
C
1     IF(T.GT.TCECO)TIME=TCECO+.8*(T-TCECO)
      GO TO 3
C
111   IF(T-TCECO)2,2,22
2     TIME=T+1.2*(T-125.)
      GO TO 3
22    TIME=T+.2*(TCECO-125.)
C
3     IF(TIME.LT.TH(1).OR.TIME.GT.TH(6))GO TO 11
C
      DO 4 I=2,6
      II=I
      IF(TIME.LE.TH(I))GO TO 5
4     CONTINUE
C
5     CON=(TIME-TH(II-1))/(TH(II)-TH(II-1))
      DO 6 J=1,2
      HP(1,J)=9.98E-1
      HTO(1,J)=9.98E-1
      HTF(1,J)=9.98E-1
C
      JI=II-2+J
6     RGHOVH(J)=9.98E-1/RGDHEQ(JI)
C
      HGOHEQ(1)=CON*(RGHOVH(2)-RGHOVH(1))+RGHOVH(1)
      ZETA(1)=ZETA1(II-1)+CON*(ZETA1(II)-ZETA1(II-1))
C
      DO 10 K=1,9
      OMGA(K)=TWOPI*(CON*(AOMGA(II,K)-AOMGA(II-1,K))+
     .AOMGA(II-1,K))
      DO 8 I=1,2
      JI=II-2+I
      DO 7 J=1,2
      C(I,J)=AHP(JI,J,K)/AHEQ(JI,K)
7     C1(I,J)=C(I,J)*AHP(JI,J,K)
C
      C2(I)=C(I,2)*AHTO(JI,K)
8     C3(I)=C(I,2)*AHTF(JI,K)
C
      DO 9 J=1,2
      HGOHEQ(K+1)=CON*(C(2,J)-C(1,J))+C(1,J)
9     HP(K+1,J)=(CON*(C1(2,J)-C1(1,J))+C1(1,J))/HGOHEQ(K+1)
C
      HTO(K+1,2)=(CON*(C2(2)-C2(1))+C2(1))/HGOHEQ(K+1)
      HTO(K+1,1)=HTO(K+1,2)
C
      HTF(K+1,2)=(CON*(C3(2)-C3(1))+C3(1))/HGOHEQ(K+1)
```

```
 10             HTF(K+1,1)=HTF(K+1,2)
C
                RETURN
C
 11             WRITE(6,12)TIME
                RETURN
C
 12             FORMAT(1H ,'TIME=',F6.3,' IS OUTSIDE THE RANGE OF ACCEPTA
     . BLE VALUES IN STRCT2')
C
        END
```

```
@FOR,S1          POGS1C.TABLEB,.TABLEB
C TITLE          TABLE SEARCH WITH LINEAR INTERPOLATION
C
C AUTHORS        BV BYE AND JE HOLCOMB
C
C DATE           7/1/65
C
                 FUNCTION TABLEB(YT,XT,XB)
                 DIMENSION XT(1),YT(1)
C
C       THE ELEMENTS XT(1)=YT(1)=NUMBER OF ELEMENTS FOLLOWING
C
                 K=XT(1)
C
C       BOUND X WITHIN THE TABLE, .GE. TO FIRST ELEMENT OF XT AND .LE.
C       TO THE LAST ELEMENT OF XT.
                 IF(XB.GE.XT(2).AND.XB.LE.XT(K+1))GO TO 10
                 WRITE(6,101) XB,XT(2),XT(K+1)
 101             FORMAT(15H *****THE VALUE,E16.8,21H  IS NOT IN THE RANGE,
                 E16.8,4H  TO,E16.8,7H  *****)
                 TABLEB=0.0
                 RETURN
C
C
C       DETERMINE THE GREATEST POWER OF TWO LESS THAN THE TABLE LENGTH
C       SAVING IT IN N AND ITS SUCCESSOR IN NN2
C
 10              N=1
 1               N=2*N
                 NN2=2*N
                 IF(NN2.LT.K)GO TO 1
C
C       INITIALIZE VARIABLES FOR BINARY SEARCH
C
                 L=2
                 NN=N
C
C       TEST TO SEE WHETHER XB IS LT,EQ,GT XT(N+1),THIS IS THE LOOP POINT
C
 2               IF(XB-XT(N+1))5,40,7
C
C       XB.LT.XT(N), DECREASE N BY BINARY FACTOR
C
 5               N=N-NN/L
C
C       MULTIPLY THE DIVISOR BY 2
C
 6               L=2*L
C
C       TEST FOR OVERSHOOTING END OF TABLE, IF OVERSHOOT DECREASE N
C
                 IF(N.GT.K)GO TO 5
C
C       TEST FOR END OF LOOP, IF L=NN2 (2*N), THEN GO INTERPOLATE
C
                 IF(L-NN2)2,20,20
C
C       XB.GT.XT(N), INCREASE N BY BINARY FACTOR
```

```
C
 7          N=N+NN/L
C
C       GO MULTIPLY THE DIVISOR BY 2 AND TEST FOR OVERSHOOT
C
           GO TO 6
C
C       TEST SEE WHETHER THE DESIRED POINT IS ABOVE OR BELOW THE PRESENT
C       XT
C
 20        IF(XB-XT(N+1))60,40,50
C
C       XB IS EQUAL TO XT(N), SO TABLEB=YT(N)
C
 40        TABLEB=YT(N+1)
           RETURN
C
C       XB.GT.XT(N), INTERPOLATE WITH N+1 AND N+2
C
 50        N=N+1
C
C       XB.LT.XT(N), DECREMENT N BY 1 AND INTERPOLATE WITH N AND N+1
C
 60        TABLEB=YT(N)+((YT(N+1)-YT(N))*(XB-XT(N)))/(XT(N+1)-XT(N))
           RETURN
C
           END
```

SAMPLE RUN

```
@      RUN      CFB,POGCFB,POG02,30,50

@HUG            C F BANICK    POG02 SAMPLE RUN

@ASG,A          POGS1C.

@ASG,T          PLOTFILE.,T,PLOT

@FOR,W          POGS1C.DATA,DATA
CYCLE 000 COMPILED BY 1201 000D2S6D 15 MAY 69 AT 14:24:30.
-219,219
                MTO(1)=MTO(2)
-235,235
                PAFT(2)=PAFT(1)
      END OF COMPILATION:        NO  DIAGNOSTICS.

@PREP           POGS1C.
E1101-0013

@MAP,IN         POGS1C.MAP,.ABS
NEW SYMBOLIC CYCLE  0   15 MAY 69 AT 14:24:49   THE COLLECTOR 1100-0009

@XQT            POGS1C.ABS
```

C F BANICK POGO2 SAMPLE RUN

```
                .15566800+00,   .35177600-03,   .00000000+00,   .00000000+00,
               -.53333299-01,   .00000000+00,   .17443700+00,   .16600000-02,
                .45340799-05,   .69842299-08,  -.21930000-01,  -.18180000-04,
                .60159999-01,   .47900000-03,   .80640000-05,   .00000000+00,
                .47808699-01,  -.18245500-03,   .18504900+00,   .22727700-02,
                .00000000+00,   .00000000+00,   .46481800+00,   .64719899-02,
                .24157200+00,   .45079100-02,   .13028100-04,   .00000000+00,
SKI     =       .12600000+04,   .34800000+01,   .58800000+00,  -.23761000+03,
               -.11310000+01,   .32650000+00,   .12600000+04,   .34800000+01,
                .58800000+00,  -.23761000+03,  -.11310000+01,   .32650000+00,
MP      =       .91200000+01,
PVCD    =       .18210000+02,   .25760000+02,   .13000000+02,   .18360000+02,
                .18210000+02,   .25760000+02,   .13000000+02,   .18360000+02,
PVCE    =       .30000000+08,   .30000000+08,   .30000000+08,   .30000000+08,
                .30000000+08,   .30000000+08,   .30000000+08,   .30000000+08,
PVCTH   =       .20600000+00,   .20600000+00,   .12900000+00,   .18600000+00,
                .20600000+00,   .20600000+00,   .12900000+00,   .18600000+00,
PVCSL   =       .25541000+02,   .39500000+01,   .20130000+02,   .67399999+01,
                .31450000+02,   .17050000+02,   .31320000+02,   .17350000+02,
PVCKS   =       .60500000+05,   .50000000+05,   .68500000+05,   .50000000+05,
PVCT    =       .00000000+00,   .00000000+00,   .00000000+00,   .00000000+00,
PVCSKG  =       .00000000+00,
ALPHA   =       .00000000+00,   .00000000+00,   .00000000+00,   .00000000+00,
BETA    =       .00000000+00,   .00000000+00,   .00000000+00,   .00000000+00,
KBCTF   =                   ,
KBCZA   =                   ,
KIEOL   =                   ,
KCENP   =                   ,
KSLNL   =                  1,
KSLCO   =                  1,
INDPNT  =                  1,
INDPLT  =                  1,
MPRNT   =                   ,
$END
$CSK
C       =       .51072499-01,   .00000000+00,   .16225730+00,   .36117000-03,
                .00000000+00,   .00000000+00,   .66889599-01,   .00000000+00,
                .15566800+00,   .35177600-03,   .00000000+00,   .00000000+00,
               -.53333299-01,   .00000000+00,   .17443700+00,   .16600000-02,
                .45340799-05,   .69842299-08,  -.21930000-01,  -.18180000-04,
                .60159999-01,   .47900000-03,   .80640000-05,   .00000000+00,
                .47808699-01,  -.18245500-03,   .18504900+00,   .22727700-02,
                .00000000+00,   .00000000+00,   .46481800+00,   .64719899-02,
                .24157200+00,   .45079100-02,   .13028100-04,   .00000000+00,
                .51072499-01,   .00000000+00,   .16225730+00,   .36117000-03,
                .00000000+00,   .00000000+00,   .66889599-01,   .00000000+00,
                .15566800+00,   .35177600-03,   .00000000+00,   .00000000+00,
               -.53333299-01,   .00000000+00,   .17443700+00,   .16600000-02,
                .45340799-05,   .69842299-08,  -.21930000-01,  -.18180000-04,
                .60159999-01,   .47900000-03,   .80640000-05,   .00000000+00,
                .47808699-01,  -.18245500-03,   .18504900+00,   .22727700-02,
                .00000000+00,   .00000000+00,   .46481800+00,   .64719899-02,
                .24157200+00,   .45079100-02,   .13028100-04,   .00000000+00,
SK      =       .12600000+04,   .34800000+01,   .58800000+00,  -.23761000+03,
               -.11310000+01,   .32650000+00,   .12600000+04,   .34800000+01,
                .58800000+00,  -.23761000+03,  -.11310000+01,   .32650000+00,
$END
```

REAL TIME CLOCK INTERROGATED AT 142521

C F BANICK POGO2 SAMPLE RUN

TIME OF FLIGHT ... 120.000 SECONDS

```
$OUTPUT
MO      =   .93275640+01,   .93275640+01,
MF      =   .33124985+01,   .33124985+01,
MTO     =   .16533728-01,   .16533728-01,
MTF     =   .87071900-02,   .87071900-02,
PAOS    =   .11950000+03,   .11750000+03,
PAFS    =   .43600000+02,   .43600000+02,
RHO     =   .41137731-01,   .29289004-01,   .41137731-01,   .29289004-01,
CBO     =   .50499999-01,   .52499999-01,
CBF     =   .46560000-01,   .59280000-01,
V       =   .15968563+03,   .15968563+03,   .22101817+03,   .22101817+03,
            .22101817+03,   .26700677+03,   .15968563+03,   .15968563+03,
            .22101817+03,   .22101817+03,   .22101817+03,   .26700677+03,
CF      =   .16598014-05,   .16598014-05,   .13139690-03,   .19973109-05,
            .19973109-05,   .36488414-05,   .16598014-05,   .16598014-05,
            .13139690-03,   .19973109-05,   .19973109-05,   .36488414-05,
SA      =   .27728615+05,   .23811555+05,   .24836667+05,   .24836667+05,
            .24836667+05,   .33227625+05,   .27728615+05,   .23811555+05,
            .24836667+05,   .24836667+05,   .24836667+05,   .33227625+05,
OMGA    =   .65684419+02,   .35449731+02,   .44623182+02,   .11474352+03,
            .77861231+02,   .90917691+02,   .93305381+02,   .10530618+03,
            .11284600+03,
ZETA    =   .13200000-01,   .60000000-02,   .10000000-01,   .20000000-01,
            .14000000-01,   .14000000-01,   .14000000-01,   .20000000-01,
            .20000000-01,
HP      =   .99799999+00,   .48515375+00,   .17627979+00,   .41021309+00,
            .94113328+00,   .36979207-02,   .57545263-03,   .14157504-02,
            .12175386+00,   .51118297+00,   .99799999+00,   .37620632+00,
            .16327863+00,   .36746880+00,   .30155485+00,   .25438240-02,
            .33068555-03,   .78111910-03,   .52700559-01,   .18228432+00,
HTO     =   .99799999+00,  -.84601991+00,   .13714032+00,   .28090161+00,
           -.84354961-01,  -.88296445-01,  -.25397886-02,  -.47715027-02,
           -.72866771-01,  -.66163943-01,   .99799999+00,  -.84601991+00,
            .13714032+00,   .28090161+00,  -.84354961-01,  -.88296445-01,
           -.25397886-02,  -.47715027-02,  -.72866771-01,  -.66163943-01,
HTF     =   .99799999+00,   .99041499+00,   .19435149+00,   .50809123+00,
           -.33734437+00,   .11969712-01,  -.11357312-02,  -.23971838-02,
           -.78265771-01,  -.17971664+00,   .99799999+00,   .99041499+00,
            .19435149+00,   .50809123+00,  -.33734437+00,   .11969712-01,
           -.11357312-02,  -.23971838-02,  -.78265771-01,  -.17971664+00,
HGOMEQ  =   .15035284-03,   .27512144-03,   .67655380-03,   .32493579-03,
            .11807936-02,   .11046729-04,   .34439592-05,   .64831683-04,
            .26052083-03,   .84966832-03,
LA      =   .54052757-05,   .54052757-05,   .54052757-05,   .54052757-05,
VAO     =   .39032206+04,   .39032206+04,   .39032206+04,   .39032206+04,
KA      =   .74422536+21,   .38138075+21,   .12147377+01,   .38138075+21,
PVCA    =   .26044125+03,   .52117263+03,   .13273229+03,   .26474955+03,
            .26044125+03,   .52117263+03,   .13273229+03,   .26474955+03,
PVCSA   =   .29789968+05,   .28206535+05,   .40195555+05,   .40366099+05,
            .29789968+05,   .28206535+05,   .40195555+05,   .40366099+05,
$END
```

FREQUENCY (HZ)	ZERO PHASE GAIN (DB)	FREQUENCY (HZ)	ZERO PHASE GA (DB)
		10.60781	-.63600911+

C F HANICK P0602 SAMPLE RUN DATE 051569

FREQUENCY (HZ)	TI AMPLITUDE	TI PHASE ANGLE	TOPRNT AMPLITUDE	TOPRNT PHASE ANGLE
10.00000	2.3188-02	1.5575+02	1.6309-01	1.4089+02
10.20000	5.0006-02	1.2353+02	4.2123-01	1.0840+02
10.40000	6.0570-02	5.7034+01	6.0675-01	3.0093+01
10.60000	3.9943-02	2.5916+01	4.8348-01	9.6960-01
10.60625	3.9519-02	2.5442+01	4.8135-01	1.7539-01
10.60703	3.9467-02	2.5384+01	4.8109-01	7.6923-02
10.60781	3.9415-02	2.5326+01	4.8083-01	-2.1384-02
10.60859	3.9363-02	2.5269+01	4.8058-01	-1.1947-01
10.80000	3.1439-02	1.8117+01	4.6341-01	-2.1766+01
11.00000	3.2125-02	1.9068+01	5.1146-01	-4.7972+01
11.20000	4.2848-02	1.0543+01	5.2982-01	-8.6308+01
11.40000	5.0611-02	-1.1394+01	3.9807-01	-1.2562+02
11.60000	5.2805-02	-3.0569+01	2.5936-01	-1.5102+02
11.80000	5.6149-02	-4.8379+01	1.7538-01	-1.6683+02
12.00000	6.1062-02	-7.0442+01	1.2551-01	-1.7786+02

FREQUENCY (HZ)	TI AMPLITUDE	TI PHASE ANGLE	TOPRNT AMPLITUDE	TOPRNT PHASE ANGLE
12.20000	6.1128-02	-1.0079+02	9.4340-02	1.7413+02
12.20000	6.1128-02	-1.0080+02	9.4540-02	1.7413+02
12.40000	4.9174-02	-1.3386+02	7.5562-02	1.6734+02
12.60000	3.1450-02	-1.5892+02	6.2774-02	1.6039+02
12.80000	1.9443-02	-1.7531+02	5.3106-02	1.5422+02
13.00000	1.1808-02	1.7348+02	4.5693-02	1.4708+02
13.20000	6.8853-03	1.6516+02	4.0005-02	1.4227+02
13.40000	3.4717-03	1.5854+02	3.5648-02	1.3714+02
13.60000	1.0810-03	1.5330+02	3.2342-02	1.3266+02
13.80000	6.6793-04	-3.3285+01	2.9891-02	1.2823+02
14.00000	1.9615-03	-3.7134+01	2.8170-02	1.2602+02
14.20000	2.9864-03	-4.1220+01	2.7111-02	1.2396+02
14.40000	3.7652-03	-4.5180+01	2.6691-02	1.2273+02
14.60000	4.3731-03	-4.9056+01	2.6934-02	1.2224+02
14.80000	4.8567-03	-5.2818+01	2.7862-02	1.2227+02
15.00000	5.2670-03	-5.7000+01	2.9524-02	1.2289+02

FREQUENCY (HZ)	TFOI AMPLITUDE	TFOI PHASE ANGLE	TFFI AMPLITUDE	TFFI PHASE ANGLE	TFOO AMPLITUDE	TFOO PHASE ANGLE	TFFO AMPLITUDE	TFFO PHASE ANGLE
10.00000	1.4118-03	-2.6285+01	1.6112-02	1.8304+02	6.5662-02	1.6722+02	1.8374-01	1.6358+02
10.20000	2.3666-03	-1.2846-01	1.5167-02	1.8070+02	7.9344-02	1.6617+02	2.2205-01	1.5913+02
10.40000	2.9950-03	8.0262+00	1.5100-02	1.7838+02	9.7061-02	1.6462+02	2.8131-01	1.5283+02
10.60000	3.3048-03	1.2891+01	1.5731-02	1.7436+02	1.2134-01	1.6244+02	3.7533-01	1.4270+02
10.60625	3.3104-03	1.3029+01	1.5760-02	1.7419+02	1.2225-01	1.6236+02	3.7903-01	1.4229+02
10.60703	3.3110-03	1.3046+01	1.5764-02	1.7417+02	1.2236-01	1.6235+02	3.7950-01	1.4224+02
10.60781	3.3117-03	1.3063+01	1.5768-02	1.7415+02	1.2248-01	1.6234+02	3.7996-01	1.4219+02
10.60859	3.3124-03	1.3080+01	1.5772-02	1.7413+02	1.2259-01	1.6233+02	3.8043-01	1.4213+02
10.80000	3.3861-03	1.7399+01	1.6782-02	1.6613+02	1.5672-01	1.5935+02	5.1943-01	1.2481+02
11.00000	3.3226-03	2.2855+01	1.6368-02	1.5205+02	2.1223-01	1.5481+02	6.5011-01	9.4628+01
11.20000	3.2102-03	3.0017+01	1.2634-02	1.3922+02	3.0801-01	1.4767+02	6.0011-01	6.1381+01
11.40000	3.1482-03	3.7538+01	9.5956-03	1.4183+02	4.9475-01	1.3511+02	4.6563-01	3.9659+01
11.60000	2.7755-03	3.7317+01	8.4536-03	1.4962+02	8.9491-01	1.0917+02	3.6549-01	2.7296+01
11.80000	1.2263-03	1.4276+02	8.1703-03	1.5599+02	1.3989+00	5.6416+01	3.0125-01	1.9662+01
12.00000	8.6189-03	1.2855+02	8.1745-03	1.6031+02	1.2882+00	5.7231-01	2.5906-01	1.4587+01
12.20000	1.5891-02	9.0527+01	8.2673-03	1.6310+02	9.8578-01	-4.9070+01	2.3236-01	1.1791+01
12.20000	1.5891-02	9.0529+01	8.2672-03	1.6310+02	9.8580-01	-4.9069+01	2.3236-01	1.1791+01
12.40000	1.6993-02	5.3146+01	8.3978-03	1.6488+02	5.5103-01	-9.2991+01	2.2274-01	1.0109+01
12.60000	1.3872-02	3.0949+01	8.3805-03	1.6478+02	2.6945-01	-1.1811+02	2.2625-01	7.5775+00
12.80000	1.1230-02	2.0555+01	8.0357-03	1.6491+02	1.4029-01	-1.3058+02	2.3908-01	3.7300+00
13.00000	9.4479-03	1.5103+01	7.3214-03	1.6592+02	7.8593-02	-1.3692+02	2.6082-01	-1.5994+00
13.20000	8.1763-03	1.1875+01	5.8897-03	1.7147+02	4.6080-02	-1.3976+02	3.2744-01	-1.0262+01
13.40000	7.2047-03	9.7657+00	4.5433-03	2.1259+02	2.7522-02	-1.3990+02	4.4751-01	-2.0330+01
13.60000	6.4184-03	8.3381+00	1.3567-02	2.3280+02	1.6321-02	-1.3701+02	5.6950-01	-7.1976+01
13.80000	5.7525-03	7.2807+00	1.8749-02	2.0629+02	9.3704-03	-1.2918+02	3.6602-01	-1.1599+02
14.00000	5.1681-03	6.4767+00	1.7956-02	1.8583+02	5.2210-03	-1.1090+02	2.0230-01	-1.7881+02
14.20000	4.6399-03	5.8536+00	1.7278-02	1.7684+02	3.4661-03	-7.4610+01	1.2505-01	-1.4765+02
14.40000	4.1514-03	5.3839+00	1.7011-02	1.7376+02	3.6734-03	-3.9123+01	8.4053-02	-1.5233+02
14.60000	3.6912-03	5.0011+00	1.7009-02	1.7472+02	4.4965-03	-2.1033+01	5.9629-02	-1.5515+02
14.80000	3.2634-03	5.1133+00	1.7165-02	1.7724+02	5.2629-03	-1.2212+01	4.3860-02	-1.5603+02
15.00000	2.8652-03	4.7286+00	1.7422-02	1.7919+02	5.8686-03	-7.5327+00	3.3092-02	-1.5816+02

-.52872214-00 .48341355-00 -.52872214-00 .48341355-00

IERR3= 0 NLAST1= 0 NLAST2= 0 NLAST3= 0

C F BANICK POGO2 SAMPLE RUN

REAL TIME CLOCK INTERROGATED AT 143206

@ FIN

RUNID: CFB ACCOUNT: POGCFB PROJECT: POGO2

LOAD PLOT 2/4 PLOTFILE -1 CFB

SERVICE 2/4 MOUNT PLOT : CFB

TIME: 00:01:00.787 IN: 93 OUT: 0 PAGES: 10

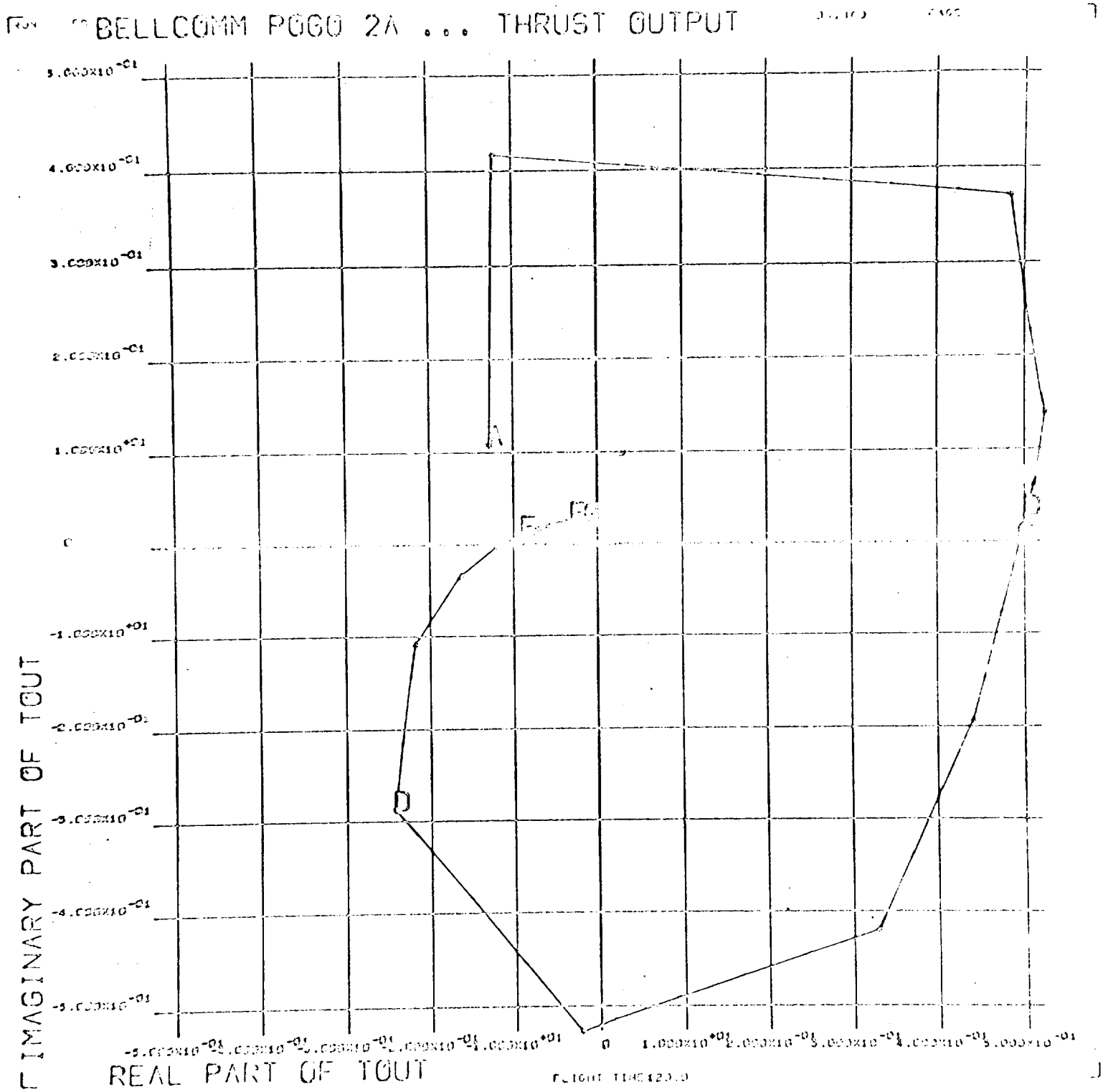
INITIATION TIME: 14:22:17-MAY 15,1969

TERMINATION TIME: 14:32:09-MAY 15,1969

CORE-SECONDS: 457

IO COUNT: 475

CHARGE: 10.152


BELLCOMM POGO 2A ... THRUST OUTPUT
IMAGINARY PART OF TOUT
REAL PART OF TOUT
A
B
C
D
E

BELLCOMM, INC.

Subject: POGO2 - A Computer Program for Longitudinal Stability Analysis of Large Launch Vehicles - Case 320

From: C. F. Banick

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