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ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.		NAA-SR TDR NO. 6484	APPROVALS <i>John C. Cooper</i> <i>S. Rocklin</i>												
TECHNICAL DATA RECORD		PAGE 1 OF 4													
AUTHOR J. C. Cooper	DEPT. & GROUP NO. 782 - 86	DATE 6/6/61	RECOMMENDED FOR OUTSIDE DISTRIBUTION ☐ YES ☒ NO												
		GO NO. 7580													
TITLE Effect of Dimensional Tolerances on Power Output of a Radiation Cooled Thermoelectric Converter.		S/A NO. 2190													
		TWR													
PROGRAM SNAP-10A	SUBACCOUNT TITLE Power Conversion System Development		SIGNATURE												
DISTRIBUTION USE AN ASTERISK (*) TO INDICATE THOSE WHO ARE TO RECEIVE COMPLETE COPIES	STATEMENT OF PROBLEM Reference (1) indicated the dimensional tolerances of the Pbte thermoelements cause the major part of the variations of electrical and thermal resistance of the SNAP-10A converter. Variations of these parameters are partially compensated by a corresponding change in radiator temperature. This analysis was performed to assess the effect on power output of the same tolerances on the Pbte as those assumed in Reference (1).														
*R. Balent *D. J. Cockeram *J. C. Cooper 10 copies *M. V. Davis *H.M. Dieckamp *R.M. Galantine *M.P. Heisler *J.O. Henrie *C.E. Johnson *D.H. Johnson *J.L. Johnson *R. D. Keen *R. F. Lampe *C. J. Morse *M. E. Noe *P.L. Pekrul *S.R. Rocklin *M. Shackelford *O.P. Steele, III *A. W. Thiele *J.B. Vetrano *R.L. Wallerstedt *J. H. Walter *J. R. Wetch *R.F. Wilson *W. W. Scott *G.L. Schmidt *R.E. Burdick	ABSTRACT: Variations in both the length and diameter of the Pbte elements of + 0.010 inches from a design size of 0.660 in diameter X 0.160 in long will cause the following maximum variations in power output, optimum load resistance, and corresponding voltage and current: <table style="margin-left: auto; margin-right: auto;"> <tr> <td>Power</td> <td>-2.3%</td> <td>+00%</td> </tr> <tr> <td>Resistance</td> <td>-9.0%</td> <td>+9.6%</td> </tr> <tr> <td>Voltage</td> <td>-3.6%</td> <td>+3.4%</td> </tr> <tr> <td>Current</td> <td>-5.6%</td> <td>+4.8%</td> </tr> </table> <p>These are values of maximum variations of the parameters. All the + or - variations obviously do not occur with the same change in dimensions.</p> <p><u>ANALYSIS</u></p> <p>Variations in thermoelement dimensions in a thermoelectric converter will change the electrical and thermal resistance of the element. The radiator temperature will vary inversely as some function of the heat flow, and the change in temperature drop across the element and in the carnot efficiency will at least partially compensate for the change in thermal and electrical properties.</p> <p>In order to assess the effect of small dimension changes due to production tolerances on the thermoelement, the simplified model shown in Figure 1. is evaluated with the following assumptions:</p> <ol style="list-style-type: none"> 1. Heat source and space temperatures do not vary. 2. The temperature drop from the heat source to the hot end of the thermoelement, and from the <p>The first several copies of page 1 of this TDR are for tear-off and retention. The TDR can then be passed on to others who wish to see it. Please do NOT remove the final copy of page 1.</p>			Power	-2.3%	+00%	Resistance	-9.0%	+9.6%	Voltage	-3.6%	+3.4%	Current	-5.6%	+4.8%
Power	-2.3%	+00%													
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ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. 6484
DATE 6/6/61
PAGE 2 OF 4

cold end of the element to the heat sink is constant.

3. The average specific material properties do not change significantly for this small variation in temperature.
4. The efficiency of the converter as a fraction of carnot efficiency is constant.

In this figure, T_H is the invariant thermoelement hot temperature; T_R is the variable heat rejection temperature from the cold end of the element.

Considering this model, the heat transferred from T_H to T_R by conduction through the element is

$$Q_K = K(T_H - T_R) \quad (1)$$

where K is the thermal conductance of the element in $\text{BTU}/\text{H}_R - ^\circ\text{F}$ and T_H and T_R are the temperatures of the heat source and radiator in $^\circ\text{F}$ or $^\circ\text{R}$. Heat radiated to space (T_S) from the radiator (T_R) is

$$Q_R = C(T_R^4 - T_S^4) \quad (2)$$

where C is a constant with units $\text{BTU}/\text{H}_R - ^\circ\text{R}^4$, and includes the Stephan-Boltzmann constant and the emissivity and area of the radiator.

The heat conducted to the radiator must equal that radiated to space, which means

$$K = \frac{C(T_R^4 - T_S^4)}{T_H - T_R} \quad (3)$$

Substituting the design point temperatures gives

$$K_0 = \frac{C(1048^4 - 460^4)}{1310 - 1048} = 4.429 \times 10^9 \text{ C} \quad \frac{\text{BTU}}{\text{H}_R - ^\circ\text{F}}$$

assuming space is at $0^\circ\text{F} = 460^\circ\text{R}$. Assuming the heat source temperature (T_H) and space temperature (T_S) remain constant, varying K from K_0 causes the radiator temperature (T_R) to vary as shown in Figure 1.

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. 6484
DATE 6/6/61
PAGE 3 OF 4

The heat transferred from T_H to T_R includes both the conduction and the Peltier heat transfer:

$$Q_K = k \frac{A}{L} (T_H - T_R) + S T_H I \quad (4)$$

where k is the specific thermal conductivity of the thermoelectric element, A its area, L its length, S its Seebeck coefficient and I the electric current through the element. At the design point for the P element

$$\begin{aligned} Q_K &= \frac{(14.5)(727 - 582)}{0.162} + (270 \times 10^6)(727)(19.5) \\ &= 13.0 + 3.83 = 16.83 \text{ watts} \end{aligned}$$

here cgs units are used for convenience in the calculation.

By equation (1) for any given $T_H - T_R$, K varies directly as Q_K . Assuming the Peltier heat is constant, K varies from K_0 with changes in A/L as shown in Figure 2. The curve calculated for the N element is identical to that for the P.

Figure 1 is perfectly general as long as heat source and space temperatures are 850°F . and 0°F ., respectively, and all heat transfer to the radiator is through the element. Figure 2 applies as long as material properties and the current in the circuit are constant.

If a Pbte pellet 0.660 in. diameter by 0.160 in. long has a tolerance of ± 0.010 in. in both length and diameter, the extreme variations in A/L will be

L	D	$(A/L)/(A/L)_0$
0.170	0.650	0.913
0.160	0.660	1.00
0.150	0.670	1.099

The corresponding variations in K/K_0 , radiator temperature and temperature drop along the pellet from figures 2 and 1 respectively, are

$(A/L)/(A/L)_0$	K/K_0	$T_R (^\circ \text{F})$	$\Delta T (^\circ \text{F})$
0.913	0.933	579	271
1.00	1.00	588	262
1.099	1.077	597.5	252.5

If the output as a fraction of Carnot efficiency does not change, the power output from an element will vary as the product of heat flux and Carnot efficiency. Since T_H remains constant

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. 6484
DATE 6/6/61
PAGE 4 OF 4

$$\frac{P}{P_o} = \frac{K}{K_o} \left(\frac{\Delta T}{\Delta T_o} \right)^2$$

the reduction in power output due to the assumed tolerances will be

$(A/L)/(A/L)_o$	$\Delta T/\Delta T_o$	P/P_o
0.913	1.034	0.977
1.00	1.00	1.00
1.099	0.964	1.00

Thus a tolerance of ± 0.010 inches on length and diameter of an 0.660 P x 0.160 L pellet would allow a maximum reduction in power to 97.7% of the design value, if this tolerance was added to the length and subtracted from the diameter of each element.

The electrical resistance of each element will vary inversely as the variation of $\frac{A}{L}$ of the element, and the EMF directly as the temperature drop along the element. The optimum load resistance and the corresponding voltage and current will vary as shown below.

$(A/L)/(A/L)_o$	R/R_o	V/V_o	I/I_o
0.913	1.096	1.034	0.944
1.00	1.00	1.00	1.00
1.099	0.910	0.964	1.048

Reference: (1) IOL from W. P. McCurnin to J. M. Walter,
"The Effect of Dimensional Tolerances on Heat
Transfer and Current Flow in A SNAP 10A
Thermoelectric Couple", dated May 16, 1961.

VARIATION OF RADIATOR TEMPERATURE
WITH CHANGE OF THERMAL CONDUCTANCE
FOR FIXED HOT TEMPERATURE

FIGURE 1

VARIATION IN THERMAL CONDUCTANCE
WITH DIMENSION CHANGES ASSUMING
CONSTANT Peltier HEAT TRANSFER
(CALCULATED FOR THE DESIGN
POINT $K_0, (A/L)_0$)

FIGURE 2