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A THERMAL STRESS EVALUATION OF THE VIKING RTG HEAT SHIELD

by J. T. STADTER and R. O. WEISS

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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FOREWORD

The work reported herein was conducted by the Aeronautics Division of the Applied Physics Laboratory for the Energy Research and Development Administration, Division of Nuclear Research and Applications. Activities of the Aeronautics Division are under the general supervision of Dr. William H. Avery. The Project Engineer for the Aerospace Nuclear Safety Program is James C. Hagan.

ABSTRACT

Thermal stress analyses of the Viking RTG heat shield are presented. The primary purpose of the analyses was to determine the effects of the end cap and the finite length of the heat shield on the peak tensile stress in the barrel wall. The SAAS III computer code was used to calculate the thermal stresses; axisymmetric and plane section analyses were performed for a variety of temperature distributions.

The study consisted of three parts. In the first phase, the influence of the end cap on the barrel wall stresses was examined by parametrically varying the modulus of elasticity of the contact zone between the end cap and the barrel. The second phase was concerned with stresses occurring as a result of an orbital decay reentry trajectory, and the effects of the magnitude and shape of the axial temperature gradient. The final part of the study was concerned with the circumferentially nonuniform temperature distribution which develops during a side-on stable reentry. This last part includes a comparison of stresses generated for a hexagonal cross section with those generated for a circular cross section.

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I. INTRODUCTION

Viking Lander spacecraft were launched during the latter part of 1975 to obtain scientific data on the planet Mars. Two SNAP-19 radioisotope thermoelectric generators (RTG's) are being used to provide the power required for the Lander portion of the mission. The SNAP-19 generators were developed by Teledyne Isotopes for the U. S. Energy Research and Development Administration.

The safety specifications for the Viking program were directed toward immobilization of the nuclear fuel during all phases of the pre- and post-launch schedule. One of the more critical accident conditions is one leading to an abort reentry of the spacecraft. To provide reentry protection through aerothermal heating and fuel retention on earth impact, the fuel capsules are enclosed in a hexagonal heat shield made of POCO AXF-Q1 graphite. The Viking heat source assembly is shown in Fig. 1. To assure adequate structural safety margins for the heat shield, an extensive parametric study is required ranging from the steep angle prompt reentry to the more probable but less severe thermal stress condition of orbital decay.

In early 1975, the Reentry Subpanel of the Interagency Nuclear Safety Review Panel (INSRP) requested that the Applied Physics Laboratory (APL) conduct supportive thermal stress analyses of the RTG heat shield design to be used in the Viking mission. The investigation was to determine the effects of the end cap and the finite length of the heat shield on the peak stress in the barrel wall. In view of the limited time available to complete the analyses, the ground rules to be followed in the study were explicit. The finite element structural model which had been developed by Teledyne Isotopes was to be used,

Fig. 1 Viking Heat Source

(Figure Extracted from Teledyne Isotopes Report)

along with the axisymmetric temperature distributions generated by Teledyne for a steep angle side-on stable reentry. The initial analysis effort examined the influence of the end cap on the barrel wall elastic stresses by parametrically varying the modulus of elasticity of the "contact elements" in the structural model. The contact elements acted to separate the end cap and the barrel wall. The study was expanded to include elastic-plastic effects and comparisons were made between results from the finite length analyses and those from plane-section analyses.

The axial variation in stress obtained from the initial study of a -30° reentry trajectory raised questions about similar effects occurring during an orbital decay reentry. Subsequently a second series of calculations was made using an orbital decay temperature distribution which was supplied by Teledyne. In addition, the sensitivity of the stress levels to the magnitude and shape of the axial temperature gradient was determined. The separate effects of the heat shield finite length and the axial temperature distribution were shown to combine additively to give approximately the peak stress computed when both effects are present.

The third and last phase of the study was concerned with the circumferentially nonuniform temperature distributions which develop during a side-on stable reentry. An orbital decay distribution supplied by Teledyne was used in plane section analyses of both circular and hexagonal cross-sections. A comparison of stress predictions using both plane stress and zero-stress-resultant (ZSR) boundary conditions was made. The ZSR plane-section boundary condition specifies zero axial force and bending moments on the ends of the cylindrical heat shield.

The results of this study were presented during a spring (1975) meeting of the Reentry Subpanel. The Subpanel used this information to formulate a procedure for correcting previously determined mid-section plane analyses to account for the combined effects of a finite length heat shield and an axial and circumferentially nonuniform temperature gradient. This correction procedure was adopted in lieu of a three-dimensional stress analysis which could not be performed in a timely fashion.

A segmented documentation of this study has appeared in the December '74 through March '75 monthly progress reports to the Safety Branch, Space Nuclear Systems Division* of the Energy Research and Development Administration (ERDA). This report places under one cover the more important results obtained from the supportive thermal stress evaluation of the Viking heat shield.

*Later changed to Advanced Energy Systems, Space and Special Purpose Division, and more recently changed to Nuclear Research and Applications Division.

II. THERMAL STRESS ANALYSES

All calculations were made with the SAAS III Code (Ref. 1), a finite element structural analysis program. This program can be used to analyze axisymmetric bodies and it can also perform plane section analyses involving either a plane stress or plane strain boundary condition. In addition, a modified version of SAAS has been developed at APL (Ref. 2) which allows for a plane section analysis with the stress resultant boundary condition (e.g., specified axial force and end bending moments). The analyses performed were limited to the two dimensional capability provided by the SAAS III code and no attempt was made to define the localized stress concentrations produced in the thread regions of the barrel wall and end cap of the heat shield.

Phase I: Steep Angle Side-on Stable Reentry

i. Axisymmetric Analyses

The preponderance of the thermal stress results reported by Teledyne in the Safety Analysis Report for the steep angle design reentry condition were derived from plane section analyses for the midsection of the heat shield. In order to determine the stresses along the barrel wall and within the end cap of the heat shield, the axisymmetric model shown in Fig. 2 was constructed by Teledyne but never successfully used. The model is one for a circular cylinder rather than a hexagonal one due to the symmetry requirement of the SAAS III program. The outer radius was chosen as the mean of the radii to the peaks and the flats of the actual hexagonal heat shield. The axisymmetric model contains 609 nodes and 544 elements. The contact region between the barrel wall and the end cap is represented by a zone of "contact elements" whose modulus may be varied to simulate any extent of

Fig. 2 Axisymmetric Model Showing Selected Temperatures for Steep-Angle Reentry Condition

interaction. The temperature distribution, selected values of which are indicated on the model in Fig. 2, is for a heat source released from the RTG at 150,000 ft. with a velocity of 35,000 fps and an entry angle of -30° . These temperatures, supplied by Teledyne, correspond to upper bound values on the heating rates. The analysis to be described subsequently accounts for the axial (Z) and radial (R) temperature variation but not for the circumferential (T) variation -- the analysis is for an axisymmetric temperature distribution.

In the initial efforts at APL to account for the interaction between the end cap and barrel wall, the tension-compression option of the SAAS code was invoked in which a modulus of 1 psi was used for those contact elements in tension and the standard compressive POCO values were applied for those contact elements in compression. However, this procedure proved to be numerically unstable due to the extreme difference between the tension and compression moduli for the contact elements.

The effect of the end cap and barrel wall interaction was subsequently examined by varying the modulus of elasticity (E) for the column of elements in the contact zone. The modulus was varied between limits of $E = 1$ psi (which corresponds to complete freedom of motion between the barrel and end cap) and $E =$ POCO values (in which the barrel, interface elements, and the end cap all have the standard POCO AXF-Q1 modulus -- this is the case in which the barrel and end cap form one continuous structure). Six different types of interaction were examined and an elastic solution was obtained in each case. If we denote by $E(R, Z, T)$ the modulus in the radial, axial and circumferential direction, then

the six cases are:

Case 1. Free: $E(R, Z, T) = 1$

Case 2. Continuous: $E(R, Z, T) = \text{POCO}$

Case 3. Soft Continuous: $E(R, Z, T) = \text{POCO} \times 10^{-3}$

Case 4. Circumferentially Free: $E(R, Z) = \text{POCO}, E(T) = 1$

Case 5. Circumferentially and Radially Free: $E(R, T) = 1, E(Z) = \text{POCO}$

Case 6. Circumferentially and Axially Free: $E(R) = \text{POCO}, E(Z, T) = 1.$

Since POCO graphite is weaker in tension than in compression, failure is likely to occur in an area of high tensile stresses. In all of the above cases the peak tensile stress occurred in the elements on the inside surface of the barrel. Figure 3 shows the circumferential (or hoop) stress distribution for the elements on the inside barrel wall ($R = 1.51$ in.) for Cases 1 through 6. The corresponding axial stresses are given in Figure 4. The stresses for all cases tend to be bracketed by the free and continuous models, Cases 1 and 2 respectively. The sharp rise in axial stress shown in Fig. 4 (Cases 2 and 4) is a result of the radial constraint imposed through the specification of a large radial modulus in the contact zone.

Although the main concern of the evaluation was with the increase in stress in the end region of the barrel wall, the results showed that substantial stresses also exist in the end cap. As an indication of the effect of various interactions, the stresses at points A, B, C (on Fig. 2) are tabulated below for Cases 1 through 6.

Fig. 3 Hoop Stress Distribution on Inside Barrel Wall (Steep Angle Reentry)

Fig. 4 Axial Stress Distribution on Inside Barrel Wall (Steep Angle Reentry)

TABLE I
SELECTED END CAP STRESSES

Case	Location A		Location B		Location C	
	σ_{θ} , psi	σ_z , psi	σ_{θ} , psi	σ_z , psi	σ_{θ} , psi	σ_z , psi
1	-1317	11656	3998	2373	9616	9625
2	13073	9174	13381	13271	9998	9998
3	945	12224	5002	3890	9824	9830
4	13140	9243	13268	13324	9944	9944
5	-1318	11655	3997	2373	9616	9625
6	9949	7539	11237	10814	10258	10258

As shown by the table, the tendency to favor either Case 1 or 2 is also indicated by the end cap stresses.

Although none of the analyses discussed above adequately describes the interaction of the barrel with the end cap, the decision was made to use Case 1, the free condition, in subsequent analyses. Contrary to the results for the continuous case, the tensile hoop stress for the free case increases from the midsection to near the end (Fig. 3). A stress amplification factor based on the ratio of the peak end-section value of 12235 psi and the peak midsection value of 7560 psi amounts to 1.62 (12235/7560).

In an attempt to determine how much the axial temperature variation influenced the end region stresses, an additional elastic calculation was made (Fig. 5) using the free specification wherein the radial temperature distribution at the mid-section was assumed to exist for every station along the length of the barrel. The factor derived from this "uniform axial temperature" calculation ($9740 \text{ psi}/7680 \text{ psi} = 1.27$) indicates that a portion of the stress amplification near the end of the heat shield results directly from the finite length and a portion of the amplification results from the influence of the axial temperature distribution.

Since the stresses obtained in the above analyses exceeded the elastic limit of the POCO graphite, an additional calculation was made for the free case using a bilinear elastic-plastic stress-strain curve. The tensile hoop stress in the mid-section of the barrel was 5250 psi and the peak tensile hoop stress was 9530 psi, occurring in the zone where the barrel and end cap overlap. A stress factor of 1.82 ($= 9530 \text{ psi}/5250 \text{ psi}$) is greater than the factor of 1.62 for the elastic solution. The reason for a higher stress factor is that, although the peak stress is decreased by 22% when plasticity is considered, the mid-section stress is decreased by 30%; the factor is just the ratio of those stresses. The hoop stress distribution for the elastic-plastic calculation is plotted in Fig. 5 along with those for the elastic calculation and the uniform axial temperature case.

ii. Plane Section Analyses

Plane section analyses were performed for comparison with the mid-section stresses resulting from the axisymmetric, finite length calculations. For these analyses the radial temperature variation at the middle of the barrel was applied to the planar element model with no circumferential temperature variation. A

Fig. 5 Comparison of Hoop Stress Distributions on Inside Barrel Wall (Steep Angle Reentry)

circular, rather than hexagonal, cross-section model was used for these plane analyses since the axisymmetric calculations were based on a circular model of the heat shield. With no circumferential temperature variation the symmetry of the problem permits the use of a model for one quadrant of the cross-section. Figure 6 shows the finite element model, which has 144 elements and 171 nodes. Two boundary conditions were considered - plane stress and zero stress resultant. The following table gives a comparison of the maximum mid-section stresses (which occur in the innermost element) for the axisymmetric and plane analyses.

TABLE II
COMPARISON OF STRESSES FOR STEEP ANGLE REENTRY

	Hoop stress (psi)		Axial stress (psi)	
	Elastic	Elastic-Plastic	Elastic	Elastic-Plastic
Axisymmetric, mid-section stress	7560	5250	8115	5560
Zero stress resultant	7875	5445	8140	5680
Plane stress	5930	4790	0	0

The zero stress resultant condition, which corresponds to generalized plane strain for this case of a circumferentially uniform temperature, gives stresses which essentially agree with the axisymmetric mid-section results. The slight differences are presumably due to the effects of the finite length of the heat shield in the axisymmetric calculations. This demonstrates the importance of the proper boundary condition in plane analyses - the elastic-plastic plane stress results for hoop stress are 9% below the axisymmetric results, while the zero stress resultant condition gives a stress which is 4% high. Accordingly, the axisymmetric and zero stress resultant calculations give axial stresses which are within 3% of each other,

Fig. 6 Circular Quadrant Model for Plane Section Analyses

while the plane stress condition, by definition, gives zero axial stress. These results show that the zero stress resultant boundary condition is the more appropriate condition for plane section analyses of the heat shield.

Phase II: Orbital Decay Side-on Stable Reentry

i. Axisymmetric Analyses

The results of the first series of calculations showed that a significant stress amplification occurs within the contact zone of the end cap and barrel wall for a steep angle reentry condition. Since a shallow angle (orbital decay) reentry is the more probable occurrence, subsequent analyses concentrated on this reentry mode. The conditions chosen involved release of the heat source at peak heating (188,000 ft.) during orbital decay -- this is a severe condition within the range of possible release altitudes. Axial temperature distributions for 3 and 8 seconds after heat source release were supplied by Teledyne. The axisymmetric finite element model with a "free" barrel-end cap interface condition was used for the analyses. Selected temperatures at 3 and 8 seconds after release are indicated on the element plot in Fig. 7. The axial variation of hoop stress along the inside row of elements in the barrel is plotted in Fig. 8 for both times. Within the region of contact between the end cap and barrel wall the stress rises steeply, amounting to a factor of 3.19 times the 1930 psi value at the mid-section for the 8 second case. Although the rise in stress is more pronounced than that determined for the steep angle reentry, the peak stresses are elastic and still within the ultimate stress limits of the POCO graphite material.

Fig. 7 Selected Temperatures (°F) for (3, 8) Seconds Into Orbital Decay Trajectory

Fig. 8 Hoop Stress Distribution on Inside Barrel Wall (Orbital Decay Reentry)

ii. Plane Section Analyses

Plane section analyses were made using orbital decay temperatures to determine the effect of the finite length and axial temperature variation on mid-section stresses. The cylindrical model (Fig. 6) used in the previous plane section analyses was again applied. For these computations the radial temperatures through the mid-section of the barrel were applied uniformly around the plane section - there was no circumferential variation in temperature. Plane stress and zero stress resultant (ZSR) boundary conditions were enforced. In all cases there was no yielding in the mid-section; the results are elastic. The following table gives a comparison of the maximum stresses in the mid-section of the heat shield for the axisymmetric, zero stress resultant, and plane stress analyses.

TABLE III
COMPARISON OF STRESSES FOR ORBITAL DECAY REENTRY

	3 seconds after release		8 seconds after release	
	Hoop stress (psi)	Axial stress (psi)	Hoop stress (psi)	Axial stress (psi)
Axisymmetric, mid-section stress	1810	1710	1930	1860
Zero stress resultant	2030	2030	2320	2280
Plane stress	1610	0	1750	0

An examination of the 3-second case results shows that the plane stress solution is 11% below the axisymmetric result while the ZSR stress is higher by a similar amount. The ZSR condition gives a good estimate of the axial stress which, for the plane stress condition, is zero by definition. Similar statements for the eight-second stresses could also be made. Plots of the radial variation of the hoop and axial stresses for the 8-second case are shown in Figs. 9 and 10.

Fig. 9 Comparison of Hoop Stress Distributions Through the Wall (Orbital Decay Reentry)

Fig. 10 Comparison of Axial Stress Distributions Through the Wall (Orbital Decay Reentry)

iii. Temperature Sensitivity Analyses

The large rise in hoop stress near the end of the barrel is due in part to the axial temperature gradient. For example, as shown in Fig. 5, a uniform axial temperature resulted in a factor of 1.27 between the peak mid-section and end-section values for the steep angle reentry. However, the temperature distributions were determined with a relatively coarse thermal model. For this reason, additional calculations were made to assess the sensitivity of peak stress to the radial and axial temperature gradients. First, using the 3-second distributions, the axial temperature gradient was suppressed and the radial gradient at the mid-section was considered to exist everywhere along the barrel. Using the axisymmetric model and the free interface condition, this assumption resulted in a peak tensile hoop stress of 2360 psi at $Z = 1.85$ in. at an innermost element ($R = 1.51$ in.). A mid-section value of 1980 psi agrees very closely with the ZSR result of 2030 psi given in Table III for the 3-second temperature distribution.

For the next computation, the axial temperature distribution along the outside of the barrel was applied uniformly through the barrel wall so there was no radial gradient. This calculation gave a peak tensile hoop stress of 2860 psi at $R = 1.51$ in., $Z = 2.27$ in. compared to a value of -230 psi at the mid-section.

The peak hoop stress (4920 psi) plotted in Fig. 8 occurs at $Z = 2.27$ in. Table IV compares the hoop and axial stresses at this location with the stresses obtained for this location by adding the values from the two separate calculations described above.

TABLE IV
DEPENDENCE OF STRESSES ON RADIAL AND
AXIAL TEMPERATURE GRADIENTS

Item*	Hoop Stress (psi)		Axial Stress (psi)	
	Mid-section	Peak at Z=2.27 in.	Mid-section	Peak at Z=2.27 in.
A.	1810	4920	1710	3460
B.	1980	2090	2090	580
C.	-230	2860	-490	2620
D.	1750	4950	1600	3200

*ITEM: A. Combined Radial and Axial Gradient
B. Radial Gradient Only
C. Axial Gradient Only
D. Items B + C

The results of these two calculations, when added together (Items B + C), give stresses that are very close to those predicted for a combined radial and axial temperature gradient (Item A). This would imply corrections to plane analyses to account for axial temperature and finite length effects should be made with an additive rather than a multiplicative factor.

Additional calculations were performed to explore the influence of the shape of the axial temperature gradient on the magnitude of the stress peak. A number of computations were made with arbitrary changes to the axial temperature gradients. The most extreme change is shown in Figure 11, where the temperature over the last 1/4-inch of the heat shield was assumed to be constant. Stress computations with this adjusted axial gradient indicated a reduction in peak stress of 18% to 4030 psi compared to the 4920 psi stress computed with the original gradients supplied by Teledyne. The results shown in Fig. 11 would

Fig. 11 Sensitivity of Hoop Stress to Axial Temperature Variation (Orbital Decay Reentry)

imply that a more accurate thermal analysis in the end region of the barrel wall would probably change the hoop stress within the contact zone by less than 18%.

Phase III: Asymmetric Temperature Variations and the Hexagonal Shape

The final phase of the study was made to determine the effect of circumferentially asymmetric temperature gradients and the hexagonal cross-section on the maximum tensile stress. Several plane section analyses were performed using a temperature distribution corresponding to 9 seconds after heat source release into an orbital decay reentry. The temperatures were provided by Teledyne for the hexagonal cross-section and were used directly to compute stresses in a circular plane section. The circular section had an outside radius equal to the mean of the radii to the peaks and the flats of the hexagon. It was found that when the temperature interpolator in the SAAS III program used the raw data, anomalous distributions in temperature were produced. These, in turn, led to rather erratic stress levels. Since it was felt that such an irregular behavior in temperature was unrealistic, the raw data were smoothed by the addition of temperature points determined by manual interpolation. Once these points were added the SAAS interpolated temperature gradients were smooth and the resulting stresses were also smoother and generally lower. The plane model used for these computations is shown in Fig. 12. Selected element temperatures are indicated on the model.

The stresses obtained with the circular model are shown in Fig. 13, where the maximum principal in-plane stress (which is essentially hoop stress) is given for the plane stress and the zero stress resultant boundary conditions. The plotted stresses are for the stagnation row of elements (at 3°) and for the

Fig. 12 Circular Cross-Section Model Used for 9-Second Orbital Decay Reentry

Fig. 13 Maximum In-Plane Stress for Circular Cross-Section Model

elements lying on a radius through the peak stress (at 27°). The peak stress resulting from a plane stress calculation is 1300 psi occurring near the middle of the wall, 27° from the stagnation line. The peak stress location at the mid-wall is contrary to previous results obtained for a circumferentially uniform temperature distribution (Refer to Fig. 9). The mid-wall peak in stress is a result of the nonuniform circumferential temperatures which are based on the hexagonal shape. The corresponding peak stress for the zero stress resultant boundary condition is 1710 psi and occurs at the same location.

The stresses near the stagnation point (3°) on the inside wall are about 50% below the corresponding stresses obtained for the plane section analysis described previously for 8 seconds after release in an orbital decay reentry (Refer to Fig. 9). In those calculations the stagnation temperature variation was in the radial direction only--there was no circumferential gradient. Although there is some difference in the temperature distribution between 8 and 9 seconds (amounting to less than 200°F on the outside surface and 5°F on the inside radius) the effect on stress levels is felt to be minor. The primary reason for the reduction in stress (at 3°) is the circumferential variation in temperature.

The same temperature data were also used with the hexagonal model shown in Fig. 14 to give some indication of stress variation due to heat shield shape. The hexagonal model has the same element distribution as the circular model (Fig. 12) so that a direct comparison of stresses can be made. The resulting stresses for the plane stress and zero stress resultant boundary conditions are plotted in Fig. 15. A comparison of values shown on Figs. 13 and 15 shows that, while there is some variation in stresses between the circular and hexagonal models, the peak stress is essentially the same for both models and it occurs at the same location. Somewhat higher peak stresses are computed with the zero stress resultant boundary condition in both models.

Fig. 14 Hexagonal Cross-Section Model Used for 9-Second Orbital Decay Reentry

Fig. 15 Maximum In-Plane Stress for Hexagonal Cross-Section Model

III. CONCLUSIONS

Although the thermal stress study of the Viking heat shield was limited in scope, a number of specific statements can be made. The heat shield is of a sufficiently large fineness ratio (length/mean diameter = 1.78) so that the nature of the contact between the end cap and barrel wall has little effect on the mid-section stresses. Using the Teledyne model, a parametric variation of the moduli in the contact zone of the end cap and barrel failed to establish an adequate description of the contact mechanism. However, the condition in which the barrel was freed from the end cap resulted in hoop stresses on the inside wall that rose steeply toward the end of the barrel. The magnitude of the rise is due to the combined effect of the finite length of the barrel and the axial temperature gradient. For the dimensions of the Viking heat shield, the finite length amplification on the maximum mid-section stress is typically 1.25 while the axial gradient effect is related to the extent of the temperature rise near the end of the barrel. The two effects taken separately add to give approximately the correct combined peak stress.

The plane stress specification is an inappropriate boundary condition for analyzing heat shields. The zero-stress resultant (ZSR) condition not only gives a good estimate of the mid-section peak hoop stress but also predicts the axial stress with good accuracy. With the plane stress condition, the axial stress is zero by definition.

Asymmetric temperature gradients result in lower stresses than those computed with the stagnation line radial gradient applied uniformly around the circumference of a circular cross-section. The use of a circular cross-section with an appropriate outside radius as a substitute for the hexagonal one has a small influence on the maximum stresses. The more important factor is the non-

uniform circumferential temperature distribution caused by the corners of the hexagonal wall. Larger stresses occur in these regions at mid-wall than on the inside radius at the thinner stagnation location. Plane section results for a specific orbital decay reentry temperature distribution show that the maximum tensile stress computed with a plane stress specification is more than 20% lower than an equivalent calculation with the ZSR condition. This is the case regardless of whether a circular or hexagonal cross-section model is used.

Larger stresses occur in the end region of the barrel wall than in the mid-section. Undoubtedly, a major reason for this is the heating on the exposed end of the barrel wall. Future thermal stress analyses should concentrate on the end regions of the heat shield in an effort to define regions of large stress.

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Air Force Weapons Laboratory	Albuquerque, N.M.	Lt. W. Holtzscheiter	1
NASA/Ames	Moffet Field, CA.	W. Pitts	1
NASA/Langley	Hampton, Va.	G. D. Walberg	1
Los Alamos Scientific Laboratory	Los Alamos, N.M.	R. N. R. Mulford	1
Oak Ridge National Laboratory	Oak Ridge, Tenn.	R. G. Donnelly	1
Oak Ridge Technical Information Center	Oak Ridge, Tenn.	R. L. Shannon	1
Aerospace Corporation	Los Angeles, CA.	C. Melfi	1
AVCO Systems Division	Wilmington, Mass.	R. Ryan	1
General Electric Co.	King of Prussia, Pa.	R. Wiley	1
		C. T. Bradshaw	1
		D. Tantino	1
Donald W. Douglas Laboratory	Richland, Wash.	J. D. Watrous	1
Fairchild Industries	Germantown, Md.	H. P. Kling	1
TRW Systems, Inc.	Redondo Beach, CA.	J. M. Bell	1
Westinghouse Electric Corp.	Pittsburgh, Pa.	W. G. Parker	1
Teledyne Isotopes	Timonium, Md.	D. C. Anderson	1
		D. Owings	1