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VOLUME ACCUMULATOR
DESIGN ANALYSIS
COMPUTER CODES

AEC Research and Development Report

Atoms International Division
Rockwell International

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MASTER

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VOLUME ACCUMULATOR
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COMPUTER CODES

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FOREWORD

The work described here was done at the Atomics International Division of Rockwell International Corporation, under the direction of the Space Nuclear Systems Division, a joint AEC-NASA office. Project management was provided by NASA-Lewis Research Center and the AEC-SNAP Project Office.

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ABSTRACT

The computer codes, VANEP and VANES, were written and used to aid in the design and performance calculation of the Volume Accumulator Units (VAU's) for the 5-kwe Reactor Thermo-electric System. VANEP computes the VAU design which meets the primary coolant loop VAU volume and pressure performance requirements. VANES computes the performance of the VAU design, determined from the VANEP code, at the conditions of the secondary coolant loop. The codes can also compute the performance characteristics of the VAU's under conditions of possible modes of failure which still permit continued system operation.

I. INTRODUCTION

A series of compact nuclear reactors and electrical power systems were designed, developed, and tested for the Systems for Nuclear Auxiliary Power (SNAP) Program. The zirconium hydride reactors for these systems were fueled by hydrided zirconium-uranium elements. Windows in the external beryllium neutron reflector were adjusted by rotating drums or sliding segments to regulate the neutron leakage from the core, and thus the power output of the reactor. A direct radiating thermoelectric module powered Power Conversion System (PCS) produced >500 w of electrical power on the flight-tested SNAP 10A System. Mercury Rankine cycle turbogenerator PCS of 3- and 30-kwe power range were demonstrated for the SNAP 2 and SNAP 8 Systems respectively. The latest 5-kwe Reactor Thermoelectric System, shown in Figure 1, was based on the use of a compact tubular thermoelectric PCS. The NaK, used to transfer the heat from the reactor to the PCS and from the PCS to the space radiator, was circulated by dc conduction electromagnetic pumps on the thermoelectric systems, and by mechanical centrifugal pumps on the mercury Rankine systems.

In the 5-kwe Reactor Thermoelectric System, volume accumulator units (VAU's)⁽¹⁾ are used in the NaK primary and secondary coolant loops to:

- 1) Accommodate NaK coolant thermal volumetric expansion and contraction during the 5-kwe Reactor Thermoelectric System startup, operation, shutdown, and storage
- 2) Provide void-free NaK coolant systems
- 3) Provide pressure regulation of the NaK coolant systems.

As indicated in Figure 1, there are two VAU's for the primary coolant loop, and one VAU for the secondary coolant loop. All three VAU's are identical.

This report describes the computer codes that were written and used to aid in the design and performance calculations of the VAU's for the 5-kwe Reactor Thermoelectric System.

Figure 1. 5-kwe Reactor Thermoelec-
tric System

II. DESCRIPTION OF VOLUME ACCUMULATOR UNIT

Figure 2 shows a design layout of the prototype VAU. All VAU parts, except the NaK inlet tube, are fabricated from Inconel 718. The NaK inlet tube material is Type 316 stainless steel. As can be seen in Figure 2, there are three cavities in the VAU (viz, the primary containment cavity, the secondary containment cavity, and the secondary bellows cavity).

The primary containment cavity, which is formed by the NaK dome, primary containment bellows, and the movable head, accommodates the NaK fluid expansion volume from the coolant loop.

The secondary containment cavity, which is formed by the primary and secondary containment bellows and the shell, is evacuated, and provides secondary containment of the NaK, in the event of leakage through, or failure of, the primary containment bellows.

The secondary bellows cavity, which is formed by the movable head, secondary containment bellows, and gas dome, is charged with inert gas, and provides the gas pressure force needed to augment the bellows spring force to obtain the desired pressure regulation of the coolant loop.

The primary and secondary containment bellows are identical, and are the nested-formed type.

The performance requirements for the prototype VAU are:

- 1) NaK Volume Capacity — The VAU at 750° F shall be capable of accommodating a NaK volume increase of 337 in.³ above the residual volume.*
- 2) NaK Pressure — The combined action of the gas charge and the bellows force shall impose the following pressures on the NaK:
 - a) Initial Pressure — The initial pressure at 100° F VAU temperature on the residual volume* of NaK in the VAU shall be 4 psia minimum.
 - b) Operating Pressure — The operating pressure shall be 28.0 psia maximum at 750° F VAU temperature.

*The NaK volume at 100° F which is required to fill the primary containment cavity with the movable head positioned 0.12 in. from the NaK dome.

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Figure 2. Prototype Volume Accumulator Unit Schematic

- c) Failed Primary Bellows — In the event of primary bellows failure, the VAU shall maintain 6 psia minimum pressure on 236 in.³ plus the residual volume of NaK in the primary and secondary containment cavities. This pressure shall be maintained at 600° F VAU temperature.
- 3) Useful Life — The VAU shall have an operational life of 5 years after being exposed to storage environment for up to 2 years, and then to preflight through launch environment, with no maintenance.
- 4) Reliability — The reliability of the VAU for 5 years of operation, without causing failure of the 5-kwe System, shall be not less than 0.997.

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Figure 3. Flow Chart for VANEP

III. DESCRIPTION OF COMPUTER CODES

A. GENERAL

Two computer codes, VANEP and VANES, were written to aid in the design and performance calculation of the VAU's for the 5-kwe Reactor Thermoelectric System. Both codes are written in BASIC Language for the Honeywell Time-Sharing Computer.

The computer code VANEP (Volume Accumulator with NEsted-formed bellows, Primary coolant loop) performs the design computations for the VAU which meets the primary coolant loop VAU volume and pressure performance requirements listed previously.

The computer code VANES (Volume Accumulator with NEsted-formed bellows, Secondary coolant loop) computes the performance of the VAU design, determined from the VANEP code, at the conditions of the secondary coolant loop.

Both codes can be used to analyze any set of conditions (e.g., NaK pressure as a function of temperature, volume, and/or gas fill pressure, bellows stress as a function of pressure or volume, etc.).

The codes can also compute the performance characteristics of the VAU's under modes of failure which still permit continued system operation (e.g., in the primary coolant loop VAU's, the failure of one or both primary containment bellows and/or the failure of one or both gas domes).

B. VANEP

The flow chart for VANEP is shown in Figure 3, and the listing for VANEP is given in the Appendix.

The equations used in the VANEP code for computing the number of bellows convolutions, bellows spring rate, bellows squirm pressure, and bellows natural frequency are taken from Reference 2.

The input data required for VANEP are listed in Table 1. The bellows shape correction factors, ζ_{IV} and β , are initially estimated from Figures 2a and 2b, respectively, of Reference 2. From the run results, more accurate values of

ζ_{IV} and β can be read from the figures; if there is sufficient difference, a rerun is made, using the more accurate values of ζ_{IV} and β , as indicated in Figure 3.

Data written into the VANEP code include the initial NaK pressure (4 psia) at 100°F, and the wall thicknesses of the NaK dome, movable head, gas dome, and shell.

From a trade study, the optimum value of the ratio of pressure stress to total stress for the bellows, from the standpoints of VAU weight, weld length, and fabrication cost, was found to be 0.445. This value is used in the VANEP code.

TABLE 1
REQUIRED INPUT DATA FOR VANEP

Input Data Description	Units	Code Nomenclature
Primary Coolant Loop VAU Volumes, Pressures and Temperature		
Maximum capable volume	in. ³	B1
Design volume	in. ³	B
Assumed NaK operating pressure	psia	P2
Initial temperature	°R	T5
Design temperature	°R	T6
Material		
Material density	lb/in. ³	R
Modulus of elasticity at initial temperature	psi	E1
Modulus of elasticity at design temperature	psi	E2
Bellows		
Design total stress	psi	F
Bellows ID	in.	D3
Number of plies	-	M
Bellows ply thickness	in.	T
Bellows convolution bend radius	in.	C0
ζ_{IV} (from Figure 2a of Reference 2)	-	C4
β (from Figure 2b of Reference 2)	-	B0

A description of the VANEP printout is given in Table 2. The items are listed in the order they appear in the printout.

C. VANES

The listing for VANES is given in the appendix.

The input data required for the VANES code are listed in Table 3. Note that some of the input data are results obtained from the VANEP code.

A description of the VANEP printout is given in Table 2. The items are listed in the order they appear in the printout.

TABLE 2
DESCRIPTION OF VANEP AND VANES PRINTOUTS

Code Nomenclature	Description	Units	Input (I)/Output (O)	
			VANEP	VANES
T	Bellows Ply Thickness	in.	I	I
L	Calculated Bellows Span	in.	O	I
Y	Calculated Bellows Deflection	in.	O	O
P2	NaK Operating Pressure	psia	O	O
N	Number of Convolutions per Bellows	-	O	I
V5	Total Gas Volume at Initial Temperature	in. ³	O	I
V6	Total Gas Volume at Design Temperature	in. ³	O	O
W8	Outer Shell Weight	lb	O	O
W9	Weight of Residual NaK at Initial Temperature	lb	O	O
Y1	Effective Stroke, Prior to System Startup	in.	O	I
L8	Height of Outer Shell	in.	O	O
H1	Natural Frequency of Bellows at Initial Temperature, With no Damping	Hz	O	O
Y2	Effective Stroke During Operation	in.	O	O

(Continued)

TABLE 2 (Continuation)

Code Nomenclature	Description	Units	Input (I)/Output (O)	
			VANEP	VANES
W0	Total VAU Weight	lb	O	O
P5	Gas Fill Pressure at Initial Temperature	psia	O	I
P6	Gas Fill Pressure at Operating Temperature	psia	O	O
S	Secondary Containment Volume	in. ³	O	O
P0	Gas Fill Pressure, Primary Bellows Failed, Design Volume	psia	O	O
N0	NaK Pressure, Primary Bellows Failed, Design Volume	psia	O	O
D3	Bellows ID	in.	I	I
D0	Calculated Bellows OD	in.	O	O
F1	Pressure Stress	psi	O	O
F2	Deflection Stress	psi	O	O
F	Design Total Stress	psi	I	O
C1	Bellows Free Length	in.	O	O
Q	Squirm Pressure at Maximum Capable Volume	psi	O	O
P1	Initial NaK Pressure at Initial Temperature	psia	written in*	O
C0	Bellows Convolution Bend Radius	in.	I	I
K2	Bellows Spring Rate Per Bellows at Design Temperature	lb/in.	O	O
L0	Total Weld Length (bellows and primary containment structure)	ft	O	O
L9	VAU total height	in.	O	O

*Already written in code

TABLE 3
REQUIRED INPUT DATA FOR VANES

Input Data Description	Units	Code Nomenclature
Secondary Coolant Loop VAU Volumes and Temperatures		
Maximum capable volume [*]	in. ³	B1
Design volume	in. ³	B
Initial temperature	°R	T5
Design temperature	°R	T6
Material		
Material density	lb/in. ³	R
Modulus of elasticity at initial temperature	psi	E1
Modulus of elasticity at design temperature	psi	E2
Bellows		
Bellows ID [*]	in.	D3
Bellows ply thickness [*]	in.	T
Bellows convolution bend radius [*]	in.	C0
ζ_{IV} (from Figure 2a of Reference 2) [*]	-	C4
β (from Figure 2b of Reference 2) [*]	-	D0
Effective stroke prior to system startup [†]	in.	Y1
Number of bellows convolutions [†]	-	N
Calculated bellows span [†]	in.	L
Total gas volume at initial temperature [†]	in. ³	V5
Gas pressure at initial temperature [†]	psia	P5

*Same as input data for VANEP

†From VANEP output

```

90   FOR M=1 TO 3 STEP 2
270  FOR D3=10 TO 12 STEP 2
281  FOR T=.008 TO .010 STEP .002
279  PRINT "NØ. PLY="M
960  NEXT T
970  NEXT D3
980  NEXT M
RUN

```

VANEP 17:12 NR T/S MAY 16, 1973

T	L	Y	P2	N
V5	V6	W8	W9	Y1
L8	H1	Y2	W0	
P5	P6	S	P0	N0
D3	D0	F1	F2	F
C1	Q	P1	C0	K2
L0	L9			

NØ. PLY= 1
BELLØWS I.D.= 10 , DELTA VOL= 337

.008	.43219	3.9426	25.45	50.051
880.61	543.61	10.337	1.4702	1.9713
10.129	39.395	1.9713	20.093	
6.6028	23.111	96.783	19.618	20.614
10	10.864	44500.	55500.	1E+5
4.3738	49.572	4.012	2	50.707
18.042	12.21			
.01	.50185	3.8905	28.6	45.089
934.48	597.48	10.887	1.8472	1.9453
10.682	40.479	1.9453	23.297	
7.5235	25.425	115.46	21.308	22.307
10	11.004	44500.	55500.	1E+5
4.6506	66.52	4.0068	2	70.686
18.409	12.783			

NØ. PLY= 1
BELLØWS I.D.= 12 , DELTA VOL= 337

.008	.46613	2.7611	22.3	30.421
919.66	582.66	10.934	1.2414	1.3805
7.0388	55.803	1.3805	19.361	
6.0117	20.502	86.787	17.844	18.716
12	12.932	44500.	55500.	1E+5
2.8407	116.69	4.0205	2	79.463
19.447	9.4199			
.01	.54568	2.7262	24.7	27.004
962.36	625.36	11.355	1.5317	1.3631
7.3232	57.269	1.3631	21.813	
6.7009	22.281	102.97	19.131	20.072
12	13.091	44500.	55500.	1E+5
2.9833	156.52	4.0216	2	109.68
19.758	9.7274			

a. Number of Plies = 1

Figure 4. Printout of Parametric Study

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IV. SOME EXAMPLES OF USE OF CODES

A. PARAMETRIC STUDY OF PRIMARY COOLANT LOOP VAU

By making some minor changes in the VANEP code, a parametric study can be made of the effects of number of plies, ply thickness, bellows ID, etc, on the primary coolant loop VAU's. An example is shown in Figures 4a and 4b, in which the parameters investigated are number of plies (1 and 3), bellows ID (10 and 12 in.) and ply thickness (0.008 and 0.010 in.). The changes made to the VANEP code are shown at the top of Figure 4a, (viz, modification of Lines 90, 270, and 281, and addition of new lines 279, 960, 970, and 980). The printout for number of plies = 1 is shown in Figure 4a, and the printout for number of plies = 3 is shown in Figure 4b.

B. DESIGNING TO SPECIFIED OPERATING PRESSURE, RATHER THAN INITIAL PRESSURE

To design a primary coolant loop VAU in which the operating NaK pressure, rather than the initial NaK pressure, is specified, Lines 694 through 699 are deleted in the VANEP code, and input P2 is the specified operating pressure. The printout of the VANES listing shown in the appendix, in which Lines 694 through 699 were deleted and the operating pressure (P2) was specified as 25 psia, is shown in Figure 5.

T	L	Y	P2	N
V5	V6	W8	W9	Y1
L8	H1	Y2	W0	
P5	P6	S	P0	N0
D3	D0	F1	F2	F
C1	Q	P1	C0	K2
L0	L9			

NO. PLY= 3
 BELLOWS I.D.= 10 , DELTA VOL= 337

.008	.56922	3.8295	41.15	27.098
855.16	518.16	10.286	1.6905	1.9147
9.5447	42.154	1.9147	28.394	
10.017	35.72	115.85	29.193	30.89
10	11.17	44500.	55500.	1E+5
4.0826	129.02	4.0018	2	124.79
17.338	11.67			
.01	.63619	3.7786	49.85	26.332
936.49	599.49	11.071	2.2171	1.8893
10.423	43.331	1.8893	35.345	
12.499	42.187	139.21	34.237	35.569
10	11.312	44500.	55500.	1E+5
4.5225	175.09	4.0104	2	180.86
17.763	12.569			

NO. PLY= 3
 BELLOWS I.D.= 12 , DELTA VOL= 337

.008	.63502	2.6809	33.7	15.389
880.38	543.38	10.906	1.3879	1.3405
6.4989	59.738	1.3405	25.473	
8.4741	29.666	105.32	24.85	26.362
12	13.302	44500.	55500.	1E+5
2.5716	299.53	4.0056	2	189.15
19.15	8.9337			
.01	.71581	2.6454	40.15	14.704
942.64	605.64	11.473	1.7774	1.3227
6.9411	61.414	1.3227	30.564	
10.261	34.507	124.84	28.61	30.072
12	13.472	44500.	55500.	1E+5
2.7931	409.42	4.0095	2	271.77
19.507	9.4006			

RUNNING TIME: 23.1 SECS I/O TIME : 2.0 SECS

OK

b. Number of Plies = 3

Figure 4. Printout of Parametric Study

ZLD:VANEP

OK

694
695
696
697
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699
700

VANEP 17:07 NR T/S MAY 16, 1973

T	L	Y	22	N
V5	V6	V3	19	V1
L8	H1	Y2	10	
D5	P6	S	P0	K0
D3	D0	F1	F2	F
C1	7	P1	C0	K2
L0	L9			

BELL'S I.D.= 11 , DELTA VEL= 337

.01	.53826	3.223	25	32.56
922.69	585.69	10.86	1.6203	1.6115
8.4972	48.799	1.6115	21.861	
6.5551	22.313	107.85	18.843	19.31
11	12.077	44500.	55500.	1E+5
3.5651	104.44	3.5791	2	87.162
18.916	10.754			

RUNNING TIME: 2.1 SECS I/O TIME : .3 SECS

OK

Figure 5. Printout for Case of Specified Operating Pressure

V. SUMMARY

Two computer codes, VANEP and VANES, written and used to aid in the design and performance calculation of the volume accumulator units for the 5-kwe Reactor Thermoelectric System, are described. VANEP computes the VAU design which meets the primary coolant loop VAU volume and pressure performance requirements. VANES computes the performance of the VAU design, determined from the VANEP code, at the conditions of the secondary coolant loop. The codes can also compute the performance characteristics of the VAU's under conditions of possible modes of failure which permit continued system operation (e.g., in the primary coolant loop VAU's, the failure of one or both primary containment bellows and/or the failure of one or both gas domes).

REFERENCES

1. W. D. Whitaker and T. T. Shimazaki, "Space Nuclear System Volume Accumulator Development Summary Report," AI-AEC-13090 (June 1973)
2. "Aerospace Recommended Practice," ARP 735 (8-15-66)

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APPENDIX – LISTING OF VANEP AND VANES CODES

VANEP

```

2 REM PRIMARY LOOP UNITS
5 REM GAS BACK, NESTING-FORM BELL; V=234 & 668, T=600&750F
6 REM 2 UNITS IN PRI LOOP, 1 UNIT IN SEC LOOP
7 REM B1=MAX CAPABLE VOL
8 LET B1=344
9 REM B=FAILURE MODE VOL
10 LET B=337
30 LET T6=1210
40 LET F=100000
50 LET R=.297
60 LET E1=28.8E6
62 LET E2=26E6
70 LET C4=.39
75 LET B0=1.19
80 LET T5=560
90 LET M=1
99 REM Q1=THICKNESS CORRECTION FACTOR
240 PRINT "T","L","Y","P2","N"
250 PRINT "V5","V6","W8","W9","Y1"
253 PRINT "L8","H1","Y2","W0"
254 PRINT
255 PRINT "P5","P6","S","P0","N0"
257 PRINT "D3","D0","F1","F2","F"
258 PRINT "C1","Q","P1","C0","K2"
259 PRINT "L0","L9"
260 LET V=B
270 LET D3=11
280 PRINT "BELLOWS I.D.="D3;"", DELTA VOL="V
281 LET T=.010
285 LET P2=25
287 LET C0=2
288 REM STRESS CORRECTED FOR THINNING
290 LET F1=.445*F
295 LET F2=F-F1
299 LET Q1=1
300 LET L=SQR(F1*2*M*(T*Q1)+2/P2)
301 IF L>=.15*D3 THEN 951
310 LET D0=D3+2*L+2*(M*T-T)
312 LET D2=D3+L+(M*T-T)
315 LET A=(3.1416*D2+2)/4
316 IF Q1<1 THEN 320
317 LET Q1=D3/D0
318 GO TO 300
320 LET Y=V/A
321 LET Z=.50
322 LET Y1=Z*Y
325 LET Y2=Y-Y1
327 REM Y5=TOTAL DEFL. FOR "B1" VOL
328 LET Y5=B1/A
330 LET N=3*Y2*E2*(T*Q1)/(F2*2*.91*B0*L+2)

```

VANEP CONTINUED

```

350 LET W=2*3.1416*D2*N*R*M*T*((L-2*C0*T)+3.1416*C0*T)
360 LET K1=3.1416*E1*D2*M*T/3/(6*.91*C4*N*L+3)
365 LET K2=K1*E2/E1
400 REM S2=S0L. HT. FORMED BELL0WS
440 LET S2=((2*C0*T)+2*M*T)*N
490 REM C1=FREE LENGTH
500 LET C1=S2+Y1
600 REM STRU: +.25" HT FOR ATTACH. PRESS D0ME: Z8=WT. 0F GAS D0ME
610 LET D8=D0+.25
620 LET L8=(2*S2)+Y5+.80+2*.25
624 REM 0UTER CAN WEIGHT
626 LET W8=3.1416*D8*.04*L8*R
628 REM NAK D0ME, M0VE. HEAD, BELL. RINGS WEIGHT
630 LET W8=W8+3.1416*R*(D8+2/4*.06+(D0-.6)*.12*.6)
632 LET W8=W8+3.1416*R*((D3-.26)+2/4*.06+(D3-.26)*(S2+2*.60)*.06)
634 LET W8=W8+3.1416*R*D2*(L+.25)*.032*2
636 REM W9=WT 0F RESID NAK AT ZERO V0L DISPL AT 100F
638 LET W9=3.1416*(D2-.02)*L*(S2+.12)*54/1728
640 LET W9=W9+3.1416*(D2-L-.10)*.10*(S2+.12)*54/1728
642 LET W9=W9+D0+2/4*.12*54/1728
648 REM Z8=GAS D0ME WEIGHT
650 LET Z8=3.1416*R*(D0+2/4*.032+(D8*.032*.4))
652 LET Z8=Z8+3.1416*D8*.08*.3*R
660 LET W0=2*W+W8+W9+Z8
680 REM V1=GAS V0L. IN ECU CAVITY
685 LET V1=3.1416*(D2+2/4*(S2+Y5)+(D2-L-.32)+2/4*(S2+.62))
686 LET V5=V1+3.1416*((1/11*D0)+2*(15-(1/11*D0)/3)-(1+2*(15-1/3)))
687 LET V5=V5+3.1416*(D3-.06)+2/4*.7
689 LET V5=V5+3.1416*D0+2/4*.6
690 LET V6=V5-A*Y
691 LET P6=P2-(K2*Y2/A)*2
692 LET P5=P6*V6*T5/(T6*V5)
693 LET P1=P5-(K1*Y1/A)*2
694 IF P1=<4.05 THEN 697
695 LET P2=P2-.3
696 G0 T0 290
697 IF P1=>4.0 THEN 700
698 LET P2=P2+.05
699 G0 T0 290
700 REM FAILURE M0DE ANAL; S=SECD V0L EXT T0 BELL0WS
705 REM P0=GAS PRESS, PRI BELL0WS FAILED, V0L=B
708 REM N0=NAK PRESS, PRE BELL0WS FAILED, V0L=B
710 LET S=3.1416*(D2*L*.5*(Y5+2*S2)+((D0+.06)*.06*(Y5+2*S2+1.75)))
715 LET S=S+3.1416*D2*L*.88
760 LET P0=T6*V5*P5/(T5*(V6+S+(V-B)))
775 LET N0=P0+2*K2*((B-S)/A-Y1)/A
820 REM Q=SQUIRM PRESS AT FULL V0L
825 LET Q=2*3.1416*K2/(S2+Y5)
830 REM H1=NATURAL FREQUENCY AT 100F
835 LET H1=9.85*SQR(K1/W)

```


VANEP CONTINUED

```
840 REM L0=WELD LENGTH, FEET
845 LET L0=(2*3.1416*D0+.75+(L-2*C0*T+3.1416*C0*T)*2*N)/12
846 LET L0=L0+(3.1416*D0)/12*3
847 LET L9=L8+(1.6/11)*D0+.50
900 SET DIGITS 5
910 PRINT T,L,Y,P2,N
920 PRINT V5,V6,W8,W9,Y1
930 PRINT L8,H1,Y2,W0
931 PRINT
935 PRINT P5,P6,S,P0,N0
940 PRINT D3,D0,F1,F2,F
942 PRINT C1,Q,P1,C0,K2
950 PRINT L0,L9
951 PRINT
999 END
```

VANES

```

2 REM SECONDARY LOOP UNITS
5 REM GAS BACK, NESTING-FORM BELL; V=234 & 668, T=600&750F
6 REM 3 IDENTICAL UNITS: 1 IN SEC, 2 IN PRI LOOP
7 REM B1=MAX CAPABLE VOL
8 LET B1=344
9 REM B=FAILURE MODE VOL
10 LET B=236
30 LET T6=1060
50 LET R=.297
60 LET E1=28.8E6
62 LET E2=26.62E6
70 LET C4=.39
75 LET B0=1.19
80 LET T5=560
90 LET M=1
99 REM Q1=THICKNESS CORRECTION FACTOR
240 PRINT "T","L","Y","P2","N"
250 PRINT "V5","V6","W8","W9","Y1"
253 PRINT "L8","H1","Y2","W0"
254 PRINT
255 PRINT "P5","P6","S","P0","N0"
257 PRINT "D3","D0","F1","F2","F"
258 PRINT "C1","Q","P1","C0","K2"
259 PRINT "L0","L9"
260 LET V=B
270 LET D3=11
275 LET T=.010
280 PRINT "BELLOWS I.D.="D3;"", DELTA VOL="V
281 LET Y1=1.6153
282 LET N=34.436
283 LET L=.52473
285 LET V5=943.48
286 LET P5=7.0502
287 LET C0=2
288 REM STRESS CORRECTED FOR THINNING
289 LET D0=D3+2*L+2*(M*T-T)
290 LET D2=D3+L+(M*T-T)
291 LET A=(3.1416*D2+2)/4
292 LET Y=V/A
293 LET Y2=Y-Y1
299 LET Q1=D3/D0
301 IF L=>.15*D3 THEN 951
302 LET V6=V5-A*Y
304 LET P6=P5*T6*V5/(V6*T5)
327 REM Y5=TOTAL DEFL. FOR "B1" VOL
328 LET Y5=B1/A
350 LET W=2*3.1416*D2*N*R*M*T*((L-2*C0*T)+3.1416*C0*T)
360 LET K1=3.1416*E1*D2*M*T+3/(6*.91*C4*N*L+3)
365 LET K2=K1*E2/E1
370 LET P2=P6+(K2*Y2/A)*2

```

VANES CONTINUED

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375 LET F1=P2*L+2/(2*M*(T*Q1)+2)
380 LET F2=3*Y2*E2*(T*Q1)/(2*.91*B0*N*L+2)
385 LET F=F1+F2
400 REM S2=S0L. HT. FORMED BELL0WS
440 LET S2=((2*C0*T)+2*M*T)*N
490 REM C1=FREE LENGTH
500 LET C1=S2+Y1
600 REM STRU: +.25" HT FOR ATTACH. PRESS D0ME: Z8=WT. 0F GAS D0ME
610 LET D8=D0+.25
620 LET L8=(2*S2)+Y5+.80+2*.25
624 REM 0UTER CAN WEIGHT
626 LET W8=3.1416*D8*.04*L8*R
628 REM NAK D0ME, M0VE. HEAD, BELL. RINGS WEIGHT
630 LET W8=W8+3.1416*R*(D8+2/4*.06+(D0-.6)*.12*.6)
632 LET W8=W8+3.1416*R*((D3-.26)+2/4*.06+(D3-.26)*(S2+2*.60)*.06)
634 LET W8=W8+3.1416*R*D2*(L+.25)*.032*2
636 REM W9=WT 0F RESID NAK AT ZERO V0L DISPL AT 100F
638 LET W9=3.1416*(D2-.02)*L*(S2+.12)*54/1728
640 LET W9=W9+3.1416*(D2-L-.10)*.10*(S2+.12)*54/1728
642 LET W9=W9+D0+2/4*.12*54/1728
648 REM Z8=GAS D0ME WEIGHT
650 LET Z8=3.1416*R*(D0+2/4*.032+(D8*.032*.4))
652 LET Z8=Z8+3.1416*D8*.08*.3*R
660 LET W0=2*W+W8+W9+Z8
680 REM V1=GAS V0L. IN ECU CAVITY
687 REM GAS PRESS CALCS: P5/P6=INIT/FINAL (AT V0L=V) GAS PRESS
693 LET P1=P5-(K1*Y1/A)*2
700 REM FAILURE M0DE ANAL; S=SECD V0L EXT T0 BELL0WS
705 REM P0=GAS PRESS, PRI BELL0WS FAILED, V0L=B
708 REM N0=NAK PRESS, PRE BELL0WS FAILED, V0L=B
710 LET S=3.1416*(D2*L*.5*(Y5+2*S2)+((D0+.06)*.06*(Y5+2*S2+1.75)))
715 LET S=S+3.1416*D2*L*.88
760 LET P0=T6*V5*P5/(T5*(V6+S+(V-B)))
775 LET N0=P0+2*K2*((B-S)/A-Y1)/A
820 REM Q=SQUIRM PRESS AT FULL V0L
825 LET Q=2*3.1416*K2/(S2+Y5)
830 REM H1=NATURAL FREQUENCY AT 100F
835 LET H1=9.85*SQR(K1/W)
840 REM L0=WELD LENGTH, FEET
845 LET L0=(2*3.1416*D0+.75+(L-2*C0*T+3.1416*C0*T)*2*N)/12
846 LET L0=L0+(3.1416*D0)/12*3
847 LET L9=L8+(1.6/11)*D0+.50
900 SET DIGITS 5
910 PRINT T,L,Y,P2,N
920 PRINT V5,V6,W8,W9,Y1
930 PRINT L8,H1,Y2,W0
931 PRINT
935 PRINT P5,P6,S,P0,N0
940 PRINT D3,D0,F1,F2,F
942 PRINT C1,Q,P1,C0,K2

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VANES CONTINUED

950 PRINT LO,L9
951 PRINT
999 END

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