NASA Technical Memorandum 105350

Parametric Studies of Phase Change Thermal Energy Storage Canisters for Space Station Freedom

Thomas W. Kerslake
Lewis Research Center
Cleveland, Ohio

Prepared for the
International Solar Energy Conference
sponsored by the American Society of Mechanical Engineers
Lahaina, Maui, Hawaii, April 4–8, 1992

NASA

PARAMETRIC STUDIES OF
PHASE CHANGE THERMAL ENERGY STORAGE CANISTERS
FOR SPACE STATION FREEDOM

Thomas W. Kerslake*
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

This paper discusses Phase Change Material (PCM) canister parametric studies wherein the thermal-structural effects of changing various canister dimensions and contained PCM mass values are examined. With the aim of improving performance, 11 modified canister designs are analyzed and judged relative to a baseline design using five quantitative performance indicators. Consideration is also given to qualitative factors such as fabrication/inspection, canister mass production, and PCM containment redundancy. Canister thermal analyses are performed using the finite-difference based computer program NUCAM-2DV. Thermal-stresses are calculated using closed-form solutions and simplifying assumptions. Canister wall thickness, outer radius, length, and contained PCM mass are the parameters considered for this study. Results show that singular canister design modifications can offer improvements on one or two performance indicators. Yet, improvement in one indicator is often realized at the expense of another. This confirms that the baseline canister is well designed. However, two alternative canister designs, which incorporate multiple modifications, are presented that offer modest improvements in mass or thermal performance, respectively.

1 INTRODUCTION

The solar dynamic power module (SDPM) proposed for the growth Space Station Freedom uses the heat of fusion of a Phase Change Material (PCM) to efficiently store thermal energy for use during eclipse periods. The PCM, a LiF-20CaF_2 salt, is contained in annular, metal canisters located in a heat receiver (Strumpf and Coombs, 1987), shown in Figure 1, which accepts focussed solar energy from an offset parabolic concentrator. Due to the cyclic PCM freeze-thaw behavior, the canisters remain near the PCM melting point, 1042 K, and are thus able to continuously heat an inert gas mixture circulating through the heat receiver during an entire orbit. The hot working gas, in turn, drives a single shaft turbine-alternator-compressor to produce electric power.

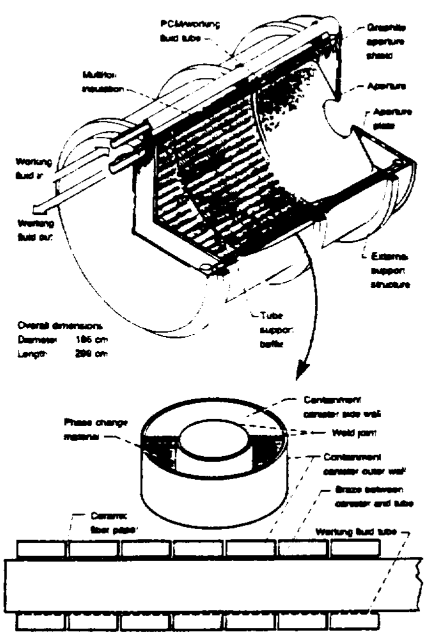

Figure 1. Heat Receiver

* Aerospace Engineer,
Associate Member ASME

The baseline PCM canister design was established by preliminary work performed during Phase B of the Space Station Freedom Program (Rockwell, 1986). Various analyses and ground-based experiments have continued to demonstrate the adequacy of this design and the ability to accurately characterize canister thermal performance (Strumpf and Coombs, 1989, Kerslake and Ibrahim, 1990, Kerslake, 1991, and Strumpf et al., 1991). However, program resources were not available to conduct rigorous design refinement studies and thus, there have been no published parametric studies which explore potential canister design improvements (although some unpublished work involving heat receiver parametric studies has been recently completed by Klann (1991a) and Klann (1991b)). Canisters account for 59 percent of the 1752 kg baseline receiver mass, strongly influence receiver cavity radiative heat transfer, and control heat transfer to the engine working gas. This suggests that significant performance and mass improvements are potentially possible through canister design refinements.

This paper discusses PCM canister parametric studies wherein the thermal-structural effects of changing various canister dimensions and contained PCM mass values are examined. The purpose of these studies is not to optimize the canister design, but instead identify design changes to improve performance as measured by: (1) maximum wall temperature, (2) maximum thermal stress, (3) receiver mass, (4) PCM melt fraction, and (5) cyclic temperature range. Once identified, the appropriate design changes can be implemented to satisfy the highest priority programmatic goals. Design changes are also considered in light of qualitative factors such as fabrication/inspection, canister mass production, and PCM containment redundancy.

2 ANALYSIS

2.1 Canister Heat Transfer

Computational canister heat transfer analyses were performed using the computer program "NUCAM-2DV" (Kerslake and Ibrahim, 1990 and Kerslake, 1991). This program employed an explicit, finite-difference numerical technique to analyze a two-dimensional, axisymmetric PCM canister geometry as shown in Figure 2. Phase-change heat transfer was modeled using the "enthalpy method", where specific enthalpy, e, was determined through the conservation of energy equation:

$$\frac{\partial(\rho e)}{\partial t} = \text{div}\,[k\,\nabla T]\,, \qquad (1)$$

where ρ, k, and T are the PCM density, conductivity, and temperature, respectively. PCM temperature and phase distributions were then related to specific enthalpy by a set of constitutive equations. A constant volume, fixed location void model that calculates radiation and PCM vapor conduction heat transfer was included. Constant material properties, evaluated at the PCM melting point, were used. Absorbed heat flux and cooling gas boundary conditions used in the analyses are shown in Figure 3. These boundary conditions are typical for canisters located in high flux, high temperature regions of the receiver. Canister analyses were executed over four consecutive simulated orbits, each 91 minutes in duration, to closely achieve cyclic thermal equilibrium.

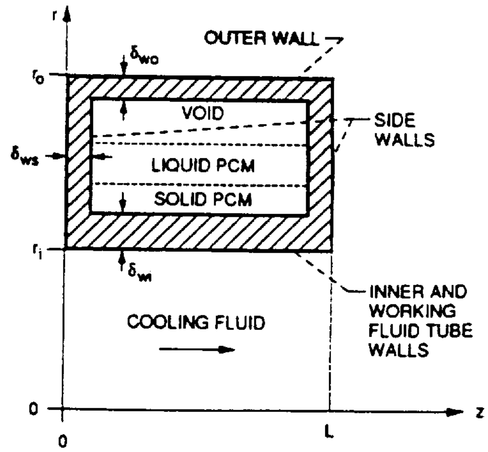

Figure 2. Canister Schematic Geometry

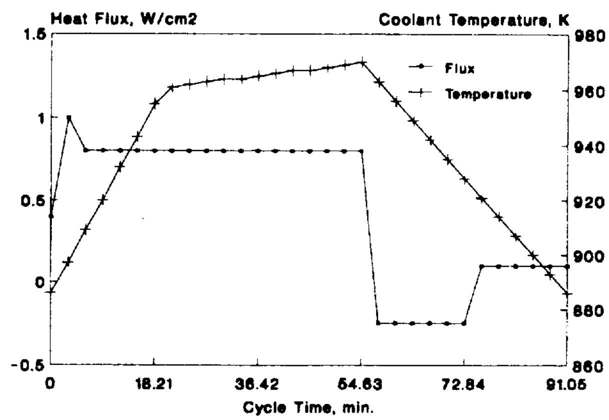

Figure 3. Boundary Conditions

2.2 Canister Thermal Stresses

Thermal stresses in the canister outer and side walls were calculated at one minute intervals throughout the simulated orbital cycles using closed-form solutions. Constant material properties, evaluated at the PCM melting point, were used. The calculation of stresses in the PCM was considered beyond the scope of the current effort and was thus not performed.

The canister outer wall was treated as a column that expands differentially with respect to the inner wall. The outer wall is constrained at each end by a side wall with an effective spring constant, κ, determined by the side wall geometry and Young's modulus, E (Roark, 1965). It was assumed that this constraint produced a uniform outer wall stress as in Boley and Weiner (1960) which is given by:

$$\sigma_o = -\alpha \Delta T L^* / [2A/\kappa + L^*/E] \, , \qquad (2)$$

where α is the coefficient of thermal expansion, L^* is the canister length minus twice the side wall thickness, δ_w, A is the outer wall cross sectional area, and ΔT is the difference in the integrated average outer and inner wall temperatures.

Each side wall was treated as a thin annular disk of inner radius r_i, outer radius r_o, and with temperature variations in the radial direction only, i.e. T=T(r). The radial and tangential stresses, σ_r and σ_t, respectively, from Ugural and Fenster (1987) were determined by:

$$\sigma_r = \alpha E/r^2 \{ -\int_{r_i}^{r} Tr\, dr + [r^2 - r_i^2]/[r_o^2 - r_i^2] \int_{r_i}^{r_o} Tr\, dr \} \, , \qquad (3)$$

$$\sigma_t = \alpha E/r^2 \{ -Tr^2 + \int_{r_i}^{r} Tr\, dr + [r^2 + r_i^2]/[r_o^2 - r_i^2] \int_{r_i}^{r_o} Tr\, dr \} \, . \qquad (4)$$

An additional radial stress exists from side wall bending caused by differential expansion of the outer and inner walls. The magnitude of the bending stress, given in Roark (1965), is maximum at r_i and reduces to zero at r_o. This bending stress was superimposed with the thermally induced radial stress in the side wall. Hence, the validity of stress predictions is restricted to the elastic range.

2.3 Canister Design Parameters

The parameters used in the canister analyses are listed in Table I along with their baseline values and the range of values studied. These parameters were selected since they offer the greatest potential for improving the canister performance and/or reducing receiver mass. Parameter values were modified to explore trade-offs in heat transfer performance, stress levels, and mass while maintaining responsiveness to canister fabrication and operational requirements. Radical parameter changes were not considered so that previous receiver/canister development and fabrication efforts remain applicable. In addition, the analyses performed apply only to receiver designs with all canisters identical.

For all analyses, the following items were held fixed at their baseline values (Rockwell, 1986): receiver cavity length, total PCM mass, total working gas flow rate, tube spacing ratio, tube diameter and wall thickness, and canister inner wall thickness. Other items, such as the number of canisters, number of tubes and receiver cavity diameter, were recalculated based on changes in canister parameters. As a result of these changes, values for the coolant flow per tube and the absorbed canister heat flux were scaled as well.

Table I. Canister Design Parameters

Parameters	Baseline Values*		Parameter Ranges Minimum	Maximum
Wall Thickness (cm)	0.1524		0.0254	0.2286
Length (cm)	2.5400		2.5400	5.0800
Canister PCM Mass (g)	43.2162	(1)	39.9540	46.4784
		(2)	30.3179	57.5758
		(3)	43.2162	86.4324
Outer Radius (cm)	2.2606		2.0345	2.4866

* Rockwell (1986)
(1) With Fixed, Baseline Canister Dimensions
(2) With Variable Outer Radius and Constant Void Volume Fraction
(3) With Variable Canister Length

2.4 Mass Calculations

Canister mass calculations were based on the specified PCM mass and the canister wall dimensions and material density. Total receiver mass calculations were made using the newly calculated total canister mass and scaled baseline receiver mass values. Receiver tube mass was scaled by the number of tubes while the remaining receiver mass (excluding the mass of the external working gas duct) was scaled based on receiver cavity diameter.

3 DISCUSSION OF RESULTS

A summary of the receiver design characteristics for 12 cases is presented in Table II. Case 1 considers the baseline design. Cases 2 through 10 incorporate single parameter modifications to the baseline canister design as described previously. Cases 11 and 12 incorporate multiple parameter changes which improve receiver mass or canister thermal performance, respectively. Computational performance results are summarized in Table III. These results were taken from the fourth simulated orbital cycle in which canister temperatures had stabilized to within 2 K. Results from the first 10 cases are discussed in sections 3.1 to 3.5. This is followed by a discussion in section 3.6 of potential canister design improvements offered by the last 2 cases.

3.1 Maximum Wall Temperature

This performance indicator is a good relative measure of the heat transfer performance of candidate canister designs. It is not, however, an absolute measure in which to quantitatively assess material degradation for any given design. For all cases examined, the maximum wall temperature occurred at the longitudinal midpoint of the outer wall. As expected, the maximum canister wall temperature was reduced by increasing receiver cavity diameter (i.e., reducing absorbed heat flux), increasing canister wall thickness, and decreasing canister outer radius or length. However, each of these design changes creates mass increases beyond that justified by the improvement in maximum temperature levels. For example, a 15 K decrease is achieved in case 4 by increasing the wall thickness by 50 percent with an associated receiver mass increase of 325 kg. Thus, a

Table II. Modified Receiver Design Characteristics

Case #	Parameter Changed	Values	Can. PCM Mass (g)	Void Vol. Frac.	No. of Can.	Total Can. Mass (kg)	Rec. Dia. (cm)	No. of Tubes	Rec. Mass (kg)
1	N/A	Table I.	43.21	0.148	7872	1037.78	172.3	82	1751.77
2	Wall Thickness (cm)	0.0254	43.21	0.353	7872	554.18	172.3	82	1268.17
3		0.1143	43.21	0.218	7872	901.11	172.3	82	1615.10
4		0.2286	43.21	0.085	7872	1342.84	178.1	82	2076.62
5	Length (cm)	3.8100	64.82	0.185	5248	968.41	172.3	82	1682.40
6		5.0800	86.43	0.202	3936	933.72	172.3	82	1647.71
7	Canister PCM Mass (g)	39.9540	39.95	0.212	8514	1094.64	184.9	88	1859.54
8		46.4784	46.47	0.084	7319	988.75	159.7	76	1651.82
9	Outer Radius (cm)	2.0345	30.31	0.148	11221	1189.66	219.4	116	2109.13
10		2.4866	57.57	0.148	5908	945.26	141.0	61	1524.72
11	Wall Thick.(cm) Outer Rad. (cm)	0.0762 2.0345	36.85	0.148	9230	768.25	181.6	96	1532.32
12	Wall Thick.(cm) Outer Rad. (cm)	0.1221 2.1050	36.85	0.148	9230	964.47	187.9	96	1749.97

Table III. Computational Performance Results

Case #	Max. Wall Temp. (K)	Max. Stress[(1)] (MPa)	Stress Orientation	PCM Melt Fractions Sun Rise	PCM Melt Fractions Sun Set	Cyclic Temp. Range (K)
1	1123.8	32.51	Radial	.016	1	88.6
2	1184.1	73.80	Tangential	.000	1	142.1
3	1134.9	37.58	Tangential	.013	1	98.6
4	1108.6	31.86	Radial	.027	1	73.9
5	1142.6	71.70	Radial	.031	1	103.2
6	1157.2	117.15	Radial	.042	1	114.1
7	1114.0	30.78	Radial	.000	1	83.7
8	1135.3	33.76	Radial	.044	1	98.5
9	1079.1	33.41	Radial	.000	1	78.9
10	1170.4	48.21	Tangential	.140	1	130.0
11	1124.0	32.79	Tangential	.000	1	107.3
12	1108.4	32.57	Radial	.000	1	89.4

(1) Restricted to local wall temperatures ≥ 1042 K.

combination of changes is required to lower wall temperatures without mass penalties. Since canister structural life and material durability strongly depend on temperature, design changes that reduce maximum temperatures with little or no mass penalty are highly desirable.

3.2 Maximum Thermal Stresses

As in the preceding section, this performance indicator is only a relative measure of canister structural loading and not a highly accurate prediction in which material damage estimates can be based. Maximum stresses were only evaluated when local wall temperatures exceeded 1042 K which is loosely considered the "creep threshold temperature" above which significant material creep relaxation can occur at typical canister stress levels.

The maximum stress for each case was tensile and located at the side wall inner radius on the PCM exposed surface. The magnitude of baseline canister side wall stress levels were also consistent with those reported in the literature for similar thermal loadings (Strumpf et al., 1991 and Tong et al., 1987). Maximum stresses occurred just prior to complete PCM liquefication at cycle times ranging from 45 to 54 minutes. At this point in the cycle, local wall temperatures ranged from 1057 K (case 9) to 1128 K (case 10). The primary contributor to radial stress was side wall bending. Maximum tangential stresses occurred in canisters with a low wall thickness-to-radius ratio relative to the baseline design. Relatively poor side wall heat transfer in such canisters result in large radial temperature gradients which elevate tangential stress levels. Maximum stresses in the outer wall were compressive (during heating) and very small compared with side wall stresses.

With the exception of cases 2, 5 and 6, side wall radial and tangential stress components were nearly equal in magnitude indicating a structurally efficient use of material. For the exceptional cases, the maximum stress component was 2 to 4 times greater than the other component. As demonstrated by cases 5 and 6, canister length increases dramatically elevate side wall radial stresses. Therefore, these longer canisters would have greatly reduced service lives while only saving 70 to 100 kg in receiver mass. The trend identified by these cases is evident in recent experiments with high length-to-radius canisters (l/r=8) that failed by cracking at the side wall inner radius weld joint, (Abe et al., 1991).

Apparently, canister parameter changes alone can do little to reduce maximum stresses. This observation is based on the facts that: 1) canister wall temperature gradients are required to transfer energy to melt the poorly conducting PCM during a finite insolation period and 2) canister wall heat transfer capability and structural compliance are directly coupled, i.e. small canisters with thick walls conduct heat well but possess high structural rigidity. Thus, to lower canister wall stresses, PCM heat transfer must be improved (i.e., by using conductive fibers or foams) to reduce thermal strains and/or canister heat transfer must be decoupled from canister structural compliance. Since the baseline canister stresses are acceptably low, there appear to be no compelling reasons to make canister design changes solely for the purpose of stress reductions.

3.3 Receiver Mass

Mass has traditionally been an important factor in aerospace systems due to the inherently high cost of launching payloads to earth orbit. Furthermore, it is desirable to have a mass margin for the heat receiver (which is the most massive component of the SDPM) to guard against future mass growth as the receiver design matures. However, it is unclear at this time whether the launch of a SDPM will be mass limited or volume limited. The answer to this question depends on the SDPM power rating, cargo element packaging, and the launch vehicle. Therefore, while mass is an important performance indicator, reliability and thermal performance should not be compromised solely to achieve mass savings.

The receiver mass is essentially driven by canister mass. The largest canister mass reductions are possible through either reducing wall thickness, which achieves a 483 kg direct mass savings in case 2, or increasing canister radius as in case 10, which allows a greater PCM packing mass per canister and hence, a 227 kg mass savings from having fewer canisters. The problem with these reduced mass designs is that wall temperatures and thermal stresses increase due to lower wall conductance or increased heat flux associated with a smaller receiver cavity diameter. Furthermore, canisters with thin walls, such as in case 2, are more susceptible to inherent material flaws (i.e., stringers) and material degradation failure modes (i.e., vacuum sublimation and PCM chemical attack) than the baseline canister with thicker walls. Therefore, canister mass reductions should be achieved through modest reductions in wall thickness balanced by measures to mitigate wall temperature increases.

3.4 PCM Melt Fraction and Cyclic Temperature Range

These performance indicators are good measures of PCM utilization and the efficiency of the PCM thermal charge/discharge process. Ideally, the range of melt fraction for all receiver canisters would vary between 0, at orbital sunrise, and 1, at orbital sunset. In this ideal case, the continual presence of two-phase PCM beneficially acts to minimize the canister cyclic temperature range and stabilize the receiver working gas outlet temperature (i.e., the turbine inlet temperature).

For all cases considered in this study, the maximum cyclic temperature range (reported in Table III) occurred at the longitudinal midpoint of the outer wall. Prior to sunset, complete PCM melting was achieved in each case as well. Increases in cyclic temperature range were primarily a consequence of increased liquid PCM sensible heating since all canister designs analyzed completed or nearly completed solidification at orbital sunrise. The last PCM to freeze was located on the outer radius at the canister longitudinal midpoint so that wall temperatures in this region were maintained near 1042 K at sunrise. Like maximum wall temperatures, liquid PCM sensible heating (and hence, cyclic temperature range) was reduced by increasing wall thickness, decreasing canister outer radius or length, and increasing receiver cavity diameter. Associated with these changes was a greater canister metal mass which enabled sensible energy storage over a smaller temperature range compared with the less massive baseline design.

3.5 Qualitative Factors

Qualitative factors pertinent to the choice of canister design include canister mass production, receiver fabrication, and PCM containment redundancy. Canister production is comprised of three major elements: metal wall forming/welding, PCM filling, and weld joint inspection. At the outset of these studies, large parameter changes were avoided so that previously developed canister fabrication techniques would remain applicable. In this sense, canister wall cold forming and welding approaches are still possible for the cases considered herein. However, for case 4, with a greater wall thickness, and cases 5 and 6, with greater lengths, bend radius restrictions and increased work hardening would increase the required number of fabrication steps and increase costs. In addition, maintaining dimensional tolerances for cold formed canisters with thin walls, i.e. case 2, would be increasingly difficult. PCM filling techniques applicable to the baseline canister would still apply for the other cases considered since the required mass of PCM changes by less than an order-of-magnitude. Canister weld joints would remain x-ray inspectable as well. Yet, canisters with thicker walls, i.e. case 4, would require either longer x-ray exposure periods, faster film, or higher energy x-rays to inspect weld joints when compared to the baseline canister.

These required adjustments are detrimental since they either slow inspection processing time or increase the minimum detectable flaw size.

Since the majority of canister mass production costs are most likely associated with development and fabrication of production tooling and inspection equipment, the number of canisters per receiver would have a minor impact on total canister production costs. Assuming one development, one qualification, and two flight receivers are built using the same tooling, the canister production numbers range from about 15,000 (case 6) to 45,000 (case 9) which should result in only minor impacts on production tooling and inspection hardware costs as well. However, receivers with more canisters also have more working gas tubes to be manifolded which proportionately increases receiver fabrication and inspection requirements. Due to the large number of canisters involved for all cases, a high degree of PCM containment redundancy is always maintained. In the event of single or multiple canister leaks, the small loss of PCM has a negligible impact on the thermal energy storage performance of the receiver. For example, the baseline receiver average orbital temperature change must increase by 0.04 K for each canister leak to account for the lost PCM latent and sensible energy storage capacity. Hence, it is inconsequential whether the fractional PCM mass loss from a single canister leak is 0.0254 percent (case 6) or 0.0089 percent (case 9).

3.6 Canister Design Modifications

Based on the results discussed in sections 3.1 through 3.4, two cases that feature potential canister design improvements were analyzed. The parameter changes associated with these cases were small enough so that the influence of PCM containment redundancy and fabrication considerations (discussed in section 3.5) on the canister design were minor. The first case, case 11, reduced the canister wall thickness by a factor of 2 and reduced the outer radius by 10 percent. This resulted in a receiver design with 17 percent more tubes and canisters, a 5 percent larger cavity diameter, and a 219 kg (13 percent) mass savings over the baseline design. The thermal-structural performance of this modified canister was nearly identical to that of the baseline canister. The primary difference between the two cases was the dominant side wall stress component, i.e. radial for the baseline canister design and tangential for the modified design. The mass savings of this modified design must be traded against the increased impact of canister material degradation from sublimation and PCM chemical attack and the added difficulty of launch vehicle packaging with a larger diameter receiver.

The second case analyzed, case 12, reduced the canister wall thickness by about 20 percent and reduced the outer radius by about 7 percent. This resulted in a receiver design with 17 percent more tubes and canisters, a 9 percent large cavity diameter, and equal mass when compared to the baseline design. However, this design reduced the maximum canister temperature by 15 K while maintaining the same maximum stress level. This decrease in maximum wall temperature will increase predicted canister service life margins and decrease the rate of material degradation thus improving canister reliability. A canister reliability improvement without mass penalties is highly desirable even with a modest increase in fabrication requirements and receiver diameter over the baseline design. Therefore, the case 12 canister design, offering performance/reliability improvements, would be preferred over the case 11 design which offers mass savings.

4 SUMMARY AND CONCLUDING REMARKS

PCM canister parametric studies were conducted to identify potential design refinements to improve canister performance and mass characteristics. Results showed that canister thermal structural performance improvements were possible through singular design changes but usually at the expense of increased mass. This indicated that the baseline canister was essentially well designed. Yet, two cases were presented that incorporated multiple canister design refinements which reduced receiver mass by 219 kg (13 percent) without performance penalties and reduced the maximum canister wall temperature by 15 K without a receiver mass penalty, respectively. These cases did, however, require a 5 to 9 percent receiver diameter increase and 17 percent more canisters than the baseline design. Since the preceding results and conclusions were based on isolated, single canister analyses, integrated, full-receiver analyses are still required to verify the accuracy of these findings. Detailed canister structural analyses are required as well to verify the thermal stress behavior predicted using simplified models. Further receiver design studies that explore changing the axial distribution of PCM along a receiver tube should be conducted. As shown in Klann (1991a) and Klann (1991b), this kind of receiver tube design modification can significantly reduce canister maximum temperatures (by reducing liquid PCM sensible heating) and reduce receiver mass (by totally eliminating canisters). Such a receiver design approach may require several different canister sizes, however, which may increase fabrication complexity and cost.

REFERENCES

Abe, Y., et al., 1991, "Development of Advanced Space Solar Dynamic Receiver," Proceedings of the 26th Intersociety Energy Conversion Engineering Conference, Vol. 1, pp. 291-296.

Boley, B.A., and Weiner, J.H., 1960, Theory of Thermal Stresses, John Wiley & Sons, Inc., pp. 416.

Kerslake, T.W. and Ibrahim, M.B., 1990, "Two-Dimensional Model of a Space Station Freedom Thermal Energy Storage Canister," Proceedings of the 25th Intersociety Energy Conversion Engineering Conference, vol. 2, pp. 151-159. (see also, NASA TM-103124).

Kerslake, T.W., 1991, "Experiments With Phase Change Thermal Energy Storage Canisters for Space Station Freedom," Proceedings of the 26th Intersociety Energy Conversion Engineering Conference, Vol. 1, pp. 248-261. (see also, NASA TM-104427).

Klann, J., 1991, "A Partial Design Study of the Heat Receiver for Freedom's Solar Dynamic Power Module," internal NASA report IBR No. SE-326, Analex Corporation, Cleveland, Ohio.

Klann, J., 1991, "Some Additional Design Study Results for Freedom's Solar Dynamic Heat Receiver," internal NASA report IBR No. SE-333, Analex Corporation, Cleveland, Ohio.

Roark, R.J., 1965, Formulas For Stress And Strain, 4th ed., McGraw-Hill Book Co., pp. 223.

Rockwell International Rocketdyne Division, 1986, Space Station WP-04 Power System, "Preliminary Analysis and Design Document: DR-02", contract NAS3-24666, Vol. 1, Sect. 2.2.2.

Strumpf, H.J. and Coombs, M.G., 1987,"Solar Receiver for the Space Station Brayton Engine," Transactions of the ASME, 87-GT-252.

Strumpf, H.J. and Coombs, M.G., 1989, "Solar Receiver Experiment for the Hybrid Space Station Brayton Engine," Proceedings of the ASME Solar Energy Division Conference, San Diego, California.

Strumpf, H.J., et al., 1991, "Design Analysis and Life Prediction for the Brayton Engine Solar Receiver for the Space Station Freedom Solar Dynamic Option," Proceedings of the 26th Intersociety Energy Conversion Engineering Conference, Vol. 1, pp. 241-247.

Tong, M.T., Kerslake, T.W. and Thompson, R.L., 1988, "Structural Assessment of a Space Station Solar Dynamic Heat Receiver Thermal Energy Storage Canister," Proceedings of the AIAA SDM Issues of the International Space Station Conference, Williamsburg, Virginia, pp. 162-172.

Ugural, A.C., and Fenster, S.K., 1987, Advanced Strength and Applied Elasticity, 2nd SI ed., Elsevier Science Publishing Co., Inc., pp. 287.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
1991

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Parametric Studies of Phase Change Thermal Energy Storage Canisters for Space Station Freedom

5. FUNDING NUMBERS
WU-474-52-10

6. AUTHOR(S)
Thomas W. Kerslake

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-6724

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-105350

11. SUPPLEMENTARY NOTES
Prepared for the International Solar Energy Conference sponsored by the American Society of Mechanical Engineers, Lahaina, Maui, Hawaii, April 4-8, 1991. Responsible person, Thomas W. Kerslake, (216) 433-5373.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 18

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

This paper discusses Phase Change Material (PCM) canister parametric studies wherein the thermal-structural effects of changing various canister dimensions and contained PCM mass values are examined. With the aim of improving performance, 11 modified canister designs are analyzed and judged relative to a baseline design using five quantitative performance indicators. Consideration is also given to qualitative factors such as fabrication/inspection, canister mass production, and PCM containment redundancy. Canister thermal analyses are performed using the finite-difference based computer program NUCAM-2DV. Thermal-stresses are calculated using closed-form solutions and simplifying assumptions. Canister wall thickness, outer radius, length, and contained PCM mass are the parameters considered for this study. Results show that singular canister design modifications can offer improvements on one or two performance indicators. Yet, improvement in one indicator is often realized at the expense of another. This confirms that the baseline canister is well designed. However, two alternative canister designs, which incorporate multiple modifications, are presented that offer modest improvements in mass or thermal performance, respectively.

14. SUBJECT TERMS
Space stations; Solar dynamic power systems; Phase change materials; Heat storage; Thermal stresses

15. NUMBER OF PAGES
8

16. PRICE CODE
A02

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	