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1. CENTRIFUGAL FLOW PUMP SIZING PROGRAM

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COMPUTER PROGRAM

CENTRIFUGAL FLOW PUMP SIZING PROGRAM

I. INTRODUCTION

Preliminary sizing of a centrifugal flow pump is performed based on an assumed or initial hydraulic efficiency. Component losses are computed and a new value of efficiency is determined. Sizing and loss computations are repeat until the hydraulic efficiency approaches a constant value and the specified hea is satisfied. With this program, a pump can be sized for a specified flow coef cient or the optimum flow coefficient can be determined by iterative process th selection of the appropriate program flag. Because of design model limitations this program is generally not recommended for final detail design.

This program was used for the design point selection of the NERVA two-st turbopump described in Reference 1.

Reference 1 - Aerojet Nuclear Systems Company Engineering Operations Report N8300R:71-076, NERVA Turbopump Design Report, Volume 1, September 1971

I. INTRODUCTION

During the design of the NERVA Turbopump, numerous computer programs were developed for the analyses of fluid dynamic problems within the machine. The programs developed are shown in the following list.

1. Centrifugal Flow Pump Sizing Program
2. Axial Thrust Balancer Stability Analysis
3. Circular Section Volute Design
4. Inducer and Impeller Performance Program
5. Impeller Discharge Traverse Data Evaluation
6. Pump Air Test Data Reduction
7. Overall Performance of a Two Stage LH_2 Pump
8. Crossover Passage Design
9. Air Pump Performance Map
10. Pump Axial Thrust Program
11. LH_2 Pump Test Data Reduction Program
12. Axial Blade Design Program
13. Multistage Axial Flow Turbine Performance Analysis Program

This report contains program descriptions, example cases, users instructions, and listings for the majority of these programs. In some cases only the listing is included.

II. COMPUTER PROGRAM DESCRIPTIONS

II. DESIGN MODEL

A. IMPELLER MODEL

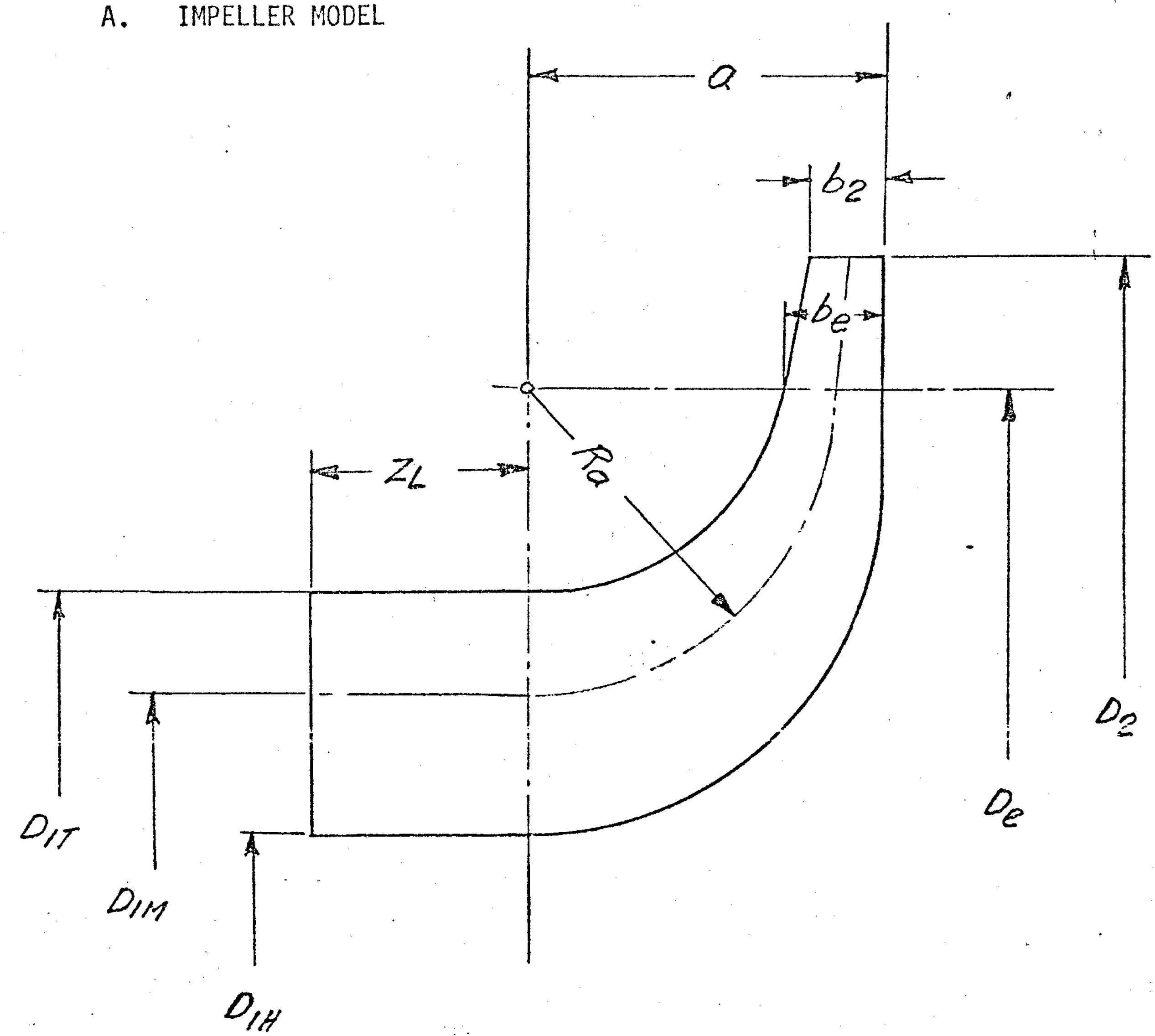


FIGURE 1

Refer to Figure 1:

$$D_{1H} = \xi D_{1T}$$

$$D_{1M} = \left(\frac{D_{1T}^2 + D_{1H}^2}{2}\right)^{1/2}$$

$$D_e = D_{M1} + 2 R_a$$

$$b_e = \frac{D_2}{D_e} b_2$$

$$Z_L = \frac{\Pi}{Z_o} D_{1T} \sigma_{IND} \sin(1.1 \beta_T)$$

$$h_1 = \frac{D_{1T} - D_{1H}}{2}$$

$$R_a = 1.5 \frac{h_1 + b_2}{2}$$

$$R_{m1} = \frac{D_{m1}}{2}$$

If the inducer (axial section) is integral to the impeller the first partial blades are assumed to begin at the start of the transition section. The transition section is divided into 3 cones. The blade angle within each conical section is constant. The radial section contains logarithmic spiral blading ($\beta = \beta_2$).

Blading of impellers without integral inducers begins at the start of the transition section. For such impellers the input parameters Z_o designating the number of inducer blades must be zero.

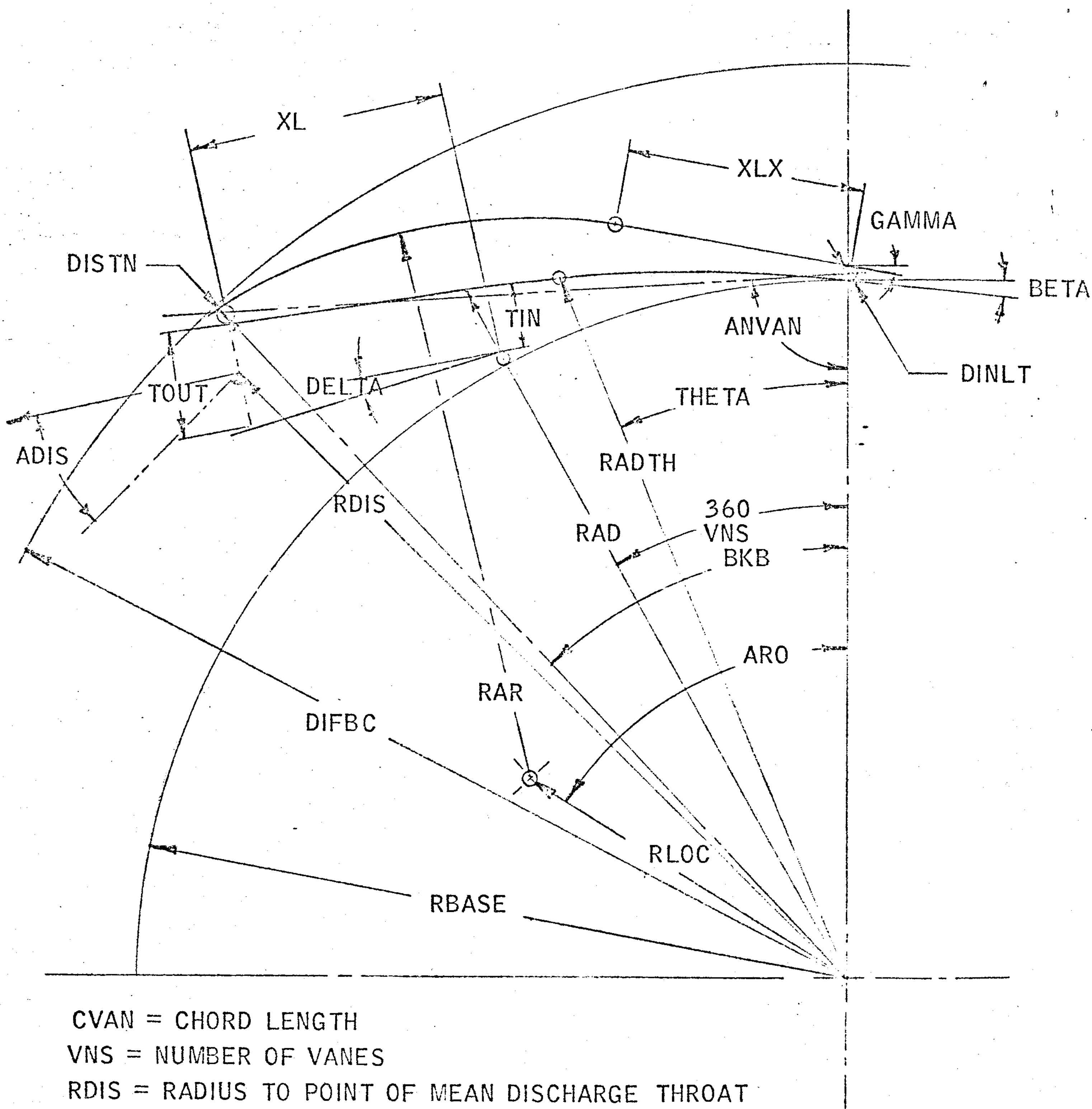
B. VANED DIFFUSER MODEL

The parallel wall vaned diffuser consists of vanes with straight line contours within the region of vane overlap. The vane shape is shown in Figure 2.

III. INSTRUCTIONS TO INPUT

1. The ratio QKI is the ratio of the impeller recirculatory flow to the net pump flow.
2. PHIMN is the limiting minimum value for the inlet tip flow coefficient.
3. The cavitation parameter VHKM is the ratio of the Net Positive Suction Head to the inlet velocity head.

DIFFUSER BLADE



CVAN = CHORD LENGTH

VNS = NUMBER OF VANES

RDIS = RADIUS TO POINT OF MEAN DISCHARGE THROAT

ADIS = ANGLE OF DISCHARGE AT THROAT (MEAN ANGLE)

FIGURE 2

4. The first partial impeller blades designated by Z1 are the longest blades next to the full blades. The inducer blades Z0 which generally extend to the impeller discharge are considered as full blades & must be added to the partial blades to obtain the total number of impeller blades. Z2, Z3 and Z4 are splitter vanes or shorter partial blades. The value to be input for the blade schedule NZ is equal to the highest number of partial blades, e.g., for Z3 NZ = 3. The blade schedule for the 24 blade M-1 oxydizer impeller, for instance, is:

Z	=	24	total number of blades
Z0	=	3	full blades or inducer blades
Z1	=	3	first or long partial blades
Z2	=	6	second or intermediate partial blades
Z3	=	6	third or short partial blades.

5. The blade angle distribution factor KBMID is the ratio of the inducer discharge mean blade angle to the inducer inlet mean blade angle. For flat plate inducers with constant hub ratio KBMID = 1.0.
6. The tip clearance factor SIG is generally 1.2.
7. To improve axial thrust balance the impeller disc is sometimes extended beyond the discharge mean diameter of the impeller, as indicated in Figure below. DR is the radial extension of the impeller disc.

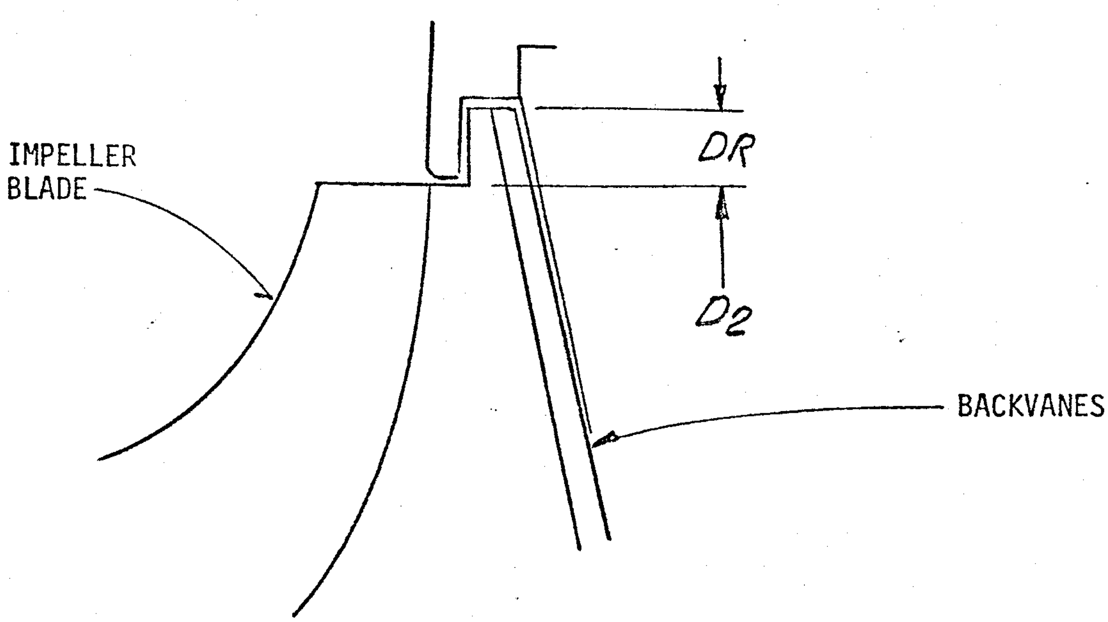


FIGURE 3

8. Impeller configuration flag FLAG

   0 unshrouded with backvanes
   1 shrouded with backvanes
   2 unshrouded with smooth backside
   3 shrouded with smooth backside

9. The labyrinth clearance factor FLACO is the ratio of the radial labyrinth clearance to the labyrinth diameter.
10. The flow coefficient factor KPHI is the ratio of the desired flow coefficient to that recommended by Stepanoff in Reference 2. For unshrouded impellers KPHI is generally less than 1.0.
11. A desired flow coefficient can be input. This will override the program recommended value. If three values are input, e.g. three pumps will be calculated in the same run.
12. The ratio XKQD is the ratio of the diffuser recirculatory flow to the net pump flow.
13. The diffuser length to throat ratio is equal to XL/TIN (see Figure 2).
14. For the parallel wall diffuser,the diffuser area ratio REX is TOUT/TIN.
15. The diffuser blade shape and especially the thickness to chord length ratio varies significantly with blade number and blade angle. If these parameters are not specified (see note 17) the program searches for an acceptable blade shape within a range of blade angles and blade number limited by RLBET and RLZD. RLBET is the difference between the maximum allowable blade angle and the minimum calculated value (generally approximately 2 to 3 degrees). RLZD is the maximum diffuser blade number specified. The acceptance criteria for the blade profile is incorporated into the main program.
16. Flag OPTFI = 1.0 if discharge flow coefficient optimization is desired.
17. SBETA and SZD are optional. If not input RLBET and RLZD must be specified in order that a low loss diffuser vane may be selected from a sample of vane shapes (see also Note 15).

Reference 2

Stepanoff, A. J. - Centrifugal and Axial Flow Pump, John Wiley & Sons, 1957

18. If the friction loss coefficient FRD is input it will override the program calculated friction coefficient based on the vane surface finish (see Note 21).

19. Diffuser loss adjustment factor FLACO $\sim$ 2.25. Value can be zero if a continuous crossover channel is used.

20. Optional housing structural constraints: RPHG, FSTHG & SSTHG. All these parameters must be either zero or positive.

21. XKFVD must be input if FRD is zero.

22. FLAHG - HOUSING TYPE DEFINITION

    1.0 Single Discharge - Single Tongue Vol. (no vaned diffuser)
    2.0 Dual Discharge Volute (no vaned Diffuser)
    3.0 Double Volute (no vaned diffuser)
    4.0 Vaned Diffuser, Single Discharge - Single Tongue Volute
    5.0 Vaned Diffuser, Dual Discharge - Volute
    6.0 Vaned Diffuser, Double Volute
    7.0 Vaned Diffuser + Crossover Channel with vaneless
    8.0 Vaned Diffuser + Reversing channel with continuous vane

23. The following parameters are related to internal crossover designs defined by housing type definition flags (FLAHG) 7.0 and 8.0:

    Friction Loss Coefficient for vaneless turn CLUT (FLAHG = 7.0). For cast channels CLUT $\approx$ 0.04. This value is lower for machined channels.

    The angle correction factor FINC applies to the inlet angle of the reversing vanes (FLAHG = 7.0). FINC is the ratio of vane inlet angle to fluid angle at the inlet to the vane.

    A fluid angle BE10 at the reversing vane discharge of 90° indicates that the fluid exits the vaned passages in radial direction.

    The number of reversing vanes ZRV is related to the number of diffuser vanes in the program. The program determined value is overridden when ZRV is input.

    The reversing vane discharge disameter D9 is related to the impeller eye diameter in the model. The program determined value is ignored if D9 is input.

The vane height B9 is indicated in Figure 4 and related to B7 in subroutine REVCH.

The ratio RBRM = r_m/B_m (Figure 4) is optional. If input it will override the program constant of 1.4.

The program constant for RB67 of 1.1 can be circumvented by inputting a specified value.

The inlet blade thickness THRV applies to housing configuration (FLAHG) 7. If input it will override the program value of 0.120.

The program constant for RDSV is 1.1.

IV. SUMMARY OF RUN MODES

1. With all optional parameters specified, e.g. discharge flow coefficient, diffuser blade number and angle.
2. As above with as many as 3 flow coefficients for evaluation purposes.
3. Flow coefficient in percent of Stepanoff's recommended value, with or without specified diffuser parameters.
4. Flow coefficient optimization, no options.

NOMENCLATURE INPUT

SYBMOL		DESCRIPTION	UNITS	FORMAT
WP		Flow Rate	lb/s	F
XN		Rotational Speed	RPM	F
RHO		Fluid Density	lb/ft^3	F
QKI	(1)*	Ratio Recirc. Flow Impeller	-	F
HNPSH		Net Positive Suction Head	ft	F
HTOT		Tot Head Required	ft	F
EPS		Inlet Hub Ratio	-	F
PHIMN	(2)*	Impeller Inlet Min Flow Coefficient	-	F
BB2		Impeller Discharge Blade Angle	Deg	F
VHKM	(3)*	Min Cavitation Parameter	-	F
SOL1		Inducer Blade Solidity	-	F
ZO		Inducer Blade Number	-	F
Z1	(4)*	First Partial Impeller Blades	-	F
Z2	(4)*	Second Partial Impeller Blades	-	F
Z3	(4)*	Third Partial Impeller Blades	-	F
Z4	(4)*	Fourth Partial Impeller Blades	-	F
KBMID	(5)*	Blade Angle Distribution Factor	-	F
NZ	(4)*	Blade Schedule	-	I
SLC		Blade Tip Clearance	In	F
SIG	(6)*	Tip Clearance Loss Factor	-	F
DR	(7)*	Radial Extension of Impeller Disk	In	F
FLAG	(8)*	Impeller Configuration	-	F
FLACO	(9)*	Labyrinth Clearance Factor	-	F
KPH1	(10)*	Flow Coefficient Factor	-	F
PHI21	(11)*	Selected Discharge Flow Coefficient	-	F
PHI22	(11)*	Selected Discharge Flow Coefficient	-	F
PHI23	(11)*	Selected Discharge Flow Coefficient	-	F
ETAHI		Initial Hydraulic Efficiency	-	F
Z		Total Number of Impeller Blades	-	F
XKQD	(12)*	Ratio Recirc. Flow Diffuser	-	F
DINLT		Diffuser Inlet Blade Thickness	In	F
RL	(13)*	Diffuser Length to Throat Ratio	-	F
REX	(14)*	Diffuser Area Ratio	-	F

SYMBOL		DESCRIPTION	UNITS	FORMAT
RLBET	(15)*	Range Diffuser Inlet Blade Angle	-	F
RLZD	(15)*	Max. Diffuser Blade Number	-	F
XKMSC		Surface Finish, Impeller	In	E
OPTFI	(16)*	Flow Coefficient Optimization Flag	-	F
SBETA	(17)*	Selected Diffuser Blade Inlet Angle	Deg	F
SZD	(17)*	Selected Diffuser Blade Number	-	F
FRD	(18)*	Friction Coefficient Diffuser	-	F
FLA	(19)*	Diffuser Loss Adjustment Factor	-	F
RPHG	(20)*	Max to Design Pressure Ratio	-	F
FSTHG	(20)*	Housing Safety Factor	-	F
SSTHG	(20)*	Housing Material Yield Strength	lb/sq in	F
VIS		Fluid Dynamic Viscosity	lb sec/sq ft	E
XKFVD	(21)*	Surface Finish Diffuser Vane	In	E
XKDVD		Diffusion Loss Factor (~.260)	-	F
XKIVD		Incidence Loss Factor (~ .300)	-	F
EVD		Diffusion Exponent Diffuser (~3.0)	-	F
FLAHG	(22)*	Housing Type Definition	-	F
XKSFS		Volute Surface Finish	In	E
CLUT	(23)*	Friction Loss Coeff, Vaneless Turn	-	F
FINC	(23)*	Angle Correction Factor		F
BE10	(23)*	Fluid Angle, REversing Vane Discharge	Deg	F
ZRV	(23)*	Number of Reversing Vanes	-	F
D9	(23)*	Reversing Vane Discharge Dia	In	F
B9	(23)*	Vane Height, Revers Vane Discharge	In	F
RBRM	(23)*	Ratio Mean Turning Radius to Mean Passage Height		F
RB67	(23)*	Ratio B6/B7	-	F
THRV	(23)*	Inlet Blade Thickness	In	F
RDSV	(23)*	Ratio DSV/D9 (~ 1.1)	-	F

*Note number, see Instructions Section III.

NOMENCLATURE OUTPUT

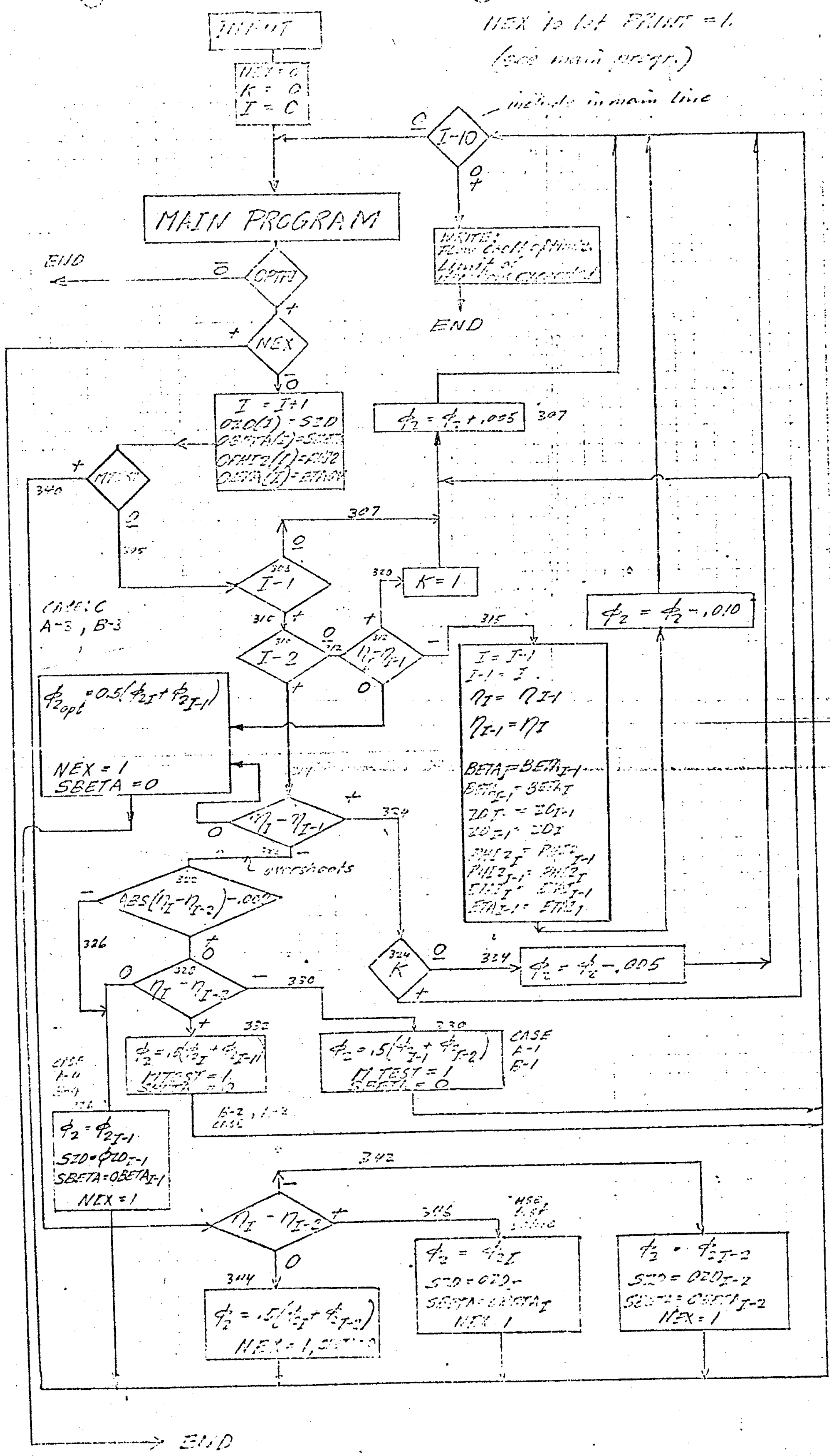
SYMBOL	DESCRIPTION	UNITS
RA	See Figure 1	In
RC	See Figure 1	In
ZL	Axial Length of Inducer Section	In
CLIND	Chord Length, Inducer	In
THIND	Blade Wrap Inducer	Deg
DHIND	Hydraulic Diameter Inducer Blade Passage	In.
CLTOT	Total Chord Length	In
RP2	Radius Locating 2nd Partial Blade	In
SOLTO	Total Solidity	-
CLIMP	Chord Length Impeller	In
THIMP	Blade Wrap Impeller	Deg
DHIMP	Hudraulic Diameter Impeller Blade Passage	In.
THTOT	Total Blade Wrap	Deg
SOL2	Blade Solidity 1st-2nd Partial	-
DH2	Hydraulic Dia. 1st-2nd Partial	In
BBC1	Blade Angle Cone 1	Deg
BBC2	Blade Angle Cone 2	Deg
BBC3	Blade Angle Cone 3	Deg
DHTOT	Hyd. Diameter Total	In
SOL3	Blade Solidity 2nd-3rd Partial	-
DH3	Hydraulic Dia. 2nd-3rd Partial	In.
CLRS	Chord Length Radial Section	In
CLC1	Chord Length Cone 1	In
CLC2	Chord Length Cone 2	In
CLC3	Chord Length Cone 3	In
CLTS	Chord Length Total	In
SOLIP	Impeller Blade Solidity	-

SYMBOL	DESCRIPTION	UNITS
THRS	Blade Wrap Radial Section	Deg
THC1	Blade Wrap Cone 1	Deg
THC2	Blade Wrap Cone 2	Deg
THC3	Blade Wrap Cone 3	Deg
THTS	Blade Wrap Total	Deg
SCL	Blade Tip Clearance	In
DELE	Clearance Loss Parameters	-
DELK	Clearance Loss Parameter	-
DELR	Clearance Loss Parameter	-
W2TH	Discharge Relative Velocity	ft/sec
RW	Relative Velocity Ratio	-
HTH	Theoretical Head	ft
SLPCF	Slip Coefficient	-
PSINC	Head Loss Coefficient Inducer	-
PSF	Head Loss Coefficient Friction	-
PSD	Head Loss Coefficient Diffusion	-
PSTIP	Head Loss Coefficient Tip	-
PSCL	Head Loss Coefficient Clearance	-
PSIBL	Head Loss Coefficient Blade	-
PSITH	Theoretical Head Coefficient	-

Parameters describing diffuser blade geometry are depicted in Figure 2. Other diffuser data:

STANG	Stagger Angle	Deg
TRACO	Chord Length(Transformed)	In.
SOLID	Solidity	-
BBM4	Inlet Mean Blade Angle	Deg
BBM5	Exit Mean Blade Angle	Deg
FEE	Blade Turning Angle	
ACROSS	Blade Cross-sectional Area	in^2
AEW	Passage End Wall Area	in^2
ABS1	Blade Surface Area	In^2
AR	Ratio AEW/(Z x ABS1)	
DH	Hydraulic Diameter	in^2
ATHT	Total Throat Area	in^2

FLOW COEFFICIENT OPTIMIZATION



@ ELT ANSWR,1,710427, 53088

```
      SUBROUTINE ANSWR
      REAL KBMID
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,          XKDVD,XK1VD,XKFVD,EVD,FLA,    XKQD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
  110 FORMAT(1X,'INLET HUB DIAMETER,DH1',13X,F10.3,2X,'INCHES',10X,'INLE
     7T MEAN RADIUS,RM1',14X,F10.3,2X,'INCHES')
  111 FORMAT(1X,'INDUCER VANE HEIGHT,H',14X,F10.3,2X,'INCHES',10X,'INLET
     8 AREA,A1',22X,F10.3,2X,'SQ IN')
  112 FORMAT(1X,'INLET BLOCKAGE,BLK1',16X,F10.3,3X,'***',12X,'INDUCER DI
     1FF PARAMETER,DPIND',7X,F10.3,3X,'***')
  113 FORMAT(1X,'INLET AREA WITH BLOCKAGE,AB1',7X,F10.3,2X,'SQ IN',11X,'
     1DISCHARGE AREA,A2',18X,F10.3,2X,'SQ IN')
  114 FORMAT(1X,'INLET MEAN BLADE ANGLE,BBM1',8X,F10.3,2X,'DEGREES')
  115 FORMAT(1X,'IMPLLR DIFF PARAMETER,DPIMP',8X,F10.3,3X,'***',12X,'DIS
     2CHARGE BLOCKAGE,BLK2',12X,F10.3,3X,'***')
  116 FORMAT(1X,'INLET TIP TO DISCHARGE DIA RATIO,XSI',F9.3,3X,'***',12X
     1,'STATIC MOMENT,SM',19X,F10.3,2X,'SQ IN',/)
  117 FORMAT(5X,7HRA     =,F10.3,5X,7HRC     =,F10.3,5X,7HZL     =,F10.3,5X
     1,7HCLRS   =,F10.3,5X,7HTHRS   =,F10.3)
  118 FORMAT(5X,7HCLIND =,F10.3,5X,7HCLIMP =,F10.3,5X,7HBBC1   =,F10.3,5X
     1,7HCLC1   =,F10.3,5X,7HTHC1   =,F10.3)
  119 FORMAT(5X,7HTHIND =,F10.3,5X,7HTHIMP =,F10.3,5X,7HBBC2   =,F10.3,5X
     1,7HCLC2   =,F10.3,5X,7HTHC2   =,F10.3)
  120 FORMAT(5X,7HDHIND =,F10.3,5X,7HDHIMP =,F10.3,5X,7HBBC3   =,F10.3,5X
     1,7HCLC3   =,F10.3,5X,7HTHC3   =,F10.3)
  121 FORMAT(5X,7HCLTOT =,F10.3,5X,7HTHTOT =,F10.3,5X,7HDHTOT =,F10.3,5X
     1,7HCLTS   =,F10.3,5X,7HTHTS   =,F10.3)
      WRITE(3,114) BBM1
      WRITE(3,110) DH1,RM1
      WRITE(3,111) H,A1
      WRITE(3,112) BLK1,DPIND
      WRITE(3,113) AB1,A2
      WRITE(3,115) DPIMP,BLK2
      WRITE(3,116) XSI,SM
      WRITE(3,117) RA,RC,ZL,CLRS,THRS
      WRITE(3,118) CLIND,CLIMP,BBC1,CLC1,THC1
      WRITE(3,119) THIND,THIMP,BBC2,CLC2,THC2
      WRITE(3,120) DHIND,DHIMP,BBC3,CLC3,THC3
      WRITE(3,121) CLTOT,THTOT,DHTOT,CLTS,THTS
      IF(NZ-2) 10,11,12
```

```
     6 FORMAT(5X,'SOLIP =',F10.4,5X,'SOLTO =',F10.4)
    10 WRITE(3,6) SOLIP,SOLTO
       GO TO 30
    22 FORMAT(5X,7HRP2    =,F10.3,5X,7HSOL2   =,F10.3,5X,7HSOL3   =,F10.3,5X
      1,7HSOLIP =,F10.3/5X,7HSOLTO =,F10.3,5X,7HDH2    =,F10.3,5X,7HDH3
      2=,F10.3)
    11 WRITE(3,22) RP2,SOL2,SOL3,SOLIP,SOLTO,DH2,DH3
       GO TO 30
    12 IF(NZ-3) 13,13,14
    24 FORMAT(5X,7HSOL2   =,F10.3,5X,7HSOL3   =,F10.3,5X,7HSOL4   =,F10.3,5X
      3,7HRP2    =,F10.3,5X,7HRP3    =,F10.3/5X,7HSOLIP =,F10.3,5X,7HSOLTO
      4=,F10.3,5X,7HDH2    =,F10.3,5X,7HDH3    =,F10.3,5X,7HDH4    =,F10.3)
    13 WRITE(3,24) SOL2,SOL3,SOL4,RP2,RP3,SOLIP,SOLTO,DH2,DH3,DH4
       GO TO 30
    27 FORMAT(5X,7HRP2    =,F10.3,5X,7HSOL2   =,F10.3,5X,7HSOL3   =,F10.3,5X
      1,7HDH2    =,F10.3,5X,7HDH3    =,F10.3/5X,7HRP3    =,F10.3,5X,7HSOL4
      2=,F10.3,5X,7HSOL5   =,F10.3,5X,7HDH4    =,F10.3,5X,7HDH5    =,F10.3/5
      3X,7HRP3    =F10.3,5X,7HSOLIP =,F10.3,5X,7HSOLTO =,F10.3)
    14 WRITE(3,27) RP2,SOL2,SOL3,DH2,DH3,RP3,SOL4,SOL5,DH4,DH5,RP3,SOLIP,
      1SOLTO
    30 RETURN
       END
```

```
@ ELT ASIN,1,710427, 65089

      FUNCTION ASIN(A)
      IF(A)1,2,2
    1 SIGN=-1.
      GO TO 3
    2 SIGN=1.
    3 ASIN=ATAN(1./SQRT(1./A**2-1.))*SIGN
      RETURN
      END
```

@ ELT CLAB,1,710427, 63091

```
      SUBROUTINE CLAB
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO, W ,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,          XKDVD,XK1VD,XKFVD,FVD,FLA,    XKQD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
      R2=D2/2.
      RT1=DT1/2.
      D=2.*RWR
      CO=FLACO*D
      PI=ESHR/16.
      T=.030
      XNTH=5.
      DPFF=.1645E-07*.025*RHO*XN**2*(R2**2-RT1**2)
      P=DPIPS-DPFF
      VI=VIS*(32.16/RHO)
      COEC=.67
      FA=2.*RHO*32.1741*P*144.
      FB=SQRT(FA)
      S=3.1416*CO*(D+CO)/144.
      CF=(XNTH-1.)*(1.-8.52/((PI-T)/CO+7.23))+1.
      DO 40 I=1,3
      COE=COEC/SQRT(CF)
      W=COE*S*FB
      RE=CO*W/(6.*S*VI*RHO)
      ZLAB=T/CO
      IF(RE-60.)200,200,300
  200 RZ=ZLAB/RE
      CALL INT4(XZ,XK,RZ,FK)
      COEC=1./SQRT(64./RE+48.*ZLAB/RE+FK)
      GO TO 40
  300 RE=ALOG(RE)
      CALL INT4(XR,XFR,RE,FFR)
      FFR=EXP(FFR)
      RE=EXP(RE)
      COEO=.62*RE**.0085
      IF(ZLAB-1.15) 310,310,320
  310 F=0
      GO TO 330
  320 F=1.-2.7183**(-.95*(ZLAB-1.15))
  330 IF(RE-6000.)340,340,350
  340 COEC=1./SQRT(1/COEO**2-F*(2*SQRT(1/COEO**2-64./RE)-2.)+2.*FFR*ZLAB
     1)
```

```
      GO TO 40
  350 COE=1./SQRT(1./COEO**2-(2./COEO-2.)*F+2.*FFR*ZLAB)
   40 CONTINUE
      IF(PRINT) 50,50,60
   60 WRITE(3,27)
      WRITE(3,29) D
      WRITE(3,31) CO
      WRITE(3,33) XNTH
      WRITE(3,37) PI
      WRITE(3,39) T
      WRITE(3,41) P
      WRITE(3,15) W
   27 FORMAT(/5X,'*** LABYRINTH DATA ***',/)
   29 FORMAT(5X,'LABYRINTH DIAMETER, D',33X,F10.4,2X,'IN')
   31 FORMAT(5X,'RADIAL CLEARANCE, CO',34X,F10.4,2X,'IN')
   33 FORMAT(5X,'NUMBER OF TEETH, XNTH',33X,F10.4,2X,'***')
   37 FORMAT(5X,'TOOTH SPACING, PI',37X,F10.4,2X,'IN')
   39 FORMAT(5X,'TOOTH WIDTH, T',40X,F10.4,2X,'IN')
   41 FORMAT(5X,'PRESSURE DROP, P',38X,F10.4,2X,'LB/SQIN')
   15 FORMAT(5X,'LABYRINTH FLOW RATE, WWR',30X,F10.4,2X,'LB/SEC')
   50 RETURN
      END
```

@ ELT CUFIT,1,710427, 53094

```
      SUBROUTINE CUFIT (M,NUMBR,X,Y,C)
      DIMENSION X(10),Y(10),A(11,11),B(11),C(11),P(20)
      MX2=2*M
      DO 13 I=1,MX2
      P(I)=0.0
      DO 13 J=1,NUMBR
   13 P(I)=P(I)+X(J)**I
      N=M+1
      DO 30 I=1,N
      DO 30 J=1,N
      K=I+J-2
      IF (K) 29,29,28
   28 A(I,J)=P(K)
      GO TO 30
   29 A(1,1)=NUMBR
   30 CONTINUE
      B(1)=0.0
      DO 21 J=1,NUMBR
   21 B(1)=B(1)+Y(J)
      DO 22 I=2,N
      B(I)=0.0
      DO 22 J=1,NUMBR
   22 B(I)=B(I)+Y(J)*X(J)**(I-1)
      NM1=N-1
      DO 300 K=1,NM1
      KP1=K+1
      L=K
      DO 400 I=KP1,N
      IF (ABS(A(I,K))-ABS(A(L,K))) 400,400,401
  401 L=I
  400 CONTINUE
      IF (L-K) 500,500,405
  405 DO 410 J=K,N
      TEMP=A(K,J)
      A(K,J)=A(L,J)
  410 A(L,J)=TEMP
      TEMP=B(K)
      B(K)=B(L)
      B(L)=TEMP
  500 DO 300 I=KP1,N
      FACT=A(I,K)/A(K,K)
      A(I,K)=0.0
      DO 301 J=KP1,N
  301 A(I,J)=A(I,J)-FACT*A(K,J)
  300 B(I)=B(I)-FACT*B(K)
      C(N)=B(N)/A(N,N)
      I=NM1
  710 IP1=I+1
      SUM=0.0
      DO 700 J=IP1,N
  700 SUM=SUM+A(I,J)*C(J)
      C(I)=(B(I)-SUM)/A(I,I)
      I=I-1
      IF(I) 800,800,710
  800 RETURN
      END
```

@ ELT DBLPR,1,710427, 63096

```
      SUBROUTINE DBLPR
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,CH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,RBASE,BETA,BFL4, ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1 RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2 ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLD ,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DHD,AR,ATHT,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,          XKDVD,XK1VD,XKFVD,EVD,FLA,    XKQD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
      ALPH4=(90.-BFL4)/57.296
      VTH = .321*QD/(ZD*B2*TIN)
      RVD=VTH/V4
      RED=0.01037*DHD*VTH*RHO/VIS
      IF (FLAHG-7.) 32,32,34
   32 V5=     VTH*RDIS/DIFBC/REX
      GO TO 9
   34 V5 = VTH*TIN/TEX5
    9 IF (FRD) 10,10,20
   10 IF(RED-1.E+05) 12,12,13
   12 FRD=0.0032+0.221/RED**0.237
      GO TO 20
   13 FRD=1./(0.86858*ALOG(2.*DHD/XKFVD)+1.74)**2
   20 BFL4=BFL4/57.296
      BBM4=BBM4/57.296
      IF(FLAHG-7.) 22,22,21
   22 BFL5=BFL5/57.296
      OMFD=FRD        *TRACO*RVD**2/(4.*DHD)
      DVD=1.-RBASE/DIFBC*COS(BBM4)/COS(BFL5)+COS(BBM4)/(2.*SOLD)*(SIN(BB
     1M4)/COS(BBM4)-RBASE/DIFBC*SIN(BFL5)/COS(BFL5))
      OMDD=XKDVD*DVD**EVD
      GO TO 23
   21 BFL5=(90.-BCM5)/57.296
      OMFD = FRD*(RL*TIN+DLDM+3.14159*RBASE/ZD)*RVD**2/(4.*DHD)
      OMDD = 0.2*(1.-(V5/V4)**2)
   23 G=BBM4
      C=COS(G)
      A=6.5797*C**2/ZD**2-19.233*C**4/ZD**3+8.6584*C**4/ZD**4*(8.*C**2-1
     1.)
      PSIA=EXP(-2.*G*SIN(2.*G)/ZD)*EXP(A)/((2.*C)**(4.*C**2/ZD))
      ASHF=ATAN(1/PSIA*(RBASE/DIFBC)**2*1/SIN(BFL5)+SIN(BBM4)/COS(BBM4))
      SAVE=BBM4
      BBM4=ASHF
      OM1D=XK1VD*(COS(BFL4))**2*(SIN(BFL4)/COS(BFL4)-SIN(BBM4)/COS(BBM4)
     1)**2
      BBM4=SAVE
      FLVLD=(2.*RBASE-D2)/(2.*SIN(ALPH4))
```

```
      REVLD=.005185*B4*C34*RHO/VIS
      IF(REVLD-1.E+05) 15,15,16
   15 FRVLD=.0032+.221/REVLD**0.237
      GO TO 18
   16 FRVLD = 1./(0.86858*ALOG(B4/XKFVD) + 1.74)**2
   18 OMVLD=FRVLD*FLVLD*(C34/V4)**2/(2.*B4)
      OMTD=OMFD+OMDD+OM1D
      IF(FLAHG-7.) 45,45,46
   45 OMTDA=FLA*OMTD
      OMTOT=OMTDA+OMVLD
      GO TO 47
   46 OMTOT = OMTD + OMVLD
   47 ALPH4=ALPH4*57.296
      BFL4=BFL4*57.296
      BFL5=BFL5*57.296
      BBM4=BBM4*57.296
      IF(PRINT) 50,50,40
   40 WRITE(3,507)
      WRITE(3,508)VTH,OMVLD
      WRITE(3,509)RVD,OMFD
      WRITE(3,510)V5,OMDD
      WRITE(3,511)ADIS,OM1D
      WRITE(3,512)RED,OMTD
      IF(FLAHG-7.) 42,42,41
   41 WRITE(3,613) FRD,OMTOT
      GO TO 43
   42 WRITE(3,513)FRD,OMTDA
      WRITE(3,515) DVD,OMTOT
   43 CONTINUE
  507 FORMAT(/45X,'PERFORMANCE-CHANNEL FLOW APPROACH'//)
  508 FORMAT(10X,'THROAT VELOCITY',15X,F10.2,' FT/SEC',7X,'FRICTION LOSS
     1 COEFF, VANELESS SECTION',F10.4/)
  509 FORMAT(10X,'THROAT TO INLET VEL. RATIO',4X,F10.4,14X,'FRICTION LOS
     1S COEFFICIENT, BLADE',5X,F10.4/)
  510 FORMAT(10X,'DIFFUSER DISCH. VELOCITY',6X,F10.1,' FT/SEC',7X,
     1 'DIFFUSION LOSS COEFFICIENT',11X,F10.4/)
  511 FORMAT(10X,'DIFF.DISCH. MEAN CHANNEL ANGLE',F10.3,' DEG',10X,
     1 'INCIDENCE LOSS COEFFICIENT',11X,F10.4/)
  512 FORMAT(10X,'REYNOLDS NUMBER,THROAT',7X,E11.4,14X,
     1 'TOTAL LOSS COEFFICIENT, BLADE',8X,F10.4/)
  513 FORMAT(10X,'FRICTION FACTOR',15X,F10.5,14X,
     1 'ADJUSTED OVERALL LOSS COEFF., BLADE',2X,F10.4/)
  515 FORMAT(10X,'DIFFUSION PARAMETER',11X,F10.4,14X,'TOTAL LOSS COEFFIC
     1IENT',15X,F10.4//)
  613 FORMAT(10X,'FRICTION FACTOR',15X,F10.5,14X,
     1'TOTAL LOSS COEFFICIENT',15X,F10.4//)
   50 RETURN
      END
```

@ ELT DFRBV,1,710427, 53098

```
      SUBROUTINE DFRBV
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3T0,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,OI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,OKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,ZZZ,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2ANVAN,BKG,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,          XKDVD,XK1VD,XKFVD,EVD,FLA,    XKQD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
      WIMP=WP*(1.+OKI)
      R2=D2/2.
      RE2=U2*R2*RHO/(386.*VIS)
      IF(FLAG-1.) 10,10,20
   10 RBV2=R2+DR
      RBV1=R2/2.
      IF(SCL) 80,80,81
   80 SCL=0.010201+0.0008095*D2+0.00011078*D2**2
   81 SBV=SCL/.17+SCL
      SBV=SCL/.17+SCL
      OMIP=.1048*XN
      TEMP=SBV/.8/SCL-1.
      XBV=TEMP*(40./(1.+5.*SBV/RBV2)*RE2 **.2/.56*(SBV/RBV2))**.5
      ROMBV=XBV/(1.+XBV)
      OMFL=OMIP*ROMBV
      TQBV=.1562E-07*RHO*40.*((RBV2)**4-(RBV1)**4)*SBV*(OMIP-OMFL)**2*(T
     1EMP)**2
      PFBV=OMIP*TQBV/550.
      PFBS=0.
      XKDF=0.
      IF(FLAG-1.) 3,20,20
    3 PFFS=0.
      GO TO 35
   20 REX=R2+DR
      RBS=.3*R2
      IF(RE2-10.**6) 21,22,22
   21 XKDF=3.68431E-06-7.869741E-07*ALOG(RE2 )+5.706801E-08*(ALOG(RE2 ))
     1**2-1.3921085E-09*(ALOG(RE2 ))**3 .
      GO TO 24
   22 XKDF=31.5E-08/RE2 **0.164
   24 ETIP=.03*D2
      XPDF=4.61E-09*XKDF*RHO*XN**3
      IF (FLAG-2.) 61,23,23
   23 PFBS=XPDF*(REX**4*(2.*REX+5.*ETIP)-2.*(RBS**5-REX**5+R2**5))
      PFBV=0.
      IF (FLAG-2.) 61,31,32
   31 PFFS=0.
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```
      GO TO 35
   61 PFBS=0.
   32 RWR=.55*DT1
      RT1=DT1/2.
      ESHR=5.*ETIP
      PFFS1=XPDF*(RWR**4*(2.*RWR+5.*ESHR)-2.*RT1**5)
      PFFS2=XPDF*(R2**4*(2.*R2+5.*ETIP)-2.*RWR**5)
      PFFS=PFFS1+PFFS2
   35 PFTOT=PFBV+PFFS+PFBS
      DLPDF=17680.*PFTOT/(U2**2*WIMP)
      PSIIP=PSITH-PSIBL
      PSIIN=PSITH+DLPDF
      PSIPS=PSIIP-.5*(PHI2**2+PSITH**2)
      DPIPS=PSIPS*U2**2/32.174*RHO/144.
      IF(PRINT) 50,50,40
   40 WRITE(3,12) RE2
      WRITE(3,13) XKDF
      WRITE(3,14) PFBV
      WRITE(3,15) PFBS
      WRITE(3,16) PFFS
      WRITE(3,17) PFTOT
      WRITE(3,18) DLPDF
      WRITE(3,11) PSIIP
      WRITE(3,43) PSIIN
      WRITE(3,41) PSIPS
      WRITE(3,53) DPIPS
   12 FORMAT(5X,'REYNOLDS NO., IMPELLER, RE2',11X,E10.4,2X,'***')
   13 FORMAT(5X,'DISK FRICTION COEFF., XKDF',12X,E10.4,2X,'***')
   14 FORMAT(5X,'POWER, BACKVANES, PFBV',16X,F10.3,2X,'HP')
   15 FORMAT(5X,'POWER, BACK FACE, PFBS',16X,F10.3,2X,'HP')
   16 FORMAT(5X,'POWER, FRONT FACE, PFFS',15X,F10.3,2X,'HP')
   17 FORMAT(5X,'POWER, TOTAL, PFTOT',19X,F10.3,2X,'HP')
   18 FORMAT(5X,'LOSS COEFF., DLPDF',20X,F10.4,2X,'***'/)
   11 FORMAT(5X,'IMPELLER HEAD COEFFICIENT, PSIIP',22X,F10.4,2X,'***')
   43 FORMAT(5X,'INPUT HEAD COEFFICIENT, PSIIN',25X,F10.4,2X,'***')
   41 FORMAT(5X,'IMPELLER STATIC HEAD COEFFICIENT, PSIPS',15X,F10.4,2X,'
     1***')
   53 FORMAT(5X,'IMPELLER STATIC PRESSURE RISE, DPIPS',18X,F10.4,2X,'LB/
     1SQIN')
   50 RETURN
      END
```

@ ELT GEOM,1,710427, 63101

```
      SUBROUTINE GEOM(IMESS,N)
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,XX,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,XXX,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,OPTPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,RBASE,BETA,BFL4,VNS,DINLT,DISTH,TIN,TOUT,XL,V5,
     1 RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2 ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHRC,PI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEO,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,            XKDVD,XK1VD,XKFVD,EVD,FLA,    XKQD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
      ALPHA=360./VNS
      DIS=TIN+DINLT/2.
      RP=RBASE+DINLT/2.
      THETA=ALPHA/2.
      K=0
  100 K=K+1
      ANG1=90.-BETA-ALPHA+THETA
      ANG2=ALPHA+BETA-THETA
      FUCT=EXP(3.14159*THETA*SIN(BETA/57.296)/COS(BETA/57.296)/180.)
      FTH=SIN((BETA+90.)/57.296)*RBASE*FUCT-RP*COS(ANG2/57.296)-DIS
      FPTH=SIN(BETA/57.296)/COS(BETA/57.296)*SIN((BETA+90.)/57.296)*
     1RBASE/57.296*FUCT-RP*SIN(ANG2/57.296)/57.296
      ERROR=FTH/FPTH
      THETA=THETA-ERROR
      IF(ABS(ERROR)-0.01) 140,140,150
  150 IF (K-30) 100,300,300
  140 C=DIS/COS(ANG2/57.296)
      RAD=RP+C
      DELTA=57.296*ATAN((TOUT-TIN)/XL)
      GAMMA=ALPHA-THETA+BETA-DELTA
      ANG3=0.
      N=0
  200 N=N+5
      ANG3=ANG3+5.
      IF(ANG3-THETA) 210,220,220
  210 RADUS(N)=RBASE*EXP(3.14159*ANG3*SIN(BETA/57.296)/COS(BETA/57.296
     1)/180.)
      GO TO 200
  220 RADTH=RBASE*EXP(3.14159*THETA*SIN(BETA/57.296)/COS(BETA/57.296)/
     1180.)
      CD=XL-DIS*SIN(ANG2/57.296)/COS(ANG2/57.296)
      AXG2=90.+ANG2
      OD=SQRT (RAD**2+CD**2-2.*RAD*CD*COS(AXG2/57.296))
      PHI=ASIN((CD/OD)*SIN(AXG2/57.296))*57.296
      BKA=PHI+ALPHA
      DE=DISTH/2.0
      ZETA=ATAN(DE/CD)*57.296
```

```
      CE=CD/COS(ZETA/57.296)
      VE=ZETA+AXG2
      OE=SQRT (RAD**2+CE**2-2.*RAD*CE*COS(VE/57.296))
      DIFBC=OE+DE
      OMEGA=ASIN((CE/OE)*SIN(VE/57.296))*57.296
      BKB=OMEGA+ALPHA
      XLX=XL/COS(THETA/57.296)
      SQ=XLX*COS(GAMMA/57.296)-(DINLT/2.0)*SIN(ANG2/57.296)
      PO=XLX*SIN(GAMMA/57.296)
      RG=DIFBC*SIN(BKB/57.296)
      OR=DIFBC*COS(BKB/57.296)
      PT=(RBASE+(DINLT/2.)+(DINLT*COS(ANG2/57.296)/2.0)+PO)-OR
      GT=RG-SQ
      GP=SQRT(PT**2+GT**2)
      PH=GP/2.0
      SI=ATAN(SQRT(1.0/(PT/GP)**2-1.0))*57.296
      TI=SI-GAMMA
      RAR=PH/COS(TI/57.256)
      RAY=OR+PT-RAR*COS(GAMMA/57.296)
      RAX=SQ+RAR*SIN(GAMMA/57.296)
      ARO=ATAN(RAX/RAY)*57.296
      RLOC=SQRT(RAY**2+RAX**2)
      FANG=ABS(ARO-360./VNS)
      HEIGH=(RBASE**2+RLOC**2-2*RBASE*RLOC*COS(FANG/57.296))**.5
      THICK=RAR-HEIGH-DINLT-TIN
      IF(RAR+RLOC-DIFBC)70,70,80
   80 IF(BKB-ARO)70,70,71
   71 XLX=XL/COS(DELTA/57.296)
      XAP=COS(GAMMA/57.296)*XLX
      YAP=RBASE+DINLT+XLX*SIN(GAMMA/57.296)
      HOP=GAMMA+ATAN(XAP/YAP)*57.296
      SAP=SQRT(XAP**2+YAP**2)
      FUNX=(DIFBC/SAP-COS(HOP/57.296))/SIN(HOP/57.296)
      RHO=ATAN(1./FUNX)*57.296
      RAR=SIN((180.-2.*RHO-HOP)/57.296)*SAP/SIN(2.*RHO/57.296)
      ARO=ATAN(XAP/YAP)*57.296+180-(2.*RHO+HOP)
      RLOC=DIFBC-RAR
      FANG=ABS(ARO-360./VNS)
      HEIGH=(RBASE**2+RLOC**2-2*RBASE*RLOC*COS(FANG/57.296))**.5
      THICK=RAR-HEIGH-DINLT-TIN
   70 CVAN=SQRT(RP**2+OE**2-2.0*RP*OE*COS(BKB/57.296))
      X=(OE/CVAN)*SIN(BKB/57.296)
      XLT=TOUT/(SIN(DELTA/57.296)/COS(DELTA/57.296))
      D2=DELTA/2.0
      DHR=XLT*(SIN(D2/57.296)/COS(D2/57.296))
      OZ=OD*ABS(COS(BKA/57.296))
      ANDX=THETA-BETA
      OV=OZ-DHR*COS(ANDX/57.296)
      DV=OD*SIN(BKA/57.296)-DHR*SIN(ANDX/57.296)
      RDIS=SQRT(OV**2+DV**2)
      DISA=ATAN(DV/OV)*57.296
      ADIS=DISA+BETA-THETA-D2
      IF (X-1.0000) 33,31,32
   33 ANVAN=ASIN((OE/CVAN)*SIN(BKB/57.296))*57.296
      GO TO 11
   31 ANVAN=90.0
      GO TO 11
   32 ANGL=ASIN ((DIS/CVAN)*SIN(BKB/57.296))*57.296
      ANVAN=180.-(BKB+ANGL)
   11 RO=DIFBC-DISTH/2.
```

```
      R1=RBASE+DINLT/2.
      STANG=90.-ATAN(  ALOG(RO/R1)/BKB*57.296)*57.296
      TRACO=(RO-R1)/SIN((90.-STANG)/57.296)+(DISTH+DINLT)/2.
      IF(FLAHG-7.) 72,72,74
   72 SOLID=((ALOG(RO/R1))**2+(BKB     /57.296)**2)**.5/360.*VNS*57.296
      GO TO 75
   74 SOLID = 2.*(RL*TIN+DLDM)/(TIN+TOUT)
   75 BBM4=90.-(GAMMA+BETA)/2.
      AIN=ASIN(SIN((BETA+90.)/57.296)*RADTH/(DIFBC-DISTH))*57.296
      IF(BK)-ARO)85,90,90
   85 AOS=90.-ASIN(RLOC*SIN((ARO-BKB)/57.296)/RAR)
      BBM5=(AOS+AIN)/2.
      GO TO 91
   90 BBM5=(90.+AIN)/2.
   91 FEE=BBM4-BBM5
      THICO=THICK/TRACO
      AW=3.14159*(DIFBC**2-(RBASE)**2)
      ACROS=TRACO*(DISTH+DINLT+4.*THICK)/6.
      AEW=2.*(AW-VNS*ACROS)
      ABS1=B4*(2.*TRACO+3.14159/2.*(DINLT+DISTH)+THICK)
      AR=AEW/VNS/ABS1
      DH=B4*(TIN+TOUT)/4./(B4+(TIN+TOUT)/2.)
      BDEX= (ASIN( RDIS/DIFBC * SIN((90.+ADIS)/57.296)))*57.296
      BCM5 = 90.-BDEX
      THEX = 90. - ADIS - BDEX
      DLDM = SIN( THEX/57.296)*DIFBC/SIN((90.+ADIS)/57.296)
      TEX5 = (XL+DLDM)/XL*(TOUT-TIN) + TIN
      GO TO 301
  300 IMESS=1
  301 RETURN
      END
```

@ ELT ILOSS,1,710427, 53104

```
      SUBROUTINE ILOSS
      REAL KBMID
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,K3MID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEO,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,        XKDVD,XK1VD,XKFVD,EVD,FLA,    XKOD,Q,OD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
      EQUIVALENCE (PSITH,PSIT),(PHI2,PHI),(U2,U)
      DM1=2.*RM1
      R2=D2/2.
      RT1=DT1/2.
      CCL=CLIMP/2.9
      DELK=25.0/CCL
      BB2R=BB2/57.296
      CU2E=U2-CM2/SIN(BB2R)*COS(BB2R)
      IF(BB2-90.) 19,25,25
   19 PSISL=.6*(1.+BB2/60.)
      PSL=PSISL*R2**2/Z/SM
      SLPCF=1./(1.+PSL)
      GO TO 26
   25 SLPCF=1.-1.98/Z
   26 CU2TH=SLPCF*CU2E
      PSITH=CU2TH/U2
      C2 = SQRT(CU2TH**2 + CM2**2)
      ALP2 = ATAN(CM2/CU2TH)*57.296
      TRNSK=.5
      CLTOT=CLIMP+CLIND
      BFM1=.575*BBM1
      BBM1R=BBM1/57.296
      BBT1R=BBT1/57.296
      BFM1R=BFM1/57.296
      WBM1=0.321*QI/(AB1*SIN(BBM1R))
      PHIM1=DT1*PHI1T/DM1
      WU2TH=U2*(1.-SLPCF*(1.-PHI2*COS(BB2R)/SIN(BB2R)))
      W2TH=SQRT(CM2**2+WU2TH**2)
      WT1 = SQRT(CM1**2 + UT1**2)
      RW = W2TH/WT1
      WMR=0.5*(WBM1+W2TH)
      PSINC=0.15*(PHIM1*(COS(BFM1R)/SIN(BFM1R)-COS(BBM1R)/SIN(BBM1R)))**
     12
      REM=DHTOT*RHO*WMR/(96.522*VIS)
      IF(CLIND) 30,30,31
   30 IF(REM-1.E+05) 33,33,35
```

```
   33 FRM=0.0032+0.221/REM**0.237
      GO TO 36
   35 FRM = 1./(0.86858*ALOG(DHTOT/(2.*XKMSC ))+1.74)**2
   36 CLF=FRM*CLTOT/(4.*DHTOT)
      HLF=WMR**2/64.348*CLF
      PSF=WMR**2/(2.*U2**2)*CLF
      FRIMP = FRM
      PSDID=0.
      GO TO 40
   31 WMIP=0.5*(WBM1*SIN(BBM1R)/SIN(KBMID*BBM1R)+W2TH)
      REIMP=DHIMP*RHO*WMIP/(96.522*VIS)
      IF(REIMP-1.E+05) 37,37,38
   37 FRIMP=0.0032+0.221/REIMP**0.237
      GO TO 39
   38 FRIMP = 1./(0.86858*ALOG(DHIMP/(2.*XKMSC))+1.74)**2
   39 HLFIP=WMIP**2/64.33*(FRIMP*CLIMP*0.25/DHIMP)
      CLFIP=64.348*HLFIP/WMR**2
      PSFIP=32.174*HLFIP/U2**2
      WIND=WBM1*SIN(BBM1R)/SIN(BBM1R*(1.+KBMID)*0.5)
      REIND=DHIND*RHO*WIND/(96.522*VIS)
      IF(REIND - 1.E+05) 41,41,42
   41 FRIND=0.0032+0.221/REIND**0.237
      GO TO 43
   42 FRIND = 1./(0.86858*ALOG(DHIND/(2.*XKMSC))+1.74)**2
   43 HLFID=FRIND*CLIND*WIND**2/(257.392*DHIND)
      CLFID=64.348*HLFID/WMR**2
      PSFID=32.174*HLFID/U2**2
      PSF=PSFIP+PSFID
      PSDID=0.03*DPIND**0.2
   40 PSTIP=TRNSK*(PHI2*BLK2)**2
      PSDIP=0.08*DPIMP**3
      PSD=PSDIP+PSDID
      PSIBL=PSINC+PSF+PSD+PSTIP
      HTH=PSITH*U2**2/32.174
      IF(FLAG-1.) 409,440,409
  409 IF(FLAG-3.) 410,440,410
  410 IF(SCL) 430,440,450
  430 SCL=0.010201+0.0008095*D2+0.00011078*D2**2
      GO TO 450
  440 IF(PRINT) 421,421,439
  439 WRITE(3,420)
  420 FORMAT(/5X,'IMPELLER IS SHROUDED',/)
  421 PSCL=0
      DELE=0.
      DELR=0.
      SCL=0.
      GO TO 470
  450 CONTINUE
      DELR=SCL/D2
      BDR=B2/D2
      DT=D2/12.
      CLPT=CLIMP/12.
      VI=32.174*VIS/RHO
      A=1.5708-BB2R
      DSTR=1.72*SQRT(VI*CLPT*COS(A)*DELK/(PHI*U))
      Y=DELR*DT/(2.*DSTR)
      IF(Y-2.)1,2,2
    1 FI=1.-(Y-.25*Y**2)**2
      GO TO 3
    2 FI=0.
```

```
    3 G=PHI*PSIT/(SIG*COS(A))
      DELE=DELR*G**.5*(1.+(COS(A))**2/G*FI)**1.5/(BDR*COS(A))
      PSCL=32.174*DELE*HTH/U2**2
      PSIBL=PSIBL+PSCL
  470 CONTINUE
      IF(PRINT) 50,50,60
   60 WRITE(3,12) SCL,PSINC,CU2TH
      WRITE(3,14) DELE,PSF,C2
      WRITE(3,16) DELK,PSD,ALP2
      WRITE(3,18) DELR,PSTIP,FRIMP
      WRITE(3,20) W2TH,PSCL
      WRITE(3,22) RW,PSIBL
      WRITE(3,10) SLPCF,PSITH
      WRITE(3,24) HTH
   10 FORMAT(5X,7HSLPCF =,3X,F10.4,24X,7HPSITH =,3X,F10.4/)
   12 FORMAT(/5X,7HSCL   =,3X,F10.3,24X,7HPSINC =,3X,F10.4,
     124X,7HCU2TH =,3X,F10.3)
   14 FORMAT(5X,7HDELE  =,3X,F10.3,24X,7HPSF   =,3X,F10.4,
     124X,7HC2    =,3X,F10.3)
   16 FORMAT(5X,7HDELK  =,3X,F10.3,24X,7HPSD   =,3X,F10.4,
     124X,7HALP2  =,3X,F10.3)
   18 FORMAT(5X,7HDELR  =,3X,F10.3,24X,7HPSTIP =,3X,F10.4,
     124X,7HFRIMP =,3X,F10.3)
   20 FORMAT(5X,7HW2TH  =,3X,F10.3,24X,7HPSCL  =,3X,F10.4)
   22 FORMAT(5X,7HRW    =,3X,F10.3,24X,7HPSIBL =,3X,F10.4)
   24 FORMAT(5X,7HHTH   =,3X,F10.3)
   50 RETURN
      END
```

@ ELT IMGEO,1,710427, 53109

```
      SUBROUTINE IMGEO
      REAL KBMID,KP1,KP2,KP3,KP4
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,          XKDVD,XK1VD,XKFVD,EVD,FLA,    XKOD,O,OD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,RCM5
      DH1=EPS*DT1
      DM1=SQRT(0.5*(DT1**2+DH1**2))
      RM1=0.5*DM1
      H=0.5*(DT1-DH1)
      RA=0.75*(H+B2)
      RC=RM1+RA
      XSI=DT1/D2
      R2=D2*0.5
      IF(R2-RC) 10,10,11
   10 RA=R2-RM1
      RC=R2
      IF(PRINT) 11,11,13
   13 WRITE(3,500)
  500 FORMAT(5X,'RC2 EQUALS R2'/)
   11 RC2=0.134*RA+RM1
      RC3=0.366*RA+RC2
      BBT1R=BBT1/57.296
      BBM1=ATAN(DT1/DM1*SIN(BBT1R)/COS(BBT1R))*57.296
      BBM1R=BBM1/57.296
      TEMP=BB2/BBM1/KBMID
      CK1=TEMP**1.05-TEMP+1.
      TEMP=BB2/(KBMID*BBM1)
      CK2=1.+(TEMP**1.05-TEMP)/6.
      CK3=1.+(TEMP**1.05-TEMP)/10.
      TEMP=KBMID*BBM1
      TMP2=BB2-TEMP
      BBC1=TEMP+CK1/6.*TMP2
      BBC2=TEMP+CK2/2.*TMP2
      BBC3=TEMP+5.*CK3/6.*TMP2
      BB2R=BB2/57.296
      BBC1R=BBC1/57.296
      BBC2R=BBC2/57.296
      BBC3R=BBC3/57.296
      CLIND=3.14159/Z0*DM1*SOL1
      CLCB=BBM1R*0.5*(1.+KBMID)
      THIND=360./Z0*SOL1*COS(CLCB)
```

```
      ZL=3.14159/Z0*DM1*SOL1*SIN(CLCB)
      CLC1=(RC2-RM1)/(0.259*SIN(BBC1R))
      CLC2=(RC3-RC2)/(0.707*SIN(BBC2R))
      CLC3=(RC-RC3)/(0.965*SIN(BBC3R))
      CLTS=CLC1+CLC2+CLC3
      THC1=57.296*(ALOG(RC2)-ALOG(RM1))/(0.259*SIN(BBC1R)/COS(BBC1R))
      THC2=57.296*(ALOG(RC3)-ALOG(RC2))/(0.707*SIN(BBC2R)/COS(BBC2R))
      THC3=57.296*(ALOG(RC)-ALOG(RC3))/(0.965*SIN(BBC3R)/COS(BBC3R))
      THTS=THC1+THC2+THC3
      CLRS=(R2-RC)/SIN(BB2R)
      THRS=57.296*(ALOG(R2)-ALOG(RC))/(SIN(BB2R)/COS(BB2R))
      CLIMP=CLTS+CLRS
      THIMP=THTS+THRS
      CLTOT=CLIMP+CLIND
      THTOT=THIMP+THIND
      IF(Z0) 20,20,21
   20 ZX=Z1
      GO TO 22
   21 ZX=Z0
   22 BLK1=0.025*ZX/(RM1*SIN(BBM1R))
      A1=0.7853975*(DT1**2-DH1**2)
      AB1=A1*(1.-BLK1)
      TM1=6.28318*RM1/ZX
      IF(Z0) 23,23,24
   23 SOL1=0
      DPIND=0
      DHIND=0
      THIND=0
      CLIND=0
      GO TO 25
   24 DHIND=(1.-BLK1)*TM1*SIN(CLCB)*H/(2.*((1.-BLK1)*TM1*SIN(CLCB)+H))
      DIND=1.-SIN(BBM1R)/SIN(KBMID*BBM1R)+(COS(KBMID*BBM1R)/SIN(KBMID*
     1BBM1R)-COS(BBM1R)/SIN(BBM1R))*SIN(BBM1R)/(2.*SOL1)
      DPIND=DIND
   25 ZX=Z0
      A2=(1.-BLK2)*3.14159*D2*B2
      RBD=B2/D2
      IF(NZ-2) 30,31,32
   30 RM2=SQRT(0.5*(R2**2+RM1**2))
      SOLIP=CLIMP*Z/(6.28318*RM2)
      SOLTO=SOL1+SOLIP
      RMC1=SQRT(0.5*(RM1**2+RC2**2))
      RMC2=SQRT(0.5*(RC2**2+RC3**2))
      RMC3=SQRT(0.5*(RC3**2+RC**2))
      TMC1=6.28318*RMC1/Z*SIN(BBC1R)-0.157
      TMC2=6.28318*RMC2/Z*SIN(BBC2R)-0.157
      TMC3=6.28318*RMC3/Z*SIN(BBC3R)-0.157
      RMRS=SQRT(0.5*(RC**2+RC2**2))
      TMRS=6.28318*RMRS/Z*SIN(BB2R)-0.157
      HMC1=R2*B2/RC+(RC-RMC1)*(H-B2*R2/RC)/(RC-RM1)
      HMC2=R2*B2/RC+(RC-RMC2)*(H-B2*R2/RC)/(RC-RM1)
      HMC3=R2*B2/RC+(RC-RMC3)*(H-B2*R2/RC)/(RC-RM1)
      HMRS=B2+(R2-RMRS)*(B2*R2/RC-B2)/(R2-RC)
      DHIMP=0.5*(CLC1*TMC1*HMC1/(TMC1+HMC1)+CLC2*TMC2*HMC2/(TMC2+HMC2)+
     1CLC3*TMC3*HMC3/(TMC3+HMC3)+CLRS*TMRS*HMRS/(TMRS+HMRS))/CLIMP
      DHTOT=(CLIMP*DHIMP+CLIND*DHIND)/CLTOT
      SM=CLC1*RMC1*SIN(BBC1R)+CLC2*RMC2*SIN(BBC2R)+CLC3*RMC3*SIN(BBC3R)+
     1CLRS*RMRS*SIN(BB2R)
      GO TO 999
   31 KP1=0.5
```

```
      KP2=KP1
      CLP1=KP1*CLIMP
      CLP2=KP2*CLIMP
      GO TO 40
   32 IF(NZ-3) 33,33,34
   33 ZDN=2.*(Z0+Z1)+Z2+Z
      KP1=0.3333
      KP2=KP1
      KP3=KP1
      CLP1=KP1*CLIMP
      CLP2=CLP1
      CLP3=CLP1
      GO TO 40
   34 IF(NZ-4) 35,35,999
   35 ZDN=3.*(Z0+Z1)+2.*Z2+Z3+Z
      KP1=0.25
      KP2=KP1
      KP3=KP1
      KP4=KP1
      CLP1=KP1*CLIMP
      CLP2=CLP1
      CLP3=CLP1
      CLP4=CLP1
   40 IF(CLP1-CLC1) 41,41,42
   41 DLC11=CLC1-CLP1
      RP2=RC2-0.259*SIN(BBC1R)*DLC11
      GO TO 50
   42 IF(CLP1-CLC1-CLC2) 43,43,44
   43 DLC21=CLC1+CLC2-CLP1
      RP2=RC3-0.707*SIN(BBC2R)*DLC21
      GO TO 50
   44 IF(CLP1-CLTS) 45,45,46
   45 DLC31=CLTS-CLP1
      RP2=RC-0.965*SIN(BBC3R)*DLC31
      GO TO 50
   46 DLR1=CLIMP-CLP1
      RP2=R2-SIN(BB2R)*DLR1
   50 RM2=SQRT(0.5*(RM1**2+RP2**2))
      SOL2=CLP1*(Z0+Z1)/(6.28318*RM2)
      HM2=R2*B2/RC+(RC-RM2)*(H-B2*R2/RC)/(RC-RM1)
      IF(CLP1-CLC1) 60,60,61
   60 SNBM2=SIN(BBC1R)
      GO TO 70
   61 IF(CLP1-CLC1-CLC2) 62,62,63
   62 SNBM2=(CLC1*SIN(BBC1R)+(CLC2-DLC21)*SIN(BBC2R))/CLP1
      GO TO 70
   63 IF(CLP1-CLTS) 64,64,65
   64 SNBM2=(CLC1*SIN(BBC1R)+CLC2*SIN(BBC2R)+(CLC3-DLC31)*SIN(BBC3R))/CL
     1P1
      GO TO 70
   65 SNBM2=(CLC1*SIN(BBC1R)+CLC2*SIN(BBC2R)+CLC3*SIN(BBC3R)+(CLRS-DLR1)
     1*SIN(BB2R))/CLP1
   70 TM2=6.28318*RM2/(Z0+Z1)*SNBM2-0.157
      DH2=TM2*HM2*0.5/(TM2+HM2)
      IF(NZ-3) 75,76,76
   75 RM3=SQRT(0.5*(RP2**2+R2**2))
      HM3=B2+(R2-RM3)*(B2*R2/RC-B2)/(R2-RC)
      SOL3=CLP2*Z/(6.28318*RM3)
      SOLTO=SOL1+SOL2+SOL3
      SOLIP=SOL2+SOL3
```

```
      IF(CLP1-CLC1) 80,80,81
   80 SNBM3=(DLC11*SIN(BBC1R)+CLC2*SIN(BBC2R)+CLC3*SIN(BBC3R)+CLRS*SIN(B
     1B2R))/CLP2
      GO TO 90
   81 IF(CLP1-CLC1-CLC2) 82,82,83
   82 SNBM3=(DLC21*SIN(BBC2R)+CLC3*SIN(BBC3R)+CLRS*SIN(BB2R))/CLP2
      GO TO 90
   83 IF(CLP1-CLTS) 84,84,85
   84 SNBM3=(DLC31*SIN(BBC3R)+CLRS*SIN(BB2R))/CLP2
      GO TO 90
   85 SNBM3=SIN(BB2R)
   90 TM3=6.28318*RM3/Z*SNBM3-0.157
      DH3=TM3*HM3*0.5/(TM3+HM3)
      DHIMP=(CLP1*DH2+CLP2*DH3)/CLIMP
      DHTOT=(CLIND*DHIND+CLIMP*DHIMP)/CLTOT
      SM=(CLP1*RM2*(Z0+Z1)*SNBM2+CLP2*RM3*Z*SNBM3)/Z
      GO TO 999
   76 CTRY=CLP1+CLP2
      IF(CTRY-CLC1) 100,100,101
  100 DLC12=CLC1-CTRY
      RP3=RC2-0.259*SIN(BBC1R)*DLC12
      GO TO 110
  101 IF(CTRY-CLC1-CLC2) 102,102,103
  102 DLC22=CLC1+CLC2-CTRY
      RP3=RC3-0.707*SIN(BBC2R)*DLC22
      GO TO 110
  103 IF(CTRY-CLTS) 104,104,105
  104 DLC32=CLTS-CTRY
      RP3=RC-0.965*SIN(BBC3R)*DLC32
      GO TO 110
  105 DLR2=CLIMP-CTRY
      RP3=R2-SIN(BB2R)*DLR2
  110 RM3=SQRT(0.5*(RP2**2+RP3**2))
      HM3=R2*B2/RC+(RC-RM3)*(H-B2*R2/RC)/(RC-RM1)
      SOL3=CLP2*(Z0+Z1+Z2)/(6.28318*RM3)
      IF(CTRY-CLC1) 111,111,112
  111 SNBM3=SIN(BBC1R)
      GO TO 130
  112 IF(CTRY-CLC1-CLC2) 113,113,114
  113 SNBM3=((CLC2-DLC22)*SIN(BBC2R)+(CLC1-CLP1)*SIN(BBC1R))/CLP2
      GO TO 130
  114 IF(CTRY-CLTS) 115,115,116
  115 IF(CLC1-CLP1) 117,117,118
  117 SNBM3=(DLC21*SIN(BBC2R)+(CLTS-DLC32)*SIN(BBC3R))/CLP2
      GO TO 130
  118 SNBM3=((CLC1-CLP1)*SIN(BBC1R)+CLC2*SIN(BBC2R)+(CLC3-DLC32)*SIN(BBC
     13R))/CLP2
      GO TO 130
  116 IF(CLC1-CLP1) 120,120,119
  119 SNBM3=((CLC1-CLP1)*SIN(BBC1R)+CLC2*SIN(BBC2R)+(CLC3-DLC32)*SIN(BBC
     13R)+(CLRS-DLR2)*SIN(BB2R))/CLP2
      GO TO 130
  120 IF(CLC1+CLC2-CLP1) 121,121,122
  300 FORMAT(//10X,'LC1+LC2-LP1 IS ZERO OR NEGATIVE, NZ=3',//)
  121 WRITE(3,300)
      GO TO 999
  122 SNBM3=((CLC2-DLC21)*SIN(BBC2R)+CLC3*SIN(BBC3R)+(CLRS-DLR2)*SIN(BB2
     1R))/CLP2
  130 TM3=6.28318*RM3/(Z0+Z1+Z2)*SNBM3-0.157
      DH3=TM3*HM3*0.5/(TM3+HM3)
```

```
      IF(NZ-3) 135,135,136
  135 RM4=SQRT(0.5*(RP3**2+R2**2))
      HM4=B2+(R2-RM4)*(B2*R2/RC-B2)/(R2-RC)
      SOL4=CLP3*Z/(6.28318*RM4)
      SOLTO=SOL1+SOL2+SOL3+SOL4
      SOLIP=SOLTO-SOL1
      IF(CTRY-CLC1) 140,140,141
  140 SNBM4=(DLC12*SIN(BBC1R)+CLC2*SIN(BBC2R)+CLC3*SIN(BBC3R)+CLRS*SIN(B
     1B2R))/CLP3
      GO TO 150
  141 IF(CTRY-CLC1-CLC2) 142,142,143
  142 SNBM4=(DLC22*SIN(BBC2R)+CLC3*SIN(BBC3R)+CLRS*SIN(BB2R))/CLP3
      GO TO 150
  143 IF(CTRY-CLTS) 144,144,145
  144 SNBM4=(DLC32*SIN(BBC3R)+CLRS*SIN(BB2R))/CLP3
      GO TO 150
  145 SNBM4=SIN(BB2R)
  150 TM4=6.28318*RM4/Z*SNBM4
      DH4=TM4*HM4*0.5/(TM4+HM4)
      DHIMP=(CLP1*DH2+CLP2*DH3+CLP3*DH4)/CLIMP
      DHTOT=(CLIND*DHIND+CLIMP*DHIMP)/CLTOT
      SM=(CLP1*RM2*(Z0+Z1)*SNBM2+CLP2*RM3*(Z0+Z1+Z2)*SNBM3+CLP3*RM4*Z*SN
     1BM4)/Z
      GO TO 999
  136 CLPT=CLP1+CLP2+CLP3
      IF(CLPT-CLC1-CLC2) 160,160,161
  160 DLC23=CLC1+CLC2-CLPT
      RP4=RC3-0.707*SIN(BBC2R)*DLC23
      GO TO 165
  161 IF(CLPT-CLTS) 162,162,163
  162 DLC33=CLTS-CLPT
      RP4=RC-0.965*SIN(BBC3R)*DLC33
      GO TO 165
  163 DLR3=CLIMP-CLPT
      RP4=R2-SIN(BB2R)*DLR3
  165 RM4=SQRT(0.5*(RP4**2+RP3**2))
      HM4=R2/RC*B2+(RC-RM4)*(H-B2*R2/RC)/(RC-RM1)
      SOL4=CLP3*(Z0+Z1+Z2+Z3)/(6.28318*RM4)
      IF(CLPT-CLC1-CLC2) 170,170,171
  170 IF(CLC1-CLP1-CLP2) 172,172,173
  172 SNBM4=SIN(BBC2R)
      GO TO 190
  173 SNBM4=(DLC12*SIN(BBC1R)+(CLC2-DLC23)*SIN(BBC2R))/CLP3
      GO TO 190
  171 IF(CLPT-CLTS) 174,174,175
  174 IF(CLC1-CLP1-CLP2) 176,176,177
  176 SNBM4=(DLC22*SIN(BBC2R)+(CLC3-DLC33)*SIN(BBC3R))/CLP3
      GO TO 190
  177 SNBM4=(DLC12*SIN(BBC1R)+CLC2*SIN(BBC2R)+(CLC3-DLC33)*SIN(BBC3R))/
     1CLP3
      GO TO 190
  175 IF(CLC1+CLC2-CLP1-CLP2) 179,179,178
  178 SNBM4=(DLC22*SIN(BBC2R)+CLC3*SIN(BBC3R)+(CLRS-DLR3)*SIN(BB2R))/CLP
     13
      GO TO 190
  179 IF(CLTS-CLP1-CLP2) 180,180,181
  301 FORMAT(//10X,' LTS-(LP1+LP2) IS ZERO OR NEGATIVE, NZ=4',//)
  180 WRITE(3,301)
      GO TO 999
  181 SNBM4=(DLC32*SIN(BBC3R)+(CLRS-DLR3)*SIN(BB2R))/CLP3
```

```
  190 TM4=(6.28318*RM4)/(Z0+Z1+Z2+Z3)*SNBM4-0.157
      DH4=TM4*HM4*0.5/(TM4+HM4)
      RM5=SQRT(0.5*(RP4**2+R2**2))
      HM5=B2+(R2-RM5)*(R2*R2/RC-B2)/(R2-RC)
      SOL5=CLP4*Z/(6.28318*RM5)
      SOLTO=SOL1+SOL2+SOL3+SOL4+SOL5
      SOLIP=SOLTO-SOL1
      IF(CLPT-CLC1-CLC2) 200,200,201
  200 SNBM5=(DLC23*SIN(BBC2R)+CLC3*SIN(BBC3R)+CLRS*SIN(BB2R))/CLP4
      GO TO 205
  201 IF(CLPT-CLTS) 202,202,203
  202 SNBM5=(DLC33*SIN(BBC3R)+CLRS*SIN(BB2R))/CLP4
      GO TO 205
  203 SNBM5=SIN(BB2R)
  205 TM5=6.28318*RM5*SNBM5/Z-0.157
      DH5=TM5*HM5*0.5/(TM5+HM5)
      DHIMP=(CLP1*DH2+CLP2*DH3+CLP3*DH4+CLP4*DH5)/CLIMP
      DHTOT=(CLIMP*DHIMP+CLIND*DHIND)/CLTOT
      SM=(CLP1*RM2*(Z0+Z1)*SNBM2+CLP2*RM3*(Z0+Z1+Z2)*SNBM3+CLP3*RM4*(Z-Z
     14)*SNBM4+CLP4*RM5*Z*SNBM5)/Z
  999 DIMP=1.-AB1/A2*SIN(BBM1R)/SIN(BB2R)+(AB1/A2*COS(BB2R)/SIN(BB2R)-CO
     1S(BBM1R)/SIN(BBM1R))/(2.*SOLIP)*SIN(BBM1R)
      DPIMP=DIMP
      RETURN
      END
```

```
@ ELT INPUT,1,710427, 63111

      SUBROUTINE INPUT
      REAL KBMID
      COMMON   XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,PI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFLS,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,          XKDVD,XK1VD,XKFVD,EVD,FLA,    XKQD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
    1 FORMAT(10F8.3)
      READ(2,1) WP,XN,RHO,QKI,HNPSH,HTOT,EPS,PHIMN,BB2,VHKM
  510 FORMAT(7F6.3,I6,F6.4,3F6.3,F8.5)
      READ(2,510) SOL1,Z0,Z1,Z2,Z3,Z4,KBMID,NZ,SCL,SIG,DR,FLAG,FLACO
  520 FORMAT(12F6.4,E8.4)
      READ(2,520)XKPH1,PHI21,PHI22,PHI23,ETAHI,Z,XKQD,DINLT,RL,REX,RLBE
     1T,RLZD,XKMSC
  530 FORMAT(4F6.3,F12.4,F6.3,F8.3,F10.4,E10.4)
      READ(2,530) OPTFI,SBETA,SZD,FRD,       FLA,RPHG,FSTHG,SSTHG,VIS
  540 FORMAT(E8.3,4F8.4,E10.4,5F6.3)
      READ(2,540) XKFVD,XKDVD,XK1VD,EVD,FLAHG,XKSFS,CLUT,FINC,BE10,ZRV,
     1D9
  550 FORMAT(5F6.3)
      READ(2,550) B9,RBRM, RB67, THRV,RDSV
    4 FORMAT(1H1)
    2 FORMAT(5X,'****** INPUT ******'//)
   10 FORMAT(1X,'FLOW RATE, WP',23X,F10.3,2X,'LB/SEC', 8X,'DIFF BLADE IN
     1LET THICKNESS, DINLT',7X,F10.3,2X,'INCH')
   12 FORMAT(1X,'TOTAL HEAD RISE, HTOT',15X,F10.3,2X,'FT',12X,'DIFF LENG
     1TH TO THROAT RATIO, RL',9X,F10.3,2X,'***')
   14 FORMAT(1X,'ROTATIONAL SPEED, XN',16X,F10.3,2X,'RPM',11X,'DIFF EXPA
     1NSION RATIO, REX',15X,F10.3,2X,'***')
   16 FORMAT(1X,'NET POSITIVE SUCTION HEAD, HNPSH',4X,F10.3,2X,'FT',12X,
     1'RANGE, DIFFUSER INLET BLADE ANGLE, RLBET',F10.3,2X,'***')
   18 FORMAT(1X,'FACTOR RECIRC FLOW, IMPELLER, QK1',3X,F10.3,2X,'***',11
     1X,'MAX DIFF BLADE NUMBER, RLZD',13X,F10.3,2X,'***')
   20 FORMAT(1X,'FACTOR RECIRC FLOW, DIFFUSER, XKQD',2X,F10.3,2X,'***',1
     11X,'SURFACE FINISH, IMPELLER, XKMSC', 9X,E10.4,2X,'IN')
   21 FORMAT(63X,'FLOW COEFFICIENT FACTOR, XKPH1',10X,F10.3,2X,'***')
   22 FORMAT(1X,'FLUID DENSITY, RHO',18X,F10.3,2X,'LB/FT**3')
   24 FORMAT(1X,'FLUID DYNAMIC VISCOSITY, VIS',8X,E10.4,2X,'LB*S/SQFT')
   26 FORMAT(1X,'IMPELLER INLET HUB RATIO, EPS',7X,F10.3,2X,'***',11X,'B
     1LADE TIP CLEARANCE, SCL',16X,F10.3,2X,'INCH')
   28 FORMAT(1X,'INDUCER SOLIDITY, SOL1',14X,F10.3,2X,'***',11X,'DIFF LO
     1G SPIRAL ANGLE, SELECTED, SBETA',2X,F10.3,2X,'DEG')
```

```
   30 FORMAT(1X,'IMP MIN INLET TIP FLOW COEFF, PHIMN',1X,F10.3,2X,'***',
     111X,'DIFF BLADE NUMBER, SELECTED, SZD',6X,F10.3,2X,'***')
   32 FORMAT(1X,'MIN CAVITATION PARAMETER, VHKM',6X,F10.3,2X,'***')
   34 FORMAT(1X,'IMP DISCHARGE BLADE ANGLE, BB2',6X,F10.3,2X,'DEG',11X,'
     1FRICTION COEFF, DIFFUSER, FRD',11X,F10.4,2X,'***')
   36 FORMAT(1X,'IMP.BLADE ANGLE DISTR FACTOR, KBMID',1X,F10.3,2X,'***',
     111X,'VOLUTE SURFACE FINISH, XKSFS',12X,F10.4,2X,'***')
   38 FORMAT(1X,'TOT NUMBER OF IMP BLADES, Z', 9X,F10.3,2X,'***',11X,'DI
     1FF LOSS ADJUSTMENT FACTOR, FLA',8X,F10.3,2X,'***')
   40 FORMAT(1X,'INITIAL HYDRAULIC EFFICIENCY, ETAHI',1X,F10.3,2X,'***')
   42 FORMAT(1X,'IMPELLER CONFIGURATION, FLAG',8X,F10.3,2X,'***',11X,'MA
     1X TO DESIGN PRESSURE RATIO, RPHG',6X,F10.3,2X,'***')
   44 FORMAT(1X,'RADIAL EXTENSION OF IMP DISK, DR',4X,F10.3,2X,'INCH',10
     1X,'HOUSING MATERIAL YIELD STRENGTH, SSTHG',2X,F10.3)
   46 FORMAT(1X,'LABYRINTH CLEARANCE FACTOR, FLACO',3X,F10.5,2X,'***',11
     1X,'HOUSG SAFETY FACTOR, FSTHG',14X,F10.3,2X,'***')
   48 FORMAT(1X,'TIP CLEARANCE LOSS FACTOR, SIG',6X,F10.3,2X,'***')
   50 FORMAT(1X,'FLOW COEFFICIENT OPTIMIZATION, OPTFI'1X,F10.3,15X,'INLE
     1T BLADE THICKNESS, THRV',13X,F10.3,2X,'IN')
   54 FORMAT(1X,'PHI21=',F8.4,5X,'PHI22=',F8.4,5X,'PHI23='F8.4,10X,'REVE
     1RSING VANE DISCHARGE DIA, D9',8X,F10.3,2X,'IN')
   55 FORMAT(1X,'HOUSING CONFIGURATION, FLAHG',8X,F10.3,2X,'***',11X,'SU
     1RFACE FINISH, DIFFUSER, XKFVD', 9X,F10.4,2X,'***')
   57 FORMAT(63X,'DIFFUSION LOSS FACTOR, DIFFUSER, XKDVD',2X,F10.3,2X,'*
     1**')
   59 FORMAT(63X,'INCIDENCE LOSS FACTOR, DIFFUSER, XK1VD',2X,F10.3,2X,'*
     1**')
   61 FORMAT(63X,'DIFFUSION EXPONENT, DIFFUSER, EVD',7X,F10.3,2X,'***')
   69 FORMAT(63X,'RATIO B/RM U-TURN, RBRM',17X,F10.3,2X,'***')
   73 FORMAT(63X,'PORT WIDTH REVERS VANE DISCHARGE, B9',4X,F10.3,2X,'IN
     1')
   75 FORMAT(63X,'RATIO B6/B7, RB67',23X,F10.3,2X,'***')
   77 FORMAT(63X,'FRIC LOSS COEFF, VANELESS TURN, CLUT',4X,F10.5,2X,'***
     1')
   79 FORMAT(63X,'OPTIONAL INPUT - RETURN CHANNEL')
   81 FORMAT(63X,'NUMBER OF REVERSING VANEO, ZRV',10X,F10.3,2X,'***')
   85 FORMAT(63X,'DIAMETER RATIO DSV/D9',19X,F10.3,2X,'***')
  103 FORMAT(63X,'FLUID ANGLE REVERS VANE DISCHARGE, BE10',1X,F10.3,2X,'
     1DEG')
  105 FORMAT( 1X,'Z0=',F3.1,5X,'Z1=',F3.1,5X,'Z2=',F4.1,5X,'Z3=',F4.1,5X
     1,'Z4=',F4.1,9X,'ANGLE CORRECTION FACTOR, FINC',11X,F10.3,2X,'***'/
     2)
  106 FORMAT( 1X,'BLADE SCHEDULE, NZ =',I2,/)
  200 FORMAT(1X,'ALTERNATE FLOW COEFFICIENTS')
      WRITE(3,4)
      WRITE(3,2)
      WRITE(3,10) WP,DINLT
      WRITE(3,12) HTOT,RL
      WRITE(3,14) XN,REX
      WRITE(3,16) HNPSH,RLBET
      WRITE(3,18) QKI,RLZD
      WRITE(3,20) XKQD,XKMSC
      WRITE(3,21) XKPH1
      WRITE(3,22) RHO
      WRITE(3,24) VIS
      WRITE(3,26) EPS,SCL
      WRITE(3,28) SOL1,SBETA
      WRITE(3,30) PHIMN,SZD
      WRITE(3,32) VHKM
      WRITE(3,34) BB2,FRD
```

```
      WRITE(3,36) KBMID,XKSFS
      WRITE(3,38) Z,FLA
      WRITE(3,40) ETAHI
      WRITE(3,42) FLAG,RPHG
      WRITE(3,44) DR,SSTHG
      WRITE(3,46) FLACO,FSTHG
      WRITE(3,48) SIG
      WRITE(3,55) FLAHG,XKFVD
      WRITE(3,57) XKDVD
      WRITE(3,59) XK1VD
      WRITE(3,61) EVD
      WRITE(3,106) NZ
      WRITE(3,103) BE10
      WRITE(3,77) CLUT
      WRITE(3,105) Z0,Z1,Z2,Z3,Z4 ,FINC
      WRITE(3,79)
      WRITE(3,200)
      WRITE(3,85) RDSV
      WRITE(3,69) RBRM
      WRITE(3,54) PHI21,PHI22,PHI23,D9
      WRITE(3,73) B9
      WRITE(3,75) RB67
      WRITE(3,50) OPTFI ,THRV
      WRITE(3,81) ZRV
      RETURN
      END
```

```
@ ELT INT4,1,710427, 63113

        SUBROUTINE INT4(X,Y,XI,YO)                                      61205002
        DIMENSION X(9),Y(9),XC(4),YC(4)                                 61205005
        EQUIVALENCE (XC(1),X1),(XC(2),X2),(XC(3),X3),(XC(4),X4),(YC(1),Y161205006
       1,(YC(2),Y2),(YC(3),Y3),(YC(4),Y4)                               61205007
        NA=1
        J=2                                                             61205009
        B=XI                                                            61205010
   21   IF(X(J))26,22,26                                                61205011
   26   GO TO(30,40),NA
   22   IF(Y(J))26,23,26                                                61205013
   23   IF(J-2)24,24,25                                                 61205014
   24   YE=0.0                                                          61205015
        GO TO 50                                                        61205016
   25   NB=1
        J=J-1                                                           61205018
   27   X1=X(J)                                                         61205019
        X2=X(J-1)                                                       61205020
        X3=X(J-2)                                                       61205021
        Y1=Y(J)                                                         61205022
        Y2=Y(J-1)                                                       61205023
        Y3=Y(J-2)                                                       61205024
        GO TO(32,42),NB
   30   IF(X(J)-B)29,37,37                                              61205026
   37   IF(J-2)31,31,28                                                 61205027
   28   NA=2
   29   J=J+1                                                           61205029
        GO TO 21                                                        61205030
   31   DO 60 J=1,3                                                     61205031
        XC(J)=X(J)                                                      61205032
   60   YC(J)=Y(J)                                                      61205033
   32   D=X2-X1                                                         61205034
        A1=B-X1                                                         61205035
        A2=B-X2                                                         61205036
        YE=A1*A2/2.0/D*((Y3-Y2)/(X3-X2)-(Y2-Y1)/D)-A2/D*Y1+A1/D*Y2      61205037
        GO TO 50                                                        61205038
   40   NB=2
        GO TO 27                                                        61205040
   42   X4=X(J-3)                                                       61205041
        Y4=Y(J-3)                                                       61205042
        D=X3-X2                                                         61205043
        A1=B-X2                                                         61205044
        A2=B-X3                                                         61205045
        XM12=(Y2-Y1)/(X2-X1)                                            61205046
        XM23=(Y3-Y2)/D                                                  61205047
        XM34=(Y4-Y3)/(X4-X3)                                            61205048
        YE=A1*A2**2/2.0/D**2*(XM12-XM23)+A2*A1**2/2.0/D**2*(XM34-XM23)-A2*61205049
       1Y2/D+A1*Y3/D                                                    61205050
   50   YO=YE                                                           61205051
        RETURN                                                          61205052
        END                                                             61205053
```

@ ELT LOSS1,1,710427, 63115

```
      SUBROUTINE LOSS1
      DIMENSION X(19),Y(19)
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2 ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,          XKDVD,XK1VD,XKFVD,EVD,FLA,    XKOD,O,OD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
  500 FORMAT(  10X,'INCIDENCE LESS THAN OPTIMUM'/)
      X(1)=1.0
      Y(1)=.004
      X(2)=1.2
      Y(2)=.0042
      X(3)=1.4
      Y(3)=.0055
      X(4)=1.6
      Y(4)=.0085
      X(5)=1.8
      Y(5)=.0132
      X(6)=2.0
      Y(6)=.02
      X(7)=2.1
      Y(7)=.026
      X(8)=2.2
      Y(8)=.032
      X(9)=2.3
      Y(9)=.0405
      X(10)=2.4
      Y(10)=.05
      X(11)=2.5
      Y(11)=.064
      X(12)=2.6
      Y(12)=.08
      X(13)=2.7
      Y(13)=.101
      X(14)=2.75
      Y(14)=.114
      X(15)=2.8
      Y(15)=.13
      X(16)=2.85
      Y(16)=.149
      X(17)=2.9
      Y(17)=.174
      X(18)=2.95
```

BRUMER,428?50,1,100,

```
      Y(18)=.21
      X(19)=2.96
      Y(19)=999999.
      RI010=.425*(90.-BBM4)
      RKTH=-.007636+19.612*THICO-132.6273*THICO**2+372.96*THICO**3
      RIO=RKTH*RI010
      RIOPT=RIO+(.75-.0145*BBM4)*FEE
      RI=BFL4-BBM4
      IF(RI-RIOPT)3,5,6
    3 IF(PRINT) 6,6,4
    4 WRITE(3,500)
    6 RIBM=RI/(90.-BBM4)
      GO TO 7
    5 BFL4=BBM4+RIOPT
      RIBM=RIOPT/(90.-BBM4)
    7 RMC=.0058*STANG-.065
      RIBL=(BETA-90.+BFL4)/BETA
      RIBH=(GAMMA-90.+BFL4)/GAMMA
      DEL=FEE*RMC/SOLID**.5
      BFL5=BBM5+DEL
      IF (FLAHG-7.) 10,10,12
   12 BFL5 = 90.-BCM5
      DEL = 0
   10 IF(PRINT) 8,8,9
    9 WRITE(3,509) RI,BFL4
      WRITE(3,502) RIOPT
      WRITE(3,504) DEL,V4
      WRITE(3,505) BFL5
      WRITE(3,506) RIBH
      WRITE(3,507) RIBM
      WRITE(3,508) RIBL
  509  FORMAT(05X,'ACTUAL INCIDENCE ANGLE,MEAN',3X,F10.3,' DEG',15X,
     1'ACTUAL FLUID INLET ANGLE, BFL4',5X,F10.3,' DEG')
  502 FORMAT(05X,'OPTIMUM INCIDENCE ANGLE',7X,F10.3,' DEG')
  504 FORMAT(05X,'DEVIATION ANGLE',15X,F10.3,' DEG',15X,
     1'FLUID INLET VELOCITY V4',12X,F10.3,' FT/SEC')
  505 FORMAT(05X,'DISCHARGE FLUID ANGLE',9X,F10.3,' DEG')
  506 FORMAT(5X,'I/BETA RATIO, HI PRESS. SIDE',2X,F10.3)
  507 FORMAT(5X,'I/BETA RATIO, MEAN',12X,F10.3)
  508 FORMAT(5X,'I/BETA RATIO, LO PRESS. SIDE',2X,F10.3)
    8 RETURN
      END
```

@ ELT MAIN,1,710427, 63118

```
      DIMENSION PSIHG(12),TBETA(12),TZD(12),OZD(10),OBETA(10),OETA(10)
      DIMENSION OPHI2(10)
      COMMON     XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,K3MID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,PWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2 ANVAN,BKB, R5  ,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHRC,RI,NOGO,NSKIP,OPTFI,PRINT,EI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,           XKDVD,XK1VD,XKFVD,EVD,FLA,    XKOD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
    1 FORMAT(8F10.0)
      READ(2,1)XK,XZ,XFR,XR
  400 CALL INPUT
      NCASE=0
      NEX=0
      MTEST=0
      K=0
      NOGO=0
      IF(WP)401,500,401
  401 CALL SIZE1
      IF(NOGO) 404,404,405
  405 WRITE(3,406)
  406 FORMAT(/////5X,'INPUT VALUE OF BB2 NOT ACCEPTABLE',////)
      GO TO 400
  404 I=0
      IF(PHI21) 280,280,279
  279 OPTFI=0
  225 IF(NCASE-1) 226,228,230
  226 PHI2=PHI21
      NCASE=1
      GO TO 280
  228 IF(PHI22) 400,400,232
  232 PHI2=PHI22
      NCASE=2
      GO TO 280
  230 IF(NCASE-2) 228,231,400
  231 IF(PHI23) 400,400,234
  234 PHI2=PHI23
      NCASE=3
  280 PRINT=0
  289 LOOP=0
      NSKIP=0
      IF(I-10) 300,300,295
  295 WRITE(3,296)
  296 FORMAT(////5X,'FLOW COEFFICIENT OPTIMIZATION, LIMIT OF ITERATIONS
     1EXCEEDED')
```

```
      GO TO 400
  300 CALL SAFE
      CALL IMGEO
      IF(PRINT) 153,153,151
  151 CALL ANSWR
  153 CALL LOSS
      CALL DERBV
      IF(FLAG-1.) 130,30,130
  130 IF(FLAG-3.) 35,30,35
   35 WWR=0.
      GO TO 31
   30 CALL CLAB
   31 IF(FLAHG-3.) 33,33,32
   33 M=0
      GO TO 301
   32 DISTH=2.*DINLT
      CU2TH=PSITH*U2
      C2=SQRT(CU2TH**2+CM2**2)
      ALP2R=ATAN(CM2/CU2TH)
      CM3=CM2*(1.-BLK2)
      R4=.5*D2*(.000157*XNS**.917+1.)
      D4=2.*R4
      B4=1.10*B2
      ALP4=ATAN(CM3/CU2TH)*57.296
      BFL4=90.-ALP4
      VU4=D2/D4*CU2TH
      ALP4R=ALP4/57.296
      V4=VU4/COS(ALP4R)
      ALP2=57.296*ALP2R
      C3=SQRT(CU2TH**2+CM3**2)
      C34=0.5*(C3+V4)
      VTHRC=C2*EXP(0.37532-0.286*ALOG(ALP2))
      OD=Q*(1.+XKOD)
      ATHRC=.321*OD/VTHRC
      ATHRC=1.1*ATHRC
      IF(SBETA) 43,43,42
   42 BETA=SBETA
      ZD=SZD
      GO TO 44
   43 ZD=7.
      BETA=FLOAT(IFIX(ALP4-.5))
      SAVE=BETA
   44 M=0
   45 TIN=ATHRC/B4/ZD
      TOUT=REX*TIN
      XL=RL*TIN
   46 IMESS=0
      CALL GEOM(IMESS,N)
      IF(IMESS)79,4,79
   79 IF(SBETA) 80,80,408
  408 WRITE(3,410)
  410 FORMAT(10X'MORE THAN 30 ITERATIONS IN SUBROUTINE GEOM')
      GO TO 400
    4 CONTINUE
C     ACCEPTANCE CRITERIA FOR BLADE PROFILE
      IF(FLAHG-6.) 101,101,49
  101 IF(ARO-BKB) 84,84,49
   49 IF((GAMMA-BETA)-1.5) 84,50,50
   50 IF((GAMMA-BETA)-5.5) 61,61,84
   84 IF(SBETA) 80,80,72
```

```
   72 WRITE(3,510) ZD,BETA,GAMMA,ARO,BKB
      WRITE(3,511)
  510 FORMAT(///5X,7HZD     =,2X,F6.3,8X,7HBETA   =,2X,F6.3,8X,7HGAMMA =,2
     1X,F6.3,8X,7HARO    =,2X,F6.3,8X,7HBKB    =,2X,F6.3/)
  511 FORMAT(5X,'DIFFUSER BLADE GEOMETRY NOT ACCEPTABLE')
   61 IF(PRINT) 73,73,74
   74 CALL OUTP1(N)
      WRITE(3,501)
  501 FORMAT('1',54X,'VANED DIFFUSER'/)
   73 CALL LOSS1
      CALL OBLPR
      IF(FLAHG-6.) 301,301,304
  304 CALL REVCH
      GO TO 92
  301 CALL SCRLL
      IF(FLAHG-3.) 303,303,302
  303 SBETA=0
      SZD=0
      GO TO 205
  302 IF(NOGO) 91,91,412
  412 WRITE(3,414)
  414 FORMAT(//5X,'NOGO=1, HOUSING STRUCTURALLY NOT ACCEPTABLE')
      GO TO 400
   91 IF(NSKIP) 92,92,90
   92 TBETA(M)=BETA
      TZD(M)=ZD
      PSIHG(M)=PSHSG
      IF(SBETA) 80,80,200
   80 IF(BETA-SAVE-RLBET) 85,86,86
   85 BETA=BETA+1.
      GO TO 46
   86 BETA=SAVE
      IF(RLZD) 89,89,87
   89 IF(M) 88,88,90
   87 IF(ZD-RLZD) 88,90,90
   88 ZD=ZD+2.
      IF(ZD-25.) 45,45,90
   90 IF(M-1) 94,200,190
   94 WRITE(3,95)
   95 FORMAT(//5X,'NO SOLUTION, RELAX CONSTRAINTS'/)
      GO TO 400
  200 LMIN=1
      PSHMI=PSIHG(1)
      GO TO 205
  190 PSHMI=PSIHG(1)
      LMIN=1
      DO 105 L=2,M
      IF(PSHMI-PSIHG(L)) 105,105,110
  110 PSHMI=PSIHG(L)
      LMIN=LMIN+1
  105 CONTINUE
      SBETA=TBETA(LMIN)
      SZD=TZD(LMIN)
      ETAHI=(PSIIP-PSIHG(LMIN))/PSITH
  205 IF(PRINT) 210,210,220
  210 IF(LOOP-2) 212,214,214
  212 LOOP=LOOP+1
      GO TO 300
  214 IF(OPTFI) 215,215,219
  219 IF(NEX) 216,216,215
```

```
  215 PRINT=1.
      GO TO 300
  216 IF(LOOP-3) 217,218,218
  217 LOOP=LOOP+1
      GO TO 300
  220 IF(NCASE) 400,400,225
  218 I=I+1
      OZD(I)=SZD
      OBETA(I)=SBETA
      OETA(I)=ETAOV
      OPHI2(I)=PHI2
      IF(MTEST) 305,305,340
  305 IF(I-1) 307,307,310
  307 PHI2=PHI2+0.005
    5 FORMAT(/5X,'ROUTE 307'/)
      WRITE(3,5)
      GO TO 290
  310 IF(I-2) 312,312,314
  312 IF(OETA(I)-OETA(I-1)) 315,318,320
  320 K=1
      GO TO 307
  318 PHI2=0.5*(OPHI2(I)+OPHI2(I-1))
      NEX=1
    6 FORMAT(/5X,'ROUTE 318'/)
      WRITE(3,6)
      GO TO 290
  315 KEEP=I
      LEAVE=I-1
      KEEP=LEAVE
      LEAVE=KEEP
      OETA(KEEP)=OETA(LEAVE)
      OBETA(KEEP)=OBETA(LEAVE)
      OETA(LEAVE)=OETA(KEEP)
      OBETA(LEAVE)=OBETA(KEEP)
      OZD(KEEP)=OZD(LEAVE)
      OZD(LEAVE)=OZD(KEEP)
      OPHI2(KEEP)=OPHI2(LEAVE)
      OPHI2(LEAVE)=OPHI2(KEEP)
      OETA(KEEP)=OETA(LEAVE)
      OETA(LEAVE)=OETA(KEEP)
      PHI2=PHI2-0.010
    7 FORMAT(/5X,'ROUTE 315'/)
      WRITE(3,7)
      GO TO 290
  314 IF(OETA(I)-OETA(I-1)) 322,318,324
  322 IF(ABS(OETA(I)-OETA(I-2))-0.001)326,328,328
  326 PHI2=OPHI2(I-1)
      SZD=OZD(I-1)
      SBETA=OBETA(I-1)
      NEX=1
    8 FORMAT(/5X,'ROUTE 326'/)
      WRITE(3,8)
      GO TO 289
  328 IF(OETA(I)-OETA(I-2)) 330,326,332
  330 PHI2=0.5*(OPHI2(I-1)+OPHI2(I-2))
      MTEST=1
    9 FORMAT(/5X,'ROUTE 330'/)
      WRITE(3,9)
      GO TO 290
  332 PHI2=0.5*(OPHI2(I)+OPHI2(I-1))
```

```
      MTEST=1
   10 FORMAT(/5X,'ROUTE 332'/)
      WRITE(3,10)
      GO TO 290
  324 IF(K) 334,334,307
  334 PHI2=PHI2-0.005
   11 FORMAT(/5X,'ROUTE 334'/)
      WRITE(3,11)
      GO TO 290
  340 IF(OETA(I)-OETA(I-2)) 342,344,346
  342 PHI2=OPHI2(I-2)
      SZD=OZD(I-2)
      SBETA=OBETA(I-2)
      NEX=1
   12 FORMAT(/5X,'ROUTE 342'/)
      WRITE(3,12)
      GO TO 289
  344 PHI2=0.5*(OPHI2(I)+OPHI2(I-2))
      NEX=1
   13 FORMAT(/5X,'ROUTE 344'/)
      WRITE(3,13)
      GO TO 290
  346 PHI2=OPHI2(I)
      SZD=OZD(I)
      SBETA=OBETA(I)
      NEX=1
   14 FORMAT(/5X,'ROUTE 346'/)
      WRITE(3,14)
      GO TO 289
  290 SBETA=0
      GO TO 289
  500 STOP
      END
```

@ELT OUTP1,1,710427, 53120

```
      SUBROUTINE OUTP1(N)
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KOMID,XSI,DPIMP
      COMMON WP,XN,RHO,OKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2 ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,          XKDVD,XK1VD,XKFVD,EVD,FLA,    XKQD,O,OD,OMTOT
      COMMON RPHG,SSTHG,FSTHS,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
  500 FORMAT('1',53X,'DIFFUSER GEOMETRY'///)
  100 FORMAT(36X,'BETA',9X,'ZD',8X,'RBASE',7X,'DINLT',7X,'DISTH',8X,'B4'
     1/)
  101 FORMAT(28X,6F12.3//)
  103 FORMAT(54X,'LOG SPIRAL DATA'///40X,'THETA',30X,'RADIUS'/40X,'(DEG)
     1',31X,'(IN)'/)
  501 FORMAT(39X,F6.2,30X,F6.3)
  502 FORMAT(///54X,'BLADE GEOMETRY'///10X,'DELTA',6X,'GAMMA',7X,'ARO',
     1 7X,'ANVAN',6X,'ADIS',8X,'RAR',8X,'RLOC',6X,'CVAN',8X,'BKB'/
     2 10X,'(DEG)',6X,'(DEG)',6X,'(DEG)',5X,'(DEG)',6X,'(DEG)',6X,
     3 '(IN)',8X,'(IN)',6X,'(IN)',7X,'(IN)'/)
  503 FORMAT(4X,5F11.2,3F11.3,F12.3//)
  504 FORMAT(10X,'DIFBC',6X,'RDIS',7X,'THICK',6X,'T/C',
     1 9X,'TIN',7X,'TOUT',8X,'XL',8X,'DLDM',6X,'BCM5',6X,'TEX5'/
     1 10X,'(IN)',7X,'(IN)',7X,'(IN)',7X,'RATIO',6X,
     3 '(IN)',7X,'(IN)',7X,'(IN)',7X,'(IN)',6X,'(DEG)',5X,'(IN)'/)
  505 FORMAT(4X,3F11.3,F11.4,5F11.3,F9.3///)
  506 FORMAT(50X,'TRANSFORMED BLADE DATA'//)
  507 FORMAT(8X,'STANG',14X,'TRACO',16X,'SOLID',15X,'BBM4',16X,'BBM5',
     116X,'FEE'/8X,'(DEG)',15X,'(IN)',36X,'(DEG)',15X,'(DEG)',14X,
     2 '(DEG)'/)
  508 FORMAT(6X,F7.3,5F20.3///)
  509 FORMAT(58X,'AREAS'///8X,'ACROS',16X,'AEW',16X,'ABS1',17X,'AR',
     1 18X,'DH',17X,'ATHT'/7X,'(SQ IN)',13X,'(SQ IN)',13X,'(SQ IN)',
     2 34X,'(IN)',14X,'(SQ IN)'/)
  510 FORMAT(3X,F10.3,5F20.3)
      WRITE(3,500)
      WRITE(3,100)
      WRITE(3,101) BETA,ZD,R4,DINLT,DISTH,B4
      WRITE(3,103)
      L=N-1
      DO 10 J=5,L,5
      XXXX=FLOAT(J)
   10 WRITE(3,501)XXXX,RADUS(J)
      WRITE(3,501)THETA,RADTH
      WRITE(3,501)ALPHA,RAD
      WRITE(3,502)
```

```
      WRITE(3,503)DELTA,GAMMA,ARO,ANVAN,ADIS,RAR,RLOC,CVAN,BKB
      WRITE(3,504)
      WRITE(3,505)DIFBC,RDIS,THICK,THICO,TIN,TOUT,XL,DLDM,BCM5,TEX5
      WRITE(3,506)
      WRITE(3,507)
      WRITE(3,508)STANG,TRACO,SOLID,BBM4,BBM5,FEE
      WRITE(3,509)
      WRITE(3,510)ACROS,AEW,ABS1,AR,DH,ATHT
      RETURN
      END
```

@ ELT REVCH,1,710427, 63124

```
      SUBROUTINE REVCH
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,OI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHT1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,C6,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2 ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,          XKDVD,XK1VD,XKFVD,EVD,FLA,    XKQD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,ADEX5,DLDM,BCM5
      LW=3
      WIMP = WP*(1.+QKI)
      B6 = B4
      ALP6 = 90. - BFL5
      ALP6R=ALP6/57.296
      IF(RB67) 10,10,12
   10 RB67 = 1.1
   12 B7 = B6/RB67
      D8 = 2.*DIFBC
      IF (FLAHG-7.) 48,48,49
   48 CM6= C6 * SIN(ALP6R)
      GO TO 50
   49 BCM5R = ALP6/57.296
      CM6 = C6*SIN(BCM5R)
   50 IF(RBRM) 16,16,17
   16 RBRM = 1.4
   17 RMUT= RBRM*(B6+B7)/2.
      R8=D8/2.
      IF(D9) 21,21,22
   21 D9 = DT1
   22 IF(RDSV) 23,23,24
   23 RDSV = 1.1
   24 DSV=D9*RDSV
      IF(FLAHG-7.) 80,80,81
   81 ZRV = ZD
      GO TO 26
   80 IF(ZRV) 25,25,26
   25 ZRV = ZD-1.
   26 TRV9=3.1416*D9 /ZRV
      R9=D9/2.
      RSV=DSV/2.
      A9 = TRV9 - 0.080
      IF(B9) 27,27,28
   27 B9 = 1.15  * B7
   28 DHRV = 2.*A9 * B9/(A9+B9)
      RHRV=DHRV/2.
      AE10 = 3.1416 *D9*B9
```

```
      CM10 = 0.321 * QD/AE10
      BE10R = BE10/57.296
      IF(BE10-90.) 15,18,15
   18 C10 = CM10
      GO TO 19
   15 C10 = CM10/SIN(BE10R)
   19 IF(FLAHG-7.) 200,200,202
  200 CU6= C6 * COS(ALP6R)
      CM7 = RB67* CM6
      CU7 = CM6*B6/(0.785*CLUT*RMUT+B6 *SIN(ALP6R)/COS(ALP6R))
      ALP7R= ATAN(CM7/CU7)
      ALP7= 57.296 * ALP7R
      C7 = SQRT(CU7**2+CM7**2)
      HLUT= 0.01554*(CU6**2-CU7**2)
      TRVT= 3.1416 * D8/ZRV
      IF(THRV) 30,30,31
   30 THRV = 0.120
   31 BET8R=ATAN(FINC*TRVT/(TRVT-THRV)*SIN(ALP7R)/COS(ALP7R))
      BET8= 57.296*BET8R
      BLA=(D8*SIN(BET8R)+ DSV)/(D8*COS(BET8R))
      BLB=(D8*COS(BET8R))/(D8*SIN(BET8R)+DSV)
      XLAG = 2./(BLA-BLB)
      IF(XLAG) 60,61,61
   60 BLAGR = 3.1417  -ATAN(ABS(XLAG))
      GO TO 63
   61 BLAGR=ATAN(XLAG)
   63 BLAG=57.296 *BLAGR
      RBLD= (R8**2- RSV**2)/(2.* R8*COS(BET8R))
      BLRV= RBLD *     BLAGR    + RSV -R9
      DMRV = SQRT((D8**2+D9**2)/2.)
      TMRV = 3.1416/ZRV*DMRV
      SOLRV= BLRV/TMRV
      C710 = SQRT(0.5*(C10**2+C7**2))
      GO TO 190
  202 DHDEX = 2.*B6*ADEX5/(B6+ADEX5)
      DHRV = 0.5*(DHDEX+DHRV)
      RHRV = 0.5*DHRV
      FLUTM = 3.1416*RMUT
      FLRCM = R8-R9
      FLCM=FLUTM+FLRCM
      BET7 = BCM5 + (90. - BCM5)*FLUTM/FLCM
      BE67R= 0.5*(BCM5+BET7)/57.296
      FLUT = FLUTM/SIN(BE67R)
      BE79R = 0.5*(BET7+BE10)/57.296
      FLRC = FLRCM/SIN(BE79R)
      FLC = FLUT + FLRC
      BLRV = FLC
      C710 = SQRT(0.5*(C6**2+C10**2))
      AEC6=ADEX5*B6
      AEC9=A9*B9
      OMDRV =((1.-AEC6/AEC9)**2+0.2*(1.-(AEC6/AEC9)**2))/2.
      CLUT = 0.28-0.15*SQRT(2.*RMUT/(B6+B7)-1.)
      HLUT = CM6**2/64.348*2.*CLUT
  190 RERV=DHRV*C710*RHO/(386.088*VIS)
      IF(RERV-1.E+05) 520,520,525
  520 FRC = 0.0032+0.221/RERV**0.237
      GO TO 530
  525 FRC = 1./(0.86858*ALOG(RHRV/XKEVD)+ 1.74)**2
  530 HLFRV = FRC*C710**2/64.348*BLRV/DHRV
      IF(FLAHG-7.) 220,220,222
```

```
   222 HLDRV=OMDRV*C6**2/64.348
       HLRC = HLFRV + HLDRV + HLUT
       PSIUT=32.174*HLUT/U2**2
       PSDRV= 32.174*HLDRV/U2**2
       PSFRV = 32.174*HLFRV/U2**2
       PSIRC = PSIUT + PSDRV + PSFRV
       IF(PRINT) 72,72,730
   730 WRITE(LW,9)
       WRITE(LW,604)
       WRITE(LW,701) RMUT,B7
       WRITE(LW,707) FLC,B9
       WRITE(LW,709) DHRV,D9
       WRITE(LW,606)
       WRITE(LW,711) CM6,C10
       WRITE(LW,715) RERV
       WRITE(LW,607)
       WRITE(LW,717) FRC
       WRITE(LW,719) HLUT,PSIUT
       WRITE(LW,721) HLDRV,PSDRV
       WRITE(LW,723) HLFRV,PSFRV
       WRITE(LW,727) HLRC,PSIRC
     9 FORMAT(45X,'REVERSING CHANNEL WITH CONTINJOUS VANE'/)
   604 FORMAT(55X,'GEOMETRY'/)
   606 FORMAT(45X,'FLUID ANGLES AND VELOCITIES'/)
   607 FORMAT(53X,'PERFORMANCE'/)
   701 FORMAT(1X,'MEAN TURNING RADIUS, U-TURN, RMUT',2X,F10.3,2X,'IN',
      112X,'CHANNEL HEIGHT B7',20X,F10.3,'IN')
   707 FORMAT(1X,'APPROX. CHANNEL LENGTH, FLC',8X,F10.3,2X,'IN',
      112X,'CHANNEL HEIGHT B9',20X,F10.3,'IN')
   709 FORMAT(1X,'HYDRAULIC DIA, CHANNEL, DHRV',     7X,F10.3,2X,'IN',
      112X,'MEAN EXIT DIA, D9',20X,F10.3,2X,'IN'//)
   711 FORMAT(1X,'MERIDIONAL VELOCITY, CM6',11X,F10.3,2X,'FT/S',10X,
      1'ABSOLUT VELOCITY, VANE EXIT, C10',6X,F10.3,2X,'FT/S')
   715 FORMAT(1X,'REYNOLDS NO, MEAN, RERV',12X,E10.4,2X,'***'//)
   717 FORMAT(1X,'FRICTION COEFFICIENT, FRC',10X,F10.5,2X,'***')
   719 FORMAT(1X,'HEAD LOSS, U-TURN, HLUT',12X,F10.3,2X,'FT',12X,
      1'HEAD LOSS COEFF, U-TURN, PSIUT',8X,F10.4,2X,'***')
   721 FORMAT(1X,'HEAD LOSS DIFFUSION, HLDRV',9X,F10.3,2X,'FT',12X,
      1'HEAD LOSS COEFF, DIFFUSION, PSDRV',5X,F10.4,2X,'***')
   723 FORMAT(1X,'HEAD LOSS FRICTION, HLFRV',10X,F10.3,2X,'FT',12X,
      1'HEAD LOSS COEFF, FRICTION, PSFRV',6X,F10.4,2X,'***')
   727 FORMAT(1X,'HEAD LOSS, REVERSING SYSTEM,HLRC',3X,F10.3,2X,'FT',12X,
      1'HEAD LOSS COEFF, REVERSING SYST, PSIRC',F10.4,2X,'***'///)
       GO TO 72
   220 DRV=1.-C10/C7 + D8 * CU7/(SOLRV*C7*(D8+D9))
       OMDRV = XKDVD * DRV**EVD
       HLDRV=OMDRV*C7**2/64.348
       HLINV=(CM7*(COS(ALP7R)/SIN(ALP7R)-COS(BET8R)/SIN(BET8R)))**2/64.34
      18
       HLRV=HLDRV + HLFRV + HLINV
       HLRC = HLRV + HLUT
       PSINV = 32.174*HLINV/U2**2
       PSIUT=32.174*HLUT/U2**2
       PSIRV=32.174*HLRV/U2**2
       PSIRC=PSIUT+PSIRV
       PSDRV= 32.174*HLDRV/U2**2
       PSFRV = 32.174*HLFRV/U2**2
       IF(PRINT) 72,72,330
   330 WRITE(LW,1)
       WRITE(LW,4)
```

```
      WRITE(LW,301) RMUT,B7
      WRITE(LW,303) BET8,BLAG
      WRITE(LW,305) DSV,RBLD
      WRITE(LW,307) BLRV,SOLRV
      WRITE(LW,309) DHRV,ZRV
      WRITE(LW,6)
      WRITE(LW,311) CM6,C7
      WRITE(LW,313) ALP7,C10
      WRITE(LW,315) RERV
      WRITE(LW,7)
      WRITE(LW,317) DRV,FRC
      WRITE(LW,319) HLUT,PSIUT
      WRITE(LW,329) HLINV,PSINV
      WRITE(LW,321) HLDRV,PSDRV
      WRITE(LW,323) HLFRV,PSFRV
      WRITE(LW,325) HLRV,PSIRV
      WRITE(LW,327) HLRC,PSIRC
    1 FORMAT(40X,'REVERSING CHANNEL WITH VANELESS U-TURN'/)
    4 FORMAT(55X,'GEOMETRY'/)
    6 FORMAT(45X,'FLUID ANGLES AND VELOCITIES'/)
    7 FORMAT(53X,'PERFORMANCE'/)
  301 FORMAT(1X,'MEAN TURNING RADIUS, U-TURN, RMUT',2X,F10.3,2X,'IN',12X
     1,'INLET VANE HEIGHT, B7',17X,F10.3,2X,'IN')
  303 FORMAT( 1X,'VANE INLET ANGLE, BET8',13X,F10.3,2X,'DEG',11X,
     1 'VANE TURNING ANGLE, BLAG',14X,F10.3,2X,'DEG')
  305 FORMAT( 1X,'DIAMETER DSV',23X,F10.3,2X,'IN',12X,
     1 'VANE TURNING RADIUS, RBLD',13X,F10.3,2X,'IN')
  307 FORMAT(1X,'VANE LENGTH, BLRV',18X,F10.3,2X,'IN',12X,
     1 'VANE SOLIDITY, SOLRV',18X,F10.3,2X,'***')
  309 FORMAT(1X,'HYDRAULIC DIA, VANE PASSAGE, DHRV',2X,F10.3,2X,'IN',
     112X,'VANE NUMBER, ZRV',20X,F10.3,2X,'***'//)
  311 FORMAT(1X,'MERIDIONAL VELOCITY, CM6',11X,F10.3,2X,'FT/S',10X,
     1 'ABSOLUT VELOCITY, VANE INLET, C7',6X,F10.3,2X,'FT/S')
  313 FORMAT (1X,'FLUID ANGLE VANE INLET, ALP7',7X,F10.3,2X,'FT/S',10X,
     1'ABSOLUT VELOCITY, VANE EXIT, C10',6X,F10.3,2X,'FT/S')
  315 FORMAT(1X,'REYNOLDS NO, MEAN, RERV',12X,F10.4,2X,'***'//)
  317 FORMAT(1X,'DIFFUSION PARAMETER VANE, DRV',6X,F10.4,2X,'***',11X,
     1'FRICTION COEFFICIENT VANE, FRC',8X,F10.5,2X,'***')
  319 FORMAT(1X,'HEAD LOSS, U-TURN, HLUT',12X,F10.3,2X,'FT',12X,
     1'HEAD LOSS COEFF, U-TURN, PSIUT',8X,F10.4,2X,'***')
  321 FORMAT(1X,'HEAD LOSS DIFFUSION, HLDRV',9X,F10.3,2X,'FT',12X,
     1'HEAD LOSS COEFF, DIFFUSION, PSDRV',5X,F10.4,2X,'***')
  323 FORMAT(1X,'HEAD LOSS FRICTION, HLFRV',10X,F10.3,2X,'FT',12X,
     1'HEAD LOSS COEFF, FRICTION, PSFRV',6X,F10.4,2X,'***')
  325 FORMAT(1X,'HEAD LOSS, VANE, HLRV',14X,F10.3,2X,'FT',12X,,
     1'HEAD LOSS COEFF, VANE, PSIRV',10X,F10.4,2X,'***')
  327 FORMAT(1X,'HEAD LOSS, REVERSING SYSTEM,HLRC',3X,F10.3,2X,'FT',12X,
     1'HEAD LOSS COEFF, REVERSING SYST, PSIRC',F10.4,2X,'***'/)
  329 FORMAT(1X,'HEAD LOSS, INCIDENCE, HLINV',8X,F10.3,2X,'FT',12X,
     1'HEAD LOSS COEFF, INCIDENCE, PSINV',5X,F10.4,2X,'***')
   72 HLVD=OMTOT*V4**2/64.35
      PSIVD=HLVD*32.174/U2**2
      PSHSG=PSIVD+PSIRC
      PSIOV=PSIIP-PSHSG
      HTOTF=PSIOV*U2**2/32.174
      ETAHI=PSIOV/PSITH
      ETAOV=PSIOV/PSIIN*WP/WIMP
      M = M+1
      IF(PRINT) 800,800,750
  750 WRITE(3,47) PSIVD
```

```
      WRITE(3,29) PSHSG
      WRITE(3,37) ETAHI
      WRITE(3,39) ETAOV
      WRITE(3,41) PSIOV
      WRITE(3,441) HTOTF
   47 FORMAT(5X,'HEAD LOSS COEFF, DIFFUSER, PSIVD',8X,F10.4,3X,'***')
   41 FORMAT(5X,'PUMP OVERALL HEAD COEFF,  PSIOV',9X,F10.4,3X,'***')
   29 FORMAT(5X,'HEAD LOSS COEFF, HOUSING, PSHSG',9X,F10.4,3X,'***')
   39 FORMAT(5X,'EFFICIENCY, OVERALL, ETAOV',14X,F10.4,2X,'***')
  441 FORMAT(5X,'TOTAL HEAD RISE, HTOTF',18X,F10.3,2X,'FT')
   37 FORMAT(5X,'EFFICIENCY, HYDRAULIC, ETAHI',12X,F10.4,2X,'***')
  800 RETURN
      END
```

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@ ELT SAFE,1,710427, 63125

      SUBROUTINE SAFE
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2ANVAN,BK3,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DFG,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,          XKDVD,XK1VD,XKFVD,EVD,FLA,    XKQD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,39
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
      BB2R=BB2/57.296
      IF(LOOP) 20,20,25
   20 PSITH=PSIO-PHI2*COS(BB2R)/SIN(BB2R)
   25 HTHI=HTOT/ETAHI
      U2=SQRT(32.174*HTHI/PSITH)
      D2=229.3*U2/XN
      R2=D2*0.5
      BLK2=0.05*Z/(D2*SIN(BB2R))
      BLK2 = .1 *  (1.-BLK2)  + BLK2
      CM2=PHI2*U2
      AB2=0.321*QI/CM2
      B2=AB2/(3.14159*D2*(1.-BLK2))
      IF(PRINT) 50,50,40
   40 WRITE(3,1) NCASE
      WRITE(3,3) PSITH
      WRITE(3,4) HTHI
      WRITE(3,6) D2
      WRITE(3,7) BLK2
      WRITE(3,9) AB2
      WRITE(3,18) B2
      WRITE(3,8) CM2
      WRITE(3,5) U2
      WRITE(3,30) PHI2
    1 FORMAT('1',5X,'*** CASE',I2,' ***'/)
    3 FORMAT(5X,'THEORETICAL HEAD COEFFICIENT',12X,F10.4,4X,'***')
    4 FORMAT(5X,'THEORETICAL HEAD',24X,F10.4,4X,'FT')
    5 FORMAT(5X,'IMPELLER TANGENTIAL VELOCITY',12X,F10.4,4X,'FT/SEC')
    6 FORMAT(5X,'IMPELLER DISCHARGE DIAMETER',13X,F10.4,4X,'INCH')
    7 FORMAT(5X,'IMPELLER DISCHARGE BLOCKAGE',13X,F10.4,5X,'***')
    8 FORMAT(5X,'IMPELLER MERIDIONAL VELOCITY',12X,F10.4,4X,'FT/SEC')
    9 FORMAT(5X,'IMPELLER DISCH BLCKD AREA',15X,F10.4,4X,'SQ IN')
   18 FORMAT(5X,'IMPELLER DISCH VANE HEIGHT',14X,F10.4,4X,'INCH')
   30 FORMAT(5X,'IMPELLER DISCH FLOW COEFFICIENT',9X,F10.4,5X,'***',/)
   50 RETURN
      END
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@ ELT SCRLL,1,710427, 63128

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      SUBROUTINE SCRLL
      DIMENSION X(10),Y(10),W(10),A(11),B(11)
      COMMON    XK(8),XZ(3),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,BFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,C5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2 ANVAN,BKB, R5   ,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT  ,PI,NCGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,              XKDVD,XK1VD,XKFVD,EVD,FLA,    XKQD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,ROSV,TEX5 ,DLDM,BCM5
      X(1)=10.
      DO 10 J=2,6
   10 X(J)=X(J-1)+5.
      Y(1)=1.086
      Y(2)=1.134
      Y(3)=1.18
      Y(4)=1.225
      Y(5)=1.27
      Y(6)=1.315
      W(1)=0.77
      W(2)=0.691
      W(3)=0.628
      W(4)=0.585
      W(5)=0.55
      W(6)=0.514
      CALL CUFIT(3,6,X,Y,A)
      CALL CUFIT(3,6,X,W,B)
      WIMP=WP*(1.+QKI)
      B5=1.1*B2
      IF(FLAHG-3.) 2,2,3
    2 ALP2R=ATAN(CM2/PSITH/U2)
      ALP5R=ALP2R
      ALPH5=57.296*ALP5R
      D5=D2
      CU2TH=PSITH*U2
      CU5=CU2TH
      GO TO 4
    3 ALPH5=90.- BFL5
      DIFBC=R5
      D5=2*DIFBC
      ALP5R=ALPH5/57.296
      CU5=C5*COS(ALP5R)
    4 D6D5=SOLVE(ALPH5,A)
      D6=D5*D6D5
      R6=D6/2.
      CU6=CU5/D6D5
```

```
      C7CU6=SOLVE(ALPH5,B)
      C7=C7CU6*CU6
      C8=C7/2.5
      A7=.321*Q/C7
      PHI7=C7/U2
      C=84530.*CU6*R6/Q
      STAY=FLAHG
      IF(FLAHG-3.) 61,61,62
   62 FLAHG=FLAHG-3.
   61 IF(FLAHG-2.) 63,64,64
   63 D7=2.*SQRT(A7/3.14159)
      DSC=SQRT((D7**2-1.21*B5**2)/2.)+1.1*B5
      RE=DSC*CU6*RHO/(386.088*VIS)
      IF(RE-1.E+05) 205,205,66
   66 FSFS=1./(0.86858*ALOG(DSC/(2.*XKSFS))+1.74)**2
      DHSFS=(0.75112E-05)*FSFS*C*R6*C7 **2*ALOG(1.+57./SQRT(0.1666*R6*C)
     1)
      GO TO 69
   64 D7=1.414*SQRT(A7/3.14159)
      DSC=SQRT((D7**2-1.21*B5**2)/2.)+1.1*B5
      RE=DSC*CU6*RHO/(386.088*VIS)
      IF(RE-1.E+05) 205,205,68
   68 FSFS=1./(0.86858*ALOG(DSC/(2.*XKSFS))+1.74)**2
      DHSFS=(0.75112E-05)*FSFS*C*R6*C7 **2*ALOG(1.+40.25/SQRT(0.1666*R6*
     1C))
      IF(FLAHG-2.) 69,69,112
  112 FSFSO=1./(0.86858*ALOG(DSC/(2.*XKSFS))+1.74)**2
      XLSC=1.57*(D6+D7)
      DHSFS=DHSFS+FSFSO*C7**2/64.35*XLSC/D7/1.414
      D7=2.*SQRT(A7/3.14159)
   69 D8=1.58*D7
      EXDL=4.*D7
      DPEXD=0.1*PHI7**2
      DHEXD=DPEXD*U2**2/32.174
      DPSFS=32.174*DHSFS/U2**2
      IF(STAY -3.) 71,71,72
   71 PSIVD=0
      GO TO 73
   72 HLVD=OMTOT*V4**2/64.35
      PSIVD=HLVD*32.174/U2**2
   73 PSHSG=PSIVD+DPSFS+DPEXD
      FLAHG=STAY
      PSIOV=PSIIP-PSHSG
      HTOTF=PSIOV*U2**2/32.174
      ETAHI=PSIOV/PSITH
      ETAOV=PSIOV/PSIIN*WP/WIMP
      IF(SSTHG) 81,81,83
   81 PM=0
      ADVRO=0
      GO TO 82
   83 RO=SQRT(.5*((D6/2.+D7)**2+(D6/2.)**2))
      RDM=SQRT(0.5*(R4**2+R5**2))
      DPTOT=RHO/144.*HTOT
      PM=DPTOT-C7**2*RHO/9266.
      FDVT=1.047*PM*(RO-RDM)*(RO+2.*RDM)
      ADVRO=FDVT/SSTHG*RPHG*FSTHG
      ACRST=ZD*ACROS
      IF(ACRST-ADVRO) 100,82,82
  100 IF(M) 201,201,207
  201 IF(SBETA) 205,205,207
```

```
  205 NOGO=1
      GO TO 200
  207 IF(LOOP) 209,209,211
  209 NSKIP=1
      GO TO 200
  211 IF(PRINT) 82,82,212
  212 WRITE(3,214)
  214 FORMAT(//5X,'HOUSING STRUCTURAL LIMIT EXCEEDED IN FINAL ITERATIONS
     1'//)
   82 M=M+1
      IF(PRINT) 200,200,210
  210 STAY=FLAHG
      IF(FLAHG-3.) 93,93,91
   91 FLAHG=FLAHG-3.
   93 IF(FLAHG-2.) 104,105,106
  104 WRITE(3,94)
   94 FORMAT(5X,'*** SINGLE DISCHARGE - SINGLE TONGUE VOLUTE ***'/)
      GO TO 97
  105 WRITE(3,95)
   95 FORMAT(5X,'*** DUAL DISCHARGE VOLUTE ***'/)
      GO TO 97
  106 WRITE(3,96)
   96 FORMAT(5X,'*** DOUBLE VOLUTE ***'/)
   97 FLAHG=STAY
   15 FORMAT(5X,'VOLUTE BASE CIRCLE DIAMETER, D6',9X,F10.3,2X,'INCH')
   19 FORMAT(5X,'VOLUTE THROAT DIAMETER, D7',14X,F10.3,2X,'INCH')
   17 FORMAT(5X,'VOLUTE THROAT ABSOLUTE VELOCITY, C7',5X,F10.3,2X,'FT/SE
     1C')
   27 FORMAT(5X,'HEAD LOSS COEFF, DIFFUSER, PSIVD',8X,F10.4,3X,'***')
   29 FORMAT(5X,'HEAD LOSS COEFF, HOUSING, PSHSG',9X,F10.4,3X,'***'/)
   31 FORMAT(5X,'PUMP OVERALL HEAD COEFF,  PSIOV',9X,F10.4,3X,'***')
   33 FORMAT(5X,'VOLUTE PRESSURE, PM',21X,F10.4,3X,'PSI')
   35 FORMAT(5X,'REQ. TOT. BLADE AREA, ADVRQ',13X,F10.4,3X,'SQIN'/)
   37 FORMAT(5X,'EFFICIENCY, HYDRAULIC, ETAHI',12X,F10.4,2X,'***')
   39 FORMAT(5X,'EFFICIENCY, OVERALL, ETAOV',14X,F10.4,2X,'***')
   41 FORMAT(5X,'HEAD LOSS COEFF, EXIT DIFF, DPEXD',7X,F10.4,3X,'***')
  441 FORMAT(5X,'TOTAL HEAD RISE, HTOTF',18X,F10.3,2X,'FT')
   43 FORMAT(5X,'MAX EXIT DIAMETER, D8',19X,F10.4,3X,'IN')
   45 FORMAT(5X,'MAX EXIT DIFFUSER LENGTH, EXDL',10X,F10.4,3X,'IN'/)
   47 FORMAT(5X,'MIN EXIT VELOCITY, C8',19X,F10.4,3X,'FT/SEC')
   48 FORMAT(5X,'REYNOLDS NUMBER, VOLUTE, RE',13X,E10.4,3X,'***')
   49 FORMAT(5X,'FRICTION COEFFICIENT VOLUTE, FSFS',7X,F10.4,3X,'***')
   50 FORMAT(5X,'VOLUTE HEAD LOSS, DHSFS',17X,F10.3,3X,'FT')
   51 FORMAT(5X,'EXIT DIFF HEAD LOSS, DHEXD',14X,F10.3,3X,'FT'/)
   52 FORMAT(5X,'HEAD LOSS COEFF, VOLUTE, DPSFS',10X,F10.4,3X,'***')
      WRITE(3,15) D6
      WRITE(3,19) D7
      WRITE(3,43) D8
      WRITE(3,17) C7
      WRITE(3,47) C8
      WRITE(3,45) EXDL
      WRITE(3,48) RE
      WRITE(3,49) FSFS
      WRITE(3,50) DHSFS
      WRITE(3,51) DHEXD
      WRITE(3,52) DPSFS
      WRITE(3,41) DPEXD
      WRITE(3,27) PSIVD
      WRITE(3,29) PSHSG
      WRITE(3,33) PM
```

```
000177            WRITE(3,35) ADVRO
000178            WRITE(3,31) PSIOV
000179            WRITE(3,37) ETAHI
000180            WRITE(3,39) ETAOV
000181            WRITE(3,441) HTOTF
000182        200 RETURN
000183            END
```

@ ELT SIZE1,1,710427, 53131

```
      SUBROUTINE SIZE1
      COMMON    XK(8),XZ(8),XFR(8),XR(8)
      COMMON DH1,RM1,H,RA,RC,BBM1,CLIND,THIND,ZL,DHIND,BLK1,A1,AB1,DPIND
     1,BBC1,BBC2,BBC3,CLC1,CLC2,CLC3,CLTS,THC1,THC2,THC3,THTS,CLRS,THRS,
     2CLIMP,THIMP,CLTOT,THTOT,BLK2,A2,SOL1,SOL2,SOL3,SOL4,SOL5,SOLIP,SOL
     3TO,DH2,DH3,DH4,DH5,DHIMP,DHTOT,RP2,RP3,RP4,SM,QI,SIG,DR,CM2,SCL
      COMMON DT1,EPS,D2,B2,BBT1,BB2,Z,Z0,Z1,Z2,Z3,Z4,NZ,KBMID,XSI,DPIMP
      COMMON WP,XN,RHO,QKI,HNPSH,HTOT,PHIMN,VHKM,ETAHI,PSITH,ESHR,RWR
      COMMON XKPH1,PHI21,PHI22,PHI23,CM1,UT1,PHI1T,S,XNS,PSIO,PHI2,NCASE
      COMMON FLAG,VIS,FLACO,WWR,U2,PSIBL,DPIPS,PSIIP,PSIIN,FRD
      COMMON B4,RL,REX,R4,BETA,RFL4,ZD,DINLT,DISTH,TIN,TOUT,XL,V5,
     1RADUS(95),THETA,RADTH,ALPHA,RAD,DELTA,GAMMA,ARO,RAR,RLOC,CVAN,
     2ANVAN,BKB,DIFBC,RDIS,ADIS,THICK,THICO,STANG,TRACO,SOLID,BBM4,
     3BBM5,FEE,ACROS,AEW,ABS1,DH,AR,ATHT ,RI,NOGO,NSKIP,OPTFI,PRINT,FI2
      COMMON RIOPT,RIBM,RIBL,RIBH,DEL,BFL5,DEQ,RMTH,OMPR,OMEW,OMOV
      COMMON V4,M,         XKDVD,XK1VD,XKFVD,EVD,FLA,    XKQD,Q,QD,OMTOT
      COMMON RPHG,SSTHG,FSTHG,XKSFS,XKMSC,D6,D7,C7,DPSSC,DPSFS,DPSMC,C34
      COMMON RLBET,RLZD,SBETA,SZD,PSHSG,ETAOV,LOOP,FLAHG,B9
      COMMON CLUT,FINC,BE10,RBRM,D9,RB67,THRV,ZRV,RDSV,TEX5 ,DLDM,BCM5
      Q=449.*WP/RHO
      QI=Q*(1.+QKI)
      WIMP=WP*(1.+QKI)
      Q1=QI
      S=XN*SQRT(QI)/HNPSH**0.75
      SPRM=S/SQRT(1.-EPS**2)
      PHI1T=3574./SPRM
   11 DT1=4.54*( QI/((1.-EPS**2)*XN*PHI1T))**0.333
      A1=0.785397*DT1**2*(1.-EPS**2)
      CM1=0.321*QI/A1
      VHKI=64.348*HNPSH/CM1**2
      IF(VHKI-VHKM) 10,15,15
   10 PHI1T=PHI1T-0.01
      GO TO 11
   15 IF(PHI1T-PHIMN) 20,25,25
   20 CM1=SQRT(2.*32.16*HNPSH/VHKM)
      A1=.321*QI/CM1
      DT1=SQRT(4.*A1/(3.1416*(1.-EPS**2)))
   12 UT1=XN*DT1/229.
      PHI1T=CM1/UT1
      IF(PHI1T-PHIMN)13,25,25
   13 XN=XN-1000.
      GO TO 12
   25 BBFL=ATAN(PHI1T)*57.296
      BBT1=1.74*BBFL
      UT1=CM1/PHI1T
      XNS=XN*SQRT(Q )/HTOT**0.75
      S0=XN*SQRT(Q)/HNPSH**.75
      S1=XN*SQRT(QI)/HNPSH**.75/SQRT(1.-EPS**2)
      IF(BB2-18.) 500,301,302
  301 PHI2=0.0465E-03*XNS+0.040
      GO TO 320
  302 IF(BB2-25.) 500,303,312
  303 PHI2=0.0535E-03*XNS+0.057
      GO TO 320
  312 IF(BB2-30.) 500,313,304
  313 PHI2=0.06121E-03*XNS+0.06258
```

[illegible].98181E-03*XNS+0.06258


```
      GO TO 320
  304 IF(BB2-35.) 500,305,306
  305 PHI2=0.0675E-03*XNS+0.067
      GO TO 320
  306 IF(BB2-45.) 500,307,308
  307 PHI2=0.0795E-03*XNS+0.075
      GO TO 320
  308 IF(BB2-60.) 500,309,310
  309 PHI2=0.0935E-03*XNS+0.086
      GO TO 320
  310 IF(BB2-90.) 500,319,500
  319 PHI2=0.12E-03*XNS+0.12
  320 G=(90.-BB2)/57.296
      C=COS(G)
      A=5.5797*C**2/Z**2-19.233*C**4/Z**3+8.6584*C**4/Z**4*(8.*C**2-1.)
      PSIO=EXP(-2.*G*SIN(2.*G)/Z)*EXP(A)/((2.*C)**(4.*C**2/Z))
      FI2=PHI2
      PHI2=XKPH1*PHI2
  516 FORMAT(///5X,'*** OUTPUT ***',/)
      WRITE(3,516)
      WRITE(3,38) XN
      WRITE(3,39) XNS
      WRITE(3,37) S0
      WRITE(3,49) S1
      WRITE(3,51) WIMP
      WRITE(3,43) QI
      WRITE(3,41) BBT1
      WRITE(3,31) DT1
      WRITE(3,32) A1
      WRITE(3,33) CM1
      WRITE(3,34) UT1
      WRITE(3,36) PHI1T
      WRITE(3,45) FI2
      WRITE(3,47) PHI2
      WRITE(3,2) PSIO
    2 FORMAT(5X,'SHUTOFF HEAD COEFFICIENT',16X,F8.3,5X,'***')
   31 FORMAT(5X,'IMPELLER INLET DIAMETER',17X,F8.3,4X,'INCHES')
   32 FORMAT(5X,'IMPELLER INLET AREA',21X,F8.3,4X,'SQ IN')
   33 FORMAT(5X,'IMPELLER INLET MERIDIONAL VELOCITY',F14.3,4X,'FT/SEC')
   34 FORMAT(5X,'IMPLLR INLET TNGNTL VELOCITY',12X,F8.3,4X,'FT/SEC')
   36 FORMAT(5X,'IMPLLR INLET FLOW COEFFICIENT',11X,F8.3,5X,'***')
   37 FORMAT(5X,'SUCTION SPECIFIC SPEED, S0',12X,E10.4,4X,'RPM*GPM**0.5/
     1FT**0.75')
   38 FORMAT(5X,'IMPELLER ROTATIONAL SPEED',13X,F10.3,5X,'RPM')
   39 FORMAT(5X,'SPECIFIC SPEED',24X,E10.4,4X,'RPM*GPM**0.5/FT**0.75')
   41 FORMAT(5X,'INLET TIP BLADE ANGLE', 19X,F8.3,4X,'DEGREES')
   43 FORMAT(5X,'IMPELLER FLOW RATE, QI',17X,F9.3,4X,'GPM')
   45 FORMAT(5X,'DISCH FLOW COEFF REC, SHROUDED IMP.',4X,F9.4,4X,'***')
   47 FORMAT(5X,'DISCH FLOW COEFF, INITIAL',14X,F9.4, 4X,'***')
   49 FORMAT(5X,'SUCTION SPECIFIC SPEED, S1',12X,E10.4,4X,'RPM*GPM**0.5/
     1FT**0.75')
   51 FORMAT(5X,'IMPELLER WEIGHT FLOW, WIMP',12X,F9.3,4X,'LB/SEC')
      GO TO 600
  500 NOGO=1
  600 RETURN
      END
```

2. AXIAL THRUST BALANCER STABILITY ANALYSIS

J. J. Brunner
5-4-72

COMPUTER PROGRAM
AXIAL THRUST BALANCER STABILITY ANALYSIS

I. INTRODUCTION

The dynamic stability of a series-flow self compensating thrust balance system operating with liquid hydrogen is analyzed. Two methods of analysis are presented: The energy method and the root locus method. In addition to stability parameters, the program also prints out balancer capacity, flow rate and orifice pressure drops for any specified balance piston position.

This program was written for the parametric evaluation of the axial thrust balancer design of the NERVA Turbopump described in Reference 1.

II. DESCRIPTION

The thrust balancer schematically shown in Figure 1 is a double acting series flow balance piston which is integral with the second stage impeller disk. Fluid is bled from the second stage impeller discharge and forced through the high pressure orifice into the balance piston cavity. From the balance piston cavity the fluid passes through the low pressure orifice and discharges into the sump. The sump is vented to the first stage impeller rear cavity through multiple internal flow passages and a common external line which permits installation of venturi flowmeter.

Maximum thrust (towards suction) is achieved with the high pressure orifice closed while minimum thrust is obtained with the low pressure orifice closed.

Reference 1 - Aerojet Nuclear Systems Company Engineering Operations Report N830OR:71-076, NERVA Turbopump Design Report, Volume 1, September 1971.

BALANCE PISTON SCHEMATIC

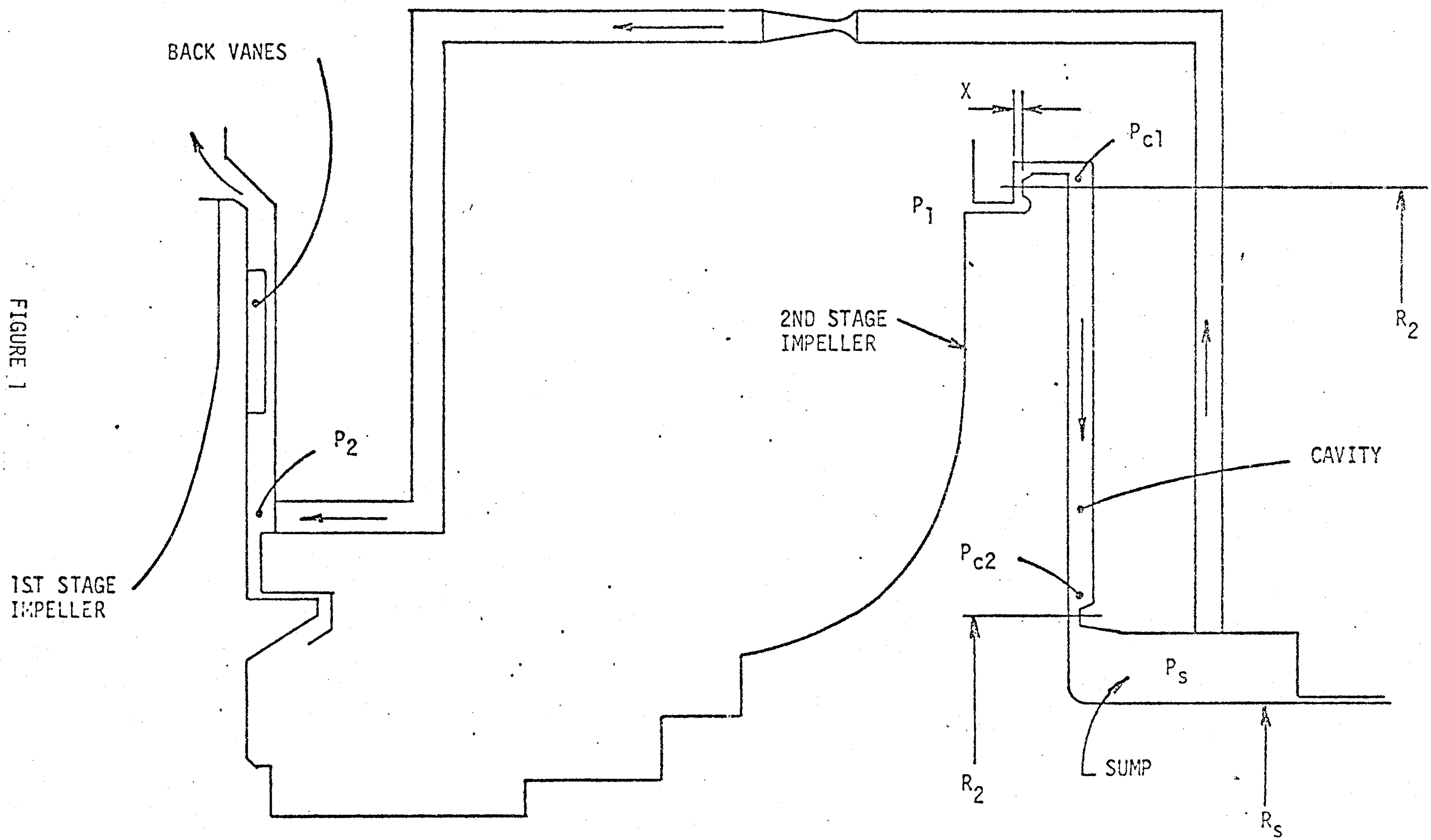


FIGURE 1

The balance piston operates between the second stage impeller discharge pressure, P_1, and the first stage impeller rear cavity pressure, P_2, (Refer to Figure 1). The effective pressure differential across the balancer face is reduced by the pressure difference, $P_{c1} - P_{c2}$, resulting from fluid rotation in the balance piston cavity. This pressure difference is calculated using the semi-empirical method presented in Reference 1. The angular velocity of the cavity fluid may exceed one half that of the rotor because of the very small axial clearance.

After assuming starting values for fluid density at each orifice the flow rate is calculated from the following equation by an iterative process.

$$\dot{W} = 2g \left[\frac{P_2 - P_1 - \Delta P_c}{\frac{1}{C_1^2 A_1^2 \rho_1} + \frac{1}{C_2^2 A_2^2 \rho_2} + \frac{1}{C_e^2 \rho_e}} \right]^{\frac{1}{2}}$$

where:

$A_1 = 2\pi R_1 X$

$A_2 = 2\pi R_2 (\delta - X)$

δ = total axial clearance

X = high pressure orifice gap

C_1 = high pressure orifice flow coefficient = .85

C_2 = low pressure orifice flow coefficient = .85

C_e = vent line resistancé, calculated = .5 Ft^2

Using the first approximation of the flow rate the pressure drop through each orifice is calculated. The fluid frictional heating in the cavity is estimated using the friction coefficients based on Schultz-Grunows data presented in Reference 2. The frictional power is calculated as follows:

$$P_{fric} = .9223\ (10^{-8})\ K\ \rho\ N^3\ (R_2^{\ 5} - R_1^{\ 5})$$

P_{ric} = disk friction horsepower

K = friction coefficient

ρ = fluid density (lb/ft^3)

N = speed (rpm)

R_2 = outer radius, (inch)

R_1 = inner radius (inch)

The friction coefficient K is a function of Reynolds number and clearance to diameter ratio. Values of K for smooth and rough disks are published in Reference 2.

The friction loss results in an enthalpy rise

$$\Delta h = \frac{550\ P_{fric}}{J\ \dot{W}}$$

and the resulting temperature rise is obtained by dividing Δh by the specific heat C_p.

Assuming an isenthalpic process through all orifices and considering the frictional heat input in the cavity, new values of fluid density are obtained for cavity, sump and exit. These new values are used in place of initial approximate densities and the entire flow calculation is repeated. Two to three iterations are generally required depending on the starting value to achieve consistent values of fluid density.

Reference 1 - Pratt & Whitney Aircraft, Florida Research and Development Center, Investigation of Pressure Prediction Methods for Radial Flow Impellers, PWA-FR-1276, 8 March 1965.

Reference 2 - A. J. Stepanoff, Centrifugal and Axial Flow Pumps, 2nd Edition, J. Wiley & Sons, Inc., New York

Cavity and sump thrust is calculated by numerical integration of the pressure profile, assuming a linear variation of pressure with R^2.

The dynamic stability analysis is in essence based on the energy method and the root locus method discussed in Reference 3.

III. INSTRUCTIONS

1. The total travel DELT is divided in even increments of 0.001 inch. Present array size limits the effective travel to be analyzed to 0.019 inches, e.g. the maximum value for LIM is 19.

KSTAR permits analysis to start at a higher value of X. To avoid rubbing X will always be larger than 0.001.

2. If NFLAG is negative only the steady state operation of the balancer will be analyzed. If NFLAG is positive the entire analysis will be carried out.

3. Orifice coefficients CORF1 and CORF2 based on Rocketdyne data are 0.85.

4. The line loss coefficient between sump and exit is

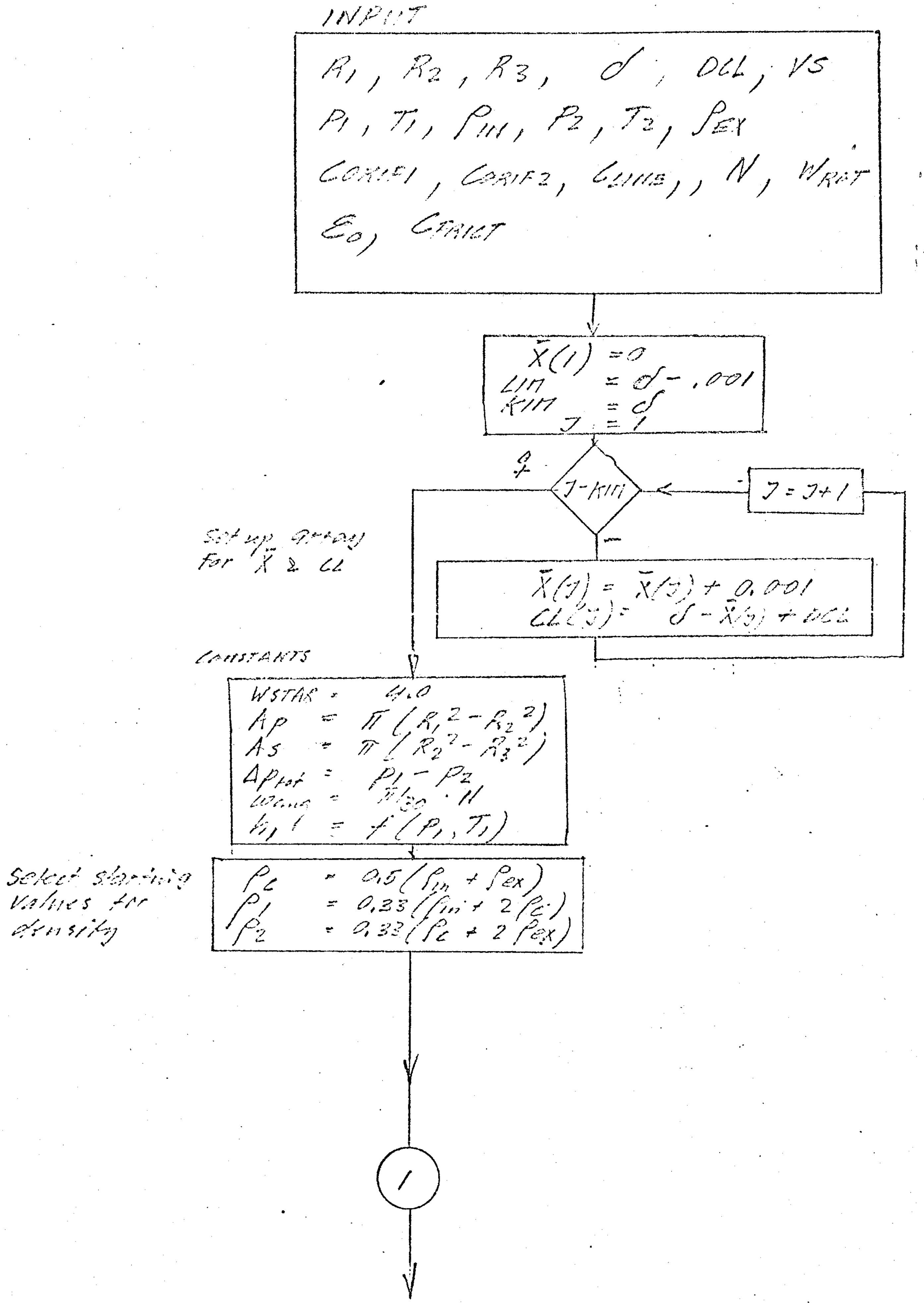
$$CLINE = K \frac{\dot{W}}{\sqrt{\Delta P_{line} \, \rho_{ex}}}$$

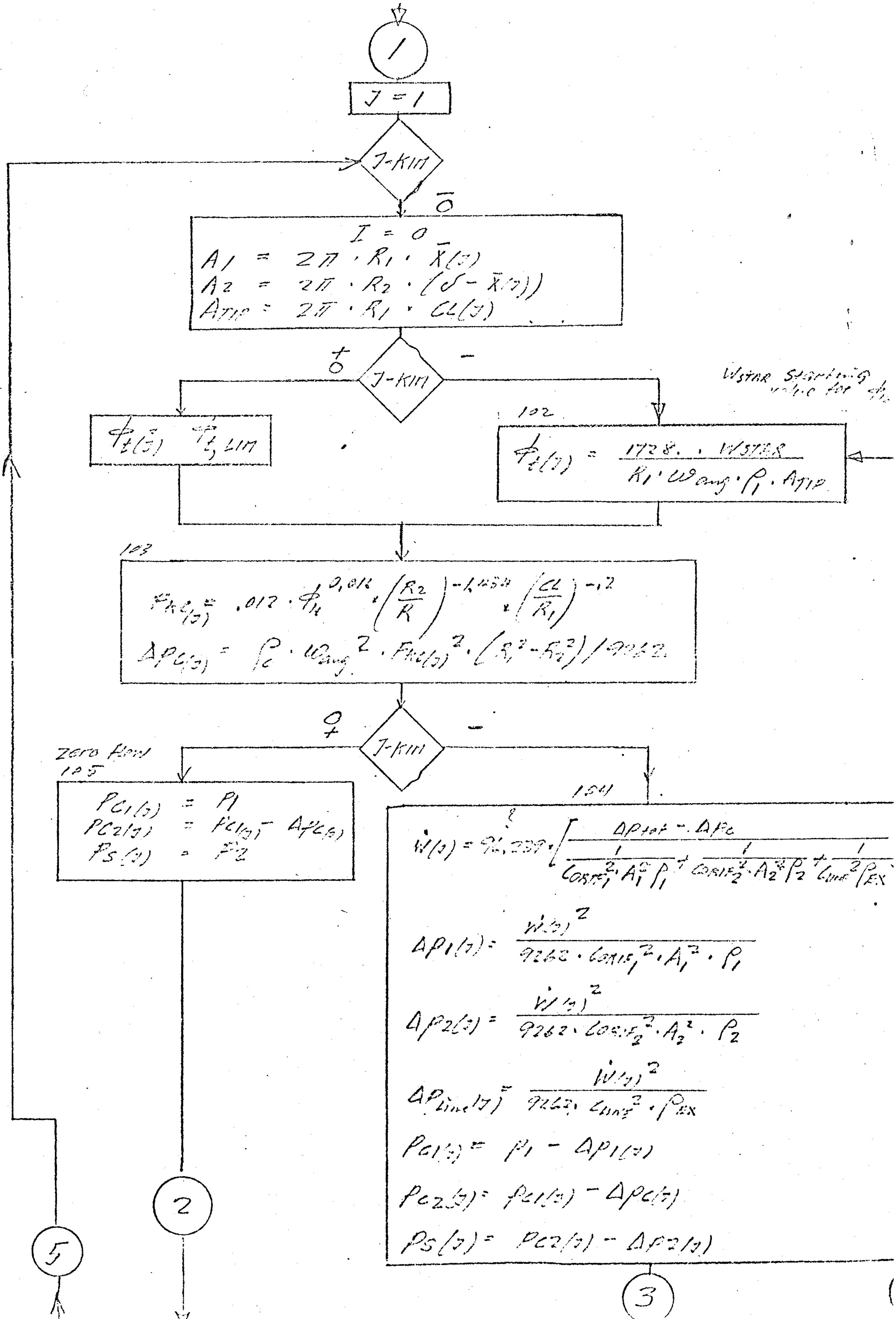
This coefficient must be estimated from ducting layout.

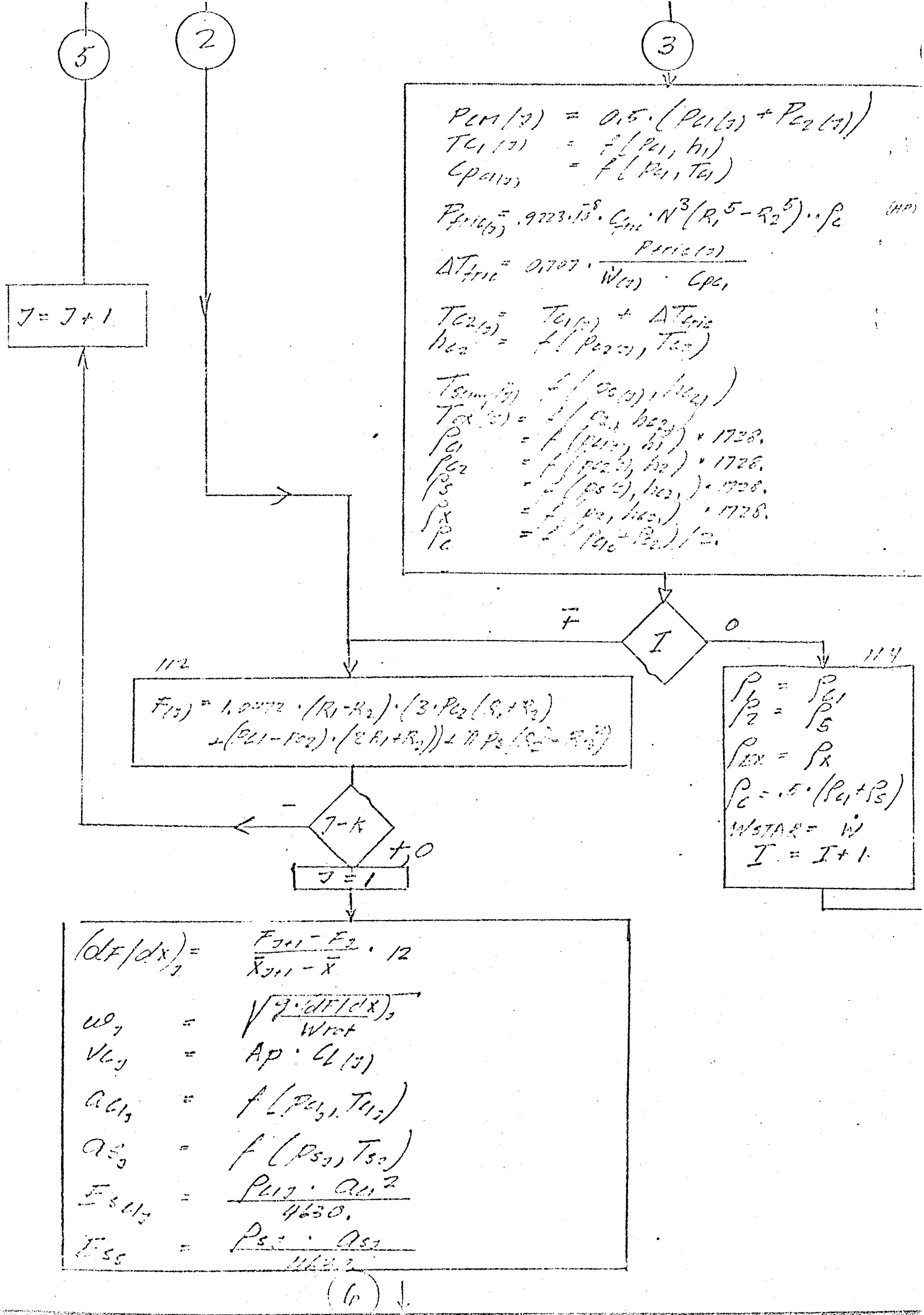
5. For disc friction coefficients refer to Reference 2. For most applications CFRIC = 0.22×10^{-7}.

Reference 3 - Dynamic Stability Study of a Series Flow Thrust Balance Piston, North American Aviation, Rocketdyne Division, Report R-6809P-1.

BALANCE PISTON STABILITY ANALYSIS




1
J = 1
J-KIM
0
I = 0
A1 = 2π · R1 · X̄(J)
A2 = 2π · R2 · (δ − X̄(J))
ATIP = 2π · R1 · CL(J)
+ 0
J-KIM
−
WSTAR starting value for φt
102
φt(J) = 1728. · WSTAR / R1 · ωang · ρ1 · ATIP
φt(J) φt,LIM
103
FKC(J) = .012 · φt^0.012 · (R2/R)^−1.458 · (CL/R1)^−.2
ΔPC(J) = ρc · ωang^2 · FKC(J)^2 · (R1^2 − R2^2)/9262.
0 +
J-KIM
−
Zero flow
105
PC1(J) = P1
PC2(J) = PC1(J) − ΔPC(J)
PS(J) = P2
104
Ẇ(J) = 91.239 · √[(ΔPtot − ΔPc) / (1/(CORIF1^2 · A1^2 · ρ1) + 1/(CORIF2^2 · A2^2 · ρ2) + 1/(CLine^2 · ρEX))]
ΔP1(J) = Ẇ(J)^2 / 9262 · CORIF1^2 · A1^2 · ρ1
ΔP2(J) = Ẇ(J)^2 / 9262 · CORIF2^2 · A2^2 · ρ2
ΔPLine(J) = Ẇ(J)^2 / 9262 · CLine^2 · ρEX
PC1(J) = P1 − ΔP1(J)
PC2(J) = PC1(J) − ΔPC(J)
PS(J) = PC2(J) − ΔP2(J)
2
5
3


5
2
3
Pcm(J) = 0.5·(Pc1(J) + Pc2(J))
Tc1(J) = f(Pc1, h1)
Cpc1(J) = f(Pc1, Tc1)
Pfric(J) = .9223·10^-8·Cfric·N^3(R1^5 − R2^5)·ρc
(HP)
ΔTfric = 0.707 · Pfric(J) / (W(J) · Cpc1)
Tc2(J) = Tc1(J) + ΔTfric
hc2 = f(Pc2(J), Tc2)
ρc1 = f(Pc1(J), h1) · 1728.
ρc2 = f(Pc2(J), h2) · 1728.
ρs = f(Ps(J), hc2) · 1728.
ρx = f(Px, hc2) · 1728.
ρc = (ρc1 + ρc2)/2.
J = J + 1
I
F
0
112
F(J) = 1.0472·(R1−R2)·(3·Pc2(R1+R2) + (Pc1−Pc2)·(2R1+R2)) + π Ps(R2^2 − R3^2)
114
ρ1 = ρc1
ρ2 = ρs
ρEX = ρx
ρc = .5·(ρc1 + ρs)
WSTAR = W
I = I + 1
J−K
−
+,0
J = 1
(dF/dx)J = (FJ+1 − FJ)/(XJ+1 − X) · 12
ωJ = √(g·(dF/dx)J / Wrot)
VcJ = Ap · CL(J)
acJ = f(PcJ, TcJ)
asJ = f(PsJ, TsJ)
EscJ = ρcJ · ac^2 / 4630.
Ess = ρsJ · asJ^2 / 4630.
6

(6)

$$\rho_{C1H} = \rho_{C1J} + 5.$$
$$\rho_{C1L} = \rho_{C1J} - 5.$$
$$V_{C1H} = f(\rho_{C1H}, h_1)$$
$$V_{C1L} = f(\rho_{C1L}, h_1)$$
$$V_{C1} = 1./\rho_{C1J}$$
$$EHC1_J = -V_{C1} \cdot \frac{10.}{V_{C1H} - V_{C1L}}$$

$$\rho_{SH} = \rho_S + 5.$$
$$\rho_{SL} = \rho_S - 5.$$
$$V_{SH} = f(\rho_{SH}, h_{C2})$$
$$V_{SL} = f(\rho_{SL}, h_{C2})$$
$$V_S = 1./\rho_{SJ}$$
$$EHS_J = -V_S \cdot \frac{10}{V_{SH} - V_S}.$$
$$EEC1_J = \left[\frac{1}{ESC1_J} + \left(\frac{1}{EHC1_J} - \frac{1}{ESC1_J}\right) \cdot \left(\frac{1}{1 + \left(\frac{\dot{w}_2 \cdot \rho_C \cdot V_{C1}}{1728 \cdot \dot{W}}\right)^2}\right)\right]^{-1}$$
$$EES_J = \left[\frac{1}{ESS_J} + \left(\frac{1}{EHS_J} - \frac{1}{ESS_J}\right) \cdot \left(\frac{1}{1 + \left(\frac{w \cdot \rho_S V_S}{1728 \cdot \dot{W}}\right)^2}\right)\right]^{-1}$$
$$\Omega_J = \frac{\bar{X}}{\delta - \bar{X}}$$
$$\Lambda = (\rho_1 - \rho_{C1J}) / (\rho_{C2J} - \rho_{SJ})$$
$$\mu = (\rho_1 - \rho_{C1J}) / (\rho_{SJ} - \rho_2)$$
$$K_C = 1. - \frac{\rho_1 - \rho_{C1J}}{EEC1_J}$$
$$K_S = 1. - \frac{\rho_{C2J} - \rho_{SJ}}{EES_J}$$

(7)

7

$$C_{1j} = 1 + \Omega$$

$$C_{2j} = \rho_{Lm} \cdot A_p \cdot \bar{X} / (\dot{W} \cdot 1728)$$

$$C_{3j} = K_{Cj} + \Lambda_j$$

$$C_{4j} = \frac{\rho_{Lm} V_L}{1728\, \dot{W}_j} \cdot \frac{2(P_1 - P_{C1j})}{E_{ESm}}$$

$$C_{5j} = |\Lambda_j \cdot K_{Sj}|$$

$$C_{6j} = |\Omega|$$

$$C_{7j} = \frac{\rho_{Sj} \cdot A_S \cdot \bar{X}_j}{\dot{W}_j \cdot 1728}$$

$$C_{8j} = \Lambda_j \cdot K_S + \mu_j$$

$$C_{9j} = \frac{\rho_{Sj} \cdot V_S}{1728 \cdot \dot{W}_j} \cdot \frac{2(P_1 - P_{C1j})}{E_{BSj}}$$

$$C_{10j} = |\Lambda|$$

$$K_{Pj} = C_{2j} / C_{4j}$$

$$\omega_1^2 = \frac{C_{1j} \cdot C_{8j} - C_{5j} \cdot C_{6j}}{C_{2j} \cdot C_{9j}}$$

$$2 \cdot \zeta \omega_1 = \frac{C_{1j} \cdot C_{10j} + C_{2j} \cdot C_{8j} + C_{7j} \cdot C_{5j}}{C_{2j} \cdot C_{9j}}$$

$$\omega_2^2 = \frac{C_{3j} \cdot C_{8j} - C_{10j} \cdot C_{5j}}{C_{4j} \cdot C_{9j}}$$

$$2 \zeta \omega_2 = \frac{C_{4j} \cdot C_{8j} + C_{3j} \cdot C_{9j}}{C_{4j} \cdot C_{9j}}$$

$$K_{Sj} = C_{4j} / C_{9j}$$

$$\omega_3^2 = \frac{C_1 \cdot C_{10} - C_{3j} \cdot C_{6j}}{C_{4j} \cdot C_{7j}}$$

$$2 \zeta \omega_3 = \frac{C_{2j} \cdot C_{10j} + C_{3j}\, C_{7j} - C_{4j} \cdot C_{6j}}{C_{4j} \cdot C_{7j}}$$

8

(8)

$$X_{Cj} = \frac{2\zeta\omega_1 \cdot \omega}{\omega_1^2 - \omega^2}$$

$$Y_{Cj} = \frac{2\zeta\omega_2 \cdot \omega}{\omega_2^2 - \omega^2}$$

$$\sin\psi_{1j} = \frac{X_{Cj} - Y_{Cj}}{\left((1+X_{Cj}^2)(1+Y_{Cj}^2)\right)^{0.5}}$$

$$Z_{Cj} = K_{Pj} \cdot \frac{2\zeta\omega_{1j}}{2\zeta\omega_{2j}} \cdot \frac{Y_{Cj}}{X_{Cj}} \cdot \left(\frac{1+X_{Cj}^2}{1+Y_C^2}\right)^{0.5}$$

$$U_{Sj} = \frac{2\zeta\omega_{3j} \cdot \omega}{\omega_3^2 - \omega^2}$$

$$Y_{Sj} = Y_{Cj}$$

$$\sin\psi_{2j} = \frac{U_{Sj} - Y_{Sj}}{\left((1+U_{Sj}^2)\cdot(1+Y_{Sj}^2)\right)}$$

$$Z_{Sj} = K_S \cdot \frac{2\zeta\omega_{3j}}{2\zeta\omega_{2j}} \cdot \frac{Y_{Sj}}{U_{Sj}} \cdot \left(\frac{1+U_{Sj}^2}{1+Y_{Sj}^2}\right)^{0.5}$$

$$P_{Cj} = 2\pi \cdot A_P (p_1 - p_{cmj}) \cdot \bar{X} \cdot Z_{Cj} \cdot \sin\psi_{1j} \cdot \mathcal{E}_0^2$$
$$P_{Sj} = 2\pi \cdot A_S (p_1 - p_{cmj}) \cdot \bar{X} \cdot Z_{Sj} \cdot \sin\psi_{2j} \cdot \mathcal{E}_0^2$$

ROOT LOCUS METHOD

STOP

NOMENCLATURE INPUT

SYMBOL	NOTE	DESCRIPTION	UNIT	FORMAT
R_1		Radius High Pressure Orifice	In	F
R_2		Radius Low Pressure Orifice	In	F
R_3		Radius Sump	In	F
DELT		Total Travel	In	F
DCL		Cavity Clearance	In	F
VS		Sump Volume	In^3	F
VOLTP		Tip Cavity Volume	In^3	F
P1		Static Pressure,HP orifice Inlet	psia	F
T1		Temperature, HP Orifice Inlet	deg R	F
RHOIN		Initial Inlet Density	lb/ft^3	F
P2		Static Pressure, exit	psia	F
ROEX		Initial exit temperature	lb/ft^3	F
LIM	(1)*	Limit of Increments of Travel (19 max)	-	I
KSTAR	(1)*	Starting Value of X	-	I
NFLAG	(2)*	Flag Defining extentof analysis	-	I
CORF1	(3)*	Orifice Coefficient HP	-	F
CORF2	(3)*	Orifice Coefficient LP	-	F
CLINE	(4)*	Line Loss Coefficient	-	F
RPM		Rotational Speed	rpm	F
WROT		Rotor Weight	lb	F
EPS		Ampltidue (~.001)	In	F
CFRIC	(5)*	Disc Friction Coefficient	-	E

*Refer to Instructions.

IBM FORTRAN Coding Form

GX28-7327-6 U/M 050
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PROGRAM BALANCE PISTON STABILITY ANALYSIS

PROGRAMMER | DATE | PUNCHING INSTRUCTIONS | GRAPHIC | PUNCH | PAGE OF | CARD ELECTRO NUMBER

R1	R2	R3	DELT	DCL	VS	VOLTP	
P1	T1	RHOIN	P2	ROEX	LIM	KSTAR	NFLAG
ØRF1	ØRF2	CLINE	RPM	WROT	EPS	CFRIC	

```
@I FOR MAIN
UNIVAC 1108 FORTRAN V LEVEL   2206 0018 F50165
THIS COMPILATION WAS DONE ON 07 SEP 71 AT 11:15:18
```

MAIN PROGRAM

STORAGE USED (BLOCK, NAME, LENGTH)

```
0001   *CODE    003432
0000   *DATA    005213
0002   *BLANK   000000
```

EXTERNAL REFERENCES (BLOCK, NAME)

```
0003   PTLNTH
0004   PHTEMP
0005   PTCP
0006   PHDENS
0007   PTSOUN
0010   NRDU$
0011   NI02$
0012   NIO1$
0013   NWDU$
0014   SQRT
0015   NEXP6$
0016   ATAN
0017   SIN
0020   NSTOP$
```

STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0000	003643 1F	0000	003633 10F	0001	000430 102L	0001	002441 1021G	0001	002452 1031G
0000	003733 11F	0001	002646 1106G	0001	000743 112L	0001	002667 1130G	0001	000727 114L
0001	003017 1150G	0001	003036 1161G	0001	003110 1202G	0001	003172 1220G	0001	003205 1232G
0001	001156 129L	0000	003735 13F	0001	003415 1316G	0000	003743 15F	0000	003773 17F
0001	002513 170L	0001	002530 172L	0001	002542 174L	0001	002553 176L	0001	002576 179L
0001	002616 179L	0001	003075 181L	0001	003106 182L	0001	002727 183L	0001	003013 184L
0001	003027 188L	0000	004012 19F	0001	003032 190L	0001	003046 194L	0001	003051 195L
0001	003101 196L	0000	003635 20F	0001	003212 201L	0001	003221 203L	0001	003230 205L
0000	004020 21F	0001	003236 211L	0001	003265 213L	0001	003272 215L	0001	003336 217L
0001	003300 221L	0001	003326 223L	0001	003365 225L	0000	004025 23F	0000	004046 25F
0001	000402 265G	0000	004070 27F	0001	000412 272G	0000	004612 299F	0000	003645 3F
0000	003637 30F	0000	004620 300F	0000	004644 302F	0000	004647 304F	0000	004662 306F
0000	004676 308F	0001	000004 31L	0000	004412 310F	0000	004424 312F	0000	004437 314F
0001	000625 32L	0000	004655 320F	0000	004711 322F	0000	004704 324F	0000	004722 326F
0000	004746 328F	0000	004760 329F	0000	004756 330F	0000	005013 331F	0000	005023 332F
0000	005046 334F	0000	005052 336F	0000	005056 338F	0000	005077 340F	0000	005113 342F
0001	001003 362G	0001	001050 413G	0001	001065 426G	0001	001137 450G	0001	001177 467G
0000	003655 5F	0000	004777 50F	0000	004104 52F	0000	004125 54F	0001	001550 543G
0000	004147 56F	0001	001605 570G	0000	004155 58F	0000	004163 60F	0001	001620 601G
0000	004173 62F	0001	001761 637G	0000	004213 64F	0000	004235 66F	0001	002013 661G
0000	004241 67F	0000	004250 65F	0000	003651 7F	0000	004301 70F	0001	002034 700G
0000	004324 72F	0001	002160 724G	0000	004442 73F	0000	004446 74F	0001	002177 741G
[illegible]	[illegible]	0001	002377 771G	0000	004477 78F	0000	004335 80F	0000	004342 82F
				0000	004502 88F	0000	003710 9F	0000	004506 90F

```
0000   004533 92F     0000   004546 93F     0000   004554 94F     0000   004604 96F     0001   003426 999L
0000 R 003542 ASP     0000 R 003551 ANVEL   0000 R 003546 AP      0000 R 002734 ART     0000 R 003547 AS
0000 R 003563 A1IP    0000 R 003561 A1      0000 R 003562 A2      0000 R 003244 BPK     0000 R 002710 BRT
0000 R 003543 CFRIC   0000 R 000024 CL      0000 R 000030 CLAMD   0000 R 003537 CLINE   0000 R 001630 COMEG
0000 R 003632 CONST   0000 R 003535 CORF1   0000 R 003536 CORF2   0000 R 001534 CPC     0000 R 003565 CPC1
0000 R 001560 CPS     0000 R 002664 CPT     0000 R 000550 C1      0000 R 001034 C10     0000 R 000574 C2
0000 R 000620 C3      0000 R 000644 C4      0000 R 000670 C5      0000 R 000714 C6      0000 R 000740 C7
0000 R 000754 C8      0000 R 001010 C9      0000 R 003522 DCL     0000 R 003521 DELT    0000 R 001654 DEX
0000 R 000120 DPC     0000 R 000264 DPL     0000 R 003550 DPTOT   0000 R 000170 DP1     0000 R 000214 DP2
0000 R 003566 DTFRC   0000 R 002614 EECM    0000 R 002354 EEC1    0000 R 001700 EFS     0000 R 002570 EHCM
0000 R 002424 EHC1    0000 R 002400 EHS     0000 R 003624 EPS     0000 R 002544 ESCM    0000 R 002304 ESC1
0000 R 002330 ESS     0000 R 001604 F       0000 R 000074 FKC     0000 R 003314 GH1     0000 R 003614 HCM
0000 R 001724 HC2     0000 R 003553 HI      0000 I 003560 I       0000 I 003557 J       0000 I 003544 KIM
0000 I 003553 KSTAR   0000 I 003631 L       0000 I 003532 LIM     0000 I 003514 LR      0000 I 003515 LW
0000 I 003630 M       0000 I 003627 N       0000 I 003534 NFLAG   0000 R 003270 OMCRO   0000 R 000240 OMEGA
0000 R 001060 OMSQ1   0000 R 001130 OMSQ2   0000 R 001200 OMSQ3   0000 R 000404 PCM     0000 R 003615 PCMH
0000 R 003616 PCFL    0000 R 000310 PC1     0000 R 003575 PC1H    0000 R 003576 PC1L    0000 R 000334 PC2
0000 R 001774 PFRIC   0006 R 000000 PHDENS  0000 R 000050 PHIIN   0000 R 003350 PHIM    0004 R 000000 PHTEMP
0000 R 000360 PS      0000 R 003604 PSH     0000 R 003605 PSL     0005 R 000000 PTCP    0003 R 000000 PTENTH
0007 R 000000 PTSOUN  0000 R 003525 P1      0000 R 003530 P2      0000 R 003564 QC1     0000 R 003570 QEX
0000 R 003567 QS      0000 R 003554 RHOC    0000 R 002520 RHOCM   0000 R 002114 RHOC1   0000 R 002140 RHOC2
0000 R 003531 RPGEX   0000 R 003527 RHOIN   0000 R 002164 RHOS    0000 R 002210 RHOX    0000 R 003555 RHO1
0000 R 003556 RHO2    0000 R 003620 RLCMH   0000 R 003622 RLCML   0000 R 003571 RLC1    0000 R 003600 RLC1H
0000 R 003602 RLC1L   0000 R 003572 RLC2    0000 R 003320 RLK     0000 R 003573 RLS     0000 R 003607 RLSH
0000 R 003611 RLSL    0000 R 003574 RL2     0000 R 003552 RMR     0000 R 003540 RPM     0000 R 003625 RT12
0000 R 003626 RT34    0000 R 003516 R1      0000 R 003517 R2      0000 R 003520 R3      0000 R 001320 SINP1
0000 R 001440 SINP2   0000 R 000500 SLAMC   0000 R 000524 SLAMS   0000 R 000454 SMU     0000 R 002640 SOUCM
0000 R 002260 SOUC1   0000 R 002234 SOUS    0000 R 002760 S1      0000 R 003004 S1I     0000 R 003030 S2
0000 R 003054 S2I     0000 R 003100 S3      0000 R 003124 S3I     0000 R 003150 S4      0000 R 003174 S4I
0000 R 003613 TCM     0000 R 001750 TC1     0000 R 002020 TC2     0000 R 003344 TEMP    0000 R 003340 TES
0000 R 002044 TS      0000 R 003470 TSET    0000 R 002070 TX      0000 R 003526 T1      0000 R 001370 US
0000 R 001510 VC      0000 R 003623 VCM     0000 R 003617 VCMH    0000 R 003621 VCML    0000 R 003603 VC1
0000 R 003577 VC1H    0000 R 003601 VC1L    0000 R 003612 VOLS    0000 R 003524 VOLTP   0000 R 003523 VS
0000 R 003606 VSH     0000 R 003610 VSL     0000 R 000144 WDOT    0000 R 003541 WROT    0000 R 003545 WSTAR
0000 R 000000 XBAR    0000 R 001250 XC      0000 R 002450 XKP     0000 R 002474 XKS     0000 R 003374 XMM
0000 R 003420 XMP     0000 R 001274 YC      0000 R 001414 YS      0000 R 001344 ZC      0000 R 003444 ZETA
0000 R 001104 ZETO1   0000 R 001154 ZETO2   0000 R 001224 ZETO3   0000 R 001464 ZS
```

```
00101      1*        DIMENSION XBAR(20),CL(20),PHIIN(20),FKC(20),DPC(20),WDOT(20),
00101      2*       1DP1(20),DP2(20),OMEGA(20),DPL(20),PC1(20),PC2(20),PS(20),PCM(20),
00101      3*       2CLAMD(20),SMU(20),SLAMC(20),SLAMS(20),C1(20),C2(20),C3(20),C4(20),
00101      4*       3C5(20),C6(20),C7(20),C8(20),C9(20),C10(20),        OMSQ1(20),
00101      5*       4ZETO1(20),OMSQ2(20),ZETO2(20),        OMSQ3(20),ZETO3(20),XC(20)
00103      6*        DIMENSION YC(20),SINP1(20),ZC(20),US(20),YS(20),SINP2(20),ZS(20),
00103      7*       1VC(20),CPC(20),CPS(20),F(20),COMEG(20),DEX(20),EFS(20),HC2(20),
00103      8*       2TC1(20),PFRIC(20),TC2(20),TS(20),TX(20),RHOC1(20),RHOC2(20),
00103      9*       3RHOS(20),RHOX(20),SOUS(20),SOUC1(20),ESC1(20),ESS(20),EEC1(20),
00103     10*       4EHS(20),EHC1(20),XKP(20),XKS(20),RHOCM(20),ESCM(20),EHCM(20),
00103     11*       5EECM(20),SOUCM(20),CPT(20)
00104     12*        DIMENSION BRT(20),ART(20),S1(20),S1I(20),S2(20),S2I(20),S3(20),
00104     13*       1S3I(20),S4(20),S4I(20),RLK(20),BPK(20),OMCPO(20),GH1(20),TES(4),
00104     14*       2TEMP(4),PHIM(20),XMM(20),XMP(20),ZETA(20),TSET(20)
00105     15*        LR = 5
00106     16*        LW = 6
00107     17*     10 FORMAT(7F8.3)
00110     18*     20 FORMAT(5F8.3,3I5)
00111     19*     30 FORMAT(3F8.3,F8.1,2F8.4,E8.2)
```

```
31 READ(LR,10) R1,R2,R3,DELT,DCL,VS,VOLTP
   IF(R1) 999,999,32
32 READ(LR,20) P1,T1,RHOIN,P2,RHOEX,LIM,KSTAR,MFLAG
   READ(LR,30) CORF1,CORF2,CLINE,RPM,WPOT,AMP,CFRIC
 1 FORMAT('1')
 3 FORMAT(30X,'BALANCE PISTON STABILITY ANALYSIS'//)
 5 FORMAT(2X,'GEOMETRY'/)
 7 FORMAT(5X,'R1, HP ORIF',6X,'R2, LP ORIF',5X,'R3, SUMP',7X,'TOT TRA
  1VEL',4X,'CAVITY CLEAR',4X,'SUMP VOL',4X,'TIP CAVITY VOL')
 9 FORMAT(9X,'IN',14X,'IN',14X,'IN',10X,'DELTA, IN',6X,'DCL, IN',
  16X,'VS, IN**3',5X,'VOLTP IN**3'/)
11 FORMAT(7F15.5//)
13 FORMAT(2X,'FLUID CONDITION, INPUT'/)
15 FORMAT(3X,'STAT PRESSURE',5X,'TEMPERATURE',3X,'DENSITY RHOIN',3X,
  1'STAT PRESSURE',3X,'DENSITY RHOEX',5X,'LIMIT X',5X,'START X')
17 FORMAT(5X,'P1, PSIA',10X,'T1, DEG R',5X,'LB/FT**3',7X,'P2, PSIA',8
  1X,'LB/FT**3'//)
19 FORMAT(2F15.2,F15.3,F15.2,F15.3,I14,I12//)
21 FORMAT(2X,'INPUT PARAMETERS'/)
23 FORMAT(15X,'ORIFICE COEFFICIENTS',7X,'SPEED',4X,'ROTOR WEIGHT',2X,
  1'AMPLITUDE',2X,'DISC FRIC')
25 FORMAT(10X,'CORF1',5X,'CORF2',5X,'CLINE',6X,'RPM',10X,'LB',8X,
  1'AMP, IN',2X,'COEFF CFRIC'/)
27 FORMAT(F15.3,2F10.3,F11.1,F11.3,F12.4,E13.2//)
   WRITE(LW,1)
   WRITE(LW,3)
   WRITE(LW,5)
   WRITE(LW,7)
   WRITE(LW,9)
   WRITE(LW,11) R1,R2,R3,DELT,DCL,VS,VOLTP
   WRITE(LW,13)
   WRITE(LW,15)
   WRITE(LW,17)
   WRITE(LW,19) P1,T1,RHOIN,P2,RHOEX,LIM,KSTAR
   WRITE(LW,21)
   WRITE(LW,23)
   WRITE(LW,25)
   WRITE(LW,27) CORF1,CORF2,CLINE,RPM,WROT,AMP,CFRIC
   XBAR(1) = 0.001
   KIM = LIM + 1
   KSTAR = 4.
   AP  = 3.1417 * (R1**2-R2**2)
   AS  = 3.1417 * (R2**2 - R3**2)
   DPTOT  = P1-P2
   ANVEL  = 0.1047 * RPM
   RAR = SQRT(0.5*(R1**2 + R2**2))
   H1   = PTENTH(P1,T1)
C-STARTING VALUES FOR DENSITY
   RHOC  = 0.5*(RHOIN + RHOEX)
   RHO1  = 0.33*(RHOIN +2.* RHOC)
   RHO2  = 0.33*(RHOC + 2.*RHOEX)
   DO 100 J=2,KIM
100 XBAR(J) =XBAR(J-1)+ 0.001
   DO 110 J=KSTAR,KIM
   I = 0
   CL(J) =DELT- XBAR(J) + DCL
   A1  = 6.2834 * R1 * XBAR(J)
   A2 = 6.2834*R2 * (DELT - XBAR(J))
   ATIP  = 6.2834 * R1 *CL(J)
102 PHIIN(J) = 1728.*WSTAR/R1/ANVEL/RHO1/ATIP
```

```
      FKC(J)= 0.12 + PHIIN(J)**0.016*(R1/RMR)**1.434*(R1/CL(J))**0.233
      DPC(J)  = RHOC * ANVEL**2*FKC(J)**2*(R1**2 - R2**2)/1333740.
      WDOT(J) =0.55833*SQRT((DPTOT-DPC(J))/(1./CORF1**2/A1**2/RHO1 +
     11./CORF2**2/A2    **2/RHO2 + 1./CLINE**2/RHOEX))
      DP1(J)=WDOT(J)**2*2.239/(CORF1**2*A1**2*RHO1)
      DP2(J)=WDOT(J)**2*2.239/( CORF2**2*A2**2*RHO2)
      DPL(J) = WDOT(J)**2*2.239/(CLINE**2*RHOEX)
      PC1(J)  = P1 - DP1(J)
      PC2(J)  = PC1(J) - DPC(J)
      PS(J)  = PC2(J) - DP2(J)
      PCM(J)  = 0.5*(PC1(J) + PC2(J))
      TC1(J)  = PHTEMP(PC1(J),H1,QC1)
      CPC1  = PTCP(PC1(J),TC1(J))
      PFRIC(J) = 0.9223E-08* CFRIC * RPM**3*(R1**5 - R2**5) * RHOC
      DTFRC   = 0.707 * PFRIC(J)/WDOT(J)/CPC1
      TC2(J)  = TC1(J)     + DTFRC
      HC2(J)= PTENTH(PC2(J),TC2(J))
      TS(J)     = PHTEMP(PS(J),HC2(J),QS)
      TX(J)  = PHTEMP(P2,HC2(J),QEX)
      RHOC1(J)  = PHDENS(PC1(J),H1,RLC1)  * 1728.
      RHOC2(J)  = PHDENS(PC2(J),HC2(J),RLC2)*1728.
      RHOS(J)  = PHDENS(PS(J),HC2(J),RLS)*1728.
      RHOX(J) = PHDENS(P2,HC2(J),RL2) * 1728.
      RHOCM(J) = (RHOC1(J) + RHOC2(J))/2.
      RHOC = RHOCM(J)
      IF(I-1) 114,114,112
  114 RHO1  = RHOC1(J)
      RHO2 = RHOS(J)
      RHOEX  = RHOX(J)
      WSTAR = WDOT(J)
      I = I + 1
      GO TO 102
  112 F(J) = 1.5708 * (R1**2 - R2**2) * (PC1(J) + PC2(J))
     1 + 3.1417 * PS(J) * (R2**2 - R3**2)
  110 CONTINUE
   50 FORMAT( /2X,'CAVITY CONDITION'/)
   52 FORMAT(9X,'HP GAP',11X,'PC1',12X,'TC1',11X,'RHOC1',11X,'PC2',12X,
     1'TC2',11X,'RHOC2')
   54 FORMAT(10X,'XBAR',11X,'PSIA',11X,'DEG R', 9X,'LB/FT**3',8X,'PSIA',
     111X,'LEG R', 9X,'LB/FT**3'/)
   56 FORMAT(F15.3,F15.2,2F15.3,F15.2,2F15.3/)
      WRITE(LW,50)
      WRITE(LW,52)
      WRITE(LW,54)
      WRITE(LW,56) (XBAR(J),PC1(J),TC1(J),RHOC1(J),PC2(J),TC2(J),RHOC2(J
     1),J=KSTAR,LIM)
   58 FORMAT( /2X,'SUMP AND EXIT CONDITIONS'/)
   60 FORMAT(40X,'SUMP',33X,'EXIT',18X,'FLOW RATE')
   62 FORMAT(10X,'XBAR',12X,'PS',13X,'TS',12X,'RHOS',12X,'TX',12X,'RHOX'
     1,12X,'WDOT')
   64 FORMAT(11X,'IN',12X,'PSIA',10X,'DEG R', 9X,'LB/FT**3',8X,'DEG R',9
     1X,'LB/FT**3',9X,'LB/SEC'/)
      WRITE(LW,58)
      WRITE(LW,60)
      WRITE(LW,62)
      WRITE(LW,64)
   66 FORMAT(F15.3,F15.2,5F15.3/)
      WRITE(LW,66) (XBAR(J),PS(J),TS(J),RHOS(J),TX(J),RHOX(J),WDOT(J),J=
     1KSTAR,LIM)
C-SPRING RATE AND FREQUENCY
```

```
      DO 128 J=KSTAR,LIM
      DFX(J)  = (F(J+1)-F(J))/(XBAR(J+1)-XBAR(J))*12.
      OMEGA(J) =(32.16 * DFX(J)/WROT) **0.5
  128 VC(J)  = AP * CL(J) + VOLTP
   67 FORMAT(/2X,'SPRING RATE AND FREQUENCY'/)
   68 FORMAT(10X,'XBAR',4X,'PRESS FORCE',3X,'SPRING RATE DFDX',4X,'FREQU
     1ENCY',4X,'DISC FRICT',3X,'CAVITY VOL',3X,'FLOW',5X,'K-PRESS')
   70 FORMAT( 11X,'IN',12X,'LP',12X,'LB/FT',11X,'OMEGA',12X,'HP',8X,'IN*
     1*3',4X,'COEFF',4X,'GRADIENT'/)
   72 FORMAT(F15.3,F15.1,E15.5,F15.1,F15.3,F10.3,F10.4,F10.3/)
      WRITE(LW,67)
      WRITE(LW,68)
      WRITE(LW,70)
      WRITE(LW,72) (XBAR(J),F(J),DFX(J),OMEGA(J),PFRIC(J),VC(J),PHIIN(J)
     1,FKC(J),J=KSTAR,LIM)
      IF(KFLAG) 31,31,129
C-BULK MODULUS
  129 DO 130 J=KSTAR,LIM
      SOUC1(J) = PTSOUN(PC1(J),TC1(J))/12.
      SOUS(J)  = PTSOUN(PS(J),TS(J))/12.
      ESC1(J)  = RHOC1(J) * SOUC1(J)**2/4630.
      ESS(J)   = RHOS(J)*SOUS(J)**2/4630.
      PC1H = PC1(J) + 5.
      PC1L = PC1(J) - 5.
      VC1H =  (PHDENS(PC1H,H1,RLC1H) * 1728.)**(-1)
      VC1L =  (PHDENS(PC1L,H1,RLC1L) * 1728.)**(-1)
      VC1 = 1./RHOC1(J)
      EHC1(J) = -VC1*10./(VC1H-VC1L)
      PSH  = PS(J) + 5.
      PSL  = PS(J) - 5.
      VSH=1./(PHDENS(PSH,HC2(J),RLSH) * 1728.)
      VSL=1./ (PHDENS(PSL,HC2(J),RLSL) * 1728.)
      VOLS = 1./RHOS(J)
      EHS(J)=-VOLS* 10./(VSH-VSL)
      TCM = (TC1(J) + TC2(J))/2.
      HCM  = PTENTH(PCM(J),TCM)
      SOUCM(J)  = PTSOUN(PCM(J),TCM)/12.
      ESCM(J) = RHOCM(J) * SOUCM(J)**2/4630.
      PCMH = PCM(J) + 5.
      PCML = PCM(J) - 5.
      VCMH  = 1./(PHDENS(PCMH,HCM,RLCMH) * 1728.)
      VCML  = 1./(PHDENS(PCML,HCM,RLCML) * 1728.)
      VCM  = 1./ RHOCM(J)
      EHCM(J) = -VCM * 10./(VCMH - VCML)
      EECM(J) = (1./ESCM(J) + (1./EHCM(J) - 1./ESCM(J))*1./(1. +'(OMEGA(
     1J) * RHOCM(J) * VC(J)/1728./WDOT(J))**2))**(-1)
      EEC1(J) = (1./ESC1(J) + (1./EHC1(J)-1./ESC1(J))*1./(1.+(OMEGA(J)
     1*RHOC1(J)*VC(J)/1728./WDOT(J))**2))**(-1)
  130 EES(J)  = (1./ESS(J) + (1./EHS(J) - 1./ESS(J))*1./(1.+(OMEGA(J)*
     1RHOS(J) * VS   /1728./WDOT(J))**2))**(-1)
   80 FORMAT( /2X,'BULK MODULUS, PSI'/)
   82 FORMAT(10X,'XBAR',3X,'SOUND VEL',11X,'CAVITY C1',18X,'SOUND VEL',1
     13X,'SUMP')
   84 FORMAT(11X,'IN',6X,'FT/S',6X,'E(S)',6X,'E(H)',6X,'E(E)',10X,'FT/S'
     1,7X,'E(S)',6X,'E(H)',6X,'E(E)'/)
   86 FORMAT(F15.3,4F10.1,F15.1,3F10.1/)
      WRITE(LW,80)
      WRITE(LW,82)
      WRITE(LW,84)
      WRITE(LW,86) (XBAR(J),SOUC1(J),ESC1(J),EHC1(J),EEC1(J),SOUS(J),
```

```
00541          1ESS(J),EHS(J),EES(J),J=KSTAR,LIM)
00557      310 FORMAT(//10X,'XBAR',3X,'SOUND VEL',7X,'MEAN CAVITY')
00560      312 FORMAT(11X,'IN',6X,'FT/S',6X,'E(S)',6X,'E(H)',6X,'E(E)'/)
00561      314 FORMAT(F15.3,4F10.1/)
00562          WRITE(LW,310)
00564          WRITE(LW,312)
00566          WRITE(LW,314)  (XBAR(J),SOUCM(J),ESCM(J),EHCM(J),EECM(J),J=KSTAR,L
00566         1IM)
00566    C-COEFFICIENTS
00600          DO 140 J=KSTAR,LIM
00603          COMEG(J) = XBAR(J)/(DELT-XBAR(J))
00604          CLAMD(J) =(P1-PC1(J))/(PC2(J)-PS(J))
00605          SMU(J)  =(P1 -PC1(J))/(PS(J)-P2)
00606          SLAMC(J)  = 1.-   (P1-PC1(J))/EEC1(J)
00607          SLAMS(J) = 1.-   (PC2(J)-PS(J))/EES(J)
00610          C1(J)  = 1.+ COMEG(J)
00611          C2(J)  = RHOCM(J)*AP*XBAR(J)/WDOT(J)/1728.
00612          C3(J)  = SLAMC(J) + CLAMD(J)
00613          C4(J)  = RHOCM(J) * VC(J) /WDOT(J)/1728. *2.*(P1-PC1(J))/EECM(J)
00614          C5(J)  = ABS(CLAMD(J)*SLAMS(J))
00615          C6(J)  = ABS(COMEG(J))
00616          C7(J)=RHOS(J) * AS * XBAR(J)/WDOT(J)/1728.
00617          C8(J) = CLAMD(J) * SLAMS(J) + SMU(J)
00620          C9(J)=RHOS(J)*  VS/WDOT(J)/1728. * 2.*(P1-PC1(J))/EES(J)
00621      140 C10(J) = ABS(CLAMD(J))
00623       73 FORMAT(/2X,'COEFFICIENTS'/)
00624       74 FORMAT(10X,'XBAR',7X,'CAP OMEGA',6X,'CAP LAMBDA',9X,'SMU',10X,'LAM
00624         1BDA C',7X,'LAMBDA S')
00625       76 FORMAT(11X,'IN',10X,'COMEG',9X,'CLAMD'/)
00626       78 FORMAT(F15.3,5F15.4/)
00627          WRITE(LW,73)
00631          WRITE(LW,74)
00633          WRITE(LW,76)
00635          WRITE(LW,78) (XBAR(J),COMEG(J),CLAMD(J),SMU(J),SLAMC(J),SLAMS(J),J
00635         1=KSTAR,LIM)
00650       88 FORMAT( /2X,'COEFFICIENTS'/)
00651       90 FORMAT(10X,'XBAR',6X,'C1',8X,'C2',8X,'C3',8X,'C4',8X,'C5',8X,'C6',
00651         18X,'C7',8X,'C8',8X,'C9'8X,'C10'/)
00652       92 FORMAT(F15.3,F8.4,E12.3,F10.4,E12.3,F10.4,F8.4,E12.3,F10.4,F10.6,
00652         1F8.3/)
00653          WRITE(LW,88)
00655          WRITE(LW,90)
00657          WRITE(LW,92) (XBAR(J),C1(J),C2(J),C3(J),C4(J),C5(J),C6(J),C7(J),
00657         1C8(J),C9(J),C10(J),J=KSTAR,LIM)
00677          DO 150 J=KSTAR,LIM
00702          XKP(J) = C2(J)/C4(J)
00703          OMSQ1(J) = (C1(J)*C8(J) - C5(J)*C6(J))/(C2(J)*C9(J))
00704          ZETO1(J) = (C1(J) * C9(J) + C2(J)*C8(J)+C7(J)*C5(J))/(C2(J)*C9(J))
00705          OMSQ2(J) = (C3(J)*C8(J)- C10(J)*C5(J))/(C4(J)*C9(J))
00706          ZETO2(J) = (C4(J)*C8(J) + C3(J)*C9(J))/ (C4(J)*C9(J))
00707          XKS(J)= C7(J)/C9(J)
00710          OMSQ3(J) = (C1(J)*C10(J) - C3(J)*C6(J))/(C4(J)*C7(J))
00711      150 ZETO3(J)  = (C2(J)*C10(J) + C3(J)*C7(J) -C4(J)*C6(J))/(C4(J)*C7(J)
00711         1)
00713       93 FORMAT(/2X,'INTERMEDIATE VALUES'/)
00714       94 FORMAT(10X,'XBAR',6X,'KP',6X,'OMEGA1**2',6X,'2ZETOM1',6X,'OMEGA2**
00714         12',5X,'2ZETOM2',7X,'KS',7X,'OMEGA3**2',6X,'2ZETOM3'/)
00715       96 FORMAT(F15.3,F10.4,4E13.4,F13.4,2E13.4/)
00716          WRITE(LW,93)
00720          WRITE(LW,94)
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00722          WRITE(LW,96) (XPAR(J),XKP(J),OMSQ1(J),ZETO1(J),OMSQ2(J),ZETO2(J),
00722         1XKS(J),OMSQ3(J),ZETO3(J),J=KSTAR,LIM)
00740          DO 160 J=1,LIM
00743          EPS = AKP/XPAR(J)
00744          XC(J) = ZETO1(J)*OMEGA(J)/(OMSQ1(J) - OMEGA(J)**2)
00745          YC(J) = ZETO2(J)*OMEGA(J)/(OMSQ2(J)-OMEGA(J)**2)
00746          SINP1(J)=(XC(J)-YC(J))/SQRT((1.+XC(J)**2)*(1.+YC(J)**2))
00747          ZC(J) =XKP(J)*ZETO1(J)/ZETO2(J)*YC(J)/XC(J)*SQRT((1.+XC(J)**2)/(1.
00747         1+YC(J)**2))
00750          US(J) = ZETO3(J)*OMEGA(J)/(OMSQ3(J)-OMEGA(J)**2)
00751          YS(J) = YC(J)
00752          SINP2(J)=(US(J)-YS(J))/SQRT((1.+US(J)**2)*(1.+YS(J)**2))
00753          ZS(J) =XKS(J)*ZETO3(J)/ZETO2(J)*YS(J)/US(J)*SQRT((1.+US(J)**2)/(1.
00753         1+YS(J)**2))
00754          CPC(J)=6.2834*AP*(P1-PCM(J))* XBAR(J)*EPS**2 * ZC(J) * SINP1(J)
00755          CPS(J)  = 6.2834 *AS*(P1-PCM(J))*XBAR(J)*EPS**2*ZS(J)*SINP2(J)
00756      160 CPT(J) = CPC(J) + CPS(J)
00760      299 FORMAT(/2X,'INTERMEDIATE VALUES'/)
00761      300 FORMAT(10X,'XBAR',6X,'X',8X,'YC',7X,'SIN(PSI1)',4X,'ZC1',7X,'U',8X
00761         1,'YS',6X,'SIN(PSI2)',4X,'ZS2'/)
00762      302 FORMAT(F15.3,8F10.4/)
00763          WRITE(LW,299)
00765          WRITE(LW,300)
00767          WRITE(LW,302) (XBAR(J),XC(J),YC(J),SINP1(J),ZC(J),US(J),YS(J),
00767         1SINP2(J),ZS(J),J=KSTAR,LIM)
01005      304 FORMAT(/2X,'STABILITY PARAMETER'/)
01006      320 FORMAT(/32X,'WORK PER CYCLE'/)
01007      306 FORMAT(10X,'XBAR',9X,'CPC, INLB',6X,'CPS, INLB',6X,'CPT, INLB'/)
01010      308 FORMAT(F15.3,3F15.4/)
01011          WRITE(LW,304)
01013          WRITE(LW,320)
01015          WRITE(LW,306)
01017          WRITE(LW,308) (XBAR(J),CPC(J),CPS(J),CPT(J),J=KSTAR,LIM)
01017    C-ROOTS
01030          DO 180 J=KSTAR,LIM
01033          BRT(J) = ZETO1(J)/2./(1.+AS*XKS(J)/AP/XKP(J))*(1.+AS*XKS(J)/AP/XKP
01033         1(J)*ZETO3(J)/ZETO1(J))
01034          ART(J)=OMSQ1(J)/(1.+AS*XKS(J)/AP/XKP(J))*(1.+AS*XKS(J)/AP/XKP(J)*
01034         1OMSQ3(J)/OMSQ1(J))
01035          RT12  = BRT(J)**2 - ART(J)
01035          IF(RT12) 172,170,170
01041      170 S1(J) = -BRT(J) + SQRT(RT12)
01042          S2(J) = -BRT(J) - SQRT(RT12)
01043          S1I(J) = 0
01044          S2I(J) = 0
01045          GO TO 174
01046      172 S1(J) = -BRT(J)
01047          S2(J) = S1(J)
01050          S1I(J) = SQRT(ABS(RT12))
01051          S2I(J) = -S1I(J)
01052      174 RT34 = (ZETO2(J)/2.)**2 - OMSQ2(J)
01053          IF(RT34) 178,176,176
01056      176 S3(J) =-ZETO2(J)/2.+SQRT(RT34)
01057          S4(J) =-ZETO2(J)/2.-SQRT(RT34)
01060          S3I(J) = 0
01061          S4I(J) = 0
01062          GO TO 179
01063      178 S3(J) = -ZETO2(J)/2.
01064          S4(J) = S3(J)
01065          S3I(J) = SQRT(ABS(RT34))
```

```
      S4I(J) = SQRT(ABS(RT34))
  179 CONTINUE
  180 CONTINUE
  322 FORMAT( /2X,'ROOTS'/)
  324 FORMAT( 10X,'XBAR',12X,'ROOT S1',19X,'ROOT S2',19X,'ROOT S3',19X,
     1'ROOT S4')
  326 FORMAT( 11X,'IN', 9X,'REAL',7X,'IMAG',11X,'REAL',7X 'IMAG',11X,
     1'REAL',7X,'IMAG',11X,'REAL',7X,'IMAG'/)
  328 FORMAT(F15.4,E14.4,E12.4,E14.4,E12.4,E14.4,E12.4,E14.4,E12.4/)
      WRITE(LW,322)
      WRITE(LW,324)
      WRITE(LW,326)
      WRITE(LW,328) (XBAR(J),S1(J),S1I(J),S2(J),S2I(J),S3(J),S3I(J),
     1S4(J),S4I(J),J=KSTAR,LIM)
C-ROOT LOCUS METHOD
  329 FORMAT(//2X,'ROOT LOCUS METHOD'//)
  330 FORMAT(10X,'XBAR',4X,'ROOT LOCUS GAIN',2X,'BODIE PLOT GAIN',4X,'MA
     1G OPEN',3X,'CROSSOVER FREQU',2X,'PHASE MARGIN')
  331 FORMAT(///5X,'NUMBER OF ITERATIONS EXCEEDED'///)
  332 FORMAT(11X,'IN',7X,'KRL, 1/S**2',7X,'K, 1/S**2',7X,'LOOP KGH1',4X,
     1'OMCRO, RAD/SEC',4X,'PHIM DEG'/)
  334 FORMAT(F15.3,2E15.5,3F15.4/)
      DO 198 J=KSTAR,LIM
      N = 0
      TES(1)= S1(J)
      TES(2)= S2(J)
      TES(3)= S3(J)
      TES(4)= S4(J)
      RLK(J) = 772.*(P1-PC1(J))*(AP*XKP(J)+AS*XKS(J))/XBAR(J)/WROT
      BPK(J) = RLK(J)*S1(J)*S2(J)/S3(J)/S4(J)
      OMCRO(J) = SQRT(BPK(J))
  182 GH1(J) = BPK(J)/OMCRO(J)**2*SQRT((1.-OMCRO(J)**2/S1(J)/S2(J))**2
     1+(OMCRO(J)/S1(J)+OMCRO(J)/S2(J))**2)/SQRT((1.-OMCRO(J)**2/S3(J)/S4
     2(J))**2 + (OMCRO(J)/S3(J)+OMCRO(J)/S4(J))**2)
      IF(ABS(GH1(J)-1.)-.01)182,182,184
  184 M = 2
      DO 190 L=1,2
      IF(OMCRO(J)/ABS(TES(L)) -1.) 190,188,188
  188 M = M-1
  190 CONTINUE
      DO 195 L=3,4
      IF(OMCRO(J)/ABS(TES(L))-1.) 195,194,194
  194 M = M+1
  195 CONTINUE
      OMCRO(J) = OMCRO(J) * GH1(J)**(1./M)
      IF(N-10) 181,181,196
  181 N=N+1
      GO TO 183
  196 WRITE(LW,331)
  182 DO 197 L=1,4
  197 TEMP(L) = OMCRO(J)/ABS(TES(L))
  198 PHIM(J) =(ATAN(TEMP(1))+ATAN(TEMP(2))-ATAN(TEMP(3))-ATAN(TEMP(4)))
     1*57.296
      WRITE(LW,329)
      WRITE(LW,330)
      WRITE(LW,332)
      WRITE(LW,334) (XBAR(J),RLK(J),BPK(J),GH1(J),OMCRO(J),PHIM(J),J=KST
     1AR,LIM)
```

```
01234         IF(PHIM(J))201,203,205
01237     201 XMM(J) =1.E+38
01240         ZETA(J) = -100.
01241         XMP(J) = 1.E+38
01242         TSET(J) = 1.E+38
01243         GO TO 225
01244     203 XMM(J) = 1.E+38
01245         ZETA(J) = 0.
01246         XMP(J) = 2.
01247         TSET(J) = 1.E+38
01250         GO TO 225
01251     205 IF(PHIM(J)-90.) 211,213,215
01254     211 XMM(J) = 1./SIN(PHIM(J)/57.296)
01255         ZETA(J) = 0.707 * SQRT(1.-SQRT(1. -   (SIN(PHIM(J)/57.296))**2))
01256         GO TO 217
01257     213 XMM(J)=1.
01260         ZETA(J) = 0.707
01261         GO TO 217
01262     215 IF(PHIM(J) - 180.) 221,221,223
01265     221 XMM(J) = 1.
01266         ZETA(J) = 0.707 * SQRT(1.+SQRT(1.-(SIN(PHIM(J)/57.296))**2))
01267         GO TO 217
01270     223 XMM(J) = 1.
01271         ZETA(J) = 100.
01272         XMP(J)=1.
01273         TSET(J) = 1.E+38
01274         GO TO 225
01275     217 CONST = 3.1417 * ZETA(J)/SQRT(1.-ZETA(J)**2)
01276         XMP(J) = 1.+1./2.718**CONST
01277         TSET(J) = 4./ZETA(J)/OMCRO(J)
01300     225 CONTINUE
01302     336 FORMAT(//2X,'RESPONSE'//)
01303     338 FORMAT(10X,'XBAR',3X,'FREQU RESP AMPL',3X,'STEP RESP AMPL',3X,'DAM
01303        1PING',4X,'SETTLING TIME')
01304     340 FORMAT(11X,'IN',6X,'XMM',18X,'XMP',10X,'ZETA',8X,'TS, SEC'/)
01305     342 FORMAT(F15.3,2F15.4,2F15.3/)
01306         WRITE(LW,336)
01310         WRITE(LW,338)
01312         WRITE(LW,340)
01314         WRITE(LW,342)  (XBAR(J),XMM(J),XMP(J),ZETA(J),TSET(J),J=KSTAR,LIM)
01326         GO TO 31
01327     999 STOP
01330         END

    END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
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BALANCE PISTON STABILITY ANALYSIS

GEOMETRY

R1, HP ORIF IN	R2, LP ORIF IN	R3, SUMP IN	TOT TRAVEL DELTA, IN	CAVITY CLEAR DCL, IN	SUMP VOL VS, IN**3	TIP CAVITY VOL VOLTP IN**3
5.600	2.600	1.750	.020	.030	4.200	.534

FLUID CONDITION, INPUT

STAT PRESSURE P1, PSIA	TEMPERATURE T1, DEG R	DENSITY RHOIN LB/FT**3	STAT PRESSURE P2, PSIA	DENSITY RHOEX LB/FT**3	LIMIT X
1235.00	52.50	4.400	498.00	3.500	18

INPUT PARAMETERS

ORIFICE COEFFICIENTS CORF1	CORF2	CLINE	SPEED RPM	ROTOR WEIGHT LB	AMPLITUDE AMP, IN	DISC FRIC COEFF CFRIC
.850	.850	.500	24700.0	68.000	.0010	.22-07

CAVITY CONDITION

HP GAP XBAR	PC1 PSIA	TC1 DEG R	RHOC1 LB/FT**3	PC2 PSIA	TC2 DEG R	RHOC2 LB/FT**3
.001	611.46	57.061	3.910	511.43	68.962	2.953
.002	656.97	56.773	3.956	546.18	63.583	3.455
.003	718.69	56.381	4.018	601.30	61.541	3.665
.004	793.81	55.905	4.094	671.09	60.345	3.801
.005	874.22	55.394	4.176	746.70	59.540	3.910
.006	950.94	54.908	4.245	819.27	58.967	3.997
.007	1018.11	54.482	4.301	882.84	58.603	4.065
.008	1073.28	53.949	4.347	934.94	58.244	4.114
.009	1116.87	53.495	4.384	975.92	58.054	4.147
.010	1150.38	53.145	4.412	1007.20	58.068	4.165
.011	1175.60	52.882	4.433	1030.52	58.279	4.172
.012	1194.29	52.687	4.449	1047.63	58.699	4.167

.013	1207.92	52.545	4.459	1060.00	59.368	4.150
.014	1217.71	52.443	4.466	1068.91	60.370	4.118
.015	1224.59	52.371	4.471	1075.42	61.871	4.065
.016	1229.28	52.322	4.475	1080.57	64.226	3.976
.017	1232.31	52.290	4.477	1085.71	68.323	3.814
.018	1234.10	52.272	4.478	1094.19	77.224	3.430

SUMP AND EXIT CONDITIONS

XBAR IN	PS PSIA	SUMP TS DEG R	RHOS LB/FT**3	EXIT TX DEG R	RHOX LB/FT**3	FLOW RATE WDOT LB/SEC
.001	500.89	68.759	2.934	68.716	2.929	.987
.002	507.62	63.426	3.400	63.370	3.386	1.912
.003	516.90	61.402	3.552	61.345	3.526	2.731
.004	526.75	60.422	3.628	60.387	3.590	3.398
.005	535.15	59.928	3.671	59.913	3.622	3.879
.006	540.70	59.763	3.688	59.759	3.633	4.164
.007	542.96	59.749	3.692	59.747	3.634	4.273
.008	542.25	59.742	3.691	59.740	3.634	4.240
.009	539.30	59.812	3.683	59.805	3.630	4.094
.010	534.86	59.982	3.667	59.965	3.619	3.862
.011	529.61	60.254	3.643	60.225	3.601	3.568
.012	524.05	60.648	3.610	60.606	3.576	3.228
.013	518.58	61.184	3.568	61.130	3.540	2.855
.014	513.47	61.950	3.511	61.888	3.489	2.459
.015	508.93	63.073	3.429	63.014	3.413	2.045
.016	505.08	64.584	3.303	64.529	3.292	1.619
.017	502.01	67.260	3.078	67.211	3.070	1.180
.018	499.79	72.506	2.553	72.467	2.549	.724

SPRING RATE AND FREQUENCY

XBAR	PRESS FORCE	SPRING RATE DFDX	FREQUENCY	DISC FRICT	CAVITY VOL	FLOW	K-PRESS

IN	LB	LB/FT	OMEGA	HP	IN**3	COEFF	GRADIENT
.001	49681.2	.38762+08	4281.6	56.822	4.321	.0175	.485
.002	52911.3	.55848+08	5139.3	61.018	4.244	.0341	.492
.003	57565.3	.68872+08	5707.2	63.289	4.166	.0490	.498
.004	63304.6	.73789+08	5907.4	65.034	4.089	.0612	.502
.005	69453.7	.70234+08	5763.4	66.609	4.012	.0700	.506
.006	75306.5	.61144+08	5377.5	67.891	3.935	.0756	.509
.007	80401.9	.49821+08	4854.1	68.920	3.857	.0784	.512
.008	84553.7	.38953+08	4292.1	69.707	3.780	.0788	.515
.009	87799.8	.29545+08	3738.0	70.273	3.703	.0772	.518
.010	90261.8	.21887+08	3217.4	70.659	3.625	.0742	.520
.011	92085.8	.15914+08	2743.5	70.888	3.548	.0700	.523
.012	93412.0	.11365+08	2318.4	70.975	3.471	.0648	.525
.013	94359.0	.80101+07	1946.4	70.925	3.394	.0587	.528
.014	95026.5	.55972+07	1627.0	70.722	3.316	.0519	.530
.015	95493.0	.39945+07	1374.5	70.325	3.239	.0443	.532
.016	95825.9	.32428+07	1238.4	69.623	3.162	.0361	.534
.017	96096.1	.40749+07	1388.2	68.306	3.084	.0271	.535
.018	96435.7	.10524+08	2231.0	65.193	3.007	.0173	.535

BULK MODULUS, PSI

XBAR	SOUND VEL		CAVITY C1		SOUND VEL		SUMP	
IN	FT/S	E(S)	E(H)	E(E)	FT/S	E(S)	E(H)	E(E)
.001	3317.7	9294.3	3860.8	9287.0	2334.5	3453.7	1563.9	3449.4
.002	3399.0	9870.7	3906.3	9848.7	2723.5	5446.8	2369.9	5432.6
.003	3507.0	10674.1	3968.1	10630.4	2981.2	6367.9	2635.5	6340.4
.004	3634.8	11683.3	4043.2	11606.3	2966.1	6894.4	2774.8	6851.3
.005	3749.5	12679.2	4123.6	12554.2	3014.2	7202.7	2850.2	7141.0
.006	3854.3	13619.2	5058.8	13473.7	3034.8	7335.8	2878.1	7252.6
.007	3919.5	14270.2	5126.0	14061.1	3039.9	7367.7	2882.0	7260.0
.008	3986.2	14919.5	5181.2	14626.0	3038.9	7362.3	2882.3	7227.8

.009	4039.5	15449.6	5224.7	15054.6	3029.1	7298.9	2870.0	7136.5
.010	4080.0	15862.1	5258.3	15350.1	3010.3	7176.8	2842.4	6987.0
.011	4110.3	16175.6	5283.5	15534.9	2982.6	6999.4	2800.3	6784.5
.012	4132.6	16409.4	5302.1	15633.1	2945.8	6766.8	2741.7	6531.3
.013	4148.7	16577.4	6123.4	15839.3	2899.2	6477.9	2665.5	6230.1
.014	4160.3	16696.9	6133.1	15872.6	2837.1	6103.6	2561.9	5857.3
.015	4168.5	16781.0	6139.9	15937.0	2751.1	5605.9	2419.3	5386.7
.016	4174.0	16838.3	6144.6	16140.4	2636.1	4957.9	2213.1	4804.1
.017	4177.6	16875.5	6147.7	16552.2	2439.8	3957.0	1777.0	3896.0
.018	4179.7	16897.4	6149.5	16846.4	2115.2	2467.0	1162.3	2459.4

XBAR IN	SOUND VEL FT/S	MEAN CAVITY E(S)	E(H)	E(E)
.001	2873.8	6120.1	2562.8	6113.9
.002	3125.4	7817.4	3464.3	7801.0
.003	3285.5	8956.9	3680.4	8922.9
.004	3439.6	10086.9	3814.4	10024.7
.005	3583.9	11215.9	3912.1	11109.8
.006	3695.0	12151.4	3997.8	11986.0
.007	3787.3	12959.6	4911.4	12775.2
.008	3851.4	13554.6	4969.8	13296.0
.009	3900.9	14018.1	5011.6	13670.4
.010	3935.9	14349.1	5032.8	13899.2
.011	3958.7	14562.9	5038.8	14001.6
.012	3971.2	14673.3	5030.8	13996.2
.013	3974.5	14686.7	5008.3	13901.4
.014	3968.5	14600.1	4969.0	13733.4
.015	3951.6	14395.0	4906.3	13520.8
.016	3919.1	14017.6	4807.6	13309.3
.017	3856.8	13318.2	4636.3	13001.0

.018	3706.2	11730.9	4255.4	11685.3

COEFFICIENTS

XBAR IN	CAP OMEGA COMEG	CAP LAMBDA CLAMD	SMU	LAMBDA C	LAMBDA S
.001	.0526	59.1410	215.8410	.9329	.9969
.002	.1111	14.9919	60.0628	.9413	.9929
.003	.1765	6.1176	27.3187	.9514	.9867
.004	.2500	3.0566	15.3449	.9620	.9789
.005	.3333	1.7054	9.7112	.9713	.9704
.006	.4286	1.0197	6.6524	.9789	.9616
.007	.5385	.6381	4.8241	.9846	.9532
.008	.6667	.4118	3.6546	.9889	.9457
.009	.8182	.2705	2.8602	.9922	.9388
.010	1.0000	.1792	2.2955	.9945	.9324
.011	1.2222	.1186	1.8793	.9962	.9262
.012	1.5000	.0778	1.5628	.9974	.9198
.013	1.8571	.0500	1.3160	.9983	.9131
.014	2.3333	.0311	1.1175	.9989	.9052
.015	3.0000	.0184	.9524	.9993	.8948
.016	4.0000	.0099	.8088	.9996	.8802
.017	5.6667	.0046	.6715	.9998	.8502
.018	9.0000	.0015	.5061	.9999	.7583

COEFFICIENTS

XBAR	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
.001	1.0526	.156-03	60.0738	.177-02	58.9602	.0526	.200-04	274.8012	.002613	59.141
.002	1.1111	.173-03	15.9332	.705-03	14.8855	.1111	.239-04	74.9484	.000920	14.992
.003	1.1765	.189-03	7.0690	.392-03	6.0362	.1765	.262-04	33.3549	.000515	6.118
.004	1.2500	.208-03	4.0185	.242-03	2.9922	.2500	.287-04	18.3371	.000334	3.057
.005	1.3333	.233-03	2.6767	.157-03	1.6549	.3333	.318-04	11.3662	.000232	1.705

.006	1.4286	.266-03	1.9986	.107-03	.9806	.4286	.357-04	7.6329	.000169	1.020
.007	1.5385	.306-03	1.6227	.742-04	.6083	.5385	.407-04	5.4324	.000125	.638
.008	1.6667	.357-03	1.4008	.531-04	.3894	.6667	.468-04	4.0440	.000095	.412
.009	1.8182	.419-03	1.2627	.386-04	.2540	.8182	.544-04	3.1142	.000072	.271
.010	2.0000	.497-03	1.1736	.284-04	.1670	1.0000	.638-04	2.4625	.000056	.179
.011	2.2222	.593-03	1.1148	.210-04	.1098	1.2222	.755-04	1.9891	.000043	.119
.012	2.5000	.716-03	1.0751	.156-04	.0715	1.5000	.902-04	1.6344	.000034	.078
.013	2.8571	.877-03	1.0483	.115-04	.0457	1.8571	.109-03	1.3617	.000026	.050
.014	3.3333	.109-02	1.0300	.843-05	.0282	2.3333	.134-03	1.1456	.000020	.031
.015	4.0000	.140-02	1.0177	.602-05	.0164	3.0000	.169-03	.9689	.000016	.018
.016	5.0000	.187-02	1.0096	.411-05	.0088	4.0000	.220-03	.8175	.000012	.010
.017	6.6667	.267-02	1.0045	.260-05	.0039	5.6667	.298-03	.6754	.000009	.005
.018	10.0000	.440-02	1.0015	.147-05	.0012	9.0000	.427-03	.5073	.000006	.002

INTERMEDIATE VALUES

XBAR	KP	OMEGA1**2	2ZETOM1	OMEGA2**2	2ZETOM2	KS	OMEGA3**2	2ZETOM3
.001	.0877	.7041+09	.1148+06	.2809+10	.1390+06	.0077	.1667+10	.2906+06
.002	.2458	.5117+09	.9011+05	.1496+10	.1041+06	.0260	.8825+09	.1720+06
.003	.4809	.3929+09	.7266+05	.9843+09	.8281+05	.0509	.5780+09	.1235+06
.004	.8589	.3192+09	.6211+05	.7980+09	.7147+05	.0859	.4053+09	.9933+05
.005	1.4831	.2696+09	.5560+05	.7557+09	.6594+05	.1369	.2764+09	.8607+05
.006	2.4865	.2341+09	.5143+05	.7917+09	.6398+05	.2119	.1573+09	.7770+05
.007	4.1305	.2089+09	.4896+05	.9053+09	.6517+05	.3240	.3581+08	.7347+05
.008	6.7240	.1917+09	.4792+05	.1095+10	.6909+05	.4945	-.9954+08	.7128+05
.009	10.8700	.1797+09	.4781+05	.1383+10	.7575+05	.7519	-.2577+09	.7172+05
.010	17.5071	.1714+09	.4847+05	.1804+10	.8543+05	1.1418	-.4503+09	.7485+05
.011	28.2396	.1663+09	.4984+05	.2415+10	.9884+05	1.7375	-.6928+09	.8123+05
.012	45.9337	.1639+09	.5198+05	.3315+10	.1172+06	2.6625	-.1008+10	.9191+05
.013	75.9971	.1644+09	.5505+05	.4680+10	.1425+06	4.1363	-.1432+10	[illegible]
.014	129.6000	.1676+09	.5915+05	.6825+10	.1701+06	[illegible]	[illegible]	[illegible]

.015	232.5178	.1736+09	.6451+05	.1040+11	.2305+06	10.7377	-.2927+10	.1765+06
.016	454.7057	.1835+09	.7193+05	.1699+11	.3149+06	18.5709	-.4422+10	.2481+06
.017	1027.6560	.1914+09	.7959+05	.2978+11	.4635+06	33.9930	-.7309+10	.3834+06
.018	2987.5216	.1827+09	.8277+05	.5478+11	.7611+06	67.6685	-.1434+11	.6702+06

INTERMEDIATE VALUES

XBAR	X	YC	SIN(PSI1)	ZC1	U	YS	SIN(PSI2)	ZS2
.001	.7169	.2133	.4003	.0259	.7550	.2133	.4228	.0055
.002	.9543	.3639	.4014	.1054	1.0328	.3639	.4373	.0205
.003	1.1507	.4966	.3843	.2486	1.2917	.4966	.4360	.0427
.004	1.2907	.5533	.3952	.4571	1.5842	.5533	.4815	.0684
.005	1.3557	.5260	.4359	.7234	2.0399	.5260	.5898	.0926
.006	1.3476	.4511	.4870	1.0234	3.2538	.4511	.7505	.1107
.007	1.2827	.3588	.5347	1.3288	29.1295	.3588	.9291	.1234
.008	1.1870	.2755	.5662	1.6196	-2.5936	.2755	-.9951	-.1452
.009	1.0787	.2068	.5805	1.8945	-.9868	.2068	-.8320	-.2053
.010	.9683	.1533	.5788	2.1630	-.5227	.1533	-.5922	-.3271
.011	.8615	.1126	.5638	2.4424	-.3182	.1126	-.4080	-.5272
.012	.7602	.0821	.5380	2.7548	-.2102	.0821	-.2851	-.8304
.013	.6669	.0593	.5046	3.1329	-.1473	.0593	-.2041	-1.2816
.014	.5833	.0425	.4668	3.6247	-.1079	.0425	-.1494	-1.9631
.015	.5166	.0305	.4317	4.3200	-.0829	.0305	-.1129	-3.0342
.016	.4895	.0230	.4189	5.4206	-.0695	.0230	-.0922	-4.8455
.017	.5832	.0216	.4850	7.5675	-.0728	.0216	-.0941	-8.3673
.018	1.0390	.0310	.6987	13.9730	-.1043	.0310	-.1345	-17.8064

STABILITY PARAMETER

WORK PER CYCLE

XBAR	CPC, INLB	CPS, INLB	CPT, INLB
.001	3.3948	.1151	3.5099

.002	6.5080	.2067	6.7147
.003	8.8931	.2606	9.1537
.004	11.0220	.3018	11.3238
.005	13.0017	.3385	13.3402
.006	14.1140	.3535	14.4675
.007	14.0248	.3402	14.3650
.008	12.8522	.3044	13.1567
.009	11.1914	.2612	11.4526
.010	9.4967	.2209	9.7175
.011	8.0205	.1883	8.2088
.012	6.8401	.1642	7.0043
.013	5.9672	.1484	6.1155
.014	5.3808	.1402	5.5210
.015	5.1311	.1417	5.2728
.016	5.5190	.1631	5.6822
.017	7.9678	.2570	8.2248
.018	18.6621	.6880	19.3500

ROOTS

XBAR	ROOT S1		ROOT S2		ROOT S3		ROOT S4	
IN	REAL	IMAG	REAL	IMAG	REAL	IMAG	REAL	IMAG
.0010	-.6477+04	.0000	-.1106+06	.0000	-.2454+05	.0000	-.1145+06	.0000
.0020	-.6065+04	.0000	-.8533+05	.0000	-.1723+05	.0000	-.8682+05	.0000
.0030	-.5856+04	.0000	-.6760+05	.0000	-.1439+05	.0000	-.6842+05	.0000
.0040	-.5618+04	.0000	-.5704+05	.0000	-.1385+05	.0000	-.5762+05	.0000
.0050	-.5319+04	.0000	-.5070+05	.0000	-.1477+05	.0000	-.5117+05	.0000
.0060	-.4985+04	.0000	-.4678+05	.0000	-.1677+05	.0000	-.4722+05	.0000
.0070	-.4636+04	.0000	-.4461+05	.0000	-.2008+05	.0000	-.4510+05	.0000
.0080	-.4296+04	.0000	-.4388+05	.0000	-.2462+05	.0000	-.4447+05	.0000
.0090	-.3973+04	.0000	-.4408+05	.0000	-.3073+05	.0000	-.4502+05	.0000

.0100	-.3670+04	.0000	-.4505+05	.0000	-.3817+05	.0000	-.4726+05	.0000
.0110	-.3388+04	.0000	-.4674+05	.0000	-.4417+05	.0000	-.5467+05	.0000
.0120	-.3126+04	.0000	-.4920+05	.0000	-.4773+05	.0000	-.6944+05	.0000
.0130	-.2880+04	.0000	-.5260+05	.0000	-.5138+05	.0000	-.9108+05	.0000
.0140	-.2646+04	.0000	-.5707+05	.0000	-.5585+05	.0000	-.1222+06	.0000
.0150	-.2421+04	.0000	-.6287+05	.0000	-.6150+05	.0000	-.1690+06	.0000
.0160	-.2195+04	.0000	-.7081+05	.0000	-.6915+05	.0000	-.2457+06	.0000
.0170	-.1949+04	.0000	-.7914+05	.0000	-.7704+05	.0000	-.3865+06	.0000
.0180	-.1605+04	.0000	-.8316+05	.0000	-.8048+05	.0000	-.6807+06	.0000

ROOT LOCUS METHOD

XBAR IN	ROOT LOCUS GAIN KRL, 1/S**2	BODIE PLOT GAIN K, 1/S**2	MAG OPEN LOOP KGH1	CROSSOVER FREQU OMCRO, RAD/SEC	PHASE MARGIN PHIM DEG
.001	.48604+08	.12397+08	1.0015	3761.5641	21.4957
.002	.63319+08	.21901+08	1.0054	5249.8405	23.9971
.003	.73770+08	.29668+08	1.0066	6297.1318	23.5024
.004	.84371+08	.33882+08	.9923	6972.4957	24.4881
.005	.95197+08	.33972+08	1.0087	7120.3950	27.5699
.006	.10461+09	.30813+08	.9904	7048.3027	32.0087
.007	.11362+09	.25958+08	.9944	6556.5781	36.7374
.008	.12058+09	.20762+08	.9960	5856.0737	40.4545
.009	.12648+09	.16015+08	1.0099	5023.5977	42.5077
.010	.13126+09	.12033+08	.9935	4309.3022	43.3900
.011	.13504+09	.88573+07	.9928	3604.5788	42.7428
.012	.13792+09	.63988+07	1.0029	2963.6966	40.9274
.013	.14003+09	.45326+07	1.0084	2423.1989	38.4935
.014	.14148+09	.31307+07	1.0054	1970.1771	35.7001
.015	.14252+09	.20862+07	1.0031	1575.1344	32.4859
.016	.14360+09	.13134+07	1.0016	1225.4713	28.8664
.017	.14363+09	.74407+06	1.0076	902.0369	24.6830

.018	.13220+09	.32207+06	1.0034	584.4755	19.9504

RESPONSE

XBAR IN	FREQU RESP AMPL XMM	STEP RESP AMPL XMP	DAMPING ZETA	SETTLING TIME TS, SEC
.001	2.7290	1.5509	.186	.006
.002	2.4589	1.5130	.208	.004
.003	2.5076	1.5203	.204	.003
.004	2.4125	1.5058	.212	.003
.005	2.1606	1.4627	.238	.002
.006	1.8866	1.4062	.276	.002
.007	1.6718	1.3524	.315	.002
.008	1.5412	1.3143	.346	.002
.009	1.4800	1.2947	.362	.002
.010	1.4557	1.2866	.370	.003
.011	1.4734	1.2926	.364	.003
.012	1.5265	1.3097	.350	.004
.013	1.6066	1.3340	.330	.005
.014	1.7137	1.3637	.306	.007
.015	1.8619	1.4005	.280	.009
.016	2.0714	1.4456	.249	.013
.017	2.3947	1.5030	.214	.021
.018	2.9308	1.5756	.173	.040

DATA CARDS IGNORED - FIRST IS LISTED BELOW

3. CIRCULAR CROSS SECTION VOLUTE DESIGN

J. J. Brunner
4-12-72

COMPUTER PROGRAM

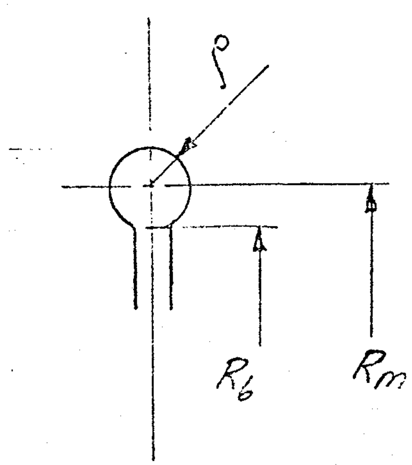
CIRCULAR CROSS SECTION VOLUTE DESIGN

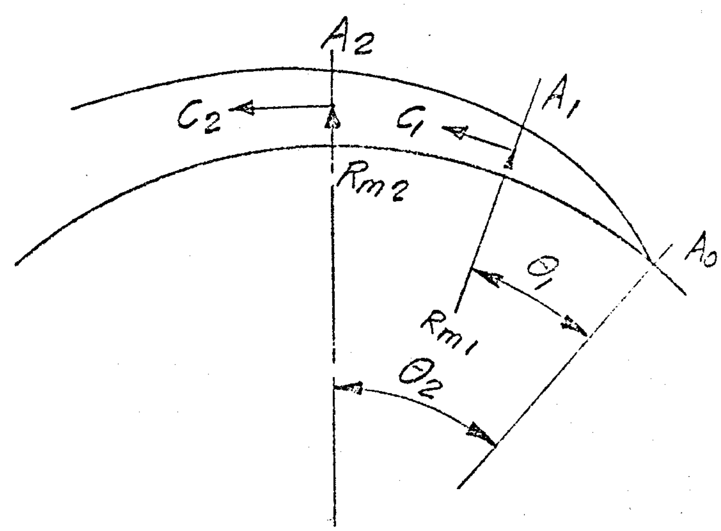
I. INTRODUCTION

This program presents an incremental method for the design of a classical pump volute with circular cross-sections which are tangent to the volute base circle. Volute area distributions as well as velocity and pressure distributions are calculated and printed out.

This program was primarily devised to determine the percentage increase in cross-sectional area required for the compensation of friction losses in the NERVA turbopump volute which is discussed in Reference 1.

II. BASIC EQUATIONS





Reference 1 - Aerojet Nuclear Systems Company Engineering Operations Report N8300R:71-076, NERVA Turbopump Design Report, Volume 1, 24 September 1971

The flow rate V in the volute is assumed to be proportional to the wrap angle θ (no back flow, zero cut water clearance flow).

The volute cross sectional area A_2 at the wrap angle θ_2 can then be calculated from the total flow at the volute throat V_{th}:

$$A_2 = \frac{\theta_2}{2\Pi} \quad \frac{V_{th}}{C_2} = \Pi\rho_2^2 \qquad (1)$$

Assuming constant moment of momentum:

$$R_{m1} \; C_1 = R_{m2} \; C_2 = K$$

where:

$$R_{m2} = R_6 + \rho_2$$

Thus:

$$C_2 = \frac{K}{R_{m2}} = \frac{K}{R_6 + \rho_2} \qquad (2)$$

Substituting C_2 in (1)

$$A_2 = \frac{\theta_2 V_{th}}{2\Pi} \quad \frac{R_6 + \rho_2}{K} = \Pi\rho^2$$

Solving for ρ the quadratic equation can be written as follows:

$$\rho^2 - \frac{\theta_2 \, V_{th}}{2\Pi^2 K} \, \rho - \frac{\theta_2 \, V_{th}}{2\Pi^2 K} \, R_6 = 0$$

Let

$$\frac{\theta_2 \, V_{th}}{2\Pi^2 K} = Y$$

then:

$$\rho^2 - Y\rho - YR_6 = 0$$

and

$$\rho = \frac{Y \pm \sqrt{Y^2 + 4 \, Y \, R_6}}{2}$$

Friction losses are calculated for the mean cross section of a volute increment:

$$A_m = \frac{A_1 + A_2}{2}$$

$$\rho_m = \left(\frac{A_m}{\Pi}\right)^{0.5}$$

Length of volute increment:

$$L_m = \Delta\theta \; R_m$$

The friction coefficient is based on the relative surface finish and the empirical relationship established by Nicuradse (Reference 2).

$$\lambda = \frac{1}{(.8685 \; \ell n \; (\frac{\rho m}{f_s}) + 1.74)^2}$$

Friction loss for volute increment

$$\Delta H_{fric} = \lambda \; \frac{L_m}{2\rho_m} \; \frac{C_m^{\;2}}{2 \; g}$$

The friction loss is recuperated by an increase in diffusion

$$\Delta H_{fric} = \Delta H_{vel}$$

which is achieved by a decrease in velocity or respectively, an increase in area.

Reference 2 - Eckert/Schnell, Axial and Radial Kompressoren, Springer-Verlag 1961

$$\Delta H_{vel} = \frac{C_2^2}{2\,g} - \frac{C_{2c}^2}{2\,g}$$

where C_{2c} is the lowered velocity corresponding to the increased or corrected area A_{2c}. From continuity:

$$C_2\,A_2 = C_{2c}\,A_{2c}$$

$$\Delta H_{fric} = \frac{C_2^2}{2\,g}\left(1 - \left(\frac{C_{2c}}{C_2}\right)^2\right) = \frac{C_2^2}{2\,g}\left(1 - \left(\frac{A_2}{A_{2c}}\right)^2\right)$$

From this expression the corrected area A_{2c} is:

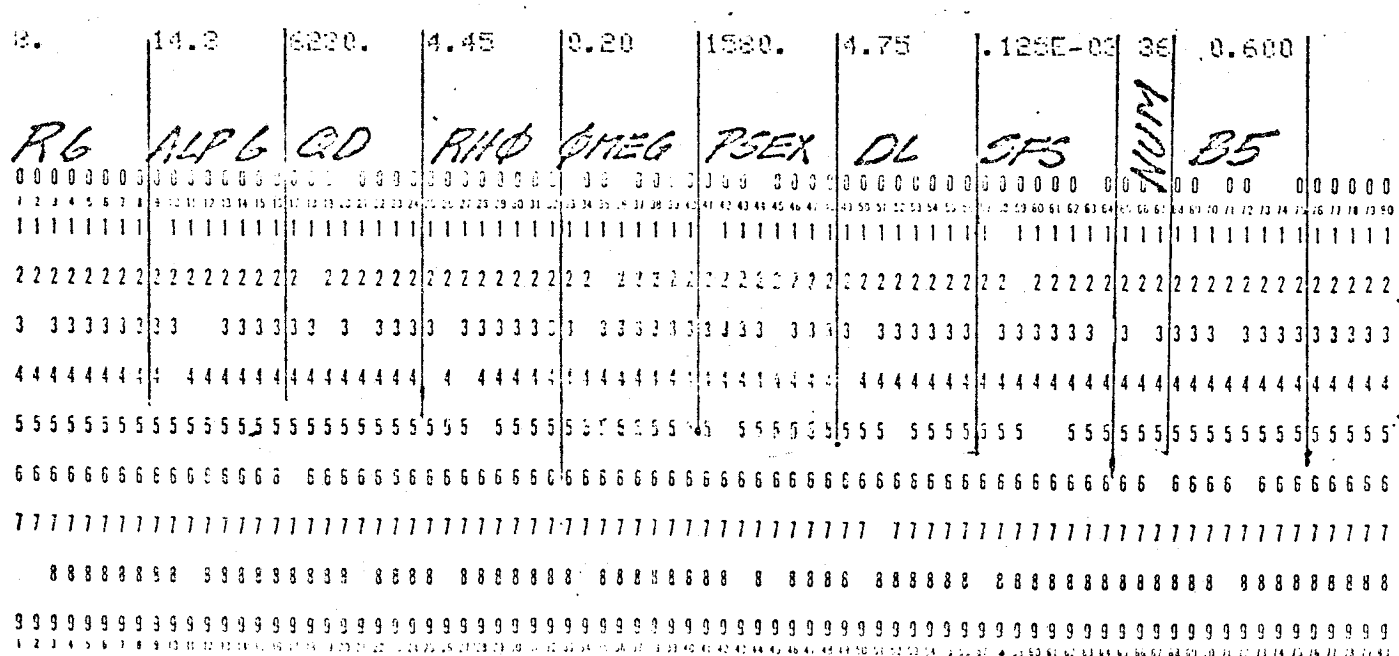
$$A_{2c} = \frac{A_2}{\left(1 - \frac{2\,g\,\Delta H_{fric}}{C_2^2}\right)^{0.5}}$$

NOMECLATURE

INPUT

SYMBOL	DESCRIPTION	UNITS	FORMAT
R6	Radius, Base Circle	In	F
ALP6	Fluid Angle at Base Circle	Deg	F
QD	Flow Rate	gpm	F
RHO	Fluid Density	lb/cu ft	F
OMEG	Exit Diffuser Loss Coefficient	(0.20)	F
PSEX	Exit Pressure, Static	psi	F
DL	Exit Diffuser Discharge Diameter	In	F
SFS	Surface Finish	In	E
NUM	Number of Increments	-	I
B5	Port Width at Base Circle	In	F

INPUT FORMAT



```
// JOB T

LOG DRIVE   CART SPEC   CART AVAIL  PHY DRIVE
  0000        0001        0001        0000

V2 M05   ACTUAL 16K  CONFIG 16K

// FOR
*IOCS(CARD,TYPEWRITER,KEYBOARD,1403 PRINTER,DISK)
*LIST ALL
      DIMENSION THET(90),RADN(90),ANC(90),VD(90),CN(90),A(90),RAD(90),
     1C(60),HVEL(90),FRIC(90),HFR(90),PS(90),HFRT(90)
      LR = 2
      LW = 5
    1 FORMAT('1')
    2 FORMAT(42X,'VOLUTE VELOCITIES + PRESSURE DISTRIBUTION'//)
    3 FORMAT(7F8.3,E8.3,I3,F8.3)
    4 FORMAT(53X,'*** INPUT ***'//)
    5 FORMAT(15X,'R6',12X,'ALP6',12X,'OD',14X,'RHO',13X,'OMEG',12X,'PSEX
     1'/)
    6 FORMAT(15X,'DLINE',10X,'SFS',13X,'NUM',13X,'B5'/)
    7 FORMAT(5X,6F15.3//)
    8 FORMAT(5X,F15.3,E15.3,I15,F15.3//)
    9 READ(LR,3) R6,ALP6,OD,RHO,OMEG,PSEX,DL,SFS,NUM,B5
      IF(R6) 500,500,11
   11 WRITE(LW,1)
      WRITE(LW,2)
      WRITE(LW,4)
      WRITE(LW,5)
      WRITE(LW,7) R6,ALP6,OD,RHO,OMEG,PSEX
      WRITE(LW,6)
      WRITE(LW,8) DL,SFS,NUM,B5
      DTHT = 360./NUM
      VDT = 0.321 * OD
      ALPR6 = ALP6/57.296
      CVOL = 360. * COS(ALPR6)/(B5 * SIN(ALPR6))
      THET(1) = DTHT
      DO 10 I=2,NUM
   10 THET(I) = THET(I-1) + DTHT
      DO 20 I=1,NUM
      RADN(I) = THET(I)/CVOL + SQRT(2.*R6 * THET(I)/CVOL)
      ANC(I)  = 3.14159 * RADN(I)**2
      VD(I)   = THET(I)/360. * VDT
   20 CN(I)   = VD(I)/ANC(I)
      A(1)   = ANC(1)
      RAD(1)  = RADN(1)
      C(1)   = CN(1)
      HVEL(1)  = C(1)**2/64.348
      FRIC(1) = 0
      HFR(1) = 0 .
      I = 2
   50 N = 0
      RXC  =(RAD(I-1) + R6) * C(I-1)
      CONST = VD(I)/(3.14159 * RXC)
      RAD(I) = (CONST + SQRT(CONST**2 + 4. * CONST * R6))/2.
      A(I) = 3.14159 * RAD(I)**2
      STAY = A(I)
   17 C(I)  = VD(I)/A(I)
      RAD(I) = SQRT(A(I)/3.14159)
      AM   = 0.5*(A(I) + A(I-1))
```

```
      RM = R6 + RADM
      XLM  = RM*DTHT/57.296
      CM  =(C(I) + C(I-1))/2.
      HFR(I)  = FRIC(I) *XLM * CM**2/(128.696*RADM)
      HVEL(I) = C(I)**2/64.348
      IF(N) 30,30,32
   30 SAFE = HVEL(I)
      STAY = A(I)
   35 A(I) = STAY/SQRT(1.-HFR(I)/HVEL(I))
      N  =  N + 1
      GO TO 17
   32 HFR(I)  = (SAFE - HVEL(I) + HFR(I))/2.
      IF(N-1) 35,35,36
   36 IF(I-NUM)   40,42,42
   40 I = I+1
      GO TO 50
   42 CONTINUE
      HFRT(1) = 0
      DO 60 I=2,NUM
   60 HFRT(I) = HFRT(I-1) + HFR(I)
      DPDIF = OMEG * HVEL(NUM)*RHO/144.
      HFT = HFRT(NUM) + OMEG*HVEL(NUM)
      AEX = .785*DL**2
      VEX = VDT/AEX
      HVEX = VEX**2/64.348
      PTEX =PSEX + HVEX*RHO/144.
      PTIN = PTEX + HFT*RHO/144.
      DO 70 I=1,NUM
   70 PS(I) = PTIN -(HVEL(I) +HFRT(I))*RHO/144.
  101 FORMAT(////53X,'*** OUTPUT ***'//)
  102 FORMAT(9X,'THETA',10X,'RNC',11X,'RCOR',10X,'VEL',12X,'FRIC',10X,
     1'HFRT',12X,'PS'//)
  103 FORMAT(7F15.4)
      WRITE(LW,101)
      WRITE(LW,102)
      WRITE(LW,103) (THET(I),RADN(I),RAD(I),C(I),FRIC(I),HFRT(I),PS(I),I
     1=1,NUM)
  120 FORMAT(////20X,'FRICTION LOSS VOLUTE                  =',F8.3,2X,'FT
     1'/)
  121 FORMAT(20X,'FRICTION LOSS INCL EXIT DIFFUSER    =',F8.3,2X,'FT'/)
  122 FORMAT(20X,'EXIT VELOCITY                       =',F8.3,2X,'FT/S'/
     1)
  123 FORMAT(20X,'TOTAL DISCHARGE PRESSURE            =',F8.3,2X,'PSI'/)
  124 FORMAT(20X,'PRESSURE LOSS, EXIT DIFFUSER        =',F8.3,2X,'PSI'/)
      WRITE(LW,120) HFRT(NUM)
      WRITE(LW,121) HFT
      WRITE(LW,122) VEX
      WRITE(LW,123) PTEX
      WRITE(LW,124) DPDIF
      GO TO 9
  500 STOP
      END
VARIABLE ALLOCATIONS
  THET(R )=0082-0000  RADN(R )=0166-0084   ANC(R )=021A-0168    VD(R )=02CE-021C    CN(R )=0382-02D0     A(R )=0436-0384
   RAD(R )=04EA-0438     C(R )=0562-04EC  HVEL(R )=0616-0564  FRIC(R )=06CA-0618   HFR(R )=077E-06CC    PS(R )=0832-0780
  HFRT(R )=08E6-0834    R6(R )=08E8       ALP6(R )=08EA         Q0(R )=08EC       RHO(R )=08EE       OMEG(R )=08F0
  PSEX(R )=08F2         DL(R )=08F4        SFS(R )=08F6         B5(R )=08F8      DTHT(R )=08FA        VDT(R )=08FC
 ALPR6(R )=08FF       CVOL(R )=0900        RXC(R )=0902      CONST(R )=0904      STAY(R )=0906         AM(R )=0908
```

VOLUTE VELOCITIES + PRESSURE DISTRIBUTION

*** INPUT ***

R6	ALP6	OD	RHO	OMEG	PSEX
8.000	14.300	6230.000	4.450	0.200	1580.000

DLINE	SFS	NUM	B5
4.750	0.125E-03	36	0.600

*** OUTPUT ***

THETA	RNC	RCOR	VEL	FRIC	HFRT	PS
10.0000	0.2649	0.2649	251.8666	0.0000	0.0000	1565.8193
20.0000	0.3772	0.3802	244.5606	0.0135	29.4864	1566.6499
30.0000	0.4643	0.4708	239.2457	0.0128	49.9385	1567.2529
40.0000	0.5384	0.5486	234.9321	0.0124	65.9318	1567.7409
50.0000	0.6042	0.6183	231.2430	0.0121	79.1969	1568.1569
60.0000	0.6641	0.6821	227.9889	0.0118	90.5940	1568.5222
70.0000	0.7195	0.7416	225.0593	0.0116	100.6198	1568.8498
80.0000	0.7713	0.7975	222.3829	0.0115	109.5898	1569.1477
90.0000	0.8203	0.8506	219.9113	0.0113	117.7176	1569.4216
100.0000	0.8669	0.9014	217.6092	0.0112	125.1567	1569.6755
110.0000	0.9114	0.9501	215.4505	0.0111	132.0197	1569.9123
120.0000	0.9541	0.9971	213.4148	0.0110	138.3931	1570.1345
130.0000	0.9952	1.0425	211.4864	0.0109	144.3446	1570.3442
140.0000	1.0349	1.0866	209.6523	0.0108	149.9283	1570.5427
150.0000	1.0734	1.1295	207.9019	0.0107	155.1881	1570.7312
160.0000	1.1108	1.1712	206.2267	0.0106	160.1603	1570.9106
170.0000	1.1471	1.2120	204.6192	0.0106	164.8751	1571.0820
180.0000	1.1825	1.2519	203.0733	0.0105	169.3560	1571.2460
190.0000	1.2171	1.2909	201.5836	0.0105	173.6309	1571.4035
200.0000	1.2509	1.3292	200.1453	0.0104	177.7126	1571.5549
210.0000	1.2839	1.3668	198.7545	0.0104	181.6193	1571.7006
220.0000	1.3163	1.4037	197.4076	0.0103	185.3655	1571.8413
230.0000	1.3480	1.4401	196.1014	0.0103	188.9636	1571.9768
240.0000	1.3791	1.4758	194.8333	0.0102	192.4246	1572.1079
250.0000	1.4097	1.5110	193.6006	0.0102	195.7583	1572.2348
260.0000	1.4398	1.5457	192.4013	0.0101	198.9736	1572.3579
270.0000	1.4694	1.5800	191.2331	0.0101	202.0782	1572.4770
280.0000	1.4985	1.6138	190.0943	0.0100	205.0796	1572.5930
290.0000	1.5271	1.6472	188.9834	0.0100	207.9838	1572.7055
300.0000	1.5554	1.6802	187.8986	0.0100	210.7969	1572.8149
310.0000	1.5832	1.7128	186.8387	0.0099	213.5241	1572.9213
320.0000	1.6107	1.7450	185.8023	0.0099	216.1704	1573.0251
330.0000	1.6378	1.7770	184.7883	0.0099	218.7399	1573.1259

```
FRICTION LOSS VOLUTE                    = 226.028  FT
FRICTION LOSS INCL EXIT DIFFUSER        = 328.834  FT
EXIT VELOCITY                           = 1121911  FT/S
TOTAL DISCHARGE PRESSURE                =1586.122  PSI
PRESSURE LOSS, EXIT DIFFUSER          . =    3.176  PSI
```

9

4. INDUCER AND IMPELLER PERFORMANCE PROGRAM

J. J. Brunner
24 April 1972

COMPUTER PROGRAM

INDUCER AND IMPELLER PERFORMANCE PROGRAM

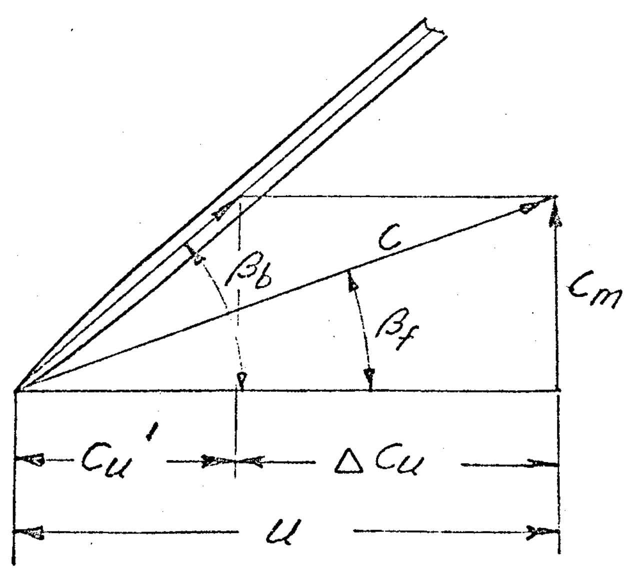
I. INTRODUCTION

A detailed loss analysis calculating incidence, friction, diffusion, discharge, blade clearance and labyrinth flow losses of inducers and impellers of arbitrary geometry is presented. Actual and ideal head coefficients, efficiency and power losses resulting from disk friction are printed out.

II. BASIC CALCULATIONS

A. Incidence Losses

It is assumed that a specified percentage of the velocity head based on the difference in tangential velocity component ΔCu_m is lost.



$$\Delta Cu = C_m \ (\text{Cot } \beta_f - \text{Cot } \beta_b)$$

If K_i is the incidence loss factor based on the inlet mean diameter, the incidence loss is:

$$\Delta\psi_{\ell i} = \frac{K_i \dfrac{(C_m(\text{Cot } \beta_f - \text{Cot } \beta_b))^2}{2g}}{\dfrac{U^2}{g}} = \frac{K_i}{2} [\phi (\text{Cot } \beta_f - \text{Cot } \beta_b)]^2$$

where: $\phi = \frac{C_m}{u}$ (inlet)

The value $\frac{Ki}{2}$ used in this program is 0.15 (program constant). Program evaluations have indicated that the incidence loss so calculated is generally excessive, especially for radial impellers with diameter ratios, R_1/R_2 lower than 0.55. It would be advisable to modify above expression to include consideration of the diameter ratio (e.g. $(U_{1m}/U_{2m})^2$).

B. Friction Losses

Friction losses are based on the mean relative velocity, the hydraulic diameter of the blade passage and the blade surface finish. If not input the friction coefficient for Reynolds numbers greater than 10^5 is determined according to Reference 1:

$$\lambda = \frac{1}{(.8685\ l_n\ (d_h/2\ f_s) + 1.74)^2}$$

For laminar flow, $Re < 10^5$, the friction coefficient is calculated according to the following expression derived by Blasius:

$$\lambda = .0032 + \frac{0.221}{R_e^{0.237}}$$

Reference 1 - Eckert/Schnell, Axial and Radial Compressors, Springer 1961

C. Diffusion Loss

The diffusion loss is related to the diffusion parameter D_I

$$D_I = 1 - \frac{W_2}{W_{1b}} + \frac{W_{u2} - W_{u1}}{2 \sigma W_{1b}}$$

where:

W_2 = relative velocity, discharge

W_{1b} = relative velocity, inlet blade passage

W_{u2}, W_{u1} = tangential components of relative velocities

σ = solidity

The diffusion loss coefficient is:

$$\Delta\psi_{\ell,d} = 0.08 D_I^3$$

D. Tip or Exit Losses

This loss is very small and generally neglected.

$$\Delta\psi_{\ell,t} = .5 \left(\frac{\phi_2}{BLK2}\right)^2$$

ϕ_2 = discharge flow coefficient

BLK2 = impeller discharge blade blockage

E. Clearance Losses

Blade tip clearance losses are related to blade loading, tip clearance and fluid viscosity. The expressions listed in subroutine ILOSS for estimating clearance losses yield reasonable values for swept back blading operating in water as liquid nitorgen. Loss coefficients for radial blading (β_2 = 90°) in liquid hydrogen calculated by the same method were found to be excessive.

F. Blade Losses

The summation of above losses constitute the blade losses.

$$\Delta\psi_{\ell,b} = \Delta\psi_{\ell,i} + \Delta\psi_{\ell,f} + \Delta\psi_{\ell,d} + \Delta\psi_{\ell,t} + \Delta\psi_{\ell,c}$$

G. Labyrinth Clearance Losses

The labyrinth clearance flow is estimated using semi-empirical equations devised by G. Vermes Reference 2. The annular orifice flow coefficient is calculated from data presented in Reference 3. Data interpolation is performed by subroutine INT4.

H. Disc Friction Losses

The disc friction losses are computed using friction coefficients based on Schultz & Grunow's data published in Reference 4. Backvane power losses are estimated according to Reference 5.

Reference 2 - Geza Vermes, A Fluid Mechanics Approach to the Labyrinth Seal Leakage Problem, Journal of Engineering for Power, April 1961

Reference 3 - K. H. Bell & O. P Bergelin, Flow Through Annular Orifices, TRANS. ASME, Vol. 7, 1957

Reference 4 - A. J. Stepanoff, Centrifugal and Axial Flow Pumps, J. Wiley & Sons, 1957

Reference 5 - K. T. Zanker, Experiments With Badvanes Used for Balancing Axial Thrust on Centrifugal Pump Impeller; The British Hydromechanics Research Association, RR 729, April 1962

I. Slip Factor

The slip factor μ for the determination of the theoretical head is calculated according to Reference 6 as follows:

$$\mu \quad \frac{1}{1 + \psi' \frac{R_2^2}{ZM_s}}$$

where:

ψ' = experience factor (see instructions)

M_s = static moment of impeller blade = $1/2\ (R_2^2 - R_1^2)$ for radial blades

Z = number of impeller blades

Reference 6: G. Pfleiderer, Die Kreiselpumpen, 5th Edition, Springer Verlag, 1961

III. GENERAL INSTRUCTIONS

A. A negative value in place of the blade tip clearance SCL will cause the program to calculate a tip clearance related to the discharge diameter of the impeller.

The program flags FLAG and IFLAG select the configuration.

FLAG

Value (Real)	Configuration
Negative	Unshrouded with backvanes
Zero	Unshrouded, smooth
Positive	Shrouded, smooth

IFLAG

Value (Integer)	Configuration
Zero	Impeller (will calculate disc friction)
Positive	Inducer (Will not calculate disc friction)

B. Values for Pfleiderer's experience factor FSLIP for slip depend on pump configuration and impeller blade discharge angle β_2.

If the impeller discharges into a vaned diffuser:

$$FSLIP = 0.6 \left(1 + \frac{\beta 2}{60}\right)$$

If a volute housing is used only:

$$FSLIP = (0.65 \text{ to } 0.85) \left(1 + \frac{\beta 2}{60}\right)$$

If a vaneless diffuser is used in conjunction with a collector:

$$FSLIP = (0.85 \text{ to } 1.0) \left(1 + \frac{\beta 2}{60}\right)$$

C. The blade chord length CLBL must be determined from layout. The blade solidity is obtained by dividing the blade chord length by the mean blade spacing.

D. For shrouded impellers, an initial or starting value for the labyrinth flow must be input. The correct value is calculated by iterations.

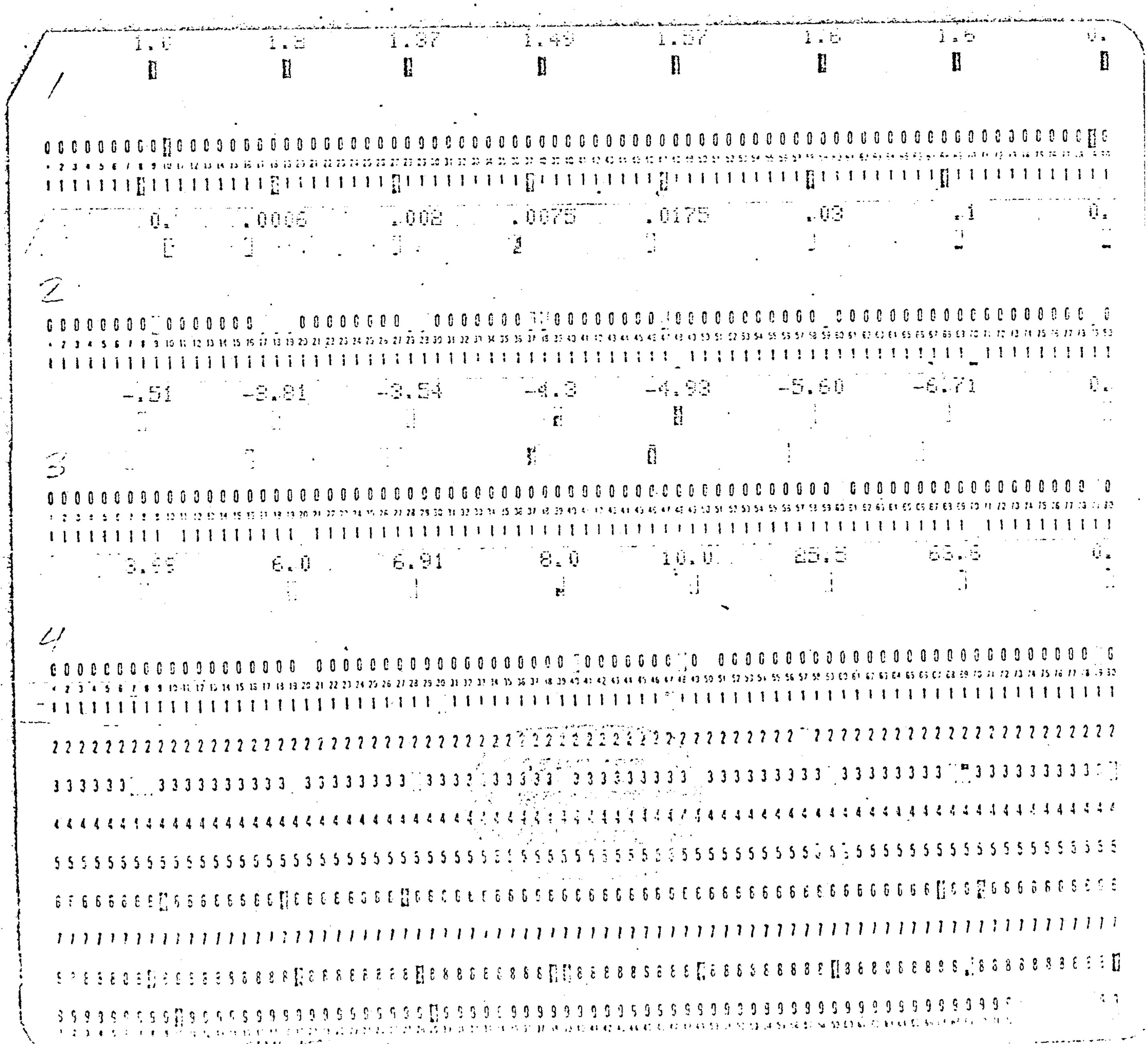
NOMENCLATURE INPUT

SYMBOL	DESCRIPTION	UNITS	FORMAT
BB2	Discharge Blade Angle	Deg	F
Z	Blade Number	---	F
SM	Stat. Moment of Blade	IN^2	F
WIMP	Impeller Flow Rate	lb/sec	F
BBMI	Inlet Mean Blade Angle	Deg	F
BBTI	Inlet Tip Blade Angle	Deg	F
ETIP	Total Pinbladed Tip Width, Shroud and Disc	IN	F
AFLIM	Inlet Mean Fluid Angle	Deg	F
D2	Discharge Diameter	IN	F
B2	Discharge Blade Width	IN	F
LLBL	Blade Chord Length	IN	F
*SCL	Blade Tip Clearance	IN	F
BLKZ	Discharge Blockage	%	F
RHØ	Weight Density	lb/sec	F
SOL	Blade Solidity	---	F
DTI	Inlet Tip Diameter	IN	F
DR	Radial Extension	IN	F
DHI	Inlet Hub Diameter	IN	F
XN	Rotating Speed	RPM	F
*FLAG	Program Flag, See Instructions	---	F
VIS	Dynamic Viscosity	lb sec/ft^2	E
*IFLAG	Program Flag, See Instructions	---	I
ESHR	Axial Length of Labyrinth		F
SFFS	Surface Finish	IN	E
D	Labyrinth Diameter	IN	F
CO	Radial Clearance Labyrinth	IN	F
SNTH	Number of Labyrinth Teeth	---	F
PI	Tooth Pitch	IN	F
T	Tooth Thickness	IN	F
XKDF	Disc Friction Factor		E
FSLIP	Pfleiderers' Experience Factor for SLIP		F

*See general instructions, Page 6.

ORIFICE DATA

These four cards must proceed regular input presented on following page.



IBM

FORTRAN Coding Form

GX28-7327-6 U/M050
Printed in U.S.A.

PROGRAM *Inducer & Impeller Performance Program*

PROGRAMMER | DATE | PUNCHING INSTRUCTIONS | GRAPHIC | PUNCH | PAGE OF | CARD ELECTRO NUMBER

FORTRAN STATEMENT

BB2	Z	SM	WIMP	BBM1	BBT1	ETIP	AFLIM
D2	B2	CLBL	SCL	BLK2	RHØ	SØL	DT1
DR	DH1	XN	FLAG	VIS	IFLAG	ESHR	SFFS
D	CØ	XNTH	PI	T	XKDF	KSLIP	WLABA

*A standard card form, IBM electro 888157, is available for punching statements from this form

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LEVEL 18 ( SEPT 69 )                    OS/360  FORTRAN H                    DATE  71.014/12.37.25

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=72,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,NOXREF
  ISN 0002             COMMON    XK(8),XZ(8),XFR(8),XR(8)
  ISN 0003             COMMON BB2,Z,SM,WIMP,BBM1,BBT1,AB1,PHI2,CM2,SOL,SFFS,AFLIM,ETIP,
                      1CU2TH,FSLIP, SCL,PRINT,D2,B2,CLBL,SIG ,BLK2,RHO,VIS,      DT1,
                      2 DP,DH1,PHI1T,XN,FLAG,P,D,XNTH,PI,IFLAG,CO,WWR,T,MESS1,QI,U2,R2,
                      3 DLPDF,RWR,ESHR,DELK,PSIBL,PSITH,SLPCF,      XKDF,WNET,WLABA,ILAB
  ISN 0004           1 FORMAT(8F10.0)
  ISN 0005             READ(5,1)XK,XZ,XFR,XR
  ISN 0006           2 CALL INP1
  ISN 0007             GO TO (3,4),MESS1
  ISN 0008           3 R2=D2/2.
  ISN 0009             RT1=DT1/2.
  ISN 0010             CCL=CLBL /2.9
  ISN 0011             DELK=25.0/CCL
  ISN 0012             ILAB = 0
  ISN 0013             IF(FLAG)60,60,61
  ISN 0014          60 PRINT = 1.
  ISN 0015             GO TO 10
  ISN 0016          61 PRINT = 0
  ISN 0017          10 CALL ILOSS
  ISN 0018             PSIIP=PSITH-PSIBL
  ISN 0019             PSIPS = PSIIP - 0.5 * (PHI2**2 + (CU2TH/U2)**2)
  ISN 0020             DPIPS=PSIPS*U2**2/32.174*RHO/144.
  ISN 0021             IF(FLAG) 35,35,30
  ISN 0022          30 DPFF=.1645E-07*.025*RHO*XN**2*(R2**2-RT1**2)
  ISN 0023             P=DPIPS-DPFF
  ISN 0024             CALL CLAB
  ISN 0025             IF(PRINT)55,55,50
  ISN 0026          55 IF(ABS(WLABA-WWR)-0.1) 102,102,103
  ISN 0027         103 IF(WLABA - WWR) 104,102,105
  ISN 0028         104 WLABA = WLABA + .1
  ISN 0029             GO TO 106
  ISN 0030         105 WLABA = WLABA - .1
  ISN 0031         106 ILAB = ILAB + 1
  ISN 0032             IF(ILAB-12) 10,10,102
  ISN 0033         102 PRINT = 1.
  ISN 0034             WLABA = WWR
  ISN 0035             GO TO 10
  ISN 0036          50 IF(IFLAG) 5,5,6
  ISN 0037           6 DLPDF = 0
  ISN 0038             WWR = 0
  ISN 0039             GO TO 8
  ISN 0040          35 WWR=0.
  ISN 0041           5 CALL DFRBV
  ISN 0042           8 PSIIN=PSITH+DLPDF
  ISN 0043             ETAIO=PSIIP/PSIIN*WIMP/(WIMP+WWR)
  ISN 0044          19 FORMAT(5X,'SLIP COEFFICIENT, SLPCF',31X,F10.4,2X,'***')
  ISN 0045           7 FORMAT(5X,'THEORETICAL HEAD COEFFICIENT, PSITH',19X,F10.4,2X,'***'
                      1)
  ISN 0046          11 FORMAT(5X,'IMPELLER HEAD COEFFICIENT, PSIIP',22X,F10.4,2X,'***')
  ISN 0047          13 FORMAT(5X,'INPUT HEAD COEFFICIENT, PSIIN',25X,F10.4,2X,'***')
  ISN 0048          21 FORMAT(5X,'IMPELLER STATIC HEAD COEFFICIENT, PSIPS',15X,F10.4,2X,'
                      1***')
  ISN 0049          23 FORMAT(5X,'IMPELLER STATIC PRESSURE RISE, DPIPS',18X,F10.4,2X,'LB/
                      1SQIN')
  ISN 0050          17 FORMAT(5X,'OPTIMIZATION PARAMETER, ETAIO',25X,F10.4,2X,'***')
  ISN 0051             WRITE(6,19) SLPCF
  ISN 0052             WRITE(6,7) PSITH
  ISN 0053             WRITE(6,11) PSIIP
  ISN 0054             WRITE(6,13) PSIIN
  ISN 0055             WRITE(6,21) PSIPS
  ISN 0056             WRITE(6,23) DPIPS
  ISN 0057             WRITE(6,17) ETAIO
  ISN 0058             IF(FLAG) 45,45,40
  ISN 0059          40 CONTINUE
  ISN 0060          27 FORMAT(/5X,'*** LABYRINTH DATA ***',/)
  ISN 0061          29 FORMAT(5X,'LABYRINTH DIAMETER, D',33X,F10.4,2X,'IN')
  ISN 0062          31 FORMAT(5X,'RADIAL CLEARANCE, CD',34X,F10.4,2X,'IN')
  ISN 0063          33 FORMAT(5X,'NUMBER OF TEETH, XNTH',33X,F10.4,2X,'***')
  ISN 0064          37 FORMAT(5X,'TOOTH SPACING, PI',37X,F10.4,2X,'IN')
  ISN 0065          39 FORMAT(5X,'TOOTH WIDTH, T',40X,F10.4,2X,'IN')
```

```
 41 FORMAT(5X,'PRESSURE DROP, P',38X,F10.4,2X,'LB/SQIN')
 15 FORMAT(5X,'LABYRINTH FLOW RATE, WWR',30X,F10.4,2X,'LB/SEC')
    WRITE(6,27)
    WRITE(6,29) Q
    WRITE(6,31) CO
    WRITE(6,33) XNTH
    WRITE(6,37) PI
    WRITE(6,39) T
    WRITE(6,41) P
    WRITE(6,15) WWR
 45 CONTINUE
    GO TO 2
  4 STOP
    END
```

```
LEVEL 1H ( SEPT 69 )                    OS/360  FORTRAN H                    DATE  71.014/12.37.34

            COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=72,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,NOXREF
      ISN 0002              SUBROUTINE ILOSS
      ISN 0003              COMMON    XK(8),XZ(8),XFR(8),XR(8)
      ISN 0004              COMMON BB2,Z,SM,WIMP,BBM1,BBT1,AB1,PHI2,CM2,SOL,SFFS,AFLIM,ETIP, ,
                           1CU2TH,FSLIP, SCL,PRINT,D2,B2,CLBL,SIG ,BLK2,RHO,VIS,       DT1,
                           2 DR,DH1,PHIIT,XN,FLAG,P,D,XNTH,PI,IFLAG,CC,HWR,T,MESS1,QI,U2,R2,
                           3 DLPDF,RWR,ESHR,DELK,PSIBL,PSITH,SLPCF,     XKDF,WNET,WLABA,ILAB
      ISN 0005              EQUIVALENCE (PSITH,PSIT),(PHI2,PHI),(U2,U)
      ISN 0006              TRNSK=.5
      ISN 0007              SIG = 1.2
      ISN 0008              BBM1R=BBM1/57.296
      ISN 0009              BBT1R=BBT1/57.296
      ISN 0010              BB2R=BB2/57.296
      ISN 0011              A1 = 0.7853975 * (DT1**2 - DH1**2)
      ISN 0012              DM1 = SQRT(0.5 * (DH1**2 + DT1**2))
      ISN 0013              WIMP = WNET + WLABA
      ISN 0014              QI=WIMP*448.8/RHO
      ISN 0015              U2=D2*XN/229.
      ISN 0016              A2 = 3.1417 * D2 * B2 * (1.-BLK2)
      ISN 0017              CM2 = .321 * QI/A2
      ISN 0018              PHI2 = CM2/U2
      ISN 0019              CU2E=U2-CM2/SIN(BB2R)*COS(BB2R)
      ISN 0020              IF(BB2-90.) 20,25,25
      ISN 0021           20 PSISL = FSLIP * (1. + BB2/60.)
      ISN 0022              PSL=PSISL*R2**2/Z/SM
      ISN 0023              SLPCF=1./(1.+PSL)
      ISN 0024              GO TO 26
      ISN 0025           25 SLPCF=1.-1.98/Z
      ISN 0026           26 CU2TH=SLPCF*CU2E
      ISN 0027              CM1 = 0.321 * QI/A1
      ISN 0028              UT1 = XN * DT1/229.
      ISN 0029              WT1 = SQRT(CM1**2 + UT1**2)
      ISN 0030              WU2TH=U2*(1.-SLPCF*(1.-PHI2*COS(BB2R)/SIN(BB2R)))
      ISN 0031              W2TH=SQRT(CM2**2+WU2TH**2)
      ISN 0032              RW = W2TH/WT1
      ISN 0033              U1M = XN * DM1/229.
      ISN 0034              IF(AFLIM) 30,35,40
      ISN 0035           30 AF1MR = ABS(AFLIM)/57.296
      ISN 0036              CU1M =-CM1 * SIN(AF1MR)/COS(AF1MR)
      ISN 0037              BFM1R = ATAN(CM1/(U1M - CU1M))
      ISN 0038              GO TO 42
      ISN 0039           35 CU1M = 0
      ISN 0040              BFM1R = ATAN(CM1/U1M)
      ISN 0041              GO TO 42
      ISN 0042           40 AF1MR = AFLIM/57.296
      ISN 0043              CU1M = CM1 * SIN(AF1MR)/COS(AF1MR)
      ISN 0044              BFM1R = ATAN(CM1/(U1M - CU1M))
      ISN 0045           42 PHIM1 = CM1/U1M
      ISN 0046              PSINC=0.15*(PHIM1*(COS(BFM1R)/SIN(BFM1R)-COS(BBM1R)/SIN(BBM1R)))**
                           12
      ISN 0047              WUM1 = U1M - CU1M
      ISN 0048              WM1  = SQRT(CM1**2 + WUM1**2)
      ISN 0049              WMR = 0.5 * (WM1 + W2TH)
      ISN 0050              PASW = D2*SIN(BB2R) * (1.-BLK2)/Z * 3.1417
      ISN 0051              DHYD = 2.* B2 * PASW/(PASW + B2)
      ISN 0052              REIMP=DHYD *RHO*WMR /(96.522*VIS)
      ISN 0053              IF(REIMP-1.E+05) 37,37,38
      ISN 0054           37 FRIMP=0.0032+0.221/REIMP**0.237
      ISN 0055              GO TO 39
      ISN 0056           38 FRIMP = 1./(0.86858*ALOG(DHYD /(2.*SFFS ))+1.74)**2
      ISN 0057           39 HLFIP=WMR **2/64.33*(FRIMP*CLBL /DHYD)
      ISN 0058              PSFIP=32.174*HLFIP/U2**2
      ISN 0059              PSTIP=TRNSK*(PHI2*BLK2)**2
      ISN 0060              DIFP = 1.-  W2TH/WM1  +(WU2TH-WUM1 )/(2. * SOL * WM1 )
      ISN 0061              PSD = 0.08 * DIFP**3
      ISN 0062              PSIBL = PSINC + PSFIP + PSD + PSTIP
      ISN 0063              PSITH = CU2TH/U2 - U1M*CU1M/U2**2
      ISN 0064              HTH=PSITH*U2**2/32.174
      ISN 0065              IF(FLAG) 410,410,440
```

```
ISN 0066     410 IF(SCL) 430,440,450
ISN 0067     430 SCL=0.010201+0.0008095*D2+0.00011078*D2**2
ISN 0068         GO TO 450
ISN 0069     440 IF(PRINT) 101,101,102
ISN 0070     102 WRITE(6,420)
ISN 0071     420 FORMAT(/5X,'IMPELLER IS SHROUDED',/)
ISN 0072     101 PSCL=0.
ISN 0073         DELE=0.
ISN 0074         DELR=0.
ISN 0075         SCL=0.
ISN 0076         GO TO 470
ISN 0077     450 CONTINUE
ISN 0078         DELR=SCL/D2
ISN 0079         BDR=B2/D2
ISN 0080         DT=D2/12.
ISN 0081         CLPT=CLBL /12.
ISN 0082         VI=32.174*VIS/RHO
ISN 0083         A=1.5708-B82R
ISN 0084         DSTR=1.72*SQRT(VI*CLPT*COS(A)*DELK/(PHI*U))
ISN 0085         Y=DELR*DT/(2.*DSTR)
ISN 0086         IF(Y-2.)1,2,2
ISN 0087       1 FI=1.-(Y-.25*Y**2)**2
ISN 0088         GO TO 3
ISN 0089       2 FI=0.
ISN 0090       3 G=PHI*PSIT/(SIG*COS(A))
ISN 0091         DELE=DELR*G**.5*(1.+(COS(A))**2/G*FI)**1.5/(BDR*COS(A))
ISN 0092         PSCL=32.174*DELE*HTH/U2**2
ISN 0093         PSIBL=PSIBL+PSCL
ISN 0094     470 CONTINUE
ISN 0095      55 FORMAT(5X,'IMPELLER LOSSES',//)
ISN 0096      57 FORMAT(/,5X,'***** OUTPUT *****',//)
ISN 0097      12 FORMAT(/5X,7HSCL    =,3X,F10.3,24X,7HPSINC =,3X,F10.4,
                1 24X,7HU2     =,3X,F10.3)
ISN 0098      14 FORMAT(5X,7HDELE   =,3X,F10.3,24X,7HPSF   =,3X,F10.4,
                1 24X,7HCU2TH =,3X,F10.3)
ISN 0099      16 FORMAT(5X,7HDELK   =,3X,F10.3,24X,7HPSD   =,3X,F10.4,
                1 24X,7HCM2    =,3X,F10.3)
ISN 0100      18 FORMAT(5X,7HDELR   =,3X,F10.3,24X,7HPSTIP =,3X,F10.4,
                1 24X,7HPHI2   =,3X,F10.3)
ISN 0101      28 FORMAT(5X,7HW2TH   =,3X,F10.3,24X,7HPSCL  =,3X,F10.4,
                1 24X,7HFRIMP =,3X,F10.4)
ISN 0102      22 FORMAT(5X,7HRW     =,3X,F10.3,24X,7HPSIBL =,3X,F10.4,
                1 24X,7HDIFP  =,3X,F10.3)
ISN 0103      24 FORMAT(5X,7HHTH    =,3X,F10.3,68X,7HU1M    =,3X,F10.3)
ISN 0104      27 FORMAT(5X,7HWIMP   =,3X,F10.3,68X,7HCU1M   =,3X,F10.3)
ISN 0105      29 FORMAT(93X,7HCM1    =,3X,F10.3)
ISN 0106         IF(PRINT) 108,108,110
ISN 0107     110 WRITE(6,55)
ISN 0108         WRITE(6,57)
ISN 0109         WRITE(6,12) SCL,PSINC,U2
ISN 0110         WRITE(6,14) DELE,PSFIP,CU2TH
ISN 0111         WRITE(6,16) DELK,PSD,CM2
ISN 0112         WRITE(6,18) DELR,PSTIP,PHI2
ISN 0113         WRITE(6,28) W2TH,PSCL,FRIMP
ISN 0114         WRITE(6,22) RW,PSIBL,DIFP
ISN 0115         WRITE(6,24) HTH,U1M
ISN 0116         WRITE(6,27) WIMP,CU1M
ISN 0117         WRITE(6,29) CM1
ISN 0118     108 RETURN
ISN 0119         END
```

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          COMPILER OPTIONS - NAME=  MAIN.OPT=02.LINECNT=72.SOURCE.EBCDIC.NOLIST.NODECK.LOAD.MAP.NOEDIT.NOID.NOXREF
ISN 0002               SUBROUTINE DFRBV
ISN 0003               COMMON    XK(8).XZ(8).XFR(8).XR(8)
ISN 0004               COMMON BB2.Z.SM.WIMP.BBM1.BBT1.AB1.PHI2.CM2.SOL.SFFS.AFLIM.ETIP.
                      1CU2TH.FSLIP. SCL.PRINT.D2.B2.CLBL .SIG.BLK2.RHO.VIS.        DT1.
                      2 DR.DH1.PHIIT.XN.FLAG.P.D.XNTH.PI.IFLAG.CC.WWR.T.MESS1.QI.U2.R2.
                      3 DLPDF.RWR.ESHR.DELK.PSIBL.PSITH.SLPCF.      XKDF.WNET.WLABA.ILAB
ISN 0005               RE2=U2*R2*RHO/(386.*VIS)
ISN 0006               IF(FLAG) 10.20.20
ISN 0007            10 RBV2=R2+DR
ISN 0008               RBV1=R2/2.
ISN 0009               SBV=SCL/.17+SCL
ISN 0010               OMIP=.1048*XN
ISN 0011               TEMP=SBV/.8/SCL-1.
ISN 0012               XBV=TEMP*(40./(1.+5.*SBV/RBV2)*RE2 **.2/.56*(SBV/RBV2))**.5
ISN 0013               ROMBV=XBV/(1.+XBV)
ISN 0014               OMFL=OMIP*ROMBV
ISN 0015               TQBV=.1562E-07*RHO*40.*((RBV2)**4-(RBV1)**4)*SBV*(OMIP-OMFL)**2*(T
                      1EMP)**2
ISN 0016               PFBV=OMIP*TQBV/550.
ISN 0017               PFBS=0.
ISN 0018               PFFS=0.
ISN 0019               XKDF=0.
ISN 0020               GO TO 35
ISN 0021            20 REX=R2+DR
ISN 0022               RBS=.3*R2
ISN 0023               IF(XKDF) 25.25.23
ISN 0024            25 IF(RE2-10.**6) 21.22.22
ISN 0025            21 XKDF=3.68431E-06-7.869741E-07*ALOG(RE2 )+5.706801E-08*(ALOG(RE2 ))
                      1**2-1.3921085E-09*(ALOG(RE2 ))**3
ISN 0026               GO TO 23
ISN 0027            22 XKDF=31.5E-08/RE2 **0.164
ISN 0028            23 CONTINUE
ISN 0029               XPDF=4.61E-09*XKDF*RHO*XN**3
ISN 0030               PFBS=XPDF*(REX**4*(2.*REX+5.*ETIP)-2.*(RBS**5-REX**5+R2**5))
ISN 0031               PFBV=0.
ISN 0032               IF(FLAG) 31.31.32
ISN 0033            31 PFFS=0.
ISN 0034               GO TO 35
ISN 0035            32 RWR = 0.5 * D
ISN 0036               RT1=DT1/2.
ISN 0037               PFFS1=XPDF*(RWR**4*(2.*RWR+5.*ESHR)-2.*RT1**5)
ISN 0038               PFFS2=XPDF*(R2**4*(2.*R2+5.*ETIP)-2.*RWR**5)
ISN 0039               PFFS=PFFS1+PFFS2
ISN 0040            35 PFTOT=PFBV+PFFS+PFBS
ISN 0041               DLPDF=17680.*PFTOT/(U2**2*WIMP)
ISN 0042            12 FORMAT(5X.'REYNOLDS NO.. IMPELLER. RE2'.11X.E10.4.2X.'****')
ISN 0043            13 FORMAT(5X.'DISK FRICTION COEFF.. XKDF'.12X.E10.4.2X.'****')
ISN 0044            14 FORMAT(5X.'POWER. BACKVANES. PFBV'.16X.F10.3.2X.'HP')
ISN 0045            15 FORMAT(5X.'POWER. BACK FACE. PFBS'.16X.F10.3.2X.'HP')
ISN 0046            16 FORMAT(5X.'POWER. FRONT FACE. PFFS'.15X.F10.3.2X.'HP')
ISN 0047            17 FORMAT(5X.'POWER./ TOTAL. PFTOT'.19X.F10.3.2X.'HP')
ISN 0048            18 FORMAT(5X.'LOSS COEFF.. DLPDF'.20X.F10.4.2X.'****'//)
ISN 0049               WRITE(6.12) RE2
ISN 0050               WRITE(6.13) XKDF
ISN 0051               WRITE(6.14) PFBV
ISN 0052               WRITE(6.15) PFBS
ISN 0053               WRITE(6.16) PFFS
ISN 0054               WRITE(6.17) PFTOT
ISN 0055               WRITE(6.18) DLPDF
ISN 0056               RETURN
ISN 0057               END
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LEVEL 18 ( SEPT 69 )                              OS/360  FORTRAN H                                DATE  71.014/12.37.58

              COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=72,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,NOXREF
      ISN 0002              SUBROUTINE INP1
      ISN 0003              COMMON    XK(8),XZ(8),XFR(8),XR(8)
      ISN 0004              COMMON BB2,Z,SM,WIMP,BBM1,BBT1,AB1,PHI2,CM2,SOL,SFFS,AFLIM,ETIP,
                           1CO2TH,FSLIP, SCL,PRINT,D2,B2,CLBL ,SIG,BLK2,RHO,VIS,       DT1,
                           2 DR,DH1,PHI1T,XN,FLAG,P,D,XNTH,PI,IFLAG,CO,WWR,T,MESS1,OI,U2,R2,
                           3 DLPDF,RWR,ESHR,DELK,PSIBL,PSITH,SLPCF,      XKDF,WNET,WLABA,ILAB
      ISN 0005              MESS1=1
      ISN 0006            1 FORMAT(8F10.0)
      ISN 0007            2 FORMAT(4F10.0,E10.4,I10,F10.0,E10.4)
      ISN 0008            3 FORMAT(4X,8E14.4)
      ISN 0009            4 FORMAT(4X,5E14.4,I10,E18.5,E14.4)
      ISN 0010            5 FORMAT(5F10.4,E10.4,2F10.3)
      ISN 0011              READ(5,1)BB2,Z,SM,WNET,BBM1,BBT1,ETIP,AFLIM
      ISN 0012              IF(WNET)51,51,50
      ISN 0013           51 MESS1=2
      ISN 0014              GO TO 100
      ISN 0015           50 READ(5,1) D2,B2,CLBL,SCL,BLK2,RHO,SOL,DT1
      ISN 0016              READ(5,2) DR,DH1,XN,FLAG,VIS,IFLAG,ESHR ,SFFS
      ISN 0017              READ(5,5) D,CO,XNTH,PI,T,XKDF,FSLIP,WLABA
      ISN 0018           10 FORMAT('1',//5X,'INPUT'//)
      ISN 0019              WRITE(6,10)
      ISN 0020            6 FORMAT(11X,'BB2',11X,'Z',13X,'SM',12X,'WNET',10X,'BBM1',10X,'BBT1'
                           1,11X,'ETIP', 8X,'AFLIM')
      ISN 0021            7 FORMAT(/11X,'D2',14X,'B2',11X,'CLBL',10X,'SCL',10X,'BLK2',10X,'RHO
                           1',10X,'SOL',10X,'DT1')
      ISN 0022            9 FORMAT(/11X,'DR',12X,'DH1',12X,'XN',10X,'FLAG',10X,'VIS',11X,'IFLA
                           1G', 9X,'ESHR',10X,'SFFS')
      ISN 0023            8 FORMAT(/11X,'D',13X,'CO',12X,'XNTH',10X,'PI',11X,'T',12X,'XKDF',11
                           1X,'FSLIP',9X,'WLABA')
      ISN 0024           11 FORMAT(4X,8E14.4///)
      ISN 0025              WRITE(6,6)
      ISN 0026              WRITE(6,3)BB2,Z,SM,WNET,BBM1,BBT1,ETIP,AFLIM
      ISN 0027              WRITE(6,7)
      ISN 0028              WRITE(6,3) D2,B2,CLBL,SCL,BLK2,RHO,SOL,DT1
      ISN 0029              WRITE(6,9)
      ISN 0030              WRITE(6,4) DR,DH1,XN,FLAG,VIS,IFLAG,ESHR ,SFFS
      ISN 0031              WRITE(6,8)
      ISN 0032              WRITE(6,11) D,CO,XNTH,PI,T,XKDF,FSLIP,WLABA
      ISN 0033          100 RETURN
      ISN 0034              END
```

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LEVEL 18 ( SEPT 69 )                         OS/360  FORTRAN H                         DATE  71.014/12.37.53

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=72,SOURCE,EBCDIC,NCLIST,NCDECK,LOAD,MAP,NCEDIT,NOID,NOXREF
 ISN 0002              SUBROUTINE CLAB
 ISN 0003              COMMON   XK(8),XZ(8),XFR(8),XR(8)
 ISN 0004              COMMON BB2,Z,SM,WIMP,BBM1,BBT1,AB1,PHI2,CM2,SOL,SFFS,AFLIM,ETIP,
                      1CU2TH,FSLIP, SCL,PRINT,D2,B2,CLBL ,SIG,BLK2,RHO,VIS,       DT1,
                      2 DR,DH1,PHI1T,XN,FLAG,P,D,XNTH,PI,IFLG,CO,W,T,MLSS1,Q1,U2,R2,
                      3 DLPOF,RWR,ESHR,DELK,PSIBL,PSITH,SLPCF,     XKDF,WNET,WLABA,ILAB
 ISN 0005              VI=VIS*(32.16/RHO)
 ISN 0006              COEC=.67
 ISN 0007              FA=2.*RHO*32.1741*P*144.
 ISN 0008              FB=SQRT(FA)
 ISN 0009              S=3.1416*CO*(D+CO)/144.
 ISN 0010              CF=(XNTH-1.)*(1.-8.52/((PI-T)/CO+7.23))+1.
 ISN 0011              DO 40 I=1,3
 ISN 0012              COF=COEC/SQRT(CF)
 ISN 0013              W=COL*S*FB
 ISN 0014              RE=CO*W/(6.*S*VI*RHO)
 ISN 0015              ZLAB=I/CO
 ISN 0016              IF(RE-60.)200,200,300
 ISN 0017          200 RZ=ZLAB/RE
 ISN 0018              CALL INT4(XZ,XK,RZ,FK)
 ISN 0019              COEC=1./SQRT(64./RE+48.*ZLAB/RE+FK)
 ISN 0020              GO TO 40
 ISN 0021          300 RE=ALOG(RE)
 ISN 0022              CALL INT4(XR,XFR,RE,FFR)
 ISN 0023              FFR=EXP(FFR)
 ISN 0024              RE=EXP(RE)
 ISN 0025              COEO=.62*RE**.0085
 ISN 0026              IF(ZLAB-1.15) 310,310,320
 ISN 0027          310 F=0
 ISN 0028              GO TO 330
 ISN 0029          320 F=1.-2.7183**(-.95*(ZLAB-1.15))
 ISN 0030          330 IF(RE-6000.)340,340,350
 ISN 0031          340 COEC=1./SQRT(1/COEO**2-F*(2*SQRT(1/COEO**2-64./RE)-2.)+2.*FFR*ZLAB
                      1)
 ISN 0032              GO TO 40
 ISN 0033          350 COEC=1./SQRT(1./COEO**2-(2./COEO-2.)*F+2.*FFR*ZLAB)
 ISN 0034           40 CONTINUE
 ISN 0035              RETURN
 ISN 0036              END
```

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LEVEL 19 ( SEPT 69 )                    OS/360  FORTRAN H                            DATE  71.014/12.37.48
            COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=72,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,NOXREF
  ISN 0002               SUBROUTINE INT4(X,Y,XI,YC)
  ISN 0003               DIMENSION X(9),Y(9),XC(4),YC(4)
  ISN 0004               EQUIVALENCE (XC(1),X1),(XC(2),X2),(XC(3),X3),(XC(4),X4),(YC(1),Y1)61205006
                        1,(YC(2),Y2),(YC(3),Y3),(YC(4),Y4)                                  61205007
  ISN 0005               NA=1
  ISN 0006               J=2
  ISN 0007               B=XI
  ISN 0008         21    IF(X(J))26,22,26
  ISN 0009         26    GO TO(30,40),NA
  ISN 0010         22    IF(Y(J))26,23,26
  ISN 0011         23    IF(J-2)24,24,25
  ISN 0012         24    YE=0.0
  ISN 0013               GO TO 50
  ISN 0014         25    NB=1
  ISN 0015               J=J-1
  ISN 0016         27    X1=X(J)
  ISN 0017               X2=X(J-1)
  ISN 0018               X3=X(J-2)
  ISN 0019               Y1=Y(J)
  ISN 0020               Y2=Y(J-1)
  ISN 0021               Y3=Y(J-2)
  ISN 0022               GO TO(32,42),NB
  ISN 0023         30    IF(X(J)-B)29,37,37
  ISN 0024         37    IF(J-2)31,31,28
  ISN 0025         28    NA=2
  ISN 0026         29    J=J+1
  ISN 0027               GO TO 21
  ISN 0028         31    DO 60 J=1,3
  ISN 0029               XC(J)=X(J)
  ISN 0030         60    YC(J)=Y(J)
  ISN 0031         32    D=X2-X1
  ISN 0032               A1=B-X1
  ISN 0033               A2=B-X2
  ISN 0034               YE=A1*A2/2.0/D*((Y3-Y2)/(X3-X2)-(Y2-Y1)/D)-A2/D*Y1+A1/D*Y2          61205037
  ISN 0035               GO TO 50
  ISN 0036         40    NB=2
  ISN 0037               GO TO 27
  ISN 0038         42    X4=X(J-3)
  ISN 0039               Y4=Y(J-3)
  ISN 0040               D=X3-X2
  ISN 0041               A1=B-X2
  ISN 0042               A2=B-X3
  ISN 0043               XM12=(Y2-Y1)/(X2-X1)
  ISN 0044               XM23=(Y3-Y2)/D
  ISN 0045               XM34=(Y4-Y3)/(X4-X3)
  ISN 0046               YE=A1*A2**2/2.0/D**2*(XM12-XM23)+A2*A1**2/2.0/D**2*(XM34-XM23)-A2*612 5 49
                        1Y2/D+A1*Y3/D
  ISN 0047         50    YC=YE
  ISN 0048               RETURN
  ISN 0049               END
```

INPUT

BB2	Z	SM	WNET	BBM1	BBT1	ETIP	AFLIM
.3000+02	.8000+01	.1280+02	.7000+02	.1210+02	.8500+01	.3500+00	.0000
D2	B2	CLHL	SCL	BLK2	RHO	SOL	DT1
.1075+02	.5120+00	.7500+01	.0000	.1770+00	.4360+01	.2190+01	.6900+01
DR	DH1	XN	FLAG	VIS	IFLAG	FSHR	SFFS
.0000	.2750+01	.2459+05	.1000+01	.9000-05	0	.65000+00	.3200-04
D	CO	XNTH	PI	T	XKDF	FSLIP	WLABA
.7100+01	.5000-02	.3000+01	.1880+00	.1950-01	.2300-07	.6500+00	.2500+01

IMPELLER IS SHROUDED

IMPELLER LOSSES

***** OUTPUT *****

SCL	= .000	PSINC	= .0203	U2	= 1154.475
DCLE	= .000	PSF	= .0105	CU2TH	= 676.059
DCLK	= 9.667	PSD	= .0000	CM2	= 168.842
DCLR	= .000	PSTIP	= .0003	PHI2	= .1462
W2TH	= 597.335	PSCL	= .0000	FRIMP	= .0102
RW	= .001	PSTBL	= .0312	DIFP	= .074
HTH	= 24258.514			U1M	= 564.056
WIMP	= 72.720			CU1M	= .000
				CM1	= 76.394

REYNOLDS NO., IMPELLER, RE2 .7789+07 ***
DISK FRICTION COEFF., XKDF .2300-07 ***
POWER, BACKVANES, PFBV .000 HP
POWER, BACK FACE, PFBS 71.592 HP
POWER, FRONT FACE, PFFS 68.570 HP
POWER, TOTAL, PFTOT 140.162 HP
LOSS COEFF., DLPDF .0256 ***

SLIP COEFFICIENT, SLPCF .7843 ***
THEORETICAL HEAD COEFFICIENT, PSITH .5856 ***
IMPELLER HEAD COEFFICIENT, PSIIP .5544 ***
INPUT HEAD COEFFICIENT, PSIIN .6112 ***
IMPELLER STATIC HEAD COEFFICIENT, PSIPS .3723 ***
IMPELLER STATIC PRESSURE RISE, DPIPS 466.9162 LB/SQIN
OPTIMIZATION PARAMETER, ETAIO .8744 ***

*** LABYRINTH DATA ***

LABYRINTH DIAMETER, D 7.1000 IN
[illegible] .0080 IN

19

NUMBER OF TEETH, XNTH	3.0000	***
TOOTH SPACING, PI	.1880	IN
TOOTH WIDTH, T	.0195	IN
PRESSURE DROP, P	448.4932	LB/SQIN
LABYRINTH FLOW RATE, WWR	2.7196	LB/SEC

J. J. Brunner
4-12-72

COMPUTER PROGRAM

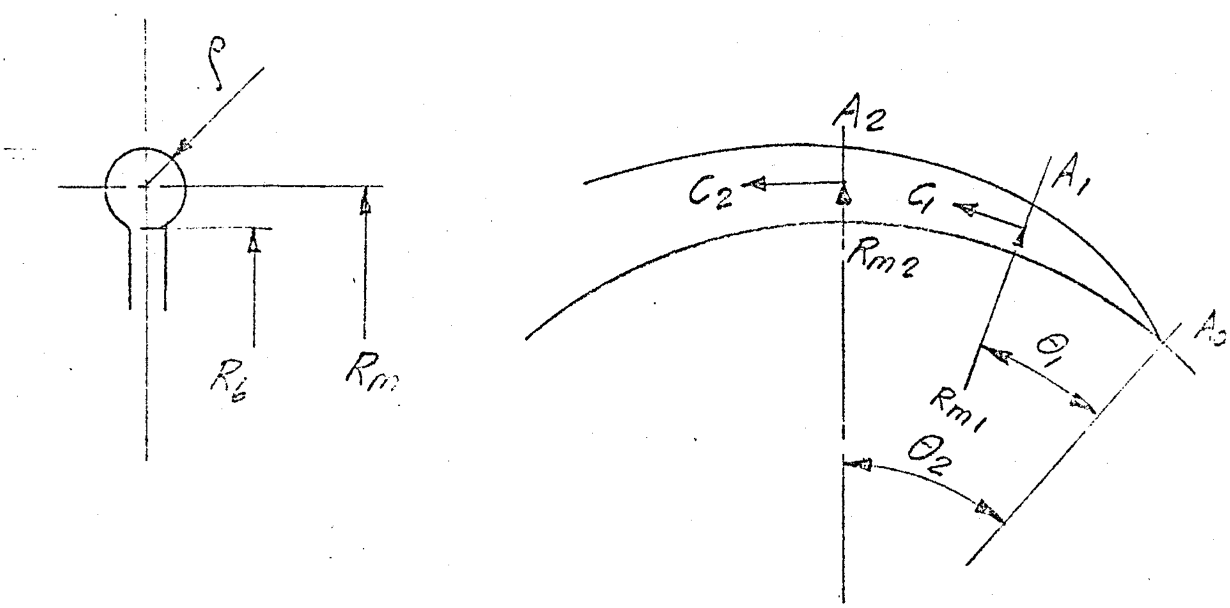
CIRCULAR CROSS SECTION VOLUTE DESIGN

I. INTRODUCTION

This program presents an incremental method for the design of a classical pump volute with circular cross-sections which are tangent to the volute base circle. Volute area distributions as well as velocity and pressure distributions are calculated and printed out.

This program was primarily devised to determine the percentage increase in cross-sectional area required for the compensation of friction losses in the NERVA turbopump volute which is discussed in Reference 1.

II. BASIC EQUATIONS



Reference 1 - Aerojet Nuclear Systems Company Engineering Operations Report N8300R:71-076, NERVA Turbopump Design Report, Volume 1, 24 September 1971

The flow rate V in the volute is assumed to be proportional to the wrap angle θ (no back flow, zero cut water clearance flow).

The volute cross sectional area A_2 at the wrap angle θ_2 can then be calculated from the total flow at the volute throat V_{th}:

$$A_2 = \frac{\theta_2}{2\Pi} \quad \frac{V_{th}}{C_2} = \Pi\rho_2^2 \qquad (1)$$

Assuming constant moment of momentum:

$$R_{m1} \; C_1 = R_{m2} \; C_2 = K$$

where:

$$R_{m2} = R_6 + \rho_2$$

Thus:

$$C_2 = \frac{K}{R_{m2}} = \frac{K}{R_6 + \rho_2} \qquad (2)$$

Substituting C_2 in (1)

$$A_2 = \frac{\theta_2 V_{th}}{2\Pi} \quad \frac{R_6 + \rho_2}{K} = \Pi\rho^2$$

Solving for ρ the quadratic equation can be written as follows:

$$\rho^2 - \frac{\theta_2 \; V_{th}}{2\Pi^2 K} \; \rho - \frac{\theta_2 \; V_{th}}{2\Pi^2 K} \; R_6 = 0$$

Let

$$\frac{\theta_2 \; V_{th}}{2\Pi^2 K} = Y$$

then:

$$\rho^2 - Y\rho - YR_6 = 0$$

and

$$\rho = \frac{Y \pm \sqrt{Y^2 + 4 \; Y \; R_6}}{2}$$

Friction losses are calculated for the mean cross section of a volute increment:

$$A_m = \frac{A_1 + A_2}{2}$$

$$\rho_m = \left(\frac{A_m}{\Pi}\right)^{0.5}$$

Length of volute increment:

$$L_m = \Delta\theta \; R_m$$

The friction coefficient is based on the relative surface finish and the empirical relationship established by Nicuradse (Reference 2).

$$\lambda = \frac{1}{(.8685 \, \ell n \, (\frac{\rho m}{f_s}) + 1.74)^2}$$

Friction loss for volute increment

$$\Delta H_{fric} = \lambda \; \frac{L_m}{2\rho_m} \; \frac{C_m^2}{2\,g}$$

The friction loss is recuperated by an increase in diffusion

$$\Delta H_{fric} = \Delta H_{vel}$$

which is achieved by a decrease in velocity or respectively, an increase in area.

Reference 2 - Eckert/Schnell, Axial and Radial Kompressoren, Springer-Verlag 1961

$$\Delta H_{vel} = \frac{C_2^{\;2}}{2\,g} - \frac{C_{2c}^{\;2}}{2\,g}$$

where C_{2c} is the lowered velocity corresponding to the increased or corrected area A_{2c}. From continuity:

$$C_2\,A_2 = C_{2c}\,A_{2c}$$

$$\Delta H_{fric} = \frac{C_2^{\;2}}{2\,g}\left(1 - \left(\frac{C_{2c}}{C_2}\right)^2\right) = \frac{C_2^{\;2}}{2\,g}\left(1 - \left(\frac{A_2}{A_{2c}}\right)^2\right)$$

From this expression the corrected area A_{2c} is:

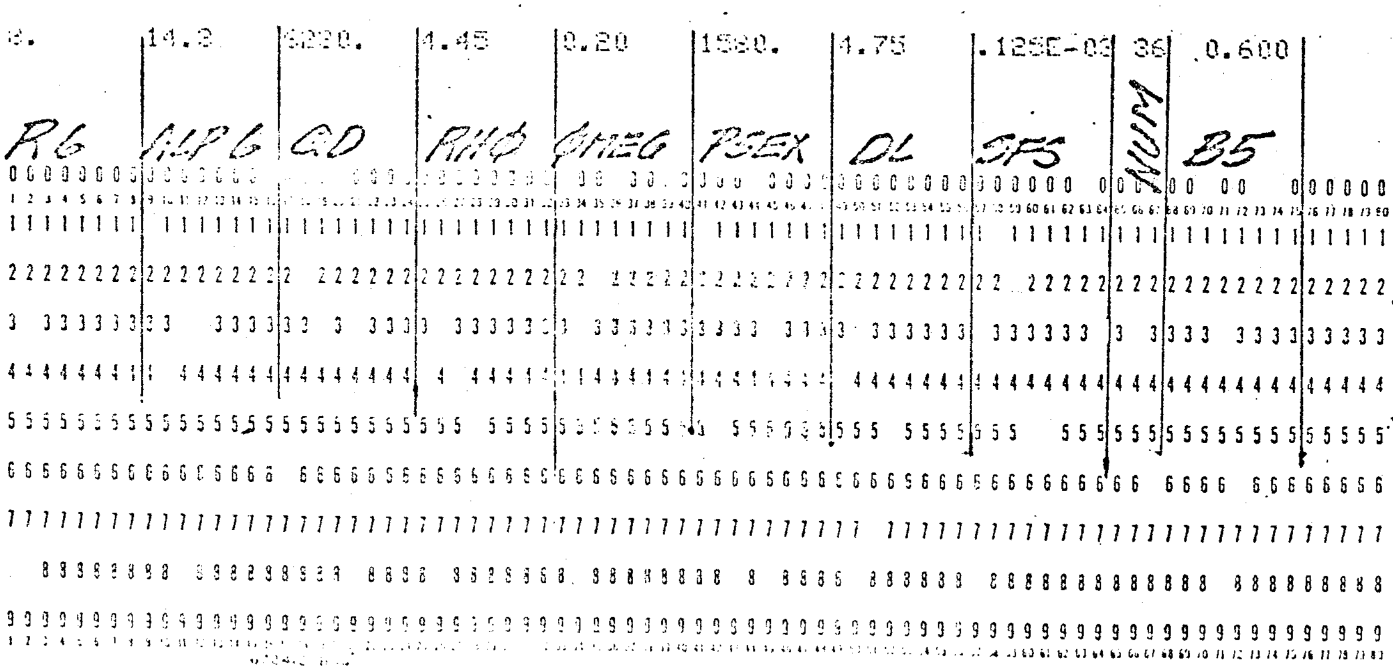
$$A_{2c} = \frac{A_2}{\left(1 - \frac{2\,g\,\Delta H_{fric}}{C_2^{\;2}}\right)^{0.5}}$$

NOMECLATURE

INPUT

SYMBOL	DESCRIPTION	UNITS	FORMAT
R6	Radius, Base Circle	In	F
ALP6	Fluid Angle at Base Circle	Deg	F
QD	Flow Rate	gpm	F
RHO	Fluid Density	lb/cu ft	F
OMEG	Exit Diffuser Loss Coefficient	(0.20)	F
PSEX	Exit Pressure, Static	psi	F
DL	Exit Diffuser Discharge Diameter	In	F
SFS	Surface Finish	In	E
NUM	Number of Increments	-	I
B5	Port Width at Base Circle	In	F

INPUT FORMAT



```
// JOB T

LOG DRIVE   CART SPEC   CART AVAIL  PHY DRIVE
  0000        0001        0001        0000

V2 M05   ACTUAL 16K  CONFIG 16K

// FOR
*IOCS(CARD,TYPEWRITER,KEYBOARD,1403 PRINTER,DISK)
*LIST ALL
      DIMENSION THET(90),RADN(90),ANC(90),VD(90),CN(90),A(90),RAD(90),
     1C(60),HVEL(90),FRIC(90),HFR(90),PS(90),HFRT(90)
      LR = 2
      LW = 5
    1 FORMAT('1')
    2 FORMAT(42X,'VOLUTE VELOCITIES + PRESSURE DISTRIBUTION'//)
    3 FORMAT(7F8.3,E8.3,I3,F8.3)
    4 FORMAT(53X,'*** INPUT ***'//)
    5 FORMAT(15X,'R6',12X,'ALP6',12X,'QD',14X,'RHO',13X,'OMEG',12X,'PSEX
     1'/)
    6 FORMAT(15X,'DLINE',10X,'SFS',13X,'NUM',13X,'BS'/)
    7 FORMAT(5X,6F15.3//)
    8 FORMAT(5X,F15.3,E15.3,I15,F15.3//)
    9 READ(LR,3) R6,ALP6,QD,RHO,OMEG,PSEX,DL,SFS,NUM,BS
      IF(R6) 500,500,11
   11 WRITE(LW,1)
      WRITE(LW,2)
      WRITE(LW,4)
      WRITE(LW,5)
      WRITE(LW,7) R6,ALP6,QD,RHO,OMEG,PSEX
      WRITE(LW,6)
      WRITE(LW,8) DL,SFS,NUM,BS
      DTHT = 360./NUM
      VDT = 0.321 * QD
      ALPR6 = ALP6/57.296
      CVOL = 360. * COS(ALPR6)/(BS * SIN(ALPR6))
      THET(1) = DTHT
      DO 10 I=2,NUM
   10 THET(I) = THET(I-1) + DTHT
      DO 20 I=1,NUM
      RADN(I) = THET(I)/CVOL + SQRT(2.*R6 * THET(I)/CVOL)
      ANC(I)  = 3.14159 * RADN(I)**2
      VD(I)   = THET(I)/360. * VDT
   20 CN(I)   = VD(I)/ANC(I)
      A(1)   = ANC(1)
      RAD(1)   = RADN(1)
      C(1)   = CN(1)
      HVEL(1)   = C(1)**2/64.348
      FRIC(1) = 0
      HFR(1) = 0 .
      I = 2
   50 N = 0
      RXC  =(RAD(I-1) + R6) * C(I-1)
      CONST = VD(I)/(3.14159 * RXC)
      RAD(I) = (CONST + SQRT(CONST**2 + 4. * CONST * R6))/2.
      A(I) = 3.14159 * RAD(I)**2
      STAY = A(I)
   17 C(I)   = VD(I)/A(I)
      RAD(I) = SQRT(A(I)/3.14159)
      AM    = 0.5*(A(I) + A(I-1))
      RADM   = SQRT(AM/3.14159)
```

```
      RM = R6 + RADM
      XLM  = RM*DTHT/57.296
      CM   =(C(I) + C(I-1))/2.
      HFR(I)  = FRIC(I) *XLM * CM**2/(128.696*RADM)
      HVEL(I) = C(I)**2/64.348
      IF(N) 30,30,32
   30 SAFE = HVEL(I)
      STAY = A(I)
   35 A(I) = STAY/SQRT(1.-HFR(I)/HVEL(I))
      N   =  N + 1
      GO TO 17
   32 HFR(I)  = (SAFE - HVEL(I) + HFR(I))/2.
      IF(N-1) 35,35,36
   36 IF(I-NUM)    40,42,42
   40 I = I+1
      GO TO 50
   42 CONTINUE
      HFRT(1) = 0
      DO 60 I=2,NUM
   60 HFRT(I) = HFRT(I-1) + HFR(I)
      DPDIF = OMEG * HVEL(NUM)*RHO/144.
      HFT = HFRT(NUM) + OMEG*HVEL(NUM)
      AEX = .785*DL**2
      VEX = VDT/AEX
      HVEX = VEX**2/64.348
      PTEX =PSEX + HVEX*RHO/144.
      PTIN = PTEX + HFT*RHO/144.
      DO 70 I=1,NUM
   70 PS(I) = PTIN -(HVEL(I) +HFRT(I))*RHO/144.
  101 FORMAT(////53X,'*** OUTPUT ***'//)
  102 FORMAT(9X,'THETA',10X,'RNC',11X,'RCOR',10X,'VEL',12X,'FRIC',10X,
     1'HFRT',12X,'PS'//)
  103 FORMAT(7F15.4)
      WRITE(LW,101)
      WRITE(LW,102)
      WRITE(LW,103) (THET(I),RADN(I),RAD(I),C(I),FRIC(I),HFRT(I),PS(I),I
     1=1,NUM)
  120 FORMAT(////20X,'FRICTION LOSS VOLUTE                  =',F8.3,2X,'FT
     1'/)
  121 FORMAT(20X,'FRICTION LOSS INCL EXIT DIFFUSER    =',F8.3,2X,'FT'/)
  122 FORMAT(20X,'EXIT VELOCITY                       =',F8.3,2X,'FT/S'/
     1)
  123 FORMAT(20X,'TOTAL DISCHARGE PRESSURE            =',F8.3,2X,'PSI'/)
  124 FORMAT(20X,'PRESSURE LOSS, EXIT DIFFUSER        =',F8.3,2X,'PSI'/)
      WRITE(LW,120) HFRT(NUM)
      WRITE(LW,121) HFT
      WRITE(LW,122) VEX
      WRITE(LW,123) PTEX
      WRITE(LW,124) DPDIF
      GO TO 9
  500 STOP
      END
VARIABLE ALLOCATIONS
  THET(R )=0082-0000  RADN(R )=0166-00B4   ANC(R )=021A-0168    VD(R )=02CE-021C    CN(R )=0382-02D0     A(R )=0436-0384
   RAD(R )=04EA-0438     C(R )=0562-04EC  HVEL(R )=0616-0564  FRIC(R )=06CA-0618   HFR(R )=077E-06CC    PS(R )=0832-0780
  HFRT(R )=08E6-0834    R6(R )=08E8       ALP6(R )=08EA         QD(R )=08EC         RHO(R )=08EE       OMEG(R )=08F0
  PSEX(R )=08F2         DL(R )=08F4        SFS(R )=08F6         B5(R )=08F8        DTHT(R )=08FA        VDT(R )=08FC
 ALPR6(R )=08FE       CVOL(R )=0900        RXC(R )=0902       CONST(R )=0904       STAY(R )=0906         AM(R )=0908
```

VOLUTE VELOCITIES + PRESSURE DISTRIBUTION

*** INPUT ***

R6	ALP6	QD	RHO	OMEG	PSEX
8.000	14.300	6230.000	4.450	0.200	1580.000

DLINE	SFS	NUM	B5
4.750	0.125E-03	36	0.600

*** OUTPUT ***

THETA	RNC	RCOR	VEL	FRIC	HFRT	PS
10.0000	0.2649	0.2649	251.8666	0.0000	0.0000	1565.8193
20.0000	0.3772	0.3802	244.5606	0.0135	29.4864	1566.6499
30.0000	0.4643	0.4708	239.2457	0.0128	49.9385	1567.2529
40.0000	0.5384	0.5486	234.9321	0.0124	65.9318	1567.7409
50.0000	0.6042	0.6183	231.2430	0.0121	79.1969	1568.1569
60.0000	0.6641	0.6821	227.9889	0.0118	90.5940	1568.5222
70.0000	0.7195	0.7416	225.0593	0.0116	100.6198	1568.8498
80.0000	0.7713	0.7975	222.3829	0.0115	109.5898	1569.1477
90.0000	0.8203	0.8506	219.9113	0.0113	117.7176	1569.4216
100.0000	0.8669	0.9014	217.6092	0.0112	125.1567	1569.6755
110.0000	0.9114	0.9501	215.4505	0.0111	132.0197	1569.9123
120.0000	0.9541	0.9971	213.4148	0.0110	138.3931	1570.1345
130.0000	0.9952	1.0425	211.4864	0.0109	144.3446	1570.3442
140.0000	1.0349	1.0866	209.6523	0.0108	149.9283	1570.5427
150.0000	1.0734	1.1295	207.9019	0.0107	155.1881	1570.7312
160.0000	1.1108	1.1712	206.2267	0.0106	160.1603	1570.9106
170.0000	1.1471	1.2120	204.6192	0.0106	164.8751	1571.0820
180.0000	1.1825	1.2519	203.0733	0.0105	169.3580	1571.2460
190.0000	1.2171	1.2909	201.5836	0.0105	173.6309	1571.4035
200.0000	1.2509	1.3292	200.1453	0.0104	177.7126	1571.5549
210.0000	1.2839	1.3668	198.7545	0.0104	181.6193	1571.7006
220.0000	1.3163	1.4037	197.4076	0.0103	185.3655	1571.8413
230.0000	1.3480	1.4401	196.1014	0.0103	188.9636	1571.9768
240.0000	1.3791	1.4758	194.8333	0.0102	192.4246	1572.1079
250.0000	1.4097	1.5110	193.6006	0.0102	195.7583	1572.2348
260.0000	1.4398	1.5457	192.4013	0.0101	198.9736	1572.3579
270.0000	1.4694	1.5800	191.2331	0.0101	202.0782	1572.4770
280.0000	1.4985	1.6138	190.0943	0.0100	205.0796	1572.5930
[illegible]	1.5271	1.6472	188.9834	0.0100	207.9838	1572.7055
[illegible]	1.5554	1.6802	187.8986	0.0100	210.7969	1572.8149
[illegible]	1.5832	1.7128	186.8387	0.0099	213.5241	1572.9213
[illegible]	1.6107	1.7450	185.8023	0.0099	216.1704	1573.0251
[illegible]	[illegible]	1.7770	184.7883	0.0099	218.7399	1573.1259

FRICTION LOSS VOLUTE	=	226.026	FT
FRICTION LOSS INCL EXIT DIFFUSER	=	328.834	FT
EXIT VELOCITY	=	112.911	FT/S
TOTAL DISCHARGE PRESSURE	=	1586.122	PSI
PRESSURE LOSS, EXIT DIFFUSER	=	3.176	PSI

5. IMPELLER DISCHARGE TRAVERSE DATA EVALUATION

J. J. Brunner
4-10-72

COMPUTER PROGRAM
IMPELLER DISCHARGE TRAVERSE DATA EVALUATION

I. INTRODUCTION

This program serves for the reduction of total pressure and flow direction data obtained from surveys conducted with traversing probes at the discharge of a pump impeller. It calculates local, integrated and mass weighted impeller head coefficients as well as efficiency and slip.

The program was first used as a supplement to the Pump Air Test Data Reduction Program (Reference 1) for the reduction of traverse data obtained from pump air tests conducted in support of the NERVA Turbopump Program. The pump air tests and the use of this computer program are discussed in Reference 1 and 2.

II. PROGRAM DESCRIPTION

The Impeller Discharge Traverse Data Evaluation Program consists of a short main program and a subroutine TRAVD. All major calculations are performed in subroutine TRAVD which in essence was written for incorporation into the Pump Air Test Data Reduction Program, Reference 1.

Reference 1 - J. J. Brunner, Pump Air Test Data Reduction Program, Aerojet Nuclear Systems Company, Engineering Operations Report

Reference 2 - J. J. Brunner, Performance of a Two-Stage Centrifugal NERVA Pump Tested with Air as the Working Fluid, Aerojet Nuclear Systems Company, Engineering Operations Report N8300R:71-090

III. ASSUMPTIONS AND BASIC EQUATIONS

The Traverse Data Evaluation Program calculated impeller total head coefficients directly from the measured total pressures. Exit or mixing losses at the impeller discharge and flow losses in the short radial annular diffuser section extending from the impeller discharge to the location of the probe are neglected. Previous loss calculations indicate that such losses are very small. The static pressure is assumed to be constant across the width of the port and equal to the average value of the measured wall static pressures.

The absolute velocity at each traverse position is obtained from:

$$C_{(b)} = \sqrt{2\,g\,(H_{t_{(b)}} - H_s)}$$

and the meridional velocity based on measured flow angle $\alpha_{(b)}$ is

$$C_{m(b)} = C_{(b)} \sin \alpha_{(b)}$$

Integrated and mass weighted values are determined as follows:

Integrated meridional velocity:

$$\overline{C}_m = \frac{\int_0^B C_{m(b)}\,db}{B}$$

wherein B = housing port width.

Tangential velocity component at each traverse position:

$$C_{u(b)} = C_{(b)} \cos \alpha_{(b)}$$

Mass weighted tangential velocity component:

$$\overline{C}_u = \frac{{}_0\int^B (C_{u(b)} \; C_{m(b)}) \, db}{\overline{C}_m}$$

Integrated flow angle:

$$\overline{\alpha} = \tan^{-1}\left[\frac{\overline{C}_m \; B}{{}_0\int^B C_{u(b)} \, db}\right]$$

Mass weighted total head:

$$\overline{H}_t = \frac{{}_0\int^B (H_{t(b)} \; C_{m(b)}) \, db}{\overline{C}_m}$$

A continuity check is performed by comparing the integrated flow

$$\overline{V} = \overline{C}_m \; A \qquad (A = 2\pi \, R_M \, B)$$

with the measured flow (corrected for recirculation when applicable).

The absolute velocity components are adjusted in subsequent computations to satisfy continuity. In these calculations the meridional velocities $C_{m(b)}$ are multiplied by the ratio of measured flow to calculated flow $V/\overline{V}$, assuming that the distribution of these velocities is correct and that the discrepancy in flow is due to the measured fluid angle. From adjusted velocity triangles determined by $C_{(b)}$ and $C_{m(b)}$, new values of fluid angle $\alpha_{(b)}$ and tangential velocity $C_{u(b)}$ are calculated. The mass weighted total head is not affected by this adjustment because the ratio of the local value of $C_{m(b)}$ to the integrated value $\overline{C}_m$ remains the same.

Impeller efficiency and slip coefficient deduced from measurements are based on the mass weighted, adjusted tangential velocity component $\overline{C}_u$.

Ideal Head Coefficient ψ_i

$$\psi_i = \frac{\frac{R_2}{R_m} \overline{C}_u}{u_2}$$

Impeller efficiency η

$$\eta = \frac{\overline{H}_t}{\psi_i \frac{U_2^2}{g}}$$

Slip coefficient μ

$$\mu = \frac{\frac{R_2}{R_M} \bar{C}_u}{u_2 - \frac{C_m^2}{\tan \beta}}$$

where:

C_{m2} = meridional velocity from one-dimensional analysis.

Nomenclature, input format, listing and sample printout are presented on the following pages.

NOMENCLATURE

SYMBOL	DESCRIPTION	UNITS	FORMAT
	MAIN PROGRAM CONSTANTS		
AI21	1st Impeller Discharge Area, Blocked	Sq In	
AI22	2nd Impeller Discharge Area, Blocked	Sq In	
DI21	1st Impeller Discharge Diameter	In	
DI22	2nd Impeller Discharge Diameter	In	
BET21	1st Impeller Discharge Blade Angle	Deg	
BET22	2nd Impeller Discharge Blade Angle	Deg	
Z21	1st Impeller Blade Number		
Z22	2nd Impeller Blade Number		
FSLIP	Empirical Factor, Pfleiderer Slip = .65		
SM1	1st Impeller Blade Static Moment	Sq In	
SM2	2nd Impeller Blade Static Moment	Sq In	
INPUT			
TRAVERSE EXCURSION CONSTANTS			
NTRA	Number of Surveys		I2
POPS(J)	Ambient Pressure	psia	F
SN(J)	Rotational Speed	rpm	F
RVBL(J)	Percent Balancer Flow Simulated	%	F
VW(J)	Net Weight Flow	lb/s	F
RHOI1(J)	Fluid Density, 1st Stage	lb/ft^3	F
RHOI2(J)	Fluid Density, 2nd Stage	lb/ft^3	F
RECI1(J)	Percent Recirculation, 1st Impeller	%	F
RECI2(J)	Percent Recirculation, 2nd Impeller	%	F
PHI1(J)	Discharge Flow Coefficient, 1st Impeller		F
PHI2(J)	Discharge Flow Ceofficient, 2nd Impeller		F
TOABS(J)	Ambient Temperature	Deg F	F
TI(J)	Temperature Interstage	Deg F	F
PTI(J)	Total Pressure Interstage	Deg F	F
QDN(J)	Flow Speed Ratio	gpm/rpm	F

NOMENCLATURE (Cont'd)

SYMBOL	DESCRIPTION	UNITS	FORMAT
J	Survey Number		I3
R4	Radius of Traverse Location	In	F
CAPB4	Port Width Wall to Wall	In	F
NST	Stage Number		I3
NTP	Number of Traverse Points		I3

TRAVERSE VARIABLES

B4(I)	Distance	In	F
PT4(I)	Total Pressure	In H_2O	F
PS4(I)	Static Pressure	In H_2O	F
ALP4(I)	Flow Angle	Deg	

IBM FORTRAN Coding Form

GX28-7327-6 U/M050
Printed in U.S.A.

PROGRAM: TRAVERSE DATA EVALUATION

PROGRAMMER: | DATE: | PUNCHING INSTRUCTIONS: GRAPHIC / PUNCH | PAGE OF | CARD ELECTRO NUMBER

FORTRAN STATEMENT

CARD NO.								
1	NTRA							
2	POPS(J)	SN(J)	RVBL(J)	VW(J)	RHOI1(J)	RHOI2(J)	RECI1(J)	RECI2(J)
3	PHI1(J)	PHI2(J)	TOABS(J)	TI(J)	PTI(J)	QDN(J)	STACK AS MANY NO. 2 & 3 CARDS AS NTRA INDICATES	
4	J	R4	CAPB4	NST	NTP			
5	B4(I)	PT4(I)	PS4(I)	ALP4(I)	← STACK AS MANY AS NTP INDICATES			

8

@ ELT LIST,1,720406, 35640

```
      COMMON POPS(12),SN(12),RVBL(12),VW(12),RHOI1(12),RHOI2(12),
     1RECI1(12),RECI2(12),AI21,AI22,DI21,DI22,BET21,BET22,TOABS(12),
     2TI(12),PTI(12),PHI1(12),PHI2(12),Z21,Z22,FSLIP,SM1,SM2,J,QDN(12),
     3PHI4(12),PHI4A(12)
    1 FORMAT(I2)
      READ(5,1) NTRA
      AI21  = 14.8
      AI22  = 15.7
      DI21= 10.95
      DI22  = 10.75
      BET21  = 30.
      BET22  = 25.
      Z21 = 8.
      Z22 = 8.
      FSLIP = .65
      SM1 = 12.8
      SM2 = 12.47
    3 FORMAT(8F10.4/6F10.4)
      READ(5,3)(POPS(J),SN(J),RVBL(J),VW(J),RHOI1(J),RHOI2(J),RECI1(J),
     1RECI2(J),PHI1(J),PHI2(J),TOABS(J),TI(J),PTI(J),QDN(J),J=1,NTRA)
      DO 20 J=1,NTRA
   20 TOABS(J) = TOABS(J) + 459.67
      DO 30 J=1,NTRA
   30 CALL TRAVD
      STOP
      END
      SUBROUTINE TRAVD
      DIMENSION B4(20),PT4(20),HT4(20),PS4(20),HS4(20),HTN4(20),HSN4(20)
     1,HTC4(20),HSC4(20),HV4(20),C4(20),CM4(20),CU4(20),DB(20),ALP4(20),
     2CM4B(20),CU4B(20),HT4CR(20),CM4A(20),ALP4A(20),CU4A(20)
      COMMON POPS(12),SN(12),RVBL(12),VW(12),RHOI1(12),RHOI2(12),
     1RECI1(12),RECI2(12),AI21,AI22,DI21,DI22,BET21,BET22,TOABS(12),
     2TI(12),PTI(12),PHI1(12),PHI2(12),Z21,Z22,FSLIP,SM1,SM2,J,QDN(12),
     3PHI4(12),PHI4A(12)
      LR = 5
      LW = 6
   10 FORMAT('1')
    1 FORMAT(////45X,'TRAVERSE DATA EVALUATION'//)
    3 FORMAT( 2X,'IMPELLER DISCHARGE, STAGE',I2,10X,'Q/N =',F7.4,8X,
     1'SPEED =',F8.1,2X,'RPM',8X,'BALANCER FLOW =',F7.3,2X,'PERCENT'//)
    5 FORMAT( 2X,'PARAMETERS BASED ON MEASURED VALUES'//)
    7 FORMAT( 5X,'DISTANCE',4X,'TOTAL HEAD',3X,'STATIC HEAD',2X,'NORM TO
     1T',4X,'NORM STAT',4X,'TOT HEAD',3X,'STAT HEAD')
    9 FORMAT( 5X,'B4/CAPB4',5X,'HT4, FT',7X,'HS4, FT',5X,'HEAD',8X,'HEAD
     1',9X,'COEFF',7X,'COEFF'/)
   11 FORMAT(F12.4,F13.2,F14.2,2E13.4,F10.4,F12.4)
   13 FORMAT(///5X,'DISTANCE',4X,'ABS VELOCITY',2X,'FLOW ANGLE',2X,'VELO
     1CITY',5X,'VELOCITY',5X,'FLOW COEFF')
   15 FORMAT( 5X,'B4/CAPB4',5X,'C4,FT/S',7X,'DEG',6X,'CM4, FT/S',4X,'CU4
     1, FT/S',6X,'CM4/U2'/)
   17 FORMAT(F12.4,F14.2,F12.2,F11.2,F13.2,F14.4)
   19 FORMAT(// 2X,'INTEGRATED VALUES WITH MASS WEIGHTED TOTAL HEAD'//)
   21 FORMAT(5X,'TOT HEAD',3X,'NORM TOT HD',2X,'TOT HEAD',6X,'CM4',11X,
     1          'ALPHA 4',8X,'FLOW RATE CUFT/S', 7X,'FLOW ERROR')
   23 FORMAT( 8X,'FT',6X,'FT/RPM**2',6X,'COEFF',6X,'FT/S',10X,
     1'DEG',8X,'INTGR',4X,'FROM CONTINUITY',4X,'PERCENT'/)
```

```
   25 FORMAT(F12.2,F14.4,F10.4,F12.2,      F12.3,F12.3,F13.3,F14.3)
   27 FORMAT(//2X,'ADJUSTED VALUES TO SATISFY CONTINUITY'//)
   29 FORMAT( 5X,'DISTANCE',5X,'CM 4',4X,'ALPHA 4',4X,'CU 4',5X,'FLOW CO
     1EFF')
   31 FORMAT( 5X,'B4/CAPB4',5X,'FT/S',6X,'DEG',6X,'FT/S',5X,'CM4/U2'/)
   33 FORMAT(F12.4,F10.2,F10.2,F10.2,F12.4)
   35 FORMAT(// 2X,'IMPELLER PERFORMANCE'//)
   37 FORMAT( 5X,'ABSOLUT FLUID ANGLE    =',F6.3/)
   39 FORMAT(5X,'SLIP                  =',F6.4/)
   41 FORMAT(// 2X,'ADJUSTED VALUES, INTEGRATED',31X,'MASS WEIGHTED TANG
     1ENTIAL VELOCITY COMPONENT CU'//)
   43 FORMAT(18X,'CM 4',4X,'ALPHA 4',4X,'CU 4',29X,'CU 4',12X,'CU 2')
   45 FORMAT(18X,'FT/S',6X 'DEG',6X,'FT/S',29X,'FT/S',12X,'FT/S'/)
   47 FORMAT(F22.2,2F10.2,F33.2,F16.2)
   71 FORMAT(I3,F7.3,F10.3,2I3)
   73 FORMAT(F6.3,3F8.2)
   75 FORMAT( 50X,'THEORETICAL HEAD COEFFICIENTS'/)
   77 FORMAT( 2X,'FLOW COEFF',8X,'EULER',15X,'ACOSTA',14X,'STODOLA',13X,
     1'PFLEIDERER',10X,'MEASURED'/)
   79 FORMAT(F10.4,F15.4,4F20.4//)
   81 FORMAT(/2X,'PARAMETERS BASED'/2X,'ON ABOVE COEFFICIENTS'///)
   83 FORMAT( 2X,'SLIP',F39.4,3F20.4//)
   85 FORMAT(2X,'IMPELLER EFFICIENCY',F24.4,3F20.4/)
   87 FORMAT(//6X,'U2',11X,'CM2')
   89 FORMAT( 5X,'FT/S',9X,'FT/S'/)
   91 FORMAT(F10.2,F13.2)
      READ(LR,71) J,R4,CAPB4,NST,NTP
      READ(LR,73) (B4(I),PT4(I),PS4(I),ALP4(I),I=1,NTP)
      IF(NST-1) 90,90,92
   90 DI2 = DI21
      AI2 = AI21
      BET2 = BET21
      Z = Z21
      SM = SM1
      PHID = PHI1(J)
      VI2 =  VW(J) * (1.+RECI1(J)/100.)/RHOI1(J)
      V4 = VW(J) * (1.+RVBL(J)/100.)/RHOI1(J)
      GO TO 94
   92 DI2 = DI22
      AI2 = AI22
      BET2 = BET22
      Z = Z22
      SM = SM2
      PHID = PHI2(J)
      VI2  =  VW(J) * (1.+RECI2(J)/100.)/RHOI2(J)
      V4 = VW(J)/RHOI2(J)
   94 U2 = SN(J) * DI2/229.
      USQG = U2**2/32.174
      BET2R = BET2/57.296
      TGB2 = SIN(BET2R)/COS(BET2R)
      PSIEU = 1. - PHID/TGB2
      SLPS = 1. - 1./PSIEU * 3.1417 * SIN(BET2R)/Z
      G = (90. - BET2)/57.296
      C = COS(G)
      A=6.5797*C**2/Z**2-19.233*C**4/Z**3+8.6584*C**4/Z**4*(8.*C**2-1.)
      PSIO=EXP(-2.*G*SIN(2.*G)/Z)*EXP(A)/((2.*C)**(4.*C**2/Z))
      PSTHS = SLPS * PSIEU
      PSTHA = PSIO - PHID/TGB2
      SLPA = PSTHA/PSIEU
      PSISL = FSLIP * (1.+BET2/60.)
```

```
      PSL = PSISL*(DI2/2.)**2/Z/SM
      SLPP = 1./(1.+PSL)
      PSTHP = SLPP * PSIEU
C-PARAMETERS BASED ON MEASURED VALUES
      DO 110 I=1,NTP
      B4(I) = B4(I)/CAPB4
      PT4(I) = PT4(I)/27.67 + POPS(J)
      PS4(I) = PS4(I)/27.67 + POPS(J)
      IF(NST-1) 96,96,97
   96 HT4(I)=186.768*TOABS(J)*((PT4(I)/POPS(J))**0.283 - 1.)
      HS4(I)=186.768*TOABS(J)*((PS4(I)/POPS(J))**.283 - 1.)
      GO TO 98
   97 HT4(I) = 186.768*(TI(J)+459.67)*((PT4(I)/PTI(J))**0.283-1.)
      HS4(I) = 186.768*(TI(J)+459.67)*((PS4(I)/PTI(J))**0.283-1.)
   98 HTN4(I) = HT4(I)/SN(J)**2
      HSN4(I) = HS4(I)/SN(J)**2
      HTC4(I) = HT4(I)/USQG
      HSC4(I) = HS4(I)/USQG
      HV4(I) = HT4(I) - HS4(I)
      C4(I)  = 8.0217 * SQRT(HV4(I))
      CM4(I) = C4(I) * SIN(ABS(ALP4(I)/57.296))
      IF(ALP4(I))95,100,100
   95 CM4(I) = -CM4(I)
  100 PHI4(I) = CM4(I)/U2
  110 CU4(I) = C4(I) * COS(ABS(ALP4(I)/57.296))
      WRITE(LW,10)
      WRITE(LW,1)
      WRITE(LW,3) NST,QDN(J),SN(J),RVBL(J)
      WRITE(LW,5)
      WRITE(LW,7)
      WRITE(LW,9)
      WRITE(LW,11) (B4(I),HT4(I),HS4(I),HTN4(I),HSN4(I),HTC4(I),HSC4(I),
     1I=1,NTP)
      WRITE(LW,13)
      WRITE(LW,15)
      WRITE(LW,17) (B4(I),C4(I),ALP4(I),CM4(I),CU4(I),PHI4(I),I=1,NTP)
C-TRAVERSE INCREMENTS
      LIM = NTP-1
      DB(1) = 0.5 * (B4(2) + B4(1))
      DB(NTP) = 1.    - 0.5 * (B4(NTP-1) + B4(NTP))
      DO 102 I=2,LIM
  102 DB(I) = (B4(I+1) - B4(I-1))*0.5
      SUM = 0
      DO 104 I=1,NTP
  104 SUM = SUM + DB(I)
C-INTEGRATED VALUES
      SCM4B = 0
      SCU4B = 0
      SCUV4 = 0
      SHT4B = 0
      DO 106 I=1,NTP
      CM4B(I) = CM4(I)  * DB(I)
      SCM4B   = SCM4B + CM4B(I)
      CU4B(I) =CU4(I) * DB(I)
      SCU4B = SCU4B + CU4B(I)
      SCUV4 = SCUV4 + CM4B(I) * CU4(I)
      HT4CB(I) = HT4(I) * CM4B(I)
  106 SHT4B  = SHT4B + HT4CB(I)
      HT4I  = SHT4B/SCM4B
      HT4IN = HT4I/SN(J)**2
```

```
      HT4IC = HT4I/USOG
      CU4I = SCUV4/SCM4B
      ALP4I  = ATAN(SCM4B/SCU4B)*57.296
      VI4 = 0.043634 * R4 * CAPB4 * SCM4B
      ERR = (VI4-V4)/V4 * 100.
      FLADJ = V4/VI4
      WRITE(LW,19)
      WRITE(LW,21)
      WRITE(LW,23)
      WRITE(LW,25) HT4I,HT4IN,HT4IC,SCM4B,       ALP4I,VI4,V4,ERR
C-ADJUSTED VALUES
      DO 114 I=1,NTP
      CM4A(I)  = FLADJ * CM4(I)
      PHI4A(I) = CM4A(I)/U2
      ALP4A(I) = ASIN(ABS(CM4A(I)/C4(I)))*57.296
      IF(CM4A(I)) 112,114,114
  112 ALP4A(I) = -ALP4A(I)
  114 CU4A(I) = C4(I) * COS(ABS(ALP4A(I)/57.296))
      WRITE(LW,27)
      WRITE(LW,29)
      WRITE(LW,31)
      WRITE(LW,33) (B4(I),CM4A(I),ALP4A(I),CU4A(I),PHI4A(I),I=1,NTP)
C-ADJUSTED VALUES INTEGRATED
      SCMAB = FLADJ * SCM4B
      SCU4A = 0
      CUV4A = 0
      DO 116 I=1,NTP
      SCU4A = SCU4A + CU4A(I) * DB(I)
      CM4BA = CM4B(I) * FLADJ
  116 CUV4A = CUV4A + CM4BA   * CU4(I)
      CU4AI = CUV4A/SCMAB
      ALPIA  = ATAN(SCMAB/SCU4A) * 57.296
      CM2 = VI2/AI2 * 144.
      CU2 = 2. * R4/DI2 * CU4AI
      ETAIA = HT4IC/PSTHA
      ETAIS = HT4IC/PSTHS
      ETAIP = HT4IC/PSTHP
      PSTHM = CU2/U2
      ETAIM = HT4IC/PSTHM
      CU2E = U2 - CM2/TGB2
      SLIPM= CU2/CU2E
      WRITE(LW,41)
      WRITE(LW,43)
      WRITE(LW,45)
      WRITE(LW,47) SCMAB,ALPIA,SCU4A,CU4AI,CU2
      WRITE(LW,35)
      WRITE(LW,75)
      WRITE(LW,77)
      WRITE(LW,79) PHID,PSIEU,PSTHA,PSTHS,PSTHP,PSTHM
      WRITE(LW,81)
      WRITE(LW,83) SLPA,SLPS,SLPP,SLIPM
      WRITE(LW,85) ETAIA,ETAIS,ETAIP,ETAIM
      WRITE(LW,87)
      WRITE(LW,89)
      WRITE(LW,91) U2,CM2
      RETURN
      END
```

2.   09:54:01

TRAVERSE DATA EVALUATION

IMPELLER DISCHARGE, STAGE 1   Q/N = .2185   SPEED = 7002.0 RPM   BALANCER FLOW = 15.215 PERCENT

PARAMETERS BASED ON MEASURED VALUES

DISTANCE R4/CAPR4	TOTAL HEAD HT4, FT	STATIC HEAD HS4, FT	NORM TOT HEAD	NORM STAT HEAD	TOT HEAD COEFF	STAT HEAD COEFF
.0794	2222.89	1500.17	.4534-04	.3060-04	.6380	.4306
.1587	2216.37	1500.17	.4521-04	.3060-04	.6361	.4306
.3175	2190.32	1500.17	.4467-04	.3060-04	.6287	.4306
.4762	2183.89	1500.17	.4454-04	.3060-04	.6268	.4306
.6349	2151.29	1500.17	.4308-04	.3060-04	.6174	.4306
.7937	2046.71	1500.17	.4175-04	.3060-04	.5874	.4306
.9524	1928.82	1500.17	.3934-04	.3060-04	.5536	.4306

DISTANCE R4/CAPR4	ABS VELOCITY C4, FT/S	FLOW ANGLE DEG	VELOCITY CM4, FT/S	VELOCITY CU4, FT/S	FLOW COEFF CM4/U2
.0794	215.65	7.80	29.27	213.66	.0874
.1587	214.68	9.00	33.58	212.03	.1003
.3175	210.74	10.00	36.59	207.53	.1093
.4762	209.74	11.30	41.10	205.67	.1227
.6349	204.69	11.20	39.76	200.78	.1187
.7937	187.53	7.50	24.48	185.93	.0731
.9524	166.09	-2.00	-5.80	165.98	-.0173

INTEGRATED VALUES WITH MASS WEIGHTED TOTAL HEAD

TOT HEAD FT	NORM TOT HD FT/RPM**2	TOT HEAD COEFF	CM4 FT/S	ALPHA 4 DEG	FLOW RATE CUFT/S INTGR	FLOW RATE CUFT/S FROM CONTINUITY	FLOW ERROR PERCENT
2175.38	.4437-04	.6244	29.27	8.380	4.587	4.095	12.015

ADJUSTED VALUES TO SATISFY CONTINUITY

DISTANCE R4/CAPR4	CM 4 FT/S	ALPHA 4 DEG	CU 4 FT/S	FLOW COEFF CM4/U2
.0794	26.13	6.96	214.06	.0780
.1587	29.90	8.03	212.57	.0895
.3175	32.67	8.92	208.19	.0976
.4762	36.69	10.07	206.50	.1096
.6349	35.49	9.99	201.50	.1060
.7937	21.85	6.69	186.25	[illegible]

.9524	-5.17	-1.79	166.00	-.0155

ADJUSTED VALUES, INTEGRATED

CM 4 FT/S	ALPHA 4 DEG	CU 4 FT/S
26.13	7.47	199.25

MASS WEIGHTED TANGENTIAL VELOCITY COMPONENT CU

CU 4 FT/S	CU 2 FT/S
205.18	213.62

IMPELLER PERFORMANCE

THEORETICAL HEAD COEFFICIENTS

FLOW COEFF	EULER	ACOSTA	STODOLA	PFLEIDERER	MEASURED
.1050	.8167	.6328	.6204	.6354	.6380

PARAMETERS BASED ON ABOVE COEFFICIENTS

	ACOSTA	STODOLA	PFLEIDERER	MEASURED
SLIP	.7748	.7596	.7780	.7828
IMPELLER EFFICIENCY	.9866	1.0064	.9826	.9786

U2 FT/S	CM2 FT/S
334.81	35.76

6. PUMP AIR TEST DATA REDUCTION

J. J. Brunner
7 April 1972

COMPUTER PROGRAM

PUMP AIR TEST DATA REDUCTION

I. INTRODUCTION

This program computes overall as well as component performance parameters of a two-stage centrifugal flow pump from measured data including pressures, temperatures, torque and shaft speed. Calculations of isentropic head and air density account for changes in relative humidity.

The program was written for the reduction of test data obtained from pump air tests conducted in support of the NERVA Turbopump Program. The pump air test results are discussed in Reference 1.

II. BASIC EQUATIONS

1. Pressure Conversion

The following conversion factors are used in the program:

$$1 \text{ PSI} = 2.036 \text{ in. Hg}$$

$$1 \text{ PSI} = 27.67 \text{ in. } H_2O$$

Reference 1 - J. J. Brunner, Performance of a Two-Stage Centrifugal NERVA Pump Tested with Air as the Working Fluid, Engineering Operations Report N8300R:71-090, 12-9-71

2. Air Properties

Measured are barometric pressure B in in. Hg and wet and dry bulb temperature t_w and t_d from psychrometer. The vapor pressure P_w in in. Hg corresponding to the wet bulb temperature t_w is obtained from the steam tables. The actual vapor pressure P_v in in. Hg is calculated from the empirical equation presented in Reference 2:

$$P_v = P_w - \frac{B\ (t_d - t_w)}{2700}$$

The relative humidity r_h is the ratio of the actual vapor pressure to the pressure of saturated vapor at the prevailing dry bulb temperature:

$$r_h = \frac{P_v}{P_d}$$

Neglecting the inert gases, the part pressures of the oxygen-nitrogen-water vapor mixture are calculated according to Dalton's Law.

Reference 2 - L. S. Marks, Mechanical Engineers' Handbook, Fifth Edition, McGraw-Hill Book Co., 1951

The pressure of dry air p_a is:

$$p_a = B - P_v \quad \text{(in. Hg)}$$

and that of its constituents:

$$P_{O_2} = .21\ p_a$$

$$P_{N_2} = .79\ p_a$$

The density ρ of each constituent is obtained from:

$$\rho = \frac{M\ P}{1546\ T}$$

M = molecular weight

P = pressure in lb/ft³

T = absolute temperature °R, (dry bulb)

The specific heats of the mixture are obtained by weighting the specific heat of each constituent as follows:

$$C_p = \frac{\rho_{O_2}\ C_{p_{O_2}}}{\Sigma\ \rho} + \frac{\rho_{N_2}\ C_{p_{N_2}}}{\Sigma\ \rho} + \frac{\rho_V\ C_{p_V}}{\Sigma\ \rho}$$

The specific heat C_v is calculated analogously. Values of specific heats for each constituent used in the program are summarized below.

SPECIFIC HEATS IN BTU/(LB, °R)

	C_p	C_v
O_2	.217	.155
N_2	.244	.173
H_2O	.445	.3345

The mixture density is equal to the sum of the densities of the constituents:

$$\rho = \rho_{O_2} + \rho_{N_2} + \rho_V$$

gas constant: $R = 778.2\ (C_p - C_v)$

Molecular Weight: $M = \frac{1546}{R}$

3. <u>Flow Measurement</u>

The following equations apply for all flow nozzles employed:

Nozzle constant $K = \phi C$

$$C = \text{velocity of approach factor} = \frac{1}{\sqrt{1 - (\frac{A_2}{A_1})^2}}$$

ϕ = nozzle discharge coefficient

A_2 = nozzle throat area, sq. in.

A_1 = pipe area, sq. in.

The compressibility effect is considered with adiabatic expansion factor Y_a from Reference 3.

$$Y_a = \left[r_p^{\left(\frac{2}{\gamma}\right)} \left(\frac{\gamma}{\gamma - 1}\right) \left(\frac{1 - r_p^{\left(\frac{\gamma - 1}{\gamma}\right)}}{1 - r_p} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 r_p^{\frac{2}{\gamma}}} \right) \right]^{1/2}$$

where:

r_p = pressure ratio across nozzle: P_{noz}/P_{line}

γ = ratio of specific heats C_p/C_V

β = ratio of throat to pipe diameter

4. Volumetric Flow Rate V_f

$$V_f = K\,(Y_a)\,\frac{A_2}{144}\left(\frac{2g}{\rho}\;\frac{144\;\Delta P}{27.67}\right)^{1/2} = 0.127\;K\;A_2\left(\frac{\Delta P}{\rho}\right)^{1/2} \qquad (ft^3/sec)$$

where:

ΔP = $P_{pipe} - P_{throat}$, in H_2O

ρ = Fluid density, lb/ft^3

Reference 3 - ASME, Fluid Meters, Fifth Edition, ASME, New York, 1959

5. Isentropic Head

$$H_{is} = 778.2\ C_p\ T_o \left[\left(\frac{P_2}{P_o} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right] \quad \text{(ft)}$$

In this calculation of the overall and stage total head rise, the velocity head

$$H_{vel} = \frac{\left(\frac{144\ V_f}{\rho\ A} \right)^2}{2g}$$

is added to obtain the correct total head.

6. Pump Efficiency

Efficiency based on measured temperature rise Δt_{act}

$$\eta_t = \frac{\Delta t_{is}}{\Delta t_{act}}$$

where:

$$\Delta t_{is} = T_o \left[\left(\frac{P_2}{P_o} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]$$

Efficiency based on measured shaft torque τ (in lb)

$$\eta_\tau = \frac{12\ \dot{W}\ \ \Delta H_{is}}{\omega\ \tau}$$

$\dot{W}$ = net flow rate, lb/sec

ω = angular velocity $= \frac{\Pi}{30}$ N, rad/sec

7. Labyrinth Flow Rate, Impeller Shroud

The recirculating impeller front shroud labyrinth flow rate is estimated to determine the impeller discharge flow coefficient. Mean labyrinth through flow area A_{lb} and orifice coefficient C_{lb} are input. The pressure gradient along the shroud is neglected.

$$\dot{W}_{lb} = C_{lb} \frac{A_{lb}}{144} \rho \left[\frac{2g\ (144)\ \Delta P_{lb}}{\rho} \right]^{1/2}$$

$$= 0.66847\ C_{lb}\ A_{lb}\ (\rho\ \Delta P_{lb})^{1/2}$$

where:

ΔP_{lb} = pressure drop in lb/sq.in. across labyrinth

C_{lb} = labyrinth flow coefficient = 0.5

8. Impeller Discharge Flow Coefficient

$$\phi_2 = 144 \frac{\dot{W} + \dot{W}_{lb}}{\rho\ A_2\ U_2}$$

A_2 = impeller discharge area blocked, sq. in.

U_2 = D_2 N/229, ft/s

For the second stage the recirculating balancer flow (when simulated) must be added to the net flow.

9. Stage Head Coefficient

$$\psi = \frac{g \, \Delta H_{is}}{U_2^2}$$

10. Impeller Discharge Total Head Coefficient (one-dimensional)

This coefficient is based on an average static pressure determined from several wall static pressures measured around the impeller periphery between diffuser inlet and impeller discharge at radius R_M. Two methods were considered for estimating the impeller total head:

Method I (based on assumed impeller efficiency)

The static head coefficient is expressed as the difference of the total head coefficient and the velocity head in coefficient form:

$$\psi_s = \psi_t - \frac{\psi_i^{\,2} + \phi_2^{\,2}}{2}$$

ψ_s = static head coefficient

ψ_t = total head coefficient

ψ_i = ideal head coefficient

ϕ_2 = discharge flow coefficient

Since the static head is based on measurements outside the impeller discharge the absolute velocity is reduced by the ratio of the impeller discharge radius R_2 to the radius of the pressure tap R_M. The velocity head therefore is multiplied by the radius ratio squared. Substituting the ratio of total head coefficient to impeller efficiency in place of the ideal head coefficient:

$$\psi_s = \psi_t - \left(\frac{R_2}{R_M}\right)^2 \left(\frac{\left(\frac{\psi_t}{\eta}\right)^2 + \phi_2^2}{2}\right)$$

Solving for ψ_t the quadratic equation can be written as:

$$\frac{\left(\frac{R_2}{\eta\, R_M}\right)^2}{2} \psi_t^2 - \psi_t + \left(\frac{R_2}{R_M}\right)^2 \left(\frac{\phi_2^2}{2}\right) + \psi_s = 0$$

and

$$\psi_t = \frac{1 \pm \sqrt{1 - \left(\frac{R_2}{\eta R_M}\right)^2 \left[\left(\frac{R_2}{R_M}\right)^2 \phi_2^2 + 2\,\psi_s\right]}}{\left(\frac{R_2}{\eta\, R_M}\right)^2}$$

Method II (based on calculated slip)

In this method the impeller total head coefficient is calculated directly from

$$\psi_t = \psi_s + \left(\frac{R_2}{R_M}\right)^2 \left(\frac{\phi_2^2 + \psi_i^2}{2}\right)$$

with a theoretical head coefficient ψ_i based on Stodola's slip correction, defined as:

$$\psi_i = 1 - \frac{\phi_2}{\tan \beta_2} - \frac{\Pi \sin \beta_2}{Z}$$

where:

β_2 = discharge blade angle

Z = number of blades

Values calculated by both methods showed excellent agreement for data points near design. For off-design points however, the slip estimate was considered more accurate and consistent than the estimate of impeller efficiency. Method II was therefore selected for incorporation into the program.

11. Housing Losses

Crossover and diffusion housing losses are expressed in head coefficient form as:

$$\Delta\psi_{\ell(Housing)} = \psi_{t(Impeller} - \psi_{t(Stage)}$$

To determine diffuser and volute losses individually, the total head at the diffuser discharge is estimated from a measured average wall static pressure and a calculated velocity head. Using Pfleiderer's criterion for slip (Reference 4) to account for flow deviation the fluid angle at the diffuser discharge is expressed as follows:

Reference 4 - C. Pfleiderer, Die Kreiselpumpen, Fifth Edition, Springer-Verlag, 1961

$$\text{Ctg}\ \alpha_5 = \frac{\beta_5 + P_\ell \dfrac{R_2\ C_{u2}}{R_5\ C_{m5}}}{1 + P_\ell}$$

with

β_5 = diffuser vane discharge angle

R_2 = impeller discharge radius

R_5 = diffuser discharge radius

C_{u2} = tangential velocity component, impeller discharge

C_{m2} = meriodinal velocity component, diffuser discharge

$$P_\ell = \frac{\psi^1\ R_5^{\ 2}}{Z\ S}$$

where:

Z = diffuser vane numbers

S = static moment of vane in meriodinal plane = $\frac{1}{2}(R_5^{\ 2} - R_4^{\ 2})$

ψ^1 = empirical factor = 0.75 $(1 + \frac{\beta_5}{60})$

The total head at the diffuser discharge then is:

$$H_t = H_s + \frac{\left(\dfrac{C_{m5}}{\sin \alpha_5}\right)^2}{2\ g} \quad \text{and} \quad \psi_t = \frac{H_t}{u^2/g}$$

Diffuser head loss coefficient:

$$\Delta\psi_{\ell(\text{Diffuser})} = \psi_{t(\text{Impeller})} - \psi_{t(\text{Diffuser})}$$

Volute head loss coefficient:

$$\Delta\psi_{\ell(\text{Volute})} = \psi_{t(\text{Diffuser})} - \psi_{t(\text{Stage})}$$

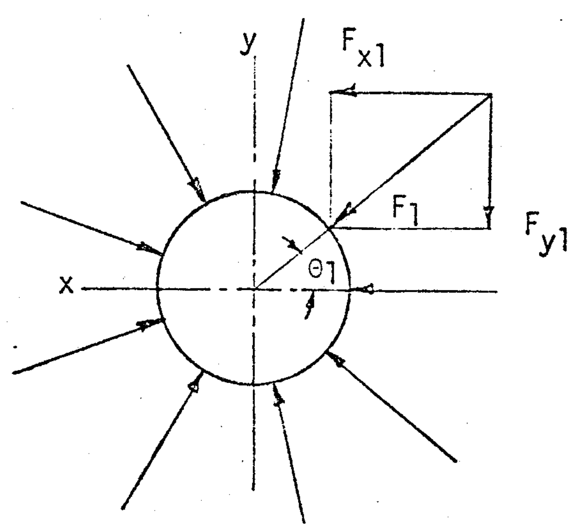
Radial Thrust

Radial thrust is determined from the wall static pressures measured around the impeller periphery. Each measured pressure multiplied by its effective area (circumferential increment x effective width) results in a force vector F shown in Figure below. The force components of F are:

$$F_y = F \sin \Theta$$

and

$$F_x = F \cos \Theta$$



The radial force $\overline{F}$ then is the resultant of the algebraic sums of the force components F_y and F_x.

$$\overline{F} = \sqrt{\Sigma F_y + \Sigma F_x}$$

The direction of the resultant force is determined by the angle

$$\Theta = \tan^{-1} \left(\frac{\Sigma F_y}{\Sigma F_x}\right)$$

Θ is measured from the pressure tap nearest to the volute tongue in direction of impeller rotation.

The radial thrust parameter used in the data presentation is defined as the ratio of the resultant radial force $\overline{F}$ (lb) to the average static pressure rise (lb/sq in) measured from the pump inlet to the second stage impeller periphery.

$$K_R = \frac{\overline{F}}{P_{2_m} - P_{amb}}$$

AIR TEST DATA REDUCTION PROGRAM

NOMENCLATURE

INPUT DATA

SYMBOL	DESCRIPTION	UNITS	FORMAT
	CONSTANTS		
IM	Month		I2
ID	Day		I2
IY	Year		I2
NOT	Test No.		I3
NODAT	Number of Data Points		I3
NOPI2	No. of Circumferential Pressures Imp, 2nd Stage		I5
NODF	No. of Circumferential Pressure Diff. Disch.		I5
CNOZ	Coeff. Disch. Flow Nozzle		F
ANOZ	Nozzle Area	Sq In	F
ADL	Area Disch. Line	Sq In	F
CORIF	Coeff. Bleed Orifice		F
ABL	Area Bleed Orifice	Sq In	F
	IMPELLER 1ST STAGE		
AI21	Area Imp. Disch. Blocked	Sq In	F
DI21	Diameter, Imp. Disch.	In.	F
CLAB1	Labyrinth Orifice Coeff.		F
Z21	Number of Blades		F
BET 21	Blade Disch. Angle	Deg.	F
ALB1	Flow Area, Labyrinth	Sq in	F
	IMPELLER 2ND STAGE		
AI22	Area Imp. Disch. Blocked	Sq In	F
DI22	Diameter, Imp. Discharge	In	F
CLAB2	Labyrinth Orifice Coeff.		F
Z22	Number of Blades		F
BET22	Disch.Blade Angle	Deg	F
ALB2	Flow Area, Labyrinth	Sq In	F

AIR TEST DATA REDUCTION PROGRAM

NOMENCLATURE

INPUT DATA

SYMBOL	DESCRIPTION	UNITS	FORMAT
	HOUSING		
ACR01	Area Crossover Channel	Sq In	F
ACR02	Area Crossover Channel	Sq In	F
ACR03	Area Crossover Channel	Sq In	F
ACR04	Area Crossover Channel	Sq In	F
ADFD	Tang. Area Diff. Discharge	Sq In	F
BDFD	Diff. Disch. Fluid Angle	Deg	F
	MEASURED DATA		
POHG	Pressure, Ambient	In Hg	F
TO	Temperature, Ambient	Def F	F
PSD	Static Pressure, Discharge	In H_2O	F
TD	Temperature, Discharge	Deg F	F
DPORI	Pressure Drop, Bleed Orifice	in H_2O	F
TI	Temperature, Total, Interstage	Deg F	F
PTI	Total Pressure, Interstage, RMR Dia.	In H_2O	F
PSI	Static Pressure, Interstage	In H_2O	F
SN	Rotational Speed	RPM	F
TQS	Shaft Torque, Measured	In Lb.	F
PSIM1	Mean Static Pressure, Imp Disch, 1st Stg.	In H_2O	F
PSIN	Mean Static Pressure, Inducer	In H_2O	F
PCR01	Stat Pressure, Crossover Channel	In H_2O	F
PCR02	Stat Pressure, Crossover Channel	In H_2O	F
PCR03	Stat Pressure, Crossover Channel	In H_2O	F
PCR04	Stat Pressure, Crossover Channel	In H_2O	F
DPN	Pressure Drop, Nozzle Disch. Line	In H_2O	F

AIR TEST DATA REDUCTION PROGRAM

NOMENCLATURE

INPUT DATA

SYMBOL	DESCRIPTION	UNITS	FORMAT
	IMPELLER SECOND STAGE CIRCUMFERENTIAL STATIC PRESSURES		
PSI2(1)-(18)	Static Pressure, Imp. Discharge	In H_2O	F
	DIFFUSER DISCHARGE CIRCUMFERENTIAL STATIC PRESSURE		
PSDF(1)-(9)	Static Pressure, Diff. Discharge	IN H_2O	F

GX28-7327-6 U/M050
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FORTRAN Coding Form

PROGRAM: AIR TEST DATA REDUCTION

PROGRAMMER	DATE	PUNCHING INSTRUCTIONS	GRAPHIC	PUNCH	PAGE OF	CARD ELECTRO NUMBER

CARD NO	FORTRAN STATEMENT	Annotation
1	IN ID IY NØT NØDAT NØPI2 NODF TDRY TWET RHUM PWET	
2	CNØZ DNOZ DDL CØRIF ABL	CONSTANTS
3	AI21 DI21 CLAB1 Z21 BET 21 ALB1 DI11T DI11H	FIRST STAGE IMPELLER
4	AI22 DI22 CLAB2 Z22 BET 22 ALB 2 B2TH DI21T	SECOND STAGE IMPELLER
5	ACRØ1 ACRØ2 ACRØ3 ACRØ4 AOFD BOFD DI21H TQBRG	HOUSING
6	THET2(1) THET2(2) THET2(3) THET2(4) THET2(5) THET2(6) THET2(7) THET2(8) THET2(9) THET2(10)	LOCATIONS OF CIRCUMFERENTIAL PRESSURES
7	THET2(11) THET2(12) THET2(13) THET2(14) THET2(15) THET2(16) THET2(17) THET2(18)	
8	PBAR(J) TO(J) PSD(J) TD(J) ORIFCE(J) TI(J) PTI(J) PSI(J)	DATA
9	SN(J) TQS(J) PSIM1(J) PSIN(J) PCRØ1(J) PCRØ2(J) PCRØ3(J) PCRØ4(J)	DATA
10	DPN(J) PMØT(J)	DATA — IF MORE THAN ONE DATA POINT STACK CARDS 8 TO 10
11	PSI2(1) PSI2(2) PSI2(3) PSI2(4) PSI2(5) PSI2(6) PSI2(7) PSI2(8) PSI2(9) PSI2(10)	
12	PSI2(11) PSI2(12) PSI2(13) PSI2(14) PSI2(15) PSI2(16) PSI2(17) PSI2(18)	
13	PSDF(1) PSDF(2) PSDF(3) PSDF(4) PSDF(5) PSDF(6) PSDF(7) PSDF(8) PSDF(9)	STACK CARDS

*A standard card form, IBM electro 888157, is available for punching statements from this form

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@ ELT MAIN,1,720405, 49940

      DIMENSION POHG(30),TO(30),PSD(30),TD(30),DPORI(30),TI(30),PTI(30),
     1PSI(30),SN(30),TOS(30),        PSIN(30),PCRO1(30),PCRO2(30),PCRO3
     2(30),PCRO4(30),PSIM1(30)
      DIMENSION        TOABS(30),RHO(30),RHOD(30),VDF(30),VDG(30),
     1VW(30),RVBL(30),RHOI(30),VIF(30),VIG(30),PROV(30),HISOV(30),HOVN2(
     230),     ODN(30),DTAOV(30),DTIOV(30),EFTOV(30),TOTOV(30),TONTO(30)
     3, TONS(30),EFS(30),PRS1(30),HIS1(30),HNS1(30),QIN(30),DTAS1(30),
     4EFTS1(30),RHOI1(30),RECI1(30),PHI1(30),HC1(30),PRS2(30),HIS2(30),
     5HNS2(30),DTAS2(30),EFTS2(30),          RHOI2(30),PHI2(30),HC2(30)
      DIMENSION RECI2(30),HSNW1(30),HCSI1(30),SLPC1(30),HCTI1(30),HTNI1(
     112),HCCRC(30),HSNW2(30),HCSI2(30),SLPC2(30),HCTI2(30),HTNI2(30),
     2      HSIM2(30),HS201(30),HS202(30),HS203(30),HS204(30),HS205(3
     30),HS206(30),HS207(30),HS208(30),HS209(30),HS210(30),HS211(30)
      DIMENSION HS212(30),HS213(30),HS214(30),HS215(30),HS216(30),
     1HS217(30),HS218(30),PSDF(30),HSDFM(30),HCDHC(30),HCDFC(30),
     2HCVOL(30),DPN(30),RELB2(30),HSNIN(30),RHF(30),THET2(18),YANOZ(30)
      COMMON J,THET(18), PSI2(18),B2TH,DI21,DI22,NOPI2,NST,RAFK(30),
     1THETR(30),DTHET(18),EFMOT(30),PMOT(30)     ,PSIM2(30),POPS(30)
      LR = 5
      LW = 6
    3 FORMAT('1')
    5 FORMAT(3A2,A4,3I5,3F8.2,F8.3)
    7 FORMAT('1 DATE ',A2,'-',A2,'-',A2/53X,'NERVA AIR TEST'/
     152X,'PERFORMANCE DATA'//)
   11 FORMAT(53X,'TEST NO.  ',A4,//)
   13 FORMAT(18X,'CONSTANTS'//)
   17 FORMAT( 2X,'NOZZLE COEFFICIENT, CNOZ',6X,F10.4,2X,'***')
   19 FORMAT( 2X,'NOZZLE DIA,  DNOZ',13X,F10.3,2X,'SQIN')
   21 FORMAT( 2X,'DISCHARGE LINE DIA,  DDL',6X,F10.3,2X,'SQIN')
   23 FORMAT( 2X,'BLEED ORIFICE COEFF, CORIF',4X,F10.4,2X,'***')
   25 FORMAT( 2X,'BLEED ORIF AREA, ABL',10X,F10.3,2X,'SQIN')
   27 FORMAT(/18X,'IMPELLER FIRST STAGE',32X,'IMPELLER SECOND STAGE'/)
   29 FORMAT( 2X,'DISCHARGE AREA BLOCKED, AI21',5X,F10.3,2X,'SQIN',10X,
     1'DISCHARGE AREA BLOCKED, AI22',5X,F10.3,2X,'SQIN')
   31 FORMAT( 2X,'DISCHARGE DIAMETER, DI12',9X,F10.3,2X,'IN',12X,
     1'DISCHARGE DIAMETER, DI22',9X,F10.3,2X,'IN')
   33 FORMAT( 2X,'LABYRINTH COEFFICIENT, CLAB1',5X,F10.4,2X,' ** ',10X,
     1'LABYRINTH COEFFICIENT, CLAB2',5X,F10.4,2X,' **')
   35 FORMAT( 2X,'NUMBER OF BLADES, Z21',12X,F10.1,2X,' ** ',10X,
     1'NUMBER OF BLADES, Z22',12X,F10.1,2X,' **')
   37 FORMAT( 2X,'DISCHARGE BLADE ANGLE, BET21',5X,F10.3,2X,'DEG',11X,
     1'DISCHARGE BLADE ANGLE, BET22',5X,F10.3,2X,'DEG')
   38 FORMAT( 2X,'LABYRINTH FLOW AREA, ALB1',8X,F10.3,2X,'SQIN',10X,
     1'LABYRINTH FLOW AREA, ALB2',8X,F10.3,2X,'SQIN')
   39 FORMAT(/53X,'HOUSING'/)
   41 FORMAT( 2X,'CROSSOVER AREA, ACRO1',12X,F10.3,2X,'SQIN',10X,
     1'CROSSOVER AREA, ACRO2',11X,F10.3,2X,'SQIN')
   43 FORMAT( 2X,'CROSSOVER AREA, ACRO3',12X,F10.3,2X,'SQIN',10X,
     1'CROSSOVER AREA, ACRO4',11X,F10.3,2X,'SQIN')
   45 FORMAT( 2X,'DIFFUSER DISCHARGE AREA, ADFD',4X,F10.3,2X,'SQIN',10X,
     1'DIFF DISCHARGE FLOW ANGLE, BDFD',1X,F10.3,2X,'DEG')
   51 FORMAT (5F10.3/8F10.3/8F10.3/8F10.3)
   53 FORMAT (8F10.3/8F10.3/2F10.4)
   55 FORMAT(10F8.3/8F8.3)
   57 FORMAT(9F8.3)
   59 FORMAT(61X,'WIDTH, RADIAL TRHUST, B2TH',7X,F10.3,2X,'IN')
```

```
   61 FORMAT( 2X,'INDUCER INLET TIP DIA, DI11T',5X,F10.3,2X,' IN ',10X,
     1'INLET TIP DIAMETER, DI21T',8X, F10.3,2X,' IN ')
   63 FORMAT( 2X,'INDUCER INLET HUB DIA, DI11H',5X,F10.3,2X,' IN ',10X,
     1'INLET HUB DIAMETER, DI21H',8X, F10.3,2X,' IN ')
   65 FORMAT(///2X,'CALCULATED CONSTANTS'//)
   67 FORMAT( 2X,'VELOCITY OF APPROACH FACTOR, FLOW NOZZLE, VLAP',10X,
     1F10.4,2X,'**'/)
   69 FORMAT( 2X,'DRAG TORQUE, TQBRG',12X,F10.3,2X,'INLB')
   71 FORMAT( 2X,'ABSOLUT HUMIDITY, AHUM',34X,F10.4)
   73 FORMAT( 2X,'MIXTURE DENSITY, ROMIX',34X,F10.4,2X,'LB/FT**3')
   75 FORMAT( 2X,'SPECIFIC HEAT CP',40X,F10.4,2X,'BTU/LB/DEG')
   77 FORMAT( 2X,'SPECIFIC HEAT CV',40X,F10.4,2X,'BTU/LB/DEG')
   79 FORMAT( 2X,'GAS CONSTANT, RMIX',38X,F10.4,2X,'FTLB/LB/DEG')
   81 FORMAT( 2X,'MOLECULAR WEIGHT, WMOL',34X,F10.4/)
   83 FORMAT( 2X,'TDRY  =',F8.2,5X,'TWET  =',F8.2,5X,'REL HUMIDITY  =',
     1F8.2,2X,'PWET  =',F8.3,2X,'INHG'//)
  520 READ (LR,5) IM,ID,IY,NOT,NODAT,NOPI2,NODF,TDRY,TWET,RHUM,PWET
      IF(NODAT) 990,990,530
  530 READ (LR,51) CNOZ,DNOZ,DDL,CORIF,ABL,AI21,DI21,CLAB1,Z21,BET21,ALB
     11,DI11T,DI11H,AI22,DI22,CLAB2,Z22,BET22,ALB2,B2TH,DI21T,ACRO1,ACRO
     22,ACRO3,ACRO4,ADFD,BDFD,DI21H,TQBRG
      READ(LR,55) (THET2(I),I=1,18)
      READ (LR,53) (PUHG(J),T0(J),PSD(J),TD(J),DPORI(J),TI(J),PTI(J),PSI
     1(J),SN(J),TQS(J),PSIM1(J),PSIN(J),PCRO1(J),PCRO2(J),PCRO3(J),PCRO4
     2(J),DPH(J),PMOT(J),J=1,NODAT)
      WRITE(LW,3)
      WRITE(LW,7) IM,ID,IY
      WRITE(LW,11) NOT
      WRITE(LW,13)
      WRITE(LW,17) CNOZ
      WRITE(LW,19) DNOZ
      WRITE(LW,21) DDL
      WRITE(LW,23) CORIF
      WRITE(LW,25) ABL
      WRITE(LW,69) TQBRG
      WRITE(LW,27)
      WRITE(LW,29) AI21,AI22
      WRITE(LW,31) DI21,DI22
      WRITE(LW,33) CLAB1,CLAB2
      WRITE(LW,35) Z21,Z22
      WRITE(LW,37) BET21,BET22
      WRITE(LW,38) ALB1,ALB2
      WRITE(LW,61) DI11T,DI21T
      WRITE(LW,63) DI11H,DI21H
      WRITE(LW,59) B2TH
      WRITE(LW,39)
      WRITE(LW,41) ACRO1,ACRO2
      WRITE(LW,43) ACRO3,ACRO4
      WRITE(LW,45) ADFD,BDFD
C-CONSTANTS
      BE21R = BET21/57.296
      TBE21 = SIN(BE21R)/COS(BE21R)
      SLP1 = 3.1416 * SIN(BE21R)/Z21
      BE22R = BET22/57.296
      TBE22 = SIN(BE22R)/COS(BE22R)
      SLP2 = 3.1416*SIN(BE22R)/Z22
      BDFDR = BDFD/57.296
      AI11 = .7854*(DI11T**2 - DI11H**2)
      AI21 = .7854*(DI21T**2 - DI21H**2)
      ANOZ = .7854 * DNOZ**2
```

```
      ADL = .7854 * DDL**2
      BENOZ = DNOZ/DDL
      VLAP = 1./SQRT(1.-(ANOZ/ADL)**2)
      RRSQ1 = (DI21/11.4)**2
      RRSQ2 = (DI22/11.4)**2
C-PROPERTIES OF AIR-WATER VAPOR MIXTURE
      PVAP = PWET - POHG(1)*(TDRY-TWET)/2700.
      PAIR = POHG(1) - PVAP
      SHUM  = PVAP/1.608/PAIR
      ROAIR = 1.326934 * PAIR/(TDRY + 459.67)
      ROVAP = SHUM* ROAIR
      ROMIX = ROAIR + ROVAP
      POXY  = .21 * PAIR   * .49115
      PNIT  = .79 * PAIR   * .49115
      ROXY  = 2.98445*POXY/(459.67 + TDRY)
      RONIT = 2.6114 *PNIT/(459.67 + TDRY)
      GTOT  = ROXY + RONIT + ROVAP
      GOXY = ROXY/GTOT
      GNIT = RONIT/GTOT
      GVAP = ROVAP/GTOT
      CPOXY = .217 * GOXY
      CVOXY = .155 * GOXY
      CVNIT = .176 * GNIT
      CPNIT = .2455* GNIT
      CPVAP = .44466 * GVAP
      CVVAP = .33442 * GVAP
      CVMIX = CVOXY + CVNIT + CVVAP
      CPMIX = CPOXY + CPNIT + CPVAP
      XKMIX   = CPMIX/CVMIX
      RMIX = 778.2 * (CPMIX - CVMIX)
      XMMIX = 1546./RMIX
      XKEXP =(XKMIX-1.)/XKMIX
C-INCREMENTS OF THETA
      DO 488 I=1,NOPI2
  488 THET(I) = THET2(I)
      DO 490 I=1,NOPI2
  490 THET(I) = THET(I)/57.296
      LIMT = NOPI2- 1
      DTHET(1) = 0.5 * (THET(2)-THET(1) + 6.2834 - THET(NOPI2))
      DTHET(NOPI2)= 0.5 * (6.2834 - THET(LIMT))
      DO 492 I=2,LIMT
  492 DTHET(I) = (THET(I+1) - THET(I-1)) * 0.5
      J = 0
  500 J = J + 1
      IF(J-NODAT) 510,510,900
C-INLET CONDITION
  510 POPS(J) = 0.49115 * POHG(J)
      TOABS(J) = 459.67 + TO(J)
      RHO(J) = 144.     * POPS(J)/TOABS(J)/RMIX
C-PUMP DISCHARGE CONDITION
      PSD(J) =  PSD(J)/ 27.67 + POPS(J)
      RHOD(J) = 144.     * PSD(J)/(TD(J) + 459.67)/RMIX
      PNOZ = PSD(J) - DPN(J)/27.67
      RPNOZ = PNOZ/PSD(J)
      YNOZ1 = (1.-RPNOZ**.286)/(1.-RPNOZ)
      YNOZ2 = (1.-BENOZ**4)/(1.-BENOZ**4 * RPNOZ**1.43)
      YANOZ(J) = SQRT(RPNOZ**1.43 * 3.5*YNOZ1 * YNOZ2)
      XKNOZ = CNOZ  * YANOZ(J) * VLAP
      VDF(J) = 0.12708 * ANOZ *XKNOZ * SQRT(DPN(J)/RHOD(J))
      VDG(J) = 448.83 * VDF(J)
```

```
      VW(J) = RHOD(J) * VDF(J)
      HDVEL    = 0.0016 * (VDG(J)/ADL)**2
      VWBL    = 0.12708 * ABL * CORIF * SQRT(DPORI(J)*RHOD(J))
      RVBL(J) = 100. * VWBL/VW(J)
C-INTERSTAGE CONDITION
      PSI(J) =  PSI(J)/27.67 + POPS(J)
      RHOI(J) = 144.     * PSI(J)/(TI(J) + 459.67)/RMIX
      VIF(J) = (VW(J) + VWBL)/RHOI(J)
      VIG(J) = 448.83 * VIF(J)
      IF(PTI(J)) 512,512,514
  512 CI21 = VIF(J)/AI21 * 144./0.966
      HIVEL = CI21**2/64.34
      PTI(J) = PSI(J) + RHOI(J)*HIVEL/144.
      GO TO 516
  514 PTI(J) =  PTI(J)/27.67 + POPS(J)
C-PUMP OVERALL PERFORMANCE
  516 PROV(J) = (PSD(J) + RHOD(J) * HDVEL   /144.)/POPS(J)
      HISOV(J) = 778.2    * TOABS(J) * (PROV(J)**XKEXP - 1.)*CPMIX
      HOVN2(J) = HISOV(J)/SN(J)**2
      ODN(J) = VDG(J)/SN(J)
      DTAOV(J) = TD(J) - TO(J)
      DTIOV(J) = TOABS(J) *  (PROV(J)**XKEXP - 1.)
C-EFFICIENCY DERIVED FROM MEASURED SHAFT TORQUE AND MOTOR POWER
      TONS(J) = TOS(J)/12./ SN(J)**2/RHOD(J)
      EFS(J) = 114.587 *VW(J)*HISOV(J)/SN(J)/TQS(J)
      IF(PMOT(J)) 518,518,519
  519 EFMOT(J) = HISOV(J)*VW(J)/(PMOT(J)*.7376 - .008727*SN(J)*TOBRG)
C-INDUCER PERFORMANCE
  518 IF(ABS(PSIN(J))) 522,522,524
  524 PSIN(J) = PSIN(J)/27.67 + POPS(J)
      PRIN = PSIN(J)/POPS(J)
      HSNIN(J) = 778.2    * TOABS(J) * (PRIN**XKEXP - 1.)/SN(J)**2*CPMIX
C-FIRST STAGE PERFORMANCE
  522 PRS1(J) = PTI(J)/POPS(J)
      HIS1(J) = 778.2    * TOABS(J)*(PRS1(J)**XKEXP - 1.)*CPMIX
      HNS1(J) = HIS1(J)/SN(J)**2
      QIN(J) = QDN(J) * RHOD(J)/RHOI(J)
      DTAS1(J) = TI(J) - TO(J)
      DTIS1    = TOABS(J) * ((PRS1(J))**XKEXP - 1.)
      EFIS1(J) = DTIS1    /DTAS1(J)
      U21     = SN(J)*DI21/229.
      PSIM1(J) = PSIM1(J)/27.67 + POPS(J)
      RHOI1(J) = 144.     * PSIM1(J)/(0.5*(TO(J)+TI(J))+459.67)/RMIX
      VWLB1    = .668476          *ALB1*CLAD1*SQRT((PSIM1(J)-PSIN(J))*RHO
     1I1(J))
      RECI1(J) =(VWLB1/VW(J)) * 100.
      PHI1(J) = 144.0     *(VW(J)+VWLB1    )/ RHOI1(J)/AI21/U21
      HC1(J) = 32.174 * HIS1(J)/U21**2
C-SECOND STAGE PERFORMANCE
      PRS2(J) = (PSD(J) + RHOD(J) * HDVEL   /144.)/PTI(J)
      HIS2(J) = 778.2    * (TI(J) + 459.67) *(PRS2(J)**XKEXP - 1.)*CPMIX
      HNS2(J) = HIS2(J)/SN(J)**2
      DTAS2(J) = TD(J) - TI(J)
      DTIS2    = (TI(J) + 459.67) * ((PRS2(J))**XKEXP - 1.)
      EFIS2(J) = DTIS2    /DTAS2(J)
      EFTOV(J) = DTIOV(J)/(DTAS1(J)+DTAS2(J)*(1.+RVBL(J)/100.))
      TOTOV(J) = 114.587 * VW(J) * HISOV(J)/SN(J)/EFTOV(J)
      TONTO(J) = TOTOV(J)/12./SN(J)**2/RHOD(J)
      XNO2= FLOAT(NOPI2)
      READ (LR,55) (PSI2(I),I=1,18)
```

```
      DO 100 I=1,NOPI2
  100 PSI2(I) = PSI2(I)/27.67 + POPS(J)
      PSI2T = 0
      DO 102 I=1,NOPI2
  102 PSI2T = PSI2T + PSI2(I)
      PSIM2(J) = PSI2T/XNO2
      RHOI2(J) = 144.     * PSIM2(J)/(0.5 * (TD(J) + TI(J)) +459.67)/RMIX
      VWLB2    = .668476           *ALB2*CLAB2*SQRT((PSIM2(J)-PSI(J))*RHOI
     12(J))
      U22      = SN(J) * DI22/229.
      PHI2(J) = 144.0   *(VW(J)+VWLB2    +VWBL    )/RHOI2(J)/AI22/U22
      HC2(J) = 32.174 * HIS2(J)/U22**2
      RELB2(J) = VWLB2/VW(J) * 100.
      RECI2(J) = (VWLB2 + VWBL)/VW(J) * 100.
      RHF(J) = (HIS1(J) + HIS2(J))/HISOV(J)
C-FIRST STAGE IMPELLER PERFORMANCE BASED ON STATIC WALL PRESSURES AND
C-CONTINUITY
      PRIS1  = PSIM1(J) / POPS(J)
      HISW1    = 778.2    * TOABS(J) *(PRIS1**XKEXP-1.) * CPMIX
      HSNW1(J) = HISW1/SN(J)**2
      HCSI1(J) = 32.174 * HISW1/U21**2
      SLPC1(J) = 1.-1./(1.-PHI1(J)/TBE21) * SLP1
      HCTH1 = 1.- PHI1(J)/ TBE21 - SLP1
      HCTI1(J) =0.5*RRS01 *(PHI1(J)**2 + HCTH1**2) + HCSI1(J)
      HTNI1(J) = HCTI1(J)*DI21**2/1687236.
C-CROSSOVER CHANNEL
      IF(PCRO1(J)) 105,105,103
  103 PCRO1(J) = PCRO1(J)/27.67 + POPS(J)
      PCRO2(J) = PCRO2(J)/27.67 + POPS(J)
      PCRO3(J) = PCRO3(J)/27.67 + POPS(J)
      PCRO4(J) = PCRO4(J)/27.67 + POPS(J)
      PCRO1(J) = 778.2    * TOABS(J)*((PCRO1(J)/POPS(J))**XKEXP-1.)*CPMIX
      PCRO2(J) = 778.2    * TOABS(J)*((PCRO2(J)/POPS(J))**XKEXP-1.)*CPMIX
      PCRO3(J) = 778.2    * TOABS(J)*((PCRO3(J)/POPS(J))**XKEXP-1.)*CPMIX
      PCRO4(J) = 778.2    * TOABS(J)*((PCRO4(J)/POPS(J))**XKEXP-1.)*CPMIX
      RHOCR    = 0.5*(RHOI1(J) + RHOI(J))
      HVCR1 = 322.247*((VW(J) + VWBL     )/RHOCR/ACRO1)**2
      HVCR2 = 322.247*((VW(J) + VWBL     )/RHOCR/ACRO2)**2
      HVCR3 = 322.247*((VW(J) + VWBL     )/RHOCR/ACRO3)**2
      HVCR4 = 322.247*((VW(J) + VWBL     )/RHOCR/ACRO4)**2
      PCRO1(J)=1687236.*(HTNI1(J)-(PCRO1(J)+HVCR1)/SN(J)**2)/DI21**2
      PCRO2(J)=1687236.*(HTNI1(J)-(PCRO2(J)+HVCR2)/SN(J)**2)/DI21**2
      PCRO3(J)=1687236.*(HTNI1(J)-(PCRO3(J)+HVCR3)/SN(J)**2)/DI21**2
      PCRO4(J)=1687236.*(HTNI1(J)-(PCRO4(J)+HVCR4)/SN(J)**2)/DI21**2
  105 HCCRC(J) = HCTI1(J) - HC1(J)
C-SECOND STAGE IMPELLER PERFORMANCE BASED ON STATIC WALL PRESSURES AND
C-CONTINUITY
      PRIS2 = PSIM2(J)/PTI(J)
      HISW2 = 778.2    *(TI(J) + 459.67) * (PRIS2**XKEXP - 1.)*CPMIX
      HSNW2(J) = HISW2/SN(J)**2
      HCSI2(J) = 32.174 * HISW2/U22**2
      SLPC2(J) = 1.-1./(1.-PHI2(J)/TBE22) * SLP2
      HCTH2 = 1.-PHI2(J)/TBE22-SLP2
      HCTI2(J) =0.5*RRS02 *(PHI2(J)**2 + HCTH2**2) + HCSI2(J)
      HTNI2(J) = HCTI2(J) * DI22**2/1687236.
C-SECOND STAGE IMPELLER CIRCUMFERENTIAL PRESSURE DISTRIBUTION
      DO 104 I=1,NOPI2
  104 PSI2(I)=778.2  *(TI(J)+459.67)*((PSI2(I)/ PTI(J))**XKEXP - 1.)
     1 * CPMIX + HIS1(J)
      HSI2T = 0
```

```
      DO 106 I=1,NOPI2
  106 HSI2T = HSI2T + PSI2(I)
      HSI2  = HSI2T/XNO2
      DO 108 I=1,NOPI2
  108 PSI2(I) = PSI2(I)/HSI2
      HSIM2(J) = HSI2 /SN(J)**2
      HS201(J) = PSI2(1)
      HS202(J) = PSI2(2)
      HS203(J) = PSI2(3)
      HS204(J) = PSI2(4)
      HS205(J) = PSI2(5)
      HS206(J) = PSI2(6)
      HS207(J) = PSI2(7)
      HS208(J) = PSI2(8)
      HS209(J) = PSI2(9)
      HS210(J)  = PSI2(10)
      HS211(J)  = PSI2(11)
      HS212(J)  = PSI2(12)
      HS213(J)  = PSI2(13)
      HS214(J)  = PSI2(14)
      HS215(J)  = PSI2(15)
      HS216(J)  = PSI2(16)
      HS217(J)  = PSI2(17)
      HS218(J)  = PSI2(18)
      NST=2
      IF(NOPI2-3) 109,109,111
  111 CALL RATHR
C-DIFFUSION HOUSING SECOND STAGE
  109 READ (LR,57) (PSDF(I),I=1,9)
      DO 110 I=1,NODF
  110 PSDF(I) = PSDF(I)/27.67 + POPS(J)
      DO 120 I=1,NODF
  120 PSDF(I) = 778.2  *(TI(J)+459.67)*((PSDF(I)/PTI(J))**XKEXP-1.)*CPMI
     1X
      HSDFT = 0
      DO 122 I=1,NODF
  122 HSDFT = HSDFT + PSDF(I)
      XNODF = FLOAT(NODF)
      HSDFM(J) = HSDFT/SN(J)**2/XNODF
C-DIFFUSER DISCHARGE ANGLE BASED ON PFLEIDERERS DEVIATION CRITERION
      CM52 = 144. * VW(J)/RHOD(J)/ADFD
      CUTH2 = U22*(1.-PHI2(J)/TBE22) * SLPC2(J)
      AL52R= ATAN(1./(2.01 + 0.245 * CUTH2/CM52))
      HVDF = .975 * (CM52/SIN(AL52R))**2/64.4
      HTNDF = HSDFM(J) + HVDF/SN(J)**2
      HCDHC(J) = HCTI2(J) - HC2(J)
      HCDF = 1687236./DI22**2 * HTNDF
      HCDFC(J) = HCTI2(J) - HCDF
      HCVOL(J) = HCDF - HC2(J)
      GO TO 500
  900 CONTINUE
      WRITE(LW,65)
      WRITE(LW,67) VLAP
      WRITE(LW,71) SHUM
      WRITE(LW,73) ROMIX
      WRITE(LW,75) CPMIX
      WRITE(LW,77) CVMIX
      WRITE(LW,79) RMIX
      WRITE(LW,81) XMMIX
  201 FORMAT(///2X,'INLET CONDITION',76X,'FLOW NOZZLE EXPANSION FACTOR'/
```

```
      1)
  203 FORMAT( 2X,'DATA',5X,'INLET TEMPERATURE',15X,'AMBIENT PRESSURE',14
     1X,'WEIGHT DENSITY',16X,'YANOZ')
  205 FORMAT( 2X,'POINT',9X,'DEG F',15X,'IN HG',16X,'PSIA',13X,'LB/CUFT'
     1/)
  207 FORMAT (I5,F17.3,2F20.3,F20.4,F26.5)
      WRITE (LW,201)
      WRITE(LW,83) TDRY,TWET,RHUM,PWET
      WRITE (LW,203)
      WRITE (LW,205)
      WRITE (LW,207) (J,TO(J),POHG(J),POPS(J),RHO(J),YANOZ(J),J=1,NODAT)
  211 FORMAT (///2X,'PUMP DISCHARGE CONDITION'//)
  213 FORMAT( 2X,'DATA',7X,'TEMPERATURE',3X,'STAT PRESSURE',4X,'WEIGHT D
     1ENSITY',4X,'VOLUMETRIC FLOW RATE',5X,'WEIGHT FLOW',5X,'BLEED FLOW'
     2)
  215 FORMAT( 2X,'POINT',9X,'DEG F',10X,'PSIA',11X,'LB/CUFT',8X,'CUFT/S'
     1,9X,'GPM',11X,'LB/S',11X,'PERCENT'/)
  217 FORMAT(I5,2F17.3,2F15.4,F15.3,2F15.4)
      WRITE(LW,211)
      WRITE(LW,213)
      WRITE(LW,215)
      WRITE(LW,217) (J,TD(J),PSD(J),RHOD(J),VDF(J),VDG(J),VW(J),RVBL(J),
     1J=1,NODAT)
  221 FORMAT(///2X,'INTERSTAGE CONDITION'//)
  223 FORMAT( 2X,'DATA',7X,'TEMPERATURE',5X,'TOT PRESSURE',4X,'STAT PRES
     1SURE',5X,'WEIGHT DENSITY',9X,'FLOW RATE')
  225 FORMAT( 2X,'POINT',9X,'DEG F',6X,'PSIA (RMR DIA)',5X,'PSIA',16X,'L
     1B/CUFT',9X,'CUFT/S',10X,'GPM'/)
  227 FORMAT(I5,F17.3,2F15.4,F21.4,2F15.3)
      WRITE(LW,221)
      WRITE(LW,223)
      WRITE(LW,225)
      WRITE(LW,227) (J,TI(J),PTI(J),PSI(J),RHOI(J),VIF(J),VIG(J),J=1,NOD
     1AT)
  231 FORMAT(///2X,'PUMP OVERALL PERFORMANCE'//)
  233 FORMAT( 2X,'DATA',5X,'SPEED',4X,'PRESSURE',3X,'TEMP RISE DEG F',4X
     1,'HEAD RISE',4X,'HIS/N**2',7X,'Q/N',4X,'ETA TEMP',2X,'TORQUE T',3X
     2,'NORM TORQUE T')
  235 FORMAT( 2X,'POINT',5X,'RPM',7X,'RATIO',4X,'ACTUAL',4X,'ISENTR',3X,
     1'ISENTR FT',4X,'FT/RPM**2',3X,'GPM/RPM',14X,'IN LB',5X,'FT**4/RPM*
     2*2'/)
  237 FORMAT(I5,F12.1,3F10.3,F10.2,E15.4,2F10.4,F10.3,E15.4)
      WRITE(LW,231)
      WRITE(LW,233)
      WRITE(LW,235)
      WRITE(LW,237)(J,SN(J),PROV(J),DTAOV(J),DTIOV(J),HISOV(J),HOVN2(J),
     1QDN(J),EFTOV(J),TOTOV(J),TQNTO(J),J=1,NODAT)
  241 FORMAT(///2X,'EFFICIENCY DERIVED FROM MEASURED SHAFT TORQUE AND MO
     1TOR POWER',37X,'REHEAT FACTOR'//)
  243 FORMAT( 2X,'DATA',6X,'MEASURED TORQUE',5X,'NORM TORQUE',8X,'EFFICI
     1ENCY',5X,'MOTOR POWER',3X,'EFFICIENCY',17X,'RHF')
  245 FORMAT( 2X,'POINT',8X,'IN LB',11X,'FT**4/RPM**2',10X,'EFS',11X,'WA
     1TT',10X,'EFMOT',13X,'(HIS1+HIS2)/HISOV'/)
  247 FORMAT(I5,F17.4,E20.4,3F15.4,F25.5)
      WRITE(LW,241)
      WRITE(LW,243)
      WRITE(LW,245)
      WRITE(LW,247) (J,TQS(J),TQNS(J),EFS(J),PMOT(J),EFMOT(J),RHF(J),J=1
     1,NODAT)
  251 FORMAT(///2X,'FIRST STAGE PERFORMANCE'//)
```

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  253 FORMAT( 2X,'DATA',5X,'PRESSURE',2X,'HEAD RISE',3X,'HIS/N**2',5X,'Q
     1/N NET',4X,'DELTA T',3X,'ETA TEMP',2X,'LAB FLOW',3X,'PHI(2)',6X,'P
     2SI')
  255 FORMAT( 2X,'POINT',5X,'RATIO',3X,'ISENTR FT',3X,'FT/RPM**2',4X,'GP
     2M/RPM',5X,'DEG F',15X,'PERCENT'/)
  257 FORMAT(I5,F12.4,F10.2,E15.4,F10.4,F10.3,F12.4,F10.3,2F10.4)
      WRITE(LW,251)
      WRITE(LW,253)
      WRITE(LW,255)
      WRITE(LW,257) (J,PRS1(J),HIS1(J),HNS1(J),QIN(J),DTAS1(J),EFTS1(J),
     1RECI1(J),PHI1(J),HC1(J),J=1,NODAT)
  261 FORMAT(///2X,'SECOND STAGE PERFORMANCE'//)
  263 FORMAT( 2X,'DATA',5X,'PRESSURE',2X,'HEAD RISE',3X,'HIS/N**2',5X,'Q
     1/N NET',4X,'DELTA T',3X,'ETA TEMP',2X,'LAB FLOW',3X,'PHI(2)',6X,'P
     2SI',3X,'TOT RECIRC')
  265 FORMAT( 2X,'POINT',5X,'RATIO',3X,'ISENTR FT',3X,'FT/RPM**2',4X,'GP
     1M/RPM',5X,'DEG F',15X,'PERCENT',23X,'PERCENT'/)
  267 FORMAT(I5,F12.4,F10.2,E15.4,F10.4,F10.3,F12.4,F10.3,3F10.4)
      WRITE(LW,261)
      WRITE(LW,263)
      WRITE(LW,265)
      WRITE(LW,267) (J,PRS2(J),HIS2(J),HNS2(J),QDN(J),DTAS2(J),EFTS2(J),
     1RELB2(J),PHI2(J),HC2(J),RECI2(J),J=1,NODAT)
  271 FORMAT(///2X,'INDUCER PERFORMANCE'//)
  273 FORMAT( 2X,'DATA',3X,'NORM STAT HEAD')
  275 FORMAT( 2X,'POINT',2X,'RISE FT/RPM**2'/)
  277 FORMAT(I5,E17.4)
      IF(ABS(PSIN(1))) 532,532,534
  534 WRITE(LW,271)
      WRITE(LW,273)
      WRITE(LW,275)
      WRITE(LW,277) (J,HSNIN(J),J=1,NODAT)
  281 FORMAT(///2X,'FIRST STAGE IMPELLER PERFORMANCE BASED ON STATIC WAL
     1L PRESSURES AND CONTINUITY'//)
  283 FORMAT( 2X,'DATA',4X,'MEAN STATIC',6X,'NORM STAT HD',3X,'STAT HEAD
     1',3X,'SLIP',6X,'TOT HEAD',5X,'NORM TOT HD',4X,'PHI(2)',4X,'DENSITY
     2 RHOI1')
  285 FORMAT( 2X,'POINT',3X,'PRESSURE PSIA',2X,'RISE FT/RPM**2',7X,'COEF
     1F',15X,'COEFF', 7X,'FT/RPM**2',18X,'LB/CUFT'/)
  287 FORMAT(I5,F17.4,E15.4,F13.4,F10.4,F12.4,F15.4,2F12.4)
  532 WRITE(LW,281)
      WRITE(LW,283)
      WRITE(LW,285)
      WRITE(LW,287) (J,PSIM1(J),HSNW1(J),HCSI1(J),SLPC1(J),HCTI1(J),HTNI
     11(J),PHI1(J),RHOI1(J),J=1,NODAT)
  291 FORMAT(///2X,'SECOND STAGE IMPELLER PERFORMANCE BASED ON STATIC WA
     1LL PRESSURES AND CONTINUITY'//)
  293 FORMAT( 2X,'DATA',4X,'MEAN STATIC',6X,'NORM STAT HD',3X,'STAT HEAD
     1',3X,'SLIP',6X,'TOT HEAD',5X,'NORM TOT HD',4X,'PHI(2)',4X,'DENSITY
     2 RHOI2')
  295 FORMAT( 2X,'POINT',3X,'PRESSURE PSIA',2X,'RISE FT/RPM**2',7X,'COEF
     1F',15X,'COEFF', 7X,'FT/RPM**2',18X,'LB/CUFT'/)
  297 FORMAT(I5,F17.4,E15.4,F13.4,F10.4,F12.4,F15.4,2F12.4)
      WRITE(LW,291)
      WRITE(LW,293)
      WRITE(LW,295)
      WRITE(LW,297) (J,PSIM2(J),HSNW2(J),HCSI2(J),SLPC2(J),HCTI2(J),HTNI
     12(J),PHI2(J),RHOI2(J),J=1,NODAT)
  301 FORMAT(///2X,'CROSSOVER CHANNEL'//)
  303 FORMAT( 2X,'DATA',4X,'TOTAL HEAD LOSS COEFFICIENT',17X,'OVERALL')
```

```
  305 FORMAT( 2X,'POINT',3X,'STA 25',4X,'STA 26',4X,'STA 27',4X,'STA 28',
     1,8X,'ONE-DIM'/)
  307 FORMAT(I5,F12.4,3F10.4,F14.4)
      WRITE(LW,301)
      WRITE(LW,303)
      WRITE(LW,305)
      WRITE(LW,307) (J,PCR01(J),PCR02(J),PCR03(J),PCR04(J),HCCRC(J),J=1,
     1NODAT)
  311 FORMAT(///2X,'CIRCUMFERENTIAL PRESSURE DISTRIBUTION - SECOND STAGE
     1 IMPELLER'//)
  313 FORMAT( 2X,'DATA',3X,'NORM AVG',5X,'RATIO OF STATIC HEAD TO AVERAG
     1E STATIC HEAD RISE')
  315 FORMAT( 2X,'POINT',2X,'STATIC HEAD',2X,'(1)',7X,'(2)',7X,'(3)',7X,
     1'(4)',7X,'(5)',7X,'(6)',7X,'(7)',7X,'(8)',7X,'(9)'/)
  317 FORMAT(I5,F15.4,9F10.6)
      WRITE(LW,311)
      WRITE(LW,313)
      WRITE(LW,315)
      WRITE(LW,317) (J,HSIM2(J),HS201(J),HS202(J),HS203(J),HS204(J),HS20
     15(J),HS206(J),HS207(J),HS208(J),HS209(J),J=1,NODAT)
      IF(NOPI2-9) 400,400,402
  402 CONTINUE
  319 FORMAT(//2X,'DATA',4X,'RATIO OF STATIC HEAD RISE TO AVERAGE STATIC
     1 HEAD RISE')
  321 FORMAT( 2X,'POINT',8X,'(10)',8X,'(11)',8X,'(12)',8X,'(13)',8X,'(14
     1)',8X,'(15)',8X,'(16)',8X,'(17)',8X,'(18)'/)
  323 FORMAT(I5,F15.6,8F11.6)
      WRITE(LW,319)
      WRITE(LW,321)
      WRITE(LW,323) (J,HS210(J),HS211(J),HS212(J),HS213(J),HS214(J),HS21
     15(J),HS216(J),HS217(J),HS218(J),J=1,NODAT)
  400 IF(NOPI2-3) 404,404,401
  401 WRITE(LW,441)
      WRITE(LW,443)
      WRITE(LW,445) (J,RAFK(J),THETR(J),J=1,NODAT)
  441 FORMAT(///2X,'RADIAL FORCE PARAMETER RAFK AND FORCE VECTOR ANGLE T
     1HETA MEASURED COUNTER-CLOCKWISE WHEN LOOKING FROM SUCTION'/ 30X,
     2'THETA = 0  AT INSTRUMENTATION STATION  34'//)
  443 FORMAT( 2X,'DATA',8X,'RAFK',13X,'THETA'/2X,'POINT',7X,'IN**2',14X,
     1'DEG'/)
  445 FORMAT(I5,F15.6,F16.2)
  404 CONTINUE
  331 FORMAT(///2X,'DIFFUSION HOUSING - SECOND STAGE'//)
  333 FORMAT( 2X,'DATA',3X,'NORM DIFF DISCH MEAN',2X,'HEAD LOSS COEFF',3
     1X,'HEAD LOSS COEFF',2X,'HEAD LOSS COEFF')
  335 FORMAT( 2X,'POINT',3X,'STAT HD  FT/RPM**2',4X,'HOUSG  ONE-DIM',3X,
     1'DIFF ONE DIM',4X,'VOLUTE  ONE-DIM'/)
  337 FORMAT(I5,E20.4,3F16.4)
      WRITE(LW,331)
      WRITE(LW,333)
      WRITE(LW,335)
      WRITE(LW,337)(J,HSDFM(J),HCDHC(J),HCDFC(J),HCVOL(J),J=1,NODAT)
      GO TO 520
  990 WRITE(LW,3)
      STOP
      END
```

```
@ ELT RATHR,1,720405, 49930

      SUBROUTINE RATHR
      DIMENSION          PSIC(18),PSIS(18)
      COMMON J,THET(18),PSI(18),B2TH    ,DI21,DI22,NOPI,NST,RAFK(30),
     1THETR(30),DTHET(18)   ,EFMOT(30),PMOT(30),PSIM2(30),POPS(30)
      IF(NST-1) 80,80,90
   80 DI2 = DI21
      GO TO 95
   90 DI2 = DI22
   95 SKY = 0
      SKX = 0
      STHET = 0
      DO 102 I=1,NOPI
      STHET = STHET + DTHET(I)
      PSIS(I) = PSI(I) * SIN(THET(I)) *DI2*B2TH*SIN(DTHET(I)/2.)
      PSIC(I) = PSI(I) * COS(THET(I)) *DI2*B2TH*SIN(DTHET(I)/2.)
      SKY = SKY + PSIS(I)
  102 SKX = SKX + PSIC(I)
      SKY = -SKY
      SKX = -SKX
      RAFK(J) =           SQRT(SKY**2+SKX**2)
      TTHET = ATAN(ABS(SKY/SKX))
      IF(SKY) 110,150,115
  115 IF(SKX) 120,155,125
  125 THETR(J) = 57.296 * TTHET
      GO TO 200
  155 THETR(J) = 90.
      GO TO 200
  120 THETR(J) = (3.1417 - TTHET) * 57.296
      GO TO 200
  110 IF(SKX) 130,170,135
  130 THETR(J) = 57.296 * (TTHET + 3.1417)
      GO TO 200
  170 THETR(J) = 270.
      GO TO 200
  135 THETR(J) = (6.2834 - TTHET) * 57.296
      GO TO 200
  150 IF(SKX) 140,160,145
  140 THETR(J) = 180.
      GO TO 200
  160 THETR(J) = 0
      GO TO 200
  145 THETR(J) = 0
  200 RETURN
      END
                                                    13:52:21
 2.
   END CUR
```

DATE 09-02-71

NERVA AIR TEST
PERFORMANCE DATA

TEST NO. 60

CONSTANTS

NOZZLE COEFFICIENT, CNOZ	.9870	***
NOZZLE DIA, DNOZ	2.110	SQIN
DISCHARGE LINE DIA, DDL	4.725	SQIN
BLEED ORIFICE COEFF, CORIF	.6727	***
BLEED ORIF AREA, ABL	.785	SQIN
DRAG TORQUE, TQBRG	5.000	INLB

IMPELLER FIRST STAGE			IMPELLER SECOND STAGE		
DISCHARGE AREA BLOCKED, AI21	14.800	SQIN	DISCHARGE AREA BLOCKED, AI22	15.700	SQIN
DISCHARGE DIAMETER, DI12	10.950	IN	DISCHARGE DIAMETER, DI22	10.750	IN
LABYRINTH COEFFICIENT, CLAB1	.5000	**	LABYRINTH COEFFICIENT, CLAB2	.5000	**
NUMBER OF BLADES, Z21	8.0	**	NUMBER OF BLADES, Z22	8.0	**
DISCHARGE BLADE ANGLE, BET21	30.000	DEG	DISCHARGE BLADE ANGLE, BET22	25.000	DEG
LABYRINTH FLOW AREA, ALB1	.123	SQIN	LABYRINTH FLOW AREA, ALB2	.120	SQIN
INDUCER INLET TIP DIA, DI11T	7.000	IN	INLET TIP DIAMETER, DI21T	6.343	IN
INDUCER INLET HUB DIA, DI11H	2.740	IN	INLET HUB DIAMETER, DI21H	4.600	IN
			WIDTH, RADIAL THRUST, B2TH	1.300	IN

HOUSING

CROSSOVER AREA, ACR01	4.000	SQIN	CROSSOVER AREA, ACR02	5.400	SQIN
CROSSOVER AREA, ACR03	6.900	SQIN	CROSSOVER AREA, ACR04	8.100	SQIN
DIFFUSER DISCHARGE AREA, ADFD	20.000	SQIN	DIFF. DISCHARGE FLOW ANGLE, BDFD	14.300	DEG

CALCULATED CONSTANTS

VELOCITY OF APPROACH FACTOR, FLOW NOZZLE, VLAP	1.0205	**
ABSOLUT HUMIDITY, AHUM	.0039	
MIXTURE DENSITY, ROMIX	.0723	LB/FT**3
SPECIFIC HEAT CP	.2409	BTU/LB/DEG
SPECIFIC HEAT CV	.1722	BTU/LB/DEG
GAS CONSTANT, RMIX	53.0587	FTLB/LB/DEG
MOLECULAR WEIGHT, WMOL	29.1420	

INLET CONDITION

FLOW NOZZLE EXPANSION FACTOR

TDRY = 85.00 TWET = 67.00 REL HUMIDITY = .37 PWET = .667 INHG

DATA POINT | INLET TEMPERATURE DEG F | IN HG | AMBIENT PRESSURE PSIA | WEIGHT DENSITY LB/CUFT | YANOZ

1	79.700	29.850	14.661	.0738	.97359
2	79.800	29.850	14.661	.0738	.97987
3	79.800	29.850	14.661	.0738	.98477
4	80.000	29.850	14.661	.0737	.98958
5	80.100	29.850	14.661	.0737	.99294
6	80.420	29.850	14.661	.0737	.99460
7	80.500	29.850	14.661	.0737	.99585
8	80.600	29.850	14.661	.0737	.99795
9	80.600	29.850	14.661	.0737	.99930

PUMP DISCHARGE CONDITION

DATA POINT	TEMPERATURE DEG F	STAT PRESSURE PSIA	WEIGHT DENSITY LB/CUFT	VOLUMETRIC FLOW RATE CUFT/S	GPM	WEIGHT FLOW LB/S	BLEED FLOW PERCENT
1	97.020	15.445	.0753	7.1137	3195.196	.5361	3.4315
2	97.700	15.799	.0769	6.2878	2820.710	.4835	4.3846
3	98.900	16.096	.0782	5.5271	2480.724	.4323	5.4857
4	100.500	16.370	.0793	4.6384	2081.851	.3679	7.0733
5	102.000	16.569	.0801	3.8789	1740.964	.3106	8.4186
6	103.000	16.677	.0805	3.4384	1543.256	.2766	10.1902
7	104.500	16.746	.0806	3.0610	1373.855	.2466	11.4441
8	105.600	16.862	.0810	2.2737	1020.949	.1842	15.7072
9	106.200	16.869	.0809	1.5723	705.693	.1272	22.7313

INTERSTAGE CONDITION

DATA POINT	TEMPERATURE DEG F	TOT PRESSURE PSIA (RMR DIA)	STAT PRESSURE PSIA	WEIGHT DENSITY LB/CUFT	FLOW RATE CUFT/S	GPM
1	88.350	15.1422	15.0981	.0748	7.415	3328.155
2	88.700	15.3006	15.2644	.0755	6.680	2998.350
3	89.300	15.4346	15.4053	.0762	5.987	2687.072
4	90.200	15.5644	15.5426	.0767	5.135	2304.631
5	91.000	15.6596	15.6438	.0771	4.367	1960.007
6	91.700	15.7073	15.6944	.0773	3.945	1770.819
7	92.500	15.7374	15.7270	.0773	3.555	1595.622
8	93.100	15.8019	15.7956	.0776	2.747	1233.159
9	93.400	15.8315	15.8262	.0777	2.010	902.181

PUMP OVERALL PERFORMANCE

DATA POINT	SPEED RPM	PRESSURE RATIO	TEMP RISE DEG F ACTUAL	ISENTR	HEAD RISE ISENTR FT	HIS/N**2 FT/RPM**2	Q/N GPM/RPM	ETA TEMP	TORQUE T IN LB	NORM TORQUE T FT**4/RPM**2
1	6996.0	1.055	17.300	8.292	1554.35	.3176-04	.4567	.4712	28.966	.6549-06
2	7000.0	1.079	17.900	11.757	2203.95	.4498-04	.4030	.6427	27.148	.6000-06
3	7002.0	1.099	19.100	14.514	2739.44	.5587-04	.3543	.7445	26.029	.5656-06
4	[illegible]	1.117	20.500	17.220	3229.71	.6603-04	.2974	.8116	23.972	.5141-06
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

6	7223.0	1.138	22.600	20.127	3773.01	.7593-04	.2284	.8474	20.154	.4257-06
7	7221.0	1.143	24.000	20.769	3893.32	.7043-04	.1962	.8155	19.200	.4051-06
8	7205.0	1.150	25.000	21.843	4024.69	.6345-04	.1457	.8101	15.228	.3194-06
9	7013.0	1.151	25.600	21.396	4104.65	.5348-04	.1006	.7680	11.110	.2325-06

EFFICIENCY DERIVED FROM MEASURED SHAFT TORQUE AND MOTOR POWER — REHEAT FACTOR

DATA POINT	MEASURED TORQUE IN LB	NORM TORQUE FT**4/RPM**2	EFFICIENCY EFS	MOTOR POWER WATT	EFFICIENCY EFMOT	RHF (HIS1+HIS2)/HISOV
1	27.8000	.6285-06	.4910	.0000	.0000	1.00273
2	27.5000	.6078-06	.6344	.0000	.0000	1.00109
3	27.2000	.5911-06	.7125	.0000	.0000	1.00133
4	26.1000	.5597-06	.7454	.0000	.0000	1.00084
5	23.6000	.5012-06	.7714	.0000	.0000	1.00063
6	22.3000	.4710-06	.7650	.0000	.0000	1.00056
7	21.3000	.4495-06	.7378	.0000	.0000	1.00091
8	19.0000	.3985-06	.6493	.0000	.0000	1.00078
9	15.6000	.3267-06	.5470	.0000	.0000	1.00077

FIRST STAGE PERFORMANCE

DATA POINT	PRESSURE RATIO	HEAD RISE ISENTR FT	HIS/N**2 FT/RPM**2	Q/N NET GPM/RPM	DELTA T DEG F	ETA TEMP	LAB FLOW PERCENT	PHI(2)	PSI
1	1.0328	920.74	.1898-04	.4599	8.650	.5728	1.731	.2072	.2670
2	1.0436	1229.73	.2510-04	.4103	8.900	.7371	1.907	.1864	.3532
3	1.0528	1482.75	.3024-04	.3638	9.500	.8326	2.110	.1665	.4256
4	1.0616	1726.76	.3525-04	.3075	10.200	.9031	2.500	.1419	.4960
5	1.0681	1904.95	.3888-04	.2583	10.900	.9323	2.974	.1200	.5471
6	1.0714	1994.87	.4068-04	.2295	11.300	.9417	3.359	.1071	.5724
7	1.0734	2051.20	.4185-04	.2045	12.000	.9119	3.768	.0959	.5889
8	1.0778	2171.19	.4425-04	.1521	12.500	.9266	5.082	.0722	.6226
9	1.0799	2226.82	.4526-04	.1048	12.800	.9277	7.386	.0508	.6369

SECOND STAGE PERFORMANCE

DATA POINT	PRESSURE RATIO	HEAD RISE ISENTR FT	HIS/N**2 FT/RPM**2	Q/N NET GPM/RPM	DELTA T DEG F	ETA TEMP	LAB FLOW PERCENT	PHI(2)	PSI	TOT RECIRC PERCENT
1	1.0218	629.86	.1287-04	.4567	8.650	.3884	1.337	.2055	.1879	4.8189
2	1.0344	978.39	.1997-04	.4030	9.000	.5799	1.656	.1848	.2915	6.0410
3	1.0440	1260.34	.2571-04	.3543	9.600	.7003	1.964	.1656	.3753	7.4497
4	1.0526	1505.65	.3074-04	.2974	10.300	.7798	2.462	.1422	.4488	9.5356
5	1.0586	1670.05	.3425-04	.2487	11.000	.8138	3.063	.1212	.5000	11.4817
6	1.0622	1780.26	.3630-04	.2204	11.300	.8404	3.519	.1097	.5300	13.7140
7	1.0644	1846.65	.3766-04	.1962	12.000	.8205	4.003	.0992	.5498	15.4523
8	1.0673	1926.70	.3926-04	.1457	12.500	.8222	5.503	.0773	.5733	-24.2156
9	1.0656	1881.78	.3828-04	.1006	12.800	.7843	8.042	.0575	.5586	30.7733

INDUCER PERFORMANCE

DATA POINT	NORM STAT HEAD RISE FT/RPM**2
1	-.5785-05
2	-.2085-05
3	-.7198-07
4	.1871-05
5	.3737-05
6	.4739-05
7	.5458-05
8	.7596-05
9	.9285-05

FIRST STAGE IMPELLER PERFORMANCE BASED ON STATIC WALL PRESSURES AND CONTINUITY

DATA POINT	MEAN STATIC PRESSURE PSIA	NORM STAT HD RISE FT/RPM**2	STAT HEAD COEFF	SLIP	TOT HEAD COEFF	NORM TOT HD FT/RPM**2	PHI(2)	DENSITY RHOI1 LB/CUFT
1	15.1085	.2077-04	.2923	.6937	.4034	.2867-04	.2072	.0758
2	15.2499	.2314-04	.3256	.7100	.4482	.3185-04	.1864	.0761
3	15.3041	.2522-04	.3549	.7241	.4902	.3483-04	.1665	.0763
4	15.3619	.2748-04	.3867	.7397	.5396	.3835-04	.1419	.0765
5	15.4125	.2943-04	.4141	.7521	.5845	.4154-04	.1230	.0767
6	15.4451	.3067-04	.4316	.7589	.6131	.4357-04	.1071	.0768
7	15.4631	.3139-04	.4417	.7646	.6334	.4532-04	.0959	.0768
8	15.5246	.3371-04	.4743	.7756	.6892	.4898-04	.0722	.0771
9	15.5716	.3542-04	.4985	.7847	.7359	.5230-04	.0508	.0773

SECOND STAGE IMPELLER PERFORMANCE BASED ON STATIC WALL PRESSURES AND CONTINUITY

DATA POINT	MEAN STATIC PRESSURE PSIA	NORM STAT HD RISE FT/RPM**2	STAT HEAD COEFF	SLIP	TOT HEAD COEFF	NORM TOT HD FT/RPM**2	PHI(2)	DENSITY RHOI2 LB/CUFT
1	15.5483	.1578-04	.2303	.7033	.3179	.2177-04	.2055	.0764
2	15.7792	.1837-04	.2682	.7281	.3685	.2524-04	.1848	.0775
3	15.9775	.2064-04	.3013	.7426	.4155	.2846-04	.1656	.0783
4	16.1871	.2349-04	.3430	.7612	.4765	.3263-04	.1422	.0792
5	16.3490	.2584-04	.3773	.7758	.5304	.3633-04	.1212	.0798
6	16.4301	.2700-04	.3942	.7830	.5590	.3829-04	.1097	.0801
7	16.4847	.2791-04	.4075	.7892	.5835	.3996-04	.0992	.0802
8	16.5899	.2928-04	.4275	.8010	.6267	.4306-04	.0773	.0806
9	16.6345	.2972-04	.4340	.8107	.6601	.4521-04	.0575	.0807

CROSSOVER CHANNEL

DATA TOTAL HEAD LOSS COEFFICIENT OVERALL
POINT STA 25 STA 26 STA 27 STA 28 ONE-DIM

1	.0000	.0000	.0000	.0000	.1364
2	.0000	.0000	.0000	.0000	.0951
3	.0000	.0000	.0000	.0000	.0647
4	.0000	.0000	.0000	.0000	.0436
5	.0000	.0000	.0000	.0000	.0375
6	.0000	.0000	.0000	.0000	.0400
7	.0000	.0000	.0000	.0000	.0446
8	.0000	.0000	.0000	.0000	.0666
9	.0000	.0000	.0000	.0000	.0991

CIRCUMFERENTIAL PRESSURE DISTRIBUTION - SECOND STAGE IMPELLER

DATA POINT	NORM AVG STATIC HEAD	RATIO OF STATIC HEAD TO AVERAGE STATIC HEAD RISE (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	.3475-04	.985765	.993774	.993774	.993774	1.005783	1.009784	1.005783	1.009784	1.001780
2	.4246-04	.992284	.995441	.995441	.998598	1.001754	1.004909	1.004909	1.004909	1.001754
3	.5038-04	.991109	.996445	.996445	.999112	.999112	1.004444	1.004444	1.007111	1.001778
4	.5374-04	.990080	.996949	.996949	.999238	1.001525	1.003815	1.003815	1.006102	1.001526
5	.6472-04	.991523	.995648	.997710	.999771	1.001833	1.003894	1.003894	1.003894	1.001833
6	.6768-04	.991354	.996946	.996946	.998910	1.000873	1.004799	1.004799	1.004799	1.000873
7	.6976-04	.993020	.996828	1.000635	.996828	1.002538	1.004440	1.002538	1.002538	1.000635
8	.7353-04	.986335	.996814	1.020133	.991426	.996814	1.018341	.991426	.995018	1.003994
9	.7498-04	.934031	.985787	.985787	.977007	.992805	1.024334	1.010332	1.013334	1.026083

RADIAL FORCE PARAMETER RAFK AND FORCE VECTOR ANGLE THETA MEASURED COUNTER-CLOCKWISE WHEN LOOKING FROM SUCTION
THETA = 0 AT INSTRUMENTATION STATION 34

DATA POINT	RAFK IN**2	THETA DEG
1	.166309	46.43
2	.097920	48.74
3	.092223	54.69
4	.087471	44.91
5	.082236	40.19
6	.058498	44.24
7	.064348	34.88
8	.075385	321.88
9	.348201	79.99

DIFFUSION HOUSING - SECOND STAGE

DATA POINT	NORM DIFF DISCH MEAN STAT HD FT/RPM**2	HEAD LOSS COEFF HOUSG ONE-DIM	HEAD LOSS COEFF DIFF ONE DIM	HEAD LOSS COEFF VOLUTE ONE-DIM
1	.6607-05	.1301	.1277	.0024
2	.1542-04	.0770	.0624	.0147
3	.2141-04	.0492	.0325	.0077
4	.2761-04	.0279	.0141	.0137

5	.3194-04	.0304	.0133	.0171
6	.3487-04	.0290	.0155	.0135
7	.3575-04	.0337	.0192	.0145
8	.3772-04	.0554	.0429	.0125
9	.3704-04	.1014	.0899	.0115

7. OVERALL PERFORMANCE OF A TWO-STAGE LIQUID HYDROGEN PUMP

J. J. Brunner
18 April 1972

COMPUTER PROGRAM

OVERALL PERFORMANCE OF A TWO-STAGE LIQUID HYDROGEN PUMP

I. INTRODUCTION

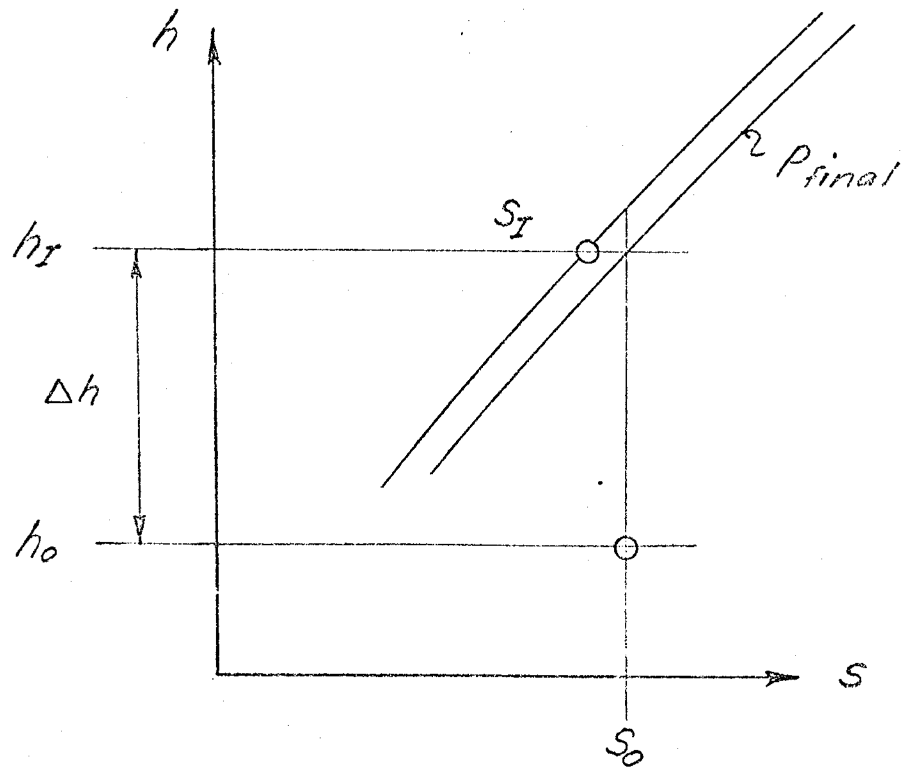
This program computes overall performance parameters of a two-stage liquid hydrogen pump. Inlet conditions and stage performance parameters in normalized form are input. Print-out includes overall isentropic head, discharge pressure, reheat factor, efficiency and power. This program makes extensive use of the liquid hydrogen property deck prepared from Reference 1.

This program was used primarily for the computation of overall performance predictions for the NERVA two-stage pump. The undesired but not too severe scatter in reheat factors obtained resulted from inadequacies in the fluid property deck.

II. BASIC CALCULATIONS

The stage discharge pressure is determined from the specified isentropic head rise Δh and the inlet entropy S_o defined by inlet temperature To and inlet pressure Po. In this program the stage discharge pressure is computed by subroutine PRETE. In PRETE, an initial pressure is first calculated using the fluid density at the inlet. The final pressure is obtained by iteration. Increments of pressure determined from the difference in entropies $S_o - S_i$ and the slope of the line of constant pressure (see diagram below) are added to the initial pressure. The solution is satisfactory when:

$$S_o - S_i \leq \text{Specified Tolerance}$$



The reheat factor herein defined as the ratio of the sum of the isentropic stage heads to the overall isentropic head rise is:

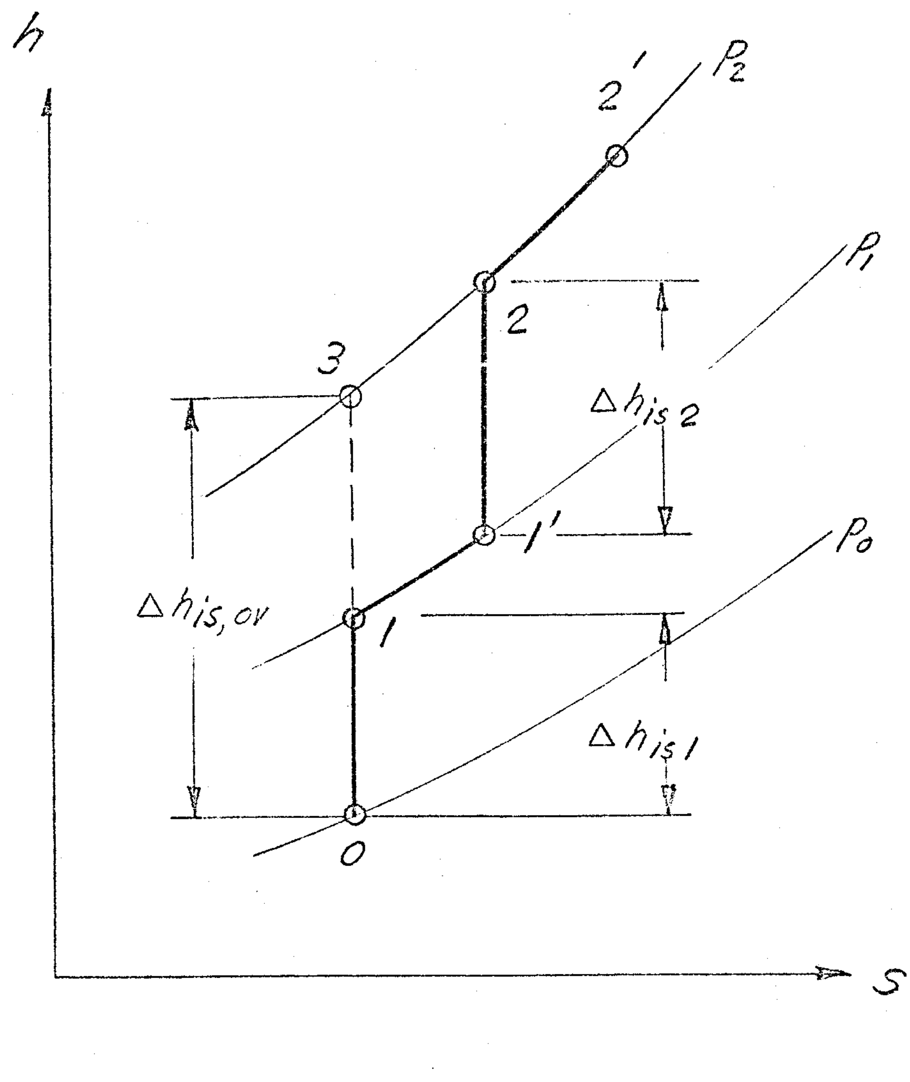
$$\mu = \frac{\Sigma \Delta h_{is,stage}}{\Delta h_{is, overall}} > 1.0$$

Reference 1 - NBS Report No. 9288 Cryogenic Engineering Laboratory National Bureau of Standards, Boulder, Colorado, 18 August 1967

The overall efficiency of a multi-stage pump is then:

$$\eta_{ov} = \frac{1}{\mu} \eta_{stage}$$

assuming that the efficiency of all stages is the same.



After the end point 2' is determined (refer to above diagram), the overall isentropic head or the pump ideal head rise is obtained using the function HFUN. This function determines the enthalpy at point 3 from the discharge pressure at point 2 and the inlet entropy S_o by an iterative method similar to that of subroutine PRETE.

III. FLUID PROPERTY FUNCTIONS

The following liquid hydrogen property functions are used in the program:

PTENTH	looks up enthalpy from pressure and temperature
PTENTR	looks up entropy from pressure and temperature
PHTEMP	looks up temperature from pressure and enthalpy
PHDENS	looks up density from pressure and enthalpy

A complete program listing and a sample print-out is presented on following pages.

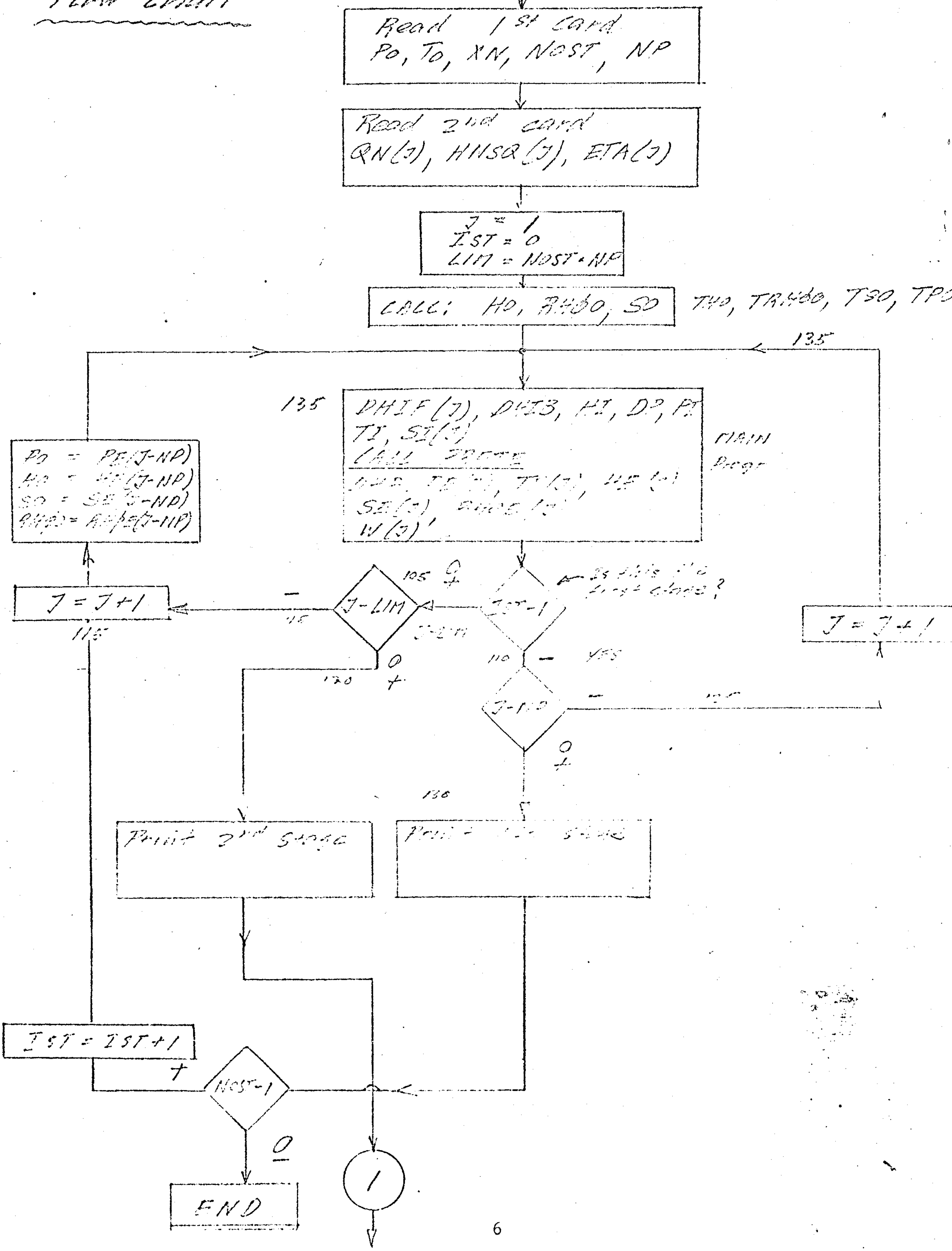
NOMENCLATURE INPUT

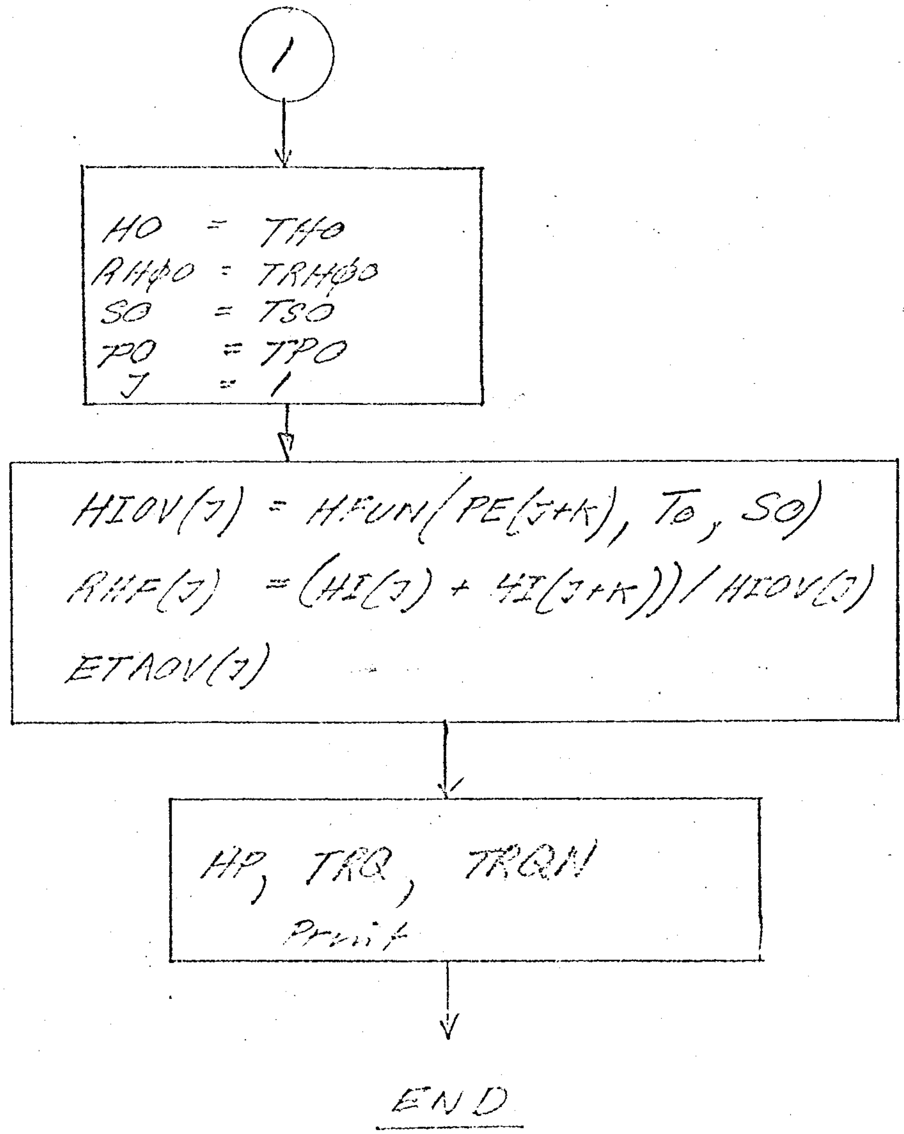
SYMBOL	DESCRIPTION	UNITS	FORMAT
PO	Inlet Pressure	psia	F
TO	Inlet Temperature	DEGR	F
XN	Rotational Speed	RPM	F
NOST	Number of Stages	-	I4
NP	Number of Data Points (Q/N)	-	I4
First and Second Stage Parameters:			
QN	Flow Parameter Q/N	GPM/RPM	F
HNSQ	Normalized Head H/N^2	$FT/(RPM)^2$	E
ETA	Efficiency	-	F

Overall Performance of a Two-Stage Liquid Hydrogen Pump

Flow Chart

J. J. Brunner
4-18-72
Page




1
HO = THO
RHφO = TRHφO
SO = TSO
TPO = TPO
J = 1
HIOV(J) = HFUN(PE(J+K), To, SO)
RHF(J) = (HI(J) + HI(J+K))/HIOV(J)
ETAOV(J)
HP, TRQ, TRQN
Print
END

IBM FORTRAN Coding Form

GX28-7327-6 U/M050
Printed in U.S.A.

PROGRAM Overall Performance of a Two-Stage Liquid Hydrogen Pump

PROGRAMMER | DATE | PUNCHING INSTRUCTIONS | GRAPHIC | PUNCH | PAGE OF | CARD ELECTRO NUMBER*

STATEMENT NUMBER	FORTRAN STATEMENT					
	PO	TO	XN	NOST	NP	
	QN	HNSQ	ETA			1st stage stack as many as NP indicates
	QN	HNSQ	ETA			2nd stage stack as many as NP indicates

8

```
@I FOR PRETE                                                                  29 SEP 71   12:59:01.013
UNIVAC 1108 FORTRAN V LEVEL   2206 0018 F50185
THIS COMPILATION WAS DONE ON 29 SEP 71 AT 12:59:01
```

```
SUBROUTINE PRETE      ENTRY POINT 000105

STORAGE USED (BLOCK, NAME, LENGTH)

      0001   *CODE   000126
      0000   *DATA   000032
      0002   *BLANK  000000

EXTERNAL REFERENCES (BLOCK, NAME)

      0003   PHTEMP
      0004   PTENTR
      0005   NWDU$
      0006   NI02$
      0007   NSTOP$
      0010   NERR3$

STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000007 10L       0000   000010 100F      0001   000072 20L       0001   000027 25L       0001   000043 30L
 0001   000050 40L       0001   000063 50L       0000 I 000000 COUNT     0000 R 000002 DP        0000 R 000006 DS
 0000 R 000001 P         0003 R 000000 PHTEMP    0004 R 000000 PTENTR    0000 R 000004 Q         0000 R 000005 S
 0000 R 000007 SLOPE     0000 R 000003 T
```

```
00101             SUBROUTINE PRETE(HI,PI,TI,S0,SI)
00103             INTEGER COUNT
00104         100 FORMAT(/2X,'NO SOLUTION IN PRETE')
00105             COUNT = 1
00106             P = PI + 20.
00107             DP = P - PI
00110          10 T = PHTEMP(P,HI,Q)
00111             S = PTENTR(P,T)
00112             DS = SI - S
00113             IF(DS) 25,20,25
00115          25 SLOPE = DP/DS
00117             IF(ABS(SI/S0-1.)-1.E-05) 20,20,30
00122          30 IF(COUNT - 15) 40,50,50
00125          40 COUNT = COUNT + 1
00126             SI = S
00127             DP = SLOPE * (SI-S0)
00130             P = P + DP
00131             GO TO 10
00132          50 WRITE( 6,100)
00134             STOP
00135          20 PI = P
00136             TI = T
00137             RETURN
```

```
@I FOR HFUN                                                        29 SEP 71   12:59:00.038
UNIVAC 1108 FORTRAN V LEVEL  12206 0018 F50185
THIS COMPILATION WAS DONE ON 29 SEP 71 AT 12:59:00

   FUNCTION HFUN        ENTRY POINT 000106

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001   *CODE    000123
         0000   *DATA    000033
         0002   *BLANK   000000

   EXTERNAL REFERENCES (BLOCK, NAME)

         0003   PTENTR
         0004   PTENTH
         0005   NWDUS
         0006   NIO2$
         0007   NSTOP$
         0010   NERR3$

   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

   0000    000010 10F       0001    000042 100L      0001    000047 150L      0001    000062 160L      0001    000071 200L
   0001    000014 50L       0001    000026 60L       0000 I 000001 COUNT      0000 R 000006 DS        0000 R 000004 DT
   0000 R 000000 HFUN       0004 R 000000 PTENTH     0003 R 000000 PTENTR     0000 R 000007 SLOPE     0000 R 000002 S21
   0000 R 000005 S22        0000 R 000003 T

 00101      1*          FUNCTION HFUN(P2,T1,S1)
 00103      2*          INTEGER COUNT
 00104      3*       10 FORMAT(/2X,'NO SOLUTION OR S2 = S1  IN HFUN')
 00105      4*          COUNT = 1
 00106      5*          S21 = PTENTR(P2,T1)
 00107      6*          T = T1 + 0.5
 00110      7*          DT = T-T1
 00111      8*       50 S22 = PTENTR(P2,T)
 00112      9*          DS = S22 - S21
 00113     10*          IF(DS) 60,200,60
 00116     11*       60 SLOPE = DT/DS
 00117     12*          IF(ABS(1.-S22/S1)-1.E-05) 200,200,100
 00122     13*      100 IF (COUNT-30) 150,160,160
 00123     14*      150 COUNT = COUNT + 1
 00126     15*          S21 = S22
 00127     16*          DT = SLOPE*(S1-S22)
 00130     17*          T = T+DT
 00131     18*          GO TO 50
 00132     19*      160 WRITE( 6,10)
 00134     20*          STOP
 00135     21*      200 HFUN  = PTENTH(P2,T)
 00136     22*          RETURN
 00137     23*          END
```

```
@I FOR MAIN                                                          29 SEP 71    12:59:02.053
UNIVAC 1108 FORTRAN V LEVEL   2206 0018 F5018S
THIS COMPILATION WAS DONE ON 29 SEP 71 AT 12:59:02

     MAIN PROGRAM

     STORAGE USED (BLOCK, NAME, LENGTH)

           0001    *CODE    000773
           0000    *DATA    001760
           0002    *BLANK   000003

     EXTERNAL REFERENCES (BLOCK, NAME)

           0003    PTENTH
           0004    PTENTR
           0005    PHDENS
           0006    PHTEMP
           0007    PRETE
           0010    HFUN
           0011    NRDU$
           0012    NIO2$
           0013    NIO1$
           0014    NWDU$
           0015    NSTOP$

     STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

  0000     001265 1F       0000     001261 10F      0000     001263 100F     0001     000302 105L     0000     001351 11F
  0001     000307 110L     0001     000472 115L     0001     000517 120L     0001     000314 125L     0000     001365 13F
  0001     000320 130L     0001     000161 135L     0000     001417 14F      0001     000427 140L     0001     000373 145L
  0001     000464 147L     0000     001430 15F      0001     000036 157G     0000     001453 16F      0000     001473 17F
  0000     001523 19F      0000     001307 2F       0001     000004 200L     0000     001546 21F      0001     000026 220L
  0000     001570 23F      0000     001577 25F      0000     001605 27F      0001     000347 270G     0000     001312 3F
  0000     001613 31F      0001     000415 315G     0001     000451 335G     0000     001620 35F      0000     001626 37F
  0001     000552 370G     0000     001656 39F      0000     001677 41F      0001     000512 412G     0000     001710 43F
  0001     000636 430G     0000     001712 45F      0001     000752 456G     0000     001725 47F      0000     001737 49F
  0000     001316 5F       0000     001323 6F       0000     001344 7F       0000     001355 8F       0001     000756 990L
  0001     000767 999L     0000 R 001072 DHB       0000 R 001034 DHIB      0000 R 000000 DHIF      0000 R 001260 DHIOB
  0000 R 000644 DHIOF     0000 R 001247 DP        0000 R 000132 ETA       0000 R 000512 ETAOV     0000 R 000264 HE
  0010 R 000000 HFUN      0000 R 001246 HI        0000 R 001165 HION      0000 R 000416 HIOV      0000 R 000036 HNSQ
  0000 R 000702 HP        0000 R 001235 HØ        0000 I 001245 IST       0000 I 001234 J         0000 I 001255 KS
  0000 I 001233 LIM       0000 I 001224 LR        0000 I 001225 LW        0000 I 001231 NOST      0000 I 001232 NP
  0000 R 001241 OMEG      0000 R 000170 PE        0005 R 000000 PHDENS    0006 R 000000 PHTEMP    0000 R 001250 PI
  0003 R 000000 PTENTH    0004 R 000000 PTENTR    0000 R 001226 PØ        0000 R 001253 QE        0000 R 001252 QI
  0000 R 001257 QII       0000 R 000776 QN        0000 R 000454 RHF       0000 R 000360 RHOE      0000 R 001237 RHOØ
  0000 R 001254 RLE       0000 R 001240 RLØ       0000 R 000322 SE        0000 R 000074 SI        0000 R 001236 SØ
  0000 R 001130 S00       0000 R 000226 TE        0000 R 001244 THØ       0000 R 001251 TI        0000 R 000550 TORQ
  0000 R 000606 TORQN     0000 R 001243 TSØ       0000 R 001242 TTØ       0000 R 001227 TØ        0000 R 001256 T00
  0000 R 000740 WDOT      0000 R 001230 XN

 00101      1*          DIMENSION DHIF(30),HNSQ(30),SI(30),ETA(30),PE(30),TE(30),HE(30),
```

```
00101          1SE(30),RHOE(30),HIOV(30),RHP(30),ETIOV(30),TCRQ(30),TORQN(30),
00101          2DHIOF(30),HP(30),WDOT(30),QN(30),DHIB(30),DHB(30),SQO(30),HION(30)
00103           LR=5
00104           LW=6
00105        10 FORMAT(2X,F15.5)
00106       100 FORMAT(2X,E10.4)
00107         1 FORMAT('1',45X,'MULTISTAGE LIQUID HYDROGEN PUMP'/37X,'OVERALL PERF
00107          1ORMANCE BASED ON STAGE PERFORMANCE'///)
00110         2 FORMAT( 2F10.3,F10.1,2I5)
00111         3 FORMAT(F10.4,E10.4,F10.4)
00112         5 FORMAT( 2X,'SUCTION CONDITION'/)
00113         6 FORMAT( 6X,'PRESSURE',4X,'TEMPERATURE',5X,'SPEED XN',5X,'NO OF STA
00113          1GES',4X,'NO OF POINTS'/)
00114         7 FORMAT( 6X,'P0, PSIA',5X,'T0, DEG R',8X,'RPM'/)
00115         8 FORMAT(2F15.3,F15.1,I10,I15)
00116        11 FORMAT(//2X,'FIRST STAGE'//)
00117        13 FORMAT( 10X,'Q/N',7X,'H/N**2',9X,'ETA',4X,'HEAD RISE',8X,'SI',
00117          15X,'PRESSURE PE',3X,'TEMP TE')
00120        14 FORMAT( 7X,'GPM/RPM',4X,'FT/RPM**2',18X,'FT',7X,'BTU/LB/DEG',5X,
00120          1'PSIA',7X,'DEG R'/)
00121        15 FORMAT(10X,'Q/N',5X,'ENTHALPY RISE',3X,'ENTHALPY RISE',5X,'ENTHALP
00121          1Y HE',4X,'ENTROPY SE',6X,'DENSITY')
00122        16 FORMAT(//20X,'ISENTROPIC',7X,'ACTUAL',10X,'DISCHARGE',6X,'DISCHARG
00122          1E',5X,'DISCHARGE')
00123        17 FORMAT(7X,'GPM/RPM',4X,'DHIB, BTU/LB',5X,'DHB,BTU/LB',7X,'BTU/LB',
00123          19X,'BTU/LB/R',5X,'LB/FT**3',6X,'WDOT LB/S'/)
00124        19 FORMAT(10X,'Q/N',5X,'ENTHALPY RISE',3X,'ENTHALPY RISE',5X,'ENTHALP
00124          1Y HE',4X,'ENTROPY SE',6X,'DENSITY',7X,'FLOW RATE')
00125        21 FORMAT(7X,'GPM/RPM',4X,'DHIB, BTU/LB',5X,'DHB,BTU/LB',7X,'BTU/LB',
00125          19X,'BTU/LB/R',7X,'LB/FT**3'/)
00126        23 FORMAT(F15.3,E13.4,F12.4,F12.1,F12.4,2F12.3/)
00127        25 FORMAT(F15.3,F12.3,F15.3,F18.3,2F15.3/)
00130        27 FORMAT(F15.3,F12.3,F15.3,F18.3,3F15.3/)
00131        31 FORMAT(//2X,'SECOND STAGE'//)
00132        35 FORMAT(//2X,'OVERALL PERFORMANCE'//)
00133        37 FORMAT(10X,'Q/N',4X,'ISENT HEAD',3X,'HIS/N**2',5X,'S0',6X,'REHEAT'
00133          1,3X,'EFFICIENCY',3X,'POWER',4X,'TORQUE',5X,'NORM TORQUE')
00134        39 FORMAT( 7X,'GPM/RPM',3X,'RISE, FT',16X,'CHECK',5X,'FACTOR',25X,'FT
00134          1LB',6X,'FTLB/RPM**2'/)
00135        41 FORMAT(F15.3,F11.1,E13.4,2F9.4,F11.4,F10.1,F12.2,E15.4/)
00136        43 FORMAT( 3F15.4//)
00137        45 FORMAT(//5X,'ENTHALPY H0',5X,'ENTROPY S0',5X,'DENSITY RHO0')
00140        47 FORMAT(5X,'BTU/LB',8X,'BTU/LB/DEG R',6X,'LB/FT**3'/)
00141        49 FORMAT(2X,F15.7)
00142       200 READ(LR,2)  P0,T0,XN,NOST,NP
00151           LIM = NOST * NP
00152           IF(P0) 999,999,220
00155       220 READ(LR,3) (QN(J),HNSQ(J),ETA(J),J=1,LIM)
00165           WRITE(LW,1)
00167           WRITE(LW,5)
00171           WRITE(LW,6)
00173           WRITE(LW,7)
00175           WRITE(LW,8)  P0,T0,XN,NOST,NP
00204           H0 = PTENTH(P0,T0)
00205           S0 = PTENTR(P0,T0)
00206           RHO0 = PHDENS(P0,H0,RL0) * 1728.
00207           OMEG = 0.10472 * XN
00210           TT0 = T0
00211           TS0 = S0
00212           TH0 = H0
```

```
00213          J = 1
00214          IST = 0
00215          WRITE(LW,45)
00217          WRITE(LW,47)
00221          WRITE(LW,43) H0,S0,RHO0
00226      135 DHIF(J) = HNSQ(J) * XN**2
00227          DHIB(J) = DHIF(J)/778.26
00230          HI = H0 + DHIB(J)
00231          DP  = RHO0/144. * DHIF(J)
00232          PI = P0 + DP
00233          TI  = PHTEMP(PI,HI,QI)
00234          SI(J) = PTENTR(PI,TI)
00235          CALL PRETE(HI,PI,TI,S0,SI(J))
00236          DHB(J) = DHIB(J)/ETA(J)
00237          HE(J) = H0 + DHB(J)
00240          PE(J) = PI
00241          TE(J) = PHTEMP(PE(J),HE(J),QE)
00242          SE(J) = PTENTR(PE(J),TE(J))
00243          RHOE(J) = PHDENS(PE(J),HE(J),RLE)*1728.
00244          WDOT(J) = RHOE(J)/448.8*XN*QN(J)
00245          IF(IST-1) 110,105,105
00250      105 IF(J-LIM)  115,120,120
00253      110 IF(J-NP) 125,130,130
00256      125 J=J+1
00257          GO TO 135
00260      130 WRITE(LW,11)
00262          WRITE(LW,13)
00264          WRITE(LW,14)
00266          WRITE(LW,23) (QN(J),HNSQ(J),ETA(J),DHIF(J),SI(J),PE(J),TE(J),
00266         1J=1,NP)
00302          WRITE(LW,16)
00304          IF(NOST-1) 140,140,145
00307      145 WRITE(LW,15)
00311          WRITE(LW,21)
00313          WRITE(LW,25) (QN(J),DHIB(J),DHB(J),HE(J),SE(J),RHOE(J),J=1,NP)
00326          GO TO 147
00327      140 WRITE(LW,19)
00331          WRITE(LW,17)
00333          WRITE(LW,27) (QN(J),DHIB(J),DHB(J),HE(J),SE(J),RHOE(J),WDOT(J),J=1
00333         1,NP)
00347          GO TO 990
00350      147 IST = IST + 1
00351          KS = IST * NP + 1
00352      115 J=J+1
00353          P0 = PE(J-NP)
00354          H0 = HE(J-NP)
00355          S0  = SE(J-NP)
00356          RHO0 = RHOE(J-NP)
00357          GO TO 135
00360      120 WRITE(LW,31)
00362          WRITE(LW,13)
00364          WRITE(LW,14)
00366          WRITE(LW,23) (QN(J),HNSQ(J),ETA(J),DHIF(J),SI(J),PE(J),TE(J),
00366         1J=KS,LIM)
00402          WRITE(LW,16)
00404          WRITE(LW,19)
00406          WRITE(LW,17)
00410          WRITE(LW,27) (QN(J),DHIB(J),DHB(J),HE(J),SE(J),RHOE(J),WDOT(J),J=K
00410         1S,LIM)
00424          S0 = TS0
```

```
00425         T0 = TT2
00426         H0 = TH2
00427         DO 150 J=1,NP
00432         HIOV(J) = HFUN(PE(J+NP),T0,S0)
00433         T00 = PHTEMP(PE(J+NP),HIOV(J),QII)
00434         S00(J) = PTENTR(PE(J+NP),T00)
00435         DHIOB    = HIOV(J) - H0
00436         DHIOF(J) = DHIOB   * 778.26
00437         HION(J) = DHIOF(J)/XN**2
00440         RHF(J) = (DHIF(J) + DHIF(J+NP))/DHIOF(J)
00441         ETAOV(J)   =DHIOF(J)/(DHIF(J)/ETA(J)+DHIF(J+NP)/ETA(J+NP))
00442         HP(J) =DHIOF(J)*WDOT(J)/550./ETAOV(J)
00443         TORQ(J) = 550. * HP(J)/OMEG
00444     150 TORQN(J)= TORQ(J)/XN**2
00446         WRITE(LW,35)
00450         WRITE(LW,37)
00452         WRITE(LW,39)
00454         WRITE(LW,41) (QN(J),DHIOF(J),HION(J),S00(J),RHF(J),ETAOV(J),HP(J),
00454        1TORQ(J),TORQN(J),J=1,NP)
00472     990 CONTINUE
00473         GO TO 200
00474     999 STOP
00475         END

      END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

MULTISTAGE LIQUID HYDROGEN PUMP
OVERALL PERFORMANCE BASED ON STAGE PERFORMANCE

SUCTION CONDITION

PRESSURE PO, PSIA	TEMPERATURE TO, DEG R.	SPEED XN RPM	NO OF STAGES	NO OF POINTS
21.900	36.400	27000.0	2	3

ENTHALPY HO BTU/LB	ENTROPY SO BTU/LB/DEG R	DENSITY RHOO LB/FT**3
-109.9985	1.8998	4.4160

FIRST STAGE

Q/N GPM/RPM	H/N**2 FT/RPM**2	ETA	HEAD RISE FT	SI BTU/LB/DEG	PRESSURE PE PSIA	TEMP TE DEG R
0.195	0.3780E-04	0.7100	27556.2	1.8999	880.601	47.130
0.220	0.3500E-04	0.7250	25515.0	1.8998	809.419	45.993
0.290	0.2850E-04	0.6400	20776.5	1.8998	660.513	46.321

Q/N GPM/RPM	ISENTROPIC ENTHALPY RISE DHIB, BTU/LB	ACTUAL ENTHALPY RISE DHB,BTU/LB	DISCHARGE ENTHALPY HE BTU/LB	DISCHARGE ENTROPY SE BTU/LB/R	DISCHARGE DENSITY LB/FT**3
0.195	35.407	49.870	-60.029	2.223	4.477
0.220	32.785	45.220	-64.678	2.187	4.477
0.290	26.696	41.713	-68.186	2.254	4.395

SECOND STAGE

Q/N GPM/RPM	H/N**2 FT/RPM**2	ETA	HEAD RISE FT	SI BTU/LB/DEG	PRESSURE PE PSIA	TEMP TE DEG R
0.195	0.3620E-04	0.6880	26389.8	2.2234	1728.537	57.840
0.220	0.3420E-04	0.6950	24931.8	2.1869	1614.314	55.965
0.290	0.2730E-04	0.6410	19901.7	2.2541	1272.553	55.556

Q/N GPM/RPM	ISENTROPIC ENTHALPY RISE DHIE, BTU/LB	ACTUAL ENTHALPY RISE DHB,BTU/LB	DISCHARGE ENTHALPY HE BTU/LB	DISCHARGE ENTROPY SE BTU/LB/R	DISCHARGE DENSITY LB/FT**3	FLOW RATE WDOT LB/S
0.195	33.909	49.286	-10.743	2.506	4.531	53.155
0.220	32.035	46.094	-18.584	2.453	4.543	60.122
0.290	25.572	39.894	-28.292	2.531	4.392	76.621

OVERALL PERFORMANCE

Q/N GPM/RPM	ISENT HEAD RISE FT	INLET ENTROPY CHECK	REHEAT FACTOR	OVERALL EFFICIENCY	POWER HP	TORQUE FTLB	NORM TORQUE FTLB/RPM**2
0.195	52948.5	1.8866	1.0188	0.686	7369.6	1433.56	0.1966E-05
0.220	49533.8	1.8878	1.0184	0.697	7655.8	1489.22	0.2043E-05
[illegible]	[illegible]	[illegible]	1.0376	0.617	[illegible]	[illegible]	[illegible]

8. CROSSOVER PASSAGE DESIGN

J. J. Brunner
4-13-72

COMPUTER PROGRAM
CROSSOVER PASSAGE DESIGN

I. INTRODUCTION

This program presents a method for determining the passage surface shapes of crossover channels employed in multistage pumps. The meridional velocity as well as the tangential velocity distribution are prescribed as a function of meridional stream line length. Coordinates defining the channel shape along the mean line are calculated. Suction and pressure surface velocities are estimated from momentum considerations assuming a linear velocity distribution from the suction surface to the pressure surface of the passage.

The method of analysis employed was devised by M. C. Huppert and the program was first used to smooth out the crossover passages of the 2nd stage NERVA Turbopump discussed in Reference 1.

II. BASIC EQUATIONS

The tangential velocity distribution is described in the following way:

$$RC_u = R_1 C_{u1} + [R2\ Cu_2 - R1\ Cu_1] \underbrace{Y^n (2 - Y^n)}_{f} \qquad (1)$$

where:

$R1\ Cu_1$	=	whirl at inlet of crossover passage
$R2\ Cu_2$	=	whirl at exit of crossover passage
f	=	whirl distribution factor
Y	=	$\frac{m}{M}$ ratio of passage length to total passage length in meridional plane.
m	=	distance along mean line of crossover passage in the meridional plane.
M	=	Total length of crossover passage in the meridional plane.
n	=	Exponent to specify whirl distribution (surface loading)

Reference 1 - Aerojet Nuclear Systems Company, Engineering Operations Report N8300R:71-076, NERVA Turbopump Design Report, Volume 1, September 1971

The whirl distribution factor f is plotted in Figure 1 as a function of Y for two values of n.

The geometry of typical pump crossover passages are depicted in Figures 2 and 3.

The meridional velocity distribution is directly input (C_m on card 2; refer to input format).

The tangential width of the crossover passage A is computed from continuity as follows:

$$A = \frac{Q}{Z\ B\ C_m} \qquad (2)$$

where:

Q	=	total flow, ft^3/s
B	=	meridional width of the crossover passage
Z	=	number of passages

The angle of the mean streamline of the crossover passage β is determined from C_m and the value of C_u obtained from expression (1).

$$\tan \beta = \frac{C_m}{C_u}$$

The wrap angle of the mean flow surface of the crossover passage is then given by:

$$\theta_m = \frac{180}{\Pi}\ M \int \frac{dx}{R \tan \beta} \qquad (3)$$

and the wrap angles of the passage surfaces are:

Suction Surface

$$\theta_s = \theta_m - \frac{A}{2R} \frac{180}{\Pi}$$

Pressure Surface

$$\theta_p = \theta + \frac{A}{2R} \frac{180}{\Pi}$$

Suction and pressure surface velocities on the mean streamline are estimated from momentum considerations.

$$H_p - H_s = \frac{Q}{g \ R \ B \ m \ Z} \qquad \frac{\partial (R \ C_u)}{\partial X} \tag{4}$$

H_p = pressure surface static head, ft

H_s = suction surface static head, ft

The rate of change in which $\frac{\partial (R \ C_u)}{\partial X}$ is obtained by differentiation of expression (1).

Thus:

$$\frac{\partial (R \ C_u)}{\partial \ X} = (R_2 \ Cu_2 - R_1 \ Cu_1) \ 2nX^{n-1} \ (1 - X^n) \tag{5}$$

Assuming constant total head (no losses) the surface velocities are:

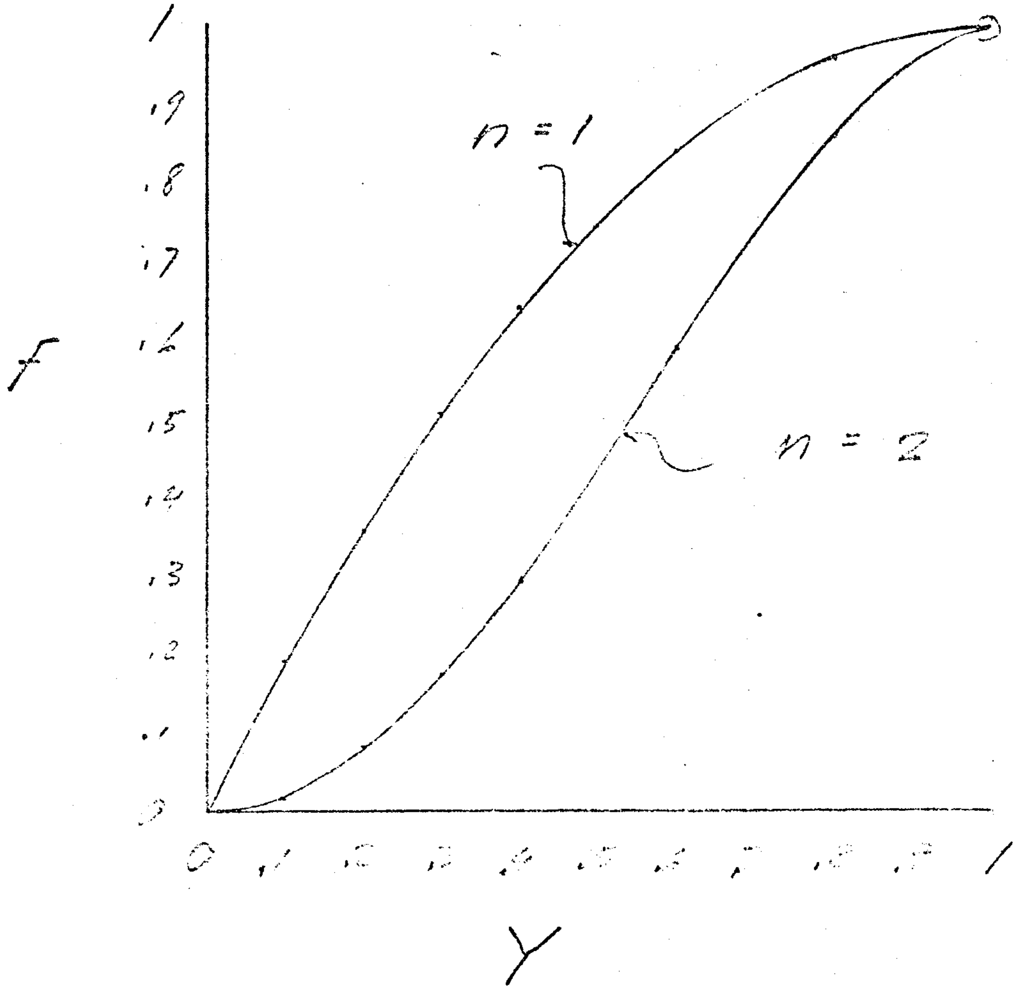
$$H_p - H_s = \frac{C_s^{\ 2} - C_p^{\ 2}}{2 \ g} = (C_s - C_p) \ \frac{C_{Ave}}{g} \tag{6}$$

where:

$$C_{Ave.} = \sqrt{C_m^{\ 2} + C_u^{\ 2}}$$

Whirl distribution factor

$$f = 1-(1-Y^n)^2 = Y^n(2-Y^n)$$



For crossover passages $n \approx 1$

Figure 1

4-13-72

Assuming a linear velocity distribution in the passage from the suction surface to the pressure surface the surface velocities C_s and C_p are:

$$C_s = C_{Ave} + \frac{C_s - C_p}{2}$$

and

$$C_p = C_{Ave} - \frac{C_s - C_p}{2}$$

A complete listing and a sample printout are presented on the following pages.

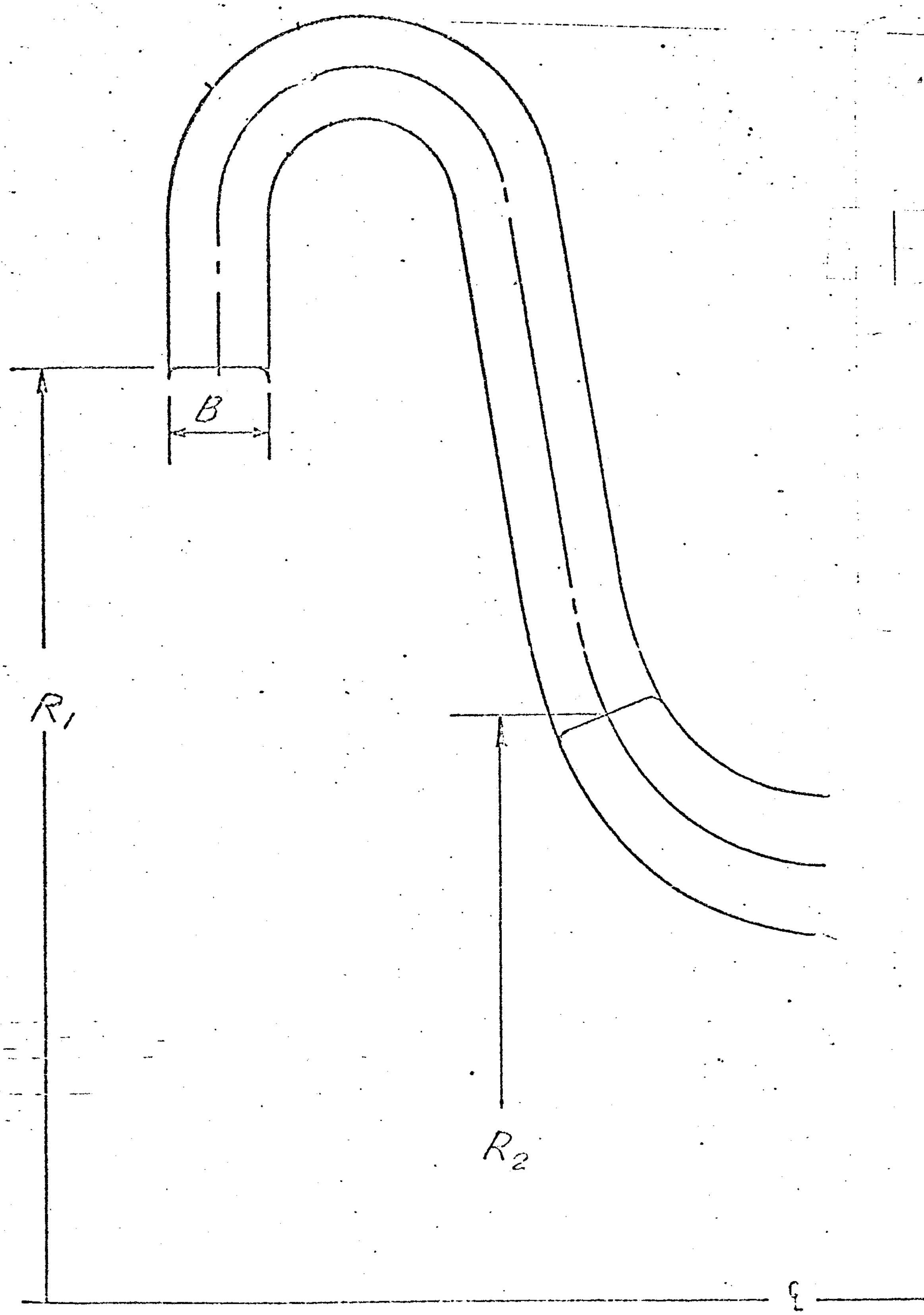


FIGURE 2 MERIDIONAL CROSS SECTION OF CROSS OVER PASSAGES

CROSSOVER CHANNEL

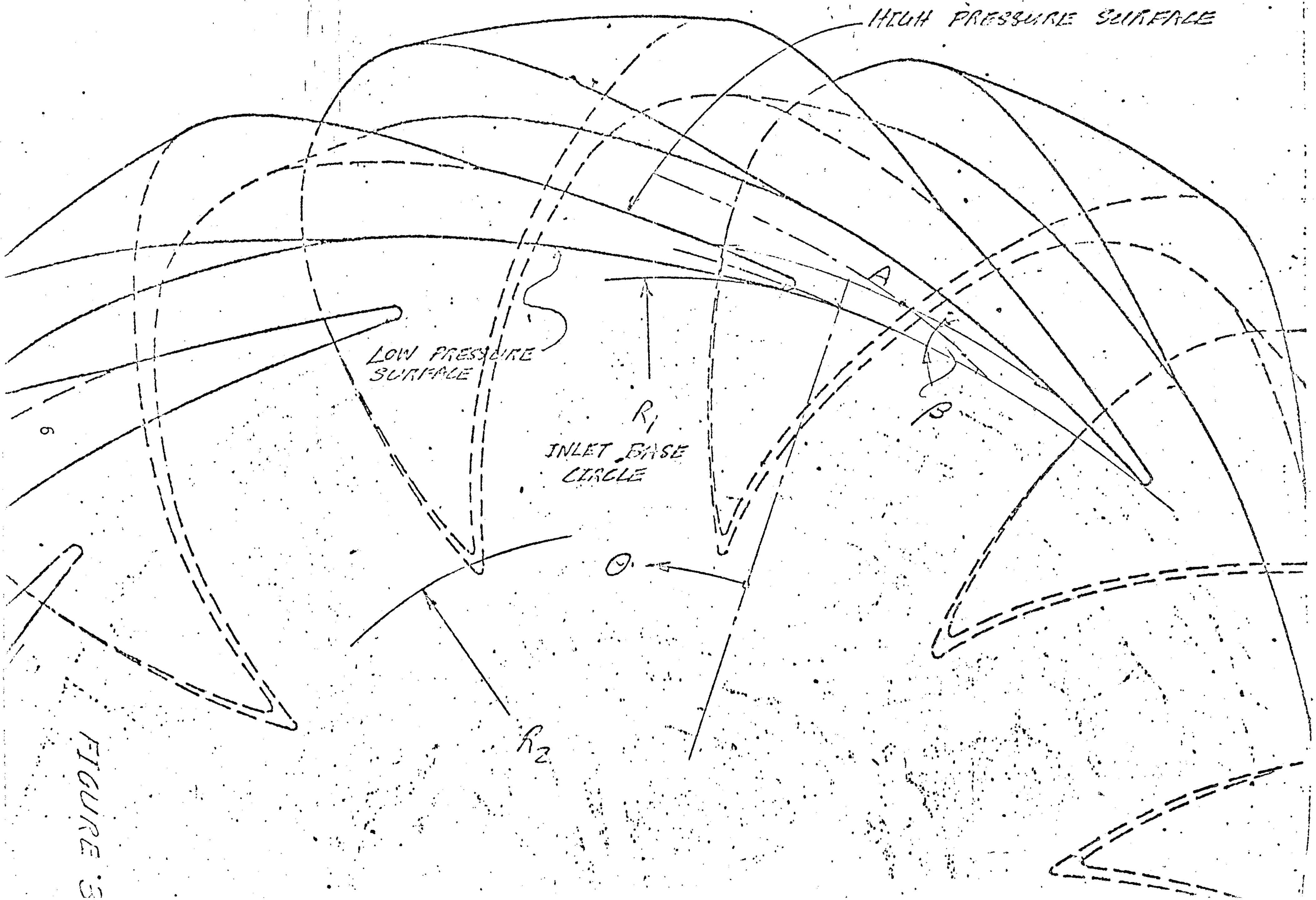


FIGURE 5

IBM

FORTRAN Coding Form

GX28-7327-6 U/M050
Printed in U.S.A.

CROSSOVER PASSAGE DESIGN

FORTRAN STATEMENT

R1	CU1	CU2Ø	CU2A	TM	Z	Q	EN	LMT
R	Y	CM	B					

Nomenclature:

R1 = Inlet Radius
CU1 = Tangential Component, inlet absolute velocity, ft/sec
CU2Ø = Tangential Component, ideal discharge absolute velocity, ft/sec
CU2A = Tangential Component, actual discharge absolute velocity, ft/sec
TM = Total passage length, inches
Z = Number of vanes
Q = Volumetric Flow, ft^3/sec
EN = Exponent, Vane loading
LMT = Total length of array, total number of points input (30 max.)
R = Local radius, inches
Y = Ratio passage length to total passage length
CM = Local meridional velocity, ft/sec
B = Local passage height, inches

```
          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=72,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,NOXREF
ISN 0002              DIMENSION TITLE (18)
ISN 0003              DIMENSION R(50),Y(50),CM(50),B(50),A(50),CU(50),THTA(50),THTS(50),
                     1THTP(50),        BETA(50)
ISN 0004              DIMENSION CUA(50),CS(50),CP(50),CAV(50),RCP(50)
ISN 0005              KR=5
ISN 0006              KW=6
ISN 0007            1 FORMAT(7F10.3,F5.2,I5)
ISN 0008            2 FORMAT(4F10.3)
ISN 0009              READ(KR,13) TITLE
ISN 0010              READ(KR,1) R1,CU1,CU20,CU2A,TM,Z,Q,EN,LMT
ISN 0011              READ(KR,2) (R(I),Y(I),CM(I),B(I),I=1,LMT)
ISN 0012              STORA=0.
ISN 0013              DY=0.
ISN 0014              RCPAV=0.
ISN 0015              R2=R(LMT)
ISN 0016              THIS=R1*CU1/(R1*CU1-R2*CU20)
ISN 0017              THAT=1.-THIS
ISN 0018              DO 100 I=1,LMT
ISN 0019              A(I)=Q/(Z*R(I)*CM(I))*144.
ISN 0020              RCUO=R1*CU1+(R2*CU20-R1*CU1)*(1.-(1.-Y(I)**EN)**2)
ISN 0021              CU(I)=RCUO/R(I)
ISN 0022              IF(CU(I)) 32,33,32
ISN 0023           33 BETA(I) = 90.
ISN 0024              RCP(I) = 0
ISN 0025              GO TO 31
ISN 0026           32 TANB=CM(I)/CU(I)
ISN 0027              BETA(I)=ATAN(TANB)*57.2958
ISN 0028              RCP(I)=1./(R(I)*TANB)
ISN 0029           31 IF(I-1) 55,55,50
ISN 0030           50 DY=Y(I)-Y(I-1)
ISN 0031              RCPAV=(RCP(I)+RCP(I-1))*0.5
ISN 0032           55 CONTINUE
ISN 0033              THTA(I)=57.2958*TM*DY*RCPAV+STORA
ISN 0034              THTS(I)=THTA(I)-A(I)*57.2958/(2.*R(I))
ISN 0035              THTP(I)=THTA(I)+A(I)*57.2958/(2.*R(I))
ISN 0036              STORA=THTA(I)
ISN 0037              CUA(I)=(THIS*R(I)*CU(I)+THAT*R1*CU1)/R(I)
ISN 0038              IF(Y(I))34,35,34
ISN 0039           35 IF(EN-1.)36,37,36
ISN 0040           37 PRTL = 0
ISN 0041              GO TO 38
ISN 0042           34 CONTINUE
ISN 0043           36 PRTL=(R2*CU2A-R1*CU1)*2.*EN*(1.-Y(I)**EN)*Y(I)**(EN-1.)
ISN 0044           38 DH=Q*144./(32.174*R(I)*B(I)*TM*Z)*PRTL *(-1.)
ISN 0045              CAV(I)=SQRT(CM(I)**2+CUA(I)**2)
ISN 0046              DLTC=DH/CAV(I)*32.174
ISN 0047              CS(I)=CAV(I)+DLTC/2.
ISN 0048              CP(I)=CAV(I)-DLTC/2.
ISN 0049          100 CONTINUE
ISN 0050              WRITE(KW,11)
ISN 0051              WRITE(KW,13) TITLE
ISN 0052              WRITE(KW,7)
ISN 0053              WRITE(KW,8)
ISN 0054              WRITE(KW,12) Z,Q,TM,EN
ISN 0055              WRITE(KW,3)
ISN 0056              WRITE(KW,4) (R(I),A(I),THTA(I),THTS(I),THTP(I),I=1,LMT)
ISN 0057              WRITE(KW,5)
ISN 0058              WRITE(KW,6) (Y(I),CU(I),BETA(I),B(I),I=1,LMT)
ISN 0059              WRITE(KW,9)
ISN 0060              WRITE(KW,10) (CUA(I),CM(I),CAV(I),CS(I),CP(I),I=1,LMT)
ISN 0061            3 FORMAT(10X,'R',10X,'A',10X,'THTM',10X,'THTS',10X,'THTP',/)
ISN 0062            4 FORMAT(6X,F7.4,3X,F7.3,7X,F7.3,7X,F7.3,7X,F7.3)
ISN 0063            5 FORMAT(/,10X,'Y',10X,'CU',10X,'BETA',10X,'B',/)
ISN 0064            6 FORMAT(7X,F5.3,6X,F8.2,5X,F7.3,8X,F5.3)
ISN 0065            7 FORMAT(5X,'*** NOMENCLATURE ***',/)
ISN 0066            8 FORMAT(5X,'R=RADIUS',/5X,'A=TANGENTIAL WIDTH',/5X,'THTM=MEAN WRAP'
                     1,/5X,'THTS=SUCTION SURFACE WRAP',/5X,'THTP=PRESSURE SURFACE WRAP',
                     2/5X,'Y=STREAMLINE PASSAGE LENGTH RATIO',/5X,'CAV=AVERAGE VELOCITY'
                     3,/)
ISN 0067            9 FORMAT(/9X,'CUA',10X,'CM',10X,'CAV',10X,'CS',10X,'CP',/) ;
```

```
ISN 0068          10 FORMAT(8X,F7.3,6X,F7.3,5X,F7.3,6X,F7.3,5X,F7.3)
ISN 0069          11 FORMAT(1H1)
ISN 0070          12 FORMAT(5X,'NO. OF BLADES=',F5.1,5X,'Q=',F5.2,5X,'TOTAL STRMLINE LE
                    1NGTH=',F5.2,5X,'EXPONENT N=',F5.2,/)
ISN 0071          13 FORMAT(18A4)
ISN 0072             STOP
ISN 0073             END
```

[illegible]	[illegible]	CA	[illegible]	[illegible]
690.000	120.000	700.357	700.357	700.187
636.963	134.000	650.906	700.947	690.865
587.732	147.000	605.836	656.750	554.922
541.974	157.500	564.395	616.154	512.635
499.429	166.000	526.203	578.864	473.724
459.833	173.000	491.200	544.630	437.968
422.987	179.500	459.498	513.493	405.501
388.977	184.200	430.206	484.913	375.670
357.578	189.000	404.454	459.553	349.354
329.078	192.500	381.212	436.740	325.683
303.109	196.800	361.393	417.149	305.637
279.636	199.500	343.506	399.489	287.523
258.391	202.500	328.287	384.343	272.226
239.165	205.000	315.000	371.06	258.918
221.722	207.500	303.672	359.677	247.667
205.822	209.000	293.330	345.315	237.364
191.283	210.000	284.058	340.015	228.101
177.805	211.000	275.927	331.802	220.052
165.365	212.000	268.647	324.622	213.113
153.552	213.100	262.669	319.177	207.140
142.453	213.000	256.246	311.680	200.811
121.251	211.000	243.357	298.561	189.154
100.947	208.000	231.202	285.625	176.779
81.673	200.800	216.774	270.445	163.104
63.614	194.000	204.163	255.946	152.380
47.004	186.000	191.647	240.710	142.085
32.140	178.000	180.878	225.174	136.533
19.405	171.000	172.098	209.577	134.618
9.334	162.500	162.768	190.914	134.622
0.0	158.000	158.000	158.000	158.000

36 K

*** CROSS OVER CHANNEL. CASE 3 ... MAR 17 . 1971 ***
*** NOMENCLATURE ***

R=RADIUS
A=TANGENTIAL WIDTH
THTM=MEAN WRAP
THTS=SUCTION SURFACE WRAP
THTP=PRESSURE SURFACE WRAP
Y=STREAMLINE PASSAGE LENGTH RATIO
CAV=AVERAGE VELOCITY

NO. OF BLADES= 11.0   C=16.70   TOTAL STRMLINE LENGTH= 6.96   EXPONENT N= 1.00

R (INPUT)	A	THTM	THTS	α	THTP	Y
5.8500	2.892	0.0	-14.161		14.161	0
6.0242	2.590	8.833	-3.482		21.148	.025
6.1983	2.361	15.981	5.071		25.892	.050
6.3725	2.203	21.888	11.984		31.797	.075
6.5466	2.090	26.871	17.723		36.019	.100
6.7208	2.006	31.133	22.583	0	39.693	.125
6.8947	1.933	34.809	25.776	6.64	42.841	.150
7.0548	1.884	38.002	30.362	17.47	45.641	.175
7.2246	1.836	40.797	33.516	28.70	48.077	[illegible]
7.3692	1.803	43.258	36.249	39.73	50.267	[illegible]
7.4993	1.763	45.449	38.696	[illegible]	52.183	[illegible]
7.5873	1.732	47.385	40.818	[illegible]	53.953	[illegible]
7.6546	1.714	49.137	42.724	[illegible]	55.551	[illegible]
7.6898	1.693	50.724	44.418	[illegible]	57.031	[illegible]
7.6917	1.672	52.173	45.944	[illegible]	58.402	[illegible]
7.6604	1.660	53.506	47.297	[illegible]	59.716	[illegible]
7.5968	1.652	54.745	48.514	[illegible]	60.976	[illegible]
7.5059	1.645	55.902	49.625	[illegible]	62.179	[illegible]
7.3939	1.637	56.988	50.639	[illegible]	63.339	[illegible]
7.2455	1.628	58.011	51.572	[illegible]	64.449	[illegible]
7.0839	1.629	58.977	52.389	[illegible]	65.566	[illegible]
6.7413	1.645	60.768	53.779	[illegible]	67.757	[illegible]
6.3978	1.668	62.374	54.904		69.845	[illegible]
6.0543	1.728	63.800	55.623		71.978	[illegible]
5.7108	1.789	65.042	56.069		74.015	[illegible]
5.3672	1.866	66.084	56.126		76.042	[illegible]
5.0237	1.950	66.912	55.795		78.029	[illegible]
4.6802	2.029	67.512	55.099	170.5	79.934	[illegible]
4.3243	2.102	67.886	53.960	162.75	81.912	[illegible]
3.6594	2.035	68.151	52.221	157.5	84.081	1.000

Y (INPUT)	CU	BETA	B (INPUT)
0.0	690.00	9.866	0.630
0.025	636.96	11.980	0.630
0.050	587.73	14.042	0.630
0.075	541.97	16.204	0.630
0.100	499.43	18.386	0.630
0.125	459.83	20.617	0.630
0.150	422.99	22.995	0.630
0.175	389.50	25.346	0.630
0.200	357.58	27.859	0.630
0.225	329.04	30.329	0.630
0.250	303.11	32.994	0.630
0.275	279.64	35.505	0.630
0.300	258.39	38.086	0.630
0.325	239.15	40.602	0.630
0.350	221.72	43.102	0.630
0.375	205.83	45.437	0.630
0.400	191.28	47.670	0.630
0.425	177.80	49.880	0.630
0.450	165.37	52.045	0.630
0.475	153.55	54.225	0.630
0.500	142.45	56.225	0.630
0.550	121.25	60.116	0.630
0.600	100.95	64.112	0.630
0.650	81.67	67.867	0.630
0.700	63.61	71.845	0.630
0.750	47.00	75.918	0.630
[illegible]	[illegible]	[illegible]	[illegible]

9. AIR PUMP PERFORMANCE MAP

J. J. Brunner
4-10-72

COMPUTER PROGRAM
AIR PUMP PERFORMANCE MAP

I. INTRODUCTION

This program generates data for plotting performance maps of pumps or blowers operating in air at low pressure ratios. Inlet condition and performance parameters in normalized form are input. Discharge pressure, temperature rise, torque, overall efficiency and flow rate at the specified speeds and flow parameters are printed out.

This program was written for producing predicted pump performance maps for the NERVA pump air test rig. The use of a digital computer for the calculation of the discharge conditions was necessary to achieve acceptable accuracy at very low pressure ratios (r_p <1.2).

II. BASIC EQUATIONS

Performance parameters are obtained from a loss analysis and specified in terms of normalized flow Q/N, normalized head H/N^2 and efficiency. Inlet conditions are defined by pressure p_o and temperature T_o. Air is treated as an ideal gas.

The air inlet density ρ_o can then be calculated as follows:

$$\rho_o = \frac{144\ P_o}{R\ T_o}$$

R = gas constant = 53.34 ft lb/lb, °F

The isentropic head rise is calculated from input parameters:

$$H = N^2\ (H/N^2)$$

and the flow rate in ft^3/s

$$V_2 = N\ (Q/N)/448.8$$

Pressure Ratio r_p

$$r_p = \left(\frac{H + J\,(C_p)\,T_o}{J\,(C_p)\,T_o}\right)^{\frac{K}{K-1}}$$

J = mechanical equivalent of heat (778.26 ft lb/btu)

C_p = specific heat = 0.240 btu/lb/°F

Neglecting the discharge velocity head the discharge pressure P_2 is:

$$P_2 = r_p \; P_o$$

Temperature rise ΔT

$$\Delta T = \frac{T_o\,(r_p)^{\frac{K-1}{K}} - T_o}{\eta}$$

η = pump efficiency (input)

thus:

$$T_2 = T_o + \Delta T$$

and

$$\rho_2 = \frac{144\,P_2}{R\,T_2}$$

Torque M_t in In. Lb.

$$M_t = 12\,\frac{V_2\,\rho_2\,H}{\eta\,\omega}$$

$$\omega = \frac{\Pi\,N}{30}$$

NOMENCLATURE

INPUT PARAMETERS

SYMBOL	DESCRIPTION	UNITS	FORMAT
XN(1)-(5)	Rotational Speed	rpm	F
NUMQ	Number of specified points (Q/N)	-	I5
NUMN	Number of Speeds	-	I5
TO	Inlet Temperature	Deg R	F
PO	Inlet Pressure	psia	F
QN(J)	Flow Parameter	gpm/rpm	F
HN(J)	Normalized Isentropic Head	ft/rpm^2	F
ETA(J)	Efficiency	-	F

IBM

FORTRAN Coding Form

GX28-7327-6 U/M050
Printed in U.S.A.

PROGRAM: AIR PUMP PERFORMANCE MAP

PROGRAMMER | DATE | PUNCHING INSTRUCTIONS | GRAPHIC | PUNCH | PAGE OF | CARD ELECTRO NUMBER

FORTRAN STATEMENT

XN(1)	XN(2)	XN(3)	XN(4)	XN(5)
J	I	To	Po	
QN(J)	HN(J)	ETA(J)		

```
[illegible] FOR MAIN                                                10 APR 72   12:04:31.789
FORTRAN V:  ISD VERSION 2.2
THIS COMPILATION WAS DONE ON 10 APR 72 AT 12:04:31

   MAIN PROGRAM

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001   *CODE    000277
         0000   *DATA    000441
         0002   *BLANK   000000

   EXTERNAL REFERENCES (BLOCK, NAME)

         0003   NRDU$
         0004   NIO2$
         0005   NIO1$
         0006   NWDU$
         0007   NEXP6$
         0010   NSTOP$

   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0000    000233 10F      0000    000330 100F     0000    000337 102F     0000    000363 104F     0000    000407 106F
    0001    000046 133G     0000    000235 15F      0001    000113 161G     0001    000141 172G     0000    000240 20F
    0001    000023 200L     0001    000251 225G     0000    000242 25F      0000    000246 30F      0000    000255 32F
    0000    000310 34F      0001    000122 40L      0001    000004 500L     0001    000273 900L     0000 R  000113 DP
    0000 R  000175 DT       0000 R  000125 DTI      0000 R  000024 ETA      0000 R  000043 H        0000 R  000012 HN
    0000 I  000232 I        0000 I  000227 J        0000 I  000221 LR       0000 I  000222 LW       0000 I  000224 NUMN
    0000 I  000223 NUMO     0000 R  000067 PR       0000 R  000226 P0       0000 R  000101 P2       0000 R  000000 ON
    0000 R  000231 RHO      0000 R  000151 RHO2     0000 R  000207 TMT      0000 R  000225 T0       0000 R  000137 T2
    0000 R  000230 VO       0000 R  000163 V0       0000 R  000055 V2       0000 R  000036 XN

 00101             DIMENSION ON(10),HN(10),ETA(10),XN(5),H(10),V2(10),PR(10),P2(10),
 00101            1DP(10),DTI(10),T2(10),RHO2(10),V0(10),DT(10),TMT(10)
 00103             LR=5
 00104             LW=6
 00105          10 FORMAT('1')
 00106          15 FORMAT(2I5,F10.1,2F10.3)
 00107          20 FORMAT(5F10.1)
 00110          25 FORMAT(F10.3,E10.3,F10.3)
 00111         500 READ(LR,20) XN(1),XN(2),XN(3)7XN(4)7XN(5)
 00120             IF(XN(1)) 900,900,200
 00123         200 READ(LR,15)  NUMO,NUMN,T0,P0
 00131             READ(LR,25) (ON(J),HN(J),ETA(J),J=1,NUMO)
 00141             VO = 0.370416* T0/P0
 00142             RHO = 1./VO
 00143          30 FORMAT(30X,'AIR TEST PUMP PERFORMANCE MAP'//)
 00144          32 FORMAT (2X,'INLET TEMPERATURE T0 =',F7.2,2X,'DEG F',10X,'INLET PRE
 00144            1SSURE P0 =',F8.3,2X,'PSIA'//2X,'INLET WEIGHT DENSITY RHO =',F8.5,2
 00144            2X,'LB/FT**3'///)
 00145          34 FORMAT (10X,'PUMP CHARACTERISTICS'//6X,'Q/N',7X,'ETA',10X,'H/N**2'
```

```
00145     20*          1///(F10.3,F10.3,E14.3))
00146     21*           WRITE(LW,10)
00150     22*           WRITE(LW,30)
00152     23*           WRITE(LW,32) T0,P0,RHO
00157     24*           WRITE(LW,34) (QN(J),ETA(J),HN(J),J=1,NUMQ)
00167     25*           I = 0
00170     26*        40 I = I + 1
00171     27*           DO 60 J=1,NUMQ
00174     28*           H(J) = HN(J) * XN(I)**2
00175     29*           V2(J) = XN(I)*QN(J)/448.83
00176     30*           PR(J) =  ((H(J) + 186.768*T0)/(186.768*T0))**3.5335
00177     31*           P2(J) = PR(J) * P0
00200     32*           DP(J) = (P2(J)-P0) * 27.67
00201     33*           DTI(J) = T0*(PR(J))**0.283 - T0
00202     34*           DT(J) = DTI(J)/ETA(J)
00203     35*           T2(J) = T0 + DT(J)
00204     36*           RHO2(J) = 1./(0.370416 * T2(J)/P2(J))
00205     37*           TMT(J) = 114.587 * H(J)*V2(J) * RHO2(J)/ETA(J) /XN(I)
00206     38*        60 V0(J) = V2(J) * RHO2(J)/RHO
00210     39*       100 FORMAT (/////2X,'SPEED =',F7.1,' RPM'//)
00211     40*       102 FORMAT (5X,'Q/N',9X,'V2',7X,'DH',8X,'PR',9X,'P2',10X,'DP',9X,'DT',
00211     41*          17X,'RHO2',8X,'V0',6X,'TORQUE')
00212     42*       104 FORMAT (16X,'FT/S',6X,'FT',18X,'PSIA',7X,'IN H2O',6X,'DEG F',4X,'L
00212     43*          1B/FT**3',4X,'FT**3/S',3X,'INLB'//)
00213     44*       106 FORMAT (2F10.3,F11.3,F9.4,F12.4,F11.3,F10.3,F12.5,F10.3,F10.3)
00214     45*           WRITE(LW,100) XN(I)
00217     46*           WRITE(LW,102)
00221     47*           WRITE(LW,104)
00223     48*           WRITE(LW,106) (QN(J),V2(J),H(J),PR(J),P2(J),DP(J),DT(J),RHO2(J),V0
00223     49*          1(J),TMT(J),J=1,NUMQ)
00242     50*           IF(NUMN-I) 500,500,40
00245     51*       900 STOP
00246     52*           END

      END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

AIR TEST PUMP PERFORMANCE MAP

INLET TEMPERATURE TO = 530.00 DEG F   INLET PRESSURE PO = 14.500 PSIA

INLET WEIGHT DENSITY RHO = .07386 LB/FT**3

PUMP CHARACTERISTICS

Q/N	ETA	H/N**2
.050	.290	.845-04
.100	.495	.840-04
.150	.615	.800-04
.200	.675	.730-04
.220	.680	.694-04
.250	.670	.640-04
.300	.632	.540-04
.350	.551	.430-04
.400	.410	.295-04
.450	.140	.850-05

SPEED = 5000.0 RPM

Q/N	V2 FT/S	DH FT	PR	P2 PSIA	DP IN H2O	DT DEG F	RHO2 LB/FT**3	VO FT**3/S	TORQUE INLB
.050	.557	2112.500	1.0775	15.6233	31.082	39.002	.07413	.559	6.893
.100	1.114	2100.000	1.0770	15.6165	30.893	22.714	.07628	1.150	8.262
.150	1.671	2000.000	1.0732	15.5620	29.385	17.412	.07675	1.736	9.558
.200	2.228	1825.000	1.0667	15.4669	26.754	14.476	.07669	2.313	10.587
.220	2.451	1735.000	1.0633	15.4182	25.405	13.661	.07656	2.541	10.972
.250	2.785	1600.000	1.0583	15.3453	23.388	12.786	.07632	2.878	11.633
.300	3.342	1350.000	1.0490	15.2109	19.671	11.437	.07584	3.432	12.408
.350	3.899	1075.000	1.0389	15.0641	15.609	10.446	.07525	3.972	13.118
.400	4.456	737.500	1.0266	14.8853	10.663	9.631	.07447	4.493	13.679
.450	5.013	212.500	1.0076	14.6103	3.052	8.127	.07330	4.975	12.781

SPEED = 6000.0 RPM

Q/N	V2 FT/S	DH FT	PR	P2 PSIA	DP IN H2O	DT DEG F	RHO2 LB/FT**3	VO FT**3/S	TORQUE INLB
.050	.668	3042.000	1.1129	16.1368	45.290	56.163	.07432	.673	9.952

.100	1.337	3024.000	1.1122	16.1267	45.012	32.709	.07737	1.400	12.067
.150	2.005	2880.000	1.1067	16.0464	42.790	25.073	.07804	2.119	13.996
.200	2.674	2628.000	1.0970	15.9066	38.921	20.845	.07796	2.822	15.498
.220	2.941	2498.400	1.0921	15.8351	36.941	19.672	.07777	3.097	16.049
.250	3.342	2304.000	1.0847	15.7281	33.982	18.412	.07742	3.503	16.993
.300	4.010	1944.000	1.0711	15.5315	28.542	16.469	.07673	4.166	18.076
.350	4.679	1548.000	1.0564	15.3172	22.613	15.042	.07587	4.806	19.046
.400	5.347	1062.000	1.0384	15.0572	15.418	13.868	.07474	5.411	19.770
.450	6.016	306.000	1.0110	14.6590	4.400	11.703	.07306	5.950	18.345

SPEED = 7000.0 RPM

Q/N	V2 FT/S	DH FT	PR	P2 PSIA	DP IN H2O	DT DEG F	RHO2 LB/FT**3	V0 FT**3/S	TORQUE INLB
.050	.780	4140.500	1.1558	16.7591	62.510	76.444	.07461	.788	13.597
.100	1.560	4116.000	1.1548	16.7451	62.121	44.520	.07868	1.662	16.704
.150	2.339	3920.000	1.1471	16.6328	59.016	34.127	.07960	2.521	19.429
.200	3.119	3577.000	1.1336	16.4378	53.618	28.373	.07947	3.356	21.504
.220	3.431	3400.600	1.1268	16.3381	50.860	26.775	.07922	3.680	22.251
.250	3.899	3136.000	1.1165	16.1894	46.746	25.060	.07874	4.157	23.523
.300	4.679	2646.000	1.0977	15.9166	39.197	22.416	.07778	4.928	24.943
.350	5.459	2107.000	1.0773	15.6203	30.999	20.474	.07661	5.662	26.176
.400	6.238	1445.500	1.0526	15.2621	21.088	18.877	.07507	6.341	27.027
.450	7.018	416.500	1.0149	14.7167	5.997	15.928	.07278	6.915	24.874

SPEED = 8000.0 RPM

Q/N	V2 FT/S	DH FT	PR	P2 PSIA	DP IN H2O	DT DEG F	RHO2 LB/FT**3	V0 FT**3/S	TORQUE INLB
.050	.891	5408.000	1.2068	17.4984	82.964	99.845	.07500	.905	17.854
.100	1.782	5376.000	1.2055	17.4794	82.440	58.149	.08023	1.936	22.246
.150	2.674	5120.000	1.1951	17.3284	78.261	44.574	.08142	2.947	25.957
.200	3.565	4672.000	1.1770	17.0663	71.010	37.058	.08125	3.922	28.715
.220	3.921	4441.600	1.1678	16.9327	67.312	34.972	.08091	4.296	29.684
.250	4.456	4096.000	1.1540	16.7336	61.803	32.732	.08028	4.843	31.324
.300	5.347	3456.000	1.1289	16.3694	51.725	29.278	.07902	5.721	33.094
.350	6.238	2752.000	1.1017	15.9753	40.822	26.741	.07747	6.543	34.572
.400	7.130	1888.000	1.0690	15.5011	27.700	24.655	.07545	7.283	35.480
.450	8.021	544.000	1.0196	14.7835	7.846	20.805	.07246	7.869	32.347

10. PUMP AXIAL THRUST PREDICTION PROGRAM

PROJECT 121
W.S. f7
FLUID DYNAMIC ANALYSIS

PUMP AXIAL THRUST PREDICTION PROGRAM

1. INTRODUCTION

a. The program was developed to predict the flow distribution and rotor axial thrust of the NERVA Turbopump. The variation in the parameters are also Monte Carlo'ed.

b. The program listing and narrative along with an input list and rotor schematic are included.

c. The program was debugged and modelled the "C" change turbopump.

d. Changes to engine operating conditions can grossly effect the internal flow within the turbopump.

e. No related activities.

f. This program was developed by R. A. Livingston.

2. CONCLUSIONS

a. Gross Conclusion

(1) The program appeared to represent the actual turbopump quite accurately.

(2) The program, analytically, performed all of its required functions.

(3) The next logical modification would be the inclusion of subroutines to determine influence coefficients.

b. Interpretation

(1) The program does not derive conclusion, i.e., values only.

(2) The accuracy of the analysis has great implication relative to thrust balancer performance .

(3) The accurate representation of the correct thermodynamic properties and processes have significant implication as to the validity of the results.

3. RECOMMENDATIONS

a. The program can allow determination of optimum clearance and yet maintain the desired reliability within the turbopump.

b. No problems have arisen as a result of this work.

c. The analytical prediction need, next, to be compared to actual test data.

d. See b.(3) under conclusions.

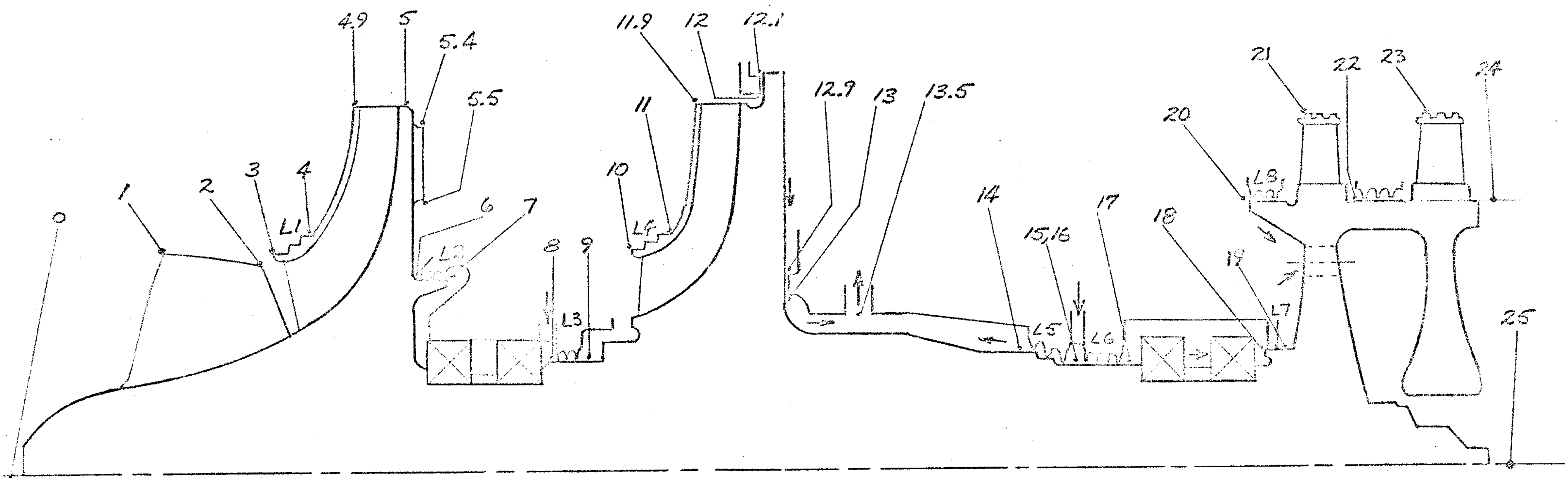
4. REFERENCES

None

I. INTRODUCTION

A mathematical model of the NERVA turbopump internal flow network was developed to permit both statistical and single point (i.e., data set) evaluation of the pump internal flows and balance piston position. The primary dependent parameters are the hydrostatic thrust balancer position in the housing and the flowrates thru the several labyrinth seals and flow circuits which include the bearing coolant and thrust balancer flow circuits. These "output" parameters are computed for each set of "input" parameters which consists of the pump component dimensions, various factors such as the rate of fluid to rotor angular velocity, and the pump operating conditions which include interface pressures, shaft speed and propellant conditions, see Table 1. For a single point computation, the mean values of the input parameters are used to compute a corresponding set of mean output parameters. For statistical analysis, the input data consists of the set of mean values of the input parameters plus a corresponding set of variances, one for each input parameter. The math model is programmed to execute any desired number of repetative solutions of the output versus input parameters, each computation using a different set in input parameters as governed by the input variances and a random distribution within any specified distribution characteristic (Figure). The program output for a statistical analysis (Monte Carlo) case consists of the mean, standard deviation and range of each computed parameter. Since all the input parameters are not independent there are correlation equations to approximate the relationship of interacting parameters. In the current version of the program, the turbine inlet pressure variation is a function of the pump discharge pressure variation, and interstage turbine pressures are maintained in constant ratio. In a real pump, there exists a relationship between pump discharge pressure, flowrate and shaft speed. In this model of the turbopump they are left independent because of the relatively weak effect of shaft speed and flowrate on the output parameters as compared to pressure distribution factors and because an accurate accounting of the relationship between speed, flow, pressure and turbine flowrate would require an overall system analysis which would exceed the scope of this project. A future goal for improving this model might include the development of an influence coefficient method predicting the interaction of these parameters. Figure 1 is a schematic of the turbopump rotor with the stations numbered for reference in the program equations and parameter list (Reference Table 1 and the program listing).

TPA 1118101-C, ROTOR SCHEMATIC
FOR AXIAL THRUST ANALYSIS



R.R, 09-11-71

-- FIG. 1

TABLE 1

PARAMETER LIST

INPUT PARAMETERS

NO.	CODE NAME	
1	PPD	Pump Discharge Pressure (at flange), psia
2	P1F	Pump 1st Stage Pressure Rise Factor = P(10)/PPD
3	PS	Suction Pressure at Inducer Inlet (0), psi
4	PIF	Inducer Discharge Pressure (2) Factor P(2)/PPD
5	PTI	Turbine Manifold Inlet Pressure, psia
6	PTE	Turbine Exhaust Pressure P(24), psia
7	TTBP	Balance Piston Total Travel (0 Clearance to Clearance), in.
8	WPD	Pump Discharge Flowrate, lb/sec
9	RPM	Pump Shaft Speed, RPM
10	P5F	Pressure P(5) Factor = P(5)/PD1
11	P12F	Pressure P(12) Factor = P(12)/(PPD-PD1)
12	TBPR	Turbine Bypass Ratio = (WPD - $\dot{w}$(Turb))/WPD
13	P21	Static Pressure at Sta. (21)
14	P22	(22)
15	P23	(23)
16	P24	(24)
17	TS	Temperature of Hydrogen in Suction Line
18	TPD	Temperature of Hydrogen at Pump Discharge
19	AT1	Flow Area thru Impeller No. 1 Turn, in^2
20	AT2	Flow Area thru Impeller No. 2 turn, in^2
21	RHOTI	Turbine Inlet Gas Density, lb/in^3
22	THOTE	Turbine Discharge gas Density, lb/in^3
23	CL1	Labyrinth Seal No. 1 Flow Coefficient = $\rho\Delta P/\dot{w}^2$
24	CL2	No. 2
25	CL3	No. 3
26	CL4	No. 4
27	CL5	No. 5
28	CL6	No. 6
29	CL7	No. 7
30	CL8	No. 8
31	RTEH	Resistance of Holes thru Turbine Discharge = $\rho\Delta P/\dot{w}^2$
32	RBPR	Resistance of Balance Piston Return Flow Circuit = $\rho\Delta P/\dot{w}^2$
33	RTBS	Resistance of Turbine Bearing Supply Circuit = $\rho\Delta P/\dot{w}^2$
34	RPBS	Resistance of Pump Bearing Supply Circuit

TABLE 1 (Continued)

NO.	CODE NAME		
35	YBV1	Inner Radius of Back Vanes (Sta. 5.5)	
36	YBV2	Outer Radius of Back Vanes (Sta. 5.4)	
37	XK4	Fluid-Rotor Angular Velocity Ratio, Sta.	4-4.9
38	XK5	↓	5-5.4
39	XK55	↓	5.5-6
40	XK7	↓	7-8
41	XK11	↓	11-11.9
42	XK12	↓	12-12.1
43	XK121	↓	12.1-12.9
44	XK129	↓	12.9-13
45	XK13	↓	13-14
46	XK17	↓	17-18
47	XK19	↓	19-20
48	XKBV	↓	5.4-5.5
49	Z0	Static Pressure Profile Factor (= .5 for Linear Dist.) Sta.	0-1
50	Z3	↓	3-4
51	Z6	↓	6-7
52	Z8	↓	8-9
53	Z10	↓	10-11
54	Z14	↓	14-15
55	Z16	↓	16-17
56	Y0	Line Radius at Sta. 0	
57	YIH	Inducer Hub Diameter at Blade L.E.	
58	Y1	Radius at Station No. 1	
59	Y2	↓ No. 2	
60	Y3	↓ No. 3	
61	Y4	↓ No. 4	
62	Y5	↓ No. 5	
63	Y6	↓ No. 6	
64	Y7	↓ No. 7	
65	Y8	↓ No. 8	
66	Y9	↓ No. 9	
67	Y10	↓ No. 10	
68	Y11	↓ No. 11	
69	Y12	↓ No. 12	
70	Y121	↓ No. 12.1	

TABLE 1 (Continued)

NO.	CODE NAME	
71	Y129	Radius at Station No. 12.9
72	Y13	No. 13
73	Y135	No. 13-5
74	Y14	No. 14
75	Y15	No. 15
76	Y16	No. 16
77	Y17	No. 17
78	Y18	No. 18
79	Y20	No. 20
80	Y21	No. 21
81	Y22	No. 22
82	Y23	No. 23
83	CD12	Balance Piston Orifice Discharge Coefficient Sta. 12
84	CD13	Balance Piston Orifice Discharge Coefficient Sta. 13
85	P5G	Pressure Gradient Between Stations 4.9 & 5 (+ if P5 > P4.9) psi
86	P12G	Pressure Gradient Between Stations 11.9 & 12 (+if P12 > P11.9) psi

OUTPUT PARAMETERS (COMPUTED)

NO.	CODE NAME	
1	T	Thrust Balancer Inner Orifice Land Clearance, In.
2	CFBP	Balance Piston Load (Sta. 12-13), lb.
3	SBP	Balance Piston Axial Stiffness, lb/in at T
4	P1	Pressure at Station 1
5	P4	4
6	P5	5
7	P54	5.4
8	P55	5.5
9	P6	6
10	P7	7
11	P8	8
12	P11	11
13	P12	12
14	P121	12.1
15	P129	12.9
16	P13	13
17	P135	13.5
18	P14	14

TABLE 1 (Continued)

NO.	CODE NAME	
19	P15	Pressure at Station 15
20	P16	↓ ↓ 16
21	P17	↓ ↓ 17
22	P18	↓ ↓ 18
23	P19	↓ ↓ 19
24	P20	↓ ↓ 20
25	WL1	Flowrate thru Labyrinth Seal No. 1, lb/sec
26	W7	↓ ↓ ↓ ↓ No. 2 ↓
27	W8	↓ ↓ ↓ ↓ No. 3 ↓
28	WL4	↓ ↓ ↓ ↓ No. 4 ↓
29	WL5	↓ ↓ ↓ ↓ No. 5 ↓
30	WL6	↓ ↓ ↓ ↓ No. 6 ↓
31	WL8	↓ ↓ ↓ ↓ No. 8 ↓
32	WPBS	Flowrate thru Pump Bearing Supply Circuit, lb/sec
33	WBPR	Flowrate thru Balance Piston Return Circuit, lb/sec
34	WBP	Flowrate thru Balance Piston, lb/sec
35	WTBS	Flowrate thru Turbine Bearing Supply Circuit, lb/sec
36	WTEH	Flowrate thru the Turbine Disc Vent Holes, lb/sec
37	F011	Summation of Axial Forces between Stations 0-11
38	F1325	↓ ↓ ↓ ↓ ↓ 13-25
39	FTURB	Summation of Axial Forces Acting on Turbine Blading
40	FM1	Fluid Turning Reaction thru Impeller No. 1
41	FM2	↓ ↓ ↓ ↓ ↓ No. 2
42	FMOM	FM1 + FM2
43	F0	Pressure Force Between Stations 0-1, psia
44	F1	↓ ↓ ↓ ↓ 1-2 ↓
45	F2	↓ ↓ ↓ ↓ 2-3 ↓
46	F3	↓ ↓ ↓ ↓ 3-4 ↓
47	F4	↓ ↓ ↓ ↓ 4-4.9 ↓
48	F5	↓ ↓ ↓ ↓ 5-5.4 ↓
49	FBV	↓ ↓ ↓ ↓ 5.4-5.5 ↓
50	F55	↓ ↓ ↓ ↓ 5.5-6 ↓
51	F6	↓ ↓ ↓ ↓ 6-7 ↓
52	F7	↓ ↓ ↓ ↓ 7-8 ↓
53	F8	↓ ↓ ↓ ↓ 8-9 ↓
54	F9	↓ ↓ ↓ ↓ 9-10 ↓

TABLE 1 (Continued)

NO.	CODE NAME	
55	F10	Pressure Force Between Stations 10-11, psia
56	F11	11-12
57	F13	13-14
58	F14	14-15
59	F15	15-16
60	F16	16-17
61	F17	17-18
62	F19	19-20
63	F25	24-25
64	RH00	Fluid Density at Station 0, lb/in^3
65	RH05	5
66	RH06	6
67	RH07	7
68	RH012	12
69	RHOPD	Pump Discharge
70	R0129	12.9
71	R0135	13.5
72	RH018	18
73	P49	Pressure at Station 4.9, psia
74	P119	Pressure at Station 11.9, psia

I Introduction

A mathematical model of the Space Shuttle pump internal flow network was developed to permit both statistical and single point (ie data set) evaluation of the pump internal flows and balance piston position. The primary dependent parameters are the hydrostatic thrust balance position in the housing and the flowrates thru the several labyrinth seals and flow circuits which include the bearing coolant and thrust balance flow circuits. These "output" parameters are computed for each set of "input" parameters which consist of the pump component dimensions, various factors such as the ratio of fluid to rotor angular velocity, and the pump operating conditions which include interface see table 1

pressures, shaft speed and propellant conditions. For a single point computation, the mean values of the input parameters are used to compute a corresponding set of mean output parameters. For statistical analysis, the input data consists of the set of mean values of the input parameters plus a corresponding set of variances, one for each input parameter. The math model is programmed to execute any desired number of repetitive solutions of the output versus input parameters, each computation using a different set in input parameters as governed by the input variances and a random distribution within any specified distribution characteristic (figure —). The program output for a statistical analysis (monte carlo) case consists of the mean, standard deviation and range of each computed parameter. Since all the input parameters are not independent, there are correlation equations to approximate the relationship of interacting parameters. In the current version of the program, the turbine inlet pressure variation is a function of the pump discharge pressure variation, and interstage turbine pressures are maintained in constant ratio. In a real pump, there exists a relationship between pump discharge pressure, flowrate and shaft speed. In this model of the turbopump they are left independent because of the relatively weak effect of shaft speed and flowrate on the output parameters as compared to pressure distribution factors and because an accurate accounting of the relationship between speed, flow, pressure and turbine flowrate would require an overall system analysis which would exceed the scope of this project. A future goal for improving

This [illegible] might indicate the development of an influence coefficient method predicting the interaction of these parameters. Figure 1 is a schematic of the turbopump rotor with the stations numbered for reference in the program equations and parameter list (reference table 1 and the program listing)

TABLE I

PARAMETER LIST

INPUT PARAMETERS

No.	Code Name	
1	PPD	pump discharge pressure (at flange), PSIA
2	P1F	pump 1st stage pressure rise factor = P(10)/PPD
3	PS	suction pressure at inducer inlet (0) PSI
4	PIF	inducer discharge pressure (2) factor P(2)/PPD
5	PTI	turbine manifold inlet pressure PSIA
6	PTE	turbine exhaust pressure P(24) PSIA
7	TTBP	balance piston total travel (0 clearance to 0 clearance) in.
8	WPD	pump discharge flowrate, lb/sec.
9	RPM	pump shaft speed, RPM
10	P5F	pressure P(5) factor = P(5)/PD1
11	P12F	pressure P(12) factor = P(12)/(PPD - PD1)
12	TBPR	turbine bypass ratio = (WPD - Ẇ(TURB)) / WPD
13	P21	static pressure at sta. (21)
14	P22	↓ (22)
15	P23	↓ (23)
16	P24	↓ (24)
17	TS	temperature of hydrogen in suction line
18	TPD	" " " at pump discharge
19	AT1	flow area thru impeller no. 1 turn, in²
20	AT2	" " " " " 2 " "
21	RHØTI	turbine inlet gas density, lb/in³.
22	RHØTE	" discharge " "

No.	Code Name	
23	CL1	impeller seal no. 1 flow coefficient = $\rho \Delta P / W^2$
24	2	2
25	3	3
26	4	4
27	5	5
28	6	6
29	7	7
30	8	8
31	RTBH	resistance of holes thru turb. disk = $\rho \Delta P / W^2$
32	R[illegible]	resistance of balance piston return flow circuit = $\rho \Delta P / W^2$
33	RTBS	resistance of turbine bearing supply circuit "
34	RPBS	" pump " " "
35	YBV1	inner radius of back vanes (STA. 5.5)
36	YBV2	outer " " " " (STA. 5.4)
37	XK4	fluid-rotor angular velocity ratio, sta. 4 - 4.9
38	XK5	" sta. 5 - 5.4
39	XK55	5.5 - 6
40	XK7	7 - 8
41	XK11	11 - 11.9
42	XK12	12 - 12.1
43	XK121	12.1 - 12.9
44	XK129	12.9 - 13
45	XK13	13 - 14
46	XK17	17 - 18
47	XK19	19 - 20
48	XKBV	5.4 - 5.5
49	Z0	STATIC PRESSURE PROFILE FACTOR (= .5 FOR LINEAR DISTRIBUTION) STA. 0 - 1
50	Z3	3 - 4
51	Z6	6 - 7
52	Z8	8 - 9
53	Z10	10 - 11
54	Z14	14 - 15
55	Z16	16 - 17

No.	CODE NAME	
56	Y0	Tire radius at sta. 0
57	YIH	Inducer hub diameter at blade L.E.
58	Y1	Radius at station no. 1
59	Y2	2
60	Y3	3
61	Y4	4
62	Y5	5
63	Y6	6
64	Y7	7
65	Y8	8
66	Y9	9
67	Y10	10
68	Y11	11
69	Y12	12
70	Y121	12.1
71	Y129	12.9
72	Y13	13
73	Y135	13.5
74	Y14	14
75	Y15	15
76	Y16	16
77	Y17	17
78	Y18	18
79	Y20	20
80	Y21	21
81	Y22	22
82	Y23	23
83	CD12	Balance piston orifice discharge coeff. sta. 12
84	CD13	" " " " " sta. 13
85	P5G	pressure gradient between stations 4.9 & 5 (+ if P5 > P4.9)
86	P12G	" " " " 11.9 & 12 (+ if P12 > P11.9)

OUTPUT PARAMETERS (CONTINUED)

No.	Code Name	
1	T	Thrust balancer inner orifice land clearance, in
2	CFBP	Balance piston load (STA. 12-13), lb.
3	SBP	Balance piston axial stiffness, lb/in at T
4	P1	Pressure at station 1
5	P4	4
6	P5	5
7	P54	5.4
8	P55	5.5
9	P6	6
10	P7	7
11	P8	8
12	P11	11.
13	P12	12
14	P121	12.1
15	P129	12.9
16	P13	13
17	P135	13.5
18	P14	14
19	P15	15
20	P16	16
21	P17	17
22	P18	18
23	P19	19
24	P20	20
25	WL1	flowrate thru labyrinth seal no. 1 — lb/sec
26	W7	" " " " " 2
27	W8	3
28	WL4	4
29	WL5	5
30	WL6	6
31	WL8	8
32	WPCS	flowrate thru pump bearing supply circuit
33	WBPR	" " balance piston return circuit
34	WBP	" "
35	WTBS	" " turbine bearing supply circuit

No.	Card Name			
36	WTCH	Flowrate thru the turbine disc vent holes, lb/sec.		
37	FO11	Summation of axial forces between stations	0-11	
38	F1325	" " " " "	13-25	
39	FTUPB	" " " " acting on turbine blading		
40	FM1	fluid pumping reaction thru impeller no. 1		
41	FM2	" " " " " " 2		
42	FMM	FM1 + FM2		
43	F0	pressure force between stations	0-1	PSIA
44	F1		1-2	
45	F2		2-3	
46	F3		3-4	
47	F4		4-4.9	
48	F5		5-5.4	
49	FBV		5.4-5.5	
50	F55		5.5-6	
51	F6		6-7	
52	F7		7-8	
53	F8		8-9	
54	F9		9-10	
55	F10		10-11	
56	F11		11-12	
57	F13		13-14	
58	F14		14-15	
59	F15		15-16	
60	F16		16-17	
61	F17		17-18	
62	F19		19-20	
63	F25		24-25	
64	RHØ0	fluid density at station	0	lb/in^3
65	RHØ5		5	
66	RHØ6		6	
67	RHØ7		7	
68	RHØ12		12	
69	RHØPD		Pump discharge	
70	RH129		12.9	

NO.	Code Name			
71	RØ135	fluid density at station	13.5	lb/in³
72	RH418		18	"
73	P49	Pressure at station 4.9		PSIA
74	P119	11.9		"

Ø9 RUN LVGSTN,428206,1,100 15 MAR 72 13:19:46.457

(LISTING)

COMPUTER PROGRAM FOR

PUMP ROTOR AXIAL FORCE BALANCE

INCL. MONTE-CARLO ANALYSIS OF BALANCE

PISTON POSITION VS. SYSTEM VARIABLES

```
DIR FOR TLU2                                                        15 MAR 72   13:19:46.517
FORTRAN V:  ISD VERSION 2.1
THIS COMPILATION WAS DONE ON 15 MAR 72 AT 13:19:46

    SUBROUTINE TLU2       ENTRY POINT 000010

    STORAGE USED (BLOCK, NAME, LENGTH)

          0001   *CODE    000014
          0000   *DATA    000007
          0002   *BLANK   000000

    EXTERNAL REFERENCES (BLOCK, NAME)

          0003   NERR3$

    STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)



 00100       1*    C      DUMMY SUBROUTINE FOR H2 DENSITY (ZARG) AS A FUNCTION OF PRESS.
 00100       2*    C      (UARG) AND TEMP. (VARG)
 00101       3*           SUBROUTINE TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
 00103       4*           ZARG=.0025
 00104       5*           RETURN
 00105       6*           END

        END OF UNIVAC 1108 FORTRAN V COMPILATION.     0 *DIAGNOSTIC* MESSAGE(S)
```

```
@I FOR NORM                                                          16 MAR 72   13:19:47,579
FORTRAN V:  ISD VERSION 2.1
THIS COMPILATION WAS DONE ON 15 MAR 72 AT 13:19:47

   FUNCTION NORM           ENTRY POINT 000134

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001   *CODE    000160
         0000   *DATA    000046
         0002   *BLANK   000000

   EXTERNAL REFERENCES (BLOCK, NAME)

         0003   NERR3$

   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

  0001    000030 1L        0001    000061 11L       0001    000050 116G      0001    000034 2L        0001    000111 29L
  0001    000066 7L        0001    000057 9L        0000 R 000003 BARG       0000 R 000005 CARG       0000 R 000006 DELTA
  0000 I 000004 I          0000 I 000001 J          0000 R 000000 NORM       0000 R 000002 U
```

THIS SUBROUTINE COMPUTES THE INPUT PARAMETER VALUES FROM INPUT MEAN (AM) & STD. DEV. WITH RANDOM NORMAL DIST.

```
 00101      1*            FUNCTION NORM (AM,S,IX,B,C)
 00103      2*            REAL NORM
 00104      3*            DIMENSION B(15),C(15)
 00105      4*            J=IX*262147
 00106      5*            IF(J) 1,2,2
 00111  *DIAGNOSTIC*      THE INDICATED ARITHMETIC PERFORMED ON CONSTANTS PRODUCED OVERFLOW.
 00111      6*          1 J=J+34359738367+1
 00112      7*          2 U=J
 00113      8*            BARG=U/34359738367.
 00114      9*            IX=J
 00115     10*          5 DO 11 I=2,15
 00120     11*            IF(B(I)-BARG) 11,9,7
 00123     12*          9 CARG=C(I)
 00124     13*         11 CONTINUE
 00126     14*            GO TO 29
 00127     15*          7 DELTA=(BARG-B(I-1))/(B(I)-B(I-1))
 00130     16*            CARG=DELTA*(C(I)-C(I-1))+C(I-1)
 00131     17*         29 NORM=AM+CARG*S
 00132     18*         30 RETURN
 00133     19*            END
```

* CROSS REFERENCE BY SEQUENCE NUMBER *

```
 NAMES------
 AM     :   0101   0131
 B      :   0104   0120   0127
 BARG   :   0113   0120   0127
 C      :   0101   0104   0123   0130
 CARG   :   0123   0130   0131
```

```
DELTA :   0127    0130
I     :   0115    0120    0123    0127    0130
IX    :   0101    0105    0114
J     :   0106    0111    0112    0114
NORM  :   0101    0103    0131
S     :   0101    0131
U     :   0112    0113

LABELS------
      1:  0106    0111
      2:  0106    0112
      5:  0115
      7:  0120    0127
      9:  0120    0123
     11:  0115    0120    0124
     29:  0126    0131
     30:  0132

INTEGER CONSTANTS------
           1:  0111    0127    0130
           2:  0115
          15:  0104    0115
      262147:  0105
 34359738367:  0111

REAL CONSTANTS------
0.34359738+11:  0113

      END OF UNIVAC 1108 FORTRAN V COMPILATION.      1 *DIAGNOSTIC* MESSAGE(S)
```

15 MAR 72   13:19:49.141

```
ΩIR FOR MAIN
FORTRAN V:  ISO VERSION 2.1
THIS COMPILATION WAS DONE ON 15 MAR 72 AT 13:19:49

   MAIN PROGRAM

   STORAGE USED (BLOCK, NAME, LENGTH)

        0001   *CODE   003702
        0000   *DATA   003345
        0002   *BLANK  000000

   EXTERNAL REFERENCES (BLOCK, NAME)

        0003   NORM
        0004   TLU2
        0005   NRDU$
        0006   NIO1$
        0007   NIO2$
        0010   NWDU$
        0011   SQRT
        0012   NEXP6$
        0013   NSTOP$

   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     002352 100L     0000     001773 1000F    0001     002357 101L     0001     002366 102L     0001     000006 107G
 0000     001774 1100F    0000     001776 1105F    0001     003315 1114G    0001     002646 113L     0001     000020 115G
 0001     000473 12L      0000     002001 1200F    0001     000032 123G     0001     000044 131G     0001     003572 1310G
 0001     003611 1322G    0001     003637 1333G    0001     003564 1347G    0001     000056 137G     0001     003127 140L
 0001     003134 141L     0001     003150 144L     0001     003153 145L     0001     003161 146L     0001     003164 147L
 0001     003214 150L     0001     003224 200L     0000     002100 2000F    0000     002116 2001F    0000     002145 2002F
 0000     002167 2003F    0000     002215 2004F    0000     002254 2005F    0000     002272 2006F    0000     002333 2007F
 0000     002354 2008F    0000     002374 2009F    0001     003231 201L     0000     002422 2010F    0000     002444 2011F
 0001     003266 205L     0001     003356 209L     0000     002466 2100F    0000     002525 2101F    0000     002557 2102F
 0000     002612 2103F    0000     002636 2104F    0000     002675 2105F    0000     002716 2106F    0001     000103 227G
 0001     000151 244G     0001     003313 250L     0000     002003 2500F    0000     002027 2501F    0000     002040 2510F
 0000     002066 2511F    0001     003335 254L     0001     003337 255L     0001     003345 256L     0001     003347 260L
 0001     003174 300L     0000     002737 3000F    0000     002755 3001F    0000     001761 3002F    0001     003205 301L
 0001     001543 38L      0001     001615 39L      0001     000024 4L       0001     001633 40L      0001     000376 400L
 0000     002766 4000F    0001     000427 403L     0001     000431 404L     0001     000437 405L     0001     000441 410L
 0000     002773 4100F    0001     001711 42L      0000     003013 4200F    0000     003030 4300F    0001     000403 431G
 0001     000466 436G     0001     001724 44L      0001     001735 45L      0001     003604 460L     0001     001772 49L
 0001     002151 50L      0000     003001 5000F    0001     002326 62L      0001     003677 999L     0000 R 001660 ABV
 0000 R 003065 AT1        0000 R 003066 AT2        0000 R 001652 A0         0000 R 001653 A1         0000 R 001666 A10
 0000 R 001667 A11        0000 R 001670 A12        0000 R 001671 A121       0000 R 001672 A129       0000 R 001673 A13
 0000 R 001674 A14        0000 R 001675 A15        0000 R 001676 A16        0000 R 001677 A17        0000 R 001700 A19
 0000 R 001654 A2         0000 R 001655 A3         0000 R 001656 A4         0000 R 001657 A5         0000 R 001661 A55
 0000 R 001662 A6         0000 R 001663 A7         0000 R 001664 A8         0000 R 001665 A9         0000 R 001560 B
 0000 R 001577 C          0000 R 003165 CD12       0000 R 003166 CD13       0000 R 003172 CFAP       0000 R 003071 CL1
 0000 R 003072 CL2        0000 R 003073 CL3        0000 R 003074 CL4        0000 R 003075 CL5        0000 R 003076 CL6
 0000 R 003077 CL7        0000 R 003100 CL8        0000 R 001737 CP7        0000 R 001172 CYM        0000 R 001753 DPL5
 0000 R 001754 DPL6       0000 R 001634 D22124     0000 R 001733 DP76       0000 R 001734 DP89       0000 R 001724 DT
 0000 R 00175[illegible]  0000 R 003[illegible]    0000 R 001720 FLAG1      0000 R 001721 FLAG2      0000 R 001630 FLAG3
 [illegible]
```

0000 R 001623 FTOL	0000 R 003237 FTURB	0000 R 003243 F0	0000 R 003235 F011	0000 R 003244 F1
0000 R 003257 F10	0000 R 003260 F11	0000 R 001750 F12	0000 R 001751 F121	0000 R 001752 F129
0000 R 003261 F13	0000 R 003236 F1325	0000 R 003262 F14	0000 R 003263 F15	0000 R 003264 F16
0000 R 003265 F17	0000 R 003266 F19	0000 R 003245 F2	0000 R 003267 F25	0000 R 003246 F3
0000 R 003247 F4	0000 R 003250 F5	0000 R 003252 F55	0000 R 003253 F6	0000 R 003254 F7
0000 R 003255 F8	0000 R 003256 F9	0000 R 001624 G	0000 I 001616 I	0000 I 001726 IB
0000 I 001725 IC	0000 I 001650 IND	0000 I 001622 IX	0000 I 001620 I$	0000 I 001617 J
0000 I 001621 K	0000 I 001760 L	0000 I 001631 N	0000 I 001627 NDU	0003 R 000000 NORM
0000 I 001625 NU	0000 I 001626 NV	0000 R 001730 PCBV	0000 R 001703 PC11	0000 R 001704 PC12
0000 R 001710 PC121	0000 R 001712 PC129	0000 R 001705 PC13	0000 R 001706 PC135	0000 R 001713 PC17
0000 R 001714 PC19	0000 R 001702 PC4	0000 R 001727 PC5	0000 R 001731 PC55	0000 R 001732 PC7
0000 R 001640 PDI	0000 R 001641 PP1	0000 R 001651 PI	0000 R 003046 PIF	0000 R 003043 PPD
0000 R 003045 PS	0000 R 003050 PTE	0000 R 003047 PTI	0000 R 003174 P1	0000 R 003044 P1F
0000 R 001717 P10	0000 R 003204 P11	0000 R 003302 P119	0000 R 003205 P12	0000 R 003055 P12F
0000 R 003170 P126	0000 R 003206 P121	0000 R 003207 P129	0000 R 003210 P13	0000 R 003211 P135
0000 R 003212 P14	0000 R 003213 P15	0000 R 003214 P16	0000 R 003215 P17	0000 R 003216 P18
0000 R 003217 P19	0000 R 003220 P20	0000 R 003057 P21	0000 R 001635 P21R	0000 R 003060 P22
0000 R 001636 P22F	0000 R 003061 P23	0000 R 001637 P23F	0000 R 003062 P24	0000 R 001715 P3
0000 R 003175 P4	0000 R 003301 P49	0000 R 003176 P5	0000 R 003054 P5F	0000 R 003167 P5G
0000 R 003177 P54	0000 R 003200 P55	0000 R 003201 P6	0000 R 003202 P7	0000 R 003203 P8
0000 R 001716 P9	0000 R 003102 RPPR	0000 R 001747 RHOBP	0000 R 003275 RHOPD	0000 R 003070 RHOTE
0000 R 003067 RHOTI	0000 R 003270 RHO0	0000 R 003274 RHO12	0000 R 003300 RHO18	0000 R 003271 RHO5
0000 R 003272 RHO6	0000 R 003273 RHO7	0000 R 001745 RO121	0000 R 003276 RO129	0000 R 003277 RO135
0000 R 003104 RPSS	0000 R 003053 RPM	0000 R 003103 RTBS	0000 R 003101 RTEH	0000 R 001633 RTIL
0000 R 001741 R12	0000 R 001742 R13	0000 R 003173 SBP	0000 R 000150 SIGX	0000 R 000410 SIGY
0000 R 000634 SBDV	0000 R 000522 SUMY	0000 R 003171 T	0000 R 003056 TBPR	0000 R 000000 TITLE
0000 R 001740 T0	0000 R 003064 TPD	0000 R 003063 TS	0000 R 003051 TTBP	0000 R 001744 T121
0000 R 001746 T129	0000 R 001644 U	0000 R 001642 UARG	0000 R 001645 V	0000 R 001643 VARG
0000 R 003232 WBP	0000 R 003231 WPPR	0000 R 001743 WBPS	0000 R 003221 WL1	0000 R 001735 WL2
0000 R 001736 WL3	0000 R 003224 WL4	0000 R 003225 WL5	0000 R 003226 WL6	0000 R 001755 WL7
0000 R 003227 WL8	0000 R 003230 WPRS	0000 R 003052 WPD	0000 R 003233 WTBS	0000 R 003234 WTEH
0000 R 001632 WIT	0000 R 003222 W7	0000 R 003223 W8	0000 R 003043 X	0000 R 001757 XCEBP
0000 R 003122 XKCV	0000 R 003113 XK11	0000 R 003114 XK12	0000 R 003115 XK121	0000 R 003116 XK129
0000 R 003117 XK13	0000 R 003120 XK17	0000 R 003121 XK19	0000 R 003107 XK4	0000 R 003110 XK5
0000 R 003111 XK55	0000 R 003112 XK7	0000 R 000022 XM	0000 R 001304 XMAX	0000 R 001432 XMIN
0000 R 001707 XM121	0000 R 001711 XM129	0000 R 001701 XRPMS	0000 R 003171 Y	0000 R 003105 YBV1
0000 R 003106 YBV2	0000 R 003133 YIH	0000 R 000276 YM	0000 R 000746 YMAX	0000 R 001060 YMIN
0000 R 003132 Y0	0000 R 003134 YJ	0000 R 003145 Y10	0000 R 003146 Y11	0000 R 003147 Y12
0000 R 003150 Y121	0000 R 003151 Y129	0000 R 003152 Y13	0000 R 003153 Y135	0000 R 003154 Y14
0000 R 003155 Y15	0000 R 003156 Y16	0000 R 003157 Y17	0000 R 003160 Y18	0000 R 003135 Y2
0000 R 003161 Y20	0000 R 003162 Y21	0000 R 003163 Y22	0000 R 003164 Y23	0000 R 003136 Y3
0000 R 003137 Y4	0000 R 003140 Y5	0000 R 003141 Y6	0000 R 003142 Y7	0000 R 003143 Y8
0000 R 003144 Y9	0000 R 001646 Z	0000 R 001647 ZARG	0000 R 003123 Z0	0000 R 003127 Z10
0000 R 003130 Z14	0000 R 003131 Z16	0000 R 003124 Z3	0000 R 003125 Z6	0000 R 003126 Z8

```
00100      1*     C        PROGRAM NAME IS TPAMOD
00100      2*     C        THIS PROGRAM IS A MATH MODEL OF THE TPA INTERNAL FLOW CIRCUITS AND
00100      3*     C        BALANCE PISTON WITH MONTE CARLO STATISTICAL ANALYSIS
00100      4*     C        R.A.LIVINGSTON 12-14-71
00101      5*            1 DIMENSION TITLE (18)
00103      6*              DIMENSION X(86),XM(86),SIGX(86),Y(74),YM(74),SIGY(74),SUMY(74),
00103      7*             1SBDV(74),YMAX(74),YMIN(74),CYM(74),XMAX(86),XMIN(86)
00104      8*              DIMENSION B(15), C(15)
00105      9*              READ(5,1100) (B(I),I=1,15)
00113     10*              READ(5,1100) (C(J),J=1,15)
00121     11*            4 READ(5,1000) TITLE
00127     12*              READ(5,2000)(XM(I),I=1,86)
```

```
00135          READ(5,5000)(SIGX(I),I=1,86)
00143        5 READ(5,1105) K,IX,FTOL,G
00151          NU=7
00152          NV=5
00153          NOU=7
00154          REAL NORM
00154     C    EQUATE X AND Y TO MAIN PROGRAM VARIABLES
00155          EQUIVALENCE (X(1),PP0),(X(2),P1F),(X(3),PS),(X(4),PIF),(X(5),PTI)
00156          EQUIVALENCE (X(6),PTE),(X(7),TTBP),(X(8),WPD),(X(9),RPM)
00157          EQUIVALENCE (X(10),P5F),(X(11),P12F),(X(12),TBPR)
00160          EQUIVALENCE (X(13),P21),(X(14),P22),(X(15),P23),(X(16),P24)
00161          EQUIVALENCE (X(17),TS),(X(18),TPD),(X(19),AT1),(X(20),AT2)
00162          EQUIVALENCE             (X(21),RHOTI),(X(22),RHOTE),(X(23),CL1)
00163          EQUIVALENCE (X(24),CL2),(X(25),CL3),(X(26),CL4),(X(27),CL5)
00164          EQUIVALENCE (X(28),CL6),(X(29),CL7),(X(30),CL8),(X(31),RTEH)
00165          EQUIVALENCE (X(32),P0PR),(X(33),RTPS),(X(34),RPRS),(X(35),YBV1)
00166          EQUIVALENCE (X(36),YBV2),(X(37),XK4),(X(38),XK5),(X(39),XK55)
00167          EQUIVALENCE (X(40),XK7),(X(41),XK11),(X(42),XK12),(X(43),XK121)
00170          EQUIVALENCE (X(44),XK129),(X(45),XK13),(X(46),XK17),(X(47),XK19)
00171          EQUIVALENCE (X(48),XKBV),(X(49),Z0 ),(X(50),Z3 ),(X(51),Z6)
00172          EQUIVALENCE (X(52),Z8),(X(53),Z10),(X(54),Z14),(X(55),Z16)
00173          EQUIVALENCE (X(56),Y0 ),(X(57),YIH),(X(58),Y1),(X(59),Y2)
00174          EQUIVALENCE (X(60),Y3),(X(61),Y4),(X(62),Y5),(X(63),Y6),(X(64),Y7)
00175          EQUIVALENCE (X(65),Y8),(X(66),Y9),(X(67),Y10),(X(68),Y11)
00176          EQUIVALENCE (X(69),Y12),(X(70),Y121),(X(71),Y129),(X(72),Y13)
00177          EQUIVALENCE (X(73),Y135),(X(74),Y14),(X(75),Y15),(X(76),Y16)
00200          EQUIVALENCE (X(77),Y17),(X(78),Y18),(X(79),Y20),(X(80),Y21)
00201          EQUIVALENCE (X(81),Y22),(X(82),Y23 ),(X(83),CD12),(X(84),CD13)
00202          EQUIVALENCE (X(85),P50),(X(86),P126)
00203          EQUIVALENCE (Y(1),T),(Y(2),CFBP),(Y(3),SBP),(Y(4),P1),(Y(5),P4)
00204          EQUIVALENCE (Y(6),P5),(Y(7),P54),(Y(8),P55),(Y(9),P6),(Y(10),P7)
00205          EQUIVALENCE (Y(11),P8),(Y(12),P11),(Y(13),P12),(Y(14),P121)
00206          EQUIVALENCE (Y(15),P129),(Y(16),P13),(Y(17),P135),(Y(18),P14)
00207          EQUIVALENCE (Y(19),P15),(Y(20),P16),(Y(21),P17),(Y(22),P18)
00210          EQUIVALENCE (Y(23),P19),(Y(24),P20),(Y(25),WL1),(Y(26),W7)
00211          EQUIVALENCE (Y(27),W8),(Y(28),WL4),(Y(29),WL5),(Y(30),WL6)
00212          EQUIVALENCE (Y(31),WL8),(Y(32),WPBS),(Y(33),WBPR),(Y(34),WBP)
00213          EQUIVALENCE (Y(35),WTBS),(Y(36),WTEH),(Y(37),F011),(Y(38),F1325)
00214          EQUIVALENCE (Y(39),FTURB),(Y(40),FM1),(Y(41),FM2),(Y(42),FMOM)
00215          EQUIVALENCE (Y(43),F0),(Y(44),F1),(Y(45),F2),(Y(46),F3),(Y(47),F4)
00216          EQUIVALENCE (Y(48),F5),(Y(49),FBV),(Y(50),F55),(Y(51),F6)
00217          EQUIVALENCE (Y(52),F7),(Y(53),F8),(Y(54),F9),(Y(55),F10)
00220          EQUIVALENCE (Y(56),F11),(Y(57),F13),(Y(58),F14),(Y(59),F15)
00221          EQUIVALENCE (Y(60),F16),(Y(61),F17),(Y(62),F19),(Y(63),F25)
00222          EQUIVALENCE (Y(64),RHO0),(Y(65),RHO5),(Y(66),RHO6),(Y(67),RHO7)
00223          EQUIVALENCE (Y(68),RHO12),(Y(69),RHOPD),(Y(70),RO129)
00224          EQUIVALENCE (Y(71),RO135),(Y(72),RHO18),(Y(73),P49),(Y(74),P119)
00225          FLAG3=0
00226          DO 310 N=1,86
00231          X(N)=XN(N)
00232      310 XNIN(N)=XN(N)
00234          WTI=WPD*(1.-TBPR)
00235          RTIL=RHOTI*(PP0-PTI)/WTI**2
00236          DP2124=P21-P24
00237          P21R=(PTI-P21)/WT1**2
00240          P22F=(P22-P24)/DP2124
00241          P23F=(P23-P24)/DP2124
00242        9 WRITE(6,2000) TITLE
00250          WRITE(6,2010) K
00253          WRITE(6,2001) PP0,P1F,PS,PIF,PTI,PTE,TTBP,WPD,RPM
```

```
00266      WRITE(6,2002) RHOTI,RHOTE,FTOL,G,TBPR,TS,TPD
00277      WRITE(6,2003) CL1,CL2,CL3,CL4,CL5,CL6,CL7,CL8
00311      WRITE(6,2009) RTEH,RBPR,RTBS,RPDS,P5F,P12F,P56,P126
00323      WRITE(6,2007)          Z0,Z3,Z6,Z8,Z10,Z14,Z16
00334      WRITE(6,2004)XK4,XK5,XK55,XKBV,XK7,YK11,XK12,XK121,XK129,XK13,
00334     1XK17,XK19
00352      WRITE(6,2005) Y1,Y2,Y3,Y4,Y5,Y6,Y7,Y8,Y9,Y10,Y11,Y12,YIH,Y0
00372      WRITE(6,2006)Y121,Y129,Y13,Y135,Y14,Y15,Y16,Y17,Y18,Y20,Y21,
00372     1Y22,Y23
00411      WRITE(6,2008)      CD12,CD13,  AT1,AT2,YBV1,YBV2
00421      WRITE(6,4000)      P21,P22,P23,P24
00427      GO TO 12
00430  400 DO 260 I=1,K
00433  402 DO 410 J=1,86
00436      X(J)=HOG4(XM(J),SIGX(J),IX,B,C)
00437      IF(X(J)-XMAX(J)) 404,404,403
00442  403 XMAX(J)=X(J)
00443  404 IF(X(J)-XMIN(J)) 405,410,410
00446  405 XMIN(J)=X(J)
00447  410 CONTINUE
00450 *DIAGNOSTIC*  THE TRANSFER TO 12 IS BAD BECAUSE 12 IS NOT IN THE INNERMOST DO OF A NEST.
00451      WTI=WPD*(1.-TEPR)
00451 C    THE FOLLOWING 5 STATEMENTS REVISE TURB. PRESS. DISTRIBUTION
00452      PTI=PPD-RTIL/RHOTI*WTI**2
00453      P21=PTI-P21R*WTI**2
00454      DP2124=P21-P24
00455      P22=P24+P22F*DP2124
00456      P23=P24+P23F*DP2124
00457   12 PDI=PPD*PIF
00460      PD1=PPD*P1F
00461      P5=PD1*P5F
00462      P49=P5-P56
00463      P12=PPD-(1.-P12F)*(PPD-PD1)
00464      P119=P12-P126
00465      UARG=P5
00466      VARG=TS
00467      CALL TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
00470      RHO0=ZARG
00471      UARG=P5
00472      VARG=.5*(TS+TPD)
00473      CALL TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
00474      RHO5=ZARG
00475      UARG=.65*P5
00476      VARG=TPD+7.
00477      CALL TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
00500      RHO6=ZARG
00501      UARG=PPD*.73
00502      VARG=TPD
00503      CALL TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
00504      RHO7=ZARG
00505      UARG=P12
00506      VARG=TPD
00507      CALL TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
00510      RHO12=ZARG
00511      RO129=RHO12
00512      VARG=TPD+7.
00513      UARG=P5*.5
00514      CALL TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
00515      RO135=ZARG
00516      UARG=P1
```

```
      VARG=TPD
      CALL TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
      RHO18=ZARG
      UARG=PPD
      VARG=TPD
      CALL TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
      RHOPD=ZARG
      CL1=CL1/RHO5
      CL2=CL2/RHO7
      CL3=CL3/RHO12
      CL4=CL4/RHO12
      CL5=CL5/RHO12
      CL6=CL6/RHO12
      CL7=CL7/RHO18
      CL8=CL8/RHOTI
      RTEH=RTEH/RHOTI
      RBPR=RBPR/RO135
      RTBS=RTBS/RHOPD
      RPBS=RPBS/RHOPD
      PI=3.14159
      A0=PI*Y1**2
      A1=PI*(Y1**2-Y2**2)
      A2=PI*(Y3**2-Y2**2)
      A3=PI*(Y4**2-Y3**2)
      A4=PI*(Y5**2-Y4**2)
      A5=PI*(Y5**2-YBV2**2)
      A5V=PI*(YBV2**2-YBV1**2)
      A55=PI*(YBV1**2-Y6**2)
      A6=PI*(Y6**2-Y7**2)
      A7=PI*(Y7**2-Y8**2)
      A8=PI*(Y9**2-Y8**2)
      A9=PI*(Y10**2-Y9**2)
      A10=PI*(Y11**2-Y10**2)
      A11=PI*(Y12**2-Y11**2)
      A12=PI*(Y121**2-Y12**2)
      A121=PI*(Y121**2-Y129**2)
      A129=PI*(Y129**2-Y13**2)
      A13=PI*(Y13**2-Y14**2)
      A14=PI*(Y14**2-Y15**2)
      A15=PI*(Y15**2-Y16**2)
      A16=PI*(Y17**2-Y16**2)
      A17=PI*(Y18**2-Y17**2)
      A19=PI*(Y20**2-Y18**2)
      XRPMS=.0055*RPM**2/G
C     INITIALIZE P15,P19,P20
      P19=PTE+10.
      P20=P19
   15 P15=P19+.2*(PPD-PTE)
      PC4=XRPMS*RHO5*XK4**2*(Y5**2-Y4**2)
      PC11=XRPMS*RHO12*XK11**2*(Y12**2-Y11**2)
      PC12=XRPMS*RHO12*(Y121**2 -Y12**2)*XK12**2
   20 PC13=XRPMS*RO135*XK13**2*(Y13**2-Y135**2)
      PC135=XRPMS*RO135*XK13**2*(Y135**2-Y14**2)
      XM121=XRPMS*(Y121**2-Y129**2)*XK121**2
      PC121=XM121*RHO12
      XM129=XRPMS*(Y129**2-Y13**2)*XK129**2
   25 PC129=XM129*RHO12
      PC17=XRPMS*RHO18*XK17**2*(Y18**2-Y17**2)
      PC19=XRPMS*RHOTI*XK19**2*(Y20**2-Y18**2)
   26 P1=P2-(P20[illegible])**2/(2.*G*RHO0)*(1./(PI*(Y1**2-Y0**2))**2-1./(PI*Y0**2)*
```

```
     1*2)
      P3=PD1
      P4=P49-PC4
      P7=.5*(PD1+PPD)
      P9=PD1
      P10=PD1
   36 P11=P119-PC11
      P135=P5+.020*(PPD-PS)
      P13=P135+PC13
      P14=P135-PC135
      SLP= A121*(P12-P13)/TIBP
   35 FLAG1=0
      FLAG2=0
      FLAG4=0
      FLAG7=0
      D1=0.
      IC=0
      IB=0
   38 PC5=XRPMS*RHO6* XK5**2*(Y5**2-YBV2**2)
      PCBV=XRPMS*RHO6*XKBV**2*(YBV2**2-YBV1**2)
      PC55=XRPMS*RHO6*XK55**2*(YBV1**2-Y6**2)
      P54=P5-PC5
      P55=P54-PCBV
      P6=P55-PC55
   39 PC7=XRPMS*RHO7 *(Y7**2-Y8**2)*XK7**2
      P8=P7-PC7
C     STATEMENTS 40-45 ITERATIVELY COMPUTE P7
   40 DP76=P7-P6
      DP89=P8-P9
      WL2=SQRT(ABS(DP76)/CL2)*DP76/ABS(DP76)
      WL3=SQRT(ABS(DP89)/CL3)*DP89/ABS(DP89)
      WPBS=WL2+WL3
      CP7=PPD-RPBS*WPBS**3/ABS(WPBS)
      IF(ABS((P7-CP7)/CP7)-.0010) 44,44,42
   42 P7=.5*(P7+CP7)
      IB=IB+1
      IF(IB-25)40,40,301
   44 P7=CP7
      P8=P7-PC7
      IF (FLAG7) 45,45,49
   45 UARG=P7
      VARG=TPD
      CALL TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IPD)
      CL2=CL2*RHO7/ZARG
      CL3=CL3*RHO7/ZARG
      RHO7=ZARG
      FLAG7=1
      GO TO 39
   49 F5=P5 *A5-PI*XRPMS* XK5**2*RHO6*(Y5**2*YBV2**2-.5*(Y5**4+YBV2**4))
      F55=P55*A55-PI*XRPMS*XK55**2*RHO6*(YBV1**2*Y6**2-.5*(Y6**4+YBV1**4
     1))
      FBV=P54*ABV-PI*XRPMS*XKBV**2*RHO6*(YBV2**2*YBV1**2-.5*(YBV2**4+YBV
     11**4))
      F6=Z6*(P6+P7)*A6
      F7=P8*A7  -3.141*XRPMS*XK7**2*RHOPD*(Y8**2*Y7**2-.5*(Y7**4+Y6**4))
      F8=Z8*(P8+P9)*A8
      IF (FLAG4) 50,50,62
   50 F0=A0*Z0*(PS+P1)
      F1=.5*(P1+PD1)*A1
      F2=P5*A2
```

```
00712          F3=Z3*(PO1+P4)*A3
00713          F4=P4*A4  -3.141*XRPMS*XK4**2*RHO5*(Y4**2*Y5**2-.5*(Y4**4+Y5**4))
00714          F9=PO1*A9
00715       60 F10=Z10*(PO1+P11)*A10
00716          F11=P11*A11  -3.141*XRPMS*XK11**2*RHO12*(Y11**2*Y12**2-.5*(Y12**4+
00716         1Y11**4))
00717          FM1=WPD**2/(386.*RHO5*AT1)
00720          FTURB=P1*(P21*(Y21**2-Y20**2)- P22*(Y21**2-Y22**2)+(P23-P24)*(Y23*
00720         1*2-Y22**2))
00721          F25=P1*Y22**2*PTE
00722       62 F011=F0-F1+F2+F3+F4-F5-F6-F7+F8+F9+F10+F11-F55-FBV
00723          IF(FLAG4) 100,100,113
00723    C     STATEMENTS 100-200 ITTERATIVELY COMPUTE BAL. PISTON POSITION
00725      100 T=.5*TTBP
00727          TO=TTBP-T
00730      101 IC=IC+1
00731          IF(IC-25)102,102,300
00734      102 R12=.05070/(G*RHO12*(CD12*(Y12+Y121)*(TO))**2)
00735          R13=.05070/(G*RO129*(CD13*(Y129+Y13)*T)**2)
00736          WBPS=(P12-P13+PC12-PC121-PC129)/(R12+R13)
00737          P121=P12-R12*WBPS+PC12
00740      104 UARG=P121
00740    C     THE FOLLOWING IS AN EMPIRICAL EQN.
00741          T121=TPO+6.2-375.*TO
00742          VARG=T121
00743          CALL TLU2(MDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
00744          RO121=ZARG
00745          PC121=      RO121*XM121
00746          P129=P121-PC121
00747          UARG=P129
00747    C     THE FOLLOWING IS AN EMPIRICAL EQN.
00750          T129=TPO+14./(1000.*TO)**.42
00751          VARG=T129
00752          CALL TLU2(MDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IND)
00753          RO129=ZARG
00754          RHOBP=.50*(RO121+RO129)
00755          PC121=      RHOBP*XM121
00756          PC129=XM129*RO129
00757          P129=P121-PC121
00760      106 F12=A12*P121
00761          F121=P129*A121-3.141*XRPMS*XK121**2*RO129*(Y121**2*Y129**2-.5*(Y12
00761         11**4+Y129**4))
00762          F129=A129*P13
00763          DPL5=P15-P14
00764          WL5=SQRT(ABS(DPL5)/CL5)*ABS(DPL5)/DPL5
00765          R12=.05070/(G*RHO12*(CD12*(Y12+Y121)*(TO))**2)
00766          R13=.05070/(G*RO129*(CD13*(Y129+Y13)*T)**2)
00767      111 WBP=SQRT((P12-P13+PC12-PC121-PC129)/(R12+R13))
00770          WBPR=WBP+WL5
00771      113 P135=P6+RBPR*WBPR**2
00772      114 P13=P135+PC13
00773          P14=P135-PC135
00774      115 P16=P15
00775          DPL6=P16-P19+PC17
00776          WL6=SQRT(ABS(DPL6)/(CL6+CL7))*ABS(DPL6)/DPL6
00777          WL7=WL6
01000          WTBS=WL5+WL6
01001          P16=PPO-RTBS*WTBS**2
01002          P15=P16
01003      120 WL8=SQRT((P21-P20)/CL8)
```

```
      WTEH=WL8+WL7
      P20=PTE+BTEH*WTEH**2+.30*PC19
      P19=P20-PC19
      P18=P19+CL7*WL7**2
      P17=P18-PC17
      F13=P14+A13-3.141*XPPMS*XK13**2*R0135*(Y13**2*Y14**2-.5*(Y13**4+Y1
     14**4))
  125 F14=A14 *Z14*(P14+P15)
      F15=A15*.5*(P15+P16)
      F16=A16 *Z16*(P16+P17)
      F17=A17  *.5*(P17+P18)
      F19=A19+P19-PI*XRPMS*XK19**2*RHOTI*(Y20**2*Y18**2-.5*(Y20**4+Y18**
     14))
      F1325=-F13-F14-F15+F16+F17+F19+FTURB-F25
  130 FM2=(WPD+WBPR)**2/(G*RHO12*AT2)
      FMOM=FM1+FM2
      FBP=F01+F1325+FMOM
  137 CFBP=F121+F129-F12
      WRITE(6,3002) T,TO,FBP,CFBP
 3002 FORMAT(1X,2HT= F8.5,5X,3HTO= F8.5,5X,4HFBP= E12.4,5X,5HCFBP= E12.4
     1,/)
  138 IF(ABS(FBP-CFBP)-FTOL)200,200,140
  140 IF(FLAG2)141,141,150
  141 DT=(CFBP-FBP)/SBP
      FLAG2=1
  142 T=T+DT
  143 IF(T)144,144,145
  144 T=.00001
      GO TO 147
  145 IF( TTOP-T)146,146,147
  146 T=TTOP-.00001
  147 TO=TTOP-T
      XCFBP=CFBP-F1325-FM2
      GO TO 101
  300 WRITE(6,3000) T,FBP,CFBP
      GO TO 209
  301 WRITE(6,3001) CP7
      GO TO 999
  150 SBP=ABS((CFBP-F1325-FM2-XCFBP)/DT)
      GO TO 141
  200 IF(FLAG4)201,201,205
C     THE FOLLOWING 4 STATEMENTS  CORRECT THE DENSITY AT STA. 6
  201 VARG=(T129*WBPR+TPD*WL2)/(WBPR+WL2)
      UARG=P6
      CALL TLU2 (NDU,U,V,Z,NU,NV,UARG,VARG,ZARG,IUD)
      RHO6=ZARG
      FLAG4=1
      FLAG7=0
      GO TO 38
  205 WL1=SQRT((P4-P3)/CL1)
      WL4=SQRT((P11-P10)/CL4)
      IF(FLAG3) 209,209,250
  250 DO 260 J=1,72
      SUMY(J)=SUMY(J)+Y(J)
      SMDV(J)=SMDV(J)+(Y(J)-YM(J))**2
      IF(Y(J)-YMAX(J))255,255,254
  254 YMAX(J)=Y(J)
  255 IF(Y(J)-YMIN(J))256,256,260
  256 YMIN(J)=Y(J)
  260 CONTINUE
```

```
  450 GO TO 460
  209 WRITE(6,2100) T,CFBP,SBP
  210 WRITE(6,2101)PS,P1,PJI,P4,P49,P5,P54,P55,P6,P7,P8
      WRITE(6,2102) PD1,P11,P119,P12,P121,P129,P13,P135,P14,P15,P16
      WRITE(6,2103) P17,P18,P19,P20,P21,P22,P23,P24
  220 WRITE(6,2104) WL1,W7 ,W8 ,WL4,WL5,WL6,WL8,WPBS,WBPR,WBP,WTBS,WTEH
      WRITE(6,2105)RHO0,RHO5,RHO6,RHO7,RHO12,RHOPD
      WRITE(6,2106)T121,T129,RO121,RO129,RO135,RHO18
      WRITE(6,2011) F011,F1325,FTURB,FM1,FM2,FMOM
      WRITE(6,4100)F0,F1,F2,F3,F4,F5,FBV,F55,F6,F7,F8,F9,F10,F11,F011
      WRITE(6,4200)F13,F14,F15,F16,F17,F19,F25,F1325
      FLAG3=1
  224 DO 225 L=1,74
      YMIN(L)=Y(L)
  225 YM(L)=Y(L)
      YMAX(38)=Y(38)
  226 IF(K) 999,999,400
  460 DO 470 J=1,74
      SIGY(J)=SQRT(SMDV(J)/FLOAT(K))
  470 CYM(J)=SUMY(J)/FLOAT(K)
      WRITE(6,2500)
      WRITE(6,2501) (I,XM(I),SIGX(I),XMIN(I),XMAX(I),I=1,92)
      WRITE(6,2510)
      WRITE(6,2511) (J,YM(J),CYM(J),SIGY(J),YMIN(J),YMAX(J),J=1,63)
  999 CONTINUE
 1000 FORMAT(18A4)
 1100 FORMAT(12F6.0)
 1105 FORMAT(2I12,2F12.0)
 1200 FORMAT(7F10.0)
 2500 FORMAT(1H1, 51X,'INPUT VARIABLES',//,10X,'VARIABLE',10X,'MEAN',12X
     1,'VARIANCE',10X,'MIN. X',10X,'MAX. X',/)
 2501 FORMAT(14X,'X',I3,6X, E12.5,5X,E12.5,5X,E12.5,5X,E12.5,)
 2510 FORMAT(1H1, 54X,'OUTPUT DATA'///,5X,'VARIABLE',10X,'MEAN'10X,'TRIA
     1L MEAN', 8X,'STD. DEV.',10X,'MIN. Y',10X,'MAX. Y',/)
 2511 FORMAT(  8X,'Y',I3,6X,E12.5,5X,E12.5, 5X,E12.5, 5X,E12.5,5X,E12.5)
 2000 FORMAT (1H1,59HTPA THRUST BALANCE AND INTERNAL FLOW PROGRAM, REV.
     1 01-10-72,////,1X,18A4,//)
 2001 FORMAT(1X,4HPPD= F6.0,5X,4HPIF=F6.4,5X,3HPS=F6.0,5X,4HPIF=F6.4,5X,
     14HPTI=F6.0,//,1X,4HPTE= F6.0,5X,5HTTBP=F8.5,5X,4HWPD= F6.0,4X,4HRP
     2M=  F6.0,//)
 2002 FORMAT(1X,6HRHOTI= F9.5,5X,6HRHOTE= F9.5,5X,5HETOL= F8.1,5X,2HG= F
     18.2,//,1X,6HTBPR= F8.4,5X,3HTS= F8.2,5X,4HTPD= F8.2,//)
 2003 FORMAT(1X,4HCL1= E12.4,5X,4HCL2= E12.4,5X,4HCL3= E12.4,5X,4HCL4=
     1E12.4,//,1X,
     2             4HCL5=E12.4,5X,4HCL6=E12.4,5X,4HCL7=E12.4,5X,4HCL8=E12.4,
     3//)
 2004 FORMAT(1X,4HXK4=F6.4,5X,4HXK5=F6.4,5X, 5HXK55=F6.4,5X,5HXKBV=F6.4,
     15X,  4HXK7=F6.4,5X,5HXK11=F6.4,//,1X
     2,5HXK12=F6.4,5X,6HXK121=F6.4,5X,6HXK129= F6.4,5X,5HXK13= F6.4,5X,
     35HXK17= F6.4,5X,5HXK19= F6.4,//)
 2005 FORMAT(1X,10HY1 TH Y12= 5X,6(F8.4,5X,),/,16X,6(F8.4,5X,),//,1X,4HY
     11H= F8.4,5X,3HY0= F8.4,//,)
 2006 FORMAT(1X,5HY121= F8.4,5X ,5HY129= F8.4,5X ,4HY13= F8.4,5X, 5HY135
     1= F8.4,5X ,4HY14= F8.4,5X,4HY15=F8.4,//, 1X,4HY16= F8.4,5X ,4HY17=
     2 F8.4,5X ,4HY18= F8.4,5X ,4HY20= F8.4,5X ,4HY21= F8.4,5X ,4HY22=
     3F8.4,5X,4HY23= F8.4,///)
 2007 FORMAT(                 1X,3HZ0=F8.5,5X,3HZ3=F6.3,5X,3HZ6=F6.3,5X,3HZ
     28=F6.3,5X,4HZ10=F6.3,5X,4HZ14=F6.3,5X,4HZ16=F6.3,//)
 2008 FORMAT(1X,                 5HCD12= F6.4,5X,5HCD13= F6.4,//,
     1     1X,4HAT1= F7.3,5X,4HAT2= F7.3,5X, 5HYPV1=F7.3,5X,5HYPV2=F7.3,//
```

```
      1)
 2009 FORMAT(1X,                                          5HRTEH= E12.4,5X,5HRBPR=
     2 E12.4,5X,5HRTBS= E12.4,//,1X,5HRPBS= E12.4,5X,4HP5F= F8.5, 5X,5HP
     312F= F8.5,5X,4HP5G= F10.2,5X,5HP12G= F10.2,//)
 2010 FORMAT (1X,'NUMBER OF TRIALS FOR MONTE CARLO ANALYSIS =',1X,I6,//,
     11X,'MEAN VALUES OF INPUT VARIABLES,',//)
 2011 FORMAT(5X,5HF011= E12.4,5X,6HF1325= E12.4,5X,6HFTURB= E12.4,5X,
     1//,5X,4HFM1= F8.0,5X,4HFM2= F8.0,5X,5HFMOM= F9.0,//)
 2100 FORMAT(1H1,5X,'COMPUTED PARAMETERS BASED ON MEAN VALUE OF INPUT VA
     1RIABLES,'                              ///5X,30HBAL. PISTON INNER LAND C
     3LEARANCE (T) =F8.4,//,5X,16HBAL.PISTON LOAD=F10.1,//,5X,12HSTIFFNE
     4SS = E12.4, ///)
 2101 FORMAT(5X,3HPS= F7.2,4X,3HP1=F7.2,4X,4HPDI=F7.2,4X,3HP4=F7.1,4X,5H
     1P49=  F7.1,5X,3HP5= F7.1,//,5X,4HP54= F7.1,
     2              4X,4HP55=F7.1,4X,3HP6=F7.1,4X,3HP7=F7.1,4X,3HP8=F7.1,//)
 2102 FORMAT(5X,4HPD1= F7.1, 4X,4HP11=F7.1,4X,5HP119=  F7.1,4X,4HP12= F7
     1.1,4X,5HP121= F7.1,4X,5HP129= F7.1,4X,4HP13=F7.1,/,1X,5HP135=F7.1,
     24HP14= F7.1,4X,4HP15= F7.1,4X,4HP16= F7.1, //)
 2103 FORMAT(            5X,4HP17=F6.1,4X,4HP18=F6.1,4X,4HP19=F6.1,4X,4HP20=
     1F6.1,4X,4HP21=F6.1,4X,4HP22=F6.1,//,5X,
     2                                      4HP23=F6.1,4X,4HP24=F6.1,///)
 2104 FORMAT(5X,4HWL1=F7.3,4X,4HWL2=F7.3,4X,4HWL3=F7.3,4X,4HWL4=F7.3,4X,
     14HWL5=F7.3,4X,4HWL6=F7.3,5X,4HWL8= F7.3,
     3                    //,5X,5HUPDS=F7.3,4X,5HWBPR=F7.3,//,5X,
     44HRBP= F7.3,4X,5HWTBS= F7.3,4X,5HWTEH= F7.3,//,)
 2105 FORMAT(1X,5HRH00=F9.5,5X,5HPH05=F9.5,5X,5HRH06=F9.5,5X,5HRH07=F9.5
     1,5X,6HRH012=F9.5,5X,6HRHOPD= F9.5,//,)
 2106 FORMAT(1X,5HT121= F8.2,5X,5HT129= F8.2,5X,6HR0121= F9.5,5X,6HR0129
     1= F9.5,//,1X,6HR0135= F9.5,5X,6HRH018= F9.5,//)
 3000 FORMAT(1H1,30HT ITERATION FAILED TO CONVERGE AT T= F7.5,5X,4HFBP=
     1E12.4,5X,5HCFBP= E12.4,//)
 3001 FORMAT(1H1,41HITERATION SOLUTION FOR P7 FAILED AT CP7= F6.0)
 4000 FORMAT(1X,                          7HP21-24= 4(F7.1,3X,),//)
 4100 FORMAT(5X, 9HF0 TH 5 = 6F9.0,//,5X,                    4HFBV=F9.0 ,5X,4
     1HF55=F9.0 ,//,5X,10HF6 TH 11 = 6F9.0,5X,5HF011= F9.0,//)
 4200 FORMAT(5X,10HF13 TH 17= 5F9.0,//,5X,4HF19=F9.0,5X,4HF25= F9.0,5X,6
     1HF1325= F9.0,//)
 4300 FORMAT(5X,'J',I3,10X,E12.4,20X,'J',I3,10X,E12.4,)
 5000 FORMAT(5F15.0)
      GO TO 4
      END

 END OF UNIVAC 1108 FORTRAN V COMPILATION.     1 *DIAGNOSTIC* MESSAGE(S)
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@ XOT MAIN 15 MAR 72 13:19:56.704

TPA THRUST BALANCE AND INTERNAL FLOW PROGRAM, REV. 01-10-72

TPA 24,239 RPM NORMAL MODE, DATA LIST DTD. 1-10-71

NUMBER OF TRIALS FOR MONTE CARLO ANALYSIS =   0

```
           1HF1325= F9.0,//)
     4300 FORMAT(5X,'J',I3,10X,F12.4,20X,'J',I3,10X,E12.4,)
     5000 FORMAT(5F15.0)
           GO TO 4
           END
```

END OF UNIVAC 1108 FORTRAN V COMPILATION.   1 *DIAGNOSTIC* MESSAGE(S)

D XOT MAIN 15 MAR 72 13:19:56.704

@ XQT MAIN 15 MAR 72 13:19:56.704

TPA THRUST BALANCE AND INTERNAL FLOW PROGRAM, REV. 01-10-72

TPA 24,239 RPM NORMAL MODE, DATA LIST DTD. 1-10-71

NUMBER OF TRIALS FOR MONTE CARLO ANALYSIS = 0

MEAN VALUES OF INPUT VARIABLES,

PPD= 1442. P1F= .5000 PS= 25. PIF= .0700 PTI= 1077.

PTE= 750. TTEP= .02500 WPD= 46. RPM=24239.

RHOTI= .00038 RHOTE= .00029 FTOL= 100.0 G= 386.00

TBPR= .0500 TS= 41.00 TPD= 60.00

CL1= .1590+00 CL2= .4250+00 CL3= .1430+01 CL4= .1590+00

CL5= .3020+01 CL6= .1710+01 CL7= .2000-01 CL8= .7600-01

RTEH= .1450-02 RPPR= .5000-02 RTBS= .3460+00

RPBS= .1320+00 P5F= .79000 P12F= .75700 P56= 10.00 P126= 10.00

Z0= .50000 Z3= .500 Z6= .500 Z8= .500 Z10= .500 Z14= .500 Z16= .500

XK4= .4800 XK5= .6800 XK55= .2400 XKBV= .9800 XK7= .4800 XK11= .4800

XK12= .4800 XK121= .4800 XK129= .4800 XK13= .4800 XK17= .4800 XK19= .4800

Y1 TH Y12=	3.4500	3.2500	3.4500	3.6500	5.4750	2.7500
	2.7500	1.5150	1.5150	3.4500	3.6500	5.5000

Y1H= 1.4000 Y0= 4.7500

Y121= 5.7000 Y129= 2.5000 Y13= 2.3000 Y135= 2.3000 Y14= 1.7500 Y15= 1.5150

Y16= 1.5150 Y17= 1.5150 Y18= 1.9000 Y20= 3.9000 Y21= 5.1830 Y22= 3.9000 Y23= 5.1830

CD12= .8500 CD14= .8500

AT1= 15.000 AT2= 15.000 YBV1= 4.000 YBV2= 5.000

P21-24= 964.2 901.6 798.9 749.8

T=	.01250	TO=	.01250	FBP=	.6121+05	CFBP=	.7812+05
T=	.01664	TO=	.00836	FBP=	.6177+05	CFBP=	.7031+05
T=	.02087	TO=	.00413	FBP=	.6194+05	CFBP=	.4734+05
T=	.01820	TO=	.00680	FBP=	.6173+05	CFBP=	.5939+05
T=	.01769	TO=	.00731	FBP=	.6165+05	CFBP=	.6400+05
T=	.01795	TO=	.00705	FBP=	.6172+05	CFBP=	.6257+05
T=	.01809	TO=	.00691	FBP=	.6169+05	CFBP=	.6174+05
T=	.01809	TO=	.00691	FBP=	.6175+05	CFBP=	.6174+05

Itteration data setting FBP = CFBP (varying T)

```
COMPUTED PARAMETERS BASED ON MEAN VALUE OF INPUT VARIABLES.

BAL. PISTON INNER LAND CLEARANCE (T) =   .0181
BAL.PISTON LOAD=   61744.3
STIFFNESS =      .587o+07

PS=  25.00    P1=  24.09    PDI= 100.94    P4=  479.3    P49=   559.6    P5=  569.6
P54=  521.4    P55=  540.5    P6=  330.4    P7= 1040.3    P8= 1014.9

P01=  721.0    P11= 1175.2    P119= 1256.8    P12= 1266.8    P121=  871.4    P129=  744.9    P13=  416.2
P135=  416.2P14=  465.4    P15= 1125.9    P16= 1125.9

P17= 753.8    P18= 760.1    P19= 755.7    P20= 764.2    P21= 964.2    P22= 901.6
P23= 798.9    P24= 749.8

WL1=  2.439    WL2=   .000    WL3=   .000    WL4=  2.672    WL5=   .766    WL6=   .745    WL8=  1.001
WPBS=  2.753    WBPR=  6.549
WBP=  5.784    WTBS=  1.511    WTEN=  1.746

RHO0=   .00250    RHO5=   .00250    RHO6=   .00250    RHO7=   .00250    RHO12=   .00250    RHOPD=   .00250

T121=   63.61    T129=   66.22    RO121=   .00250    RO129=   .00250
RO135=   .00250    RHO18=   .00250

F011=    .6707+05    F1325=  -.5648+04    FTURB=    .4089+04
FM1=    146.    FM2=    191.    FMOM=    337.

F0 TH 5 =     918.    263.    425.    1294.   27175.    9280.
F0V=   17301.    F55=    9162.
F6 TH 11 =      0.   17397.      0.   21761.    4229.   64665.    F011=   67065.

F13 TH 17=    2875.    1846.      0.      0.    3127.
F19=   27694.    F25=   35838.    F1325=   -5648.
```

N8300R:72-106
May 1972

11. LH_2 PUMP TEST DATA REDUCTION PROGRAM

TAD•428249•2•100 • DATE 05 APR 72 PAGE 1

```
@9 RUN TAD•428249•2•100                05 APR 72   11:08:19.523
@ CTL UN=24ZZZX                        05 APR 72   11:08:19.523
@I    ELT LIST                         05 APR 72   11:08:19.584
@ ELT DATA                             05 APR 72   11:08:22.514
```

LH_2 PUMP TEST DATA REDUCTION PROGRAM

SEE: FINAL REPORT —
LH_2 PUMP COMPONENT DEVELOPMENT
TESTING IN THE ELECTRIC PUMP
ROOM AT TEST CELL "C"
PROJECT 121, MAY 1972
N8300R:72 — 101;
FOR COMPLETE DESCRIPTION
AND LISTING

TAD.428249.2.100 . DATE 05 APR 72 PAGE 2

@ XQT CUR 05 APR 72 11:08:23.907

1. LIST 1 11:08:24

05 APR 72 11:08:10.523

05 APR 72 11:08:10.584

TAD,428249,2,100 DATE 05 APR 72 PAGE 3

@ ELT DATA,1,720405, 40102

000001	9 10 11 13 15 16 16 17 17 18 19 20 43 43 43 43 43 42 42 42 42 42 41 40 41							
000002	40 40 39 39 38							
000003	24.9029	25.2000	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000
000004	36.4823							
000005	0.20788	0.20828	0.21058	0.21305	0.21575	0.21869	0.22487	0.22528
000006	0.22632							
000007	-132.27	-131.80	-128.88	-125.77	-122.46	-118.96	-115.25	-111.28
000008	-110.18							
000009	1.186	1.205	1.316	1.427	1.539	1.650	1.761	1.874
000010	1.905							
000011	24.9336	25.2000	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000
000012	37.8000	39.0995						
000013	0.20780	0.20812	0.21042	0.21289	0.21559	0.21853	0.22163	0.22512
000014	0.22894	0.23196						
000015	-131.97	-131.55	-128.65	-125.53	-122.25	-118.75	-115.02	-111.07
000016	-106.85	-103.63						
000017	1.186	1.202	1.314	1.425	1.536	1.648	1.759	1.872
000018	1.985	2.070						
000019	24.9641	25.2000	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000
000020	37.8000	39.6000	41.1497					
000021	0.20772	0.20804	0.21026	0.21281	0.21543	0.21829	0.22147	0.22489
000022	0.22870	0.23291	0.23697					
000023	-131.67	-131.31	-128.39	-125.30	-122.01	-118.51	-114.80	-110.86
000024	-106.66	-102.16	-98.04					
000025	1.186	1.201	1.312	1.424	1.534	1.645	1.757	1.869
000026	1.983	2.099	2.201					
000027	25.0254	25.2000	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000
000028	37.8000	39.6000	41.4000	43.2000	44.3376			
000029	0.20756	0.20780	0.21003	0.21249	0.21511	0.21797	0.22107	0.22449
000030	0.22814	0.23236	0.23705	0.24237	0.24618			
000031	-131.10	-130.82	-127.92	-124.83	-121.54	-118.07	-114.38	-110.45
000032	-106.27	-101.79	-96.99	-91.85	-88.38			
000033	1.187	1.197	1.309	1.420	1.530	1.641	1.752	1.863
000034	1.977	2.092	2.211	2.333	2.412			
000035	25.0865	25.2000	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000
000036	37.8000	39.6000	41.4000	43.2000	45.0000	46.8000	46.8414	
000037	0.20740	0.20756	0.20979	0.21225	0.21479	0.21766	0.22067	0.22401
000038	0.22767	0.23180	0.23641	0.24157	0.24769	0.25493	0.25508	
000039	-130.52	-130.35	-127.45	-124.36	-121.10	-117.62	-113.95	-110.03
000040	-105.87	-101.43	-96.67	-91.56	-86.03	-79.95	-79.80	
000041	1.187	1.194	1.305	1.415	1.526	1.636	1.747	1.859
000042	1.971	2.086	2.203	2.324	2.450	2.581	2.585	
000043	25.1459	25.2000	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000
000044	37.8000	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	48.9365
000045	0.20724	0.20732	0.20955	0.21193	0.21456	0.21734	0.22036	0.22362
000046	0.22719	0.23124	0.23577	0.24086	0.24674	0.25381	0.26232	0.26414
000047	-129.95	-129.86	-126.96	-123.89	-120.63	-117.17	-113.50	-109.60
000048	-105.46	-101.05	-96.33	-91.26	-85.80	-79.80	-73.17	-71.85
000049	1.188	1.192	1.302	1.412	1.522	1.631	1.743	1.853
000050	1.965	2.079	2.196	2.316	2.439	2.570	2.709	2.737
000051	25.2071	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000052	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	50.7564
000053	0.20709	0.20931	0.21162	0.21424	0.21694	0.21996	0.22322	0.22679
000054	0.23069	0.23514	0.24014	0.24587	0.25262	0.26089	0.27130	0.27368
000055	-129.37	-126.49	-123.44	-120.18	-116.72	-113.08	-109.19	-105.06

000057	1.188	1.298	1.408	1.517	1.628	1.738	1.848	1.959
000058	2.073	2.189	2.308	2.430	2.559	2.695	2.844	2.876
000059	25.2665	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000060	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
000061	52.3745							
000062	0.20693	0.20907	0.21138	0.21392	0.21662	0.21956	0.22282	0.22632
000063	0.23021	0.23450	0.23943	0.24507	0.25159	0.25945	0.26923	0.28242
000064	0.28401							
000065	-128.79	-126.02	-122.97	-119.71	-116.28	-112.63	-108.77	-104.65
000066	-100.30	-95.63	-90.66	-85.29	-79.48	-73.09	-65.90	-57.50
000067	-56.58							
000068	1.189	1.295	1.405	1.514	1.623	1.733	1.843	1.953
000069	2.067	2.182	2.299	2.421	2.547	2.682	2.827	2.990
000070	3.008							
000071	25.3278	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000072	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
000073	53.8380							
000074	0.20677	0.20883	0.21114	0.21360	0.21630	0.21924	0.22242	0.22584
000075	0.22965	0.23395	0.23871	0.24420	0.25055	0.25810	0.26748	0.27964
000076	0.29561							
000077	-128.22	-125.53	-122.48	-119.26	-115.83	-112.18	-100.34	-104.25
000078	-99.92	-95.29	-90.34	-85.03	-79.29	-73.00	-65.98	-57.92
000079	-48.92							
000080	1.189	1.291	1.401	1.510	1.619	1.728	1.837	1.949
000081	2.060	2.175	2.291	2.412	2.538	2.669	2.810	2.968
000082	3.137							
000083	25.3871	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000084	39.6000	41.4000	43.2000	45.0000	46.8000	48:6000	50.4000	52.2000
000085	54.0000	55.1717						
000086	0.20661	0.20860	0.21082	0.21336	0.21599	0.21893	0.22203	0.22544
000087	0.22918	0.23339	0.23808	0.24340	0.24960	0.25683	0.26573	0.27710
000088	0.29315	0.30896						
000089	-127.64	-125.06	-122.01	-118.79	-115.38	-111.75	-107.91	-103.84
000090	-99.53	-94.93	-90.02	-84.77	-79.10	-72.89	-66.05	-58.24
000091	-48.84	-41.01						
000092	1.189	1.289	1.407	1.506	1.615	1.724	1.833	1.943
000093	2.054	2.168	2.284	2.404	2.527	2.657	2.795	2.948
000094	3.124	3.267						
000095	25.4465	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000096	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
000097	54.0000	55.8000	56.4029					
000098	0.20645	0.20836	0.21058	0.21305	0.21567	0.21853	0.22163	0.22505
000099	0.22870	0.23283	0.23744	0.24261	0.24865	0.25564	0.26414	0.27487
000100	0.28933	0.31238	0.32525					
000101	-127.07	-124.59	-121.54	-118.32	-114.91	-111.31	-107.49	-103.44
000102	-99.15	-94.56	-89.70	-84.50	-78.87	-72.79	-66.07	-58.48
000103	-49.56	-37.94	-32.54					
000104	1.190	1.285	1.394	1.502	1.611	1.719	1.828	1.938
000105	2.048	2.162	2.277	2.394	2.517	2.644	2.780	2.929
000106	3.096	3.308	3.404					
000107	25.5960	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000108	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
000109	54.0000	55.8000	57.6000	59.1047				
000110	0.20613	0.20772	0.20995	0.21241	0.21495	0.21773	0.22075	0.22401
000111	0.22751	0.23148	0.23585	0.24078	0.24642	0.25294	0.26057	0.26994
000112	0.28186	0.29847	0.32597	0.41744				
000113	-125.62	-123.40	-120.37	-117.17	-113.78	-110.20	-106.42	-102.41
000114	-98.17	-93.65	-88.87	-83.77	-78.29	-72.40	-65.96	-58.86
000115	-50.78	-41.12	-28.19	-1.36				
000116	1.192	1.277	1.385	1.492	1.600	1.708	1.816	1.925

000117	2.034	2.145	2.259	2.374	2.494	2.617	2.747	2.886
000118	3.038	3.214	3.442	3.900	[illegible]	[illegible]	[illegible]	[illegible]
000119	25.7435	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000120	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
000121	54.0000	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000
000122	68.4000	70.2000	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000
000123	82.8000	84.6000	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000
000124	97.2000	99.0000	100.8000					
000125	0.20574	0.20717	0.20939	0.21170	0.21424	0.21694	0.21980	0.22298
000126	0.22640	0.23021	0.23442	0.23911	0.24436	0.25040	0.25747	0.26581
000127	0.27614	0.28941	0.30825	0.34011	0.44994	0.75143	0.90298	1.01590
000128	1.11047	1.19573	1.27433	1.34799	1.41808	1.48531	1.55016	1.61310
000129	1.67436	1.73428	1.79301	1.85062	1.90728	1.96315	2.01830	2.07265
000130	2.12653	2.17978	2.23238					
000131	-124.19	-122.20	-119.20	-116.02	-112.88	-109.09	-105.33	-101.37
000132	-97.17	-92.73	-88.02	-83.00	-77.65	-71.91	-65.73	-58.97
000133	-51.44	-42.82	-32.46	-18.36	12.47	61.59	80.53	93.62
000134	104.16	113.40	121.76	129.52	136.84	143.81	150.53	157.01
000135	163.32	169.47	175.50	181.41	187.21	192.95	198.60	204.19
000136	209.73	1.94	7.40					
000137	1.193	1.269	1.376	1.483	1.591	1.697	1.804	1.912
000138	2.021	2.130	2.241	2.355	2.471	2.592	2.717	2.849
000139	2.990	3.147	3.330	3.571	4.080	4.874	5.172	5.371
000140	5.527	5.660	5.778	5.884	5.982	6.073	6.159	6.240
000141	6.317	6.391	6.461	6.528	6.595	6.658	6.718	6.777
000142	6.835	6.891	6.945					
000143	26.0369	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000144	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
000145	54.0000	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000
000146	68.4000	70.2000	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000
000147	82.8000	84.6000	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000
000148	97.2000	99.0000	100.8000					
000149	0.20502	0.20605	0.20820	0.21042	0.21281	0.21535	0.21813	0.22107
000150	0.22433	0.22783	0.23172	0.23601	0.24078	0.24610	0.25214	0.25914
000151	0.26732	0.27726	0.28957	0.30570	0.32851	0.36491	0.43071	0.53719
000152	0.64455	0.73618	0.81533	0.88589	0.95058	1.01082	1.06636	1.12072
000153	1.17293	1.22339	1.27234	1.31994	1.36651	1.41204	1.45670	1.50065
000154	1.54388	1.58647	1.62835					
000155	-121.33	-119.82	-116.83	-113.69	-110.37	-106.87	-103.16	-99.26
000156	-95.14	-90.81	-86.22	-81.38	-76.24	-70.76	-64.94	-58.67
000157	-51.86	-44.42	-36.06	-26.48	-14.92	0.00	20.68	45.94
000158	66.65	82.43	95.16	106.04	115.70	124.49	132.55	140.29
000159	147.67	154.75	161.60	168.23	174.69	181.03	187.21	193.29
000160	199.26	205.17	211.04					
000161	1.196	1.253	1.360	1.465	1.571	1.676	1.782	1.888
000162	1.994	2.102	2.209	2.320	2.431	2.546	2.664	2.786
000163	2.914	3.049	3.198	3.361	3.552	3.792	4.117	4.501
000164	4.808	5.037	5.215	5.365	5.494	5.609	5.712	5.808
000165	5.898	5.983	6.063	6.140	6.212	6.281	6.348	6.412
000166	6.474	6.534	6.594					
000167	26.3268	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000168	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
000169	54.0000	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000
000170	68.4000	70.2000	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000
000171	82.8000	84.6000	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000
000172	97.2000	99.0000	100.8000					
000173	0.20430	0.20502	0.20701	0.20915	0.21146	0.21392	0.21654	0.21940
000174	0.22242	0.22568	0.22934	0.23323	0.23760	0.24237	0.24777	0.25381
000175	0.26073	0.26875	0.27821	0.28965	0.30396	0.32239	0.34719	0.38160

000177	0.08208	0.12651	0.16934	0.21074	0.25087	0.29013	0.32843	0.36602
000178	0.40281	0.43897	0.47433					
000179	-118.47	-117.41	-114.46	-111.37	-108.06	-104.61	-100.98	-97.12
000180	-93.09	-88.83	-84.37	-79.66	-74.66	-69.42	-63.85	-57.92
000181	-51.59	-44.81	-37.40	-29.30	-20.24	-9.96	1.98	16.01
000182	32.24	49.35	65.54	79.83	92.37	103.48	113.55	122.80
000183	131.44	139.59	147.33	154.77	161.94	168.89	175.65	182.29
000184	188.75	195.10	201.42					
000185	1.199	1.238	1.343	1.449	1.553	1.657	1.761	1.865
000186	1.969	2.074	2.180	2.288	2.395	2.506	2.618	2.733
000187	2.853	2.976	3.106	3.246	3.395	3.561	3.749	3.962
000188	4.202	4.449	4.676	4.873	5.041	5.186	5.315	5.430
000189	5.535	5.634	5.724	5.809	5.890	5.966	6.039	6.109
000190	6.176	6.242	6.304					
000191	26.6130	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000192	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
000193	54.0000	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000
000194	68.4000	70.2000	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000
000195	82.8000	84.6000	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000
000196	97.2000	99.0000	100.8000					
000197	0.20367	0.20407	0.20597	0.20804	0.21019	0.21257	0.21503	0.21773
000198	0.22060	0.22369	0.22711	0.23077	0.23474	0.23911	0.24396	0.24936
000199	0.25540	0.26224	0.27002	0.27916	0.28981	0.30268	0.31834	0.33789
000200	0.36236	0.39280	0.42936	0.47092	0.51518	0.55984	0.60379	0.64614
000201	0.68699	0.72624	0.76415	0.00611	0.04164	0.07620	0.10982	0.14272
000202	0.17490	0.20645	0.23744					
000203	-115.64	-115.02	-112.09	-109.02	-105.78	-102.35	-98.74	-94.97
000204	-90.98	-86.82	-82.45	-77.84	-73.00	-67.92	-62.55	-56.90
000205	-50.90	-44.53	-37.72	-30.41	-22.50	-13.86	-4.37	6.14
000206	17.78	30.52	44.02	57.71	70.95	83.37	94.82	105.42
000207	115.25	124.44	133.15	141.40	149.31	156.91	164.26	171.39
000208	178.32	185.10	191.86					
000209	1.201	1.224	1.329	1.432	1.535	1.638	1.741	1.843
000210	1.946	2.049	2.152	2.257	2.362	2.469	2.578	2.688
000211	2.801	2.917	3.036	3.162	3.292	3.432	3.580	3.740
000212	3.913	4.097	4.287	4.475	4.653	4.814	4.961	5.093
000213	5.213	5.323	5.425	5.519	5.608	5.692	5.771	5.847
000214	5.918	5.988	6.056					
000215	26.8955	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
000216	39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
000217	54.0000	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000
000218	68.4000	70.2000	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000
000219	82.8000	84.6000	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000
000220	97.2000	99.0000	100.8000					
000221	0.20295	0.20311	0.20494	0.20693	0.20899	0.21130	0.21368	0.21622
000222	0.21893	0.22187	0.22505	0.22846	0.23220	0.23625	0.24070	0.24555
000223	0.25095	0.25691	0.26367	0.27122	0.27996	0.28997	0.30165	0.31548
000224	0.33177	0.35116	0.37397	0.40035	0.42983	0.46186	0.49539	0.52948
000225	0.56358	0.59703	0.62985	0.66196	0.69319	0.72370	0.75350	0.78267
000226	0.01652	0.04458	0.07199					
000227	-112.80	-112.63	-109.73	-106.68	-103.46	-100.09	-96.53	-92.79
000228	-88.87	-84.77	-80.47	-75.97	-71.25	-66.30	-61.10	-55.66
000229	-49.90	-43.87	-37.45	-30.66	-23.43	-15.69	-7.40	1.43
000230	11.17	21.51	32.54	44.06	55.85	67.63	79.08	90.08
000231	100.54	110.43	119.82	128.73	137.26	145.45	153.32	160.94
000232	168.34	175.55	182.67					
000233	1.205	1.210	1.314	1.417	1.518	1.620	1.722	1.823
000234	1.924	2.026	2.128	2.230	2.333	2.436	2.541	2.647
000235	2.756	2.866	2.978	3.094	3.214	3.339	3.469	3.605
[illegible]	3.767	[illegible]	[illegible]	[illegible]	4.368	[illegible]	[illegible]	[illegible]

000237	4.933	5.052	5.161	5.264	5.359	5.449	5.534	5.615
000238	5.692	5.765	5.836					
000239	27.1745	28.2000	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000
000240	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000
000241	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000
000242	70.2000	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000	82.8000
000243	84.6000	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000	97.2000
000244	99.0000	100.8000						
000245	0.20232	0.20399	0.20589	0.20788	0.21003	0.21233	0.21479	0.21742
000246	0.22020	0.22322	0.22640	0.22989	0.23363	0.23776	0.24221	0.24706
000247	0.25238	0.25834	0.26494	0.27233	0.28067	0.29013	0.30094	0.31325
000248	0.32740	0.34369	0.36213	0.38287	0.40575	0.43047	0.45653	0.48355
000249	0.51097	0.53846	0.56580	0.59290	0.61952	0.64574	0.67157	0.69692
000250	0.72179	0.74635						
000251	-109.96	-107.36	-104.33	-101.15	-97.81	-94.29	-90.60	-86.74
000252	-82.70	-78.46	-74.05	-69.44	-64.60	-59.54	-54.25	-48.73
000253	-42.91	-36.81	-30.39	-23.63	-16.46	-8.89	-0.85	7.67
000254	16.69	26.21	36.19	46.51	57.07	67.69	78.23	88.55
000255	98.53	108.17	117.43	126.34	134.92	143.19	151.21	158.97
000256	166.52	173.99						
000257	1.207	1.299	1.401	1.503	1.603	1.703	1.803	1.904
000258	2.003	2.103	2.203	2.304	2.405	2.507	2.610	2.714
000259	2.821	2.927	3.038	3.150	3.265	3.384	3.506	3.632
000260	3.763	3.897	4.033	4.172	4.309	4.445	4.577	4.704
000261	4.822	4.935	5.041	5.141	5.236	5.325	5.410	5.490
000262	5.567	5.642						
000263	27.4500	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000
000264	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000
000265	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000
000266	70.2000	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000	82.8000
000267	84.6000	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000	97.2000
000268	99.0000	100.6000						
000269	0.20168	0.20303	0.20486	0.20677	0.20391	0.21106	0.21344	0.21591
000270	0.21861	0.22139	0.22449	0.22775	0.23124	0.23506	0.23919	0.24364
000271	0.24849	0.25381	0.25969	0.26613	0.27336	0.28131	0.29021	0.30022
000272	0.31151	0.32406	0.33821	0.35386	0.37103	0.38978	0.40981	0.43102
000273	0.45304	0.47561	0.49849	0.52154	0.54150	0.56731	0.58996	0.61237
000274	0.63454	0.65539						
000275	-107.13	-104.99	-101.99	-98.83	-95.52	-92.03	-88.40	-84.56
000276	-80.59	-76.43	-72.08	-67.56	-62.83	-57.90	-52.74	-47.36
000277	-41.76	-35.89	-29.75	-23.33	-16.59	-9.51	-2.06	5.73
000278	13.92	22.50	31.43	40.71	50.22	59.93	69.72	79.51
000279	89.17	98.68	107.94	116.96	125.70	134.19	142.44	150.46
000280	158.27	165.99						
000281	1.209	1.286	1.387	1.487	1.587	1.686	1.785	1.884
000282	1.982	2.080	2.179	2.277	2.376	2.476	2.577	2.677
000283	2.780	2.884	2.988	3.094	3.204	3.315	3.427	3.544
000284	3.661	3.782	3.905	4.028	4.153	4.277	4.399	4.519
000285	4.635	4.746	4.852	4.954	5.050	5.141	5.229	5.311
000286	5.391	5.469						
000287	27.7235	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000
000288	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000
000289	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000
000290	70.2000	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000	82.8000
000291	84.6000	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000	97.2000
000292	99.0000	100.8000						
000293	0.20105	0.20208	0.20391	0.20574	0.20772	0.20987	0.21217	0.21456
000294	0.21710	0.21980	0.22266	0.22576	0.22910	0.23267	0.23649	0.24062
000295	0.24507	0.24992	0.25524	0.26096	0.26732	0.27424	0.28186	0.29037
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.34758	[illegible]	0.37834	[illegible]

000297	0.41298	0.43150	0.45057	0.46996	0.48959	0.50938	0.52909	0.54879
000298	0.56834	0.58781						
000299	-104.33	-102.63	-99.64	-96.50	-93.22	-89.79	-86.18	-82.41
000300	-78.46	-74.37	-70.10	-65.64	-60.99	-56.17	-51.14	-45.89
000301	-40.45	-34.78	-28.87	-22.71	-16.27	-9.55	-2.55	4.75
000302	12.37	20.28	28.51	37.00	45.74	54.70	63.79	72.98
000303	82.17	91.30	100.34	109.24	117.96	126.49	134.83	142.96
000304	150.91	158.80						
000305	1.213	1.272	1.373	1.472	1.571	1.669	1.767	1.865
000306	1.962	2.059	2.155	2.252	2.349	2.448	2.546	2.644
000307	2.744	2.843	2.944	3.047	3.150	3.256	3.362	3.470
000308	3.580	3.692	3.804	3.918	4.033	4.147	4.260	4.373
000309	4.482	4.590	4.693	4.792	4.888	4.981	5.069	5.154
000310	5.234	5.314						
000311	28.2617	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000
000312	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000
000313	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000
000314	70.2000	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000	82.8000
000315	84.6000	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000	97.2000
000316	99.0000	100.8000						
000317	0.19985	0.20033	0.20200	0.20383	0.20566	0.20764	0.20971	0.21193
000318	0.21432	0.21678	0.21940	0.22218	0.22520	0.22838	0.23172	0.23538
000319	0.23919	0.24332	0.24777	0.25262	0.25771	0.26335	0.26931	0.27582
000320	0.28290	0.29053	0.29879	0.30769	0.31731	0.32764	0.33860	0.35029
000321	0.36268	0.37564	0.38914	0.40313	0.41759	0.43230	0.44724	0.46241
000322	0.47767	0.49309						
000323	-98.72	-97.87	-94.95	-91.88	-88.63	-85.24	-81.70	-78.03
000324	-74.17	-70.19	-66.01	-61.70	-57.20	-52.55	-47.71	-42.69
000325	-37.51	-32.11	-26.55	-20.77	-14.71	-8.59	-2.17	4.45
000326	11.30	18.38	25.70	33.20	40.90	48.79	56.83	65.00
000327	73.28	81.60	89.96	98.32	106.63	114.91	123.08	131.14
000328	139.10	147.05						
000329	1.218	1.247	1.346	1.444	1.541	1.637	1.733	1.829
000330	1.924	2.019	2.112	2.207	2.301	2.395	2.489	2.584
000331	2.679	2.773	2.868	2.964	3.060	3.157	3.256	3.354
000332	3.452	3.552	3.653	3.752	3.853	3.954	4.054	4.155
000333	4.253	4.351	4.446	4.540	4.633	4.721	4.808	4.891
000334	4.973	5.052						
000335	28.7910	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000
000336	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000
000337	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000
000338	70.2000	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000	82.8000
000339	84.6000	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000	97.2000
000340	99.0000	100.8000						
000341	0.19874	0.19874	0.20033	0.20200	0.20375	0.20558	0.20756	0.20963
000342	0.21177	0.21408	0.21646	0.21909	0.22179	0.22465	0.22767	0.23085
000343	0.23434	0.23792	0.24181	0.24595	0.25032	0.25500	0.26001	0.26534
000344	0.27106	0.27718	0.28369	0.29069	0.29808	0.30594	0.31429	0.32311
000345	0.33241	0.34218	0.35235	0.36292	0.37389	0.38517	0.39669	0.40853
000346	0.42061	0.43277						
000347	-93.13	-93.11	-90.26	-87.21	-84.03	-80.70	-77.22	-73.60
000348	-69.82	-65.92	-61.85	-57.64	-53.27	-48.75	-44.06	-39.24
000349	-34.23	-29.07	-23.73	-18.23	-12.58	-6.71	-0.70	5.50
000350	11.87	18.42	25.14	32.03	39.09	46.30	53.63	61.10
000351	68.69	76.35	84.09	91.88	99.70	107.53	115.34	123.12
000352	130.86	138.67						
000353	1.224	1.224	1.321	1.417	1.513	1.607	1.702	1.796
000354	1.888	1.981	2.073	2.166	2.257	2.348	2.439	2.530
000355	2.622	2.713	2.804	2.894	2.987	3.078	3.169	3.262
[illegible]	3.353	3.445	[illegible]	[illegible]	3.722	3.814	3.906	3.997

000357	4.087	4.178	4.266	4.354	4.439	4.524	4.606	4.687
000358	4.766	4.845						
000359	29.3093	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000	41.4000
000360	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000	55.8000
000361	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000	70.2000
000362	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000	82.8000	84.6000
000363	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000	97.2000	99.0000
000364	100.8000							
000365	0.19763	0.19866	0.20025	0.20192	0.20367	0.20550	0.20748	0.20947
000366	0.21162	0.21384	0.21622	0.21869	0.22131	0.22409	0.22703	0.23013
000367	0.23339	0.23681	0.24046	0.24428	0.24833	0.25262	0.25723	0.26208
000368	0.26716	0.27257	0.27837	0.28441	0.29076	0.29752	0.30459	0.31198
000369	0.31969	0.32780	0.33614	0.34488	0.35386	0.36308	0.37254	0.38223
000370	0.39216							
000371	-87.59	-85.54	-82.56	-79.42	-76.14	-72.72	-69.16	-65.45
000372	-61.61	-57.62	-53.51	-49.24	-44.83	-40.09	-35.57	-30.73
000373	-25.74	-20.60	-15.31	-9.87	-4.28	1.45	7.33	13.37
000374	19.55	25.89	32.35	38.96	45.68	52.55	59.52	66.60
000375	73.77	81.02	88.34	95.72	103.12	110.56	118.00	125.45
000376	133.00							
000377	1.228	1.297	1.392	1.487	1.579	1.673	1.765	1.856
000378	1.946	2.038	2.126	2.216	2.305	2.394	2.483	2.571
000379	2.658	2.747	2.835	2.923	3.009	3.097	3.185	3.271
000380	3.359	3.445	3.532	3.618	3.704	3.790	3.875	3.959
000381	4.044	4.127	4.208	4.290	4.369	4.449	4.526	4.602
000382	4.678							
000383	29.8137	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000	41.4000
000384	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000	55.8000
000385	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000	70.2000
[illegible]	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000	82.8000	84.6000
[illegible]	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000	97.2000	99.0000
000388	100.8000							
000389	0.19660	0.19715	0.19866	0.20025	0.20192	0.20367	0.20542	0.20732
000390	0.20939	0.21146	0.21368	0.21599	0.21837	0.22091	0.22362	0.22640
000391	0.22934	0.23252	0.23577	0.23919	0.24277	0.24658	0.25055	0.25477
000392	0.25922	0.26390	0.26875	0.27392	0.27924	0.28488	0.29084	0.29696
000393	0.30340	0.31008	0.31699	0.32414	0.33153	0.33916	0.34695	0.35497
000394	0.36316							
000395	-82.09	-80.85	-77.91	-74.81	-71.57	-68.20	-64.68	-61.04
000396	-57.26	-53.36	-49.31	-45.15	-40.82	-36.38	-31.80	-27.06
000397	-22.22	-17.23	-12.11	-6.84	-1.47	4.05	9.70	15.48
000398	21.41	27.42	33.59	39.86	46.26	52.76	59.37	66.07
000399	72.85	79.74	86.67	93.69	100.75	107.85	114.97	122.14
000400	129.41							
000401	1.234	1.274	1.368	1.462	1.553	1.645	1.735	1.825
000402	1.914	2.003	2.092	2.180	2.266	2.353	2.439	2.526
000403	2.611	2.696	2.782	2.866	2.950	3.034	3.118	3.201
000404	3.284	3.367	3.450	3.532	3.613	3.694	3.776	3.855
000405	3.935	4.014	4.092	4.169	4.245	4.320	4.394	4.468
000406	4.540							
000407	30.3191	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000	41.4000
000408	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000	55.8000
000409	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000	70.2000
000410	72.0000	73.8000	75.6000	77.4000	79.2000	81.0000	82.8000	84.6000
000411	86.4000	88.2000	90.0000	91.8000	93.6000	95.4000	97.2000	99.0000
000412	100.8000							
000413	0.19556	0.19580	0.19715	0.19866	0.20025	0.20192	0.20359	0.20542
000414	0.20732	0.20923	0.21130	0.21344	0.21575	0.21805	0.22060	0.22314
000415	0.22584	0.22870	0.23168	0.23474	0.23800	0.24142	0.24499	0.24873

000417	0.29084	0.29649	0.30237	0.30841	0.31468	0.32112	0.32780	0.33455
000418	0.34146							
000419	-76.61	-76.16	-73.26	-70.21	-67.01	-63.68	-60.20	-56.62
000420	-52.91	-49.05	-45.08	-40.97	-36.74	-32.37	-27.89	-23.29
000421	-18.55	-13.69	-8.70	-3.58	1.64	6.99	12.45	18.04
000422	23.73	29.53	35.44	41.48	47.60	53.83	60.14	66.56
000423	73.06	79.63	86.29	92.99	99.77	106.59	113.46	120.35
000424	127.39							
000425	1.239	1.253	1.346	1.437	1.528	1.618	1.708	1.797
000426	1.885	1.972	2.059	2.144	2.231	2.315	2.400	2.484
000427	2.567	2.650	2.733	2.815	2.897	2.978	3.060	3.141
000428	3.220	3.299	3.379	3.458	3.536	3.613	3.692	3.769
000429	3.843	3.919	3.994	4.067	4.141	4.213	4.284	4.354
000430	4.425							
000431	31.2983	32.4000	34.2000	36.0000	37.8000	39.6000	41.4000	43.2000
000432	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000	55.8000	57.6000
000433	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000	70.2000	72.0000
000434	73.8000	75.6000	77.4000	79.2000	81.0000	82.8000	84.6000	86.4000
000435	88.2000	90.0000	91.8000	93.6000	95.4000	97.2000	99.0000	100.8000
000436	0.19366	0.19366	0.19580	0.19723	0.19866	0.20025	0.20184	0.20359
000437	0.20534	0.20717	0.20907	0.21106	0.21313	0.21527	0.21750	0.21988
000438	0.22226	0.22481	0.22743	0.23021	0.23299	0.23601	0.23903	0.24221
000439	0.24555	0.24897	0.25254	0.25628	0.26009	0.26406	0.26820	0.27241
000440	0.27678	0.28131	0.28600	0.29076	0.29569	0.30070	0.30586	0.31111
000441	-65.71	-63.96	-60.97	-57.86	-54.62	-51.22	-47.73	-44.10
000442	-40.37	-36.51	-32.52	-28.43	-24.22	-19.89	-15.46	-10.89
000443	-6.22	-1.45	3.41	8.40	13.50	18.68	23.97	29.34
000444	34.82	40.39	46.04	51.78	57.60	63.53	69.52	75.58
000445	81.72	87.93	94.20	100.54	106.91	113.35	119.84	126.47
000446	1.248	1.304	1.393	1.482	1.571	1.657	1.744	1.830
000447	1.914	1.998	2.083	2.164	2.247	2.329	2.410	2.490
000448	2.570	2.649	2.727	2.805	2.882	2.959	3.036	3.111
000449	3.187	3.262	3.335	3.408	3.481	3.554	3.625	3.696
000450	3.766	3.836	3.905	3.974	4.041	4.108	4.174	4.240
000451	32.2467	32.4000	34.2000	36.0000	37.8000	39.6000	41.4000	43.2000
000452	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000	55.8000	57.6000
000453	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000	70.2000	72.0000
000454	73.8000	75.6000	77.4000	79.2000	81.0000	82.8000	84.6000	86.4000
000455	88.2000	90.0000	91.8000	93.6000	95.4000	97.2000	99.0000	100.8000
000456	0.19183	0.19191	0.19318	0.19445	0.19588	0.19731	0.19874	0.20025
000457	0.20184	0.20351	0.20526	0.20701	0.20891	0.21082	0.21281	0.21487
000458	0.21702	0.21916	0.22147	0.22385	0.22632	0.22886	0.23148	0.23418
000459	0.23697	0.23991	0.24285	0.24595	0.24912	0.25246	0.25580	0.25930
000460	0.26287	0.26653	0.27026	0.27416	0.27813	0.28218	0.28631	0.29061
000461	-54.94	-54.70	-51.78	-48.73	-45.55	-42.22	-38.81	-35.27
000462	-31.60	-27.85	-23.97	-19.98	-15.88	-11.68	-7.37	-2.96
000463	1.55	6.16	10.87	15.67	20.58	25.57	30.64	35.78
000464	41.03	46.34	51.76	57.22	62.78	68.42	74.11	79.87
000465	85.69	91.60	97.55	103.59	109.64	115.78	121.95	128.28
000466	1.258	1.265	1.353	1.440	1.527	1.612	1.696	1.780
000467	1.863	1.945	2.027	2.107	2.187	2.266	2.344	2.423
000468	2.500	2.576	2.651	2.727	2.802	2.875	2.949	3.021
000469	3.093	3.164	3.236	3.305	3.374	3.443	3.512	3.579
000470	3.645	3.712	3.777	3.842	3.906	3.970	4.033	4.097
000471	33.1758	34.2000	36.0000	37.8000	39.6000	41.4000	43.2000	45.0000
000472	46.8000	48.6000	50.4000	52.2000	54.0000	55.8000	57.6000	59.4000
000473	61.2000	63.0000	64.8000	66.6000	68.4000	70.2000	72.0000	73.8000
000474	75.6000	77.4000	79.2000	81.0000	82.8000	84.6000	86.4000	88.2000
000475	90.0000	91.8000	93.6000	95.4000	97.2000	99.0000	100.8000	
000476	0.19616	[illegible]	[illegible]	[illegible]	0.19861	[illegible]	0.19739	0.19882

000477	0.20033	0.20192	0.20351	0.20518	0.20693	0.20875	0.21058	0.21249
000478	0.21448	0.21646	0.21861	0.22075	0.22298	0.22528	0.22767	0.23013
000479	0.23259	0.23522	0.23784	0.24062	0.24340	0.24626	0.24920	0.25222
000480	0.25532	0.25850	0.26176	0.26510	0.26851	0.27193	0.27551	
000481	-44.27	-42.61	-39.62	-36.49	-33.25	-29.88	-26.40	-22.84
000482	-19.15	-15.35	-11.45	-7.46	-3.34	0.85	5.14	9.53
000483	14.01	18.59	23.26	28.02	32.84	37.77	42.76	47.81
000484	52.95	58.16	63.42	68.78	74.20	79.68	85.22	90.83
000485	96.50	102.22	108.00	113.84	119.73	125.66	131.76	
000486	1.266	1.316	1.401	1.485	1.570	1.652	1.735	1.816
000487	1.897	1.976	2.054	2.132	2.209	2.286	2.362	2.437
000488	2.512	2.585	2.658	2.731	2.803	2.873	2.944	3.013
000489	3.081	3.150	3.218	3.284	3.350	3.416	3.481	3.545
000490	3.609	3.672	3.734	3.796	3.856	3.917	3.978	
000491	34.0793	34.2000	36.0000	37.8000	39.6000	41.4000	43.2000	45.0000
000492	46.8000	48.6000	50.4000	52.2000	54.0000	55.8000	57.6000	59.4000
000493	61.2000	63.0000	64.8000	66.6000	68.4000	70.2000	72.0000	73.8000
000494	75.6000	77.4000	79.2000	81.0000	82.8000	84.6000	86.4000	88.2000
000495	90.0000	91.8000	93.6000	95.4000	97.2000	99.0000	100.8000	
000496	0.18857	0.18865	0.18976	0.19095	0.19215	0.19342	0.19469	0.19604
000497	0.19747	0.19890	0.20041	0.20192	0.20351	0.20518	0.20685	0.20860
000498	0.21034	0.21217	0.21408	0.21599	0.21805	0.22012	0.22218	0.22433
000499	0.22656	0.22886	0.23124	0.23363	0.23609	0.23855	0.24118	0.24380
000500	0.24650	0.24920	0.25206	0.25493	0.25787	0.26081	0.26383	
000501	-33.69	-33.48	-30.54	-27.47	-24.27	-20.96	-17.55	-14.03
000502	-10.40	-6.69	-2.87	1.04	5.05	9.17	13.37	17.65
000503	22.05	26.51	31.07	35.70	40.41	45.19	50.05	54.98
000504	59.97	65.02	70.14	75.35	80.59	85.90	91.28	96.72
000505	102.20	107.74	113.35	118.98	124.70	130.44	136.34	
000506	1.276	1.280	1.365	1.449	1.530	1.612	1.693	1.773
000507	1.852	1.930	2.007	2.084	2.160	2.234	2.308	2.381
000508	2.455	2.526	2.597	2.668	2.738	2.807	2.875	2.943
000509	3.009	3.076	3.141	3.206	3.270	3.334	3.397	3.458
000510	3.520	3.581	3.642	3.701	3.760	3.820	3.879	
000511	34.9613	36.0000	37.8000	39.6000	41.4000	43.2000	45.0000	46.8000
000512	48.6000	50.4000	52.2000	54.0000	55.8000	57.6000	59.4000	61.2000
000513	63.0000	64.8000	66.6000	68.4000	70.2000	72.0000	73.8000	75.6000
000514	77.4000	79.2000	81.0000	82.8000	84.6000	86.4000	88.2000	90.0000
000515	91.8000	93.6000	95.4000	97.2000	99.0000	100.8000		
000516	0.18706	0.18770	0.18881	0.18992	0.19111	0.19231	0.19358	0.19485
000517	0.19620	0.19755	0.19898	0.20049	0.19405	0.20351	0.20510	0.20669
000518	0.20844	0.21011	0.21193	0.21368	0.21559	0.21750	0.21940	0.22147
000519	0.22346	0.22560	0.22775	0.22989	0.23212	0.23442	0.23681	0.23919
000520	0.24157	0.24404	0.24658	0.24920	0.25183	0.25445		
000521	-23.18	-21.49	-18.47	-15.31	-12.05	-8.70	-5.22	-1.66
000522	1.98	5.73	9.59	13.52	17.55	21.69	25.89	30.17
000523	34.57	39.03	43.55	48.15	52.85	57.58	62.40	67.28
000524	72.21	77.20	82.28	87.40	92.58	97.81	103.09	108.45
000525	113.84	119.30	124.81	130.35	135.94	141.70		
000526	1.284	1.331	1.413	1.495	1.575	1.655	1.733	1.811
000527	1.887	1.963	2.039	2.112	2.186	2.259	2.330	2.401
000528	2.472	2.542	2.611	2.680	2.747	2.814	2.880	2.945
000529	3.009	3.073	3.136	3.200	3.262	3.322	3.384	3.443
000530	3.502	3.561	3.619	3.677	3.734	3.792		

000531	-8.0377310E-07	1.2281445E-06	-2.1059322E-06	-3.8373024E-06	-8.7732374E-06
000532	-1.5259414E-05	-2.6335328E-05	-4.1334596E-05	-6.5248416E-05	-9.5611221E-05
000533	-1.3180607E-04	-1.7020696E-04	-2.1873437E-04	-2.5922335E-04	-3.1173105E-04
000534	-3.6397233E-04	-4.2257714E-04	-4.5541749E-04	-5.0527305E-04	-5.4852158E-04
000535	-5.8649584E-04	-6.1718419E-04	-6.4380987E-04	-6.5827104E-04	-6.5781804E-04
000536	[illegible]	[illegible]	[illegible]	-5.5021366E-04	-4.9570493E-04

000537	-4.3643903E-04	-3.7869989E-04	-3.2988888E-04	-2.9135311E-04	-2.7009731E-04
000538	-2.7696572E-04	-2.9812312E-04	-3.5004592E-04	-4.2455082E-04	-5.2401202E-04
000539	-6.4125592E-04	-7.8212495E-04	-9.3448052E-04	-1.0934784E-03	-1.2559322E-03
000540	-1.3698538E-03	-1.5478358E-03	-1.7219023E-03	-1.8920438E-03	-2.0561721E-03
000541	-2.2143473E-03	-2.4177387E-03	-2.6272401E-03	-2.8407149E-03	-2.9235301E-03
000542	-3.2097408E-03	-3.4133669E-03	-3.4292715E-03	-4.0583221E-03	-4.0351868E-03
000543	-5.2023678E-03	-5.5757572E-03	-6.2069722E-03	-6.8678927E-03	-7.1803709E-03
000544	-7.6073285E-03	-7.9515444E-03	-9.1273819E-03	-9.5657506E-03	-1.1015059E-02
000545	-1.1959132E-02	-1.3886189E-02	-1.5505519E-02	-1.7400006E-02	-2.0124586E-02
000546	-2.2408441E-02	-2.3006439E-02	-2.3612257E-02	-2.1131850E-02	-1.5787078E-02
000547	-7.2297747E-03	-1.1157932E-02	2.0572108E-04	9.1201507E-03	-3.6886842E-02
000548	-2.5967306E-01	2.0399673E-02	4.1266163E-02	6.8570651E-02	1.4766631E-01
000549	4.1671141E-02	8.3815085E-02	1.2820967E-01	1.7331713E-01	2.2031547E-01
000550	2.6879575E-01	3.1955518E-01	3.7255940E-01	4.2889084E-01	4.8814042E-01
000551	5.5015636E-01	6.1401927E-01	6.8175290E-01	7.4882307E-01	8.2030192E-01
000552	8.9316323E-01	9.6889537E-01	1.0395381E+00	1.1158471E+00	1.1918611E+00
000553	1.2680118E+00	1.3430317E+00	1.4195863E+00	1.4938576E+00	1.5657673E+00
000554	1.6369293E+00	1.7064442E+00	1.7737101E+00	1.8403582E+00	1.9056878E+00
000555	1.9713662E+00	2.0390411E+00	2.1107021E+00	2.1868961E+00	2.2692860E+00
000556	2.3605869E+00	2.4577571E+00	2.5647236E+00	2.6795942E+00	2.8029003E+00
000557	2.9331360E+00	3.0713863E+00	3.2149294E+00	3.3623746E+00	3.5129883E+00
000558	3.6532274E+00	3.8122308E+00	3.9723517E+00	4.1335542E+00	4.2953206E+00
000559	4.4572955E+00	4.6326102E+00	4.8109381E+00	4.9917539E+00	5.1482192E+00
000560	5.3505627E+00	5.5385032E+00	5.6917803E+00	5.9679756E+00	6.1196071E+00
000561	6.4955823E+00	6.7236159E+00	7.0098332E+00	7.2845818E+00	7.5091781E+00
000562	7.7573489E+00	7.9939722E+00	8.3571042E+00	8.6083924E+00	9.0096826E+00
000563	9.3389942E+00	9.8044979E+00	1.0229200E+01	1.0686035E+01	1.1241795E+01
000564	1.1740469E+01	1.2016333E+01	1.2275667E+01	1.2205924E+01	1.1833711E+01
000565	1.1143704E+01	1.1728386E+01	1.0774412E+01	1.0186019E+01	1.4999411E+01
000566	3.7406308E+01	1.0508182E+01	9.6191112E+00	8.3929369E+00	4.3831287E+00
000567	-5.7318471E-02	-1.8093034E-01	-4.9784230E-01	-8.8737394E-01	-1.4439885E+00
000568	-2.1308185E+00	-3.0135132E+00	-4.0968010E+00	-5.4553331E+00	-7.0653434E+00
000569	-8.9079311E+00	-1.0891583E+01	-1.3194912E+01	-1.5409693E+01	-1.7982500E+01
000570	-2.0641264E+01	-2.3494803E+01	-2.5827529E+01	-2.8601520E+01	-3.1270310E+01
000571	-3.3868301E+01	-3.6312903E+01	-3.8676869E+01	-4.0770123E+01	-4.2521120E+01
000572	-4.4057432E+01	-4.5291856E+01	-4.6171278E+01	-4.6823811E+01	-4.7185354E+01
000573	-4.7400820E+01	-4.7608307E+01	-4.7991765E+01	-4.8607001E+01	-4.9585045E+01
000574	-5.1154888E+01	-5.3068125E+01	-5.5648849E+01	-5.8727770E+01	-6.2332962E+01
000575	-6.6339776E+01	-7.0798392E+01	-7.5474072E+01	-8.0216248E+01	-8.4945172E+01
000576	-8.8378554E+01	-9.3209590E+01	-9.7775742E+01	-1.0205513E+02	-1.0598185E+02
000577	-1.0947043E+02	-1.1370972E+02	-1.1770864E+02	-1.2139729E+02	-1.2287832E+02
000578	-1.2737635E+02	-1.3032203E+02	-1.3031157E+02	-1.3843027E+02	-1.3730741E+02
000579	-1.5065102E+02	-1.5333181E+02	-1.5864047E+02	-1.6366492E+02	-1.6426362E+02
000580	-1.6578472E+02	-1.6593847E+02	-1.7221788E+02	-1.7159915E+02	-1.7825786E+02
000581	-1.8042763E+02	-1.8864278E+02	-1.9410328E+02	-2.0004923E+02	-2.0932852E+02
000582	-2.1504047E+02	-2.0928329E+02	-2.0118944E+02	-1.7942589E+02	-1.4498536E+02
000583	-9.8067031E+01	-9.7440413E+01	-3.8944428E+01	2.2018214E+00	-1.5324378E+02
000584	-9.6215597E+02	3.6778774E+01	7.2762252E+01	1.1458652E+02	1.9525322E+02
000585	-3.4652970E-01	-2.3328599E+00	-2.0682478E+00	-3.2165717E+00	-2.6094543E+00
000586	-1.2407244E+00	3.2160865E+00	1.1342612E+01	2.5378825E+01	4.4994254E+01
000587	6.9440852E+01	9.5141850E+01	1.2866170E+02	1.5495204E+02	1.9055501E+02
000588	2.2540166E+02	2.6281975E+02	2.7566446E+02	3.0073723E+02	3.1701581E+02
000589	3.2576079E+02	3.2333676E+02	3.1249379E+02	2.8602308E+02	2.4109665E+02
000590	1.8228715E+02	1.0647785E+02	1.1968543E+01	-9.6472164E+01	-2.2083220E+02
000591	-3.5521484E+02	-4.9429203E+02	-6.3011102E+02	-7.5967443E+02	-8.7793619E+02
000592	-9.7611348E+02	-1.0620580E+03	-1.1236298E+03	-1.1665448E+03	-1.1896026E+03
000593	-1.1965205E+03	-1.1861179E+03	-1.1663516E+03	-1.1427383E+03	-1.1180923E+03
000594	-1.1428658E+03	-1.1103218E+03	-1.0857529E+03	-1.0696396E+03	-1.0641185E+03
000595	-1.0733223E+03	-1.0591141E+03	-1.0340018E+03	-1.0264770E+03	-1.0823485E+03
000596	-1.0365[illegible]E+03	-1.03[illegible]E+03	-1.11[illegible]E+03	-9.[illegible]E+02	-1.0518[illegible]E+03

000597	-7.3317710E+02	-7.1729678E+02	-6.1916306E+02	-5.2271128E+02	-5.3825987E+02
000598	-5.1531466E+02	-5.1639302E+02	-3.6579871E+02	-3.6543501E+02	-1.8416297E+02
000599	-8.7846858E+01	1.5419294E+02	3.5588009E+02	5.7942490E+02	8.7722455E+02
000600	1.1212214E+03	1.1541824E+03	1.1518611E+03	9.4203092E+02	5.4030442E+02
000601	-3.5545003E+01	1.5041468E+02	-5.6987252E+02	-8.9772310E+02	1.9715175E+03
000602	1.5643871E+04	0.0E+00	0.0E+00	0.0E+00	0.0E+00
000603	1.0761355E+00	9.0125519E+00	-1.6858820E+01	-3.7102804E+01	-8.6642049E+01
000604	-1.5703564E+02	-2.7513041E+02	-4.5130837E+02	-7.0776183E+02	-1.0446450E+03
000605	-1.4487078E+03	-1.8692702E+03	-2.3880154E+03	-2.8067078E+03	-3.3410802E+03
000606	-3.8559030E+03	-4.3843916E+03	-4.5542515E+03	-4.8694049E+03	-5.0390446E+03
000607	-5.0769555E+03	-4.9279847E+03	-4.6275005E+03	-4.0775766E+03	-3.2393895E+03
000608	-2.1710548E+03	-8.3495872E+02	7.8810918E+02	2.6316170E+03	4.7142330E+03
000609	6.9491255E+03	9.2604127E+03	1.1524025E+04	1.3685515E+04	1.5672403E+04
000610	1.7362219E+04	1.8840761E+04	1.9943022E+04	2.0737451E+04	2.1205585E+04
000611	2.1388423E+04	2.1278368E+04	2.0977596E+04	2.0559050E+04	2.0065004E+04
000612	2.0212248E+04	1.9492025E+04	1.8829911E+04	1.8237987E+04	1.7749108E+04
000613	1.7442580E+04	1.6669838E+04	1.5978421E+04	1.5412988E+04	1.5529079E+04
000614	1.4476561E+04	1.3941732E+04	1.4340021E+04	1.2070660E+04	1.2720182E+04
000615	9.0641995E+03	8.6428251E+03	7.4271301E+03	6.3105084E+03	6.3673451E+03
000616	6.0708932E+03	6.0532802E+03	4.8294821E+03	4.9320575E+03	3.5624987E+03
000617	2.9059444E+03	1.1351017E+03	-3.1705787E+02	-1.8692257E+03	-3.8552011E+03
000618	-5.4197643E+03	-5.4462613E+03	-5.1573924E+03	-3.6215951E+03	-9.1656659E+02
000619	2.7670921E+03	2.0174573E+03	6.5948069E+03	8.2338889E+03	-9.3307466E+03
000620	-9.3572403E+04	0.0E+00	0.0E+00	0.0E+00	0.0E+00

000621	0.0005	0.0010	0.0015	0.0020	0.0025	0.0030	0.0035	0.0040	0.0045	0.0050
000622	0.0055	0.0060	0.0065	0.0070	0.0075	0.0080	0.0085	0.0090	0.0095	0.0100
000623	0.0105	0.0110	0.0115	0.0120	0.0125	0.0130	0.0135	0.0140	0.0145	0.0150
000624	0.0155	0.0160	0.0165	0.0170	0.0175	0.0180	0.0185	0.0190	0.0195	0.0200
000625	0.0205	0.0210	0.0215	0.0220	0.0225	0.0230	0.0235	0.0240	0.0245	0.0250
000626	0.0255	0.0260	0.0265	0.0270	0.0275	0.0280	0.0285	0.0290	0.0295	0.0300
000627	0.0305	0.0310	0.0315	0.0320	0.0325	0.0330	0.0335	0.0340	0.0345	0.0350
000628	0.0355	0.0360	0.0365	0.0370	0.0375	0.0380	0.0385	0.0390	0.0395	0.0400
000629	0.0405	0.0410	0.0415	0.0420	0.0425	0.0430	0.0435	0.0440	0.0445	0.0450

000630	0.73234603E-02	-0.44074261E-03	0.66207946E-03	-0.29226363E-03
000631	0.40084907E-04	0.0E+00	0.0E+00	0.0E+00
000632	-0.27176666E+02	0.21129340E+03	0.13364318E+02	-0.19311670E+04
000633	0.67461013E+04	0.0E+00	0.0E+00	0.0E+00
000634	-0.71967724E-02	0.14495527E-02	0.32403130E-02	-0.44640177E-02
000635	0.0E+00	0.0E+00	0.0E+00	0.0E+00
000636	0.17724540E+01	-0.44368880E+02	0.20554680E-01	0.0E+00
000637	0.0E+00	0.0E+00	0.0E+00	0.0E+00
000638	0.20006200E+01	-0.50097080E+02	0.10044000E+01	0.17484950E-01
000639	0.0E+00	0.0E+00	0.0E+00	0.0E+00
000640	-0.87239000E+03	0.26248000E+02	-0.09787200E+01	0.00271270E+01
000641	0.0E+00	0.0E+00	0.0E+00	0.0E+00
000642	0.10111000E+04	-0.29485000E+02	0.25312000E+01	-0.00666590E+01
000643	0.0E+00	0.0E+00	0.0E+00	0.0E+00
000644	-0.22172000E+02	0.52157000E+01	-0.02737800E+01	0.58282000E-02
000645	0.04826500E+01	-0.29189000E-01	0.0E+00	0.0E+00
000646	-0.06839500E+01	0.18552000E+01	-0.00378920E+01	0.40527000E+02
000647	0.54573000E+01	-0.32436000E+01	-0.01769100E+01	0.00641000E+01

@ ELT LIST,1,720405, 40099

```
      COMPILER (DATA=SHORT)
      COMMON /TITLE/ TESTID(12),DAY(2),RUNTME(2),IPAGE
      COMMON /TAPEIN/ CHAN1(100),CHAN2(100),CHAN3(100),CHAN4(100),
     1PARID(100),CHANID(200),UNITS(200),DEC(200),NPAR
      COMMON /TAPE/ TSTART,TSTOP,INT1,INT2,IAVE,NSETS,INPUT(100,50),
     1ATIME(50),TIME,IEND
      COMMON /CALC/ INPT(100),GEOM(50),OUT(120)
      INTEGER TESTID,DAY,PARID,CHAN1,CHAN2,CHAN3,CHAN4,CHANID,UNITS,DEC,
     1TAPEIN,TAPEOT
      REAL INPUT,INPT
      DIMENSION OUTPUT(120,50)
      DATA NSAT,NPAR,MPAR /22,33,95/
      CALL INPROP
      CALL SATUR(NSAT)
      CALL CHINPI(TAPEIN,TAPEOT)
      CALL GEOMT
      CALL OUTHOM(MPAR)
      NSETS=0
      IFILE=0
   10 READ (5,1000) TSTART,TSTOP,INT1,INT2,IAVE,IFLAG,NRTHR,IEND
 1000 FORMAT(F10.0,F10.0,6I5)
      GO TO 50
   20 CALL TAPE2
      GO TO 55
   50 CALL TAPE1
   55 IF (NSETS.GE.50) GO TO 60
      IF (IEND.EQ.0) GO TO 10
   60 DO 540 I=1,NSETS
      DO 100 J=1,NPAR
  100 INPT(J)=INPUT(J,I)
      CALL FLOW(JFLG)
      IF (JFLG.GT.1) GO TO 540
      CALL SUCTON (IFLAG,JFLG)
      IF (JFLG.GT.1) GO TO 540
      CALL RADTHR (NRTHR)
      CALL AXFOR
      CALL PERFOR(JFLG)
      IF (JFLG.GT.1) GO TO 540
      DO 500 J=1,36
  500 OUTPUT(J,I)=OUT(J)
      DO 510 J=40,75
      K=J-3
  510 OUTPUT(K,I)=OUT(J)
      DO 520 J=80,83
      K=J-7
  520 OUTPUT(K,I)=OUT(J)
      DO 530 J=85,103
      K=J-8
  530 OUTPUT(K,I)=OUT(J)
  540 CONTINUE
      CALL OUTPT (OUTPUT,ATIME,MPAR,NSETS,IFILE,TAPEIN,TAPEOT)
      NSETS=0
      IF (TIME.LT.TSTOP) GO TO 20
      IF (IEND.EQ.0) GO TO 10
      END FILE 2
```

```
      IF (IEND.EQ.1) GO TO 10
      STOP
      END
      SUBROUTINE CHINPT(TAPEIN,TAPEOT)
      COMPILER (DATA=SHORT)
      COMMON /TAPEIN/ CHAN1(100),CHAN2(100),CHAN3(100),CHAN4(100),
     1PARID(100),CHANID(200),UNITS(200),DEC(200),NPAR
      COMMON /TITLE/ TESTID(12),DAY(2),RUNTME(2),IPAGE
      INTEGER CHAN1,CHAN2,CHAN3,CHAN4,PARID,CHANID,UNITS,DEC,END,
     1PARCK(100),TAPEIN,TAPEOT
      DIMENSION DEF(100,10),ICHAN(4),IDN(4),DEFIN(10)
      DATA BLANK /'      '/
      DATA PARID /'PATM  ','PSD   ','TD    ','PLFI  ','PLFO  ','PLRI  ',
     1'PLRO  ','WREF  ','DPORF1','DPORF2','PORF  ','PTK   ','TTK   ',
     2'P1    ','T1    ','P2    ','T2    ','PID   ','P708  ','P726  ',
     3'PDIFI1','PDIFI2','PDIFI3','PDIFI4','PDIFI5','PDIFI6','PDIFI7',
     4'PDIFI8','PDIFI9','PDIFO ','N     ','P707  ','P725  '/
      DATA END/'END   '/
      LINE=0
      IPAGE=1
      READ (1) DAY,RUNTME,TESTID,TAPEIN,TAPEOT
      READ (1) MWORDS,(CHANID(I),I=1,MWORDS)
      READ (1) MWORDS,(UNITS(I),I=1,MWORDS)
      READ(1) MWORDS,(DEC(I),I=1,MWORDS)
      TAPEIN=TAPEOT
      DO 100 I=1,2
      DAY(I)=BLANK
  100 RUNTME(I)=BLANK
      CALL DATE (9,DAY)
      CALL TOD (8,RUNTME)
      IFLAG=0
      DO 210 I=1,NPAR
  210 PARCK(I)=0
      READ (5,20) TAPEOT
  240 READ (5,20)IDENT,(DEFIN(J),J=1,10),(ICHAN(I),I=1,4)
   20 FORMAT (A6,1X,10A6,1X,4I3)
      K=0
  250 K=K+1
      IF (IDENT.EQ.END) GO TO 270
      IF (PARID(K).EQ.IDENT) GO TO 260
      IF (K.GE.NPAR) GO TO 255
      GO TO 250
  255 WRITE (6,1000) IDENT
 1000 FORMAT (//10X,A6,' IS AN UNRECOGNIZABLE PARAMETER IDENTIFICATION')
      GO TO 240
  260 PARCK(K)=1
      CHAN1(K)=ICHAN(1)
      CHAN2(K)=ICHAN(2)
      CHAN3(K)=ICHAN(3)
      CHAN4(K)=ICHAN(4)
      N=1
      DO 265 I=2,4
      IF (ICHAN(I).EQ.0) GO TO 266
  265 N=I
  266 DO 267 I=1,N
      J=ICHAN(I)
  267 IDN(I)=CHANID(J)
      DO 268 I=1,10
  268 DEF(K,I)=DEFIN(I)
```

```
      WRITE (6,1100) IPAGE
 1100 FORMAT ('1',52X,'LH2 PUMP TEST',44X,'PAGE ',I2)
 1110 FORMAT (12A6,12X,'DATE ',2A6,'TIME ',2A6)
      WRITE (6,1110) TESTID,DAY,RUNTME
 1130 FORMAT (/' INPUT TAPE = ',A6,5X,'OUTPUT TAPE = ',A6/)
      WRITE (6,1130) TAPEIN,TAPEOT
      WRITE (6,1120)
 1120 FORMAT (1X,'PARAMETER',20X,'DEFINITION',33X,'CHANNELS USED'/)
  269 WRITE (6,1010) PARID(K),(DEF(K,L),L=1,10),(ICHAN(I),IDN(I),I=1,N)
 1010 FORMAT (1X,A6,2X,10A6,4(2X,I3,1X,A6))
      LINE=LINE+1
      IF (LINE.LT.50) GO TO 240
      LINE=0
      IPAGE=IPAGE+1
      GO TO 240
  270 DO 300 I=1,NPAR
      IF (PARCK(I).EQ.1)  GO TO 300
      WRITE (6,1020) PARID(I)
 1020 FORMAT (//10X,' NO CHANNEL IDENTIFICATION FOR ',A6)
      IFLAG=1
  300 CONTINUE
      IF (IFLAG.NE.0) STOP
      RETURN
      END
      SUBROUTINE OUTNOM(MPAR)
      COMMON /TITLE/ TESTID(12),DAY(2),RUNTME(2),IPAGE
      COMMON /NOMEN/ HED(120),DEC(120),UN(120)
      DIMENSION DEF(10)
      INTEGER HED,DEC,UN,BLANK,TESTID,DAY,RUNTME
      DATA BLANK /'      '/
      LINE=0
      DO 100 I=1,MPAR
  100 UN(I)=BLANK
      DO 200 I=1,MPAR
      READ (5,1000) HED (I),DEF,UN(I),DEC(I)
      IF (LINE.GT.0) GO TO 150
      IPAGE=IPAGE+1
      WRITE (6,2000) IPAGE
      WRITE (6,2010) TESTID,DAY,RUNTME
  150 LINE=LINE+1
      WRITE (6,1010) HED(I),DEF,UN(I)
      IF (LINE.LT.50) GO TO 200
      LINE=0
  200 CONTINUE
 1000 FORMAT (A6,1X,10A6,1X,A6,5X,A1)
 1010 FORMAT (1X,A6,1X,10A6,1X,A6)
 2000 FORMAT ('1',52X,'LH2 PUMP TEST',44X,'PAGE ',I4)
 2010 FORMAT (12A6,12X,'DATE ',2A6,'TIME ',2A6/)
      RETURN
      END
      SUBROUTINE OUTPT (OUTPUT,ATIME,MPAR,NSETS,IFILE,TAPEIN,TAPEOT)
      COMMON /TITLE/ TESTID(12),DAY(2),RUNTME(2),IPAGE
      COMMON /NOMEN/ HED(120),DEC(120),UN(120)
      INTEGER HED,DEC,UN,TESTID,DAY,RUNTME,F(22),G(22),V(14),BLANK,
     1TAPEIN,TAPEOT
      DIMENSION OUTPUT(120,50),ATIME(50),NUM(10)
      DATA F(1),F(2),F(4),F(6),F(8),F(10),F(12),F(14),F(16),F(18),F(20),
     1F(22) /'(F9.1,','10'F11.',')'/
      DATA V(1),V(3),V(4),V(5),V(6),V(8),V(9),V(10),V(11),V(13),V(14)
     1/'(4X,','(9X,I3',  '0)/3X,',  'GHIJK',  '3X,',  '(5X,A6',
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      26H)/4X,',  6HSEC',3,  'X,',  '(5X,A6',  ')/)'/
      DATA G(22) /')'/
      DATA NUM/'1','2','3','4','5','6','7','8','9','10'/
      DATA BLANK /'      '/
      IF (IFILE.GT.0) GO TO 100
      WRITE(2) DAY,RUNTME,TESTID,TAPEIN,TAPEOT
      WRITE (2) MPAR,(HED(I),I=1,MPAR)
      WRITE (2) MPAR,(UN(I),I=1,MPAR)
      WRITE (2) MPAR,(DEC(I),I=1,MPAR)
  100 DO 200 K=1,MPAR,10
      IPAGE=IPAGE+1
      L=K+9
      NCOL=10
      IF (L.LE.MPAR) GO TO 150
      L=MPAR
      NCOL=MPAR-K+1
  150 V(2)=NUM(NCOL)
      V(7)=NUM(NCOL)
      V(12)=NUM(NCOL)
      WRITE (6,2000) IPAGE
      WRITE (6,2010) TESTID,DAY,RUNTME
      WRITE (6,V) (I,I=K,L),(HED(I),I=K,L),(UN(I),I=K,L)
      M=1
      DO 180 I=K,L
      M=M+2
  180 F(M)=DEC(I)
      DO 182 I=1,M
  182 G(I)=F(I)
      IF (M.EQ.21) GO TO 200
      M1=M+1
      DO 185 I=M1,21
  185 G(I)=BLANK
  200 WRITE (6,G) (ATIME(M),(OUTPUT(I,M),I=K,L),M=1,NSETS)
      DO 300 J=1,NSETS
  300 WRITE (2) MPAR,ATIME(J),(OUTPUT(I,J),I=1,MPAR)
      DO 400 I=1,MPAR
      DO 400 J=1,50
  400 OUTPUT(I,J)=0.0
      IFILE=1
 2000 FORMAT ('1',52X,'LH2 PUMP TEST',44X,'PAGE ',I4)
 2010 FORMAT (12A6,12X,'DATE ',2A6,'TIME ',2A6/)
      RETURN
      END
      SUBROUTINE GEOMT
      COMMON /CALC/ INPT(100),GEOM(50),OUT(120)
      COMMON /TITLE/ TESTID(12),DAY(2),RUNTME(2),IPAGE
      REAL INPT
      DATA NUM/30/
      EQUIVALENCE  (GEOM(1),DSL1),(GEOM(2),DSL2),(GEOM(3),ALBF),
     1             (GEOM(4),CLABF),(GEOM(5),ALBR),(GEOM(6),CLABR),
     2             (GEOM(7),AI2),(GEOM(8),DI2),(GEOM(9),BET2),
     3             (GEOM(10),Z2),(GEOM(11),RPTAP),(GEOM(12),ADFD),
     4             (GEOM(13),DDL),(GEOM(14),RHOREF),(GEOM(15),ORFD),
     5             (GEOM(16),ORFCOE),(GEOM(17),ORFBTA),(GEOM(18),W),
     6             (GEOM(19),R706),(GEOM(20),R707),(GEOM(21),R708),
     7             (GEOM(22),R724),(GEOM(23),R725),(GEOM(24),R726),
     8             (GEOM(25),RLF),(GEOM(26),RLM),(GEOM(27),RLI),
     9             (GEOM(28),RIN),(GEOM(29),RLD),(GEOM(30),RLS)
      IPAGE=IPAGE+1
```

```
1010 FORMAT('1',52X,'LH2 PUMP TEST',44X,'PAGE ',I4)
     WRITE (6,1020) TESTID,DAY,RUNTME
1020 FORMAT(12A6,12X,'DATE ',2A6,'TIME ',2A6)
     READ (5,1000) (GEOM(I),I=1,NUM)
1000 FORMAT(8F10.0)
     WRITE(6,2000) DSL1
2000 FORMAT (' DSL1       SUCTION LINE DIAMETER UPSTREAM FLOW COND.',30X
    1,F6.3,' IN')
     WRITE(6,2010) DSL2
2010 FORMAT (' DSL2       SUCTION LINE DIAMETER DOWNSTREAM FLOW COND.',
    128X,F6.3,' IN')
     WRITE(6,2020) ALBF
2020 FORMAT (' ALBF       FRONT LABYRINTH FLOW AREA',46X,F6.3,' SQ-IN')
     WRITE(6,2030) CLABF
2030 FORMAT (' CLABF      FRONT LABYRINTH COEFFICIENT',44X,F6.4)
     WRITE(6,2040) ALBR
2040 FORMAT (' ALBR       REAR LABYRINTH FLOW AREA',47X,F6.3,' SQ-IN')
     WRITE(6,2050) CLABR
2050 FORMAT (' CLABR      REAR LABYRINTH COEFFICIENT',45X,F6.4)
     WRITE (6,2060) AI2
2060 FORMAT (' AI2        IMPELLER DISCHARGE BLOCKED AREA',40X,F6.2
    1' SQ-IN')
     WRITE (6,2070) DI2
2070 FORMAT (' DI2        IMPELLER DISCHARGE DIAMETER',44X,F6.3,' IN')
     WRITE (6,2080) BET2
2080 FORMAT (' BET2       IMPELLER DISCHARGE BLADE ANGLE',41X,F6.2,
    1' DEG')
     WRITE (6,2080) Z2
2090 FORMAT(' Z2         NUMBER OF IMPELLER BLADES',50X,I2)
     WRITE (6,3000) RPTAP

3000 FORMAT('RPTAP       DIFFUSER INLET PRESSURE TAP RADIAL LOCATION',
    1,7X,F6.3,' IN')
     WRITE (6,3010) ADFD
3010 FORMAT(' ADFD       DIFFUSER DISCHARGE FLOW AREA',42X,F6.2,
    1'SQ-IN')
     WRITE (6,3020) DDL
3020 FORMAT(' DDL        DISCHARGE LINE DIAMETER',48X,F6.3,' IN')
     WRITE (6,3030) RHOREF
3030 FORMAT(' RHOREF     REFERENCE DENSITY',54X,F6.4,' LB/CU-FT')
     WRITE (6,3040) ORFD
3040 FORMAT (' ORFD       BEARING COOLANT ORIFICE DIAMETER',39X,F6.4,
    1' IN')
     WRITE (6,3050) ORFCOE
3050 FORMAT (' ORFCOE     BEARING COOLANT ORIFICE COEFFICIENT',36X,
    1F6.4)
     WRITE (6,3060) ORFBTA
3060 FORMAT (' ORFBTA     BEARING COOLANT ORIFICE BETA',43X,F6.4)
3070 FORMAT (' R707        RADIAL LOCATION OF PRESSURE TAP 707',35X,
    1F6.4,' IN')
     WRITE (6,3070) R707
3080 FORMAT (' W           DIFFUSER VANE INLET WIDTH',45X,F6.4,' IN')
     WRITE (6,3080) W
3090 FORMAT (' R706        RADIAL LOCATION OF PRESSURE TAP 706',35X,
    1F6.4,' IN')
     WRITE (6,3090) R706
4000 FORMAT (' R708        RADIAL LOCATION OF PRESSURE TAP 708',35X,
    1F6.4,' IN')
     WRITE (6,4000) R708
4010 FORMAT (' R709        RADIAL LOCATION OF PRESSURE TAP 709',35X,
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       1[illegible]' [illegible])
     / WRITE (6,4010) R724
 4020 FORMAT (' R725   RADIAL LOCATION OF PRESSURE TAP 725',35X,
     / 1F6.4,' IN')
       WRITE (6,4020) R725
 4030 FORMAT (' R726   RADIAL LOCATION OF PRESSURE TAP 726',35X,
     1F6.4,' IN')
       WRITE (6,4030) R726
 4040 FORMAT (' RLF    LABYRINTH LAND RADIUS',49X,F6.4,' IN')
       WRITE (6,4040) RLF
 4050 FORMAT (' RL1    LABYRINTH LAND RADIUS',49X,F6.4,' IN')
       WRITE (6,4050) RL1
 4060 FORMAT (' RLT    LABYRINTH LAND RADIUS',49X,F6.4,' IN')
       WRITE (6,4060) RLT
 4070 FORMAT (' RIH    INDUCER RADIUS',56X,F6.4, ' IN')
       WRITE (6,4070) RIH
 4080 FORMAT (' RL2    LABYRINTH LAND RADIUS',49X,F6.4,' IN')
       WRITE (6,4080) RL2
 4090 FORMAT (' RLS    SHAFT RADIUS',58X,F6.4,' IN')
       WRITE (6,4090) RLS
       RETURN
       END
       SUBROUTINE SUCTON (IFLAG,JFLG)
C---------------------------------SYMBOLS-----------------------------------------
C  A1=FLOW AREA UPSTREAM OF FLOW CONDITIONER---SQ-IN
C A2=FLOW AREA DOWNSTREAM OF FLOW CONDITIONER---SQ-IN
C  ALPHA=VAPOR VOLUME/TOTAL VOLUME DOWNSTREAM OF FLOW CONDITIONER
C  GAVA=VAPOR VOLUME/LIQUID VOLUME DOWNSTREAM OF FLOW CONDITIONER
C H1=ENTHALPY UPSTREAM OF FLUID CONDITIONER---BTU/LB
C  H1T=STAGNATION ENTHALPY UPSTREAM OF FLUID CONDITIONER---BTU/LB
C  H2=ENTHALPY DOWNSTREAM OF FLUID CONDITIONER---BTU/LB
C  H2T=STAGNATION ENTHALPY DOWNSTREAM OF FLUID CONDITIONER---BTU/LB
C  H[illegible]=SATURATION ENTHALPY CORRESPONDING TO S2---BTU/LB
C  HTK=ENTHALPY IN TANK---BTU/LB
C  HPSH=NET POSITIVE SUCTION HEAD USING NPSP AND RHOSAT---FT
C  HPSH[illegible]=NET POSITIVE SUCTION HEAD USING (H2-HL,O2)---FT
C  NPSP=NET POSITIVE SUCTION PRESSURE=P2T-PVAP2---PSI
C  P1=PRESSURE UPSTREAM OF FLOW CONDITIONER---PSIA
C  P2=PRESSURE DOWNSTREAM OF FLOW CONDITIONER---PSIA
C  P2T=STAGNATION PRESSURE DOWNSTREAM OF FLOW CONDITIONER---PSIA
C  PTK=TANK PRESSURE---PSIA
C  PVAP1=VAPOR PRESSURE UPSTREAM OF FLOW CONDITIONER---PSIA
C  PVAP2=VAPOR PRESSURE CORRESPONDING TO S2---PSIA
C  PVAPTK=VAPOR PRESSURE IN TANK---PSIA
C  RHO1=FLUID DENSITY UPSTREAM OF FLOW CONDITIONER---LB/CU-FT
C RHO2=FLUID DENSITY DOWNSTREAM OF FLOW CONDITIONER---LB/CU-FT
C  RHOLIQ=LIQUID DENSITY DOWNSTREAM OF FLOW CONDITIONER---LB/CU-IN
C  RHOSAT=SATURATION DENSITY CORRESPONDING TO S2---LB/CU-FT
C  RHOVAP=VAPOR DENSITY DOWNSTREAM OF FLOW CONDITIONER---LB/CU-IN
C  S2=ENTROPY DOWNSTREAM OF FLUID CONDITIONER---BTU/LB-DEG R
C  T1=TEMPERATURE UPSTREAM OF FLOW CONDITIONER---DEG R
C  T2=MEASURED TEMPERATURE DOWNSTREAM OF FLOW CONDITIONER DEG R
C  T2CALC=VAPOR TEMPERATURE CORRESPONDING TO S2---DEG R
C  TTK=TANK TEMPERATURE---DEG R
C  V1=AVERAGE FLUID VELOCITY UPSTREAM OF FLUID CONDITIONER---FT/SEC
C  [illegible] OF FLUID CONDITIONER---FT/SEC
C  [illegible]
C  X2=QUALITY DOWNSTREAM OF FLUID CONDITIONER
C---------------------------------------------------------------------------------
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      COMMON /SAT/ HSAT(25),PSAT(25),TSAT(25),SSAT(25),RHOSAT(25),
     1EMPT(25),EMPS(25),EMTS(25),EMHS(25),EMRHOS(25)
      COMMON /[illegible]/ INPT(100),GEOM(50),OUT(120)
      [illegible]
      EQUIVALENCE (INPT(12),PTK),(INPT(13),TTK),(INPT(14),P1),
     1            (INPT(15),T1),(INPT(16),P2),(INPT(17),T2)
      EQUIVALENCE (OUT(11),WDOT),(OUT(12),QS),(OUT(13),PVAPTK),
     1            (OUT(14),HTK),(OUT(15),RHO1),(OUT(16),V1),
     2            (OUT(17),H1),(OUT(18),H1T),(OUT(19),PVAP1),
     3            (OUT(20),RHO2),(OUT(21),V2),(OUT(22),H2),
     4            (OUT(23),H2T),(OUT(24),PVAP2),(OUT(25),S2),
     5            (OUT(26),T2),(OUT(27),P2T),(OUT(28),HPSP),
     6            (OUT(29),HPSHA),(OUT(30),HPSHB),(OUT(31),B),
     7            (OUT(32),ALPHA),(OUT(33),T2CALC),(OUT(34),RHOLIQ),
     8            (OUT(35),RHOL2),(OUT(36),[illegible])
      EQUIVALENCE (GEOM(1),DSL1),(GEOM(2),DSL2)
      A1=3.14159*DSL1**2/4.
      A2=3.14159*DSL2**2/4.
      N=22
C*** COMPUTE TANK CONDITIONS
      CALL PTENTH(PTK,TTK,1,HTK,JFLG)
      IF (JFLG.GT.1) RETURN
      CALL SPLNT (N,TSAT,PSAT,EMPT,TTK,PVAPTK)
C*** CHECK FOR VAPOR UPSTREAM OF FLOW CONDITIONER
      IF (P1.GT.PVAPTK) GO TO 90
      WRITE (6,1020)
 1020 FORMAT (' POSSIBLE VAPOR UPSTREAM OF FLOW CONDITIONER')
   90 CALL PTDENS(P1,T1,1,RHO1,JFLG)
      IF (JFLG.GT.1) RETURN
      V1=144.*WDOT/(RHO1*A1)
      [illegible](P1,T1,2,H1,JFLG)
      [illegible]
      H1T=H1+V1**2/(2.*32.174*778.16)
      CALL SPLNT (N,TSAT,PSAT,EMPT,T1,PVAP1)
      IF (P2.LE.(PVAP1+3.)) GO TO 100
C*** SINGLE PHASE DOWNSTREAM OF FLOW CONDITIONER
      CALL PTDENS(P2,T2,2,RHO2,JFLG)
      IF (JFLG.GT.1) RETURN
      CALL PTENTH(P2,T2,3,H2,JFLG)
      IF (JFLG.GT.1) RETURN
      V2=144.*WDOT/(RHO2*A2)
      H2T=H2+V2**2/(2.*32.174*778.16)
      CALL PTENTR(P2,T2,1,S2,JFLG)
      IF (JFLG.GT.1) RETURN
      RHOLIQ=RHO2
      X2=0.0
      B=0.
      ALPHA=0.
      RHOVAP=0.
      GO TO 160
C*** POSSIBLE TWO PHASE DOWNSTREAM OF FLOW CONDITIONER
  100 H2=H1
      IF (IFLAG.NE.0) GO TO 105
      HTOT=H1T
      GO TO 106
  105 HTOT=HTK
  106 ICOUNT=0
  110 ICOUNT=ICOUNT+1
      CALL PHTEMP(P2,H2,1,T2CALC,X2,JFLG)
```

```
      CALL PHDENS(P2,H2,1,RHO2,RHOLIQ,X2,JFLG)
      IF (JFLG.GT.1) RETURN
      IF (RHOLIQ.GT.0.0) GO TO 120
      RHOLIQ=RHO2
  120 V2=144.*WDOT/(RHO2*A2)
      H2NEW=HTOT-V2**2/(2.*32.174*778.16)
      IF (ABS(1.-H2/H2NEW).LE.0.00001) GO TO 150
      [illegible]
      IF (IC[illegible]) GO TO 110
      WRITE (6,1000)
 1000 FORMAT (' SOLUTION FOR ENTHALPY DOWNSTREAM OF FLOW CONDITIONER DID
     1 NOT CONVERGE IN 20 ITERATIONS')
  150 CALL PHENTR(P2,H2,1,S2,JFLG)
      IF (JFLG.GT.1) RETURN
      H21=H2+V2**2/(2.*32.174*778.16)
      RHOVAP=X2*RHOLIQ/(RHOLIQ/RHO2+X2-1.0)
      B=X2*RHOLIQ/((1.-X2)*RHOVAP)
      ALPHA=B/(B+1.)
C *** FIND SATURATION PRESSURE CORRESPONDING TO S2
  160 CALL SPLNT (N,SSAT,TSAT,EMTS,S2,T2CALC)
      CALL SPLNT (N,SSAT,PSAT,EMPS,S2,PVAP2)
      CALL SPLNT (N,SSAT,HSAT,EMHS,S2,HLIQ2)
      CALL SPLNT (N,SSAT,RHOSAT,EMRHOS,S2,RHOL2)
      QS=448.86*WDOT/RHO2
  300 P2T=P2+RHO2*V2**2/(2.*32.174*144.)
      PTEST=P2T+0.5
      CALL PHENTR(PTEST,H2T,2,S11,JFLG)
      IF (JFLG.GT.1) RETURN
      DP=PTEST-P2T
      ICOUNT=1
  315 CALL PHENTR(P2T,H2T,2,STEST,JFLG)
      IF (JFLG.GT.1) RETURN
      DS=S11-STEST
      DPDS=DP/DS
      IF (ABS(1.-STEST/S2)-1.0E-05) 350,350,320
  320 IF (ICOUNT-30) 330,340,340
  330 ICOUNT=ICOUNT+1
      S11=STEST
      DP=DPDS*(STEST-S2)
      P2T=P2T-DP
      GO TO 315
  340 WRITE (6,1030)
 1030 FORMAT (' NO SOLUTION FOR P2T')
  350 NPSP=P2T-PVAP2
      NPSHA=144.*NPSP/RHOL2
  450 NPSHB=778.16*(H2T-HLIQ2)
  500 RETURN
      END
      SUBROUTINE FLOW(JFLG)
      COMMON / CALC/ INPT(100),GEOM(50),OUT(120)
      REAL INPT
      EQUIVALENCE(GEOM(3),ALBF),(GEOM(4),CLABF),(GEOM(5),ALBR),
     1               (GEOM(6),CLABR),(GEOM(13),DDL),(GEOM(14),RHOREF),
     2               (GEOM(15),OREFD),(GEOM(16),ORFCOE),(GEOM(17),ORFBTA)
      EQUIVALENCE (INPT(2),PSD),(INPT(3),TD),(INPT(4),PLFI),
     1               (INPT(5),PLFO),(INPT(6),PLRI),(INPT(7),PLRO),
     2               (INPT(8),WREF),(INPT(9),DPORF1),(INPT(10),DPORF2),
     3               (INPT(11),PORF)
      EQUIVALENCE (OUT(1),RHOD),(OUT(2),VD),(OUT(3),OD),(OUT(4),HSDR),
```

```
     2          (OUT(8),RHORL),(OUT(9),WLBR),(OUT(10),BLDR),
     3          (OUT(11),WS),(OUT(103),WBRG)
      CALL PTDENS(PSD,TD,3,RHOD,JFLG)
      IF (JFLG.GT.1) RETURN
      WD=WREF*RHOD/RHOREF
      QD=448.86*WD/RHOD
      CALL PTENTH(PSD,TD,4,HSDB,JFLG)
      IF (JFLG.GT.1) RETURN
      CALL PHDENS(PORF,HSDB,2,RHOBRG,RHOLBG,QUAL,JFLG)
      IF (JFLG.GT.1) RETURN
      WB1=0.5252*ORFCOE*ORFBTA**2*ORFD**2*SQRT(RHOBRG*DPORF1)
      WB2=0.5252*ORFCOE*ORFBTA**2*ORFD**2*SQRT(RHOBRG*DPORF2)
      WBRG=WB1+WB2
C     FRONT LABYRINTH FLOW
      CALL PHDENS(PLFO,HSDR,3,RHOFL,RHOLFL,QUAL,JFLG)
      IF (JFLG.GT.1) RETURN
      DPLBF=PLFI-PLFO
      WLBF=0.66847*CLABF*ALBF*SQRT(RHOFL*DPLBF)
C     REAR LABYRINTH FLOW
      DPLBR=PLRI-PLRO
      CALL PHDENS(PLRO,HSDR,4,RHORL,RHOLRL,QUAL,JFLG)
      IF (JFLG.GT.1) RETURN
      WLBR=0.66847*CLABR*ALBR*SQRT(RHORL*DPLBR)
C     BEARING HOUSING FLOW
C     SUCTION FLOW
      WS=WD+WBRG+WLBR
      RECF=WLBF/WS
      BLDR=WLBR/WS
      RETURN
      END
      SUBROUTINE AXFOR
      COMMON /CALC/ INPT(100),GEOM(50),OUT(120)
      REAL INPT
      EQUIVALENCE (GEOM(8),D2),(GEOM(19),R706),(GEOM(20),R707),
     1          (GEOM(21),R708),(GEOM(22),R724),(GEOM(23),R725),
     2          (GEOM(24),R726),(GEOM(25),PLF),(GEOM(26),RLM),
     3          (GEOM(27),RLI),(GEOM(28),RIN),(GEOM(29),RLD),
     4          (GEOM(30),RLS)
      EQUIVALENCE (INPT(16),PS),(INPT(19),P708),(INPT(20),P726),
     1          (INPT(4),P706),(INPT(5),P705),(INPT(6),P724),
     2          (INPT(7),P723),(INPT(32),P707),(INPT(33),P725),
     3          (INPT(31),SN)
      EQUIVALENCE (OUT(11),VWIN),(OUT(34),RHOSL),(OUT(85),P2F),
     1          (OUT(86),PLF),(OUT(87),XKSOU),(OUT(88),XKSOV),
     2          (OUT(89),FF),(OUT(90),FFLB),(OUT(91),FIN),
     3          (OUT(92),FFOV),(OUT(93),FMT),(OUT(94),P2R),
     4          (OUT(95),PLD),(OUT(96),XKDOU),(OUT(97),XKDOV),
     5          (OUT(98),FP),(OUT(99),F723),(OUT(100),FAS),
     6          (OUT(101),FROV),(OUT(102),FAX),(OUT(20),RHO2)
      PAMB=INPT(1)/2.036
C-CONSTANTS
      R2 = D2/2.
      R7080 = R708**2
      R7070 = R707**2
      R7060 = R706**2
      R7260 = R726**2
      R7250 = R725**2
      R7240 = R724**2
      R20   = R2**2
```

```
      PLMQ  = RLM**2
      RLIQ  = RLI**2
      RINQ  = RIN**2
      R7260 = R726**2
      R7250 = R725**2
      R7240 = R724**2
      RLDQ  = RLD**2
      RLSQ=RLS**2
C-PRESSURE EXTRAPOLATIONS SHROUD
      P2F = (R2Q-R7070)*(P708-P707)/(R7080-R7070)+P707
      PLF = P706-(P7060-RLFQ)*(P707-P706)/(R7070-R7060)
C-K-VALUES SHROUD
      XKK = 11028./SN/SQRT(RHO2)
      XKSOU = XKK * SQRT((P708-P707)/(R7080-R7070))
      XKSOV = XKK * SQRT((P708-P706)/(R7080-R7060))
C-SHROUD PRESSURE FORCES
      FF27 = 1.5708*(R2Q-R7070)*(P2F+P707)
      FF7L = 1.5708*(R7070-RLFQ)*(P707+PLF)
      FF   = FF27 + FF7L
C-LABYRINTH PRESSURES
      PLFI = P705 + (PLF - P705)/3.
      PLFM = PLF - (PLF - P705)/3.
C-PRESSURE FRONT LABYRINTH
      FLFM = 3.1417*(RLFQ - RLMQ)*PLFM
      FLFI = 3.1417*(RLMQ - RLIQ)*PLFI
      F705 = 3.1417*(RLIQ - RINQ)*P705
      FFLB = FLFM + FLFI + F705
C-PRESSURE FORCE INDUCER
      FIN = 3.1417 * RINQ * PS
C-MOMENTUM FORCE
      FMT = 0.145 * VWIN**2/RHOSL
C-FRONT SIDE PRESSURE FORCE
      FFOV = FF + FFLB + FIN
C-PRESSURE EXTRAPOLATIONS DISK
      P2R = (R2Q-R7250)*(P726-P725)/(R7260-R7250)+P725
      PLD = P725 - (R7250-RLDQ)*(P725-P724)/(R7250-R7240)
C-K-VALUES DISK
      XKDOU = XKK * SQRT((P726-P725)/(R7260-R7250))
      XKDOV = XKK * SQRT((P726-P724)/(R7260-R7240))
C-DISK PRESSURE FORCES
      FR25  = 1.5708*(R2Q - R7250)*(P2R+P725)
      FR5L  = 1.5708*(R7250 - RLDQ)*(P725+PLD)
      FR    = FR25 + FR5L
      F723  = 3.1417*(RLDQ-RLSQ)*P723
      FAS   = 3.1417* RLS**2* PAMB
C-BACKSIDE PRESSURE FORCE
      FROV  = FR + F723 + FAS
C-AXIAL THRUST POSITIVE TOWARDS SUCTION
      FAX=FROV-FFOV-FMT
      RETURN
      END
      SUBROUTINE RADTHR(N)
      COMMON /CALC/ INPT(100),GEOM(50),OUT(120)
      DIMENSION P(9),THETA(10),FX(9),FY(9)
      EQUIVALENCE (INPT(21),P(1))
      EQUIVALENCE (GEOM(8),DI2),(GEOM(18),W)
      EQUIVALENCE (OUT(80),RUSL),(OUT(81),BETA),(OUT(82),RFP),
     1(OUT(83),PAVE)
      DTHETA=360./N
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```
      DO 10 I=2,N
   10 THETA(I)=THETA(I-1)+DTHETA
      THETA(N+1)=THETA(1)+360.
      SUMFX=0.0
      SUMFY=0.0
      DO 110 I=1,N
      PHI = (THETA(I+1)-THETA(I)) / 2.+ THETA(I)
      IF (PHI.LT.0.0) GO TO 40
      IF (PHI.LE.90.0) GO TO 50
      IF (PHI.LE.180.0) GO TO 60
      IF (PHI.LE.270.0) GO TO 70
      IF (PHI.LE.360.0) GO TO 80
   40 WRITE (6,1000)
 1000 FORMAT (' ANGLE LESS THAN 0 OR GREATER THAN 360 DEG, RADIAL THRUST
     1CALCULATION TERMINATED')
      RETURN
   50 PSI=PHI
      SIGNY=-1.
      SIGNX=-1.
      GO TO 100
   60 PSI=180.-PHI
      SIGNY=-1.
      SIGNX=1.
      GO TO 100
   70 PSI=PHI-180.0
      SIGNY=1.
      SIGNX=1.0
      GO TO 100
   80 PSI=360.-PHI
      SIGNY=1.
      SIGNX=-1.
  100 F=P(I)*W*DI2*ABS(SIN((THETA(I+1)-THETA(I))/(2.*57.296)))
      FX(I)=F*SIGNX*COS(PSI/57.296)
      FY(I)=F*SIGNY*SIN(PSI/57.296)
      SUMFX=SUMFX+FX(I)
  110 SUMFY=SUMFY+FY(I)
      IF (SUMFX.LE.0.0) GO TO 150
      IF (SUMFY.LE.0.0) GO TO 130
      BETA=57.296*ATAN(SUMFY/SUMFX)
      GO TO 200
  130 BETA=57.296*ATAN(SUMFY/SUMFX)+360.
      GO TO 200
  150 BETA=57.296*ATAN(SUMFY/SUMFX)+180.0
  200 RUSL=SQRT(SUMFX**2+SUMFY**2)
      SUMP=0.0
      DO 300 I=1,N
  300 SUMP=SUMP+P(I)
      PAVE=SUMP/N
      PFP=RUSL/PAVE
      RETURN
      END
      SUBROUTINE PERFOR(JFLG)
      COMMON /CALC/ INPT(100),GEOM(50),OUT(120)
      REAL INPT,N
      EQUIVALENCE (GEOM(9),BET2),(GEOM(10),Z2),(GEOM(13),DDL),
     1            (GEOM(8),DI2),(GEOM(7),AI2),(GEOM(11),RPTAP),
     2            (GEOM(12),ADED)
      EQUIVALENCE (INPT(2),PSO),(INPT(3),TO),(INPT(18),PIO),
     1            (INPT(19),PTIO),(INPT(20),PRTIP),(INPT(21),PDIFI1),
                  (INPT(22),PDIFI2),(INPT(23),PDIFI3),(INPT(24),PDIFI4),
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     3              (INPT(25),PDIFI5),(INPT(26),PDIFI6),(INPT(27),PDIFI7),
     4              (INPT(28),PDIFI8),(INPT(29),PDIFI9),(INPT(30),PDIFO),
     5(INPT(31),N),(INPT(16),PS)
      EQUIVALENCE (OUT(1),RHOD),(OUT(2),WD),(OUT(3),QD),(OUT(4),HSDB),
     1              (OUT(6),WLBF),(OUT(9),WLBR),(OUT(11),WS),(OUT(12),QS),
     2              (OUT(25),SS),(OUT(40),U2),(OUT(41),VOIS),
     3              (OUT(42),HTOD),(OUT(43),DPTD),(OUT(44),PTD),
     4              (OUT(45),DHISO),(OUT(46),HN2O),(OUT(47),HCO),
     5              (OUT(48),QND),(OUT(49),DHTAB),(OUT(50),DHTI),
     6              (OUT(51),EFTD),(OUT(52),EFTDO),(OUT(53),DPSIN),
     7              (OUT(54),DHSIN),(OUT(55),HSIN2),(OUT(56),QNS),
     8              (OUT(57),PHI2),(OUT(58),PSITH),(OUT(59),HBIMP),
     9              (OUT(60),RHOID),(OUT(61),HISIB),(OUT(62),DHISI),
     1              (OUT(63),HN2IS),(OUT(64),HCIS),(OUT(65),HCIT),
     2              (OUT(66),DHITI),(OUT(67),HN2IT),(OUT(68),EFIMP),
     3              (OUT(69),DHCHG),(OUT(70),DHISD),(OUT(71),HN2DS),
     4              (OUT(72),DHITD),(OUT(73),HCTD),(OUT(74),DHCDE),
     5              (OUT(75),DHCVO)
      EQUIVALENCE (OUT(83),PDIFIA)
      EQUIVALENCE (OUT(23),HTSB),(OUT(22),HSB),(OUT(27),PTS),
     1              (OUT(34),RHOSL)
C     CONSTANTS
      BET2R=BET2/57.296
      TBE2=TAN(BET2R)
      SLP=3.14159*SIN(BET2R)/Z2
      ADL=3.14159/4.*DDL**2
C     PUMP OVERALL PERFORMANCE
      U2=3.14159*DI2*N/720.
      CALL PTLHTR(PSD,TD,2,SD,JFLG)
      IF (JFLG.GT.1) RETURN
      VOIS=QD*144./(ADL*448.86)
      HDVEL=VOIS**2/2./32.174
      PTD=PSD+RHOD*HDVEL/144.
      HTDB=HSDB+HDVEL/778.16
      DH=HTDB-HTSB
      DPTD=PTD-PTS
      CALL PSENTH(PTD,SS,1,HISOB,JFLG)
      IF (JFLG.GT.1) RETURN
      DHISO=(HISOB-HTSB)*778.16
      HN2O=DHISO/N**2
      HCO=DHISO*32.174/U2**2
      QND=QD/N
      DHTAB=(HTDB-HTSB)
      DHTI=(HISOB-HTSB)
      EFTD=DHTI/DHTAB
      EFTDO=EFTD*WD/WS
C     INDUCER PERFORMANCE
      DPSIN=PIO-PS
      DHSIN=144.*DPSIN/RHOSL
      HSIN2=DHSIN/N**2
      QNS=QS/N
C     IMPELLER FLOW COEFFICIENT
      WSIMP=WS+WLBF
      PIMP=(PTIP+PBTIP)/2.
      RHOID=RHOD
  100 PHI2=144.*WSIMP/(RHOID*AI2*U2)
      PSITH=1.-PHI2/TBE2-SLP
      HVEL2=0.015547*U2**2*(PSITH**2+PHI2**2)
      HBIMP=HTDB-HVEL2/778.16
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      CALL PHDENS(PIMP,HBIMP,2,RHOID,RHOL,QUAL,JFLG)
      IF (JFLG.GT.1) RETURN
      IF (ABS(1.-RHOLD/RHOID)-1.0E-05) 150,150,100
C     IMPELLER STATIC HEAD COEFFICIENT
  150 CALL PHTEMP(PDIFIA,HBIMP,2,TID,QI2,JFLG)
      IF (JFLG.GT.1) RETURN
      CALL PSENTH(PDIFIA,SS,2,HISIB,JFLG)
      IF (JFLG.GT.1) RETURN
      DHISI=(HISIB-HSB)*778.16
      HN2IS=DHISI/N**2
      HCIS=32.174*DHISI/U2**2
C     IMPELLER TOTAL HEAD COEFFICIENT
      HCIT=HCIS+(DI2/2./RPTAP)**2*(PSITH**2+PHI2**2)/2.
      DHITI=U2**2*HCIT/32.174
      HN2IT=DHITI/N**2
      EFIMP=HCIT/PSITH
C     HOUSING HEAD LOSS COEFFICIENT
      DHCHG=HCIT-HCO
C     DIFFUSER AND VOLUTE LOSSES
      CALL PSENTH(PDIFO,SS,3,HISDB,JFLG)
      IF (JFLG.GT.1) RETURN
      DHISD=(HISDB-HSB)*778.16
      HN2DS=DHISD/N**2
C     DIFFUSER DISCHARGE ANGLE BASED ON PFLEIDERS DEVIATION CRITERION
      CM52=144.*(WS-WLBR)/RHOD/ADFD
      CUTH2=U2*PSITH
      AL52R=ATAN(1./(2.01+0.245*CUTH2/CM52))
      HVDF=.975*(CM52/SIN(AL52R))**2/(2.*32.174)
      DHITD=DHISD+HVDF
      HCTD=32.174*DHITD/U2**2
      DHCDF=HCIT-HCTD
      DHCVO=HCTD-HCO
      RETURN
      END
      SUBROUTINE TAPE1
      COMMON / TITLE/ TESTID(12),DAY(2),RUNTME(2),IPAGE
      COMMON /TAPEIN/ CHAN1(100),CHAN2(100),CHAN3(100),CHAN4(100),
     1PARID(100),CHANID(200),UNITS(200),DEC(200),NPAR
      COMMON /TAPE/ TSTART,TSTOP,INT1,INT2,IAVE,NSETS,INPUT,ATIME,TIME,
     1IEND
      INTEGER CHAN1,CHAN2,CHAN3,CHAN4,PARID,CHANID,UNITS,UN(100),D(100)
      REAL INPUT
      DIMENSION INPUT(100,50),ATIME(50),DATA(200),NUM(10)
      INTEGER PGAGE
      INTEGER BLANK,F(22),G(22),V(14)
      INTEGER DEC,DAY,RUNTME,TESTID
      DATA BLANK /'      '/
      DATA PGAGE /'PSIG  '/
      DATA F(1),F(2),F(4),F(6),F(8),F(10),F(12),F(14),F(16),F(18),F(20),
     1F(22) /'(F9.1,',10*'F11.',')'/
      DATA V(1),V(3),V(4),V(5),V(6),V(8),V(9),V(10),V(11),V(13),V(14)
     1/'(8X,',  '(8X,I3',  6H)/3X,',  6HTIME',,  '3X,',  '(5X,A6',
     26H)/4X,',  6HSEC',3,  'X,',  '(5X,A6',  ')/)'/
      DATA G(22) /')'/
      DATA NUM/'1','2','3','4','5','6','7','8','9','10'/
      KENTR=1
  100 READ(1) NCHAN,TIME, (DATA(I),I=1,NCHAN)
      IF (TIME.LT.TSTART) GO TO 100
      BACKSPACE 1
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      ENTRY TAPE2
  250 KENTR=2
  260 NSETS=NSETS+1
      DO 270 J=1,NPAR
  270 INPUT(J,NSETS)=0.0
      ATIME(NSETS)=0.0
      DO 300 I=1,INT1
      READ(1) NCHAN,TIME,(DATA(J),J=1,NCHAN)
      IF (KENTR.EQ.1) GO TO 310
      IF (TIME.GE.TSTOP) GO TO 310
  300 CONTINUE
  310 NAVE=1
  320 ATIME(NSETS)=ATIME(NSETS)+TIME
      DO 350 J=1,NPAR
      N=1
      K=CHAN1(J)
      PAR=DATA(K)
      UN(J)=UNITS(K)
      D(J)=DEC(K)
      IF (CHAN2(J).EQ.0) GO TO 350
      N=2
      K=CHAN2(J)
      PAR=PAR+DATA(K)
      IF (CHAN3(J).EQ.0) GO TO 350
      N=3
      K=CHAN3(J)
      PAR=PAR+DATA(K)
      IF (CHAN4(J).EQ.0) GO TO 350
      N=4
      K=CHAN4(J)
      PAR=PAR+DATA(K)
  350 INPUT(J,NSETS)=INPUT(J,NSETS)+PAR/N
      IF (NAVE.GE.IAVE.OR.TIME.GE.TSTOP) GO TO 450
      DO 400 I=1,INT2
      READ (1) NCHAN,TIME,(DATA(J),J=1,NCHAN)
      IF (TIME.GE.TSTOP) GO TO 410
  400 CONTINUE
  410 NAVE=NAVE+1
      GO TO 320
  450 DO 500 J=1,NPAR
      INPUT (J,NSETS)=INPUT(J,NSETS)/NAVE
      IF (UN(J).NE.PGAGE) GO TO 500
      INPUT(J,NSETS)=INPUT(J,NSETS)+INPUT(1,NSETS)/2.036
      UN(J)='PSIA'
  500 CONTINUE
      ATIME(NSETS)=ATIME(NSETS)/NAVE
      IF (NSETS.LT.50.AND.TIME.LT.TSTOP) GO TO 260
      IF (IEND.EQ.0) RETURN
      DO 600 K=1,NPAR,10
      IPAGE=IPAGE+1
      L=K+9
      NCOL=10
      IF (L.LE.NPAR) GO TO 550
      L=NPAR
      NCOL=NPAR-K+1
  550 V(2)=NUM(NCOL)
      V(7)=NUM(NCOL)
      V(12)=NUM(NCOL)
      WRITE (6,6050) IPAGE
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          WRITE (6,V) (I,I=K,L),(PARID(I),J=K,L),(UN(I),I=K,L)
          M=1
          DO 580 I=K,L
          M=M+2
      580 F(M)=D(I)
          DO 582 I=1,M
      582 G(I)=F(I)
          IF (M.EQ.21) GO TO 600
          M1=M+1
          DO 585 I=M1,21
      585 G(I)=BLANK
      600 WRITE (6,G) (ATIME(M),(INPUT(I,M),I=K,L),M=1,NSETS)
     6000 FORMAT (12A6,12X,'DATE ',2A6,'TIME ',2A6)
     6050 FORMAT ('1',52X,'LH2 PUMP TEST',44X,'PAGE ',I4)
          RETURN
          END
C
C  SPLINT CALCULATES INTERPOLATED POINTS AND DERIVATIVES
C  FOR A SPLINE CURVE
          SUBROUTINE SPLNT (N,X,Y,EM,XX,YINT)
          DIMENSION Z(10),X(25),Y(25),EM(25)
     1000 FORMAT (' SPLNT USED FOR EXTRAPOLATION',3E20.7/)
          MAX=1
          Z(1)=XX
          DO140I=1,MAX
          K=2
          IF(Z(I)-X(1))70,60,90
       60 YINT   =Y(1)
          SK=X(K)-X(K-1)
          GO TO 130
       70 IF (Z(I)-(1.1*X(1)-0.1*X(2))) 75,120,120
       75 WRITE (6,1000) Z(I),X(1),X(2)
          SRW=16
          GO TO 120
       80 K=N
          IF (Z(I)-(1.1*X(N)-0.1*X(N-1))) 120,120,85
       85 WRITE (6,1000) Z(I),X(N-1),X(N)
          SRW=16
          GO TO 120
       90 IF(Z(I)-X(K))120,100,110
      100 YINT   =Y(K)
          SK=X(K)-X(K-1)
          GO TO 130
      110 K=K+1
          IF(K-N)90,90,80
      120 CONTINUE
          SK=X(K)-X(K-1)
          YINT   =EM(K-1)*(X(K)-Z(I))**3/6.  /SK+EM(K)*(Z(I)-X(K-1))**3/6.
         1/SK+(Y(K)/SK-EM(K)*SK/6.  )*(Z(I)-X(K-1))+(Y(K-1)/SK-EM(K-1)*SK/6.
         2  )*(X(K)-Z(I))
      130 DYDX   =-EM(K-1)*(X(K)-Z(I))**2/2.0  /SK+EM(K)*(X(K-1)-Z(I))** 2/2
         1  /SK+(Y(K)-Y(K-1))/SK-(EM(K)-EM(K-1))*SK/6.
          D2YDX=(X(K)-Z(I))*EM(K-1)/SK+(Z(I)-X(K-1))*EM(K)/SK
          RCURV=((1.+DYDX**2)**1.5)/ABS(D2YDX)
      140 CONTINUE
      500 RETURN
          END
          SUBROUTINE SPLNE (N,X,Y,EM)
          INTEGER SRW
C
```

```
      C  SPLINE CALCULATES FIRST AND SECOND DERIVATIVES AT SPLINE POINTS      3K
      C  END CONDITION-SECOND DERIVATIVES ARE THE SAME AT END POINT AND
      C  ADJACENT POINT
      C
         DIMENSION X(25),Y(25),EM(25),G(25),SB(25),SLOPE(25),CURV(25)
         SRW=0
         SB(1)=-1.0
         G(1)=0.
         NO=N-1
         IF (NO-2) 20,7,7
       7 DO10I=2,NO
         A=(X(I)-X(I-1))/6.
         C=(X(I+1)-X(I))/6.
         W=2.  *(A+C)-A*SB(I-1)
         SB(I)=C/W
         F=(Y(I+1)-Y(I))/(X(I+1)-X(I))-(Y(I)-Y(I-1))/(X(I)-X(I-1))
      10 G(I)=(F-A*G(I-1))/W
      20 EM(N)=G(N-1)/(1.  +SB(N-1))
         DO30I=2,N
         K=N+1-I
      30 EM(K)=G(K)-SB(K)*EM(K+1)
         SLOPE(1)=(X(1)-X(2))/6.  *(2.  *EM(1)+EM(2))+(Y(2)-Y(1))/(X(2)-X(1
        1))
         DO40I=2,N
      40 SLOPE(I)=(X(I)-X(I-1))/6.  *(2.  *EM(I)+EM(I-1))+(Y(I)-Y(I-1))/(X(
        1I)-X(I-1))
         DO 45 I=1,N
      45 CURV(I)=((1.+SLOPE(I)**2)**1.5)/ABS(EM(I))
         IF (SRW) 50,100,50
      50 WRITE (6,1000) N, (X(I),Y(I),SLOPE(I),EM(I),CURV(I),I=1,N)
     100 RETURN
    1000 FORMAT ('1',15HNO. OF POINTS =,I3/10X,1HX,19X,1HY,19X,5HSLOPE,15X,
        A2HEM,15X,4HCURV/(5E20.8))
         END
         SUBROUTINE SATUR(N)
         COMPILER (DATA=SHORT)
         COMMON /SAT/ HSAT(25),PSAT(25),TSAT(25),SSAT(25),RHOSAT(25),
        1EMPT(25),EMPS(25),EMTS(25),EMHS(25),EMRHOS(25),EMTP(25),
        2HSATV(25),SSATV(25),RHOSTV(25),EMHLP(25),EMHVP(25),EMSLP(25),
        3EMSVP(25),EMROLP(25),EMROVP(25),EMPH(25)
      C*** SATURATION DATA
         DATA HSAT /-132.81,-132.25,-129.29,-126.13,-122.79,-119.2,-115.38,
        1-111.31,-110.18,-106.96,-102.31,-97.32,-91.966,-86.208,-79.959,
        2-73.176,-65.733,-57.436,-48.009,-36.876,-22.458,16.550/
         DATA PSAT /1.0214,1.1433,1.9546,3.1302,4.7762,6.9953,9.8904,13.564
        1,14.696,18.120,23.705,30.406,38.371,47.688,58.519,70.967,85.149,
        2101.21,119.30,139.63,162.40,187.51/
         DATA TSAT /24.845,25.2,27.0,28.8,30.6,32.4,34.2,36.0,36.482,37.8,
        139.6,41.4,43.2,45.0,46.8,48.6,50.4,52.2,54.0,55.8,57.6,59.3568/
         DATA SSAT /1.18491,1.20743,1.31999,1.43138,1.54157,1.65296,1.76315
        1,1.87572,1.90534,1.98628,2.10204,2.21816,2.33665,2.45751,2.58193,
        22.71227,2.84553,2.99428,3.15306,3.33553,3.56422,4.19696/
         DATA RHOSAT/4.8086,4.7975,4.7434,4.6884,4.6298,4.5693,4.5055,
        14.4371,4.4185,4.3664,4.2889,4.2086,4.1205,4.0256,3.9226,3.8086,
        23.6805,3.5358,3.3664,3.1578,2.8711,1.9619/
         DATA HSATV / 60.315,61.104,64.965,68.612,72.045,75.223,78.103,
        180.683,81.408,82.987,84.590,86.207,87.124,87.530,87.316,86.357,
        284.480,81.472,76.866,69.891,58.502,16.358 /
         DATA SSATV / 8.9615,8.8821,8.5187,8.1936,7.9093,7.6545,7.4223,
        [illegible],6.1592,5.9968,
```

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      25.8310,5.6568,5.4672,5.2492,4.9707,4.1946/
       DATA RHOSTV /.007837,.008666,.07390,.021130,.030722,.043083,
      1.05864,.077866,.08351,.10105,.12927,.16304,.20317,.25074,
      2.3072,.3745,.4555,.5547,.6795,.8452,1.0422,1.9619 /
       CALL SPLNE(N,TSAT,PSAT,EMPT)
       CALL SPLNE(N,HSAT,PSAT,EMPH)
       CALL SPLNE(N,SSAT,PSAT,EMPS)
       CALL SPLNE(N,PSAT,TSAT,EMTP)
       CALL SPLNE(N,SSAT,TSAT,EMTS)
       CALL SPLNE(N,SSAT,HSAT,EMHS)
       CALL SPLNE(N,SSAT,RHOSAT,EMRHOS)
       CALL SPLNE (N,PSAT,HSAT,EMHLP)
       CALL SPLNE (N,PSAT,HSATV,EMHVP)
       CALL SPLNE (N,PSAT,SSAT,EMSLP)
       CALL SPLNE (N,PSAT,SSATV,EMSVP)
       CALL SPLNE (N,PSAT,RHOSAT,EMROLP)
       CALL SPLNE (N,PSAT,RHOSTV,EMROVP)
       RETURN
       END
       SUBROUTINE PARAH
       COMMON /PROP/ T(30,50),SV(30,50),H(30,50),S(30,50),NUM(30),P(30),
      1AA(5,90),RHOX(90),B(9,8)
       COMMON /SAT/ HSAT(25),PSATUR(25),TSAT(25),SSAT(25),RHOSAT(25),
      1EMPT(25),EMPS(25),EMTS(25),EMHS(25),EMRHOS(25),EMTP(25),
      2HSATVP(25),SSATV(25),RHOSTV(25),EMHLP(25),EMHVP(25),EMSLP(25),
      3EMSVP(25),EMROLP(25),EMROVP(25),EMPH(25)
       DATA PCRIT /187.55/
       DATA N/22/
C      ENTRY POINT FOR DENSITY(PP,TT)
C
       ENTRY PTDENS(PP,TT,K,RHO,JFLG)
       ENTR='PTDENS'
       IF (PP.GT.PCRIT) GO TO 100
       CALL SPLNT(N,TSAT,PSATUR,EMPT,TT,PSAT)
       IF (PP.LT.PSAT) GO TO 160
  100  CALL HPROP(PP,TT,SV,T,1,2,C,JFLG,XMIN,XMAX)
       IF (JFLG.GT.1) GO TO 110
       RHO=1./C
       RETURN
C      ENTRY FOR ENTHALPY(PP,TT)
C
       ENTRY PTENTH(PP,TT,K,ENTH,JFLG)
       ENTR='PTENTH'
       IF (PP.GT.PCRIT) GO TO 101
       CALL SPLNT(N,TSAT,PSATUR,EMPT,TT,PSAT)
       IF (PP.LT.PSAT) GO TO 160
  101  CALL HPROP(PP,TT,H,T,1,3,ENTH,JFLG,XMIN,XMAX)
       IF (JFLG.GT.1) GO TO 110
       RETURN
C      ENTRY FOR ENTROPY(PP,TT)
C
       ENTRY PTENTR(PP,TT,K,ENTRO,JFLG)
       ENTR='PTENTR'
       IF (PP.GT.PCRIT) GO TO 102
       CALL SPLNT(N,TSAT,PSATUR,EMPT,TT,PSAT)
       IF (PP.LT.PSAT) GO TO 160
  102  CALL HPROP(PP,TT,S,T,1,4,ENTRO,JFLG,XMIN,XMAX)
       IF (JFLG.GT.1) GO TO 110
  105  RETURN
  110  GO TO (105,100,150,160,160),JFLG
```

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  120 WRITE (6,2000) XMIN,XMAX,PP,ENTR,K
 2000 FORMAT (' MINIMUM TABULATED PRESSURE IS GREATER THAN P'/
     1' PMIN=',F10.2,5X,'PMAX=',F10.2,5X,'P=',F10.2,5X,A6,I2)
      RETURN
  130 WRITE (6,2010) XMIN,XMAX,PP,ENTR,K
 2010 FORMAT (' MAXIMUM TABULATED PRESSURE IS LESS THAN P'/
     1' PMIN=',F10.2,5X,'PMAX=',F10.2,5X,'P=',F10.2,5X,A6,I2)
      RETURN
  140 WRITE (6,2020) XMIN,XMAX,TT,ENTR,K
 2020 FORMAT (' MINIMUM TABULATED TEMPERATURE IS GREATER THAN T'/
     1' TMIN=',F10.2,5X,'TMAX=',F10.2,5X,'T=',F10.2,5X,A6,I2)
      RETURN
  150 WRITE (6,2030) XMIN,XMAX,TT,ENTR,K
 2030 FORMAT (' MAXIMUM TABULATED TEMPERATURE IS LESS THAN T'/
     1' TMIN=',F10.2,5X,'TMAX=',F10.2,5X,'T=',F10.2,5X,A6,I2)
      RETURN
  160 WRITE (6,2040) PSAT,PP,ENTR,K
 2040 FORMAT (' P IS LESS THAN SAT. PRESS. CORRESPONDING TO T'/
     1' PSAT=',F10.2,5X,'P=',F10.2,5X,A6,I2)
      JFLG=6
      RETURN
C     ENTRY FOR TEMPERATURE(PP,HH)
C
      ENTRY PHTEMP(PP,HH,K,TEMP,X,JFLG)
      ENTR='PHTEMP'
      IF (PP.GT.PCRIT) GO TO 200
      CALL SPLNT(N,HSAT,PSATUR,EMPH,HH,PSAT)
      IF (PP.LT.PSAT) GO TO 260
  200 CALL HPROP(PP,HH,T,H,3,1,TEMP,JFLG,XMIN,XMAX)
      IF (JFLG.GT.1) GO TO 210
      X=0.0
      RETURN
C     ENTRY FOR DENSITY(PP,HH)
C
      ENTRY PHDENS(PP,HH,K,RHO,RHOL,X,JFLG)
      ENTR='PHDENS'
      IF (PP.GT.PCRIT) GO TO 201
      CALL SPLNT(N,HSAT,PSATUR,EMPH,HH,PSAT)
      IF (PP.LT.PSAT) GO TO 280
  201 CALL HPROP(PP,HH,SV,H,3,2,C,JFLG,XMIN,XMAX)
      IF (JFLG.GT.1) GO TO 210
      RHO=1./C
      X=0.0
      RHOL=0.0
      RETURN
C     ENTRY FOR ENTROPY(PP,HH)
C
      ENTRY PHENTR(PP,HH,K,ENTRO,JFLG)
      ENTR='PHENTR'
      IF (PP.GT.PCRIT) GO TO 202
      CALL SPLNT(N,HSAT,PSATUR,EMPH,HH,PSAT)
      IF (PP.LT.PSAT) GO TO 290
  202 CALL HPROP(PP,HH,S,H,3,4,ENTRO,JFLG,XMIN,XMAX)
      IF (JFLG.GT.1) GO TO 210
  205 RETURN
  210 GO TO (205,120,130,240,250),JFLG
  240 WRITE (6,3000) XMIN,XMAX,HH,ENTR,K
 3000 FORMAT (' MINIMUM TABULATED ENTHALPY IS GREATER THAN H'/
     1' HMIN=',F10.4,5X,'HMAX=',F10.4,5X,'H=',F10.4,5X,A6,I2)
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  250 WRITE (6,3010) XMIN,XMAX,HH,ENTR,K
 3010 FORMAT (' MAXIMUM TABULATED ENTHALPY IS LESS THAN H'/
     1' HMIN=',F10.4,5X,'HMAX=',F10.4,5X,'H=',F10.4,5X,A6,I2)
      RETURN
  260 CALL SPLNT(N,PSATUR,HSAT,EMHLP,PP,HSATL)
      CALL SPLNT(N,PSATUR,HSATVP,EMHVP,PP,HSATV)
      CALL SPLNT(N,PSATUR,TSAT,EMTP,PP,TEMP)
      IF (HH.GT.HSATV) GO TO 270
      X=(HH-HSATL)/(HSATV-HSATL)
      RETURN
  270 WRITE (6,3020) PSAT,PP,HSATV,HH,ENTR,K
 3020 FORMAT (' P IS LESS THAN SAT. PRESS. CORRESPONDING TO H AND H IS G
     1REATER THAN H SATURATED VAPOR'/' PSAT=',F10.2,5X,'P=',F10.2,5X,
     2'HSATV=',F10.4,5X,'H=',F10.4,5X,A6,I2)
      JFLG=6
      RETURN
  280 CALL SPLNT(N,PSATUR,RHOSAT,EMROLP,PP,RHOL)
      CALL SPLNT(N,PSATUR,RHOSTV,EMROVP,PP,RHOV)
      CALL SPLNT(N,PSATUR,HSAT,EMHLP,PP,HSATL)
      CALL SPLNT(N,PSATUR,HSATVP,EMHVP,PP,HSATV)
      IF (HH.GT.HSATV) GO TO 270
      X=(HH-HSATL)/(HSATV-HSATL)
      RHO=RHOL*RHOV/(X*RHOL+ (1.-X)*RHOV)
      RETURN
  290 CALL SPLNT(N,PSATUR,SSAT,EMSLP,PP,SL)
      CALL SPLNT(N,PSATUR,SSATV,EMSVP,PP,SVP)
      CALL SPLNT(N,PSATUR,HSAT,EMHLP,PP,HSATL)
      CALL SPLNT(N,PSATUR,HSATVP,EMHVP,PP,HSATV)
      IF (HH.GT.HSATV) GO TO 270
      XS=(HH-HSATL)/(HSATV-HSATL)
      ENTRO=XS*SVP+(1.-XS)*SL
      RETURN
C     ENTRY FOR ENTHALPY(PP,SS)
C
      ENTRY PSENTH(PP,SS,K,ENTH,JFLG)
      ENTR='PSENTH'
      IF (PP.GT.PCRIT) GO TO 300
      CALL SPLNT(N,SSAT,PSATUR,EMPS,SS,PSAT)
      IF (PP.LT.PSAT) GO TO 360
  300 CALL HPROP(PP,SS,H,S,4,3,ENTH,JFLG,XMIN,XMAX)
      IF (JFLG.GT.1) GO TO 310
  305 RETURN
  310 GO TO (305,120,130,340,350), JFLG
  340 WRITE (6,4000) XMIN,XMAX,SS,ENTR,K
 4000 FORMAT (' MINIMUM TABULATED ENTROPY IS GREATER THAN S'/
     1' SMIN=',F10.5,5X,'SMAX=',F10.5,5X,'S=',F10.5,5X,A6,I2)
      RETURN
  350 WRITE (6,4010) XMIN,XMAX,SS,ENTR,K
 4010 FORMAT (' MAXIMUM TABULATED ENTROPY IS LESS THAN S'/
     1' SMIN=',F10.5,5X, 'SMAX=',F10.5,5X,'S=',F10.5,5X,A6,I2)
      RETURN
  360 CALL SPLNT(N,PSATUR,HSAT,EMHLP,PP,HSATL)
      CALL SPLNT(N,PSATUR,HSATVP,EMHVP,PP,HSATV)
      CALL SPLNT(N,PSATUR,SSAT,EMSLP,PP,SL)
      CALL SPLNT(N,PSATUR,SSATV,EMSVP,PP,SVP)
      IF (SS.GT.SVP) GO TO 370
      XS=(SS-SL)/(SVP-SL)
      ENTH=XS*HSATV+(1.-XS)*HSATL
      RETURN
  370 WRITE (6,4020) PSAT,PP,SVP,SS,ENTR,K
```

```
 4020 FORMAT (' P IS LESS THAN SAT. PRESS. CORRESPONDING TO S AND S IS G
     1REATER THAN S SATURATED VAPOR'/' PSAT=',F10.2,5X,'P=',F10.2,5X,
     2'SV=',F10.5,5X,'S=',F10.5,5X,A6,I2)
      JFLG=6
      RETURN
      END
C**** THIS SUBROUTINE READS IN THE HYDROGEN PROPERTIES DATA TO BE USED  FILE 001
C**** IN SUBROUTINE HPROP                                               FILE 002
C                                                                       FILE 003
      SUBROUTINE INPROP
      DIMENSION A(30)
      COMMON /PROP/ T(30,50),SV(30,50),H(30,50),S(30,50),NUM(30),P(30),
     1AA(5,90),RHOX(90),B(9,8)
   10 FORMAT (9F10.0)                                                   FILE 009
   20 FORMAT (25I3)                                                     FILE 010
C                                                                       FILE 011
C**** READ NUMBER OF DATA POINTS FOR EACH ISOBAR                        FILE 012
C                                                                       FILE 013
      READ (5,20) (NUM(I),I=1,30)
      DO 50 I=1,30
      M=NUM(I)                                                          FILE 016
C                                                                       FILE 017
C**** READ TEMPERATURES FOR ISOBAR I                                    FILE 018
C                                                                       FILE 019
      READ (5,10) (T(I,J),J=1,M)
C                                                                       FILE 021
C**** READ SPECIFIC VOLUMES FOR ISOBAR I                                FILE 022
C                                                                       FILE 023
      READ (5,10) (SV(I,J),J=1,M)
C                                                                       FILE 025
C**** READ ENTHALPYS FOR ISOBAR I                                       FILE 026
C                                                                       FILE 027
      READ (5,10) (H(I,J),J=1,M)
C                                                                       FILE 029
C**** READ ENTROPYS FOR ISOPAR I                                        FILE 030
C                                                                       FILE 031
   50 READ (5,10) (S(I,J),J=1,M)
C                                                                       FILE 037
C**** CONVERT PRESSURES FROM ATMOSPHERES TO PSIA                        FILE 038
C                                                                       FILE 039
      A(1)=1.                                                           FILE 040
      A(2)=1.5                                                          FILE 041
      DO 55 I=2,10                                                      FILE 042
   55 A(I+1)=I                                                          FILE 043
      A(12)=12.5                                                        FILE 044
      DO 60 I=1,8                                                       FILE 045
   60 A(I+12)=10+5*I                                                    FILE 046
      DO 65 I=1,5                                                       FILE 047
   65 A(I+20)=50+10*I                                                   FILE 048
      DO 70 I=1,5
   70 A(I+25)=100+20*I
      DO 80 I=1,30
   80 P(I)=14.696*A(I)                                                  FILE 050
   25 FORMAT (5E16.7)                                                   FILE 057
   30 FORMAT (10F8.4)                                                   FILE 058
   35 FORMAT (4E20.8)                                                   FILE 059
C                                                                       FILE 060
C**** READ EMPIRICAL COEFFICIENTS                                       FILE 061
C                                                                       FILE 062
      READ (5,25) ((AA(I,J),J=1,90),I=1,5)
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      READ (5,30) (RHOX(I),I=1,90)
      READ (5,35) ((B(I,J),J=1,8),I=1,9)
      RETURN                                                           FILE 066
      END
C**** SUBROUTINE HPROP ****                                             HPROP000
C**** THIS SUBROUTINE PROVIDES THE FOLLOWING HYDROGEN PROPERTIES DATA TOHPROP001
C**** THE MAIN PROGRAM:                                                 HPROP002
C**** SUCTION LINE SONIC VELOCITY AS A FUNCTION OF TEMPERATURE AND      HPROP003
C**** PRESSURE                                                          HPROP004
C**** INDUCER INLET SPECIFIC VOLUME AS A FUNCTION OF TEMPERATURE AND    HPROP005
C**** PRESSURE                                                          HPROP006
C**** PUMP INLET SPECIFIC VOLUME AS A FUNCTION OF TEMPERATURE AND       HPROP007
C**** PRESSURE                                                          HPROP008
C                                                                       HPROP009
      SUBROUTINE HPROP(A,B,Y,X,KJ,K,C,JFLG,XMIN,XMAX)
      DIMENSION X(30,50),Y(30,50),CP(2)
      COMMON /PROP/ T(30,50),SV(30,50),H(30,50),S(30,50),N(30),P(30),
     1AA(5,90),RHOX(90),D(9,8)
      COMMON /SAT/ HSAT(25),PSAT(25),TSAT(25),SSAT(25),RHOSAT(25),
     1EMPT(25),EMPS(25),EMTS(25),EMHS(25),EMRHOS(25),EMTP(25),
     2HSATV(25),SSATV(25),RHOSTV(25),EMHLP(25),EMHVP(25),EMSLP(25),
     3EMSVP(25),EMROLP(25),EMROVP(25),EMPH(25)
C                                                                       HPROP012
C**** P IS THE PRESSURE ARRAY                                           HPROP013
C**** X IS THE INDEPENDENT PROPERTY ARRAY                               HPROP014
C**** Y IS THE DEPENDENT PROPERTY ARRAY                                 HPROP015
C**** N IS THE OF DATA POINTS FOR EACH ISOBAR ARRAY                     HPROP016
C**** A IS PRESSURE                                                     HPROP017
C**** B IS THE SECOND INDEPENDENT VARIABLE                              HPROP018
C**** KJ DETERMINES THE INDEPENDENT PARAMETER USED                       HPROP019
C**** KJ=1,B IS TEMPERATURE                                             HPROP020
C**** KJ NOT=1,B IS SPECIFIC VOLUME,ENTHALPY,ENTROPY OR SONIC VELOCITY  HPROP021
C**** K DETERMINES THE DEPENDENT PARAMETER REQUESTED                    HPROP022
C**** K=1,C IS TEMPERATURE                                              HPROP023
C**** K=2,C IS SPECIFIC VOLUME                                          HPROP024
C**** K=3,C IS ENTHALPY                                                 HPROP025
C**** K=4,C IS ENTROPY                                                  HPROP026
C**** K=5,C IS SONIC VELOCITY                                           HPROP027
C**** C IS THE REQUESTED DEPENDENT PROPERTY                             HPROP028
C**** D IS THE ARRAY OF EMPIRICAL CONSTANTS USED IN THE SATURATED       HPROP029
C**** PRESSURE SUBPROGRAM SVSL                                          HPROP030
C                                                                       HPROP031
      NSAT=22                                                           HPROP032
      JFLG=1                                                            HPROP033
      I=0                                                               HPROP034
      LIMIT=0                                                           HPROP035
C                                                                       HPROP036
C**** SET XMIN=MINIMUM TABULATED PRESSURE                               HPROP037
C                                                                       HPROP038
      XMIN=P(1)                                                         HPROP039
C                                                                       HPROP040
C**** SET XMAX=MAXIMUM TABULATED PRESSURE                               HPROP041
C                                                                       HPROP042
      XMAX=P(25)                                                        HPROP043
   50 I=I+1                                                             HPROP044
C                                                                       HPROP045
C**** SEARCH PRESSURE TABLE FOR VALUE CORRESPONDING TO A                HPROP046
C                                                                       HPROP047
      IF(P(I)-A) 60,80,55                                               HPROP048
C
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C**** TABULATED PRESSURE IS GREATER THAN A,TEST FOR MINIMUM TABLE VALUE HPROP049
C                                                                       HPROP050
   55 IF (I-1) 200,200,150                                              HPROP051
C                                                                       HPROP052
C**** TABULATED PRESSURE IS LESS THAN A,TEST FOR MAXIMUM TABLE VALUE    HPROP053
C                                                                       HPROP054
   60 IF (I-25) 50,250,250                                              HPROP055
C                                                                       HPROP056
C**** TABULATED PRESSURE=A                                              HPROP057
C                                                                       HPROP058
   80 M=N(I)                                                            HPROP059
C                                                                       HPROP060
C**** SET XMIN=MINIMUM TABULATED INDEPENDENT PROP.                      HPROP061
C                                                                       HPROP062
      XMIN=X(I,1)                                                       HPROP063
C                                                                       HPROP064
C**** SET XMAX=MAXIMUM TABULATED INDEPENDENT PROP.                      HPROP065
C                                                                       HPROP066
      XMAX=X(I,M)                                                       HPROP067
      J=0                                                               HPROP068
   85 J=J+1                                                             HPROP069
C                                                                       HPROP070
C**** SEARCH INDEPENDENT PROPERTY TABLE FOR VALUE CORRESPONDING TO B    HPROP071
C                                                                       HPROP072
      IF (X(I,J)-B) 95,100,90                                           HPROP073
C                                                                       HPROP074
C**** TABULATED PROP. IS GREATER THAN B,TEST FOR MINIMUM TABLE VALUE    HPROP075
C                                                                       HPROP076
   90 IF (J-1) 300,300,110                                              HPROP077
C                                                                       HPROP078
C**** TABULATED PROP. IS LESS THAN B,TEST FOR MAXIMUM TABLE VALUE       HPROP079
C                                                                       HPROP080
   95 IF (J-M) 85,350,350
C                                                                       HPROP082
C**** TABULATED PROP=B,SET C=TABULATED VALUE                            HPROP083
C                                                                       HPROP084
  100 C=Y(I,J)                                                          HPROP085
      GO TO 500                                                         HPROP086
C                                                                       HPROP087
C**** INTERPOLATE ALONG ISOBAR I FOR C                                  HPROP088
C                                                                       HPROP089
  110 C=Y(I,J-1)+(B-X(I,J-1))/(X(I,J)-X(I,J-1))*(Y(I,J)-Y(I,J-1))       HPROP090
      GO TO 500                                                         HPROP091
C                                                                       HPROP092
C**** A LIES BETWEEN TWO TABULATED ISOBARS,INTERPOLATE ALONG EACH ISOBARHPROP093
C**** FOR PROPER B                                                      HPROP094
C                                                                       HPROP095
  150 NM=I-1                                                            HPROP096
      DO 160 IK=NM,I                                                    HPROP097
      M=N(IK)                                                           HPROP098
      JK=IK-I+2                                                         HPROP099
      J=0
C                                                                       HPROP101
C**** SET XMIN=MINIMUM TABULATED INDEPENDENT PROP.                      HPROP102
C                                                                       HPROP103
      XMIN=X(IK,1)                                                      HPROP104
C                                                                       HPROP105
C**** SET XMAX=MAXIMUM TABULATED INDEPENDENT PROP.                      HPROP106
C                                                                       HPROP107
      XMAX=X(IK,M)                                                      HPROP108
```

```
  155 J=J+1                                                                HPROP109
C                                                                          HPROP110
C**** SEARCH INDEPENDENT PROPERTY TABLE FOR VALUE CORRESPONDING TO B        HPROP111
C                                                                          HPROP112
      IF (X(IK,J)-B) 165,170,160                                           HPROP113
C                                                                          HPROP114
C**** TABULATED PROP. IS GREATER THAN B,TEST FOR MINIMUM TABLE VALUE       HPROP115
C                                                                          HPROP116
  160 IF (J-1) 300,300,550                                                 HPROP117
C                                                                          HPROP118
C**** TABULATED PROP. IS LESS THAN B,TEST FOR MAXIMUM TABLE VALUE          HPROP119
C                                                                          HPROP120
  165 IF (J-N(IK)) 155,510,510                                             HPROP121
C                                                                          HPROP122
C**** TABULATED VALUE=B,SET CP=TABULATED VALUE                             HPROP123
C                                                                          HPROP124
  170 CP(JK)=Y(IK,J)                                                       HPROP125
      GO TO 180                                                            HPROP126
C                                                                          HPROP127
C**** MAXIMUM TABULATED VALUE IS LESS THAN B,IF ISOBAR LESS THAN A SET     HPROP128
C**** LIMIT=1 AND CONTINUE,IF ISOBAR GREATER THAN A SET ERROR FLAG AND     HPROP129
C**** RETURN                                                               HPROP130
C                                                                          HPROP131
  510 IF (JK-1) 520,520,350                                                HPROP132
  520 LIMIT = 1                                                            HPROP133
      GO TO 180
C                                                                          HPROP135
C**** CHECK LIMIT SET=1                                                    HPROP136
C                                                                          HPROP137
  550 IF (LIMIT) 175,175,600                                               HPROP138
C                                                                          HPROP139
C**** LIMIT=0,NORMAL INTERPOLATION SEQUENCE ON ISOBAR                      HPROP140
C                                                                          HPROP141
  175 CP(JK)=Y(IK,J-1)+(B-X(IK,J-1))/(X(IK,J)-X(IK,J-1))*                  HPROP142
     1(Y(IK,J)-Y(IK,J-1))                                                  HPROP143
  180 CONTINUE                                                             HPROP144
C                                                                          HPROP145
C**** NORMAL INTERPOLATION FOR C                                           HPROP146
C                                                                          HPROP147
      C=CP(1)+(A-P(I-1))/(P(I)-P(I-1))*(CP(2)-CP(1))                       HPROP148
      GO TO 500                                                            HPROP149
C                                                                          HPROP150
C**** LIMIT=1,CHECK FOR TEMPERATURE AS INDEPENDENT PROPERTY                HPROP151
C                                                                          HPROP152
  600 IF (KJ.EQ.1) GO TO 610
      IF (KJ.EQ.3) GO TO 611
      IF (KJ.EQ.4) GO TO 612
      GO TO 350
C                                                                          HPROP154
C**** TEMPERATURE IS INDEPENDENT PROPERTY,FIND CORRESPONDING VAPOR         HPROP155
C**** PRESSURE                                                             HPROP156
C                                                                          HPROP157
  610 CALL SPLNT(NSAT,TSAT,PSAT,EMPT,B,PSL)
      GO TO 615
  611 CALL SPLNT(NSAT,HSAT,PSAT,EMPH,B,PSL)
      GO TO 615
  612 CALL SPLNT(NSAT,SSAT,PSAT,EMPS,B,PSL)
  615 GO TO (620,620,630,640,645),K                                        HPROP160
C                                                                          HPROP161
C**** FIND SATURATED LIQUID SPEC. VOL. CORRESPONDING TO TEMPERATURE=B
```

```
      C                                                                 HPROP162
  620 CALL SPLNT(NSAT,PSAT,RHOSAT,EMROLP,PSL,CP(2))
      CP(2)=1./CP(2)
      GO TO 650                                                         HPROP164
      C                                                                 HPROP165
      C**** FIND SATURATED LIQUID ENTHALPY CORRESPONDING TO TEMPERATURE=B HPROP166
      C                                                                 HPROP167
  630 CALL SPLNT(NSAT,PSAT,HSAT,EMHLP,PSL,CP(2))
      GO TO 650                                                         HPROP169
      C                                                                 HPROP170
      C**** FIND SATURATED LIQUID ENTROPY CORRESPONDING TO TEMPERATURE=B  HPROP171
      C                                                                 HPROP172
  640 CALL SPLNT(NSAT,PSAT,SSAT,EMSLP,PSL,CP(2))
      GO TO 650                                                         HPROP174
      C                                                                 HPROP175
      C**** SET SATURATED LIQUID SONIC VELOCITY                         HPROP176
      C                                                                 HPROP177
  645 CP(2)=3940.                                                       HPROP178
      C                                                                 HPROP179
      C**** INTEPOLATE FOR CP ON ISOBAR GREATER THAN A                  HPROP180
      C                                                                 HPROP181
  650 CP(1)=Y(I,J-1)+(B-X(I,J-1))*(Y(I,J)-Y(I,J-1))/(X(I,J)-X(I,J-1))  HPROP182
      C                                                                 HPROP183
      C**** INTEPOLATE FOR C USING SATURATED CONDITIONS                  HPROP184
      C                                                                 HPROP185
      C=CP(1)+(A-P(I))*(CP(2)-CP(1))/(PSL-P(I))                         HPROP186
      GO TO 500                                                         HPROP187
      C                                                                 HPROP188
      C**** MINIMUM TABULATED PRESSURE IS GREATER THAN A,SET ERROR FLAG  HPROP189
      C                                                                 HPROP190
  200 JFLG=2                                                            HPROP191
      GO TO 500                                                         HPROP192
      C                                                                 HPROP193
      C**** MAXIMUM TABULATED PRESSURE IS LESS THAN A,SET ERROR FLAG     HPROP194
      C                                                                 HPROP195
  250 JFLG=3                                                            HPROP196
      GO TO 500                                                         HPROP197
      C                                                                 HPROP198
      C**** MINIMUM TABULATED INDEPENDENT PROP. IS GREATER THAN B,SET ERROR HPROP199
      C**** FLAG                                                        HPROP200
      C                                                                 HPROP201
  300 JFLG=4                                                            HPROP202
      GO TO 500                                                         HPROP203
      C                                                                 HPROP204
      C**** MAXIMUM TABULATED INDEPENDENT PROP. IS LESS THAN B,SET ERROR FLAG HPROP205
      C                                                                 HPROP206
  350 JFLG=5                                                            HPROP207
  500 RETURN                                                            HPROP208
      END                                                               HPROP20
      NTAB$  10
      TAPE 1,'B'    . KEN KIRK 'S TAPE
      TAPE 2,'K'    . OUTPUT TAPE FOR KIRK.
      READ 5
      PRINT 6
      END
```

2. 11:08:28

END CUR

```
<***Δ****1****Δ****2****Δ****3****Δ****4****Δ****5****Δ****6****Δ****7****Δ****8****Δ****9****Δ****0****Δ****1****Δ****2****Δ****3*>
******************************************ISD-27.10:INFORMATION-SYSTEMS-DESIGN:05-APR-1972*****************************************
***Δ***1***Δ***2***Δ***3***Δ***4***Δ***5***Δ***6***Δ***7***Δ***0***Δ***1***Δ***2***Δ***3***Δ***4***Δ***5***Δ***6***Δ***7***Δ***0***Δ
[ ]#Δ ABCDEFGHIJKLMNOPQRSTUVWXYZ)-+<=>&$*(%:?!,\0123456789';/.\ @[ ]#Δ ABCDEFGHIJKLMNOPQRSTUVWXYZ)-+<=>&$*(%:?!,\0123456789';/.\ @[ ]#Δ
```


```
05 APR 72 P 11:08:28   IDENT=TAD     ACCOUNT=428249  CARDS IN= 2085, OUT=     0

PAGES=   37, LINES=  2125, TIME=00:00:09 (HMS)
```


***   USER NOTICES   -   APRIL 5, 1972   ***

(1) ISD 1108 TERMINAL SERVICE IS SCHEDULED AS FOLLOWS

```
MON :          07:00 - 24:00
TUE - FRI :    00:00 - 04:00 ;  07:00 - 24:00
SAT :          00:00 - 22:00
SUN :          04:00 - 22:00
```

(2) LARGE-CORE (LCR) PRODUCTION JOBS ARE NOW BEING RUN ON AN OVERNIGHT BASIS STARTING AT 04:00 EACH DAY.

(3) ISD NOW HAS AVAILABLE REMOTE-BATCH JOB ENTRY VIA LOW-SPEED TELETYPE COMPATIBLE TERMINALS USING DIAL-UP COMMUNICATION LINES.
THIS SERVICE HAS BEEN IN USE FOR OVER TWO MONTHS AND IS CALLED RON/I.
THE DIAL-UP TELEPHONE NUMBERS AND TRANSMISSION RATES ARE LISTED BELOW.

```
415-562-4035     10 CHAR/SEC
415-562-4036     10 CHAR/SEC
415-562-5186     10 CHAR/SEC
415-562-4176     30 CHAR/SEC
```

***   NOTE   ***
BY APRIL 6, 1972 PARITY CHECKING ON RON/I INPUT WILL NOT BE DONE AUTOMATICALLY.
USE OF THE @@PN KEYIN WILL TURN PARITY CHECKING ON.

ADDITIONAL INFORMATION ON (2) & (3) IS NOW AVAILABLE TO ALL INTERESTED USERS BY CONTACTING YOUR SALESMAN AT 415-562-4204.

12. AXIAL BLADE DESIGN PROGRAM

AXIAL BLADE DESIGN PROGRAM

1. INTRODUCTION

a. A computer program has been developed to assist in defining the blade profiles for axial machines. Given basic blade data such as inlet and discharge angles, leading and trailing edge radii, aspect ratio, and thickness to chord ratio; a profile can be developed using this program which minimizes local fluid acceleration on the blade surface.

b. Included is a listing of the program with a brief description of its application. A complete description of the analysis associated with this program appears in the NERVA Turbopump Design Report, N8300R:71-076.

c. The program is complete and was used to develop the NERVA turbine blade profiles.

d. This program is applicable as long as the turbine remains axial flow.

e. No related activities.

f. This program was developed by K. G. Kirk.

2. CONCLUSIONS

a. Gross Conclusions

(1) This program was used successfully to develop the blade profiles for the NERVA Turbine. The program also provides the data necessary for defining the blade profiles in a plane normal to a stacking line and the data used in velocity distribution calculations.

(2) The program is complete in its present form.

3. RECOMMENDATIONS

a. Achieving a satisfactory blade with this program requires an iterative process. A set of spline points are selected, the surface is spline fit and checked, spline points are adjusted as needed and the process is repeated until a satisfactory blade profile is obtained. With some programming effort this iterative process could be done within the program, resulting in considerable savings in time and effort.

b. The program can be used to supply digital data alone, or digital data and punched output which serves as input to a section property program, velocity distribution program, and blade stacking program. In addition, it is recommended that the program be used with the plot option if a plotter is available.

@ ELT CDIN1,1,720519, 31505

```
      SUBROUTINE CDIN1 (LREC,TITLE,XC,YC)
      DIMENSION LREC(6),X(2),Y(2),TITLE(20),XC(1000,2),YC(1000,2)
   10 FORMAT (4E20.9)
   20 FORMAT (20A4)
   30 FORMAT (I5)
      LREC(J)=N
      READ (5,20) TITLE
      DO 100 J=1,2
      READ (5,30) N
      READ (5,10) (XC(I,J),YC(I,J),I=1,N)
  100 CONTINUE
      RETURN
      END
```

AXIAL BLADE DESIGN PROGRAM

@ ELT CDOUT,1,720519, 31498

```
      SUBROUTINE CDOUT(LREC,TITLE,XC,YC)
      DIMENSION LREC(6),XX(2),YY(2),TITLE(20),XC(1000,2),YC(1000,2)
   10 FORMAT (4E20.9)
   20 FORMAT (20A4)
   30 FORMAT (I5)
      WRITE (2,20) TITLE
      DO 50 J=1,2
      N=LREC(J)
      WRITE (2,30) N
      ICONT=0
      DO 50 I=1,N
      ICONT=ICONT+1
      X=XC(I,J)
      Y=YC(I,J)
      XX(ICONT)=X
      YY(ICONT)=Y
      IF (ICONT-2) 35,40,40
   35 IF (I-N) 50,40,40
   40 WRITE (2,10) (XX(K),YY(K),K=1,ICONT)
      ICONT=0
   50 CONTINUE
      RETURN
      END
```

@ ELT CPLOT,1,720519, 31516

```
      SUBROUTINE CPLOT (ARGX,ARGY,INARG)
C THE ARRAY A IS THE DATA STORAGE CONTAINING 50 PLOT CURVES EACH WITH A
C MAXIMUM OF 50 X-Y PAIRS.  NP DEFINES NUMBER OF DATA PAIRS PER CURVE.
      COMMON /SPLFIT/
     1       G(100),SB(100),EM(50),SLOPE(50),CURV(50),X(50),Y(50)
      COMMON /DATA/ A(2,50,50), NP(51)
      DIMENSION ARGX(1000,6), ARGY(1000,6), INARG(6)
      DIMENSION Z(1000),YINT(1000)
      DIMENSION XTITL(10),TITLES(10)
      DIMENSION AYLEN(5),YMIN(5),YMAX(5),NYSTRT(5),NYSCAL(5),NYSIZE(5)
     1,NYFRAC(5),YTITL(10,5)
C THESE CELLS TO BE USED BY SPLINE CURVE FIT
C ***
C THE PLOT ROUTINE READS INPUT CARDS FOR PLOT SETUP AND CONTROL
    1 FORMAT (I2,I1)
 2    FORMAT (I2, 3F9.0, 3I3, I2, 6A6,A4 )
C READ CARD 00
    3 READ (5,1) ID, NYAXIS
      IF (ID.NE.0) GO TO 999
      IF (NYAXIS.GT.5) GO TO 999
C READ CARD 01 FOR X-AXIS CONTROL
      READ (5,2) ID,AXLEN,XMIN,XMAX,NXSTRT,NXSCAL,NXSIZE,NXFRAC
     1  ,(XTITL(J),  J=1,7)
      IF (ID.NE.1) GO TO 999
      IF (NXSIZE.EQ.0) NXSIZE = 2
C READ CARDS 02 FOR Y-AXIS CONTROL
      DO 10 I=1,NYAXIS
      READ (5,2) ID,AYLEN(I),YMIN(I),YMAX(I),NYSTRT(I),NYSCAL(I)
     1  ,NYSIZE(I), NYFRAC(I), (YTITL(J,I), J=1,7)
      IF (ID.NE.2) GO TO 999
      IF (NYSIZE(I).EQ.0) NYSIZE(I) = 2
   10 CONTINUE
C COMPUTE PRELIMINARY CONTROL FOR SETUP OF X AND Y AXIS
C SET UP THE X-AXIS AND THE BASIC Y-AXIS
      IF(NXSTRT.EQ.0)          NXSTRT=50
C X-AXIS UP 1 INCH ON PLOT
      IF (NYSTRT(1).EQ.0) NYSTRT(1) = 500
C Y-AXIS STARTS 3 INCHES FROM MARGIN ON DEFAULT
C COMPUTE PRELIMINARY CONTROL FOR SETUP OF X AND Y AXIS
      XLABLD = (XMAX - XMIN) / AXLEN
      YLABLD = (YMAX(1) - YMIN(1)) / AYLEN(1)
      NXLINE = NXSTRT - 25
      NYLINE = NYSTRT(1)
      MAXX=IFIX(100.*AXLEN)+NYSTRT(1)
      MAXY=IFIX(100.*AYLEN(1))+NXSTRT
      CALL PLTSU  (0,XMIN,YMIN(1),NYSTRT(1),NXSTRT,XLABLD,YLABLD,100,100
     1,NXFRAC,NYFRAC(1),NXLINE,NYLINE,MAXX,MAXY,NXSCAL,NYSCAL(1))
      NXBEGN = NYSTRT(1) + (100 * IFIX(AXLEN)) / 2 - 320
      CALL PLTBC (XTITL,40,NXBEGN,NXLINE-35,NXSIZE,0)
C HORIZONTAL AXIS NOW LABELED
      NYBEGN = NXSTRT + (100 * IFIX(AYLEN(1))) / 2 - 320
      NXBEGN = NYLINE-60
      CALL PLTBC (YTITL(1,1),40,NXBEGN,NYBEGN,NYSIZE(1),1)
C BASIC Y AXIS NOW COMPLETED
      NCODE = 1
      ZMAX = AYLEN(1)
```

```
      IF (NYAXIS.EQ.1) GO TO 21
C SET UP SECONDARY Y AXIS
      DO 20 I=2,NYAXIS
      MAXY=IFIX(100.*AYLEN(I))+NXSTRT
      IF (AYLEN(I).GT.ZMAX) ZMAX = AYLEN(I)
      IF (NYSTRT(I).EQ.0) NYSTRT(I) = NYSTRT(I-1) - 100
      YLABLD = (YMAX(I) - YMIN(I)) / AYLEN(I)
      NYLINE = NYSTRT(I)
      CALL PLTSU  (1,XMIN,YMIN(I),NYSTRT(I),NXSTRT,XLABLD,YLABLD,100,100
     1,NXFRAC,NYFRAC(I),0,NYLINE,MAXX,MAXY,NXSCAL,NYSCAL(I))
      NXBEGN = NYLINE - 60
      NYBEGN = NXSTRT + (100 * IFIX(AYLEN(I))) / 2 - 320
      CALL PLTBC (YTITL(1,I),40,NXBEGN,NYBEGN,NYSIZE(I),1)
   20 NCODE = I
   21 CONTINUE
      MAXY = IFIX(100. * ZMAX) + NXSTRT
C SET UP FOR TEST OF LAST POSITION OF THE PEN
      XCOD = 0.
      YCOD = 0.
      MARG = 0
   30 READ (5,31,END=201)
     1          ID,NFILE,NAXIS,LFIT,LPRINT,LARGPL,NSYMBL,INTV,LINE
     1 ,XSTART, YSTART, (TITLES(K),  K=1,7)
   31 FORMAT (2I2, 4I1, 2I3, I1, T21, 2F10.0,  6A6, A4 )
      IF (ID.NE.3) GO TO 100
      IF (NFILE.GT.50) GO TO 98
      IF (NAXIS.GT.NYAXIS) GO TO 98
      IF (LARGPL.GT.6) GO TO 98
C     IF(NSYMBL.EQ.0)       NSYMBL=64
C GO TO PLOT THE DATA GIVEN THROUGH THE ARGUMENT TO CPLOT
      N = NP(NFILE)
      IF (NAXIS.EQ.NCODE) GO TO 40
      I = NAXIS
      NCODE = NAXIS
      YLABLD = (YMAX(I) - YMIN(I)) / AYLEN(I)
      CALL PLTSU  (1,XMIN,YMIN(I),NYSTRT(1),NXSTRT,XLABLD,YLABLD,100,100
     1,NXFRAC,NYFRAC(I),0,0,MAXX,MAXY,NXSCAL,NYSCAL(I))
   40 IF (LARGPL.NE.0) GO TO 90
      IF (LFIT.EQ.0) GO TO 80
      DO 41 J=1,N
      X(J) = A(1,J,NFILE)
      Y(J) = A(2,J,NFILE)
   41 CONTINUE
      CALL SPLINE (N,LPRINT)
      XMIND = .05 * XLABLD
      DELTAX = (X(N) - X(1)) / 999.
      IF (DELTAX.LT.XMIND) DELTAX = XMIND
      MAX = IFIX( (X(N) - X(1)) / DELTAX ) + 1
      M = MAX - 1
      Z(1) = X(1)
      Z(MAX) = X(N)
      DO 42 L=2,M
   42 Z(L) = Z(L-1) + DELTAX
      CALL SPLINT (N,Z,YINT,MAX)
      R1 = (XCOD - Z(1))**2 + (YCOD - YINT(1))**2
      R2 = (XCOD - Z(MAX))**2 + (YCOD - YINT(MAX))**2
      IF (R1.GT.R2) GO TO 43
      YCOD = Z(MAX)
      YCOD = YINT(MAX)
      LOC = 1
```

```
      INC = 4
      GO TO 44
   43 XCOD = Z(1)
      YCOD = YINT(1)
      LOC = MAX
      INC = -4
   44 CALL PLTPT (LINE,MAX,INC,INC,NSYMBL,INTV,Z(LOC),YINT(LOC))
      GO TO 30
C PLOT THE DATA FROM RAW POINTS
   80 R1 = (XCOD - A(1,1,NFILE))**2 + (YCOD - A(2,1,NFILE))**2
      R2 = (XCOD - A(1,N,NFILE))**2 + (YCOD - A(2,N,NFILE))**2
      IF (R1.GT.R2) GO TO 81
      XCOD = A(1,N,NFILE)
      YCOD = A(2,N,NFILE)
      LOC = 1
      INC = 8
      GO TO 82
   81 XCOD = A(1,1,NFILE)
      YCOD = A(2,1,NFILE)
      LOC = N
      INC = -8
   82 CALL PLTPT (LINE,N,INC,INC,NSYMBL,INTV,
     1 A(1,LOC,NFILE),A(2,LOC,NFILE))
      GO TO 30
C PLOT FROM THE ARGUMENT TO CPLOT
      ENTRY CPLOT1 (ARGX,ARGY,INARG)
   90 K = LARGPL
      NARG = INARG(K)
      IF (NARG.GT.1000) GO TO 98
      R1 = (XCOD - ARGX(1,K))**2 + (YCOD - ARGY(1,K))**2
      R2 = (XCOD - ARGX(NARG,K))**2 + (YCOD - ARGY(NARG,K))**2
      IF (R1.GT.R2) GO TO 91
      XCOD = ARGX(NARG,K)
      YCOD = ARGY(NARG,K)
      LOC = 1
      INC = 4
      GO TO 92
   91 XCOD = ARGX(1,K)
      YCOD = ARGY(1,K)
      LOC = NARG
      INC = -4
   92 WRITE (6,1000) LINE,NARG,INC,INC,NSYMBL,INTV,(ARGX(IK,K),ARGY(IK,K
     1),IK=1,NARG)
 1000 FORMAT ('1    ENTRY PLTPT'/6I5/(2E20.6))
      CALL PLTPT (LINE,NARG,INC,INC,NSYMBL,INTV
     1,ARGX(LOC,K),ARGY(LOC,K))
      GO TO 30
   98 WRITE (6,99) NFILE,NAXIS,LARGPL,NARG
   99 FORMAT (' CHECK ONE OF THE FOLLOWING INPUT ON 03 CARD. NFILE=',I2,
     1' NAXIS=',I1,' LARGPL=',I1,' NARG=',I4)
      GO TO 30
C PLOT THE TITLES FROM THE 04 AND 05 CARDS
  100 NXBEGN = NYSTRT(1) + (100 * IFIX(AXLEN)) / 2 - 320
  101 IF ((ID.NE.4).AND.(ID.NE.5) ) GO TO 200
      IF (XSTART.NE.0.) NXBEGN = IFIX(XSTART)
      IF (YSTART.NE.0.) MAXY = IFIX(YSTART)
      IF (ID.EQ.4) MAXY = MAXY - 31
      IF (ID.EQ.5) MAXY = MAXY - 24
      ISIZE = 7 - ID
      CALL PLTBC (TITLES,40,NXBEGN,MAXY,ISIZE,0)
```

```
      READ (5,102,END=201)
     1   ID,XSTART,YSTART, (TITLES(K), K=1,7)
  102 FORMAT (I2, 18X, 2F10.0, 6A6, A4)
      GO TO 101
  200 IF (ID.EQ.88) GO TO 3
      IF (ID.EQ.77) RETURN
  201 CALL PLTFIN
      RETURN
  999 WRITE (6,998) ID
  998 FORMAT (' THE CARD WITH ID OF ',I2,' WAS ENCOUNTERED UNEXPECTEDLY,
     1 ID OF 0,1 OR 2 WAS EXPECTED')
      RETURN
      END
```

@ ELT INPUT,1,720519, 31500

```
      SUBROUTINE INPUT (NUM,DELX,IFLAG)
      INTEGER SURF
      DIMENSION NUM(2),IFLAG(14)
      COMMON /SPLFIT/ G(100),SB(100),EM(50),SLOPE(50),CURV(50),X(50),
     1Y(50)
      COMMON IM,ID,IY,TITLE(20),DATA(28),XB(2,25),YB(2,25),NBL,NBBI
      EQUIVALENCE (DATA(1),GAM),(DATA(2),AR),(DATA(3),T1P),(DATA(4),
     1RHOIP),(DATA(5),WTFL),(DATA(6),OMEGA),(DATA(7),ORF),(DATA(8),
     2BETI ),(DATA(9),BETO ),(DATA(10),CHORD),(DATA(11),STGR),
     3(DATA(12),REDFA),(DATA(13),DENTO),(DATA(14),RI1),(DATA(15),RO1),
     4(DATA(16),BETI1),(DATA(17),BETO1),(DATA(18),DUMY1),(DATA(19),RI2),
     5(DATA(20),RO2),(DATA(21),BETI2),(DATA(22),BETO2),(DATA(23),DUMY2)
      EQUIVALENCE (DATA(24),P0),(DATA(25),W ),(DATA(26),
     1RAD),(DATA(27),CP),(DATA(28),W2)
    5 FORMAT (3A2,4X,14I5)
    6 FORMAT (20A4)
   20 FORMAT (8F10.0/8F10.0/3F10.0,2I5)
   30 FORMAT (I5,4F10.0)
   40 FORMAT (8F10.0)
   60 FORMAT (4X, 'GAM' ,9X,'CP',8X,'R',7X,'SPEED',7X,'W',8X,'TTI',7X,
     1'PTI',7X,'BETAI',4X,'BETAO',6X,'WX',7X,'RADIUS',4X,'W2' /13X,
     2'BTU/LB-R',2X,'FT/DEG-R',4X,'RPM',6X,'LB/SEC',4X,'DEG-R',6X,'PSIA'
     3,7X,'DEG',6X,'DEG',6X,'FT/SEC',6X,'IN',4X,'FT/SEC'/14X,'LB/FT3',5X
     4,'IN',9X,'IN',8X,'IN'/)
   61 FORMAT (F9.3,F11.3,5F10.1,2F10.2,F10.1,F10.4,F10.1/)
   65 FORMAT(3X,'REDFAC',5X,'DENTOL',4X,'CHORD',6X,'STGR',6X,'DELX',6X,
     1'SCALE',5X,'ORF',6X,'NBL',7X,'NBBI'/14X,'LB/FT3',5X,'IN',9X,'IN'
     2,8X,'IN'/)
   66 FORMAT (F8.3,F12.4,2F10.4,F9.3,F10.4,F10.5,I9,I10/)
   70 FORMAT (44X 'BLADE COORDINATES, SURFACE ',I1  /6X,5('X',9X,'Y',9X)
     1,'X',9X,'Y'/)
   71 FORMAT (12F10.6)
   75 FORMAT (5X,'RI',9X,'RO',6X,'BETAI',5X,'BETAO'/5X,'IN',9X,'IN',7X,
     1'DEG',7X,'DEG'/)
   76 FORMAT (2F10.4,2F10.2)
 1000 FORMAT ('1DATE ',A2,'-',A2,'-',A2,36X,'BLADE PROFILE PROGRAM'/)
 1005 FORMAT (1X,20A4/)
 1020 FORMAT (56X,'INPUT DATA'/)
      READ (5,5)IM,ID,IY,IFLAG
      IF (IFLAG(10)) 200,78,200
   78 IF (IFLAG(11)) 200,79,200
   79 WRITE (6,1000) IM,ID,IY
      READ (5,6) TITLE
      WRITE (6,1005) TITLE
      WRITE (6,1020)
      READ (5,20) GAM,CP,AR,OMEGA,WTFL,T1P,P0,BETI ,BETO ,W,W2,RAD,ORF,
     1REDFA,DENTO,CHORD,STGR,DELX,SCALE,NBL,NBBI
      IF (SCALE) 300,300,310
  300 SCALE=1.0
  310 WRITE (6,60)
      WRITE (6,61) GAM,CP,AR,OMEGA,WTFL,T1P,P0,BETI ,BETO ,W ,RAD,W2
      WRITE (6,65)
      WRITE (6,66) REDFA,DENTO,CHORD,STGR,DELX,SCALE,ORF,NBL,NBBI
      STGR=STGR*SCALE
      CHORD=CHORD*SCALE
      DO 100 SURF=1,2
```

```
      READ (5,30) NUM(SURF),RI,RO,BETAI,BETAO
      IF (SURF-1) 80,80,90
   80 RI1=RI*SCALE
      RO1=RO*SCALE
      BETI1=BETAI
      BETO1=BETAO
      GO TO 95
   90 RI2=RI*SCALE
      RO2=RO*SCALE
      BETI2=BETAI
      BETO2=BETAO
   95 NM1=NUM(SURF)-1
      READ (5,40) (X(I),Y(I),I=2,NM1)
      DO 150 I=2,NM1
      XB(SURF,I)=X(I)*SCALE
  150 YB(SURF,I)=Y(I)*SCALE
      WRITE (6,70) SURF
      WRITE (6,71) (X(I), Y(I), I=2,NM1)
      WRITE (6,75)
  100 WRITE (6,76) RI,RO,BETAI,BETAO
  200 RETURN
      END
```

@ ELT MAIN,1,720519, 31485

```
      INTEGER SURF
      DIMENSION Z(500 ),LREC(6),NUM(2),DATA(28),XB(2,25),YB(2,25),
     1IFLAG(14),XC(1000,2),YC(1000,2),SLO(1000,2),RCURVE(1000,2),
     2XSH(1000,2),YSH(1000,2),XST(1000,2),YST(1000,2),SLENTH(2),
     3ARGX(6000),ARGY(6000)
      COMMON /SPLFIT/ G(100),SB(100),EM(50),SLOPE(50),CURV(50),X(50),
     1Y(50)
      COMMON IM,ID,IY,TITLE(20),DATA,XB,YB,NBL,NBBI
      EQUIVALENCE (DATA(1),GAM),(DATA(2),AR),(DATA(3),T1P),(DATA(4),
     1RHOIP),(DATA(5),WTFL),(DATA(6),OMEGA),(DATA(7),ORF),(DATA(8),
     2BETI ),(DATA(9),BETO ),(DATA(10),CHORD),(DATA(11),STGR),
     3(DATA(12),REDFA),(DATA(13),DENTO),(DATA(14),RI1),(DATA(15),RO1),
     4(DATA(16),BETI1),(DATA(17),BETO1),(DATA(18),DUMY1),(DATA(19),RI2),
     5(DATA(20),RO2),(DATA(21),BETI2),(DATA(22),BETO2),(DATA(23),DUMY2)
      EQUIVALENCE (DATA(24),PO),(DATA(25),WX),(DATA(26),
     1RAD),(DATA(27),CP),(DATA(28),W2)
      EQUIVALENCE (ARGX(1),XC(1,1),XST(1,1))
      EQUIVALENCE (ARGX(2001),XSH(1,1))
      EQUIVALENCE (ARGY(1),YC(1,1),YST(1,1))
      EQUIVALENCE (ARGY(2001),YSH(1,1))
      EQUIVALENCE (ARGY(4001),RCURVE(1,1))
   10 FORMAT (//' SURFACE LENGTH=',F10.3)
      CALL ERRSET(259,300,-1,0,0,0)
      ISTK=0
   50 CALL INPUT (NUM,DELX,IFLAG)
      IF (IFLAG(10)) 60,65,60
   60 CALL CDIN1 (LREC,TITLE,XC,YC)
      GO TO 659
   65 IF (IFLAG(11)) 70,75,70
   70 CALL CDIN1 (LREC,TITLE,XC,YC)
      GO TO 651
   75 DUMY1=0.0
      DUMY2=0.0
      RHOIP=0.0
      JFLAG=0
      KFLAG=0
      N1=NUM(1)
      N2=NUM(2)
      BETAI=BETI1/57.295779
      CALL XYI (BETAI,RI1,1.,XB(1,1),YB(1,1),DYDX)
      BETAI=BETI2/57.295779
      CALL XYI (BETAI,RI2,-1.,XB(2,1),YB(2,1),DYDX)
      BETAO=BETO1/57.295779
      CALL XYO (BETAO,RO1,CHORD,STGR,1.,XB(1,N1),YB(1,N1),DYDX)
      BETAO=BETO2/57.295779
      CALL XYO (BETAO,RO2,CHORD,STGR,-1.,XB(2,N2),YB(2,N2),DYDX)
      DO 650 SURF=1,2
      LFLAG=0
      NM1=NUM(SURF)-1
      N=NUM(SURF)
      IF (SURF-1) 80,80,90
   80 L=1
      RI=RI1
      RO=RO1
      BETAI=BETI1
      BETAO=BETO1
```

```
      GO TO 95
   90 L=2
      RI=RI2
      RO=RO2
      BETAI=BETI2
      BETAO=BETO2
   95 BETAI=BETAI/57.295779
      BETAO=BETAO/57.295779
      SLOPI=TAN(BETAI)
      SLOPO=TAN(BETAO)
   96 IF (L-1) 110,100,110
  100 SIGN=1.
      GO TO 150
  110 SIGN=-1.
  150 DO 160 I=1,N
      X(I)=XB(SURF,I)
  160 Y(I)=YB(SURF,I)
      SLENTH(SURF)=RI*(1.570795-SIGN*BETAI)
      IF (SURF-1) 170,170,410
  170 DTHET=0.001*SIGN/RI
      THETA=3.14159*SIGN/2.
      S=0.0
      T=0.0
      XC(1,SURF)=S
      YC(1,SURF)=T
      RCURVE(1,SURF)=RI
      SLO(1,SURF)=1.0E50*SIGN
      I=1
  200 I=I+1
      THETA=THETA-DTHET
      CALL XYI (THETA,RI,SIGN,S,T,DYDX)
      IF (JFLAG) 210,210,240
  210 IF (S-XB(2,1)) 240,240,220
  220 JFLAG=1
      S=XB(2,1)
      T=SQRT(RI**2-ABS(S-RI)**2)
  240 IF(S-X(1)) 250,300,300
  250 XC(I,SURF)=S
      YC(I,SURF)=T
      RCURVE(I,SURF)=RI
      SLO(I,SURF)=DYDX
      J=I
      GO TO 200
  300 I=1
      Z(1)=X(1)
      IF (JFLAG) 360,360,350
  350 I=I+1
      Z(I)=Z(I-1)+DELX
      IF (Z(I)-XB(1,N1)) 370,375,375
  370 IF (Z(I)-XB(2,N2)) 350,380,380
  375 Z(I)=XB(1,N1)
      GO TO 490
  380 KFLAG=1
      Z(I)=XB(2,N2)
      THETA=-BETO2/57.295779
      DTHET=0.001*SIGN/RO
  385 I=I+1
      THETA=THETA-DTHET
      CALL XYO(THETA,RO,CHORD,STGR,SIGN,S,T,DYDX)
      IF (S-XB(1,N1)) 390,375,375
```

```
  390 Z(I)=S
      GO TO 385
  360 I=I+1
      CALL XYI (THETA,RI,SIGN,S,T,DYDX)
      IF (S-XB(2,1)) 361,365,365
  361 Z(I)=S
      THETA=THETA-DTHET
      GO TO 360
  365 Z(I)=XB(2,1)
      GO TO 350
  410 IRM1=0
      I=0
  412 IRM1=IRM1+1
      S=XC(IRM1,1)
      T=YC(IRM1,1)
      DYDX=SLO(IRM1,1)
      IF (JFLAG) 415,415,430
  415 IF (S-XB(1,1)) 420,420,430
  420 T=-T
      DYDX=-DYDX
  425 XC(IRM1,SURF)=S
      YC(IRM1,SURF)=T
      RCURVE(IRM1,SURF)=RI
      SLO(IRM1,SURF)=DYDX
      J=IRM1
      GO TO 412
  430 IF (S-XB(2,1)) 440,450,460
  440 T=-SQRT(RI**2-ABS(S-RI)**2)
      IF (T) 442,441,442
  441 DYDX=1.0E50*SIGN
      GO TO 425
  442 DYDX=(RI-S)/T
      GO TO 425
  450 I=I+1
      Z(I)=S
      GO TO 412
  460 IF (S-XB(2,N2)) 450,450,490
  490 CALL SPLN2 (N,SURF,SLOPI,SLOPO)
      CALL SPLNT (N,SURF,Z,J,I,L,LREC,XC,YC,SLO,RCURVE,SLENTH)
      SLENTH(SURF)=SLENTH(SURF)+RO*(1.570795+SIGN*BETAO)
      WRITE (6,10) SLENTH(SURF)
      THETA=BETAO
      DTHET=0.001*SIGN/RO
      M=0
  500 J=J+1
      THETA=THETA-DTHET
      IF (SIGN*THETA+3.14159/2.) 550,600,600
  550 THETA=-SIGN*3.14159/2.
      M=1
  600 CALL XYO(THETA,RO,CHORD,STGR,SIGN,S,T,DYDX)
      IF (LFLAG) 601,601,624
  601 IF (SURF-1) 602,602,605
  602 IF (KFLAG) 603,603,624
  603 IF (S-XB(2,N2)) 624,624,604
  604 THETA=-BETO2/57.295779
      LFLAG=1
      GO TO 600
  605 IF (KFLAG) 624,624,606
  606 IF(S-XB(1,N1)) 624,624,607
  607 THETA=-BETO1/57.295779
```

```
      LFLAG=1
      GO TO 600
  624 XC(J,SURF)=S
      YC(J,SURF)=T
      RCURVE(J,SURF)=RO
      SLO(J,SURF)=DYDX
      IF (M) 625,500,625
  625 LREC(L)=J
      LREC(L+4)=J
      DO 640 LOC=1,J
      LOCA=LOC+1000*(SURF+3)
  640 ARGX(LOCA)=XC(LOC,SURF)
  650 CONTINUE
      IF (IFLAG(9)) 654,658,654
  654 CALL CDOUT (LREC,TITLE,XC,YC)
  658 IF (IFLAG(8)) 651,659,651
  651 IF (ISTK) 653,652,653
  652 ISTK=1
      CALL STAK(1,RAD,LREC,XHT,YHT,YCENT,TITLE,IM,ID,IY,
     1XTRAN,YTRAN,XC,YC,XSH,YSH,XST,YST)
      GO TO 50
  653 CALL STAK(2,RAD,LREC,XHT,YHT,YCENT,TITLE,IM,ID,IY,
     1XTRAN,YTRAN,XC,YC,XSH,YSH,XST,YST)
  659 IF (IFLAG(5)) 660,670,660
  660 IF (IFLAG(6)) 661,665,661
  661 PITCH=2.*3.14159*RAD/NBL
      CALL OFSET (LREC,PITCH,XC,YC,ARGX,ARGY)
  665 CALL CPLOT (ARGX,ARGY,LREC)
  670 IF (IFLAG(2)) 730,760,730
  730 CALL VELIN(NUM)
  760 IF(IFLAG(7)) 761,765,761
  761 CALL SECIN(LREC(1),N1,N2,IM,ID,IY,TITLE,XB,DELX,XC,YC)
  765 IF (IFLAG(1)) 50,800,50
  800 STOP
      END
```

```
@ ELT NTAB$,1,720519, 31518
000001    NTAB$ 10 [illegible]
000002    TAPE 9,'K[illegible] PLOTXTAPE.
000003    READ 5 [illegible]
000004    PRINT 6 [illegible]
000005    END [illegible]
```

@ ELT OFSET,1,720519,31492

```
      SUBROUTINE OFSET(LREC,PITCH,XC,YC,ARGX,ARGY)
      DIMENSION LREC(6),XC(1000,2),YC(1000,2),ARGX(6000),ARGY(6000)
      DO 100 J=1,2
      N=LREC(J)
      LREC(J+2)=LREC(J)
      DO 100 I=1,N
      L=I+1000*(J+1)
      ARGX(L)=XC(I,J)
  100 ARGY(L)=YC(I,J)+PITCH
      RETURN
      END
```

```
@ ELT PLTSU,1,720519, 31512

      SUBROUTINE PLTSU (MOVEON,XORIG,  YORIG,  NXPLOT,NYPLOT,XLABLD,
     1 YLABLD,NXLAB,NYLAB,NXFRAC,NYFRAC,NXLINE,NYLINE,
     2 MAXX,MAXY,NXSCAL,NYSCAL)
      COMMON /PLOTCM/ IPLOTF, NPLOTS
      DIMENSION IBUF(1000)
C-----------------------------------------------------------------------
      IF(IPLOTF .EQ. 1)       GO TO 10
      CALL PLOTS (IBUF,1000,9)
C-----------------------------------------------------------------------
C     CONVERT OFF-SET ORIGIN TO INCHES.
C-----------------------------------------------------------------------
      IPLOTF = 1
      NPLOTS = 0
      XCONST = 0.
      YORI=0.
      SUMY=0.0
      GO TO 15
C10   XLEN = MAXLEN
C     CALL PLOT (XLEN,0.,998)
 10   CONTINUE
      IF(MOVEON .EQ. 1)       GO TO 15
      XCONST=FLOAT(MAXLEN)
      YCONST=YORI
   15 SCALEY = 1.
      IF(NYSCAL .NE. 0)       SCALEY = 10.**NYSCAL
      YORIGN = YORIG*SCALEY
      YORI=FLOAT(NYPLOT)/100.
      DYL  = FLOAT(NYLAB )/100.
      DELTAY = YLABLD/DYL*SCALEY
      IF (NXLINE.EQ.0) GO TO 105
      NPLOTS = NPLOTS+1
      SCALEX = 1.
      IF(NXSCAL .NE. 0)       SCALEX = 10.**NXSCAL
      XORIGN = XORIG*SCALEX
      XORI = FLOAT(NXPLOT)/100.
      DXL  = FLOAT(NXLAB )/100.
      DELTAX = XLABLD/DXL*SCALEX
      MAXLEN=(MAXX-NXPLOT)/100+3
C-----------------------------------------------------------------------
C     SET-UP NEW LOGICAL ORIGIN.
C-----------------------------------------------------------------------
      XNEW=XORI+XCONST
      YNEW=YORI-YCONST
      SUMY=SUMY+YNEW
      CALL PLOT(XNEW,YNEW,-3)
      LEN=MAXX-NXPLOT
C-----------------------------------------------------------------------
C     CONVERT LENGTH OF X-AXIS TO INCHES.
C-----------------------------------------------------------------------
      ITICK  = LEN/NXLAB + 1
      XLEN = FLOAT(ITICK-1)*DXL
      XL   = XLEN + DXL
      XV = FLOAT(ITICK)  *XLABLD*SCALEX+XORIGN
      XLIMIT=XV
      IF (NXLINE.EQ.0) GO TO 105
      HEIGHT=0.14
```

```
C-----------------------------------------------------------------------
C      DRAW X-AXIS
C-----------------------------------------------------------------------
       CALL PLOT (0.,0.,3)
       CALL PLOT (XLEN,0.,2)
C-----------------------------------------------------------------------
C      DRAW TICK MARKS AND LABELS.
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
       WRITE (6,6000) NPLOTS, XORI, YORI, XLEN, DXL, XORIGN,  YORIGN,
     1   ITICK
C-----------------------------------------------------------------------
       DO 100  I=1,ITICK
       XL = XL - DXL
       CALL PLOT (XL,0.,3)
       CALL PLOT(XL,-0.14,2)
       XV = XV-XLABLD*SCALEX
       CALL NUMBER (XL,-.35,HEIGHT,XV,0.,NXFRAC)
  100  CONTINUE
C-----------------------------------------------------------------------
C      DRAW Y-AXIS.
C-----------------------------------------------------------------------
   105 YLEN=MAXY
       YLEN=YLEN-YORI*100.
       ITICK = IFIX(YLEN)/NYLAB + 1
       YLEN = FLOAT(ITICK-1)*DYL
       YL = YLEN+DYL
       YV = FLOAT(ITICK)  *YLABLD*SCALEY+YORIGN
       YLIMIT=YV
       IF(NYLINE.EQ.0) RETURN
       HEIGHT=0.14
       OFFSET=FLOAT(NXPLOT/100)-XORI
       XO=OFFSET
       CALL PLOT (XO,0.,3)
       CALL PLOT (XO,YLEN,2)
       DO 110  I=1,ITICK
       YL = YL - DYL
       XO=OFFSET
       CALL PLOT(XO,YL,3)
       XO=OFFSET-0.14
       CALL PLOT (XO,YL,2)
       YV = YV-YLABLD*SCALEY
       XO=OFFSET-0.25
       CALL NUMBER (XO,YL,HEIGHT,YV,90.,NYFRAC)
   110 CONTINUE
       RETURN
C-----------------------------------------------------------------------
       ENTRY PLTBC (BCI,NUMBCI,NXBEGN,NYBEGN,ISIZE,IVERT)
C-----------------------------------------------------------------------
C      CONVERT TO INCHES.
C-----------------------------------------------------------------------
       XPAGE  = FLOAT(NXBEGN)/100.-XORI
       YPAGE  = FLOAT(NYBEGN)/100.-YORI
       NCHAR  = NUMBCI
       ANGLE  = 0.
       IF(IVERT .EQ. 1)      ANGLE = 90.
       HEIGHT = FLOAT(ISIZE)*0.07
       CALL SYMBOL (XPAGE,YPAGE,HEIGHT,BCI,ANGLE,NCHAR)
       RETURN
C-----------------------------------------------------------------------
```

```
      ENTRY PLTPT (IPLOT,NUMPT,INCX,INCY,ICODE,INCSYM,X,Y)
C-----------------------------------------------------------------------
      DIMENSION XARRAY(102),YARRAY(102),X(1), Y(1)
C-----------------------------------------------------------------------
      INTEQ  = ICODE
      LINTYP = INCSYM
      IF(IPLOT .EQ. 1)       LINTYP = - LINTYP
      ICOUNT = NUMPT
      IX = INCX/4
      IY = INCY/4
      II = 1
      JJ = 1
      GO TO 190
  180 JJ=JJ+1
      II=II+1
      ICOUNT=ICOUNT-1
      IF (ICOUNT.LT.1) RETURN
  190 XARRAY(1)=X(II)*SCALEX
      YARRAY(1)=Y(JJ)*SCALEY
      IF ((XARRAY(1).LT.XORIGN) .OR. (XARRAY(1).GT.XLIMIT) .OR.
     1(YARRAY(1).LT.YORIGN) .OR. (YARRAY(1).GT.YLIMIT)) GO TO 180
  200 I=1
  210 I=I+1
  215 II=II+IX
      JJ=JJ+IY
      ICOUNT=ICOUNT-1
      IF (ICOUNT.LE.0) GO TO 220
      XARRAY(I)=X(II)*SCALEX
      YARRAY(I)=Y(JJ)*SCALEY
      IF ((XARRAY(I).LT.XORIGN) .OR. (XARRAY(I).GT.XLIMIT) .OR.
     1(YARRAY(I).LT.YORIGN) .OR. (YARRAY(I).GT.YLIMIT)) GO TO 215
      NPTS=I
      IF (I.GE.100) GO TO 230
      GO TO 210
  220 IF (I.LE.2) RETURN
  230 XARRAY(NPTS+1)=XORIGN
      XARRAY(NPTS+2) = DELTAX
      YARRAY(NPTS+1) = YORIGN
      YARRAY(NPTS+2) = DELTAY
       CALL LINE (XARRAY,YARRAY,NPTS,1,  LINTYP,INTEQ)
      XARRAY(1)  = XARRAY(100)
      YARRAY(1)  = YARRAY(100)
      IF(ICOUNT .GT. 0)      GO TO 200
      RETURN
C-----------------------------------------------------------------------
      ENTRY PLTNU (XLOC,NUMDEC,NXLOC,NYLOC,ISIZE,IVERT)
C-----------------------------------------------------------------------
      XORR = FLOAT (NXLOC)/100. - XORI
      YORR = FLOAT (NYLOC)/100. - YORI
      HEIGHT = FLOAT (ISIZE)*.14
      ANGLE  = 0.
      IF(IVERT .GT. 0)       ANGLE = 90.
      CALL NUMBER (XORR,YORR,HEIGHT,XLOC,ANGLE,NUMDEC)
      RETURN
C-----------------------------------------------------------------------
      ENTRY PLTFIN
C-----------------------------------------------------------------------
      XLEN = MAXLEN
      CALL PLOT (XLEN,-SUMY,999)
      IPLOTF=0
```

```
      RETURN
 6000 FORMAT ('1 ENTRY PLTSU, PLOT NO.',I3/ '  Y-ORIG DIST = ', F10.6/
     1 '  Y-ORIG DIST = ', F10.6 / '  PLOT SIZE = ', F10.4, ' INCHES'/
     2 '  TICK MARK INCR. = ', F10.6,' INCHES'/ '  1ST TICK MARK AT : '/
     3  '  X = ', F10.6, '   Y = ', F10.6 /
     4 '  NO. OF TICK MARKS ON X-AXIS = ', I6 )
      END
```

```
@ ELT SECIN,1,720519, 31504
      SUBROUTINE SECIN (N,N1,N2,IM,ID,IY,TITLE,XB,DELX,XC,YC)
      DIMENSION TITLE(20),XB(2,25),XC(1000,2),YC(1000,2)
    5 FORMAT('1DATE ',A2,'-',A2,'-',A2,36X,'BLADE PROFILE PROGRAM'/)
   10 FORMAT(41X,'SECTION PROPERTIES PROGRAM INPUT DATA'/)
   15 FORMAT(' X COORDINATES OF UPPER AND LOWER SURFACES ARE NOT THE SA
     1ME'/10X,'XU=',E15.8,'XL=',E15.8,'YU=',E15.8,'YL=',E15.8)
   20 FORMAT(I5,5X,3F10.6)
    6 FORMAT(20A4)
   24 FORMAT(25X,'YU',18X,'YL',18X,'XU'/)
   25 FORMAT(10X,3F20.7)
   30 FORMAT (' MORE THAN 49 POINTS')
      K=1
      WRITE(6,5) IM,ID,IY
      WRITE(6,10)
      WRITE(6,6) TITLE
      WRITE(2,6) TITLE
      DX=5.*DELX
      J=0
      DO 200 I=1,N
      XU=XC(I,1)
      YU=YC(I,1)
      XL=XC(I,2)
      YL=YC(I,2)
      IF (ABS(XU-XL)-0.0000001) 60,50,50
   50 WRITE(6,15)XU,XL,YU,YL
      GO TO 300
   60 IF(I-1)65,65,70
   65 WRITE(6,24)
      GO TO 190
   70 IF(I-N)80,190,190
   80 IF(XOLD-XB(1,1))100,100,90
   90 IF(XOLD-XB(2,1))100,100,110
  100 IF(XU-(XOLD+DELX))200,190,190
  110 IF(XU-XB(1,N1))120,120,100
  120 IF(XU-XB(2,N2))130,130,100
  130 IF(XU-(XOLD+DX))200,190,190
  190 XOLD=XU
      WRITE(2,20)K,YU,YL,XU
      WRITE(6,25)YU,YL,XU
      J=J+1
      IF(J-49)200,200,250
  200 CONTINUE
      GO TO 300
  250 WRITE(6,30)
  300 RETURN
      END
```

@ ELT SPLINE,1,720519, 31507

```
      SUBROUTINE SPLINE (N,SRW)
      INTEGER SRW
C
C  SPLINE CALCULATES FIRST AND SECOND DERIVATIVES AT SPLINE POINTS       3KIRK917
C  END CONDITION-SECOND DERIVATIVES ARE THE SAME AT END POINT AND        3KIRK918
C  ADJACENT POINT
C
      COMMON /SPLFIT/
     1      G(100),SB(100),EM(50),SLOPE(50),CURV(50),X(50),Y(50)
      SB(1)=-1.0
      G(1)=0.
      NO=N-1
      IF (NO-2) 20,7,7
    7 DO10I=2,NO
      A=(X(I)-X(I-1))/6.
      C=(X(I+1)-X(I))/6.
      W=2.  *(A+C)-A*SB(I-1)
      SB(I)=C/W
      F=(Y(I+1)-Y(I))/(X(I+1)-X(I))-(Y(I)-Y(I-1))/(X(I)-X(I-1))         3K
   10 G(I)=(F-A*G(I-1))/W
   20 EM(N)=G(N-1)/(1.  +SB(N-1))
      DO30I=2,N
      K=N+1-I
   30 EM(K)=G(K)-SB(K)*EM(K+1)
      SLOPE(1)=(X(1)-X(2))/6.  *(2.  *EM(1)+EM(2))+(Y(2)-Y(1))/(X(2)-X(13KIRK940
     1))
      DO40I=2,N
   40 SLOPE(I)=(X(I)-X(I-1))/6.  *(2.  *EM(I)+EM(I-1))+(Y(I)-Y(I-1))/(X(3KIRK943
     1I)-X(I-1))
      DO 45 I=1,N
   45 CURV(I)=((1.+SLOPE(I)**2)**1.5)/ABS(EM(I))
      IF (SRW) 50,100,50
   50 WRITE (6,1000) N, (X(I),Y(I),SLOPE(I),EM(I),CURV(I),I=1,N)
  100 RETURN
 1000 FORMAT ('1',15HNO. OF POINTS =,I3/10X,1HX,19X,1HY,19X,5HSLOPE,15X, 3KIRK94
     A2HEM,15X,4HCURV/(5E20.8))
      END
```

@ ELT SPLINT,1,720519, 31509

```
      SUBROUTINE SPLINT (N,Z,YINT,MAX)
C
C  SPLINT CALCULATES INTERPOLATED POINTS AND DERIVATIVES
C  FOR A SPLINE CURVE
      DIMENSION Z(1000),YINT(1000)
      COMMON /SPLFIT/
     1      G(100),SB(100),EM(50),SLOPE(50),CURV(50),X(50),Y(50)
 1000 FORMAT (' SPLNT USED FOR EXTRAPOLATION',E15.7/)
      DO140I=1,MAX
      K=2
      IF(Z(I)-X(1))70,60,90
   60 YINT(I) = Y(1)
      SK=X(K)-X(K-1)
      GO TO 130
   70 IF (Z(I)-(1.1*X(1)-0.1*X(2))) 75,120,120
   75 WRITE (6,1000) Z(I)
      GO TO 120
   80 K=N
      IF (Z(I)-(1.1*X(N)-0.1*X(N-1))) 120,120,85
   85 WRITE (6,1000) Z(I)
      GO TO 120
   90 IF(Z(I)-X(K))120,100,110
  100 YINT(I) = Y(K)
      SK=X(K)-X(K-1)
      GO TO 130
  110 K=K+1
      IF(K-N)90,90,80
  120 CONTINUE
      SK=X(K)-X(K-1)
      YINT(I)=EM(K-1)*(X(K)-Z(I))**3/6.  /SK+EM(K)*(Z(I)-X(K-1))**3/6.  3KIRK 41
     1/SK+(Y(K)/SK-EM(K)*SK/6.  )*(Z(I)-X(K-1))+(Y(K-1)/SK-EM(K-1)*SK/6.3KIRK 42
     2  )*(X(K)-Z(I))
  130 DYDX   =-EM(K-1)*(X(K)-Z(I))**2/2.0  /SK+EM(K)*(X(K-1)-Z(I))** 2/2.3S9R2 4
     1  /SK+(Y(K)-Y(K-1))/SK-(EM(K)-EM(K-1))*SK/6.
      D2YDX=(X(K)-Z(I))*EM(K-1)/SK+(Z(I)-X(K-1))*EM(K)/SK
      RCURV=((1.+DYDX**2)**1.5)/ABS(D2YDX)
  140 CONTINUE
  500 RETURN
      END
```

@ ELT SPLNT,1,720519, 31494

```
      SUBROUTINE SPLNT (N,SURF,Z,J,MAX,L,LREC,XC,YC,SLO,RCURVE,SLENTH)
C
C SPLINT CALCULATES INTERPOLATED POINTS AND DERIVATIVES              3KIRK990
C FOR A SPLINE CURVE
      INTEGER SURF
      DIMENSION Z(1000),LREC(6),XC(1000,2),YC(1000,2),SLO(1000,2),
     1RCURVE(1000,2),SLENTH(2)
      COMMON /SPLFIT/ G(100),SB(100),EM(50),SLOPE(50),CURV(50),X(50),
     1Y(50)
      COMMON IM,ID,IY,TITLE(20),DATA(28),XB,YB,NBL,NBBI
      WRITE (6,1030) IM,ID,IY
 1030 FORMAT ('1DATE ',A2,'-',A2,'-',A2,36X,'BLADE PROFILE PROGRAM'/)
      WRITE (6,1040) TITLE
 1040 FORMAT (1X,20A4/)
      WRITE (6,1050) SURF
 1050 FORMAT (' INTERPOLATED X-Y COORDINATES FOR BLADE SURFACE ',I1)
      IF (MAX) 500,500,5
    5 III=SRW
      DO140I=1,MAX                                                   3KIRK 18
      J=J+1                                                          3KIRK 19
      K=2                                                            3KIRK 20
      IF(Z(I)-X(1))70,60,90
   60 YINT   =Y(1)                                                   3KIRK 22
      SK=X(K)-X(K-1)                                                 3KIRK 23
      GO TO 130
   70 IF (Z(I)-(1.1*X(1)-0.1*X(2))) 75,120,120
   75 WRITE (6,1000) Z(I)                                            3KIRK 26
      SRW=16
      GO TO 120
   80 K=N
      IF (Z(I)-(1.1*X(N)-0.1*X(N-1))) 120,120,85
   85 WRITE (6,1000) Z(I)                                            3KIRK 31
      SRW=16                                                         3KIRK 32
      GO TO 120                                                      3KIRK 33
   90 IF(Z(I)-X(K))120,100,110
  100 YINT   =Y(K)                                                   3KIRK 35
      SK=X(K)-X(K-1)                                                 3KIRK 36
      GO TO 130
  110 K=K+1
      IF(K-N)90,90,80                                                3KIRK 39
  120 CONTINUE                                                       3KIRK 40
      SK=X(K)-X(K-1)                                                 3KIRK 41
      YINT   =EM(K-1)*(X(K)-Z(I))**3/6.  /SK+EM(K)*(Z(I)-X(K-1))**3/6.3KIRK 42
     1/SK+(Y(K)/SK-EM(K)*SK/6.   )*(Z(I)-X(K-1))+(Y(K-1)/SK-EM(K-1)*SK/6.
     2  )*(X(K)-Z(I))
  130 XC(J,L)=Z(I)
      YC(J,L)=YINT
      DYDX   =-EM(K-1)*(X(K)-Z(I))**2/2.0  /SK+EM(K)*(X(K-1)-Z(I))**2/2.3KIRK 44
     1  /SK+(Y(K)-Y(K-1))/SK-(EM(K)-EM(K-1))*SK/6.
      SLO(J,L)=DYDX
      D2YDX=(X(K)-Z(I))*EM(K-1)/SK+(Z(I)-X(K-1))*EM(K)/SK
      RCURV=((1.+DYDX**2)**1.5)/ABS(D2YDX)
      RCURVE(J,L)=RCURV
      IF(I-1) 155,155,160
  155 WRITE (6,1010) N,MAX
      GO TO 170
```

```
  160 SLENTH(L)=SLENTH(L)+SQRT((Z(I)-Z(I-1))**2+(YINT-YSAVE)**2)
  170 WRITE(6,1020) Z(I),YINT,DYDX,D2YDX,RCURV,SLENTH(L)
      YSAVE=YINT
  140 CONTINUE
      SRW=III
  500 RETURN
 1000 FORMAT (54H SPLINT USED FOR EXTRAPOLATION. EXTRAPOLATED VALUE =  ,3KIRK 52
     1E14.6)
 1010 FORMAT (    22H NO. OF POINTS GIVEN =,I3,30H, NO. OF INTERPOLATED P
     1OINTS =,I3/
     1          5X,11HX-INTERPOL.,9X,11HY-INTERPOL.,8X,14HDYDX-INTERPOL.
     2,6X,15HD2YDX-INTERPOL.,5X,15HRCURV-INTERPOL.,5X,16HSLENTH-INTERPOL
     3.)
 1020 FORMAT(6E20.8)
      END                                                       3KIRK 57
```

```
@ ELT SPLN2,1,720519, 31490

      SUBROUTINE SPLN2 (N,SURF,Y1P,YNP)
      INTEGER SURF
C                                                                       3KIRK952
C  SPLN22 CALCULATES FIRST AND SECOND DERIVATIVES AT SPLINE POINTS      3KIRK953
C  END CONDITION - DERIVATIVES SPECIFIED AT END POINTS                  3KIRK954
      COMMON /SPLFIT/ G(100),SB(100),EM(50),SLOPE(50),CURV(50),X(50),
     1Y(50)
      COMMON IM,ID,IY,TITLE(20),DATA(28),XB(2,25),YB(2,25),NBL,NBBI
      WRITE (6,1010) IM,ID,IY
 1010 FORMAT ('1DATE ',A2,'-',A2,'-',A2,36X,'BLADE PROFILE PROGRAM'/)
      WRITE (6,1005) TITLE
 1005 FORMAT (1X,20A4/)
      WRITE (6,1020) SURF
 1020 FORMAT (' INPUT SPLINE POINTS FOR SURFACE ',I1)
      SB(1)=0.5
      F=(Y(2)-Y(1))/(X(2)-X(1))-Y1P                                     3KIRK960
      G(1)=F*3.  /(X(2)-X(1))
      NO=N-1                                                            3KIRK962
      IF (NO-2) 20,7,7
    7 DO10I=2,NO
      A=(X(I)-X(I-1))/6.
      C=(X(I+1)-X(I))/6.
      W=2.  *(A+C)-A*SB(I-1)
      SB(I)=C/W                                                         3KIRK968
      F=(Y(I+1)-Y(I))/(X(I+1)-X(I))-(Y(I)-Y(I-1))/(X(I)-X(I-1))         3KIRK969
   10 G(I)=(F-A*G(I-1))/W                                               3KIRK970
   20 F=YNP-(Y(N)-Y(N-1))/(X(N)-X(N-1))                                 3KIRK971
      W=(X(N)-X(N-1))/6.  *(2.  -SB(N-1) )
      EM(N)=(F-(X(N)-X(N-1))*G(N-1)/6.  )/W
      DO30I=2,N                                                         3KIRK974
      K=N+1-I                                                           3KIRK975
   30 EM(K)=G(K)-SB(K)*EM(K+1)
      SLOPE(1)=(X(1)-X(2))/6.  *(2.  *EM(1)+EM(2))+(Y(2)-Y(1))/(X(2)-X(13KIRK977
     1))
      DO40I=2,N                                                         3KIRK979
   40 SLOPE(I)=(X(I)-X(I-1))/6.  *(2.  *EM(I)+EM(I-1))+(Y(I)-Y(I-1))/
     1   (X(I)-X(I-1))
      DO 45 I=1,N
   45 CURV(I)=((1.+SLOPE(I)**2)**1.5)/ABS(EM(I))
      WRITE (6,1000) N, (X(I),Y(I),SLOPE(I),EM(I),CURV(I),I=1,N)
      RETURN
 1000 FORMAT (   16H NO. OF POINTS =,I3/10X,1HX,19X,1HY,19X,5HSLOPE,15X, 3KIRK94
     A2HEM,15X,4HCURV/(5E20.8))
      END                                                               3KIRK986
```

@ ELT STAK,1,720519, 31502

```
      SUBROUTINE STAK (L,RAD,LREC,XHT,YHT,YCENT,TITLE,IM,ID,IY,
     1XTRAN,YTRAN,XC,YC,XSH,YSH,XST,YST)
      DIMENSION LREC(6),TITLE(20),XX(2),YY(2),XC(1000,2),YC(1000,2),
     1XSH(1000,2),YSH(1000,2),XST(1000,2),YST(1000,2)
    5 FORMAT (4E20.9)
   10 FORMAT (6F10.0)
   20 FORMAT (2F20.8)
 1000 FORMAT('1DATE ',A2,'-',A2, '-',A2,36X' BLADE PROFILE PROGRAM'/)
 1005 FORMAT (1X,20A4)
 1010 FORMAT (42X,'WRAPPED BLADE COORDINATES,HUB,UPPER SURFACE',
     1//9X,'X',19X,'Y'/)
 1015 FORMAT (42X,'WRAPPED BLADE COORDINATES,HUB,LOWER SURFACE',
     1//9X,'X',19X,'Y'/)
 1020 FORMAT (42X,'WRAPPED BLADE COORDINATES,TIP,UPPER SURFACE',
     1//9X,'X',19X,'Y'/)
 1025 FORMAT (42X,'WRAPPED BLADE COORDINATES,TIP,LOWER SURFACE',
     1//9X,'X',19X,'Y'/)
 1030 FORMAT (20A4)
 1035 FORMAT (I5)
 1045 FORMAT (' X-Y COORDINATES OF HUB CENTROID, X=',F20.8,'Y=',F20.8/)
      GO TO (30,60),L
   30 RADH=RAD
      READ (5,10) XHT,YHT,XCENT,YCENT,XTRAN,YTRAN
      WRITE (2,1030) TITLE
      DO 50 J=1,2
      ICONT=0
      WRITE (6,1000) IM,ID,IY
      WRITE (6,1005) TITLE
      IF (J-1) 35,35,40
   35 WRITE (6,1010)
      WRITE (6,1045) XTRAN,YTRAN
      XTRAN=XTRAN-XCENT
      GO TO 45
   40 WRITE (6,1015)
   45 N=LREC(J)
      WRITE (2,1035) N
      LREC(J+2)=N
      DO 50 I=1,N
      ICONT=ICONT+1
      X=XC(I,J)
      Y=YC(I,J)
      Y=Y-YCENT
      Y=RADH*SIN(Y/RADH)+YTRAN
      X=X+XTRAN
      XX(ICONT)=X
      YY(ICONT)=Y
      XSH(I,J)=X
      YSH(I,J)=Y
      IF (ICONT-2) 46,47,47
   46 IF (I-N) 50,47,47
   47 WRITE (2,5) (XX(IN),YY(IN),IN=1,ICONT)
      ICONT=0
   50 WRITE (6,20) X,Y
      GO TO 200
   60 RADT=RAD
      WRITE (2,1030) TITLE
```

```
      DO 100 J=1,2
      ICONT=0
      WRITE (6,1000) IM,ID,IY
      WRITE (6,1005) TITLE
      IF (J-1) 65,65,70
   65 WRITE (6,1020)
      GO TO 75
   70 WRITE (6,1025)
   75 N=LREC(J)
      WRITE (2,1035) N
      DO 100 I=1,N
      ICONT=ICONT+1
      X=XC(I,J)
      Y=YC(I,J)
      Y=Y-YCENT+YHT
      Y=RADT*SIN(Y/RADT)+YTRAN
      X=X+XHT+XTRAN
      XX(ICONT)=X
      YY(ICONT)=Y
      XST(I,J)=X
      YST(I,J)=Y
      IF (ICONT-2) 80,85,85
   80 IF (I-N) 100,85,85
   85 WRITE (2,5) (XX(IN),YY(IN),IN=1,ICONT)
      ICONT=0
  100 WRITE (6,20) X,Y
  200 RETURN
      END
```

W ELT VELIN,1,720519, 31488

```
      SUBROUTINE VELIN (N)
      DIMENSION DATA(28),TITLE(20),N(2)
      COMMON /SPLFIT/ G(100),SB(100),EM(50),SLOPE(50),CURV(50),XXX(50),
     1YYY(50)
      COMMON IM,ID,IY,TITLE,DATA,X(2,25),Y(2,25),NBL,NBBI
      EQUIVALENCE (DATA(1),GAM),(DATA(2),AR),(DATA(3),T1P),(DATA(4),
     1RHOIP),(DATA(5),WTFL),(DATA(6),OMEGA),(DATA(7),ORF),(DATA(8),
     2BETAI),(DATA(9),BETAO),(DATA(10),CHORD),(DATA(11),STGR),
     3(DATA(12),REDFA),(DATA(13),DENTO),(DATA(14),RI1),(DATA(15),RO1),
     4(DATA(16),BETI1),(DATA(17),BETO1),(DATA(18),SPLN1),(DATA(19),RI2),
     5(DATA(20),RO2),(DATA(21),BETI2),(DATA(22),BETO2),(DATA(23),SPLN2)
      EQUIVALENCE (DATA(24),P0),(DATA(25),W ),(DATA(26),
     1RAD),(DATA(27),CP),(DATA(28),W2)
    5 FORMAT (20A4)
   10 FORMAT (F10.3,2F10.1,2F10.6,10X,F10.2,F10.6)
   20 FORMAT (2F10.3,2F10.6)
   30 FORMAT (F10.2,F10.6)
   40 FORMAT (2I5,10X,4I5)
   50 FORMAT (2F10.6,2F10.3,F10.1)
   60 FORMAT (8F10.7)
 1000 FORMAT ('1DATE ',A2,'-',A2,'-',A2,36X,'BLADE PROFILE PROGRAM'/)
 1005 FORMAT (1X,20A4/)
 1020 FORMAT (40X,'VELOCITY DISTRIBUTION PROGRAM INPUT DATA'/)
 1110 FORMAT (7X,3HGAM,14X,2HAR,13X,3HTIP,12X,5HRHOIP,12X,4HWTFL,11X,6H
     1      ,10X,5HOMEGH,12X,3HORF)
 1040 FORMAT (1X,F16.6,F16.2,F16.3,2F16.7,10X   ,F16.2,F16.5/)
 1120 FORMAT (6X,5HBETAI,10X,5HBETAO,11X,6HCORDF,11X,5HSTGRF)
 1121 FORMAT (2F16.5,2F16.7/)
 1125 FORMAT (6X,6HREDFAC,10X,6HDENTOL)
 1126 FORMAT (2F16.7/)
 1130 FORMAT (41H   MBI  MBO               MM  NBBI  NBL NRSP)
 1010 FORMAT (2I5,10X,4I5/)
 1140 FORMAT (40H     BLADE SURFACE 1  --  UPPER  SURFACE)
 1180 FORMAT (7X,2HRI,I1,12X,2HRO,I1,12X,4HBETI,I1,11X,4HBETO,I1,11X,5HS
     1PLNO,I1)
 1181 FORMAT (2F16.7,2F16.5,F16.1/)
 1190 FORMAT (7X,3HMSP,I1,2X,5HARRAY)
 1191 FORMAT (1X,8F16.7/)
 1200 FORMAT (7X,4HTHSP,I1,2X,5HARRAY)
 1150 FORMAT (39H     BLADE SURFACE 2  --  LOWER SURFACE)
 1210 FORMAT (7X,8HMR ARRAY)
 1220 FORMAT (7X,11HRMSP  ARRAY)
 1230 FORMAT (7X,11HBESP  ARRAY)
      SPLN1=N(1)
      SPLN2=N(2)
      OMEGA=2.*3.14159*OMEGA/60.
      RAD=RAD/12.
      AR=32.174*AR
      RHOIP=P0*144./T1P/AR
      WTFL=WTFL/32.174/NBL
      WU=W*SIN(BETAI/57.296)
      WX=W*COS(BETAI/57.296)
      U=RAD*OMEGA
      VU=WU+U
      V=SQRT(VU**2+WX**2)
      T1=T1P-V **2/(2.*32.174*778.16*CP)
```

```
      P1=P0*(T1/T1P)**(GAM/(GAM-1.))
      RHO=P1*144./T1/AR
      AN=WTFL/RHO/WX
      PITCH=2.*3.14159*RAD/NBL
      H1=AN/PITCH
      H2=H1
      WX2=W2*COS(BETA0/57.296)
      TTR=T1+W**2/(2.*32.174*778.16*CP)
      PTR=P1*(TTR/T1)**(GAM/(GAM-1.))
      T2=TTR-W2**2/(2.*32.174*778.16*CP)
      P2=PTR*(T2/TTR)**(GAM/(GAM-1.))
      RHO2=P2*144./T2/AR
      AN2=WTFL/RHO2/WX2
      H3=AN2/PITCH
      H4=H3
      CHORD=CHORD/12.
      STGR=STGR/RAD/12.
      DO 200 I=1,2
      K=N(I)
      DO 200 J=1,K
      X(I,J)=X(I,J)/12.
  200 Y(I,J)=Y(I,J)/RAD/12.
      RI1=RI1/12.
      RI2=RI2/12.
      RO1=RO1/12.
      RO2=RO2/12.
      HT=PITCH/NBBI
      NUM=CHORD/HT
      MBI=15
      MBO=NUM+MBI
      MM=MBO+15
      NRSP=4
      X1=-14.*HT
      X2=0.0
      X3=CHORD
      X4=14.*HT+CHORD
      WRITE (2,5) TITLE
      WRITE (2,10) (DATA(I),I=1,7)
      WRITE (2,20) (DATA(I),I=8,11)
      WRITE (2,30) (DATA(I),I=12,13)
      WRITE (2,40) MBI,MBO,MM,NBBI,NBL,NRSP
      WRITE (2,50) (DATA(I),I=14,18)
      J=1
  205 IF (N(1)-J-7) 210,210,215
  210 MAX=N(1)
      GO TO 220
  215 MAX=J+7
  220 WRITE (2,60) (X(1,I),I=J,MAX)
      J=MAX+1
      IF (N(1)-MAX) 225,225,205
  225 J=1
  230 IF (N(1)-J-7) 235,235,240
  235 MAX=N(1)
      GO TO 245
  240 MAX=J+7
  245 WRITE (2,60) (Y(1,I),I=J,MAX)
      J=MAX+1
      IF (N(1)-MAX) 250,250,230
  250 WRITE (2,50) (DATA(I),I=19,23)
      J=1
```

```
  255 IF (N(2)-J-7) 260,260,265
  260 MAX=N(2)
      GO TO 270
  265 MAX=J+7
  270 WRITE (2,60) (X(2,I),I=J,MAX)
      J=MAX+1
      IF (N(2)-MAX) 275,275,255
  275 J=1
  280 IF (N(2)-J-7) 285,285,290
  285 MAX=N(2)
      GO TO 295
  290 MAX=J+7
  295 WRITE (2,60) (Y(2,I),I=J,MAX)
      J=MAX+1
      IF (N(2)-MAX) 296,296,280
  296 WRITE (2,60) X1,X2,X3,X4
      WRITE (2,60) RAD,RAD,RAD,RAD
      WRITE (2,60) H1,H2,H3,H4
      WRITE (6,1000) IM,ID,IY
      WRITE (6,1005) TITLE
      WRITE (6,1020)
      WRITE (6,1110)
      WRITE (6,1040) (DATA(I),I=1,7)
      WRITE (6,1120)
      WRITE (6,1121) (DATA(I),I=8,11)
      WRITE (6,1125)
      WRITE (6,1126) (DATA(I),I=12,13)
      WRITE (6,1130)
      WRITE (6,1010) MBI,MBO,MM,NBBI,NBL,NRSP
      WRITE (6,1140)
      J=1
      MAX=N(1)
      WRITE (6,1180) J,J,J,J,J
      WRITE (6,1181) (DATA(I),I=14,18)
      WRITE (6,1190) J
      WRITE (6,1191) (X(1,I),I=1,MAX)
      WRITE (6,1200) J
      WRITE (6,1191) (Y(1,I),I=1,MAX)
      WRITE (6,1150)
      J=2
      MAX=N(2)
      WRITE (6,1180) J,J,J,J,J
      WRITE (6,1181) (DATA(I),I=19,23)
      WRITE (6,1190) J
      WRITE (6,1191) (X(2,I),I=1,MAX)
      WRITE (6,1200) J
      WRITE (6,1191) (Y(2,I),I=1,MAX)
      WRITE (6,1210)
      WRITE (6,1191) X1,X2,X3,X4
      WRITE (6,1220)
      WRITE (6,1191) RAD,RAD,RAD,RAD
      WRITE (6,1230)
      WRITE (6,1191) H1,H2,H3,H4
      DO 300 I=1,2
      K=N(I)
      DO 300 J=1,K
  300 X(I,J)=12.*X(I,J)
      RETURN
      END
```

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13. MULTISTAGE AXIAL FLOW TURBINE PERFORMANCE ANALYSIS PROGRAM

Project 121
W.S. f7
Fluid Dynamic Analyses

MULTISTAGE AXIAL FLOW TURBINE PERFORMANCE ANALYSIS PROGRAM

1. INTRODUCTION

a. A computer program has been developed for performance analysis of multistage axial flow gas turbines. Its primary purpose is for predesign analysis of axial flow turbines to establish turbine operating characteristics, pressures, temperatures, gas velocities, flow channel geometry, and approximate blade root stresses.

b. Included is Report 7740R-70-032 which describes the program in detail and includes a listing of the program, input instructions, and example case.

c. The program is complete and was used for predesign performance analysis of the NERVA turbine.

d. The program is application as long as the turbine remains axial flow.

e.

f. This program was developed by K. G. Kirk.

2. CONCLUSIONS

a. Gross Conclusions

(1) This program evolved over the past several years of NERVA work. It proved to be an extremely valuable tool, both in the parametric phase of component selection and the final turbine design.

(2) The blade root stress predictions of the program required prior knowledge of the blade geometry, hence it was not extremely useful in predesign calculations.

3. RECOMMENDATIONS

a. Since the program has evolved over a several year period and was originally written for a small scale computer with limited storage, there is room for improvement in the coding to make a cleaner more efficient program.

b. The program has been used principally in connection with rocket engine turbopump applications; however, there are no known program limitations which prevent its use on any other axial flow gas turbine application.

4. REFERENCES

The method of analysis used in the turbine loss analysis is based on the work of Reference (a).

(a) Stewart, Warner L.; A Study of Axial-Flow Turbine Efficiency Characteristicsin Terms of Velocity Diagram Parameters; ASME Paper Number 61-WA-37.

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NERVA THREE-STAGE AXIAL FLOW TURBINE PERFORMANCE AND AERODYNAMIC ANALYSIS REFERENCE TURBOPUMP

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I. INTRODUCTION

The three-stage axial flow turbine discussed here is the result of an extensive turbopump parametric analysis, including turbopump structural and reliability considerations, leading to the following turbine requirements:

Shaft Horsepower	= 7,280
Turbine Inlet Temperature	= 1,660°R
Turbine Inlet Pressure	= 305 psia
Turbine Pressure Ratio	= 7.01 (Total to Static)
Rotative Speed	= 19,000 rpm

The basic design philosophy maintained for this turbine and those which preceded it during the parametric study included the following:

1. Insure impulse or slightly positive reaction at the blade root by selecting some small amount of reaction at the mean line.

2. Twisted blades are unnecessary because the NERVA turbine blades are relatively short.

3. Maintain constant rotor tip diameter for all stages to maximize tip speed for the first stage which has lower blade stresses, to reduce the total turbine rotor overhung moment and to simplify the turbine housing.

4. Distribute stage loading such that the first stage produces the most work and the last stage produces the least. This assures turbine flow control by the first stage nozzle, resulting in more reliable off-design performance predictions without sacrificing turbine performance.

5. A single tangential inlet line and dual tangential exhaust lines are used, with line sizes being selected as a compromise between line weight and pressure losses.

II. METHOD OF ANALYSIS

Performance analysis for the turbine centers around the method of predicting losses for both the blading and associated inlet and exhaust ducting. The loss analysis selected for the blading is similar to that of Reference (1) and includes these several major assumptions.

1. One-dimensional flow at the mean radius.

2. Adiabatic flow through static components, i.e., manifolds and nozzles.

3. Blading losses may be satisfactorily predicted on the basis of

   a. Reynolds Number

   b. Nozzle Exit Angle

   c. Average Kinetic energy level of the stage

   d. Rotor Tip Clearance

Losses in the inlet manifold and exhaust collector are based on a total pressure loss coefficient.

Utilizing the required shaft power and assumed turbine flow rate, (which eventually must satisfy the pressure ratio requirement) the specific work requirement of the turbine is determined from the relation

$$\overline{\Delta h} = \frac{SHP\ 550}{\dot{W}\ J} \qquad (1)$$

and is distributed to each individual stage in a manner consistant with the basic design philosophy.

For the turbine considered here, the stage loading is:

First Stage	40%
Second Stage	33%
Third Stage	27%

Further reduction in last stage loading would result in insufficient axial acceleration of the flow.

Selection of nozzle angles is based on the following criteria:

1. Performance
2. Blade Height
3. Flow Passage
4. Manufacturing Feasibility

Use of hot hydrogen drive gas tends to result in short turbine blades, especially for the first stage, and a pronounced rotor tip clearance effect on turbine performance. Hence, a high nozzle angle (measured from the axial direction) is desirable for the first stage to produce maximum blade length, however, excessively high nozzle angles degrade performance because of the increased wetted area, and increases manufacturing difficulty. These considerations have led to a first stage nozzle angle of 75 degrees. The remaining nozzle angles of 70.5 degrees for the second stage and 66 degrees for the third stage were selected to produce a reasonably good flow passage within the constant rotor tip diameter constraint.

First stage blade speed was selected primarily to satisfy critical speed considerations by maintaining low disc weight. The trade-off between disc weight and turbine performance has led to a first stage mean blade speed of 1200 ft/sec. Remaining stage blade speeds satisfy a constant tip configuration resulting in an average blade speed of 1185 ft/sec.

The above parameters, namely stage load, nozzle angle, degree of reaction and blade speed dictate the gas velocities for the stages and with the gas velocities determined, the blade loss analysis is conducted resulting in interstage pressures and temperatures as well as blade heights and efficiencies. The loss coefficient used for the blade loss analysis was based on data presented in Reference (1) together with correlations made with the M-1 scale model fuel pump test data and NASA three-stage turbine test data. Inasmuch as the effect of rotor tip clearance on stage loss is a function of rotor blade height, it was necessary to provide for blade loss coefficient variation from stage to stage. This was done based on tip clearance leakage data presented in Reference (2).

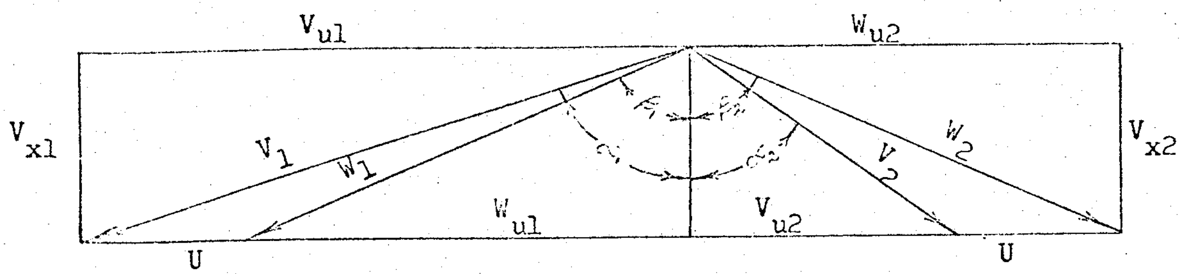
Loss coefficients for the inlet manifold and exhaust collector were based on limited data obtained from the technology turbopump.

In order to facilitate the parametric study that has been made on the NERVA turbine, the above performance analysis procedure has been computerized. A detailed report on this turbine performance program is currently being written and will be published as "Design Point Performance Analysis of Multistage Turbines," RN-TM-0411. A brief preliminary explanation of the program and its use together with an example case are included as Appendix B.

The results of this analysis for the three-stage turbine considered here are summarized as follows:

		FIRST STAGE	SECOND STAGE	THIRD STAGE	THREE STAGE
Flow Rate	Lb/Sec	4.05	4.05	4.05	4.05
Pressure Ratio (Total-to-Static)	---	2.519	2.169	1.808	7.01
Velocity Ratio	U/Co	0.147	0.164	0.190	0.106
Actual Enthalpy Drop	BTU/Lb	508	419	342	1,269
Static Efficiency	%	38.1	40.3	45.6	51.7

VELOCITY DIAGRAMS



NOZZLE EXIT (1)				ROTOR EXIT (2)		
1	2	3		1	2	3
1,200	1,186	1,170	U	1,200	1,186	1,170
6,434	5,500	4,683	V_u	4,154	3,342	2,646
1,724	1,948	2,085	V_x	1,724	1,948	2,085
6,662	5,835	5,126	V	4,498	3,868	3,369
75.0	70.5	66.0	α	67.5	59.8	51.8
5,234	4,314	3,512	W_u	5,354	4,528	3,817
5,511	4,734	4,084	W	5,625	4,929	4,349
71.8	65.7	59.3	β	72.2	66.7	61.4
ABSOLUTE NOZZLE EXIT			MACH NO.	RELATIVE ROTOR EXIT		
0.958	0.866	0.784		0.811	0.735	0.668

A complete computer output for the base case is included as Appendix A.

The above aerodynamic analysis is, of necessity, a predesign analysis; following it, the blade profiles are designed to satisfy the velocity triangle requirements. Once the blade profiles have been generated two more phases of the turbine aerodynamics are executed. First a detailed blade loss analysis based on blade section properties is made using Soderberg's Method. The performance prediction from this method of analysis is compared with the pre-design analysis and any significant discrepancies are resolved through blade profile and/or clearance modifications. Secondly, the surface velocity distribution is analyzed for adverse diffusion characteristics using the NASA velocity distribution program.

Design of the NERVA turbine has not progressed to the point of conducting these final aerodynamic design studies, however, the final turbine design will have these considerations incorporated.

REFERENCES

1. A Study of Axial-Flow Turbine Efficiency Characteristics in Terms of Velocity Diagram Parameters, by Warner L. Stewart, ASME Paper 61-WA-37

2. Experimental Investigation of Three Tip-Clearance Configurations Over a Range of Tip Clearance Using a Single-Stage Turbine of High Hub-to-Tip Radius Ratio, by Milton G. Kofskey, NASA TMX-472.

APPENDIX A

BASE CASE

COMPUTER PRINTED OUTPUT

DATE07-19-68

3 STAGE
GAS TURBINE DESIGN
ANALYSIS

SPOOL NUMBER 1 OF 1

CASE NUMBER 0180-05

APPLICATION-------MAIN TURBINE, NERVA LARGE DIAMETER ROCKET ENGINE
CHARACTERISTICS---SINGLE SPOOL TURBINE
OBJECTIVE---------NON TWISTED BLADES

GAS PROPERTIES

GAS CONSTANT FT/DEG R	SPECIFIC HEAT RATIO	CONSTANT PRESSURE SPECIFIC HEAT BTU/LB-DEG R	ABSOLUTE VISCOSITY LB/FT-SEC
766.37	1.391	3.504	0.1340E-04

CASE CONDITIONS

SHAFT HORSEPOWER	FLOW RATE LB/SEC	INLET TOTAL TEMPERATURE DEG R	INLET TOTAL PRESSURE PSIA	MEAN BLADE SPEED FT/SEC	ROTATIVE SPEED RPM	MAN. LOSS COEFFICIENT	E.C. LOSS COEFFICIENT
7280.0	4.05	1660.0	305.0	1200.0	19000.0	0.750	5.000

BLADE CROSS SECTION AREA DISTRIBUTION			DELTA	OVERSPEED FACTOR	OVERSPEED EXPONENT
0.10000E 01	0.00000E 00	0.00000E 00	1.000	1.000	3.000

STRESS LIMIT PSI	MATERIAL DENSITY LB/CU-IN	PARAMETER INDEX	DATA SWITCHES ON
50000.0	0.300	0	3

STAGE INPUT PARAMETERS

STAGE	STAGE REACTION	NOZZLE ANGLE DEG	STAGE LOAD RATIO	MEAN RADIUS RATIO	AXIAL VELOCITY RATIO	NOZZLE LOSS COEFF.	ROTOR LOSS COEFF.	ROTOR CLEAR IN	ASPECT RATIO	TH/CD RATIO	SECTION MODULUS CONST.	SOLIDITY
1	0.050	75.00	1.000	1.000	1.000	0.400	0.400	0.035	1.00	0.40	0.100	1.700
2	0.090	70.50	0.825	0.987	1.000	0.400	0.400	0.035	1.25	0.35	0.093	1.650
3	0.130	66.00	0.675	0.975	1.000	0.400	0.400	0.035	1.50	0.30	0.087	1.600

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STAGE VELOCITIES

NON TWISTED BLADES

STAGE	U FT/SEC	VU1 FT/SEC	VX1 FT/SEC	V1 FT/SEC	WU1 FT/SEC	W1 FT/SEC	VU2 FT/SEC	VX2 FT/SEC	V2 FT/SEC	WU2 FT/SEC	W2 FT/SEC	REACTION
1	1161.2	6587.3	1765.1	6819.7	5426.1	5706.0	-4353.7	1775.9	4701.9	-5514.9	5793.8	0.039
	1200.0	6432.7	1723.6	6659.6	5232.7	5509.2	-4152.7	1723.6	4496.2	-5352.7	5623.4	0.050
	1238.7	6285.3	1684.1	6507.1	5046.6	5320.2	-3972.2	1678.0	4312.1	-5211.0	5474.5	0.065
2	1132.3	5693.4	2016.1	6039.9	4561.1	4986.8	-3560.8	2018.9	4093.3	-4693.1	5109.0	0.058
	1185.5	5498.5	1947.1	5833.1	4313.0	4732.2	-3340.9	1947.1	3866.9	-4526.4	4927.4	0.090
	1238.7	5317.3	1883.0	5640.9	4078.5	4492.2	-3150.0	1887.9	3672.4	-4388.8	4777.6	0.126
3	1101.7	4895.9	2179.8	5359.3	3794.2	4375.8	-2868.0	2168.6	3595.6	-3969.7	4523.4	0.076
	1170.2	4681.5	2084.3	5124.5	3511.2	4083.3	-2645.2	2084.3	3367.7	-3815.5	4347.7	0.130
	1238.7	4486.6	1997.6	4911.2	3247.9	3813.0	-2457.5	2019.2	3180.7	-3696.3	4211.8	0.186

STAGE MACH NUMBERS

NON TWISTED BLADES

STAGE	ABSOLUTE NOZZLE EXIT	RELATIVE ROTOR EXIT
1	0.985	0.839
	0.958	0.811
	0.932	0.787
2	0.902	0.765
	0.866	0.734
	0.833	0.710
3	0.824	0.697
	0.783	0.668
	0.747	0.645

STAGE GEOMETRY

NON TWISTED BLADES

STAGE	MEAN RADIUS IN	BLADE HEIGHT 1 IN	BLADE HEIGHT 2 IN	ANNULUS AREA 1 SQ-IN	ANNULUS AREA 2 SQ-IN	ALPHA1 DEG	BETA1 DEG	ALPHA2 DEG	BETA2 DEG
1	7.2373	0.366	0.467	16.749	21.275	75.00	71.98	-67.80	-72.15
						75.00	71.76	-67.45	-72.15
						75.00	71.54	-67.09	-72.15
2	7.1501	0.553	0.642	24.996	28.847	70.50	66.15	-60.44	-66.72
						70.50	65.70	-59.76	-66.72
						70.50	65.21	-59.06	-66.72
3	7.0579	0.742	0.826	33.141	36.643	66.00	60.12	-52.90	-61.35
						66.00	59.30	-51.76	-61.35
						66.00	58.40	-50.59	-61.35

DATE07-19-68 PRESSURES TEMPERATURES

NON TWISTED BLADES

STAGE	PT1 PSIA	P1 PSIA	PT2 PSIA	P2 PSIA	PRS	PRT	TT1 DEG R	T1 DEG R	TT2 DEG R	T2 DEG R
1	272.7	146.8	158.8	116.6			1660.0	1394.9	1515.1	[illegible]
	272.7	151.5	157.2	118.6	2.518	1.900	1660.0	1407.2	1515.2	[illegible]
	272.7	155.9	155.9	120.4			1660.0	1418.6	1515.1	[illegible]
2	137.3	81.2	91.7	71.3			1515.2	1307.2	1395.7	[illegible]
	137.3	84.3	90.7	72.5	2.168	1.732	1515.2	1321.2	1395.7	[illegible]
	137.3	87.2	90.0	73.5			1515.2	1333.8	1395.6	[illegible]
3	83.9	53.8	60.8	49.4			1395.7	1232.0	1298.2	[illegible]
	83.9	56.0	60.2	50.2	1.807	1.507	1395.7	1246.0	1298.0	[illegible]
	83.9	58.0	59.7	50.8			1395.7	1258.2	1297.6	[illegible]

STAGE PERFORMANCE

STAGE	LAMDA	DEL H BTU/LB	ETS	ETT	U/CO
1	0.113	507.3	0.381	0.528	0.147
2	0.134	418.5	0.403	0.550	0.164
3	0.159	342.4	0.456	0.642	0.190

OVERALL BLADE PERFORMANCE

DEL H BTU/LB	UMA FT/SEC	U/CO	U/CO'	PRST	PRTT	ETST	ETTT	RET	RES
1268.4	1185.2	0.110	0.115	5.953	4.964	0.552	0.601	1.068	1.077

OVERALL TURBINE PERFORMANCE INCLUDING MANIFOLD

U/CO	U/CO'	PRST	PRTT	ETST	ETTT
0.110	0.114	6.075	5.065	0.548	0.595

OVERALL TURBINE PERFORMANCE INCLUDING MANIFOLD AND EXHAUST COLLECTOR

U/CO	U/CO'	PRST	PRTT	ETST	ETTT
0.106	0.108	7.011	6.589	0.517	0.530

INLET MANIFOLD CONDITIONS

AREA SQ-IN	MACH NUM	P PSIA	T DEG-R	PTME PSIA
11.48	0.200	296.6	1647.1	298.8

EXHAUST COLLECTOR EXIT FLANGE CONDITIONS

AREA SQ-IN	MACH NUM	PT PSIA	P PSIA	TT DEG R	T DEG R
45.94	0.300	46.2	43.5	1298.0	1275.5

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ROTOR BLADE ROOT STRESS

STAGE	MEAN RADIUS IN	AVERAGE BLADE HEIGHT IN	STAGE LOAD PERCENT	CENTRIPETAL STRESS PSI	BENDING STRESS PSI	TOTAL STRESS PSI
1	7.2373	0.416	40.0	9283.4	1293.8	10577.2
2	7.1501	0.597	33.0	13143.3	1725.3	14868.7
3	7.0579	0.784	27.0	17029.8	2384.8	19414.6

APPENDIX B

MULTISTAGE AXIAL FLOW TURBINE

PERFORMANCE ANALYSIS PROGRAM

ABSTRACT

A computer program has been developed for performance analysis of mult-stage axial flow gas turbines. Its primary purpose is for predesign analysis of turbines to establish turbine operating characteristics, pressures, temperatures, gas velocities, flow channel geometry and approximate blade root stresses. The program has been used principally in connection with rocket engine turbopump applications, however there are no known program limitations which prevent its use on any other axial flow gas turbine application.

This program is in the IBM 1130 version of Fortran IV.

A. PROGRAM DESCRIPTION

This computer program has been devised for parametric analysis of multi-stage, single or two-spool, axial flow gas turbines. Because of the fact that a large number of independent variables are considered during parametric analysis of turbines and because of the many mathematical relations involved (some requiring numerical solution), it was necessary to employ a high-speed digital computer. The program is in the IBM 1130 version of Fortran IV and is used on that machine. All major parameters consistent with conventional gas turbine design have been included in the analytic procedure. Specific information determined by the program includes the following:

1. Velocity diagrams
2. Mach numbers
3. Flow channel geometry
4. Gas state at each axial station
5. Performance
6. Blade root stresses

B. METHOD OF SOLUTION

The analysis utilized in this program is based on the following major assumptions:

1. One-dimensional flow at the mean radius
2. Subsonic and/or transonic flow
3. Adiabatic flow in stators

The loss analysis used in the performance section of the program is a modified version of that discussed by Stewart in Reference (1). In this loss analysis blade row losses are assumed to be a function primarily of the average kinetic energy of the blade row. Hence, specification of the velocity triangle for a stage through the specific work requirement, stage reaction, nozzle discharge angle and blade speed leads to turbine performance and associated parameters such as gas state.

Inlet manifold and exhaust collector losses are calculated using a total pressure loss coefficient defined by

$$Y_P = \frac{Po_1 - Po_2}{Po_2 - P_2}$$

where

Y_P = Total pressure loss coefficient

Po_1 = Inlet total pressure

Po_2 = Exhaust total pressure

P_2 = Exhaust static pressure

These two component losses are included in over-all turbine performance.

Although performance is based on a one dimensional analysis at the mean line, the radial variation of flow properties based on the mean line values is determined assuming simple radial equilibrium.

This is accomplished for either of the following two types of blading:

1. Free Vortex
2. Non-twisted

Determination of the radial variation of flow properties serves at least these three purposes;

1. Evaluation of axial bearing loads
2. Evaluation of blade gas bending loads
3. Evaluation of blade root reaction

Distribution of work between stages is specified by the "stage load ratio" defined as follows:

$$X_i = \frac{\Delta h_i}{\Delta h_1}$$

where

X_i = Stage load ratio of stage i

Δh_i = The specific work of stage i

Δh_1 = The specific work of the first stage

Obviously the stage load ratio for the first stage is always one (1).

The meridional curvature of the turbine is determined by the "mean radius ratio" defined by

$$Y_i = \frac{Um_i}{Um_1}$$

where

Y_i = The mean radius ratio of stage i

Um_i = Mean blade speed of stage i

Um_1 = Mean blade speed of stage 1

Also for the first stage this parameter is always one by definition.

Axial acceleration of the flow across the rotor is given by the "axial velocity ratio" defined as

$$Z_i = \frac{Vx_{2,i}}{Vx_{1,i}}$$

where

Z_i = the axial velocity ratio of stage i

$Vx_{1,i}$ = rotor inlet axial velocity of stage i

$Vx_{2,i}$ = rotor exit axial velocity of stage i

In addition to the aero-thermal aspects of the program, provision is made for determining blade root stress for each rotor. Blade root stress is determined for uniform cross section blades, hollow blades, tapered blades or a combination of hollowing and tapering. The radial distribution of blade cross section area is given by

$$\frac{A(r)}{A_b} = B + C\,\phi + D\,\phi^2$$

$$\phi = \frac{r - R_h}{R_T - R_h}$$

$$\xi = \frac{R_b - R_h}{R_T - R_h}$$

where

$A(r)$ = blade cross section area at any radius r

A_b = blade cross section area at the point where area begins to change

B = constant

C = constant

D = constant

r = radius corresponding to $A(r)$

R_h = hub radius

R_T = tip radius

R_b = radius at which area begins to change

$\emptyset$ = non-dimensional radius

δ = $\emptyset$ at which area begins to change

The centripetal stress equation is then dependent only on the constants B, C, D and δ. Although the precise blade geometry will generally not be known in the initial turbine design phase, the required constants may be determined from a similar family of blades with reasonable accuracy. If the blades are of uniform cross section, then

$$B = 1$$
$$C = 0$$
$$D = 0$$

and the stress equation is independent of δ.

Assuming symetrical beam bending, the bending stress at the blade root is given by

$$\sigma_b = \frac{M}{Z}$$

where

σ_b = bending stress

M = bending moment

Z = section modulus

and the section modulus is assumed to be

$$Z = \xi \, Ct^2$$

where

ξ = section modulus constant

C = blade chord

t = blade thickness

The bending stress equation can then be reduced to a form which is dependent on the following blade properties:

Solidity

Aspect Ratio

Thickness/Chord ratio

Section modulus constant (ξ)

If a blade were of rectangular cross section then

$$\xi = 1/6$$

For actual blades, ξ may be only fifty or sixty percent of this theoretical value.

The stress calculation may be done at a speed other than that for which nominal performance is done. The speed at which stress is determined is given by

$$N_s = N_n \times F_{os}$$

where

N_s = stress speed (or overspeed)

N_n = nominal speed

F_{os} = overspeed factor

The power used for gas bending stress is then given by

$$SHP_s = SHP_n \times F_{os}^{E_{os}}$$

where

SHP_s = stress shaft power

SHP_n = nominal shaft power

E_{os} = overspeed exponent (normally 3 for turbopumps)

Special features of the program provide for the following:

1. Specification of turbine pressure ratio or turbine weight flow rate, whichever is considered independent.

2. Internal modification of the meridional flow curvature to give all rotors the same tip diameter.

3. Internal modification of one of the following parameters to arrive at some blade root stress limit:

   a. Rotative speed

   b. Mean blade speed

   c. Pressure Ratio

   d. Inlet pressure

4. Single turbine or two turbines in series (two spool).

The maximum number of stages per turbine is ten (ten for each spool in the two spool configuration).

The above discussion is only a brief explanation of the methods employed in this program and is intended to provide the minimum information necessary for program use. A complete report with all equations and numerical solutions employed (AGC RN-TM-0411, Design Point Performance Analysis of Multi Stage Turbines) is currently being written.

C. OPERATING INSTRUCTIONS

Two types of cases should be considered in the following discussion. The first which is the basic case contains all information necessary for the case to be executed and must be the first case for any given job loading. The second type of case may not be used as the first case and is used to change one or more parameters in the previous case. This provides a convenient method of stacking cases, requiring only a few cards. Base cases may also be stacked and is advised if a large number of parameters are to be changed. Loading of each type of case is discussed in detail in the following section. All options are controlled by either a flag or a data switch.

1. Base Case

The card format for each data card is shown on the attached loading sheets (Pages 18, 19, and 20).

Parameters appearing on each card are as follows:

CARD 1 - The date is placed on this card using three two digit fields.

*(1) Month

(2) Day

(3) Year

Leading zeros should be used where necessary to make two digits.

CARD 2 - This card is for gas property data.

(4)	Gas constant	ft/°R
(5)	Specific heat ratio	---
(6)	Constant pressure specific heat	BTU/lb - °R
(7)	Absolute viscosity	lb/ft - sec

These first two cards are unique in that this data may not be altered for successive stacked cases in a given job load.

*NOTE: Circled numbers are parameter numbers and correspond to load sheet numbers.

CARD 3 - This card is for an identifying case number consisting of any six alpha-numeric characters.

(8) Case number

CARDS 4, 5, and 6 - These three cards are title cards and may contain any alpha-numeric data. This information has been divided into three categories (one for each card).

(9) Turbine Application (Card 1)

(10) Turbine Characteristics (Card 2)

(11) Case Objectives (Card 3)

CARD 7 - This card is for the six option control flags and number of spools (one or two). The values to be assigned each flag for the desired case options are shown on page 25.

(12) Radial velocity distribution option flag

(13) Stress option flag

(14) Index page option flag - This option provides for printing a duplicate of the case input data, identical to the first page of output, to be used for filing purposes.

(15) Typewriter option flag - If one of the stress adjusting options is selected (via flag (13)), intermediate values of the adjusting parameter may be observed on the 1130 console typewriter during the adjusting cycle. This is a diagnostic device and is controlled by this flag.

(16) Pressure ratio option flag

(17) Number of spools

(18) Case flag - indicates whether next case is a change case or base case.

CARD 8 - The required pressure ratio is placed on the card. If flag (16) is option five (5), this card <u>must</u> be omitted.

(19) Pressure ratio

The next two cards contain information which is independent of whether the case is for a single or two-spool configuration.

CARD 9

(20)	Turbine flow rate	lb/sec
(21)	First spool, first rotor mean blade speed	ft/sec
(22)	Exhaust collector flange Mach number	---

A value must be input for this parameter regardless of whether an exhaust collector exists on the turbine analyzed or not. Its value must be greater than zero (0) and less than one (1).

(23)	Spool radius ratio	---
	Defined as the ratio of first spool last rotor mean blade radius to second spool first rotor mean blade radius. If the case is for a single spool, any value may appear in this field.	
(24)	Inlet total temperature	^oR
(25)	Inlet total pressure	psia
(26)	Inlet manifold flange Mach number required as is parameter (22).	
(27)	Inlet manifold total pressure loss coefficient defined on page 2.	---

<u>CARD 10</u>

(28)	Exhaust collector total pressure loss coefficient defined on page 2.	---

Parameters (27) and (28) must be input but may be zero (0) in which case the losses of the manifold and/or exhaust collector are zero.

(29)	Inlet tangential velocity	ft/sec
	This parameter is used only if data switch two is up. Its primary use is in single spool analysis of the second spool of a two spool pair where the tangential velocity component leaving the first spool is known.	

<u>CARD 11</u> - This is the first card containing individual spool information. Specifically it contains information pertaining to stress calculations and <u>must</u> be omitted if flag (13) is opiton five (5).

(30)	Rotor material density	lb/in^3
(31)	First spool rotor stress limit	psi
(32)	Over speed factor defined on page 5.	---

(33) Over speed exponent
defined on page 5.

(34) Delta
defined on page 3.

CARD 12

(35)	Shaft power of spool	Hp
(36)	Rotative speed of spool	RPM
(37)	Number of stages in spool	---

The next series of cards contain information pertaining to individual stages. Each card must have as many values as there are stages. Additional values will be ignored.

CARD 13

(38)	Stage reactions	---

CARD 14

(39)	Stage nozzle angles	Degrees

CARD 15

(40)	Stage load ratios - defined on page 2.	---

CARD 16

(41)	Mean radius ratio - defined on page 3.	---

CARD 17

(42)	Axial velocity ratios - defined on page 3.	---

CARD 18

(43)	Nozzle blade loss coefficients defined in reference (1)	---

CARD 19

(44)	Rotor blade loss coefficients defined in Reference (1)	---

CARD 20

(45)	Rotor tip clearance	in.

CARD 21

(46) Rotor aspect ratio ---

CARD 22

(47) Rotor thickness/chord ratio ---

CARD 23

(48) Rotor solidity ---

CARD 24

(49) Rotor blade section modulus constant defined on page 5. ---

CARD 25 - This card has the coefficients determining the blade radial cross sectional area distribution. They are the coefficients of a quadratic equation as defined on pages 3 and 4.

(50) Constant term

(51) Linear term coefficient

(52) Quadratic term coefficient

For a constant cross section blade, the following parameter values must be used:

(34) = 1.0

(50) = 1.0

(51) = 0.0

(52) = 0.0

Cards 21 through 25 contain information pertaining to the stress analysis portion of the program only. They may be omitted if flag (13) is option five (5) but must be included if blade root stress is desired.

The above cards constitute a complete base case for a single spool turbine. If there are two spools, cards 11 through 25 must be repeated for the second spool.

Additional base cases may be stacked by starting over with Card 3. This requires flag (18) to be two (2) for each case preceding a base case.

For a change case flag (18) must be one (1) on the preceding case and the following cards make up the change case:

CARD 1a - This card contains a new case number.

(8) Case number

CARD 2a - This card contains the number of parameters to be changed and the code number of each.

(53) Number of parameters to be changed

(54) Parameter code numbers (as many as indicated by (53)).

Code numbers for each parameter appear on pages 21 through 24 together with restrictions on their use. Code numbers should not be confused with circled parameter numbers.

CARD 3a

(55) New parameter values

New parameters must appear in the same order as the corresponding code numbers on Card 2a, one parameter per card except for parameters with code numbers (25) thru (46) (see page 24).

In addition to those options controlled by the flags on Card 7, other options may be exercised through use of the IBM 1130 Console data switches. Switch 1 is used to control the type of velocity triangle. The normal selection is with this switch off (down) and this normal switch position should be used almost exclusively.

Switch 2 is used in conjunction with the inlet tangential velocity (parameter (29)) and must be on whenever it is desired to input this parameter.

Switch 3 is used to control the constant tip radius option. It causes internal adjustment of the mean radius ratio of successive stages after the first until all rotors have the same tip radius.

For switch positions and their effect, see page 26.

D. RESTRICTIONS

This program is restricted to a maximum of ten stages per spool. The blade loss analysis includes no provision for shock losses, therefore use of the program should be restricted to subsonic and transonic flow.

Selecting the option of controlling blade root stress by internal adjustment of mean blade speed should be done with caution since blade root stress is relatively insensitive to blade speed, at constant rotative speed, and only small adjustments can be made.

E. TIMING (IBM 1130 COMPUTER)

Initial loading of the program requires approximately seven (7) minutes in object deck form. Execution of each case thereafter requires between two (2) and ten (10) minutes depending on the number of stages and the options selected.

F. STORAGE REQUIREMENTS

The core-storage requirement of the mainline program and all of its associated subroutines is approximately 20000 word bits. However, the program is used on the IBM 1130, with only 5000 (aprox.) word bits of core storage, by maintaining the subroutines on a "load on call" (LOCAL) basis.

G. LISTING

A listing of the program with all control cards required for compilation, production of an object, deck and execution of the program on the IBM 1130 computer is attached. Data cards for the following example case are also listed at the end of the program following the "LOCAL" cards.

H. EXAMPLE CASE

The printed output for an example case is attached to exemplify the information generated by the program. This case is for a twin-spool case with seven (7) stages on the first spool and three (3) stages on the second spool. Hydrogen gas properties are used for this case.

Input data for the case is listed on page one (1) and the optional index page of the output. Some of the parameter values listed here may differ from the values appearing on the input data cards. This is the result of program modification of certain input data to satisfy specified options. In any case, the data printed on the first page is consistent with the remaining information generated by the program. Two additional pieces of input information, inlet manifold and exhaust collector Mach numbers, appear on succeeding pages of the output.

Listed on page two (2) of the output are the blade and gas velocities. The radial distribution used (free vortex or non-twisted blades) is listed at the top of this page and on all other pages where it has an effect on the parameters listed. The velocities or velocity components are given for three radial blade positions; hub, mean, and tip; in that order.

The absolute nozzle exit and relative rotor exit Mach numbers are printed on page three (3), again for three radial blade positions.

Mean rotor radius, blade heights, annulus areas, and gas angles are given on page four (4).

On page five (5) pressures and temperatures are given at the various axial stations. One (1) denotes stator exit conditions and two (2) denotes rotor exit conditions.

Turbine performance is listed on page six (6) with individual stage performance preceding over-all performance.

Stress information is given on page seven (7) for each rotor.

If the case is for a two-spool configuration (as is this example), then pages one (1) through seven (7) are repeated for the second spool as pages eight (8) through fourteen (14). Over-all two-spool performance is given on page fifteen (15) and is based on the following four (4) loss configurations:

1. Both spools excluding manifold and exhaust collector losses.
2. Both spools including manifold losses.
3. Both spools including exhaust collector losses.

4. Both spools including manifold and exhaust collector losses.

Parameters listed on the printed output in symbolic form which are not explained elsewhere are defined as follows:

Page 2 and 9 Output

U = Mean blade speed

VU1 = Stator exit tangential gas velocity component

VX1 = Stator exit axial gas velocity component

V1 = Stator exit gas velocity

WU1 = Rotor inlet relative tangential gas velocity component

W1 = Rotor inlet relative gas velocity

VU2 = Rotor exit absolute tangential gas velocity component

VX2 = Rotor exit absolute axial gas velocity component

V2 = Rotor exit absolute gas velocity

WU2 = Rotor exit relative tangential gas velocity component

W2 = Rotor exit relative gas velocity

Page 4 and 11 Output

Blade Height 1 - Stator trailing edge blade height

Blade Height 2 - Rotor trailing edge blade height

Annulus Area 1 - Stator trailing edge annulus area

Annulus Area 2 - Rotor trailing edge annulus area

Page 5 and 12 Output

PT1 - Stator exit total pressure

P1 - Stator exit static pressure

PT2 - Rotor exit total pressure

P2 - Rotor exit static pressure

TT1 - Stator exit total temperature

T1 - Stator exit static temperature

TT2 - Rotor exit absolute total temperature

T2 - Rotor exit static temperature

STAGE PERFORMANCE

LAMDA - Stage Work-Speed Parameter (Reference 1)

DEL H - Stage Specific Work

ETS - Stage Total to Static Efficiency

ETT - Stage Total to Total Efficiency

U/Co - Stage Isentropic Spouting Velocity Ratio

OVER-ALL BLADE PERFORMANCE

(No manifold or exhaust collector losses)

DEL H - Over-all turbine specific work

UMA - Average mean blade speed

U/Co - Over-all isentropic spouting velocity ratio (based on static pressure ratio)

U/Co' - Over-all isentropic spouting velocity ratio (based on total pressure ratio)

PRST - Over-all total to static pressure ratio

PRTT - Over-all total to total pressure ratio

ETST - Over-all total to static efficiency

ETTT - Over-all total to total efficiency

RET - Total reheat factor

RES - Static reheat factor

Following the above performance data is essentially the same information including the manifold loss (page 6) or exhaust collector loss (page 13).

INLET MANIFOLD CONDITIONS

AREA - Inlet manifold flow area

P - Static pressure corresponding to inlet conditions and inlet Mach number

T - Static temperature corresponding to inlet conditions and inlet Mach number

PTME - Manifold exit total pressure

REFERENCE:

(1) Stewart, Warner L.; A Study of Axial-Flow Turbine Efficiency Characteristics In Terms of Velocity Diagram Parameters; ASME Paper Number 61-WA-37.

REPORT TITLE: GAS TURBINE DESIGN PROGRAM, INPUT FORMAT

DATE: 2/8/68 PAGE 18 OF 26

1. DATA OF CARDS 1, 3, 7, 1a, 2a AND THE LAST PARAMETER OF 12 MUST BE RIGHT ADJUSTED WITH NO DECIMAL POINT.
2. DATA OF CARDS 4, 5, 6 MAY BE ANY ALPHA NUMERIC DATA.
3. ALL REMAINING DATA REQUIRES A DECIMAL POINT.
4. SEE ATTACHED SHEET FOR DETAILED EXPLANATION OF PARAMETERS DENOTED BY CIRCLED NUMBERS.

DATE: MONTH, DAY, YEAR (1) (2) (3) — CARD 1

GAS PROPERTIES: GAS CONSTANT, SPECIFIC HEAT RATIO, CONSTANT PRESSURE SPECIFIC HEAT, ABSOLUTE VISCOSITY (4) (5) (6) (7) — CARD 2

REQUIRED FOR EACH LOAD OF THE PROGRAM

START OF FIRST CASE

CASE NUMBER (8) — CARD 3

THREE TITLE CARDS (80 CHARACTERS EACH)

(9) APPLICATION — CARD 4

(10) CHARTERISTICS — CARD 5

(11) OBJECTIVE — CARD 6

CONTROL FLAGS & NUMBER OF SPOOLS: IFLAG, M, JFLAG, KFLAG, MFLAG, LFLAG, INPAR (12) (13) (14) (15) (16) (17) (18) ISW JSW KSW LSW — CARD 7

REQUIRED PRESSURE RATIO (19) — OMIT THIS CARD IF KFLAG = 5 — CARD 8

FLOW RATE, 1st SPOOL 1st ST. MEAN BLADE SP., EXH. FLANGE MACH NO., SPOOL RADIUS RATIO, INLET TOTAL TEMP., INLET TOTAL PRES., INLET MANI. FLANGE AREA, MANI. LOSS COEFFICIENT (20) (21) (22) (23) (24) (25) (26) (27)

EXHAUST COLLECTOR LOSS COEFFICIENT, ##INLET TANGENTIAL VELOCITY (28) (29) — ## USED ONLY IF SWITCH TWO IS UP ## — CARD 10

SPOOL CARD CONT. (STRESS PARAMETERS) MATERIAL DENSITY, STRESS LIMIT OF FIRST SPOOL LAST ROTOR, OVERSPEED FACTOR, OVERSPEED EXPONENT, DELTA (30) (31) (32) (33) (34) — OMIT THIS CARD IF M = 5 — CARD 11

SPOOL HORSEPOWER, ROTATIVE SPEED, NUMBER OF STAGES (35) (36) (37) — CARD 12

FIELDS, 8 CHARACTERS EACH — NEED AS MANY VALUES AS STAGES — CARD 13

CHARACTERS EACH

REPORT TITLE: GAS TURBINE DESIGN PROGRAM, INPUT FORMAT (CONTINUED)

DATE

(40) STAGE LOAD RATIO	(10 FIELDS, 8 CHARACTERS EACH)	NEED AS MANY VALUES AS STAGES	CARD 15
(41) MEAN RADIUS RATIO	(10 FIELDS, 8 CHARACTERS EACH)	NEED AS MANY VALUES AS STAGES	CARD 16
(42) AXIAL [illegible]	(10 FIELDS, 8 CHARACTERS EACH)	NEED AS MANY VALUES AS STAGES	CARD 17
[illegible]OSS COEFFICIENT	(10 FIELDS, 8 CHARACTERS EACH)	NEED AS MANY VALUES AS STAGES	CARD 18
(44) BLADE LOSS COEFFICIENT	(10 FIELDS, 8 CHARACTERS EACH)	NEED AS MANY VALUES AS STAGES	CARD 19
TIP CLEARANCE [illegible]	(10 FIELDS, 8 CHARACTERS EACH)	NEED AS MANY VALUES AS STAGES	CARD 20
[illegible]	(10 FIELDS, 8 CHARACTERS EACH)	(OMIT IF M = 5) NEED AS MANY VALUES AS STAGES	CARD 21
[illegible] RATIO	(10 FIELDS, 8 CHARACTERS EACH)	(OMIT IF M = 5) NEED AS MANY VALUES AS STAGES	CARD 22
[illegible]	(10 FIELDS, 8 CHARACTERS EACH)	(OMIT IF M = 5) NEED AS MANY VALUES AS STAGES	CARD 23
[illegible] CONSTANT	(10 FIELDS, 8 CHARACTERS EACH)	(OMIT IF M = 5) NEED AS MANY VALUES AS STAGES	CARD 24
[illegible] AREA DISTRIBUTION COEFFICIENTS (51) (52)			CARD 25

GAS TURBINE DESIGN PROGRAM, INPUT FORMAT (CONTINUED)

FOR A TWO SPOOL TURBINE (LFLAG = 2) CARDS 11 TO 25 ARE TO BE REPEATED FOR THE SECOND SPOOL. ADDITIONAL CASES MAY BE STACKED BY REPEATING CARDS 3 TO 25

IF THIS OPTION IS SELECTED, THE LAST VARIABLE OF CARD 7 (INPAR) MUST BE 2. IF ONLY A FEW PARAMETERS ARE TO BE CHANGED FROM THE FIRST CASE IN SUCCESIVE CASES, A SECOND OPTION MAY BE SELECTED BY MAKING INPAR = 1 AND ADDING THE FOLLOWING CARDS;

CASE NUMBER

(8) — CARD 1a

NUMBER OF PARAMETERS AND PARAMETER CODE NUMBERS (SEE ATTACHED SHEET FOR CODE NUMBERS)

(53) (54) → (16 FIELDS, 5 CHARACTERS EACH) — CARD 2a

PARAMETERS TO BE CHANGED FROM PREVIOUS CASE IN SAME ORDER AS CODE NUMBERS ON CARD 2a, ONE PARAMETER PER CARD EXCEPT STAGE PARAMETERS CODE NUMBERS 25 THRU 46.

(55) — CARD 3a

SUBJECT

GAS TURBINE DESIGN PROGRAM.......
PARAMETER CHANGE CODE SHEET......

DATE 2/8/68

WORK ORDER

BY K. KIRK

CHK. BY

DATE

CODE NO.	PARAMETER	FORTRAN SYMBOL
1	CHARACTERISTIC TITLE CARD........................	TITL2
2	OBJECTIVE TITLE CARD........................	TITL3
3	BLADE TYPE PARAMETER........................	IFLAG
4	STRESS CALCULATION PARAMETER........................	MI (M)
5	INDEX PAGE PRINT PARAMETER........................	JFLAG
6	PRESSURE RATIO PARAMETER........................	MFLAG
# 7	NUMBER OF SPOOLS........................	LFLAG
## 8	PRESSURE RATIO........................	PREQS; PREQT; PRQOS; PRQOT.
9	FLOW RATE........................	W
10	FIRST STAGE, FIRST SPOOL, MEAN BLADE SPEED............	UM (1)
11	EXHAUST FLANGE MACH NUMBER........................	EMACH
12	SPOOL MEAN RADIUS RATIO........................	RFACT
13	INLET TOTAL TEMPERATURE........................	TTI (1)
14	INLET TOTAL PRESSURE........................	PTI (1)
15	FIRST SPOOL SHAFT HORSEPOWER........................	SHP (1)
16	SECOND SPOOL SHAFT HORSEPOWER........................	SHP (2)
17	FIRST SPOOL ROTATIVE SPEED........................	SP (1)
18	SECOND SPOOL ROTATIVE SPEED........................	SP (2)
19	FIRST SPOOL BLADE LOSS COEFFICIENTS........................	COE (1,1,I) COE (1,2,I)
20	SECOND SPOOL BLADE LOSS COEFFICIENTS........................	COE (2,1,I) COE (2,2,I)
21	FIRST SPOOL MANIFOLD LOSS COEFFICIENT........................	COEM (1)
22	SECOND SPOOL MANIFOLD LOSS CEEFF. (EXH. COLL.).........	COEM(2)
#23	FIRST SPOOL NUMBER OF STAGES........................	N (1)

SUBJECT

GAS TURBINE DESIGN PROGRAM.......
PARAMETER CHANGE CODE SHEET.....CONTINUED

BY K. KIRK

CHK. BY

CODE NO.	PARAMETER	FORTRAN SYMBOL
# 24	SECOND SPOOL NUMBER OF STAGES..........................	N (2)
25	STAGE REACTIONS, FIRST SPOOL...........................	REA (1,I)
26	STAGE REACTIONS, SECOND SPOOL..........................	REA (2,I)
27	NOZZLE ANGLES, FIRST SPOOL.............................	AD1 (1,I)
28	NOZZLE ANGLES, SECOND SPOOL............................	AD1 (2,I)
29	STAGE LOAD RATIOS, FIRST SPOOL.........................	X (1,I)
30	STAGE LOAD RATIOS, SECOND SPOOL........................	X (2,I)
31	MEAN BLADE RATIOS, FIRST SPOOL.........................	Y (1,I)
32	MEAN BLADE RATIOS, SECOND SPOOL........................	Y (2,I)
33	AXIAL VELOCITY RATIOS, FIRST SPOOL.....................	Z (1,I)
34	AXIAL VELOCITY RATIOS, SECOND SPOOL....................	Z (2,I)
35	ROTOR TIP CLEARANCES, FIRST SPOOL......................	CLEAR (1,I)
36	ROTOR TIP CLEARANCES, SECOND SPOOL.....................	CLEAR(2,I)
37	ROTOR ASPECT RATIOS, FIRST SPOOL.......................	ARS (1,I)
38	ROTOR ASPECT RATIOS, SECOND SPOOL......................	ARS (2,I)
39	ROTOR THICKNESS/CHORD RATIO, FIRST SPOOL...............	TCRS (1,I)
40	ROTOR THICKNESS/CHORD RATIO, SECOND SPOOL..............	TCRS (2,I)
41	ROTOR SOLIDITIES, FIRST SPOOL..........................	SOLID (1,I)
42	ROTOR SOLIDITIES, SECOND SPOOL.........................	SOLID (2,I)
43	ROTOR SECTION MODULUS CONSTANT, FIRST SPOOL............	SECON (1,I)
44	ROTOR SECTION MODULUS CONSTANT, SECOND SPOOL...........	SECON (2,I)
45	ROTOR BLADE AREA DISTRIBUTION, FIRST SPOOL.............	ARCON (1,I)
46	ROTOR BLADE AREA DISTRIBUTION, SECOND SPOOL............	ARCON (2,I)
47	ROTOR MATERIAL DENSITY, FIRST SPOOL....................	RHO (1)
48	ROTOR MATERIAL DENSITY, SECOND SPOOL...................	RHO (2)

SUBJECT
GAS TURBINE DESIGN PROGRAM.....
PARAMETER CHANGE CODE SHEET.....CONTINUED

DATE 2/8/68

WORK ORDER

BY K. KIRK

CHK BY

DATE

CODE NO.	PARAMETER	FORTRAN SYMBOL
49	STRESS LIMIT..	STRL
50	OVERSPEED FACTOR, FIRST SPOOL..........................	OSF (1)
51	OVERSPEED FACTOR, SECOND SPOOL.........................	OSF (2)
52	OVERSPEED EXPONENT, FIRST SPOOL........................	CSEXP (1)
53	OVERSPEED EXPONENT, SECOND SPOOL.......................	CSEXP (2)
54	ROTOR BLADE TAPER DEPTH, FIRST SPOOL...................	DELTA (1)
55	ROTOR BLADE TAPER DEPTH, SECOND SPOOL..................	DELTA (2)
56	INLET TANGENTIAL VELOCITY..............................	VU1IN
57	INLET FLANGE MACH NUMBER...............................	BMACH
### 58	INPUT PARAMETER..	INPAR

NOTES:

#	THESE PARAMETERS MAY BE REDUCED FROM THE BASE CASE BUT MAY NOT BE INCREASED FROM THE BASE CASE.
##	THIS PARAMETER NUMBER REFERS TO THE FOLLOWING PARAMETER DEPENDING ON THE MOST RECENT VALUE OF MFLAG;

PREQS FOR MFLAG = 1
PREQT FOR MFLAG = 2
PRQOS FOR MFLAG = 3
PRQOT FOR MFLAG = 4

###	THIS PARAMETER MUST BE CHANGED TO 2 IF A NEW BASE CASE IS TO FOLLOW. (CODE NUMBER IS ALL THAT IS REQUIRED)

IF PARAMETERS 25 THROUGH 46 ARE TO BE CHANGED, THEY MUST BE RESPECIFIED FOR ALL STAGES OF A GIVEN SPOOL.

FOR PARAMETERS 19 AND 20 , BOTH ROTOR AND STATOR LOSS COEFFICIENT OF THE SPOOL MUST BE RESPECIFIED.

SUBJECT

GAS TURBINE DESIGN PROGRAM.......CONTROL FLAGS FOR CARD SEVEN

DATE 2/8/68

WORK ORDER

BY K. KIRK

CHK BY

DATE

GROUP ONE

1 = FREE VORTEX BLADES.
2 = NON TWISTED BLADES.

GROUP TWO

0 = STRESS CALCULATED.
1 = STRESS ADJUSTED BY Um.
2 = STRESS ADJUSTED BY Pti.
3 = STRESS ADJUSTED BY Pr.
4 = STRESS ADJUSTED BY N.
5 = STRESS NOT CALCULATED........(OMIT CARD 11)

GROUP THREE

1 = PRINT INDEX PAGE.
2 = DO NOT PRINT INDEX PAGE.

GROUP FOUR

1 = TYPEWRITER OUTPUT.
2 = NO TYPEWRITER OUTPUT.

GROUP FIVE

1 = PRESSURE RATIO IS MAIN STATIC. } EXCLUDING EXHAUST COLLECTOR
2 = PRESSURE RATIO IS MAIN TOTAL. }
3 = PRESSURE RATIO IS OVERALL STATIC.
4 = PRESSURE RATIO IS OVERALL TOTAL.
5 = NO PRESSURE RATIO REQUIRED.......(OMIT CARD 8)

GROUP SIX

1 = SINGLE SPOOL.
2 = TWO SPOOL.

GROUP SEVEN

1 = NEXT CASE IS CHANGE ONLY.
2 = NEXT CASE IS A COMPLETE CASE.

GROUP EIGHT

ISW=0 — STANDARD VELOCITY TRIANGLE
ISW>0 — VELOCITY TRIANGLE OPTION

GROUP NINE

JSW=0 – Inlet Tangential velocity =0
JSW>0 – Inlet Tangential velocity Input ON CARD 10

GROUP TEN

KSW=0 – ROTOR MEAN LINE MAINTAINED AS ~~INPUT~~
KSW>0 – ROTOR MEAN LINE ADJUSTED FOR ~~constant~~ tip

GROUP ELEVEN

LSW=0 – Input Mach Numbers for Manifold and E.C.
LSW>0 – Input Areas " " " "

SWITCH ONE;
DOWN (STANDARD)......VELOCITY TRIANGLE, TYPE 1.

UP (OPTION)........VELOCITY TRIANGLE, TYPE 2.

SWITCH TWO;
DOWN (STANDARD)......INLET TANGENTIAL VELOCITY IS ASSUMED ZERO AND NOT TO BE SPECIFIED ON INPUT CARD NUMBER 10.

UP (OPTION)........INLET TANGENTIAL VELOCITY IS NOT ZERO AND IS TO BE SPECIFIED ON INPUT CARD NUMBER 10.

SWITCH THREE;
DOWN (STANDARD)......ROTOR BLADE MEAN LINE IS MAINTAINED AS SPECIFIED ON INPUT BY Y(I).

UP (OPTION)........ROTOR BLADE MEAN LINE IS ADJUSTED, USING THE INPUT VALUES OF Y(I) AS AN INITIAL GUESS, TO OBTAIN A CONSTANT RADIUS BLADE TIP LINE.

Not Used ON 1108
SEE NEW FLAGS ISW, JSW, KSW, LSW

PROGRAM

LISTING

```
// JOB T
// FOR
C
C MULTISTAGE AXIAL FLOW TURBINE DESIGN PERFORMANCE ANALYSIS PROGRAM
C K. G. KIRK, DEPT.7740,NUCLEAR ROCKET OPERATIONS, AEROJET GENERAL CORP.
C 3/6/68
C
      SUBROUTINE INPT1                                                  INPT1001
C                                                                       INPT1002
C SUBROUTINE READS IN DATE AND GAS PROPERTIES                           INPT1003
C                                                                       INPT1004
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       INPT1005
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      INPT1006
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), INPT1007
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, INPT1008
     4PROOS,PROOT,PRSMM,PRTMM,                                          INPT1009
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,PFACT,IPAGE,EMACH             INPT1010
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRIOL,   INPT1011
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          INPT1012
      COMMON UM(10),RAS(10),RHS(10),EMACH,INPAR,TMANI,PMANI,            INPT1013
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     INPT1014
     2W2(10),WU2(10),CD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     INPT1015
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   INPT1016
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   INPT1017
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       INPT1018
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)INPT1019
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     INPT1020
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   INPT1021
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), INPT1022
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), INPT1023
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        INPT1024
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      INPT1025
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  INPT1026
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  INPT1027
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)INPT1028
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      INPT1029
     5,RT(10)                                                           INPT1030
    2 FORMAT (3A2/4F10.5)                                               INPT1031
      READ (2,2) IM,ID,IY,R,GAM,CP,VIS                                  INPT1032
      RETURN                                                            INPT1033
      END                                                               INPT1034
// DUP
*STORE      WS  UA  INPT1
*DUMP       UA  CD  INPT1
```

```
// FOR
      SUBROUTINE INPT2 (VU1IN)                                          INPT2001
C                                                                       INPT2002
C SUBROUTINE READS IN ALL DATA FOR BASE CASE                            INPT2003
C EXCEPT DATE AND GAS PROPERTIES                                        INPT2004
C                                                                       INPT2005
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       INPT2006
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      INPT2007
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), INPT2008
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, INPT2009
     4PROOS,PROOT,PRSMM,PRTMM,                                          INPT2010
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             INPT2011
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   INPT2012
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          INPT2013
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            INPT2014
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     INPT2015
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     INPT2016
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   INPT2017
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   INPT2018
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       INPT2019
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)INPT2020
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     INPT2021
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   INPT2022
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), INPT2023
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), INPT2024
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        INPT2025
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      INPT2026
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  INPT2027
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  INPT2028
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)INPT2029
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      INPT2030
     5,RT(10)                                                           INPT2031
    1 FORMAT (10F8.5)                                                   INPT2032
    2 FORMAT (20A4)                                                     INPT2033
    3 FORMAT (A4,A3)                                                    INPT2034
    4 FORMAT (2F10.5,I5)                                                INPT2035
    5 FORMAT (7I5)                                                      INPT2036
    6 FORMAT (8F10.5)                                                   INPT2037
      READ (2,3) CASE1,CASE2                                            INPT2038
      READ (2,2) TITL1                                                  INPT2039
      READ (2,2) TITL2                                                  INPT2040
      READ (2,2) TITL3                                                  INPT2041
      READ (2,5) IFLAG,M,JFLAG,KFLAG,MFLAG,LFLAG,INPAR                  INPT2042
      GO TO (21,22,23,24,25),MFLAG                                      INPT2043
```

```
   21 READ (2,4) PREQS                                                  INPT2044
      GO TO 25                                                          INPT2045
   22 READ (2,4) PREQT                                                  INPT2046
      GO TO 25                                                          INPT2047
   23 READ (2,4) PRQOS                                                  INPT2048
      GO TO 25                                                          INPT2049
   24 READ (2,4) PRQOT                                                  INPT2050
      GO TO 25                                                          INPT2051
   25 READ (2,6) W,UM1(1),EMACH,REACT,TTI(1),PTI(1),BMACH,COEM(1),COEM(2INPT2052
     1),VU1IN                                                           INPT2053
      DO 50 L=1,LFLAG                                                   INPT2054
      IF (M-4) 30,30,35                                                 INPT2055
   30 READ (2,6) RHO(L),STRL(L),OSF(L),OSEXP(L),DELTA(L)                INPT2056
   35 READ (2,4) SHP(L),SP(L),N(L)                                      INPT2057
      K=N(L)                                                            INPT2058
      READ (2,1) (REA(L,I),I=1,K)                                       INPT2059
      READ (2,1) (ADI(L,I),I=1,K)                                       INPT2060
      READ (2,1) (X(L,I),I=1,K)                                         INPT2061
      READ (2,1) (Y(L,I),I=1,K)                                         INPT2062
      READ (2,1) (Z(L,I),I=1,K)                                         INPT2063
      READ (2,1) (COF(L,1,I),I=1,K)                                     INPT2064
      READ (2,1) (COF(L,2,I),I=1,K)                                     INPT2065
      READ (2,1) (CLEAR(L,I),I=1,K)                                     INPT2066
      IF (M-4) 45,45,46                                                 INPT2067
   45 READ (2,1) (ARS(L,I),I=1,K)                                       INPT2068
      READ (2,1) (TCRS(L,I),I=1,K)                                      INPT2069
      READ (2,1) (SOLID(L,I),I=1,K)                                     INPT2070
      READ (2,1) (SECON(L,I),I=1,K)                                     INPT2071
      READ (2,1) (ARCON(L,I),I=1,3)                                     INPT2072
      GO TO 50                                                          INPT2073
   46 DO 47 I=1,3                                                       INPT2074
   47 ARCON(L,I)=0.0                                                    INPT2075
      DO 48 I=1,K                                                       INPT2076
      ARS(L,I)=0.0                                                      INPT2077
      TCRS(L,I)=0.0                                                     INPT2078
      SOLID(L,I)=0.0                                                    INPT2079
   48 SECON(L,I)=0.0                                                    INPT2080
   50 CONTINUE                                                          INPT2081
      RETURN                                                            INPT2082
      END                                                               INPT2083
// DUP
*STORE      WS  UA  INPT2
*DUMP       UA  CD  INPT2
```

```
// FOR
C
C SUBROUTINE READS IN NEW PARAMETER VALUES FOR CHANGE CASE
C
      SUBROUTINE INPT3(MI)
      DIMENSION ICODE(20)
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2),
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L,
     4PRQOS,PRQOT,PRSMM,PRTMM,
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREA1
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),
     3ES(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10),
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10),
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)
     5,RT(10)
    2 FORMAT (20A4)
    3 FORMAT (A4,A3)
    4 FORMAT (16I5)
    5 FORMAT (F10.0)
    6 FORMAT (10F8.0)
      K1=N(1)
      K2=N(2)
      READ (2,3) CASE1,CASE2
      READ (2,4) NUMBR, (ICODE(J),J=1,NUMBR)
      DO 200 J=1,NUMBR
      KCODE=ICODE(J)
      GO TO (20,21,22,23,24,25,26,27,32,33,34,35,36,37,38,39,40,41,42,
```

```
     143,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,   INPT3044
     264,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81),KCODE      INPT3045
  20 READ (2,2) TITL2                                                   INPT3046
     GO TO 200                                                          INPT3047
  21 READ (2,2) TITL3                                                   INPT3048
     GO TO 200                                                          INPT3049
  22 READ (2,4) IFLAG                                                   INPT3050
     GO TO 200                                                          INPT3051
  23 READ (2,4) MI                                                      INPT3052
     GO TO 200                                                          INPT3053
  24 READ (2,4) JFLAG                                                   INPT3054
     GO TO 200                                                          INPT3055
  25 READ (2,4) MFLAG                                                   INPT3056
     GO TO 200                                                          INPT3057
  26 READ (2,4) LFLAG                                                   INPT3058
     GO TO 200                                                          INPT3059
  27 GO TO (28,29,30,31),MFLAG                                          INPT3060
  28 READ (2,5) PREQS                                                   INPT3061
     GO TO 200                                                          INPT3062
  29 READ (2,5) PREQT                                                   INPT3063
     GO TO 200                                                          INPT3064
  30 READ (2,5) PRQOS                                                   INPT3065
     GO TO 200                                                          INPT3066
  31 READ (2,5) PRQOT                                                   INPT3067
     GO TO 200                                                          INPT3068
  32 READ (2,5) W                                                       INPT3069
     GO TO 200                                                          INPT3070
  33 READ (2,5) UM1(1)                                                  INPT3071
     GO TO 200                                                          INPT3072
  34 READ (2,5) EMACH                                                   INPT3073
     GO TO 200                                                          INPT3074
  35 READ (2,5) RFACT                                                   INPT3075
     GO TO 200                                                          INPT3076
  36 READ (2,5) TTI(1)                                                  INPT3077
     GO TO 200                                                          INPT3078
  37 READ (2,5) PTI(1)                                                  INPT3079
     GO TO 200                                                          INPT3080
  38 READ (2,5) SHP(1)                                                  INPT3081
     GO TO 200                                                          INPT3082
  39 READ (2,5) SHP(2)                                                  INPT3083
     GO TO 200                                                          INPT3084
  40 READ (2,5) SP(1)                                                   INPT3085
     GO TO 200                                                          INPT3086
  41 READ (2,5) SP(2)                                                   INPT3087
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```
      GO TO 200                                          INPT3088
   42 READ(2,6) (COE(1,1,I),I=1,K1)                      INPT3089
      READ(2,6) (COE(1,2,I),I=1,K1)                      INPT3090
      GO TO 200                                          INPT3091
   43 READ(2,6) (COE(2,1,I),I=1,K2)                      INPT3092
      READ(2,6) (COE(2,2,I),I=1,K2)                      INPT3093
      GO TO 200                                          INPT3094
   44 READ (2,5) COEM(1)                                 INPT3095
      GO TO 200                                          INPT3096
   45 READ (2,5) COEM(2)                                 INPT3097
      GO TO 200                                          INPT3098
   46 READ (2,4) N(1)                                    INPT3099
      K1=N(1)                                            INPT3100
      GO TO 200                                          INPT3101
   47 READ (2,4) N(2)                                    INPT3102
      K2=N(2)                                            INPT3103
      GO TO 200                                          INPT3104
   48 READ (2,6) (REA(1,I),I=1,K1)                       INPT3105
      GO TO 200                                          INPT3106
   49 READ (2,6) (REA (2,I),I=1,K2)                      INPT3107
      GO TO 200                                          INPT3108
   50 READ (2,6) (AD1 (1,I),I=1,K1)                      INPT3109
      GO TO 200                                          INPT3110
   51 READ (2,6) (AD1 (2,I),I=1,K2)                      INPT3111
      GO TO 200                                          INPT3112
   52 READ (2,6) (X (1,I),I=1,K1)                        INPT3113
      GO TO 200                                          INPT3114
   53 READ (2,6) (X (2,I),I=1,K2)                        INPT3115
      GO TO 200                                          INPT3116
   54 READ (2,6) (Y (1,I),I=1,K1)                        INPT3117
      GO TO 200                                          INPT3118
   55 READ (2,6) (Y (2,I),I=1,K2)                        INPT3119
      GO TO 200                                          INPT3120
   56 READ (2,6) (Z (1,I),I=1,K1)                        INPT3121
      GO TO 200                                          INPT3122
   57 READ (2,6) (Z (2,I),I=2,K2)                        INPT3123
      GO TO 200                                          INPT3124
   58 READ (2,6) (CLEAR(1,I),I=1,K1)                     INPT3125
      GO TO 200                                          INPT3126
   59 READ (2,6) (CLEAR(2,I),I=1,K2)                     INPT3127
      GO TO 200                                          INPT3128
   60 READ (2,6) (ARS(1,I),I=1,K1)                       INPT3129
      GO TO 200                                          INPT3130
   61 READ (2,6) (ARS(2,I),I=1,K2)                       INPT3131
```

```
      GO TO 200                                                         INPT3132
   62 READ (2,6) (TCRS(1,I),I=1,K1)                                     INPT3133
      GO TO 200                                                         INPT3134
   63 READ (2,6) (TCRS(2,I),I=1,K2)                                     INPT3135
      GO TO 200                                                         INPT3136
   64 READ (2,6) (SOLID(1,I),I=1,K1)                                    INPT3137
      GO TO 200                                                         INPT3138
   65 READ (2,6) (SOLID(2,I),I=1,K2)                                    INPT3139
      GO TO 200                                                         INPT3140
   66 READ (2,6) (SECON(1,I),I=1,K1)                                    INPT3141
      GO TO 200                                                         INPT3142
   67 READ (2,6) (SECON(2,I),I=1,K2)                                    INPT3143
      GO TO 200                                                         INPT3144
   68 READ (2,6) (ARCON(1,I),I=1,3)                                     INPT3145
      GO TO 200                                                         INPT3146
   69 READ (2,6) (ARCON(2,I),I=2,3)                                     INPT3147
      GO TO 200                                                         INPT3148
   70 READ (2,5) RHO(1)                                                 INPT3149
      GO TO 200                                                         INPT3150
   71 READ (2,5) RHO(2)                                                 INPT3151
      GO TO 200                                                         INPT3152
   72 READ (2,5) STRL(1)                                                INPT3153
      GO TO 200                                                         INPT3154
   73 READ (2,5) OSF(1)                                                 INPT3155
      GO TO 200                                                         INPT3156
   74 READ (2,5) OSF(2)                                                 INPT3157
      GO TO 200                                                         INPT3158
   75 READ (2,5) OSEXP(1)                                               INPT3159
      GO TO 200                                                         INPT3160
   76 READ (2,5) OSEXP(2)                                               INPT3161
      GO TO 200                                                         INPT3162
   77 READ (2,5) DELTA(1)                                               INPT3163
      GO TO 200                                                         INPT3164
   78 READ (2,5) DELTA(2)                                               INPT3165
      GO TO 200                                                         INPT3166
   79 READ (2,5) VU1IN                                                  INPT3167
      GO TO 200                                                         INPT3168
   80 READ (2,5) BMACH                                                  INPT3169
      GO TO 200                                                         INPT3170
   81 INPAR=2                                                           INPT3171
  200 CONTINUE                                                          INPT3172
      RETURN                                                            INPT3173
      END                                                               INPT3174
// DUP
```

```
*STORE      WS  UA  INPT3
*DUMP       UA  CD  INPT3
```

```
// FOR
      SUBROUTINE LOA
C
C     SUBROUTINE CALCULATES THE STAGE LOADING,SPEED AND LAMDA
C
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,EITI,EISIM,
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHI(2),
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L,
     4PROOS,PROOT,PRSMM,PRTMM,
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRIOL,
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PI2(10),
     4PTO(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2I(10)
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10),
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10),
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)
     5,RT(10)
      K=N(L)
      DHO(L)=550.*SHP(L)/(778.16*W)
      PAO=UM1(L)**2/(32.174*778.16*DHO(L))
      SUX=0.
      DO 10 I=1,K
   10 SUX=SUX+X(L,I)
      DO 100 I=1,K
      IF (I-1) 20,20,30
   20 PAS(I)=PAO*SUX
   30 PAS(I)=Y(L,I)**2*PAS(1)/X(L,I)
      DHS(I)=UM1(L)**2*Y(L,I)**2/(32.174*778.16*PAS(I))
      IF (I-1) 40,40,100
   40 UM(I)=UM1(L)
```

```
  100 UM(I)=Y(L,I)*UM1(L)                                              LOA  044
      RETURN                                                           LOA  045
      END                                                              LOA  046
// DUP
*STORE      WS  UA  LOA
*DUMP       UA  CD  LOA
```

```
// FOR
      SUBROUTINE CALC1
C
C SUBROUTINE CALCULATES VELOCITY PARAMETERS AND MEAN BLADE VELOCITIES
C
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2),
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L,
     4PRQOS,PRQOT,PRSMM,PRTMM,
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10),
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10),
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)
     5,RT(10)
      K=N(L)
C
C DATA SWITCH 1 CONTROLS VELOCITY TRIANGLE BRANCH
C
      CALL DATSW (1,JSW)
      DO 100 I=1,K
C
C CALCULATION OF VELOCITY PARAMETERS
C
      AR1=AD1(L,I)/57.296
      COT(I)=COS(AR1)/SIN(AR1)
      DVU(I)=UM(I)/PAS(I)
      F=0.5*COT(I)**2*(1.-Z(L,I)**2)
```

```
      G=-((1.-REA(L,I))*PAS(I)+0.5)                                      CALC1044
      IF (F-0.) 30,20,30                                                 CALC1045
   20 VEP(I)=-G                                                          CALC1046
      GO TO 35                                                           CALC1047
C                                                                        CALC1048
C VELOCITY TRIANGLE TYPE BRANCH                                          CALC1049
C                                                                        CALC1050
   30 GO TO (32,31),JSW                                                  CALC1051
   31 VEP(I)=(SQRT(1.-4.*F*G)-1.)/(2.*F)                                 CALC1052
      GO TO 35                                                           CALC1053
   32 VEP(I)=(-SQRT(1.-4.*F*G)-1.)/(2.*F)                                CALC1054
C                                                                        CALC1055
C     START CALCULATION OF MEAN BLADE VELOCITIES                         CALC1056
C                                                                        CALC1057
   35 VU1(I)=VEP(I)*DVU(I)                                               CALC1058
      VX1(I)=VU1(I)*COT(I)                                               CALC1059
      V1(I)=VU1(I)/SIN (AR1)                                             CALC1060
      WU1(I)=VU1(I)-UM(I)                                                CALC1061
      BR1=ATAN (WU1(I)/VX1(I))                                           CALC1062
      BD1(I)=BR1*57.296                                                  CALC1063
      W1(I)=VX1(I)/COS (BR1)                                             CALC1064
      VU2(I)=VU1(I)-DVU(I)                                               CALC1065
      VX2(I)=VX1(I)*Z(L,I)                                               CALC1066
      AR2=ATAN (VU2(I)/VX2(I))                                           CALC1067
      AD2(I)=AR2*57.296                                                  CALC1068
      V2(I)=VX2(I)/COS (AR2)                                             CALC1069
      WU2(I)=VU2(I)-UM(I)                                                CALC1070
      BR2=ATAN (WU2(I)/VX2(I))                                           CALC1071
      BD2(I)=BR2*57.296                                                  CALC1072
  100 W2(I)=VX2(I)/COS (BR2)                                             CALC1073
      RETURN                                                             CALC1074
      END                                                                CALC1075
// DUP
*STORE      WS  UA  CALC1
*DUMP       UA  CD  CALC1
```

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// FOR
      SUBROUTINE CALC2 (KJ,VU1IN)                                       CALC2001
C                                                                       CALC2002
C SUBROUTINE DETERMINES STAGE LOSSES,MANIFOLD LOSSES.                   CALC2003
C PRESSURES,TEMPERATURES.ANNULUS AREAS,BLADE HEIGHTS AND STAGE          CALC2004
C EFFICIENCYS                                                           CALC2005
C                                                                       CALC2006
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       CALC2007
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      CALC2008
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), CALC2009
     3SUMHS(2),PREOS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, CALC2010
     4PROOS,PROOT,PRSMM,PRTMM,                                          CALC2011
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             CALC2012
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   CALC2013
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          CALC2014
      COMMON UM(10),PAS(10),DHS(10),EMACH,INPAR,TMANI,PMANI,            CALC2015
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     CALC2016
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     CALC2017
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   CALC2018
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   CALC2019
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       CALC2020
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)CALC2021
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     CALC2022
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   CALC2023
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), CALC2024
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), CALC2025
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        CALC2026
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      CALC2027
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  CALC2028
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  CALC2029
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)CALC2030
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      CALC2031
     5,RT(10)                                                           CALC2032
C                                                                       CALC2033
C DATA SWITCH 2 CONTROLS INPUT OF VU1IN                                 CALC2034
C DATA SWITCH 3 CONTROLS TIP RADIUS OPTION                              CALC2035
C                                                                       CALC2036
      CALL DATSW(2,JSW)                                                 CALC2037
      CALL DATSW(3,KSW)                                                 CALC2038
      KJ=1                                                              CALC2039
      J=N(L)                                                            CALC2040
      CON3=GAM/(GAM-1.)                                                 CALC2041
      DO 145 I=1,J                                                      CALC2042
      D=2.*COT(I)**2*VEP(I)**2+(VEP(I)-PAS(I))**2+(VEP(I)-PAS(I)-1.)**2 CALC2043
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      GO TO (30,20),JSW                                                 CALC2044
   20 IF (L-1) 25,25,21                                                 CALC2045
   21 IF (I-1) 55,55,50                                                 CALC2046
   25 IF (I-1) 40,40,50                                                 CALC2047
   30 VU0=VU1IN                                                         CALC2048
      GO TO 55                                                          CALC2049
   40 VU0=0.                                                            CALC2050
      GO TO 55                                                          CALC2051
   50 VU0=VU2(I-1)                                                      CALC2052
   55 C=(1.+2.*COT(I)**2)*VEP(I)**2+(VU0/DVU(I))**2                     CALC2053
      FRO=2.                                                            CALC2054
      GO TO (70,56),JSW                                                 CALC2055
   56 IF(L-1) 57,57,70                                                  CALC2056
   57 IF (I-1) 90,90,70                                                 CALC2057
   70 IF (PAS(I)-0.5) 80,80,90                                          CALC2058
   80 FST=2.*(1.-PAS(I))                                                CALC2059
      GO TO 95                                                          CALC2060
   90 FST=1.                                                            CALC2061
   95 RM(I)=30.*UM(I)/(3.14159*SP(L))                                   CALC2062
      RE=W/(RM(I)*VIS)                                                  CALC2063
      HSAVE=0.0                                                         CALC2064
      SLOSS=COE(L,1,I)                                                  CALC2065
      RLOSS=COE(L,2,I)                                                  CALC2066
      GO TO 97                                                          CALC2067
   96 RLOSS=COE(L,2,I)*(0.802+5.66*CLEAR(L,I)/H2(I))                    CALC2068
      SLOSS=COE(L,1,I)*(0.802+5.66*CLEAR(L,I)/H2(I))                    CALC2069
      HSAVE=H2(I)                                                       CALC2070
   97 STL=SLOSS /(2.*32.174*778.16*COT(I)*RE**0.2)*(FST*C*DVU(I)**2)    CALC2071
      A=(FST*SLOSS*C+FRO*RLOSS*D)/(RE**0.2*COT(I))                      CALC2072
      ETT(I)=PAS(I)/(PAS(I)+0.5*A)                                      CALC2073
      IF (I-1) 100,100,110                                              CALC2074
  100 TT1(I)=TTI(L)                                                     CALC2075
      GO TO (101,102),L                                                 CALC2076
C                                                                       CALC2077
C INLET MANIFOLD CONDITIONS DETERMINED                                  CALC2078
C                                                                       CALC2079
  101 FMACH=1.+(GAM-1.)/2.*BMACH**2                                     CALC2080
      TMANI=TTI(1)/FMACH                                                CALC2081
      PMANI=PTI(1)/FMACH**CON3                                          CALC2082
      PTME(1)=PTI(1)/(1.+COEM(1)*(1.-1./FMACH**CON3))                   CALC2083
      AREAI=W/PTI(1)*SORT(R*TTI(1)/GAM/32.174)*FMACH**((GAM+1.)/(2.*    CALC2084
     1(GAM-1.)))/BMACH                                                  CALC2085
      PTO(I)=PTME(1)                                                    CALC2086
      GO TO 120                                                         CALC2087
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  102 PTO(I)=PTI(2)                                                    CALC2088
      GO TO 120                                                        CALC2089
  110 TT1(I)=TT2(I-1)                                                  CALC2090
      PTO(I)=PT2(I-1)                                                  CALC2091
  120 TT2(I)=TT1(I)-DHS(I)/CP                                          CALC2092
      RMF(I)=12.*RM(I)                                                 CALC2093
C                                                                      CALC2094
C TOTAL PRESSURE RATIO CALCULATED FROM EFFICIENCY AND STAGE SPECIFIC   CALC2095
C WORK                                                                 CALC2096
C                                                                      CALC2097
      PRT(I)=1./(1.-DHS(I)/(ETT(I)*CP*TT1(I)))**CON3                   CALC2098
      CON1=2.*32.174*778.16*CP                                         CALC2099
      T1(I)=TT1(I)-V1(I)**2/CON1                                       CALC2100
      T2(I)=TT2(I)-V2(I)**2/CON1                                       CALC2101
      PRN(I)=(1.-STL/(CP*T1(I)))**CON3                                 CALC2102
      PT1(I)=PTO(I)*PRN(I)                                             CALC2103
      PT2(I)=PTO(I)/PRT(I)                                             CALC2104
      P1(I)=PT1(I)*(T1(I)/TT1(I))**CON3                                CALC2105
      P2(I)=PT2(I)*(T2(I)/TT2(I))**CON3                                CALC2106
      PRS(I)=PTO(I)/P2(I)                                              CALC2107
      ETS(I)=DHS(I)/(CP*TT1(I)*(1.-(1./PRS(I))**(1./CON3)))            CALC2108
      RO1=144.*P1(I)/(R*T1(I))                                         CALC2109
      RO2=144.*P2(I)/(R*T2(I))                                         CALC2110
      AN1(I)=144.*W/(RO1*VX1(I))                                       CALC2111
      AN2(I)=144.*W/(RO2*VX2(I))                                       CALC2112
      IF (N(L)-1) 123,123,124                                          CALC2113
  123 RMA(1)=RMF(1)                                                    CALC2114
      GO TO 128                                                        CALC2115
  124 IF (I-2) 127,125,126                                             CALC2116
C                                                                      CALC2117
C     NOZZLE MEAN RADIUS FOR THE FIRST STAGE IS THAT OF THE FIRST STAGE CALC2118
C     ROTOR PLUS THE DIFFERENCE BETWEEN THE FIRST STAGE ROTOR AND      CALC2119
C     SECOND STAGE NOZZLE MEAN RADII                                   CALC2120
C                                                                      CALC2121
  125 RMA(1)=(3.*RMF(1)-RMF(2))/2.                                     CALC2122
      H1(1)=AN1(1)/(2.*3.14159*RMA(1))                                 CALC2123
      RMA(2)=(RMF(1)+RMF(2))/2.                                        CALC2124
      H1(2)=AN1(2)/(2.*3.14159*RMA(2))                                 CALC2125
      GO TO127                                                         CALC2126
C                                                                      CALC2127
C     THE MEAN RADIUS OF ALL NOZZLES BUT THE FIRST IS THE AVERAGE OF   CALC2128
C     THE MEAN RADII OF THE UPSTREAM AND DOWNSTREAM ROTORS             CALC2129
C                                                                      CALC2130
  126 RMA(I)=(RMF(I)+RMF(I-1))/2.                                      CALC2131
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126 H1(I)=AN1(I)/(2.*3.14159*RMA(I))                           CALC2132
127 H2(I)=AN2(I)/(2.*3.14159*RMF(I))                           CALC2133
    RT(I)=RMF(I)+H2(I)/2.                                      CALC2134
    IF(ABS(1.-HSAVE/H2(I))-.001) 129,129,96                    CALC2135
129 GO TO (135,145),KSW                                        CALC2136
135 IF (ABS(RT(1)-RT(I))-0.001) 145,145,140                    CALC2137
140 KJ=2                                                       CALC2138
    Y(L,I)=(RT(1)-H2(1)/2.)/RMF(1)                             CALC2139
145 CONTINUE                                                   CALC2140
    IF (LFLAG-1) 200,200,190                                   CALC2141
190 VU0=VU2(J)                                                 CALC2142
200 RETURN                                                     CALC2143
    END                                                        CALC2144
// DUP
*STORE        WS  UA  CALC2
*DUMP         UA  CD  CALC2
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// FOR
      SUBROUTINE CALC9                                                  CALC9001
C                                                                       CALC9002
C SUBROUTINE DETERMINES EXHAUST COLLECTOR LOSSES AND CONDITIONS         CALC9003
C                                                                       CALC9004
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       CALC9005
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTIM(2),EISI,EIII,EISIM,      CALC9006
     2ETITM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), CALC9007
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, CALC9008
     4PRQOS,PRQOT,PRSMM,PRTMM,                                          CALC9009
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             CALC9010
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   CALC9011
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          CALC9012
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            CALC9013
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     CALC9014
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     CALC9015
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   CALC9016
     4PTO(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   CALC9017
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       CALC9018
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)CALC9019
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     CALC9020
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   CALC9021
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), CALC9022
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), CALC9023
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        CALC9024
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      CALC9025
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  CALC9026
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  CALC9027
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)CALC9028
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      CALC9029
     5,RT(10)                                                           CALC9030
      J=N(L)                                                            CALC9031
      CON3=GAM/(GAM-1.)                                                 CALC9032
      GO TO (150,129) ,LFLAG                                            CALC9033
  129 GO TO (200,150),L                                                 CALC9034
  150 FMACH=1.+(GAM-1.)/2.*EMACH**2                                     CALC9035
      PTME(2)=PT2(J)/(1.+COEM(2)*(1.-1./FMACH**CON3))                   CALC9036
      AREAF=W/PTME(2)*SQRT(R*TT2(J)/GAM/32.174)*FMACH**((GAM+1.)/(2.*   CALC9037
     1(GAM-1.)))/EMACH                                                  CALC9038
      PECE=PTME(2)/FMACH**CON3                                          CALC9039
      TECE=TT2(J)/FMACH                                                 CALC9040
  200 RETURN                                                            CALC9041
      END                                                               CALC9042
// DUP
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*STORE        WS   UA   CALC9
*DUMP         UA   CD   CALC9
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// FOR
      SUBROUTINE CALC3                                                  CALC3001
C                                                                       CALC3002
C SUBROUTINE DETERMINES OVERALL TURBINE PERFORMANCE                     CALC3003
C                                                                       CALC3004
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       CALC3005
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      CALC3006
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), CALC3007
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, CALC3008
     4PRQOS,PRQOT,PRSMM,PRTMM,                                          CALC3009
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             CALC3010
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRIOL,   CALC3011
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          CALC3012
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            CALC3013
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     CALC3014
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     CALC3015
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PI1(10),PI2(10),   CALC3016
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UI(10),VU1I(10),AD1I(10),   CALC3017
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       CALC3018
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)CALC3019
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     CALC3020
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   CALC3021
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), CALC3022
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),I2I(10), CALC3023
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        CALC3024
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      CALC3025
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  CALC3026
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  CALC3027
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),ICRS(2,10)CALC3028
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      CALC3029
     5,RT(10)                                                           CALC3030
C                                                                       CALC3031
C     CALCULATION OF OVERALL PERFORMANCE                                CALC3032
C                                                                       CALC3033
      CON4=(GAM-1.)/GAM                                                 CALC3034
      K=N(L)                                                            CALC3035
      DO 200 I=1,K                                                      CALC3036
      IF (I-N(L)) 140,130,130                                           CALC3037
  130 PRST(L)=PRST(L)*PRS(I)                                            CALC3038
      SUMHS(L)=SUMHS(L)+DHS(I)/ETS(I)                                   CALC3039
      GO TO 150                                                         CALC3040
  140 PRST(L)=PRST(L)*PRT(I)                                            CALC3041
      SUMHS(L)=SUMHS(L)+DHS(I)/ETT(I)                                   CALC3042
  150 PRTT(L)=PRTT(L)*PRT(I)                                            CALC3043
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      SUMHT(L)=SUMHT(L)+DHS(I)/ETT(I)                                   CALC3044
      CS(I)=SQRT (2.*32.174*DHS(I)*778.16/ETS(I))                       CALC3045
      UC(I)=UM(I)/CS(I)                                                 CALC3046
  200 UMS=UMS+UM(I)                                                     CALC3047
      DV=K                                                              CALC3048
      UMA(L)=UMS/DV                                                     CALC3049
      GO TO (210,220),L                                                 CALC3050
  210 PRSTM(1)=PTI(1)/P2(K)                                             CALC3051
      PRTTM(1)=PTI(1)/PT2(K)                                            CALC3052
      GO TO (215,230),LFLAG                                             CALC3053
  215 PRSOL=PTI(1)/PECE                                                 CALC3054
      PRTOL=PTI(1)/PTME(2)                                              CALC3055
      DHSOL=CP*TTI(1)*(1.-(1./PRSOL)**CON4)                             CALC3056
      DHTOL=CP*TTI(1)*(1.-(1./PRTOL)**CON4)                             CALC3057
      ETSOL=DHO(1)/DHSOL                                                CALC3058
      ETTOL=DHO(1)/DHTOL                                                CALC3059
      UCSOL=UMA(1)/SQRT(2.*32.174*778.16*DHSOL)                         CALC3060
      UCTOL=UMA(1)/SQRT(2.*32.174*778.16*DHTOL)                         CALC3061
      PRSMM=PRSOL                                                       CALC3062
      PRTMM=PRTOL                                                       CALC3063
      ETSMM=ETSOL                                                       CALC3064
      ETTMM=ETTOL                                                       CALC3065
      GO TO 230                                                         CALC3066
  220 PRTTM(2)=PTI(2)/PTME(2)                                           CALC3067
      PRSTM(2)=PTI(2)/PECE                                              CALC3068
  230 DHIS=CP*TTI(L)*(1.-(1./PRST(L))**CON4)                            CALC3069
      DHIT=CP*TTI(L)*(1.-(1./PRTT(L))**CON4)                            CALC3070
      DHISM=CP*TTI(L)*(1.-(1/PRSTM(L))**CON4)                           CALC3071
      DHITM=CP*TTI(L)*(1.-(1./PRTTM(L))**CON4)                          CALC3072
      ETST=DHO(L)/DHIS                                                  CALC3073
      ETTT=DHO(L)/DHIT                                                  CALC3074
      ETSTM=DHO(L)/DHISM                                                CALC3075
      ETTTM=DHO(L)/DHITM                                                CALC3076
      COS=2.*32.174*778.16*DHIS                                         CALC3077
      CO=SQRT (COS)                                                     CALC3078
      UCO=UMA(L)/CO                                                     CALC3079
      UCOT=UMA(L)/SQRT(2.*32.174*778.16*DHIT)                           CALC3080
      COSM=2.*32.174*778.16*DHISM                                       CALC3081
      COM=SQRT (COSM)                                                   CALC3082
      UCOM=UMA(L)/COM                                                   CALC3083
      UCOTM=UMA(L)/SQRT(2.*32.174*778.16*DHITM)                         CALC3084
      RET(L)=SUMHT(L)/DHIT                                              CALC3085
      RES(L)=SUMHS(L)/DHIS                                              CALC3086
      RETURN                                                            CALC3087
```

```
      END                                                    CALC3088
// DUP
*STORE        WS  UA   CALC3
*DUMP         UA  CD   CALC3
```

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// FOR
      SUBROUTINE CALC4                                                  CALC4001
C                                                                       CALC4002
C SUBROUTINE CALCULATES RADIAL VELOCITY DISTRIBUTION FOR FREE VORTEX     CALC4003
C BLADING                                                               CALC4004
C                                                                       CALC4005
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       CALC4006
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),EISI,EITI,EISIM,      CALC4007
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRSI(2),PRTI(2),UMS,SUMHT(2), CALC4008
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, CALC4009
     4PRQOS,PRQOT,PRSMM,PRTMM,                                          CALC4010
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             CALC4011
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   CALC4012
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          CALC4013
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            CALC4014
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     CALC4015
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),EIS(10),EIT(10),E(10),     CALC4016
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   CALC4017
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   CALC4018
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2I(10)       CALC4019
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)CALC4020
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     CALC4021
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   CALC4022
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), CALC4023
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), CALC4024
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        CALC4025
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      CALC4026
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  CALC4027
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  CALC4028
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)CALC4029
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      CALC4030
     5,RT(10)                                                           CALC4031
      K=N(L)                                                            CALC4032
      DO 100 I=1,K                                                      CALC4033
      UT(I)=(RM(I)+H2(I)/24.)*UM(I)/RM(I)                               CALC4034
      VU1T(I)=VU1(I)*RMA(I)/(RMA(I)+H1(I)/2.)                           CALC4035
      VX1T(I)=VX1(I)                                                    CALC4036
      AR1T=ATAN (VU1T(I)/VX1T(I))                                       CALC4037
      AD1T(I)=57.296*AR1T                                               CALC4038
      V1T(I)=VU1T(I)/SIN (AR1T)                                         CALC4039
      WU1T(I)=VU1T(I)-UT(I)                                             CALC4040
      BR1T=ATAN (WU1T(I)/VX1T(I))                                       CALC4041
      BD1T(I)=57.296*BR1T                                               CALC4042
      W1T(I)=VX1T(I)/COS (BR1T)                                         CALC4043
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      VU2T(I)=VU2(I)*RM(I)/(RM(I)+H2(I)/24.)                            CALC4044
      VX2T(I)=VX2(I)                                                    CALC4045
      AR2T=ATAN (VU2T(I)/VX2T(I))                                       CALC4046
      AD2T(I)=57.296*AR2T                                               CALC4047
      V2T(I)=VX2T(I)/COS (AR2T)                                         CALC4048
      WU2T(I)=VU2T(I)-UT(I)                                             CALC4049
      BR2T=ATAN (WU2T(I)/VX2T(I))                                       CALC4050
      BD2T(I)=57.296*BR2T                                               CALC4051
      W2T(I)=VX2T(I)/COS (BR2T)                                         CALC4052
      REAT(I)=1.-(VX1T(I)**2-VX2T(I)**2)/(2.*UT(I)*(VU1T(I)-VU2T(I)))   CALC4053
     1-(VU1T(I)+VU2T(I))/(2.*UT(I))                                     CALC4054
      UH(I)=(RM(I)-H2(I)/24.)*UM(I)/RM(I)                               CALC4055
      VU1H(I)=VU1(I)*RMA(I)/(RMA(I)-H1(I)/2.)                           CALC4056
      VX1H(I)=VX1(I)                                                    CALC4057
      AR1H=ATAN (VU1H(I)/VX1H(I))                                       CALC4058
      AD1H(I)=57.296*AR1H                                               CALC4059
      V1H(I)=VU1H(I)/SIN (AR1H)                                         CALC4060
      WU1H(I)=VU1H(I)-UH(I)                                             CALC4061
      BR1H=ATAN (WU1H(I)/VX1H(I))                                       CALC4062
      BD1H(I)=57.296*BR1H                                               CALC4063
      W1H(I)=VX1H(I)/COS (BR1H)                                         CALC4064
      VU2H(I)=VU2(I)*RM(I)/(RM(I)-H2(I)/24.)                            CALC4065
      VX2H(I)=VX2(I)                                                    CALC4066
      AR2H=ATAN (VU2H(I)/VX2H(I))                                       CALC4067
      AD2H(I)=57.296*AR2H                                               CALC4068
      V2H(I)=VX2H(I)/COS (AR2H)                                         CALC4069
      WU2H(I)=VU2H(I)-UH(I)                                             CALC4070
      BR2H=ATAN (WU2H(I)/VX2H(I))                                       CALC4071
      BD2H(I)=57.296*BR2H                                               CALC4072
      W2H(I)=VX2H(I)/COS (BR2H)                                         CALC4073
  100 REAH(I)=1.-(VX1H(I)**2-VX2H(I)**2)/(2.*UH(I)*(VU1H(I)-VU2H(I)))   CALC4074
     1-(VU1H(I)+VU2H(I))/(2.*UH(I))                                     CALC4075
      RETURN                                                            CALC4076
      END                                                               CALC4077
// DUP
*STORE      WS  UA  CALC4
*DUMP       UA  CD  CALC4
```

```
// FOR
      SUBROUTINE CALC5                                                  CALC5001
C                                                                       CALC5002
C SUBROUTINE CALCULATES HUB AND TIP PRESSURES AND TEMPERATURES FOR      CALC5003
C FREE VORTEX   BLADING                                                 CALC5004
C                                                                       CALC5005
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       CALC5006
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      CALC5007
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), CALC5008
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, CALC5009
     4PRQOS,PRQOT,PRSMM,PRTMM,                                          CALC5010
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             CALC5011
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   CALC5012
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          CALC5013
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            CALC5014
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     CALC5015
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     CALC5016
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   CALC5017
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   CALC5018
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       CALC5019
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)CALC5020
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     CALC5021
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   CALC5022
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), CALC5023
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), CALC5024
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        CALC5025
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      CALC5026
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  CALC5027
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  CALC5028
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),ICRS(2,10)CALC5029
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      CALC5030
     5,RT(10)                                                           CALC5031
      CON1=2.*32.174*778.16*CP                                          CALC5032
      CON3=GAM/(GAM-1.)                                                 CALC5033
      K=N(L)                                                            CALC5034
      DO 100 I=1,K                                                      CALC5035
      TT2T(I)=TT2(I)                                                    CALC5036
      TT2H(I)=TT2(I)                                                    CALC5037
      PT1T(I)=PT1(I)                                                    CALC5038
      PT1H(I)=PT1(I)                                                    CALC5039
      PT2T(I)=PT2(I)                                                    CALC5040
      PT2H(I)=PT2(I)                                                    CALC5041
      T1H(I)=TT1(I)-V1H(I)**2/CON1                                      CALC5042
      T1T(I)=TT1(I)-V1T(I)**2/CON1                                      CALC5043
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      T2H(I)=TT2H(I)-V2H(I)**2/CON1                                     CALC5044
      T2T(I)=TT2T(I)-V2T(I)**2/CON1                                     CALC5045
      P1H(I)=PT1H(I)*(T1H(I)/TT1(I))**CON3                              CALC5046
      P1T(I)=PT1T(I)*(T1T(I)/TT1(I))**CON3                              CALC5047
      P2H(I)=PT2H(I)*(T2H(I)/TT2H(I))**CON3                             CALC5048
  100 P2T(I)=PT2T(I)*(T2T(I)/TT2T(I))**CON3                             CALC5049
      RETURN                                                            CALC5050
      END                                                               CALC5051
// DUP
*STORE      WS  UA  CALC5
*DUMP       UA  CD  CALC5
```

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// F
      SUBROUTINE CALC6
C
C SUBROUTINE CALCULATES STATOR EXIT RADIAL VELOCITY DISTRIBUTION FOR
C NON-TWISTED BLADES USING THE RUNGE-KUTTA METHOD
C
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2),
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L,
     4PRQOS,PRQOT,PRSMM,PRTMM,
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10),
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10),
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)
     5,RT(10)
      DERVP(P,TT1,VU1,RADA,RMA)=      P*VU1**2*(RMA/(RADA*12.))**(2.*
     1SIN(AR1)**2)/(32.174*R*RADA*(TT1-VU1**2*(1.+(COS(AR1)/SIN(AR1))**2
     2)*(RMA/(RADA*12.))**(2.*SIN(AR1)**2)/CON1))
      CON1=2.*32.174*778.16*CP
      CON3=GAM/(GAM-1.)
      J=N(L)
      DO 100 I=1,J
      AR1=AD1(L,I)/57.296
      UT(I)=(RM(I)+H2(I)/24.)*UM(I)/RM(I)
      VU1T(I)=VU1(I)*(RMA(I)/(RMA(I)+H1(I)/2.))**SIN(AR1)**2
      AD1T(I)=AD1(L,I)
      VX1T(I)=VU1T(I)*COT(I)
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      V1T(I)=VU1T(I)/SIN(AR1)                                           CALC6044
      WU1T(I)=VU1T(I)-UT(I)                                             CALC6045
      BR1T=ATAN(WU1T(I)/VX1T(I))                                        CALC6046
      BD1T(I)=57.296*BR1T                                               CALC6047
      W1T(I)=VX1T(I)/COS(BR1T)                                          CALC6048
      UH(I)=(RM(I)-H2(I)/24.)*UM(I)/RM(I)                               CALC6049
      VU1H(I)=VU1(I)*(RMA(I)/(RMA(I)-H1(I)/2.))**SIN(AR1)**2            CALC6050
      AD1H(I)=AD1(L,I)                                                  CALC6051
      VX1H(I)=VU1H(I)*COT(I)                                            CALC6052
      V1H(I)=VU1H(I)/SIN(AR1)                                           CALC6053
      WU1H(I)=VU1H(I)-UH(I)                                             CALC6054
      BR1H=ATAN(WU1H(I)/VX1H(I))                                        CALC6055
      BD1H(I)=57.296*BR1H                                               CALC6056
      W1H(I)=VX1H(I)/COS(BR1H)                                          CALC6057
      K=1                                                               CALC6058
      DELT1=H1(I)/(10.*12.)                                             CALC6059
      PR=P1(I)                                                          CALC6060
      R1=RMA(I)/12.                                                     CALC6061
      GO TO 30                                                          CALC6062
   25 K=K+1                                                             CALC6063
      R1=R1+DELT1                                                       CALC6064
   30 RADA=R1                                                           CALC6065
      PRR=PR                                                            CALC6066
      CK1=DERVP(PRR,TT1(I),VU1(I),RADA,RMA(I))                          CALC6067
      RADA=R1+DELT1/2.                                                  CALC6068
      PRR=PR+DELT1*CK1/2.                                               CALC6069
      CK2=DERVP(PRR,TT1(I),VU1(I),RADA,RMA(I))                          CALC6070
      PRR=PR+DELT1*CK2/2.                                               CALC6071
      CK3=DERVP(PRR,TT1(I),VU1(I),RADA,RMA(I))                          CALC6072
      RADA=R1+DELT1                                                     CALC6073
      PRR=PR+DELT1*CK3                                                  CALC6074
      CK4=DERVP(PRR,TT1(I),VU1(I),RADA,RMA(I))                          CALC6075
      PR=PR+DELT1/6.*(CK1+2.*CK2+2.*CK3+CK4)                            CALC6076
      IF (K-5)  25,35,35                                                CALC6077
   35 P1T(I)=PR                                                         CALC6078
      K=1                                                               CALC6079
      DELT1=-H1(I)/(10.*12.)                                            CALC6080
      PR=P1(I)                                                          CALC6081
      R1=RMA(I)/12.                                                     CALC6082
      GO TO 45                                                          CALC6083
   40 K=K+1                                                             CALC6084
      R1=R1+DELT1                                                       CALC6085
   45 RADA=R1                                                           CALC6086
      PRR=PR                                                            CALC6087
```

```
      CK1=DERVP(PRR,TT1(I),VU1(I),RADA,RMA(I))                          CALC6088
      RADA=R1+DELT1/2.                                                  CALC6089
      PRR=PR+DELT1*CK1/2.                                               CALC6090
      CK2=DERVP(PRR,TT1(I),VU1(I),RADA,RMA(I))                          CALC6091
      PRR=PR+DELT1*CK2/2.                                               CALC6092
      CK3=DERVP(PRR,TT1(I),VU1(I),RADA,RMA(I))                          CALC6093
      RADA=R1+DELT1                                                     CALC6094
      PRR=PR+DELT1*CK3                                                  CALC6095
      CK4=DERVP(PRR,TT1(I),VU1(I),RADA,RMA(I))                          CALC6096
      PR=PR+DELT1/6.*(CK1+2.*CK2+2.*CK3+CK4)                            CALC6097
      IF (K-5)  40,50,50                                                CALC6098
   50 P1H(I)=PR                                                         CALC6099
      T1T(I)=TT1(I)-V1T(I)**2/CON1                                      CALC6100
      T1H(I)=TT1(I)-V1H(I)**2/CON1                                      CALC6101
      PT1T(I)=P1T(I)*(TT1(I)/T1T(I))**CON3                              CALC6102
  100 PT1H(I)=P1H(I)*(TT1(I)/T1H(I))**CON3                              CALC6103
      RETURN                                                            CALC6104
      END                                                               CALC6105
// DUP
*STORE      WS  UA  CALC6
*DUMP       UA  CD  CALC6
```

```
// FOR
      SUBROUTINE CALC7                                                    CALC7001
C                                                                         CALC7002
C SUBROUTINE CALCULATES ROTOR EXIT RADIAL VELOCITY DISTRIBUTION FOR      CALC7003
C NON-TWISTED BLADES USING THE RUNGE-KUTTA METHOD                         CALC7004
C                                                                         CALC7005
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),         CALC7006
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,        CALC7007
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2),  CALC7008
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L,  CALC7009
     4PRQOS,PRQOT,PRSMM,PRTMM,                                            CALC7010
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,FMACH               CALC7011
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,     CALC7012
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                            CALC7013
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,              CALC7014
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),       CALC7015
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),       CALC7016
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),     CALC7017
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),     CALC7018
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)         CALC7019
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)CALC7020
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),       CALC7021
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),     CALC7022
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10),  CALC7023
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10),  CALC7024
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)         CALC7025
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),        CALC7026
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                    CALC7027
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(   CALC7028
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)CALC7029
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)        CALC7030
     5,RT(10)                                                             CALC7031
      DERV(VU2R,RAD,RADA,VU1,RMA)=OMEGA-((VU2R/RAD)**2+VU1*OMEGA*(RMA/(RCALC7032
     1ADA*12.))**SIN(AR1)**2*COS(AR1)**2-RAD*OMEGA**2)/((1.+COTB**2)*(VUCALC7033
     22R-RAD*OMEGA))                                                      CALC7034
      VU1R(VU1,RMA)=VU1*(RMA/(RADA*12.))**SIN(AR1)**2                     CALC7035
      TTR(TT1)=TT1-RAD*OMEGA*(VU1RR-VU2RR)/(32.174*778.16*CP)             CALC7036
      TR(TTRR)=TTRR-(VU2RR**2+VX2RR**2)/(2.*32.174*778.16*CP)             CALC7037
      VX2R(VU2RR)=(VU2RR-RAD*OMEGA)*COS(BR2)/SIN(BR2)                     CALC7038
      DERVP(PRR)=PRR*VU2RR**2/(32.174*R*TRR*RAD)                          CALC7039
      OMEGA=3.14159*SP(L)/30.                                             CALC7040
      CON3=GAM/(GAM-1.)                                                   CALC7041
      J=N(L)                                                              CALC7042
      DO 100 I=1,J                                                        CALC7043
```

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      AR1=AD1(L,I)/57.296                                               CALC7044
      BR2=BD2(I)/57.296                                                 CALC7045
      COTB=COS(BR2)/SIN(BR2)                                            CALC7046
      DO 100 NDIR=1,2                                                   CALC7047
      K=1                                                               CALC7048
      GO TO (10,15),NDIR                                                CALC7049
   10 DELT1=H1(I)/(10.*12.)                                             CALC7050
      DELT2=H2(I)/(10.*12.)                                             CALC7051
      GO TO 20                                                          CALC7052
   15 DELT1=-H1(I)/(10.*12.)                                            CALC7053
      DELT2=-H2(I)/(10.*12.)                                            CALC7054
   20 VU2R=VU2(I)                                                       CALC7055
      PR=P2(I)                                                          CALC7056
      R1=RMA(I)/12.                                                     CALC7057
      R2=RM(I)                                                          CALC7058
      GO TO 30                                                          CALC7059
   25 K=K+1                                                             CALC7060
      R1=R1+DELT1                                                       CALC7061
      R2=R2+DELT2                                                       CALC7062
   30 RADA=R1                                                           CALC7063
      RAD=R2                                                            CALC7064
      VU2RR=VU2R                                                        CALC7065
      CK1=DERV(VU2RR,RAD,RADA,VU1(I),RMA(I))                            CALC7066
      VU1RR=VU1R(VU1(I),RMA(I))                                         CALC7067
      TTRR=TTR(TT1(I))                                                  CALC7068
      VX2RR=VX2R(VU2RR)                                                 CALC7069
      TRR=TR(TTRR)                                                      CALC7070
      PRR=PR                                                            CALC7071
      CKP1=DERVP(PRR)                                                   CALC7072
      RADA=R1+DELT1/2.                                                  CALC7073
      RAD=R2+DELT2/2.                                                   CALC7074
      VU2RR=VU2R+DELT2*CK1/2.                                           CALC7075
      CK2=DERV(VU2RR,RAD,RADA,VU1(I),RMA(I))                            CALC7076
      VU1RR=VU1R(VU1(I),RMA(I))                                         CALC7077
      TTRR=TTR(TT1(I))                                                  CALC7078
      VX2RR=VX2R(VU2RR)                                                 CALC7079
      TRR=TR(TTRR)                                                      CALC7080
      PRR=PR+DELT2*CKP1/2.                                              CALC7081
      CKP2=DERVP(PRR)                                                   CALC7082
      VU2RR=VU2R+DELT2*CK2/2.                                           CALC7083
      CK3=DERV(VU2RR,RAD,RADA,VU1(I),RMA(I))                            CALC7084
      VU1RR=VU1R(VU1(I),RMA(I))                                         CALC7085
      TTRR=TTR(TT1(I))                                                  CALC7086
      VX2RR=VX2R(VU2RR)                                                 CALC7087
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      TRR=TR(TTRR)                                                      CALC7088
      PRR=PR+DELT2*CKP2/2.                                              CALC7089
      CKP3=DERVP(PRR)                                                   CALC7090
      RADA=R1+DELT1                                                     CALC7091
      RAD=R2+DELT2                                                      CALC7092
      VU2RR=VU2R+DELT2*CK3                                              CALC7093
      CK4=DERV(VU2RR,RAD,RADA,VU1(I),RMA(I))                            CALC7094
      VU1RR=VU1R(VU1(I),RMA(I))                                         CALC7095
      TTRR=TTR(TT1(I))                                                  CALC7096
      VX2RR=VX2R(VU2RR)                                                 CALC7097
      TRR=TR(TTRR)                                                      CALC7098
      PRR=PR+DELT2*CKP3                                                 CALC7099
      CKP4=DERVP(PRR)                                                   CALC7100
      VU2R=VU2R+DELT2/6.*(CK1+2.*CK2+2.*CK3+CK4)                        CALC7101
      PR=PR+DELT2/6.*(CKP1+2.*CKP2+2.*CKP3+CKP4)                        CALC7102
      IF (K-5) 25,35,35                                                 CALC7103
   35 GO TO (36,50),NDIR                                                CALC7104
   36 VU2T(I)=VU2R                                                      CALC7105
      P2T(I)=PR                                                         CALC7106
      T2T(I)=TRR                                                        CALC7107
      TT2T(I)=TTRR                                                      CALC7108
      WU2T(I)=VU2T(I)-UT(I)                                             CALC7109
      BD2T(I)=BD2(I)                                                    CALC7110
      VX2T(I)=WU2T(I)*COS(BR2)/SIN(BR2)                                 CALC7111
      AR2T=ATAN(VU2T(I)/VX2T(I))                                        CALC7112
      AD2T(I)=57.296*AR2T                                               CALC7113
      V2T(I)=VX2T(I)/COS(AR2T)                                          CALC7114
      W2T(I)=VX2T(I)/COS(BR2)                                           CALC7115
      REAT(I)=1.-(VX1T(I)**2-VX2T(I)**2)/(2.*UT(I)*(VU1T(I)-VU2T(I)))   CALC7116
     1-(VU1T(I)+VU2T(I))/(2.*UT(I))                                     CALC7117
      GO TO 100                                                         CALC7118
   50 VU2H(I)=VU2R                                                      CALC7119
      P2H(I)=PR                                                         CALC7120
      T2H(I)=TRR                                                        CALC7121
      TT2H(I)=TTRR                                                      CALC7122
      WU2H(I)=VU2H(I)-UH(I)                                             CALC7123
      VX2H(I)=WU2H(I)*COS(BR2)/SIN(BR2)                                 CALC7124
      AR2H=ATAN(VU2H(I)/VX2H(I))                                        CALC7125
      AD2H(I)=57.296*AR2H                                               CALC7126
      V2H(I)=VX2H(I)/COS(AR2H)                                          CALC7127
      BD2H(I)=BD2(I)                                                    CALC7128
      W2H(I)=VX2H(I)/COS(BR2)                                           CALC7129
      PT2T(I)=P2T(I)*(TT2T(I)/T2T(I))**CON3                             CALC7130
      PT2H(I)=P2H(I)*(TT2H(I)/T2H(I))**CON3                             CALC7131
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      REAH(I)=1.-(VX1H(I)**2-VX2H(I)**2)/(2.*UH(I)*(VU1H(I)-VU2H(I)))   CALC7132
     1-(VU1H(I)+VU2H(I))/(2.*UH(I))                                     CALC7133
  100 CONTINUE                                                          CALC7134
      RETURN                                                            CALC7135
      END                                                               CALC7136
// DUP
*STORE      WS  UA  CALC7
*DUMP       UA  CD  CALC7
```

```
// FOR
      SUBROUTINE CALC8                                                  CALC8001
C                                                                       CALC8002
C SUBROUTINE CALCULATES MACH NUMBERS                                    CALC8003
C                                                                       CALC8004
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       CALC8005
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      CALC8006
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), CALC8007
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, CALC8008
     4PRQOS,PRQOT,PRSMM,PRTMM,                                          CALC8009
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             CALC8010
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   CALC8011
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          CALC8012
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            CALC8013
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     CALC8014
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     CALC8015
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   CALC8016
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   CALC8017
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       CALC8018
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)CALC8019
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     CALC8020
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   CALC8021
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), CALC8022
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), CALC8023
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        CALC8024
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      CALC8025
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  CALC8026
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  CALC8027
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)CALC8028
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      CALC8029
     5,RT(10)                                                           CALC8030
C                                                                       CALC8031
C     CALCULATION OF MACH NUMBERS                                       CALC8032
C                                                                       CALC8033
      CON2=32.174*GAM*R                                                 CALC8034
      K=N(L)                                                            CALC8035
      DO 100 I=1,K                                                      CALC8036
      SQ1=SQRT (CON2*T1(I))                                             CALC8037
      SQ2=SQRT (CON2*T2(I))                                             CALC8038
      SQ1H=SQRT (CON2*T1H(I))                                           CALC8039
      SQ1T=SQRT (CON2*T1T(I))                                           CALC8040
      SQ2H=SQRT (CON2*T2H(I))                                           CALC8041
      SQ2T=SQRT (CON2*T2T(I))                                           CALC8042
      AC1(I)=V1(I)/SQ1                                                  CALC8043
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      AC2(I)=W2(I)/SQ2                                                  CALC8044
      AC1H(I)=V1H(I)/SQ1H                                               CALC8045
      AC1T(I)=V1T(I)/SQ1T                                               CALC8046
      AC2H(I)=W2H(I)/SQ2H                                               CALC8047
  100 AC2T(I)=W2T(I)/SQ2T                                               CALC8048
      RETURN                                                            CALC8049
      END                                                               CALC8050
// DUP
*STORE      WS  UA  CALC8
*DUMP       UA  CD  CALC8
```

```
// FOR
      FUNCTION ROOT (A,B,C,D,X,STRES)
C
C FUNCTION SUBPROGRAM DETERMINES A NEW BLADE HEIGHT FOR STRESS
C PRESSURE AND PRESSURE RATIO ADJUSTING OPTIONS USING THE NEWTON RAPHSON
C METHOD
C
   10 FORMAT (//1X,'NO SOLUTION FOR AVERAGE BLADE HEIGHT')
      NCONT=0
      ROOT=X
   45 FH=B/ROOT+A*C*ROOT+A*D*ROOT**2-STRES
      DFH=-B/ROOT**2+A*C+2.*A*D*ROOT
      COR=FH/DFH
      ROOT=ROOT-COR
      NCONT=NCONT+1
      IF(ABS(COR/ROOT)-0.001) 100,100,50
   50 IF(NCONT-30) 45,45,60
   60 WRITE (3,10)
      STOP
  100 RETURN
      END
// DUP
*STORE      WS  UA  ROOT
*DUMP       UA  CD  ROOT
```

```
// FOR
      SUBROUTINE STRES
C
C SUBROUTINE CALCULATES LAST STAGE BLADE ROOT STRESS,TESTS IT AGAINST
C STRESS LIMIT IF REQUIRED AND DETERMINES BRANCH TO CALCULATE OTHER
C BLADE ROOT STRESSES OR TO STRESS ADJUSTING SUBROUTINE
C
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2),
     3SUMHS(2),PREOS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L,
     4PRQOS,PRQOT,PRSMM,PRTMM,
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10),
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10),
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)
     5,RT(10)
      K=N(L)
      SUMW=X(L,1)
      IF (K-1) 11,11,9
    9 DO 10 I=2,K
   10 SUMW=SUMW+X(L,I)
   11 WF(K)=X(L,K)/SUMW
      HAVE(K)=(H1(K)+H2(K))/2.0
      RH=RMF(K)-HAVE(K)/2.0
      F1=ARCON(L,1)/2.*(1.-DELTA(L)**2)+ARCON(L,2)/3.*(1.-DELTA(L)**3)+
     1ARCON(L,3)/4.*(1.-DELTA(L)**4)
      F2=ARCON(L,1)*(1.-DELTA(L))+ARCON(L,2)/2.*(1.-DELTA(L)**2)+ARCON(
```

```
     1L,3)/3.*(1.-DELTA(L)**3)                                          STRES044
      STRC(K)=RHO(L)*HAVE(K)*(3.14159*SP(L)*OSF(L)/30.)**2/386.09*(RH*  STRES045
     1DELTA(L)+HAVE(K)*DELTA(L)**2/2.+HAVE(K)*F1+RH*F2)                 STRES046
      STRB(K)=33000.*SHP(L)*WF(K)*OSF(L)**OSEXP(L)*ARS(L,K)**2/(8.*3.141STRES047
     159**2*OSF(L)*SP(L)*RMF(K)**2*SECON(L,K)*SOLID(L,K)*HAVE(K)/12.*TCRSTRES048
     2S(L,K)**2)                                                        STRES049
      STRT(K)=STRC(K)+STRB(K)                                           STRES050
      IF (M-1) 20,12,12                                                 STRES051
   12 GO TO (15,15,14,15,15) ,NFLAG                                     STRES052
   14 NFLAG=4                                                           STRES053
      IF(STRT(K)-STRL(L))40,40,25                                       STRES054
   15 ERR=ABS(STRL(L)-STRT(K))                                          STRES055
      IF(ERR-200.0)20,20,40                                             STRES056
   20 NFLAG=1                                                           STRES057
   25 IF (K-1) 31,31,26                                                 STRES058
   26 J=K-1                                                             STRES059
      DO 30 I=1,J                                                       STRES060
      WF(I)=X(L,I)/SUMW                                                 STRES061
      HAVE(I)=(H1(I)+H2(I))/2.0                                         STRES062
      RH=RMF(I)-HAVE(I)/2.0                                             STRES063
      STRC(I)=RHO(L)*HAVE(I)*(3.14159*SP(L)*OSF(L)/30.)**2/386.09*(RH*  STRES064
     1DELTA(L)+HAVE(I)*DELTA(L)**2/2.+HAVE(I)*F1+RH*F2)                 STRES065
      STRB(I)=33000.*SHP(L)*WF(I)*OSF(L)**OSEXP(L)*ARS(L,I)**2/(8.*3.141STRES066
     159**2*OSF(L)*SP(L)*RMF(I)**2*SECON(L,I)*SOLID(L,I)*HAVE(I)/12.    STRES067
     2*TCRS(L,I)**2)                                                    STRES068
      WF(I)=WF(I)*100.0                                                 STRES069
   30 STRT(I)=STRC(I)+STRB(I)                                           STRES070
   31 WF(K)=WF(K)*100.0                                                 STRES071
      GO TO 43                                                          STRES072
   40 GO TO (41,41,41,42,42),NFLAG                                      STRES073
   41 NFLAG=2                                                           STRES074
      GO TO 43                                                          STRES075
   42 NFLAG=5                                                           STRES076
   43 RETURN                                                            STRES077
      END                                                               STRES078
// DUP
*STORE      WS  UA  STRES
*DUMP       UA  CD  STRES
```

```
// FOR
      SUBROUTINE STRS1
C
C SUBROUTINE ADJUSTS STRESS BY CHANGING MEAN BLADE SPEED
C
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2),
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L,
     4PRCOS,PROOT,PRSMM,PRTMM,
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10),
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10),
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)
     5,RT(10)
    5 FORMAT (//1X,'NO SOLUTION TO NEW BLADE SPEED')
      K=N(L)
      F1=ARCON(L,1)/2.*(1.-DELTA(L)**2)+ARCON(L,2)/3.*(1.-DELTA(L)**3)+
     1ARCON(L,3)/4.*(1.-DELTA(L)**4)
      F2=ARCON(L,1)*(1.-DELTA(L))+ARCON(L,2)/2.*(1.-DELTA(L)**2)+ARCON(
     1L,3)/3.*(1.-DELTA(L)**3)
      F3=33000.*ARS(L,K)**2/(8.*3.14159**2*SECON(L,K)*SOLID(L,K)*
     1TCRS(L,K)**2/12.)
      HU=(UM(K)**1.50)*HAVE(K)
      NCONT=0
      RU=RMF(K)*UM(K)
   51 FU=STRL(L)-RHO(L)*HU*(3.14159*SP(L)*OSF(L)/30.)**2/(386.09*UM(K)**
     11.5)*(DELTA(L)*(RU/UM(K)-HU/2./UM(K)**1.5)+HU*DELTA(L)**2/2./UM(K)
```

```
     2**                                                                        STRS1044
     31.5+HU*F1/UM(K)**1.5+F2*(RU/UM(K)-HU/2./UM(K)**1.5))-F3*SHP(L)*WF STRS1045
     4(K)*OSF(L)**OSEXP(L)*UM(K)**3.5/(SP(L)*OSF(L)*RU**2*HU)               STRS1046
      DFU=RHO(L)*HU*(3.14159*SP(L)*OSF(L)/30.)**2/386.09*(3./2./UM(K)**  STRS1047
     12.5*(DELTA(L)*(RU/UM(K)-HU/2./UM(K)**1.5)+HU*DELTA(L)**2/2./UM(K)  STRS1048
     2**1.5+HU*F1/UM(K)**1.5+F2*(RU/UM(K)-HU/2./UM(K)**1.5))-1./UM(K)**  STRS1049
     33.5*(DELTA(L)*(3.*HU/4./UM(K)**0.5-RU)-3.*HU*DELTA(L)**2/4./UM(K)  STRS1050
     4**0.5-3.*HU*F1/2./UM(K)**0.5+F2*(3.*HU/4./UM(K)**0.5-RU)))-3.5*F3*STRS1051
     5SHP(L)*WF(K)*OSF(L)**OSEXP(L)*UM(K)**2.5/(SP(L)*OSF(L)*RU**2*HU)   STRS1052
      COR=FU/DFU                                                            STRS1053
      UM(K)=UM(K)-COR                                                       STRS1054
      NCONT=NCONT+1                                                         STRS1055
      IF (ABS(COR/UM(K))-0.001) 53,53,52                                    STRS1056
   52 IF(NCONT-30) 51,51,105                                                STRS1057
   53 TUML=UM(K)                                                            STRS1058
      TUM1=TUML/Y(L,K)                                                      STRS1059
      GO TO 110                                                             STRS1060
  105 WRITE (3,5)                                                           STRS1061
      STOP                                                                  STRS1062
  110 RETURN                                                                STRS1063
      END                                                                   STRS1064
// DUP
*STORE      WS  UA  STRS1
*DUMP       UA  CD  STRS1
```

```
// F
      SUBROUTINE STRS2
C
C SUBROUTINE ADJUSTS STRESS BY CHANGING INLET PRESSURE ,PRESSURE RATIO
C OR ROTATIVE SPEED
C
      DIMENSION Q(4)
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2),
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L,
     4PRQOS,PRQOT,PRSMM,PRTMM,
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10),
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10),
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)
     5,RT(10)
      K=N(L)
      F1=ARCON(L,1)/2.*(1.-DELTA(L)**2)+ARCON(L,2)/3.*(1.-DELTA(L)**3)+
     1ARCON(L,3)/4.*(1.-DELTA(L)**4)
      F2=ARCON(L,1)*(1.-DELTA(L))+ARCON(L,2)/2.*(1.-DELTA(L)**2)+ARCON(
     1L,3)/3.*(1.-DELTA(L)**3)
      F3=33000.*ARS(L,K)**2/(8.*3.14159**2*SECON(L,K)*SOLID(L,K)*
     1TCRS(L,K)**2/12.)
      GO TO (60,70,60,100) ,M
   60 GO TO (110,65,70,70,70) ,NFLAG
   65 NFLAG=3
      GO TO 110
```

```
   70 Q(1)=RHO(L)*(3.14159*SP(L)*OSF(L)/30.)**2/386.09                  STRS2044
      Q(2)=F3*SHP(L)*WF(K)*OSF(L)**OSEXP(L)/(SP(L)*OSF(L)*RMF(K)**2)    STRS2045
      Q(3)=DELTA(L)*RMF(K)*(DELTA(L)+F2)                                STRS2046
      Q(4)=DELTA(L)**2/2.-0.5*(DELTA(L)+F2)+F1                          STRS2047
      THAVE=ROOT(Q(1),Q(2),Q(3),Q(4),HAVE(K),STRL(L))                   STRS2048
      IF(M-3)80,140,140                                                 STRS2049
   80 TPTI=PTI(L)*HAVE(K)/THAVE                                         STRS2050
      GO TO 110                                                         STRS2051
  140 TPRST=PRSTM(L)                                                    STRS2052
      FACT=1.3333333                                                    STRS2053
      C=(1.-(1./PRSTM(L))**((GAM-1.)/GAM))*(HAVE(K)/PRSTM(L)/THAVE)**FACSTRS2054
     1T                                                                 STRS2055
  150 F=1.0-(1.0/TPRST)**((GAM-1.0)/GAM)-C*TPRST**FACT                  STRS2056
      FP=(GAM-1.0)/GAM*(1.0/(TPRST**((2.0*GAM-1.0)/GAM)))-FACT   *C*    STRS2057
     1TPRST**(FACT-1.)                                                  STRS2058
      IF (FP) 160,155,155                                               STRS2059
  155 TPRST=TPRST+1.                                                    STRS2060
      GO TO 150                                                         STRS2061
  160 CORR=F/FP                                                         STRS2062
      TPRST=TPRST-CORR                                                  STRS2063
      IF (ABS(CORR/TPRST)-0.001)110,110,150                             STRS2064
  100 ARA=2.*3.14159*RMF(K)*HAVE(K)                                     STRS2065
      F4=RHO(L)*ARA*(3.14159/30.)**2/60./386.09/UM(K)/OSF(L)            STRS2066
      F5=F4*(DELTA(L)*ARA*(DELTA(L)-1.)/120./UM(K)/OSF(L)+ARA*(F1-F2/2.)STRS2067
     1/60./UM(K)/OSF(L))/144.                                           STRS2068
      F6=F4*30.*UM(K)*OSF(L)*(DELTA(L)+F2)/3.14159                      STRS2069
      F7=F3*SHP(L)*OSF(L)**OSEXP(L)*WF(K)*2.*3.14159**2/30./UM(K)/OSF(L)STRS2070
     1/ARA/12.-STRL(L)                                                  STRS2071
      IF (ABS(ARCON(L,2))+ABS(ARCON(L,3))) 105,104,105                  STRS2072
  104 TSP=SQRT(-F7/F6)/OSF(L)                                           STRS2073
      GO TO 110                                                         STRS2074
  105 TSP=SQRT((-F6+SQRT(F6**2-4.*F5*F7))/2./F5)/OSF(L)                 STRS2075
  110 RETURN                                                            STRS2076
      END                                                               STRS2077
// DUP
*STORE        WS   UA   STRS2
*DUMP         UA   CD   STRS2
```

```
// FOR
      SUBROUTINE OVALL(J)
C
C SUBROUTINE CALCULATES OVERALL TWO-SPOOL PERFORMANCE AND PRINTS THIS
C INFORMATION
C
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2),
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L,
     4PRQOS,PRQOT,PRSMM,PRTMM,
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10),
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10),
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)
     5,RT(10)
      DH(PR)=CP*T*(1.-(1./PR)**CON4)
      ET(DH)=(D1+D2)/DH
      UCOVL(DH)=UMAOL/SQRT(2.*32.174*778.16*DH)
      K=N(2)
      T=TTI(1)
      D1=DHO(1)
      D2=DHO(2)
      DHOVL=DHO(1)+DHO(2)
   10 FORMAT (///6H DATE ,A2,1H-,A2,1H-,A2,32X,30HOVER-ALL TWO-SPOOL PER
     1FORMANCE,38X,4HPAGE,I3///)
   15 FORMAT (41X,38HFIRST SPOOL INLET TO SECOND SPOOL EXIT//)
   20 FORMAT (42X,35HMANIFOLD INLET TO SECOND SPOOL EXIT//)
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25 FORMAT (41X,39HMANIFOLD EXIT TO EXHAUST COLLECTOR EXIT//)          OVALL044
30 FORMAT (40X,40HMANIFOLD INLET TO EXHAUST COLLECTOR EXIT//)         OVALL045
35 FORMAT (100H  I  DEL H     UMA        U/CO       U/CO'     PRST    OVALL046
  1 PRTT       ETST       ETTT        RET        RES /20H   BTU/LB   FTOVALL047
  2/SEC/2F10.1,8F10.3///)                                             OVALL048
40 FORMAT (40X,40HEXHAUST COLLECTOR EXIT FLANGE CONDITIONS///60H      OVALL049
  1AREA     MACH NUM     PT         P         TT         T  /60H    SQOVALL050
  2-IN                   PSIA       PSIA      DEG R     DEG R//F10.2,F10.3OVALL051
  3,4F10.1)                                                           OVALL052
45 FORMAT (1H1)                                                       OVALL053
   CON4=(GAM-1.)/GAM                                                  OVALL054
   PRSOL=PRTT(1)*PRST(2)                                              OVALL055
   PRSOM=PRTTM(1)*PRST(2)                                             OVALL056
   PRSML=PRTT(1)*PRSTM(2)                                             OVALL057
   PRSMM=PRTTM(1)*PRSTM(2)                                            OVALL058
   PRTOL=PRTT(1)*PRTT(2)                                              OVALL059
   PRTOM=PRTTM(1)*PRTT(2)                                             OVALL060
   PRTML=PRTT(1)*PRTTM(2)                                             OVALL061
   PRTMM=PRTTM(1)*PRTTM(2)                                            OVALL062
   DHSOL=DH(PRSOL)                                                    OVALL063
   DHSOM=DH(PRSOM)                                                    OVALL064
   DHSML=DH(PRSML)                                                    OVALL065
   DHSMM=DH(PRSMM)                                                    OVALL066
   DHTOL=DH(PRTOL)                                                    OVALL067
   DHTOM=DH(PRTOM)                                                    OVALL068
   DHTML=DH(PRTML)                                                    OVALL069
   DHTMM=DH(PRTMM)                                                    OVALL070
   ETSOL=ET(DHSOL)                                                    OVALL071
   ETSOM=ET(DHSOM)                                                    OVALL072
   ETSML=ET(DHSML)                                                    OVALL073
   ETSMM=ET(DHSMM)                                                    OVALL074
   ETTOL=ET(DHTOL)                                                    OVALL075
   ETTOM=ET(DHTOM)                                                    OVALL076
   ETTML=ET(DHTML)                                                    OVALL077
   ETTMM=ET(DHTMM)                                                    OVALL078
   UMAOL=(UMA(1)+UMA(2))/2.                                           OVALL079
   UCSOL=UCOVL(DHSOL)                                                 OVALL080
   UCSOM=UCOVL(DHSOM)                                                 OVALL081
   UCSML=UCOVL(DHSML)                                                 OVALL082
   UCSMM=UCOVL(DHSMM)                                                 OVALL083
   UCTOL=UCOVL(DHTOL)                                                 OVALL084
   UCTOM=UCOVL(DHTOM)                                                 OVALL085
   UCTML=UCOVL(DHTML)                                                 OVALL086
   UCTMM=UCOVL(DHTMM)                                                 OVALL087
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```
      DHOOL=DHO(1)+DHO(2)
      SUHTO=SUMHT(1)+SUMHT(2)
      SUHSO=SUMHS(1)+SUMHS(2)
      RESOL=SUHSO/DHSOL
      RESOM=SUHSO/DHSOM
      RESML=SUHSO/DHSML
      RESMM=SUHSO/DHSMM
      RETOL=SUHTO/DHTOL
      RETOM=SUHTO/DHTOM
      RETML=SUHTO/DHTML
      RETMM=SUHTO/DHTMM
      IF (J-1) 200,200,100
  100 IPAGE=IPAGE+1
      WRITE (3,45)
      WRITE (3,10) IM,ID,IY,IPAGE
      WRITE (3,15)
      WRITE (3,35) DHOVL,UMAOL,UCSOL,UCTOL,PRSOL,PRTOL,ETSOL,ETTOL,
     1RESOL,RETOL
      WRITE (3,20)
      WRITE (3,35) DHOVL,UMAOL,UCSOM,UCTOM,PRSOM,PRTOM,ETSOM,ETTOM,
     1RESOM,RETOM
      WRITE (3,25)
      WRITE (3,35) DHOVL,UMAOL,UCSML,UCTML,PRSML,PRTML,ETSML,ETTML,
     1RESML,RETML
      WRITE (3,30)
      WRITE (3,35) DHOVL,UMAOL,UCSMM,UCTMM,PRSMM,PRTMM,ETSMM,ETTMM,
     1RESMM,RETMM
      WRITE (3,40) AREAF,EMACH  ,PTME(2),PECE,TT2(K),TECE
  200 RETURN
      END
// DUP
*STORE      WS  UA  OVALL
*DUMP       UA  CD  OVALL
```

```
// FOR
      SUBROUTINE OUTPT                                                  OUTPT001
C                                                                       OUTPT002
C SUBROUTINE PRINTS INPUT INFORMATION FOR BOTH SPOOLS                   OUTPT003
C                                                                       OUTPT004
      DIMENSION NSW(16)                                                 OUTPT005
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       OUTPT006
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      OUTPT007
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), OUTPT008
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, OUTPT009
     4PRQOS,PROOT,PRSMM,PRTMM,                                          OUTPT010
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PFCE,RFACT,IPAGE,EMACH             OUTPT011
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   OUTPT012
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          OUTPT013
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            OUTPT014
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     OUTPT015
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     OUTPT016
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   OUTPT017
     4PTO(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   OUTPT018
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       OUTPT019
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)OUTPT020
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     OUTPT021
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   OUTPT022
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), OUTPT023
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), OUTPT024
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        OUTPT025
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      OUTPT026
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  OUTPT027
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  OUTPT028
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)OUTPT029
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      OUTPT030
     5,RT(10)                                                           OUTPT031
    3 FORMAT (1H1)                                                      OUTPT032
    5 FORMAT (///5H DATE,A2,1H-,A2,1H-,A2,43X,I2,6H STAGE,48X,4HPAGE,I3,OUTPT033
     1/51X,18HGAS TURBINE DESIGN/56X,8HANALYSIS///)                     OUTPT034
    6 FORMAT (//52X,15HCASE CONDITIONS//3X,5HSHAFT,10X,4HFLOW,7X,11HINLEOUTPT035
     1T TOTAL,6X,11HINLET TOTAL,6X,10HMEAN BLADE,6X,8HROTATIVE,7X,      OUTPT036
     2          9HE.C. LOSS/1X,10HHORSEPOWER,7X,4HRATE,7X,11HTEMPERATUROUTPT037
     3E,7X,8HPRESSURE,10X,5HSPEED,10X,5HSPEED,8X,11HCOEFFICIENT         OUTPT038
     4          /17X,6HLB/SEC,8X,5HDEG R,13X,4HPSIA,12X,6HFT/SEC,10X,3HRPOUTPT039
     5M)                                                                OUTPT040
    7 FORMAT (//52X,15HCASE CONDITIONS//3X,5HSHAFT,8X,4HFLOW,5X,11HINLETOUTPT041
     1 TOTAL,4X,11HINLET TOTAL,4X,10HMEAN BLADE,4X,8HROTATIVE,5X        OUTPT042
     2          ,9HMAN. LOSS,5X,9HE.C. LOSS/1X,10HHORSEPOWER,5X,4HRATE,5XOUTPT043
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  3,11HTEMPERATURE,5X,8HPRESSURE,8X,5HSPEED,8X,5HSPEED,6X,11HCOEFFICIOUTPT044
  4ENT,3X,11HCOEFFICIENT                       /15X,6HLB/SEC,6X,5HDEG R,11OUTPT045
  5X,4HPSIA,10X,6HFT/SEC,8X,3HRPM)                                      OUTPT046
 8 FORMAT (1X,F8.1,6X,F6.2,6X,F6.1,2(9X,F6.1),6X,F7.1,7X,F5.3,9X,F5.3OUTPT047
  1//)                                                                  OUTPT048
10 FORMAT (1H+,48X,13HSPOOL NUMBER ,I2,4H OF ,I2)                       OUTPT049
34 FORMAT (                                 53X,14HGAS PROPERTIES/OUTPT050
  2/17X,3HGAS,18X,13HSPECIFIC HEAT,15X,17HCONSTANT PRESSURE,15X,        OUTPT051
  38HABSOLUTE/15X,8HCONSTANT,19X,5HRATIO,21X,13HSPECIFIC HEAT,17X,      OUTPT052
  49HVISCOSITY/15X,8HFT/DEG R,45X,12HBTU/LB-DEG R,18X,9HLB/FT-SEC)      OUTPT053
13 FORMAT (15X,F7.2,19X,F6.3,24X,F6.3,20X,E11.4)                        OUTPT054
14 FORMAT (//52X,15HCASE CONDITIONS//3X,5HSHAFT,10X,4HFLOW,7X,11HINLEOUTPT055
  1T TOTAL,6X,11HINLET TOTAL,6X,10HMEAN BLADE,6X,8HROTATIVE,7X          OUTPT056
  2         ,9HMAN. LOSS/1X,10HHORSEPOWER,7X,4HRATE,7X,11HTEMPERATUROUTPT057
  3E,7X,8HPRESSURE,10X,5HSPEED,10X,5HSPEED,8X,11HCOEFFICIENT            OUTPT058
  4        /17X,6HLB/SEC,8X,5HDEG R,13X,4HPSIA,12X,6HFT/SEC,10X,3HRPOUTPT059
  5M)                                                                   OUTPT060
17 FORMAT (1X,F8.1,8X,F6.2,8X,F6.1,2(11X,F6.1),8X,F7.1,9X,              OUTPT061
  2F5.3//)                                                              OUTPT062
18 FORMAT (49X,'STAGE INPUT PARAMETERS'//1X,'STAGE',4X,'STAGE',6X,      OUTPT063
  1'NOZZLE',3X,'STAGE',4X,'MEAN',5X,'AXIAL',5X,'NOZZLE',3X,'ROTOR',     OUTPT064
  23X,'ROTOR',4X,'ASPECT',3X,'TH/CD',3X,'SECTION',3X,'SOLIDITY')        OUTPT065
19 FORMAT (2X,I2,6X,F6.3,5X,F5.2,4X,F5.3,3X,F5.3,5X,F5.3,5X,F5.3,4X,   OUTPT066
  1F5.3,3X,F5.3,4X,F4.2,5X,F4.2,5X,F5.3,5X,F5.3)                        OUTPT067
20 FORMAT (6X,'BLADE CROSS SECTION AREA DISTRIBUTION',5X,'DELTA',5X,    OUTPT068
  1'OVERSPEED FACTOR',5X,'OVERSPEED EXPONENT'//3E14.5,F11.3,F15.3,      OUTPT069
  2F23.3//)                                                             OUTPT070
21 FORMAT(9X,'REACTION',4X,'ANGLE',4X,'LOAD',4X,'RADIUS',3X,'VELOCITYOUTPT071
  1',4X,'LOSS',5X,'LOSS',3X,'CLEAR',4X,'RATIO',4X,'RATIO',3X,'MODULUSOUTPT072
  2'/22X,'DEG',5X,'RATIO',3X,'RATIO',5X,'RATIO',5X,'COEFF.',3X,'COEFFOUTPT073
  3.',3X,'IN',24X,'CONST.')                                             OUTPT074
31 FORMAT (1X,18HAPPLICATION-------,20A4)                               OUTPT075
32 FORMAT (100X,11HCASE NUMBER/)                                        OUTPT076
33 FORMAT (1H.,99X,A4,A3)                                               OUTPT077
35 FORMAT (1X,18HCHARACTERISTICS---,20A4)                               OUTPT078
36 FORMAT (1X,18HOBJECTIVE---------,20A4)                               OUTPT079
37 FORMAT (///5H DATE,A2,1H-,A2,1H-,A2,43X,I2,6H STAGE,45X,10HINDEX POUTPT080
  1AGE/51X,18HGAS TURBINE DESIGN/56X,8HANALYSIS///)                     OUTPT081
38 FORMAT (1X,12HSTRESS LIMIT,5X,16HMATERIAL DENSITY,5X,15HPARAMETER OUTPT082
  1INDEX,10X,'DATA SWITCHES ON'/5X,3HPSI,14X,8HLB/CU-IN,/F10.1,F18.3,OUTPT083
  216X,I2)                                                              OUTPT084
40 FORMAT ('+',50X,14I5//)                                              OUTPT085
41 FORMAT ('+',70X,'NONE'//)                                            OUTPT086
42 FORMAT (64X,'DATA SWITCHES ON'/)                                     OUTPT087
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      K=N(L)                                                            OUTPT088
      JFLG=JFLAG                                                        OUTPT089
      KSW=0                                                             OUTPT090
      DO 165 ISW=1,16                                                   OUTPT091
      LSW=ISW-1                                                         OUTPT092
      CALL DATSW (LSW,JSW)                                              OUTPT093
      GO TO (160,165),JSW                                               OUTPT094
  160 KSW=KSW+1                                                         OUTPT095
      NSW(KSW)=LSW                                                      OUTPT096
  165 CONTINUE                                                          OUTPT097
      GO TO (200,210),L                                                 OUTPT098
  200 IPAGE=1                                                           OUTPT099
      GO TO 230                                                         OUTPT100
  210 JFLG=2                                                            OUTPT101
      IF (M-4) 215,215,220                                              OUTPT102
  215 IPAGE=8                                                           OUTPT103
      GO TO 230                                                         OUTPT104
  220 IPAGE=7                                                           OUTPT105
  230 WRITE (3,3)                                                       OUTPT106
      GO TO (115,135),JFLG                                              OUTPT107
  115 WRITE (3,37) IM,ID,IY,K                                           OUTPT108
      GO TO 136                                                         OUTPT109
  134 JFLG=2                                                            OUTPT110
      WRITE (3,3)                                                       OUTPT111
  135 WRITE (3,5) IM,ID,IY,K,IPAGE                                      OUTPT112
  136 WRITE (3,10) L,LFLAG                                              OUTPT113
      WRITE (3,32)                                                      OUTPT114
      WRITE (3,31) TITL1                                                OUTPT115
      WRITE (3,33) CASE1,CASE2                                          OUTPT116
      WRITE (3,35) TITL2                                                OUTPT117
      WRITE (3,36) TITL3                                                OUTPT118
      WRITE (3,34)                                                      OUTPT119
      WRITE (3,13) R,GAM,CP,VIS                                         OUTPT120
      GO TO (118,117) ,LFLAG                                            OUTPT121
  117 GO TO (137,138),L                                                 OUTPT122
  137 WRITE (3,14)                                                      OUTPT123
      GO TO 139                                                         OUTPT124
  138 WRITE (3,6)                                                       OUTPT125
  139 WRITE (3,17) SHP(L),W,TTI(L),PTI(L),UM1(L),SP(L),COEM(L)          OUTPT126
      GO TO 119                                                         OUTPT127
  118 WRITE (3,7)                                                       OUTPT128
      WRITE (3,8)  SHP(L),W,TTI(L),PTI(L),UM1(L),SP(L),COEM(1),COEM(2)  OUTPT129
  119 IF (M-4) 120,120,130                                              OUTPT130
  120 WRITE (3,20) (ARCON(L,I),I=1,3),DELTA(L),OSF(L),OSEXP(L)          OUTPT131
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      WRITE (3,38) STRL(L),RHO(L),M                                     OUTPT132
      GO TO 155                                                         OUTPT133
  130 WRITE (3,42)                                                      OUTPT134
  155 IF (KSW) 128,128,125                                              OUTPT135
  125 WRITE (3,40) (NSW(I),I=1,KSW)                                     OUTPT136
      GO TO 131                                                         OUTPT137
  128 WRITE (3,41)                                                      OUTPT138
  131 WRITE (3,18)                                                      OUTPT139
      WRITE (3,21)                                                      OUTPT140
      WRITE (3,19) (I,REA(L,I),AD1(L,I),X(L,I),Y(L,I),Z(L,I),COE(L,1,I),OUTPT141
     1COE(L,2,I),CLEAR(L,I),ARS(L,I),TCRS(L,I),SECON(L,I),SOLID(L,I),I=1OUTPT142
     2,K)                                                               OUTPT143
      GO TO (134,150),JFLG                                              OUTPT144
  150 RETURN                                                            OUTPT145
      END                                                               OUTPT146
// DUP
*STORE      WS  UA  OUTPT
*DUMP       UA  CD  OUTPT
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// FOR
      SUBROUTINE OUTP1                                                  OUTP1001
C                                                                       OUTP1002
C SUBROUTINE PRINTS ALL CALCULATED INFORMATION EXCEPT STRESS AND        OUTP1003
C PERFORMANCE INFORMATION                                               OUTP1004
C                                                                       OUTP1005
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       OUTP1006
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      OUTP1007
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), OUTP1008
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, OUTP1009
     4PRQOS,PRQOT,PRSMM,PRTMM,                                          OUTP1010
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             OUTP1011
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   OUTP1012
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          OUTP1013
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            OUTP1014
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     OUTP1015
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     OUTP1016
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   OUTP1017
     4PTO(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   OUTP1018
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       OUTP1019
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)OUTP1020
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     OUTP1021
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   OUTP1022
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), OUTP1023
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), OUTP1024
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        OUTP1025
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      OUTP1026
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  OUTP1027
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  OUTP1028
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)OUTP1029
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      OUTP1030
     5,RT(10)                                                           OUTP1031
    3 FORMAT (1H1)                                                      OUTP1032
    6 FORMAT (///5H DATE,A2,1H-,A2,1H-,A2,39X,16HSTAGE VELOCITIES,45X,  OUTP1033
     14HPAGE,I3 //)                                                     OUTP1034
   27 FORMAT (               119H    STAGE      U        VU1   ,  VX1   OUTP1035
     2V1        WU1        W1        VU2        VX2        V2        WU2        W2 OUTP1036
     3  REACTION    /113H             FT/SEC    FT/SEC    FT/SEC    FT/SEC    FOUTP1037
     4T/SEC    FT/SEC    FT/SEC    FT/SEC    FT/SEC    FT/SEC    FT/SEC    )OUTP1038
   19 FORMAT (5X,I2,1X,11F9.1,F9.3/8X,11F9.1,F9.3/8X,11F9.1,F9.3//)     OUTP1039
    7 FORMAT (///5H DATE,A2,1H-,A2,1H-,A2,40X,14HSTAGE GEOMETRY,46X,    OUTP1040
     14HPAGE,I3//)                                                      OUTP1041
   29 FORMAT (   120H       STAGE        MEAN        BLADE        BLADE OUTP1042
     2   ANNULUS       ANNULUS       ALPHA1        BETA1        ALPHA2        BEOUTP1043
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     3TA2)                                                                   OUTP1044
  21 FORMAT (                                                                OUTP1045
     3    72H                      RADIUS     HEIGHT 1     HEIGHT 2     AREA OUTP1046
    41      AREA 2/120H                           IN           IN        IN   OUTP1047
     5      SQ-IN       SQ-IN        DEG         DEG         DEG          OUTP1048
     6 DEG  )                                                                OUTP1049
  22 FORMAT (9X,I2,1X,F12.4,F10.3,2X,F10.3,2X,2F12.3,4F12.2/72X,             OUTP1050
     14F12.2/72X,4F12.2//)                                                   OUTP1051
   8 FORMAT (///5H DATE,A2,1H-,A2,1H-,A2,17X,9HPRESSURES,55X,                OUTP1052
     112HTEMPERATURES,7X,4HPAGE,I3//)                                        OUTP1053
  30 FORMAT (                               120H     STAGE      PT1       P1   OUTP1054
     2    PT2         P2          PRS         PRT                TT1       T1OUTP1055
     3        TT2         T2    )                                            OUTP1056
  23 FORMAT (                                                                OUTP1057
     3                          120H                   PSIA       PSIA       PSIOUTP1058
     4A       PSIA                                         DEG R      DEG R   OUTP1059
     5 DEG R       DEG R/(7X,I2,1X,4F10.1,30X,4F10.1/10X,4F10.1,2F10.3,      OUTP1060
     610X,4F10.1/10X,4F10.1,30X,4F10.1//))                                   OUTP1061
  11 FORMAT (///5H DATE,A2,1H-,A2,1H-,A2,38X,18HSTAGE MACH NUMBERS,44X,OUTP1062
     14HPAGE,I3//)                                                           OUTP1063
  28 FORMAT (    40H      STAGE      ABSOLUTE         RELATIVE /10X,30H      OUTP1064
     2NOZZLE EXIT     ROTOR EXIT/(7X,I2,8X,F5.3,F15.3/17X,F5.3,F15.3/        OUTP1065
     317X,F5.3,F15.3//))                                                     OUTP1066
  25 FORMAT (54X,11HFREE VORTEX//)                                           OUTP1067
  26 FORMAT (51X,18HNON TWISTED BLADES//)                                    OUTP1068
     K=N(L)                                                                  OUTP1069
     WRITE (3,3)                                                             OUTP1070
     IPAGE=IPAGE+1                                                           OUTP1071
     WRITE (3,6) IM,ID,IY,IPAGE                                              OUTP1072
     IF (IFLAG-2) 40,50,50                                                   OUTP1073
  40 WRITE (3,25)                                                            OUTP1074
     GO TO 60                                                                OUTP1075
  50 WRITE (3,26)                                                            OUTP1076
  60 WRITE (3,27)                                                            OUTP1077
     WRITE (3,19) (I,UH(I),VU1H(I),VX1H(I),V1H(I),WU1H(I),W1H(I),            OUTP1078
     1VU2H(I),VX2H(I),V2H(I),WU2H(I),W2H(I),REAH(I),UM(I),VU1(I),VX1(I),OUTP1079
     2V1(I),WU1(I),W1(I),VU2(I),VX2(I),V2(I),WU2(I),W2(I),REA(L,I),UT(I)OUTP1080
     3,VU1T(I),VX1T(I),V1T(I),WU1T(I),W1T(I),VU2T(I),VX2T(I),V2T(I),        OUTP1081
     4WU2T(I),W2T(I),REAT(I),I=1,K)                                          OUTP1082
     WRITE (3,3)                                                             OUTP1083
     IPAGE=IPAGE+1                                                           OUTP1084
     WRITE (3,11) IM,ID,IY,IPAGE                                             OUTP1085
     IF (IFLAG-2) 65,70,70                                                   OUTP1086
  65 WRITE (3,25)                                                            OUTP1087
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      GO TO 75                                                          OUTP1088
   70 WRITE (3,26)                                                      OUTP1089
   75 WRITE (3,28)                    (I,AC1H(I),AC2H(I),AC1(I),AC2(I), OUTP1090
     1AC1T(I),AC2T(I),I=1,K)                                            OUTP1091
      WRITE (3,3)                                                       OUTP1092
      IPAGE=IPAGE+1                                                     OUTP1093
      WRITE (3,7) IM,ID,IY,IPAGE                                        OUTP1094
      IF (IFLAG-2) 80,85,85                                             OUTP1095
   80 WRITE (3,25)                                                      OUTP1096
      GO TO 90                                                          OUTP1097
   85 WRITE (3,26)                                                      OUTP1098
   90 WRITE (3,29)                                                      OUTP1099
      WRITE (3,21)                                                      OUTP1100
      WRITE (3,22)                (I,RMF(I),H1(I),H2(I),AN1(I),AN2(I),  OUTP1101
     1AD1H(I),BD1H(I),                                                  OUTP1102
     1AD2H(I),BD2H(I),AD1(L,I),BD1(I),AD2(I),BD2(I),AD1T(I),BD1T(I),    OUTP1103
     2AD2T(I),BD2T(I),I=1,K)                                            OUTP1104
      WRITE (3,3)                                                       OUTP1105
      IPAGE=IPAGE+1                                                     OUTP1106
      WRITE (3,8) IM,ID,IY,IPAGE                                        OUTP1107
      IF (IFLAG-2) 95,100,100                                           OUTP1108
   95 WRITE (3,25)                                                      OUTP1109
      GO TO 105                                                         OUTP1110
  100 WRITE (3,26)                                                      OUTP1111
  105 WRITE (3,30)                                                      OUTP1112
      WRITE (3,23)                (I,PT1H(I),P1H(I),PT2H(I),P2H(I),TT1(I), OUTP1113
     1T1H(I),TT2H(I),T2H(I),PT1(I),P1(I),PT2(I),P2(I),PRS(I),PRT(I),    OUTP1114
     2TT1(I),T1(I),TT2(I),T2(I),PT1T(I),P1T(I),PT2T(I),P2T(I),TT1(I),   OUTP1115
     3T1T(I),TT2T(I),T2T(I),I=1,K)                                      OUTP1116
      RETURN                                                            OUTP1117
      END                                                               OUTP1118
// DUP
*STORE        WS   UA   OUTP1
*DUMP         UA   CD   OUTP1
```

```
// FOR
      SUBROUTINE OUTP2                                                  OUTP2001
C                                                                       OUTP2002
C SUBROUTINE PRINTS CALCULATED STRESS DATA                              OUTP2003
C                                                                       OUTP2004
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       OUTP2005
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      OUTP2006
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), OUTP2007
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, OUTP2008
     4PRQOS,PROOT,PRSMM,PRTMM,                                          OUTP2009
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             OUTP2010
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   OUTP2011
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          OUTP2012
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            OUTP2013
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     OUTP2014
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     OUTP2015
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   OUTP2016
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   OUTP2017
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       OUTP2018
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)OUTP2019
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     OUTP2020
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   OUTP2021
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), OUTP2022
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), OUTP2023
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        OUTP2024
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      OUTP2025
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  OUTP2026
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  OUTP2027
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)OUTP2028
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      OUTP2029
     5,RT(10)                                                           OUTP2030
    1 FORMAT(///5H DATE,A2,1H-,A2,1H-,A2,35X,23HROTOR BLADE ROOT STRESS,OUTP2031
     142X,4HPAGE,I3 ///)                                                OUTP2032
    2 FORMAT (2X,'STAGE',11X,'MEAN',14X,'AVERAGE',13X,'STAGE',11X,      OUTP2033
     1'CENTRIPETAL',10X,'BENDING',10X,'TOTAL'/17X,'RADIUS',10X,         OUTP2034
     2'BLADE HEIGHT',11X,'LOAD',15X,'STRESS',13X,'STRESS',10X,          OUTP2035
     3'STRESS'/19X,'IN',17X,'IN',15X,'PERCENT',14X,'PSI',16X,'PSI',13X, OUTP2036
     4'PSI'/)                                                           OUTP2037
    3 FORMAT (3X,I2,11X,F7.4,15X,F5.3,13X,F5.1,13X,F8.1,12X,F7.1,8X,F8.1OUTP2038
     1//)                                                               OUTP2039
    4 FORMAT (//2X,80HNOTE.  TURBINE PRESSURE RATIO CANNOT BE ADJUSTED TOUTP2040
     10 ARRIVE AT A STRESS VALUE OF ,F7.1,22H PSI IN THE LAST ROTOR/9X,1OUTP2041
     202HBLADE.  THE ABOVE STRESS VALUES ARE AT A PRESSURE RATIO OF 4.0.OUTP2042
     3  MINIMUM STRESS IS AT A PRESSURE RATIO/9X,21HOF APPROXIMATELY 4.0OUTP2043
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     4.)                                                                OUTP2044
    6 FORMAT (//2X,103HNOTE, NUMBER OF ITERATIONS THROUGH THE STRESS SUBOUTP2045
     1ROUTINE EXCEEDED 15 WITHOUT REACHING THE STRESS LIMIT.)           OUTP2046
   15 FORMAT (1H1)                                                      OUTP2047
      K=N(L)                                                            OUTP2048
      WRITE (3,15)                                                      OUTP2049
      IPAGE=IPAGE+1                                                     OUTP2050
      WRITE (3,1) IM,ID,IY,IPAGE                                        OUTP2051
      WRITE(3,2)                                                        OUTP2052
      WRITE (3,3)(I,RMF(I),HAVE(I)         ,WF(I),STRC(I),STRB(I),     OUTP2053
     1STRT(I),I=1,K)                                                    OUTP2054
      GO TO (10,10,10,5,10,7),NFLAG                                     OUTP2055
    5 WRITE (3,4) STRL(L)                                               OUTP2056
      GO TO 10                                                          OUTP2057
    7 WRITE (3,6)                                                       OUTP2058
   10 RETURN                                                            OUTP2059
      END                                                               OUTP2060
// DUP
*STORE      WS  UA  OUTP2
*DUMP       UA  CD  OUTP2
```

```
// FOR
      SUBROUTINE OUTP3                                                  OUTP3001
C                                                                       OUTP3002
C SUBROUTINE PRINTS CALCULATED PERFORMANCE DATA FOR EACH STAGE AND      OUTP3003
C EACH SPOOL                                                            OUTP3004
C                                                                       OUTP3005
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       OUTP3006
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      OUTP3007
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), OUTP3008
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, OUTP3009
     4PRQOS,PRQOT,PRSMM,PRTMM,                                          OUTP3010
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             OUTP3011
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   OUTP3012
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          OUTP3013
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            OUTP3014
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     OUTP3015
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     OUTP3016
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   OUTP3017
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   OUTP3018
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       OUTP3019
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)OUTP3020
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     OUTP3021
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   OUTP3022
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), OUTP3023
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), OUTP3024
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        OUTP3025
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      OUTP3026
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  OUTP3027
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  OUTP3028
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)OUTP3029
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      OUTP3030
     5,RT(10)                                                           OUTP3031
    3 FORMAT (1H1)                                                      OUTP3032
    1 FORMAT (//47X,25HINLET MANIFOLD CONDITIONS//50H        AREA     MACH OUTP3033
     1NUM       P          T          PTME /50H      SQ-IN           PSIA OUTP3034
     2      DEG-R      PSIA / F10.2,F10.3,3F10.1)                       OUTP3035
    2 FORMAT (40X,40HEXHAUST COLLECTOR EXIT FLANGE CONDITIONS//60H     AOUTP3036
     1REA      MACH NUM      PT         P          TT         T   /60H     SQ-OUTP3037
     2IN                PSIA       PSIA       DEG R      DEG R//F10.2,F10.3,OUTP3038
     34F10.1)                                                           OUTP3039
    4 FORMAT (//26X,68HOVERALL TURBINE PERFORMANCE INCLUDING MANIFOLD ANOUTP3040
     1D EXHAUST COLLECTOR///60H       U/CO        U/CO'       PRST       PRTT  OUTP3041
     2     ETST       ETTT /6F10.3)                                     OUTP3042
    5 FORMAT (//32X,55HOVERALL TURBINE PERFORMANCE INCLUDING EXHAUST COLOUTP3043
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  1LECTOR///60H       U/CO        U/CO'       PRST        PRTT        ETST        OUTP3044
  2 ETTT /6F10.3)                                                                 OUTP3045
 9 FORMAT (///5H DATE,A2,1H-,A2,1H-,A2,38X,17HSTAGE PERFORMANCE,45X,              OUTP3046
  14HPAGE,I3///60H      STAGE      LAMDA      DEL H      ETS         ETT          OUTP3047
  2    U/CO /24X,6HBTU/LB/(7X,I2,1X,F10.3,F10.1,3F10.3/))                         OUTP3048
 10 FORMAT (//47X,25HOVERALL BLADE PERFORMANCE///100H       DEL H               UMOUTP3049
  1A         U/CO        U/CO'       PRST        PRTT        ETST        ETTT     OUTP3050
  2   RET          RES /20H     BTU/LB     FT/SEC/2F10.1,8F10.3)                  OUTP3051
 12 FORMAT (//37X,46HOVERALL TURBINE PERFORMANCE INCLUDING MANIFOLD///OUTP3052
  160H       U/CO        U/CO'       PRST        PRTT        ETST        ETTT /   OUTP3053
  26F10.3)                                                                        OUTP3054
   K=N(L)                                                                         OUTP3055
   WRITE (3,3)                                                                    OUTP3056
   IPAGE=IPAGE+1                                                                  OUTP3057
   WRITE (3,9) IM,ID,IY,IPAGE,(I,PAS(I),DHS(I),ETS(I),ETT(I),UC(I),               OUTP3058
  1I=1,K)                                                                         OUTP3059
   WRITE (3,10) DHO(L),UMA(L),UCO,UCOT,PRST(L),PRTT(L),ETST,ETTT,                 OUTP3060
  1RET(L),RES(L)                                                                  OUTP3061
   GO TO (130,135) ,L                                                             OUTP3062
130 WRITE (3,12) UCOM,UCOTM,PRSTM(L),PRTTM(L),ETSTM,ETTTM                         OUTP3063
   GO TO 140                                                                      OUTP3064
135 WRITE (3,5) UCOM,UCOTM,PRSTM(L),PRTTM(L),ETSTM,ETTTM                          OUTP3065
140 GO TO (125,150),LFLAG                                                         OUTP3066
125 WRITE (3,4) UCSOL,UCTOL,PRSOL,PRTOL,ETSOL,ETTOL                               OUTP3067
150 GO TO (151,152),L                                                             OUTP3068
151 WRITE (3,1) AREAI,BMACH,PMANI,TMANI,PTME(1)                                   OUTP3069
152 GO TO (155,160),LFLAG                                                         OUTP3070
155 WRITE (3,2) AREAF,EMACH,PTME(2),PECE,TT2(K),TECE                              OUTP3071
160 RETURN                                                                        OUTP3072
    END                                                                           OUTP3073
// DUP
*STORE       WS  UA  OUTP3
*DUMP        UA  CD  OUTP3
```

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// FOR
      SUBROUTINE PRATO (MFLG,JK,K)                                      PRATO001
C                                                                       PRATO002
C SUBROUTINE CALCULATES NEW FLOW RATE TO SATISFY PRESSURE RATIO         PRATO003
C REQUIREMENT                                                           PRATO004
C                                                                       PRATO005
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),       PRATO006
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,      PRATO007
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2), PRATO008
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L, PRATO009
     4PROOS,PROOT,PRSMM,PRTMM,                                          PRATO010
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH             PRATO011
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,   PRATO012
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI                          PRATO013
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,            PRATO014
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),     PRATO015
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),     PRATO016
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),   PRATO017
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),   PRATO018
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2T(10)       PRATO019
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)PRATO020
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),     PRATO021
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),   PRATO022
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1T(10), PRATO023
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10), PRATO024
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)        PRATO025
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),      PRATO026
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),                  PRATO027
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(  PRATO028
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)PRATO029
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)      PRATO030
     5,RT(10)                                                           PRATO031
      CON4=(GAM-1.)/GAM                                                 PRATO032
      IF (LFLAG-1) 50,50,40                                             PRATO033
   40 GO TO (60,70,80,90,100),MFLG                                      PRATO034
   50 GO TO (60,70,82,92,100),MFLG                                      PRATO035
   60 IF(ABS(PRSTM(1)-PREQS)-0.01) 100,100,65                           PRATO036
   65 W=550.*SHP(1)/(ETSTM*778.16*CP*TTI(1)*(1.-(1./PREQS)**CON4))      PRATO037
      JK=1                                                              PRATO038
      GO TO 150                                                         PRATO039
   70 IF (ABS(PRTTM(1)-PREQT)-0.01) 100,100,75                          PRATO040
   75 W=550.*SHP(1)/(ETTTM*778.16*CP*TTI(1)*(1.-(1./PREQT)**CON4))      PRATO041
      JK=1                                                              PRATO042
      GO TO 150                                                         PRATO043
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   80 IF(L-1) 81,81,82                                                  PRATO044
   81 L=2                                                               PRATO045
      TTI(2)=TT2(K)                                                     PRATO046
      PTI(2)=PT2(K)                                                     PRATO047
      UM1(2)=SP(2)*3.14159*RM(K)*RFACT/30.                              PRATO048
      JK=1                                                              PRATO049
      GO TO 150                                                         PRATO050
   82 IF (ABS(PRSMM-PRQOS)-0.01) 96,96,85                               PRATO051
   85 W=550.*(SHP(1)+SHP(2))/(ETSMM*778.16*CP*TTI(1)*(1.-(1./PRQOS)     PRATO052
     1**CON4))                                                          PRATO053
      L=1                                                               PRATO054
      JK=1                                                              PRATO055
      GO TO 150                                                         PRATO056
   90 IF (L-1) 91,91,92                                                 PRATO057
   91 L=2                                                               PRATO058
      TTI(2)=TT2(K)                                                     PRATO059
      PTI(2)=PT2(K)                                                     PRATO060
      UM1(2)=SP(2)*3.14159*RM(K)*RFACT/30.                              PRATO061
      JK=1                                                              PRATO062
      GO TO 150                                                         PRATO063
   92 IF(ABS(PRTMM-PRQOT)-0.01)  96, 96,95                              PRATO064
   95 W=550.*(SHP(1)+SHP(2))/(ETTMM*778.16*CP*TTI(1)*(1.-(1./PRQOT)     PRATO065
     1**CON4))                                                          PRATO066
      L=1                                                               PRATO067
      JK=1                                                              PRATO068
      GO TO 150                                                         PRATO069
   96 IF (LFLAG-1) 100,100,97                                           PRATO070
   97 MFLG=5                                                            PRATO071
      L=1                                                               PRATO072
      JK=1                                                              PRATO073
      GO TO 150                                                         PRATO074
  100 JK=2                                                              PRATO075
  150 RETURN                                                            PRATO076
      END                                                               PRATO077
// DUP
*STORE         WS   UA   PRATO
*DUMP          UA   CD   PRATO
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// FOR
*IOCS)CARD,TYPEWRITER,KEYBOARD,1132 PRINTER,DISK*
C
C MAIN PROGRAM FOR CONTROL OF SUBROUTINES
C
      COMMON IM,ID,IY,R,GAM,CP,VIS,SHP(2),W,TTI(2),PTI(2),UM1(2),
     1COEM(2),N(2),DHO(2),SP(2),PRSTM(2),PRTTM(2),ETST,ETTT,ETSTM,
     2ETTTM,UMA(2),UCO,UCOM,RET(2),RES(2),PRST(2),PRTT(2),UMS,SUMHT(2),
     3SUMHS(2),PREQS,PREQT,IFLAG,CASE1,CASE2,JFLAG,KFLAG,MFLAG,LFLAG,L,
     4PRQOS,PRQOT,PRSMM,PRTMM,
     5ETSMM,ETTMM,PTME(2),AREAF,TECE,PECE,RFACT,IPAGE,EMACH
      COMMON X(2,10),Y(2,10),REA(2,10),Z(2,10),AD1(2,10),PRSOL,PRTOL,
     1ETSOL,ETTOL,UCSOL,UCTOL,UCOT,UCOTM,AREAI
      COMMON UM(10),PAS(10),DHS(10),BMACH,INPAR,TMANI,PMANI,
     1V1(10),VU1(10),VX1(10),W1(10),WU1(10),V2(10),VU2(10),VX2(10),
     2W2(10),WU2(10),BD1(10),AD2(10),BD2(10),ETS(10),ETT(10),E(10),
     3RM(10),TT1(10),TT2(10),PRT(10),PRS(10),PRN(10),PT1(10),PT2(10),
     4PT0(10),AN1(10),H1(10),AN2(10),H2(10),UT(10),VU1T(10),AD1T(10),
     5V1T(10),WU1T(10),BD1T(10),W1T(10),VU2T(10),AD2T(10),V2I(10)
      COMMON WU2T(10),BD2T(10),W2T(10),REAT(10),UH(10),VU1H(10),AD1H(10)
     1,V1H(10),WU1H(10),BD1H(10),W1H(10),VU2H(10),AD2H(10),V2H(10),
     2WU2H(10),BD2H(10),W2H(10),REAH(10),T1(10),T2(10),P1(10),P2(10),
     3CS(10),UC(10),RMF(10),AC1(10),AC2(10),AC1H(10),AC2H(10),AC1I(10),
     4AC2T(10),T1H(10),T1T(10),T2H(10),P1H(10),P1T(10),P2H(10),T2T(10),
     5P2T(10),COT(10),VEP(10),DVU(10),VX1T(10),VX2T(10),VX1H(10)
      COMMON VX2H(10),RMA(10),TT2T(10),TT2H(10),PT2T(10),PT2H(10),
     1PT1T(10),PT1H(10),TITL1(20),TITL2(20),TITL3(20),
     2STRL(2),TUM1,TPTI,TPRST,TSP,M,RHO(2),NFLAG,WF(10),HAVE(10),STRC(
     310),STRB(10),STRT(10),COE(2,2,10),CLEAR(2,10),ARS(2,10),TCRS(2,10)
     4,SECON(2,10),ARCON(2,3),SOLID(2,10),DELTA(2),OSF(2),OSEXP(2)
     5,RT(10)
    5 FORMAT (5X,4HITER,10X,2HUM,10X,3HPTI,10X,5HPREQS,10X,2HSP,10X,
     16HSTRESS/)
   10 FORMAT (7X,I2,F15.1,F11.1,F14.2,F15.1,F15.1)
   11 FORMAT (' NO SOLUTION FOR CONSTANT TIP RADIUS ADJUSTMENT,KJ=',I1)
      CALL INPT1
      GO TO 18
   15 GO TO (12,18),INPAR
   12 CALL INPT3 (MI)
      GO TO 19
   18 CALL INPT2 (VU1IN)
      MI=M
   19 JOVAL=1
      MFLG=MFLAG
```

```
      M=MI                                                              MAIN 043
      L=1                                                               MAIN 044
      ITER=0                                                            MAIN 045
      NFLAG=1                                                           MAIN 046
      K=N(1)                                                            MAIN 047
      IF (M-4) 13,13,16                                                 MAIN 048
   13 GO TO (17,16),KFLAG                                               MAIN 049
   17 WRITE (1,5)                                                       MAIN 050
   14 GO TO (7,8),KFLAG                                                 MAIN 051
    7 WRITE (1,10) ITER,UM1(1),PTI(1),PREQS,SP(1),STRT(K)               MAIN 052
    8 MFLG=MFLAG                                                        MAIN 053
   16 KCONT=0                                                           MAIN 054
   25 UMS=0.                                                            MAIN 055
      SUMHS(L)=0.                                                       MAIN 056
      SUMHT(L)=0.                                                       MAIN 057
      PRTT(L)=1.                                                        MAIN 058
      PRST(L)=1.                                                        MAIN 059
      CALL LOA                                                          MAIN 060
      CALL CALC1                                                        MAIN 061
      CALL CALC2(KJ,VU1IN)                                              MAIN 062
      KCONT=KCONT+1                                                     MAIN 063
      IF(KCONT-10) 49,48,48                                             MAIN 064
   48 WRITE (3,11) KJ                                                   MAIN 065
      GO TO 15                                                          MAIN 066
   49 GO TO (50,25),KJ                                                  MAIN 067
   50 CALL CALC9                                                        MAIN 068
      CALL CALC3                                                        MAIN 069
      GO TO (65,65,55,55,100),MFLG                                      MAIN 070
   55 GO TO (65,60),L                                                   MAIN 071
   60 CALL OVALL(JOVAL)                                                 MAIN 072
   65 CALL PRATO(MFLG,JK,K)                                             MAIN 073
      GO TO (16,100),JK                                                 MAIN 074
  100 IF (IFLAG-2) 20,30,30                                             MAIN 075
   20 CALL CALC4                                                        MAIN 076
      CALL CALC5                                                        MAIN 077
      GO TO 40                                                          MAIN 078
   30 CALL CALC6                                                        MAIN 079
      CALL CALC7                                                        MAIN 080
   40 CALL CALC8                                                        MAIN 081
      IF (M-4) 105,105,150                                              MAIN 082
  105 IF (L-1) 110,110,106                                              MAIN 083
  106 M=0                                                               MAIN 084
      NFLAG=1                                                           MAIN 085
  110 CALL STRES                                                        MAIN 086
```

```
      IF (M-1) 150,111,111
  111 GO TO (150,112,112,150,112) ,NFLAG
  112 IF (M-1) 113,113,114
  113 CALL STRS1
      GO TO 115
  114 CALL STRS2
  115 GO TO (150,120,117,150,136) ,NFLAG
  117 PREQS=4.0
      ITER=ITER+1
      MFLAG=1
      GO TO 14
  120 ITER=ITER+1
      IF (ITER-15) 121,121,141
  121 IF (M-2) 125,130,135
  125 UM1(L)=TUM1
      GO TO 14
  130 PTI(L)=TPTI
      GO TO 14
  135 IF (M-4) 136,140,150
  136 PREQS=TPRST
      ITER=ITER+1
      IF (ITER-15) 137,137,141
  137 MFLAG=1
      GO TO 14
  140 SP(L)=TSP
      GO TO 14
  141 NFLAG=6
  150 CALL OUTPT
      CALL OUTP1
      CALL OUTP3
      IF (M-4) 160,160,170
  160 CALL OUTP2
  170 IF (LFLAG-1) 15,15,180
  180 IF (L-1) 190,190,200
  190 L=2
      MFLG=5
      TTI(2)=TT2(K)
      PTI(2)=PT2(K)
      UM1(2)=SP(2)*3.14159*RM(K)*RFACT/30.
      GO TO 16
  200 JOVAL=2
      CALL OVALL(JOVAL)
      GO TO 15
      END
```

```
// DUP
*STORE      WS  UA  MAIN
*DUMP       UA  CD  MAIN
```

```
// XEQ MAIN     03
*LOCALMAIN,LOA,INPT1,INPT2,INPT3,CALC1,CALC2,CALC3,CALC4,CALC5,CALC6,
*LOCALCALC7,CALC8,CALC9,STRES,STRS1,STRS2,OUTPT,OUTP1,OUTP2,OUTP3,
*LOCALPRATO,OVALL
030668
766.3700001.391000003.50400000.00001340
9999-99
EXAMPLE CASE.............................................................
TWO SPOOL-7STAGES, FIRST SPOOL--3 STAGES, SECOND SPOOL...........
TO DEMONSTRATE COMPUTER PROGRAM..................................
    1      0      1      2      3      2      1
10.0
10.        1400.      0.3        1.         1660.      300.       0.2        0.5
1.0
.300       50000.     1.         3.         1.
40000.     20000.          7
.0         .02        .04        .06        .08        .10        .12
75.        73.        71.        69.        67.        65.        63.
1.         .9         .8         .7         .6         .5         .5
1.         1.         1.         1.         1.         1.         1.
1.         1.         1.         1.         1.         1.         1.
.4         .4         .4         .4         .4         .4         .4
.4         .4         .4         .4         .4         .4         .4
.01        .01        .01        .01        .01        .01        .01
1.         1.         1.         1.         1.         1.         1.
.3         .3         .3         .3         .3         .3         .3
1.5        1.5        1.5        1.5        1.5        1.5        1.5
.09        .09        .09        .09        .09        .09        .09
1.         .0         .0
.300       50000.     1.         3.         1.
10000.     15000.          3
.0         .0         .0
60.        58.        56.
1.         1.         1.
1.         1.         1.
1.         1.         1.
.4         .4         .4
0.4        0.4        0.4
.01        .01        .01
1.         1.         1.
.3         .3         .3
1.5        1.5        1.5
.09        .09        .09
1.         .0         .0
```

EXAMPLE CASE

COMPUTER PRINTED OUTPUT

DATE03-01-68

7 STAGE
GAS TURBINE DESIGN
ANALYSIS

INDEX PAGE

SPOOL NUMBER 1 OF 2

CASE NUMBER

9999-99

APPLICATION-------EXAMPLE CASE..
CHARACTERISTICS---TWO SPOOL-7STAGES, FIRST SPOOL--3 STAGES, SECOND SPOOL..........
OBJECTIVE---------TO DEMONSTRATE COMPUTER PROGRAM...................................

GAS PROPERTIES

GAS CONSTANT FT/DEG R	SPECIFIC HEAT RATIO	CONSTANT PRESSURE SPECIFIC HEAT BTU/LB-DEG R	ABSOLUTE VISCOSITY LB/FT-SEC
766.37	1.391	3.504	0.1340E-04

CASE CONDITIONS

SHAFT HORSEPOWER	FLOW RATE LB/SEC	INLET TOTAL TEMPERATURE DEG R	INLET TOTAL PRESSURE PSIA	MEAN BLADE SPEED FT/SEC	ROTATIVE SPEED RPM	MAN. LOSS COEFFICIENT
40000.0	15.45	1660.0	300.0	1400.0	20000.0	0.500

BLADE CROSS SECTION AREA DISTRIBUTION			DELTA	OVERSPEED FACTOR	OVERSPEED EXPONENT
0.10000E 01	0.00000E 00	0.00000E 00	1.000	1.000	3.000

STRESS LIMIT PSI	MATERIAL DENSITY LB/CU-IN	PARAMETER INDEX	DATA SWITCHES ON
50000.0	0.300	0	NONE

STAGE INPUT PARAMETERS

STAGE	STAGE REACTION	NOZZLE ANGLE DEG	STAGE LOAD RATIO	MEAN RADIUS RATIO	AXIAL VELOCITY RATIO	NOZZLE LOSS COEFF.	ROTOR LOSS COEFF.	ROTOR CLEAR IN	ASPECT RATIO	TH/CD RATIO	SECTION MODULUS CONST.	SOLIDITY
1	0.000	75.00	1.000	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
2	0.020	73.00	0.900	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
3	0.040	71.00	0.800	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
4	0.060	69.00	0.700	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
5	0.080	67.00	0.600	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
6	0.100	65.00	0.500	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
7	0.120	63.00	0.500	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500

DATE03-01-68

7 STAGE
GAS TURBINE DESIGN
ANALYSIS

SPOOL NUMBER 1 OF 2

CASE NUMBER
9999-99

APPLICATION-------EXAMPLE CASE...
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766.37	1.391	3.504	0.1340E-04

CASE CONDITIONS

SHAFT HORSEPOWER	FLOW RATE LB/SEC	INLET TOTAL TEMPERATURE DEG R	INLET TOTAL PRESSURE PSIA	MEAN BLADE SPEED FT/SEC	ROTATIVE SPEED RPM	MAN. LOSS COEFFICIENT
40000.0	15.45	1660.0	300.0	1400.0	20000.0	0.500

BLADE CROSS SECTION AREA DISTRIBUTION			DELTA	OVERSPEED FACTOR	OVERSPEED EXPONENT
0.10000E 01	0.00000E 00	0.00000E 00	1.000	1.000	3.000

STRESS LIMIT PSI	MATERIAL DENSITY LB/CU-IN	PARAMETER INDEX	DATA SWITCHES ON
50000.0	0.300	0	NONE

STAGE INPUT PARAMETERS

STAGE	STAGE REACTION	NOZZLE ANGLE DEG	STAGE LOAD RATIO	MEAN RADIUS RATIO	AXIAL VELOCITY RATIO	NOZZLE LOSS COEFF.	ROTOR LOSS COEFF.	ROTOR CLEAR IN	ASPECT RATIO	TH/CD RATIO	SECTION MODULUS CONST.	SOLIDITY
1	0.000	75.00	1.000	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
2	0.020	73.00	0.900	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
3	0.040	71.00	0.800	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
4	0.060	69.00	0.700	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
5	0.080	67.00	0.600	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
6	0.100	65.00	0.500	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
7	0.120	63.00	0.500	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500

FREE VORTEX

STAGE	U FT/SEC	VU1 FT/SEC	VX1 FT/SEC	V1 FT/SEC	WU1 FT/SEC	W1 FT/SEC	VU2 FT/SEC	VX2 FT/SEC	V2 FT/SEC	WU2 FT/SEC	W2 FT/SEC	REACTION
1	1278.0	5096.1	1251.8	5247.6	3818.1	4018.1	-2050.6	1251.8	2402.5	-3328.6	3556.2	-0.191
	1400.0	4671.9	1251.8	4836.7	3271.9	3503.2	-1871.9	1251.8	2252.0	-3271.9	3503.2	0.000
	1521.9	4312.9	1251.8	4490.9	2790.9	3058.8	-1721.9	1251.8	2128.9	-3243.9	3477.1	0.148
2	1255.2	4793.2	1319.7	4971.6	3537.9	3776.1	-1754.1	1319.7	2195.1	-3009.3	3286.0	-0.210
	1400.0	4316.7	1319.7	4514.0	2916.7	3201.4	-1572.7	1319.7	2053.1	-2972.7	3252.5	0.020
	1544.7	3926.4	1319.7	4142.3	2381.7	2722.9	-1425.4	1319.7	1942.6	-2970.1	3250.1	0.190
3	1229.0	4491.4	1364.1	4694.0	3262.3	3536.1	-1450.7	1364.1	1991.3	-2679.7	3006.9	-0.237
	1400.0	3961.5	1364.1	4189.8	2561.5	2902.1	-1273.5	1364.1	1866.2	-2673.5	3001.4	0.040
	1570.9	3543.5	1364.1	3797.0	1972.6	2398.3	-1135.0	1364.1	1774.5	-2705.9	3030.3	0.233
4	1199.1	4189.2	1384.3	4412.1	2990.1	3295.0	-1137.5	1384.3	1791.7	-2336.7	2716.0	-0.272
	1400.0	3606.3	1384.3	3862.9	2206.3	2604.7	-974.3	1384.3	1692.9	-2374.3	2748.4	0.060
	1600.8	3165.8	1384.3	3455.3	1565.0	2089.4	-852.1	1384.3	1625.6	-2452.9	2816.6	0.277
5	1165.4	3884.7	1380.0	4122.6	2719.3	3049.5	-811.0	1380.0	1600.7	-1976.5	2410.6	-0.318
	1400.0	3251.1	1380.0	3531.9	1851.1	2308.9	-675.1	1380.0	1536.3	-2075.1	2492.1	0.080
	1634.5	2795.2	1380.0	3117.4	1160.7	1803.2	-578.2	1380.0	1496.3	-2212.8	2607.9	0.321
6	1127.4	3575.7	1350.4	3822.3	2448.2	2796.0	-466.8	1350.4	1428.8	-1594.3	2089.4	-0.378
	1400.0	2895.9	1350.4	3195.3	1495.9	2015.3	-375.9	1350.4	1401.8	-1775.9	2231.1	0.100
	1672.5	2433.3	1350.4	2782.9	760.8	1550.0	-314.7	1350.4	1386.6	-1987.2	2402.6	0.366
7	1109.6	3593.4	1461.3	3879.2	2483.7	2881.7	-509.6	1461.3	1547.6	-1619.3	2181.2	-0.389
	1400.0	2867.9	1461.3	3218.8	1467.9	2071.3	-403.9	1461.3	1516.1	-1803.9	2321.6	0.120
	1690.3	2386.2	1461.3	2798.1	695.9	1618.5	-334.6	1461.3	1499.1	-2024.9	2497.1	0.393

FREE VORTEX

STAGE	ABSOLUTE NOZZLE EXIT	RELATIVE ROTOR EXIT
1	0.730	0.492
	0.668	0.484
	0.616	0.480
2	0.713	0.468
	0.642	0.463
	0.585	0.462
3	0.693	0.441
	0.613	0.439
	0.552	0.443
4	0.669	0.408
	0.580	0.413
	0.515	0.423
5	0.640	0.371
	0.542	0.383
	0.476	0.401
6	0.606	0.328
	0.501	0.350
	0.434	0.377
7	0.630	0.351
	0.516	0.373
	0.446	0.401

FREE VORTEX

STAGE	MEAN RADIUS IN	BLADE HEIGHT 1 IN	BLADE HEIGHT 2 IN	ANNULUS AREA 1 SQ-IN	ANNULUS AREA 2 SQ-IN	ALPHA1 DEG	BETA1 DEG	ALPHA2 DEG	BETA2 DEG
1	8.0214	1.335	1.397	67.302	70.448	76.19	71.84	-58.59	-69.38
						75.00	69.06	-56.22	-69.06
						73.81	65.84	-53.98	-68.89
2	8.0214	1.594	1.658	80.378	83.584	74.60	69.54	-53.04	-66.31
						73.00	65.65	-49.99	-66.06
						71.42	61.00	-47.20	-66.04
3	8.0214	1.892	1.958	95.390	98.719	73.10	67.30	-46.76	-63.02
						71.00	61.96	-43.03	-62.96
						68.94	55.33	-39.76	-63.24
4	8.0214	2.232	2.301	112.504	115.978	71.71	65.15	-39.41	-59.35
						69.00	57.89	-35.13	-59.75
						66.38	48.50	-31.61	-60.56
5	8.0214	2.616	2.688	131.874	135.477	70.44	63.09	-30.44	-55.07
						67.00	53.29	-26.07	-56.37
						63.72	40.06	-22.73	-58.05
6	8.0214	3.049	3.122	153.717	157.382	69.31	61.11	-19.07	-49.73
						65.00	47.92	-15.55	-52.75
						60.97	29.39	-13.11	-55.80
7	8.0214	3.238	3.326	163.234	167.660	67.87	59.52	-19.22	-47.93
						63.00	45.13	-15.45	-50.99
						58.51	25.46	-12.89	-54.18

FREE VORTEX

STAGE	PT1 PSIA	P1 PSIA	PT2 PSIA	P2 PSIA	PRS	PRT	TT1 DEG R	T1 DEG R	TT2 DEG R	T2 DEG R
1	289.0	202.9	219.1	203.0			1660.0	1503.0	1555.5	1522.6
	289.0	214.5	219.1	204.9	1.443	1.350	1660.0	1526.6	1555.5	1526.6
	289.0	223.9	219.1	206.4			1660.0	1545.0	1555.5	1529.7
2	211.7	151.0	163.6	153.0			1555.5	1414.6	1461.5	1434.1
	211.7	160.6	163.6	154.3	1.420	1.338	1555.5	1439.4	1461.5	1437.5
	211.7	168.0	163.6	155.2			1555.5	1457.7	1461.5	1440.0
3	159.4	115.8	125.7	118.5			1461.5	1335.9	1378.0	1355.4
	159.4	123.9	125.7	119.4	1.370	1.301	1461.5	1361.5	1378.0	1358.1
	159.4	129.7	125.7	120.0			1461.5	1379.4	1378.0	1360.0
4	123.3	91.4	99.3	94.5			1378.0	1267.0	1304.9	1286.6
	123.3	98.3	99.3	95.0	1.323	1.265	1378.0	1292.9	1304.9	1288.5
	123.3	102.9	99.3	95.3			1378.0	1309.9	1304.9	1289.6
5	97.9	74.4	80.9	77.5			1304.9	1208.0	1242.2	1227.6
	97.9	80.2	80.9	77.8	1.277	1.228	1304.9	1233.8	1242.2	1228.5
	97.9	83.9	80.9	77.9			1304.9	1249.5	1242.2	1229.5
6	80.1	62.5	67.9	65.5			1242.2	1159.0	1190.0	1176.4
	80.1	67.5	67.9	65.6	1.231	1.190	1242.2	1184.0	1190.0	1178.5
	80.1	70.4	67.9	65.7			1242.2	1198.1	1190.0	1179.9
7	67.2	51.5	56.6	54.2			1190.0	1104.2	1137.8	1124.1
	67.2	56.1	56.6	54.3	1.249	1.199	1190.0	1131.0	1137.8	1124.7
	67.2	58.7	56.6	54.4			1190.0	1145.4	1137.6	1125.0

STAGE PERFORMANCE

STAGE	LAMDA	DEL H BTU/LB	ETS	ETT	U/CO
1	0.213	365.9	0.641	0.776	0.261
2	0.237	329.3	0.643	0.767	0.276
3	0.267	292.7	0.674	0.800	0.300
4	0.305	256.1	0.700	0.828	0.327
5	0.356	219.5	0.722	0.854	0.358
6	0.427	182.9	0.738	0.876	0.397
7	0.427	182.9	0.722	0.881	0.393

OVERALL BLADE PERFORMANCE

DEL H BTU/LB	UMA FT/SEC	U/CO	U/CO'	PRST	PRTT	ETST	ETTT	RET	RES
1829.6	1400.0	0.133	0.134	5.444	5.224	0.830	0.846	1.039	1.040

OVERALL TURBINE PERFORMANCE INCLUDING MANIFOLD

U/CO	U/CO'	PRST	PRTT	ETST	ETTT
0.132	0.134	5.518	5.295	0.824	0.840

INLET MANIFOLD CONDITIONS

AREA SQ-IN	MACH NUM	P PSIA	T DEG-R	PTME PSIA
44.46	0.200	291.8	1647.1	295.9

STAGE	MEAN RADIUS IN	AVERAGE BLADE HEIGHT IN	STAGE LOAD PERCENT	CENTRIPETAL STRESS PSI	BENDING STRESS PSI	TOTAL STRESS PSI
1	8.0214	1.366	20.0	37362.2	1877.8	39240.0
2	8.0214	1.626	18.0	44471.6	1419.8	45891.4
3	8.0214	1.925	16.0	52648.5	1066.0	53714.6
4	8.0214	2.266	14.0	61971.4	792.4	62763.9
5	8.0214	2.652	12.0	72513.9	580.5	73094.4
6	8.0214	3.086	10.0	84379.9	415.7	84795.6
7	8.0214	3.282	10.0	89749.1	390.8	90139.9

3 STAGE
GAS TURBINE DESIGN
ANALYSIS

SPOOL NUMBER 2 OF 2

CASE NUMBER
9999-99

APPLICATION-------EXAMPLE CASE...
CHARACTERISTICS---TWO SPOOL-7STAGES, FIRST SPOOL--3 STAGES, SECOND SPOOL...........
OBJECTIVE---------TO DEMONSTRATE COMPUTER PROGRAM...................................

GAS PROPERTIES

GAS CONSTANT FT/DEG R	SPECIFIC HEAT RATIO	CONSTANT PRESSURE SPECIFIC HEAT BTU/LB-DEG R	ABSOLUTE VISCOSITY LB/FT-SEC
766.37	1.391	3.504	0.1340E-04

CASE CONDITIONS

SHAFT HORSEPOWER	FLOW RATE LB/SEC	INLET TOTAL TEMPERATURE DEG R	INLET TOTAL PRESSURE PSIA	MEAN BLADE SPEED FT/SEC	ROTATIVE SPEED RPM	E.C. LOSS COEFFICIENT
10000.0	15.45	1137.8	56.6	1050.0	15000.0	1.000

BLADE CROSS SECTION AREA DISTRIBUTION			DELTA	OVERSPEED FACTOR	OVERSPEED EXPONENT
0.10000E 01	0.00000E 00	0.00000E 00	1.000	1.000	3.000

STRESS LIMIT PSI	MATERIAL DENSITY LB/CU-IN	PARAMETER INDEX	DATA SWITCHES ON
50000.0	0.300	0	NONE

STAGE INPUT PARAMETERS

STAGE	STAGE REACTION	NOZZLE ANGLE DEG	STAGE LOAD RATIO	MEAN RADIUS RATIO	AXIAL VELOCITY RATIO	NOZZLE LOSS COEFF.	ROTOR LOSS COEFF.	ROTOR CLEAR IN	ASPECT RATIO	TH/CD RATIO	SECTION MODULUS CONST.	SOLIDITY
1	0.000	60.00	1.000	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
2	0.000	58.00	1.000	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500
3	0.000	56.00	1.000	1.000	1.000	0.400	0.400	0.010	1.00	0.30	0.090	1.500

FREE VORTEX

STAGE	U FT/SEC	VU1 FT/SEC	VX1 FT/SEC	V1 FT/SEC	WU1 FT/SEC	W1 FT/SEC	VU2 FT/SEC	VX2 FT/SEC	V2 FT/SEC	WU2 FT/SEC	W2 FT/SEC	REACTION
1	828.7	3619.6	1655.7	3980.3	2790.9	3245.1	-972.7	1655.7	1920.3	-1801.4	2446.7	-0.596
	1050.0	2867.7	1655.7	3311.4	1817.7	2458.7	-767.7	1655.7	1825.0	-1817.7	2458.7	0.000
	1271.2	2374.5	1655.7	2894.7	1103.2	1989.6	-634.1	1655.7	1773.0	-1905.3	2524.2	0.315
2	814.9	3679.4	1791.9	4092.6	2864.5	3378.8	-989.2	1791.9	2046.9	-1804.1	2542.8	-0.650
	1050.0	2867.7	1791.9	3381.6	1817.7	2552.5	-767.7	1791.9	1949.5	-1817.7	2552.5	0.000
	1285.0	2349.4	1791.9	2954.8	1064.4	2084.2	-627.3	1791.9	1898.6	-1912.3	2620.7	0.329
3	797.8	3756.2	1934.3	4225.0	2958.4	3534.6	-1010.4	1934.3	2182.3	-1808.2	2647.9	-0.720
	1050.0	2667.7	1934.3	3459.1	1817.7	2654.4	-767.7	1934.3	2081.1	-1817.7	2654.4	0.000
	1302.1	2319.1	1934.3	3019.9	1017.0	2185.4	-619.0	1934.3	2030.9	-1921.2	2726.3	0.347

FREE VORTEX

STAGE	ABSOLUTE NOZZLE EXIT	RELATIVE ROTOR EXIT
1	0.664	0.403
	0.545	0.404
	0.473	0.415
2	0.699	0.428
	0.569	0.429
	0.493	0.440
3	0.740	0.456
	0.595	0.457
	0.515	0.469

STAGE GEOMETRY

FREE VORTEX

STAGE	MEAN RADIUS IN	BLADE HEIGHT 1 IN	BLADE HEIGHT 2 IN	ANNULUS AREA 1 SQ-IN	ANNULUS AREA 2 SQ-IN	ALPHA1 DEG	BETA1 DEG	ALPHA2 DEG	BETA2 DEG
1	8.0214	3.332	3.380	167.961	170.371	65.41	59.32	-30.43	-47.41
						60.00	47.67	-24.87	-47.67
						55.11	33.67	-20.95	-49.01
2	8.0214	3.539	3.591	178.367	181.011	64.03	57.97	-28.89	-45.19
						58.00	45.40	-23.19	-45.40
						52.66	30.70	-19.29	-46.[illegible]
3	8.0214	3.794	3.853	191.252	194.203	62.75	56.82	-27.58	-43.07
						56.00	43.22	-21.64	-43.22
						50.17	27.73	-17.74	-44.80

FREE VORTEX

STAGE	PT1 PSIA	P1 PSIA	PT2 PSIA	P2 PSIA	PRS	PRT	TT1 DEG R	T1 DEG R	TT2 DEG R	T2 DEG R
1	55.9	41.7	48.0	44.8			1137.8	1047.5	1094.3	1073.3
	55.9	45.7	48.0	45.1	1.254	1.179	1137.8	1075.3	1094.3	1075.3
	55.9	48.0	48.0	45.3			1137.8	1090.0	1094.3	1076.4
2	47.4	34.2	40.4	37.2			1094.3	998.8	1050.8	1026.9
	47.4	38.1	40.4	37.5	1.278	1.187	1094.3	1029.1	1050.8	1029.1
	47.4	40.1	40.4	37.7			1094.3	1044.5	1050.8	1030.2
3	39.9	27.7	33.8	30.7			1050.8	949.0	1007.3	980.1
	39.9	31.4	33.8	30.9	1.306	1.195	1050.8	962.6	1007.3	982.6
	39.9	33.3	33.8	31.1			1050.8	998.8	1007.3	983.7

DATE03-01-68

STAGE PERFORMANCE

STAGE	LAMDA	DEL H BTU/LB	ETS	ETT	U/CO
1	0.288	152.4	0.618	0.844	0.298
2	0.288	152.4	0.595	0.843	0.293
3	0.288	152.4	0.572	0.844	0.287

OVERALL BLADE PERFORMANCE

DEL H BTU/LB	UMA FT/SEC	U/CO	U/CO'	PRST	PRTT	ETST	ETTT	RET	RES
457.4	1050.0	0.188	0.202	1.828	1.674	0.735	0.850	1.007	1.008

OVERALL TURBINE PERFORMANCE INCLUDING EXHAUST COLLECTOR

U/CO	U/CO'	PRST	PRTT	ETST	ETTT
0.183	0.192	1.888	1.775	0.700	0.770

DATE03-01-68 ROTOR BLADE ROOT STRESS

STAGE	MEAN RADIUS IN	AVERAGE BLADE HEIGHT IN	STAGE LOAD PERCENT	CENTRIPETAL STRESS PSI	BENDING STRESS PSI	TOTAL STRESS PSI
1	8.0214	3.356	33.3	51618.6	424.7	52043.3
2	8.0214	3.565	33.3	54829.4	399.8	55229.3
3	8.0214	3.823	33.3	58807.9	372.8	59180.8

FIRST SPOOL INLET TO SECOND SPOOL EXIT

DEL H BTU/LB	UMA FT/SEC	U/CO	U/CO'	PRST	PRTT	ETST	ETTT	RET	RES
2287.0	1225.0	0.104	0.106	9.554	8.747	0.837	0.861	1.069	1.050

MANIFOLD INLET TO SECOND SPOOL EXIT

DEL H BTU/LB	UMA FT/SEC	U/CO	U/CO'	PRST	PRTT	ETST	ETTT	RET	RES
2287.0	1225.0	0.104	0.106	9.685	8.866	0.833	0.857	1.064	1.046

MANIFOLD EXIT TO EXHAUST COLLECTOR EXIT

DEL H BTU/LB	UMA FT/SEC	U/CO	U/CO'	PRST	PRTT	ETST	ETTT	RET	RES
2287.0	1225.0	0.104	0.105	9.867	9.273	0.828	0.845	1.058	1.030

MANIFOLD INLET TO EXHAUST COLLECTOR EXIT

DEL H BTU/LB	UMA FT/SEC	U/CO	U/CO'	PRST	PRTT	ETST	ETTT	RET	RES
2287.0	1225.0	0.103	0.104	10.002	9.400	0.825	0.841	1.053	1.026

EXHAUST COLLECTOR EXIT FLANGE CONDITIONS

AREA SQ-IN	MACH NUM	PT PSIA	P PSIA	TT DEG R	T DEG R
223.57	0.300	31.9	29.9	1007.3	989.8