NASA TM 81622

NASA Technical Memorandum 81622

NASA-TM-81622 19810008746

Commercial (Terrestrial) and Modified Solar Array Design Studies for Low Cost, Low Power Space Applications

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December 1980

NASA

COMMERCIAL (TERRESTRIAL) AND MODIFIED SOLAR ARRAY DESIGN STUDIES FOR LOW COST, LOW POWER SPACE APPLICATIONS

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E-632

SUMMARY

The Long Duration Exposure Facility/Space Power Experiment (LDEF/SPEX) was designed to demonstrate the use of industrial hardware for possible low cost (<\$200 per sq. ft.), low power (<100 W peak) space applications (ref. 1). Laboratory studies were conducted to determine the suitability of commercial (terrestrial) solar arrays for use in low earth orbit. These studies showed that commercial solar arrays degrade under thermal cycling because of material flexure, and that certain types of silicones used in the construction of these arrays outgas severely. Based on the results of these studies, modifications were made. The modified array retains the essential features of typical commercial arrays and can be easily built by commercial fabrication techniques at low cost. The modified array uses a metal tray for containment, but eliminates the high outgassing potting materials and glass cover sheets. Cells are individually mounted with an adhesive and individually covered with glass cover slips, or clear plastic tape. The modified array was found to withstand severe thermal cycling for long intervals of time.

INTRODUCTION

The advent of Space shuttle (ref. 2) will provide new opportunities to perform manned and unmanned experiments in space. Many of these experiments will be sponsored by universities, research institutions, and private industries. To encourage widest possible participation, components, including those to provide electrical power, should be available at low cost.

Many means are currently available for generating electrical power in space (ref. 3), the most well known and widely used being solar arrays. Typically, solar arrays for use in space are built to rigid specifications and undergo rigid qualification testing. These arrays are expensive (\$7,000 to \$10,000 per square foot) and could deter some potential shuttle users. The Long Duration Exposure Facility/Space Power Experiment (LDEF/SPEX) was conceived to demonstrate the use of commercially manufactured terrestrial solar arrays as a low cost alternative to the traditional space solar arrays for those applications where power system demands do not exceed ~100 peak.

The Long Duration Exposure Facility (LDEF) spacecraft (ref. 4) is a low earth orbit platform (<300 nautical miles) for space experiments. The LDEF is a passive, gravity-gradient-stabilized satellite which will be carried into space as a shuttle payload. In space, the LDEF will be exposed to solar radiation (136 mW/cm^2) and Earth albedo (30-40 percent) making possible steady state temperatures ranging from $+100^\circ$ to -54° C. These temperatures are important in establishing a solar array design suitable for use on LDEF, or any other spacecraft occupying a similar orbit.

In preparation for the LDEF/SPEX, laboratory studies were conducted to determine the suitability of terrestrial solar arrays for space use. Such arrays have been developed by the Department of Energy (DOE) for weather stations and remote instrument application (refs. 5 and 6). Such arrays consist of groups of 18 to 24 solar cells, wired in series, containing about one square foot of active cell area, and capable of producing 5 to 7 W at max power. The arrays may be used individually, or assembled into larger array structures.

The LDEF solar arrays were divided into two groups:

1. "Off the shelf", manufacturer designed arrays, and
2. Modified designs using manufacturer-supplied parts.

The first group consists largely of arrays in which the solar cells and their metal interconnects are immersed in silicone rubber, mounted in a metal tray, and covered with a glass plate. Because of potential outgassing of the silicone rubber in these arrays, and the possibility of contaminating adjoining experiments on LDEF, a second, or modified, group of solar arrays was built. This group consists of arrays in which the silicone rubber and glass cover plates were eliminated. Arrays in this group had cells individually cemented down with either an RTV, a polyurethane, or an epoxy. Cells were individually covered with either thin glass cover slips or clear adhesive plastic. In both groups, fiber mattes were used to insulate the solar cells from the metal trays in which they were mounted.

Solar arrays from both groups were thermal cycled, vibration tested, and electrically characterized. The objective of these tests was to determine which materials and configurations were best suited to endure the low earth orbit environment with minimum degradation.

EXPERIMENTAL (I)

Physical Description of Solar Arrays

The solar arrays selected for the LDEF/SPEX laboratory studies were divided into two groups. The first group consisted of commercially designed, "off the shelf" solar arrays. This group contained three different configurations:

1. A metal tray with solar cells and interconnects potted in silicone rubber.
2. A metal tray with solar cells and interconnects potted in silicone rubber with a plate of glass or a sheet of clear plastic over the array.
3. A metal frame with no silicone rubber. Solar cells were mounted on a kapton sheet with a printed interconnect pattern. The cells and sheet were placed in the frame and a glass cover was held in place over the cells.

The second group consisted of modified solar arrays, similar but not identical to the commercial solar arrays. The configuration of this modified group was a metal tray with solar cells individually cemented into place. Cements included silicones, polyurethanes, and epoxies. Cells were individually covered with clear adhesive film, or a thin cover glass.

Cells in both groups were standard, commercial grade Silicon solar cells. The metal trays in both groups were Aluminum, except for the metal frame used in configuration 3 of the commercial group which was stainless steel. A fiber matte was used in arrays of both groups to electrically isolate the solar cells from the metal trays in which they were contained. The mattes served an additional function in the modified group. This function will be discussed later. Examples of arrays from both groups are shown in figures 1 and 2.

The design of the modified solar arrays was made subject to the constraint that modified arrays must be built on currently existing production lines without having to significantly alter those lines. Thus, while some latitude was allowed, the configuration and materials of the modified arrays had to be similar to those currently used in the manufacture of commercial arrays.

The materials chosen to cement the individual cells in place in the modified arrays was subject to two constraints:

1. These materials had to exhibit low vacuum outgassing - less than 1 percent weight loss at 10^{-6} torr and 125° (275° F), (ref. 4).

2. These materials had to have thermal expansion coefficients of the same oraer of magnitude as Silicon or Aluminum.

The first constraint was easily met by a wide variety of epoxies and polyurethanes. The second constraint could not be met by epoxies or polyurethanes since these materials have thermal expansion coefficients ranging 10 to 100 times higher than Silicon or Aluminum. This mismatch could result in fracturing the solar cells during thermal cycling. The second constraint could be met, however, by epoxies or polyurethanes with the addition of fiber reinforcement. The fiber would be made of a low expansion material such as glass and would be woven into matrix-matte structures. The effect of including such reinforcement would be to restrain expansion of the epoxies and polyurethanes during thermal cycling.

EXPERIMENTAL (II)

Physical Description of Materials

The various adhesive, matte, and cover materials used in building both groups of SPEX solar arrays, along wth their physical and thermal properties, are listed in tables I and II. These materias are discussed below.

Adnesives

Silicone rubber/gel (low cost). - Most commercial terrestrial solar arrays use some type of silicone material to encapsulate the solar cells and interconnects. The silicone serves the dual function of protection and heat transfer. All but one of the commercial solar arrays considered for LDEF/SPEX used silicone rubber. One array used silicone gel. Since the array with gel failed early in thermal cycling and was eliminated, no further discussion will be given about silicone gel.

The low cost silicone rubber compounds used in most terrestrial solar arrays presented one major problem for use on LDEF/SPEX. The problem was one of outgassing. All silicone rubbers contain low molecular weight ingredients which are slowly released when subjected to vacuum less than 10^{-6} torr and temperatures exceeding 100° C. Total weight losses greater than 3 percent of the original weight of the material are typical. Shuttle requirements prohibit use of any 100 percent exposed material having more than 1 percent total weight loss due to outgassing (ref. 4). Materials having up to 3 percent total weight loss may be flown provided that the exposed outgassing surface area does not exceed 13 cm^2. These specifications could not be met by the proposed LDEF arrays. An attempt was maae to cover the exposed outgassing area by heat-shrinking a 20 mil thick Teflon sheet over the individual solar arrays. The teflon, however, ruptured under thermal cycling. Low cost silicone rubbers were therefore eliminated from further consideration.

Silicone rubber (high cost). - While low cost silicone rubbers were found unsuitable for use on the LDEF/SPEX solar arrays, other silicone rubbers remained a possibility. These rubbers are vacuum processed to remove the low molecular weight ingredients and exhibit total weight loss due to outgassing in the neighborhood of 0.1 percent. While the total weight loss of these silicone rubbers is almost 1/40th that of low cost silicone rubbers, the cost is almost 40 times as great. Encapsulating whole arrays with this rubber would be prohibitively expensive (~$800 per array).

Low outgassing silicone rubber was used as a cement for mounting individual cells in the modified solar arrays. The cost, in this application, is not unreasonable (~$30 per array).

Epoxy (flexible). - Epoxies were considered for use in mounting individual cells in the modified solar arrays. Not only are epoxies among the best adhesives available, they possess many of the features desirable for use in SPEX. Epoxies exhibit low outgassing, have the lowest unit cost of any of the adhesives considered, and can be processed by most industrial firms. Epoxies may be divided into two groups: rigid and flexible. Rigid epoxies have an elongation at the point of breaking of less than 4 percent of their original length. Flexible epoxies, on the other hand, have an elongation of greater than 50 percent of their original length. Since any adhesive used in the modified arrays is sandwiched between two surfaces (the cell and the metal plate), materials with greater elongation are preferable to those with lesser elongation. Thus, flexible epoxy was chosen as a possible material for use on the LDEF/SPEX modified solar arrays.

Polyurethane. - Polyurethanes are about midway between epoxies and silicone rubbers in terms of outgassing, cost, adhesion, and flexibility. Polyurethanes are also easily processed, and are readily available in premixed and frozen cartridges to aid handling in production. Two polyurethanes were chosen as possible adhesives for use in the modified solar arrays.

Mattes

Teflon coated glass screen. - Of all the possible mattes considered for use on SPEX, teflon coated glass screen is the only matte used in commercially manufactured solar arrays. This matte was initially considered least likely to restrain the expansion of the adhesives because of its low packing density (<10 percent solid). Testing, however, showed that both low and high packing density mattes had about the same restraining effect, reducing the expansion by a factor of at least 5.

Glass matte. - Glass matte is typically used in transformer construction. This material was originally considered for use on SPEX because of its relatively higher packing density of low expansion glass. Although packing density was later shown to make little difference in a matte's restraining effect on adhesives, glass matte remained a desirable choice because of low cost and ease of handling. Glass matte presents the problem of releasing small fibers when cut, however, which could make it a physically uncomfortable material to work with if proper precautions are not taken.

Kevlar. - Kevlar is an exceptional polymer which is used widely as a tough, wear-resistant cloth able to withstand high temperature. Additionally, Kevlar has an outstanding low coefficient of thermal expansion, which makes it unique among the polymers. As expected, Kevlar had the best restraining effect of all the mattes tested. Kevlar, however, is difficult to work with. Cutting tools (scissors) must be very sharp; once in use, they tend to dull quickly.

Graphite. - Since graphite has a high modulus of elasticity and a low coefficient of thermal expansion, samples of graphite fiber woven into mattes were investigated for use on SPEX. Graphite presents some immediate difficulties, however. These difficulties center around the ability of certain resins to wet graphite. Tests showed, for example, that epoxy was better able to wet graphite than polyurethane. Thus, use of graphite must be restricted to those adhesives for which sufficient wetting takes place.

Covers

Tedlar. - In most space applications, solar cells are covered with quartz or borosilicate glass to minimize particle-radiation damage and increase cell life. The total particle-radiation dose to be received by SPEX, however, is considered to be so small (approximately 10^{11}-10^{12} MeV electrons/cm^2) that, even with no covers at all, negligible cell damage would be expected. Thus, while the SPEX solar cells still need to be covered for protection from possible contamination during handling, shiping, and storage, less expensive options than quartz and borosilicate glass are possible. One of these options is polyvinyl fluoride, or Tedlar. Tedlar is easily handled, relatively inexpensive, and is stable in ultraviolet light. For use on SPEX, Tedlar sheets, coated on one side with acrylic adhesive, were purchased. Pieces of Tedlar were cut from these sheets and applied as covers to individual solar cells. Although the cell surfaces contained a grid pattern which was somehwat "bumpy", the Tedlar conformed sufficiently to ensure reasonable adhesion.

Glass. - Borosilicate glass was also tested as a possible solar cell cover material. The glass was purchased in round wafers, 2" in diameter and 0.020" thick. Borosilicate glass is typical of the kind of low cost glass used on high cost flight arrays.

The major concern (and the major cost factor) in using glass covers is the labor involved in mounting them on the solar cells. Cell surfaces are generally uneven because of the presence of electrical contacts and interconnects. In mounting glass covers on the SPEX cells, each cell/cover combination had to be individually leveled while the RTV adhesive used to hold the glass cured. Failure to do so usually resulted in the glass cover sliding off the cell.

Mylar tape. - Clear, one mil thick Mylar (polyester) tape was also tested as a possible solar cell cover material. The tape was cut into disks two inches in diameter. The disks were individually placed on the solar cells.

Although Mylar does not possess the same radiation stability as Tedlar, Mylar is nonetheless considered suitable for SPEX since the total radiation dosage is not sufficient to cause significant degradation. Mylar has the advantage of greater flexibility than Tedlar. Otherwise, both materials are very similar in properties required for SPEX.

TEST DESCRIPTION

Commercial and modified solar arrays were subjected to thermal cycling, vibration testing, and electrical characterization. The objective of these tests was to determine which materials and configurations were best suited to endure six months in the low earth orbit environment of the LDEF spacecraft with minimum degradation. Test procedures are described below.

Thermal Cycling

The LDEF spacecraft is to remain in low earth orbit for 6 months. During this time, the spacecraft will experience a variety of thermal fluctuations. These fluctuations are due primarily to the spacecraft passing in and out of earth shadow during any particular orbit, and to a slow but steady precession of the orbit plane (ref. 4). These thermal fluctuations were simulated in laboratory thermal cycling tests.

The orbital period of the LDEF spacecraft is about 90 minutes (ref. 4). Thus, the total number of orbits or cycles in six months is approximately 3,000. The SPEX solar arrays were thermal cycled in an air-nitrogen gas environment for a total of 3,300 cycles, more than covering the actual expected space total.

Computer generated thermal flux data for LDEF (ref. 4) and solar array thermal/optical characteristics (ref. 7) were used to calculate a typical set of temperatures for the solar arrays (ref. 1). These ranges are shown below:

+100° to +20° C
+20° to -5° C
-5° to -30° C
+30° to -54° C

The solar arrays were temperature cycled eighteen to twenty times a day within a given range. Ranges were changed cyclically once a week. An electric counter was used to monitor the number of cycles, and a chart recorder was used to keep a record of cell temperatures. Typically, temperatures changed at a rate of 2° to 4° C per minute with a 15 to 20 minute dwell at each extreme. Temperatures were obtained from thermocouples mounted on the ends of the arrays.

Vibration Testing

Vibration testing was performed on the SPEX solar arrays to determine their response to the spacecraft vibration expected during launch and reentry (ref. 1). The solar arrays were vibrated in both a sine mode and a random mode in all three axes. The panels were placed on mounts similar to those to be used on LDEF. An accelerometer was mounted on the bottom center of each array, and observations were made with a strobe light during vibration. The frequency range for the sine mode was 5 to 35 Hz with a maximum acceleration of 5 g applied between the frequencies 14 to 20 Hz. The frequency range for the random mode was 18 to 1,000 Hz. Curves of acceleration vs. frequency for the sine mode, and acceleration spectral density for the random mode, are shown in figures 3 and 4.

Electrical Characterization

Electrical data were taken on the SPEX solar arrays at zero thermal cycles, 800 cycles, 1600 cycles, 2400 cycles, and 3300 cycles. A flash simulator (ref. 8) was used to obtain a voltage current (V-I) curve for each array. The data were computer corrected to standard conditions of 20° C at either AM1 or AM0.*

In addition to the flash simulator, the solar arrays were checked once a week under a laboratory source consisting of a small flood lamp mounted on a metal frame. These tests only measured open-circuit voltage and short circuit current and were performed to ensure that no catastrophic failures had occurred. Arrays showing large changes were examined under a microscope to detect possible physical damage such as cracked cells or broken interconnects.

RESULTS

Response of Solar Arrays to Thermal Cycling

Commercial arrays. - The solar arrays consisting of a metal tray with solar cells and interconnects potted in silicone rubber degraded to the point of zero output power in less than 1500 thermal cycles. The temperature excursions to which the arrays were subjected resulted in a regular expansion and contraction of the silicone rubber. This expansion and contraction caused flexure, work hardening, and, ultimately, breakage of the metal interconnects. The onset of breakage was marked by an increase in internal electrical resistance resulting in lower power capability. As breakage progressed, the internal resistance continued to increase until the array failed open circuit. Drawings and photographs showing broken interconnects are shown in figure 5.

The solar arrays consisting of a metal tray with cells and interconnects potted in silicone rubber with a glass plate over the array showed only a 17 percent drop in maximum power in 1500 cycles. The same expansion and contraction mechanism is believed responsible for the degradation here as in the previous case. The rate of degradation, however, was reduced by the restraining effect of the glass.

The arrays potted and covered with a sheet of clear plastic failed open circuit in less than 500 thermal cycles. These arrays used a silicone gel rather than silicone rubber as the potting material. The same expansion and contraction mechanism is believed responsible here, with negligible restraining effect from the plastic cover.

The last group of commercial arrays, those with no potting material, showed essentially no power degradation in 3300 cycles.

Modified arrays. - Materials used in building the modified solar arrays were found to have some significant effects as shown in table III.

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*AM1 or "Air Mass One" refers to conditions of sunlight on the surface of the earth under one standard atmosphere. AM0 or "Air Mass Zero" refers to conditions of sunlight in space at one astronomical unit (92,956,000 miles) from the sun. Most curves were given for both conditions.

The solar arrays in which the cells were mounted with flexible epoxy failed within 400 thermal cycles. The solar cells in these arrays were shattered because of large differences in amount of thermal expansion and contraction coupled with the rigidity of the epoxy. Photographs of shattered cells are shown in figure 6. Solar arrays in which the cells were mounted in silicone rubber or polyurethane showed less drastic effects. While some cracking occurred, most cells in these arrays remained undamaged.

Solar cells which were covered with clear (flexible) plastic, or simply left exposed, failed by physical delamination of the silicon wafer from the metal/solder backing customarily applied to solar cells to serve as a back contact. Examples of delamination are shown in figure 7. Cells covered with glass did not delaminate, probably because of the restraining influence of the glass. These cells, however, did exhibit breaking around the edges. This breaking did not result in any significant power loss.

Table III shows a total of 25 cell/adhesive/matte combinations of which 13 were not affected mechanically after 3300 thermal cycles. Thus, a wide choice of material combinations remains available to designers of future SPEX-type arrays.

Response to Vibration Testing

No significant damage occurred to any of the SPEX solar arrays during vibration. Electrical measurements for both groups before and after vibration showed no change in electrical characteristics. Physical examination showed that no mechanical breakage had occurred.

Electrical Response

Electrical degradation occurred in all of the modified array samples. Typically, maximum power decreased, and internal resistances changed such that there was a steady deterioration of electrical characteristics. These changes were due primarily to the various mechanical failures which occurred during thermal cycling.

CONCLUSIONS

The SPEX solar array studies have demonstrated the possibility of using commercially available solar arrays and solar array hardware for low cost, low power space applications. One commercial design which was tested survived with no cell failure and negligible electrical degradation. This design eliminated the high outgassing rubber or gel potting materials used in many commercial arrays. Cells in this design were mounted on a Kaptan substrate with a printed interconnect pattern, and enclosed in a metal/glass frame. In addition, thirteen modified systems which were tested survived with no cell failure. These new systems used a variety of cell covers, adhesives, and mattes to restrain thermal expansion of the adhesives. Testing for all cases included thermal cycling, vibration testing, and electrical characterization. It has thus been shown that material costing less than $10.00 per pound has the potential for space qualification, and may possibly be used to replace those costing close to $400 per pound. Typical use of SPEX-type solar arrays would be space-borne electrical systems requiring 100 W peak power, or less.

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TABLE I. - SPEX MATERIALS

Material	Approximate cost, \$/lb	Physical form used as SPEX solar arrays	Expansion coefficient, cm/cm/^{o}C	Prime advantage	Relative disadvantage
Low cost silicone rubber	5 to 10	Two part castable encapsulant	$2.7x10^{-5}$	Flexible; rugged	Exceeds outgassing limits; high expansion
High cost silicone rubber	400	Two part adhesive	$2.7x10^{-5}$	Flexible; rugged	High cost
Flexible epoxy	1.50	Two part adhesive	$18x10^{-5}$	Inexpensive; good adhesive; low outgassing	Rigid for thermal cycling
Rigid epoxy	1.00	Two part adhesive	$18x10^{-5}$	Inexpensive; good adhesive; low outgassing	Very rigid for thermal cycling
Polyurethane	4.00	Two part adhesive	$17x10^{-5}$	Inexpensive; good adhesive; low outgassing	Tends to harden slightly in thermal cycling
Tedlar (polyvinyl flouride) with acrylic adhesive	<10	Film cover for cells, with adhesive	$5x10^{-5}$	Clear; easily applied	Slight U-V degradation
Teflon coated fiberglass screen	<1	Matte under cells	$<0.1x10^{-5}$	Easily handled	Low density for restraint of adhesives
Fiberglass cloth	<1	Matte under cells	$<0.1x10^{-5}$	Easily handled	Releases small fibers when cut
Kevlar (aromatic polyamide)	3 to 5	Matte under cells	$<0.1x10^{-5}$	Best restraint of adhesive expansion	Difficult to cut
Graphite	5 to 10	Matte under cells	$<0.1x10^{-5}$	Good restraint of adhesive expansion	Slightly conductive (electrically)

TABLE II. - THERMAL EXPANSION COEFFICIENTS* OF VARIOUS MATTE AND RESIN COMBINATIONS

[Units: 10^{-5} in./in./°F]

Resin system with expansion coefficient	Matte composition			
	Teflon coated glass	Plain fiber glass	Kevlar	Graphite
Polyurethane (Thiokol C113) ~17	1.99	2.45	0.42	1.07
Polyurethane (PR 1564) ~17	3.07	2.73	0.08	0.87
Flexible epoxy (Epon 825 + D400) ~18	2.68	2.70	0.38	0.09
Flexible epoxy (Hysol C15-015) ~18	3.45	3.03	0.96	0.756
Average**	2.80	2.72	0.46	0.69

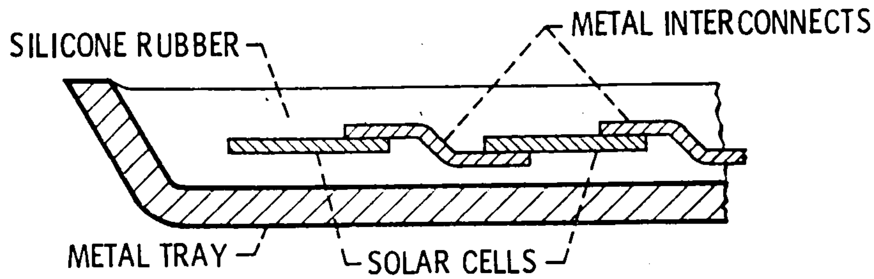
*Measured in the range +75° F to -75° F. For comparison, aluminum is 1.2×10^{-5} in./in./°F and silicon is 0.16 to 0.32×10^{-5} in./in./°F. The mattes are all less than 0.10×10^{-5} in./in./°F.

**Indicates the relative effect of matte materials.

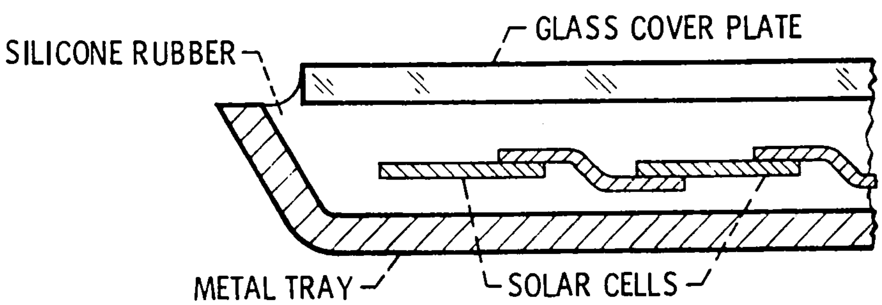
TABLE III. - VISUAL RESULTS OBSERVED ON MODIFIED ARRAYS AFTER 3300 THERMAL CYCLES

Resin system	Matte material			
	Teflon coated glass	Plain fiber glass	Kevlar	Graphite
High cost silicone rubber	A	B	B	B
Polyurethane (Thiokol C113)	C	A	A	A
Polyurethane (PR 1564)	A	A	A	A
Polyurethane (EN 5)	A	A, D	A	A
Flexible epoxy (Epon 825 + D400)	E	C	E	E
Flexible epoxy (Hysol C15-015)	E	C	A, F	E
Rigid epoxy (Epon 825 + Z)	E	E	E	E

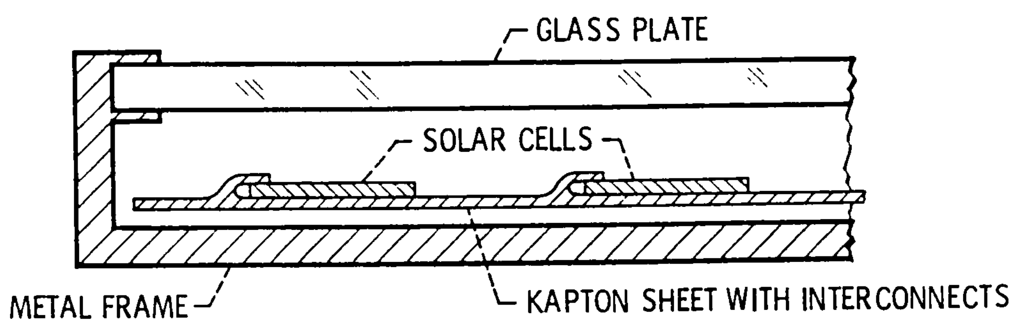
A - No mechanical failure of solar cell due to adhesive influence.
B - This combination not evaluated.
C - Some portions of cell's edge broken.
D - Glass cover cracked but stayed in place.
E - Severe cracks all over cell.
F - Glass cover could have affected results.



1. CROSS SECTION SHOWING METAL TRAY WITH CELLS AND INTERCONNECTS POTTED IN SILICONE RUBBER.



2. CROSS SECTION SHOWING METAL TRAY WITH CELLS AND INTERCONNECTS POTTED IN SILICONE RUBBER WITH PLATE OF GLASS OVER ARRAY.



3. CROSS SECTION SHOWING METAL FRAME WITH GLASS COVER. CELLS ARE MOUNTED ON A KAPTON SHEET WITH PRINTED INTERCONNECT PATTERN.

Figure 1. - Cross sections of various commercial solar array configurations tested for SPEX.

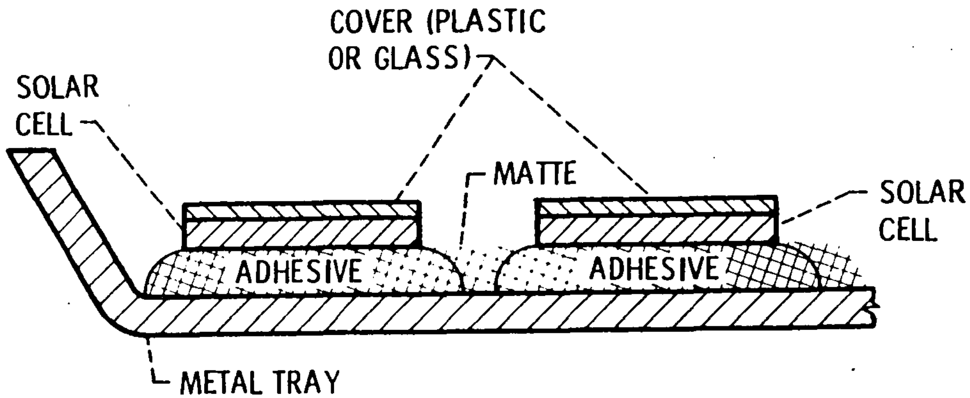


Figure 2. - Cross section of typical modified solar array configuration tested for SPEX.

APPLIED ALONG EACH OF THREE AXES.
DURATIONS:

5 - 20 Hz	4 octaves/minute
20 - 35 Hz	4 octaves/minute

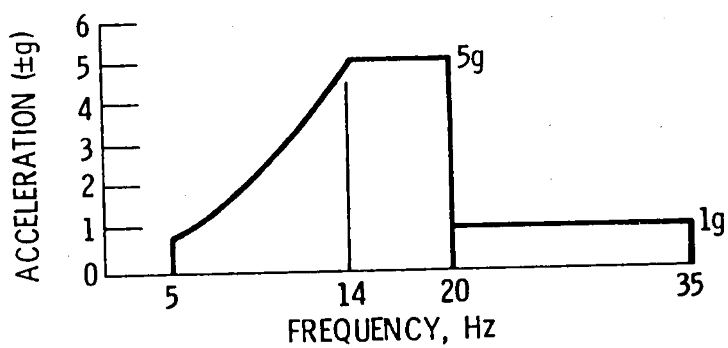


Figure 3. - Environmental levels for sinusoidal vibration.

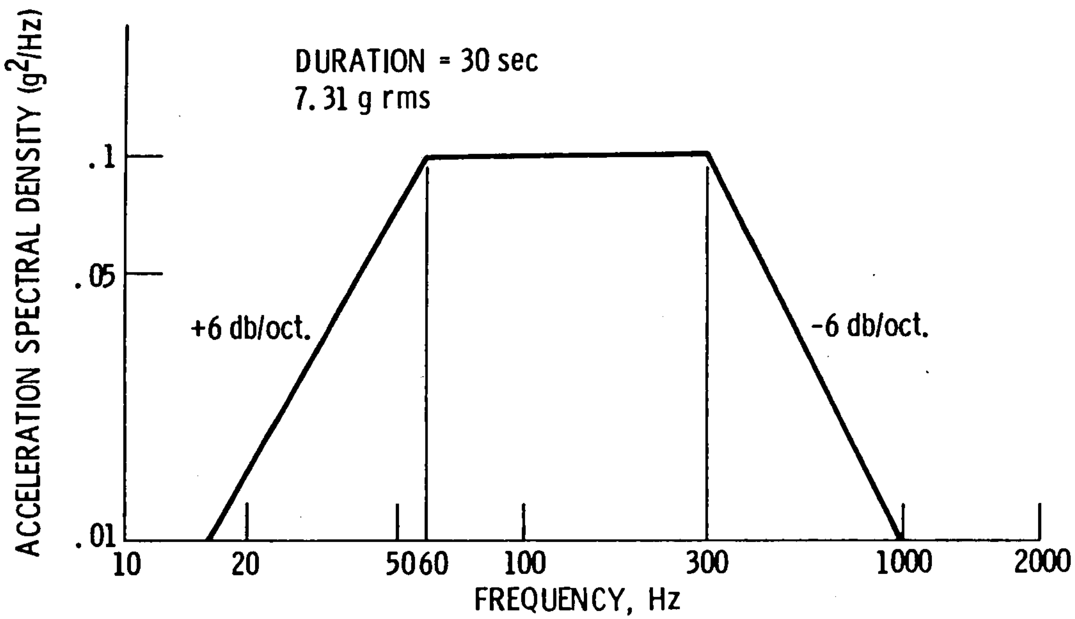
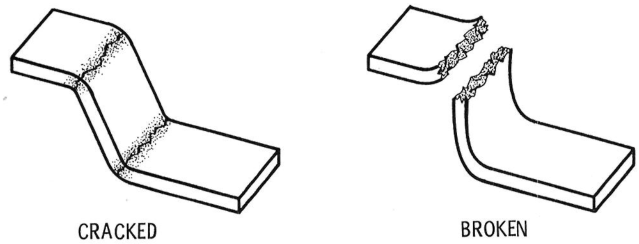
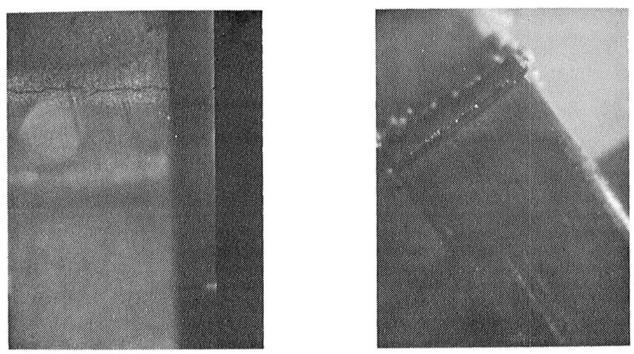


Figure 4. - Ramdom vibration conditions.



SCHEMATIC REPRESENTATION OF TYPICAL INTERCONNECT FAILURE



PHOTOGRAPHS SHOWING TYPICAL INTERCONNECT FAILURE

Figure 5. - Interconnects broken because of flexure during thermal cycling.

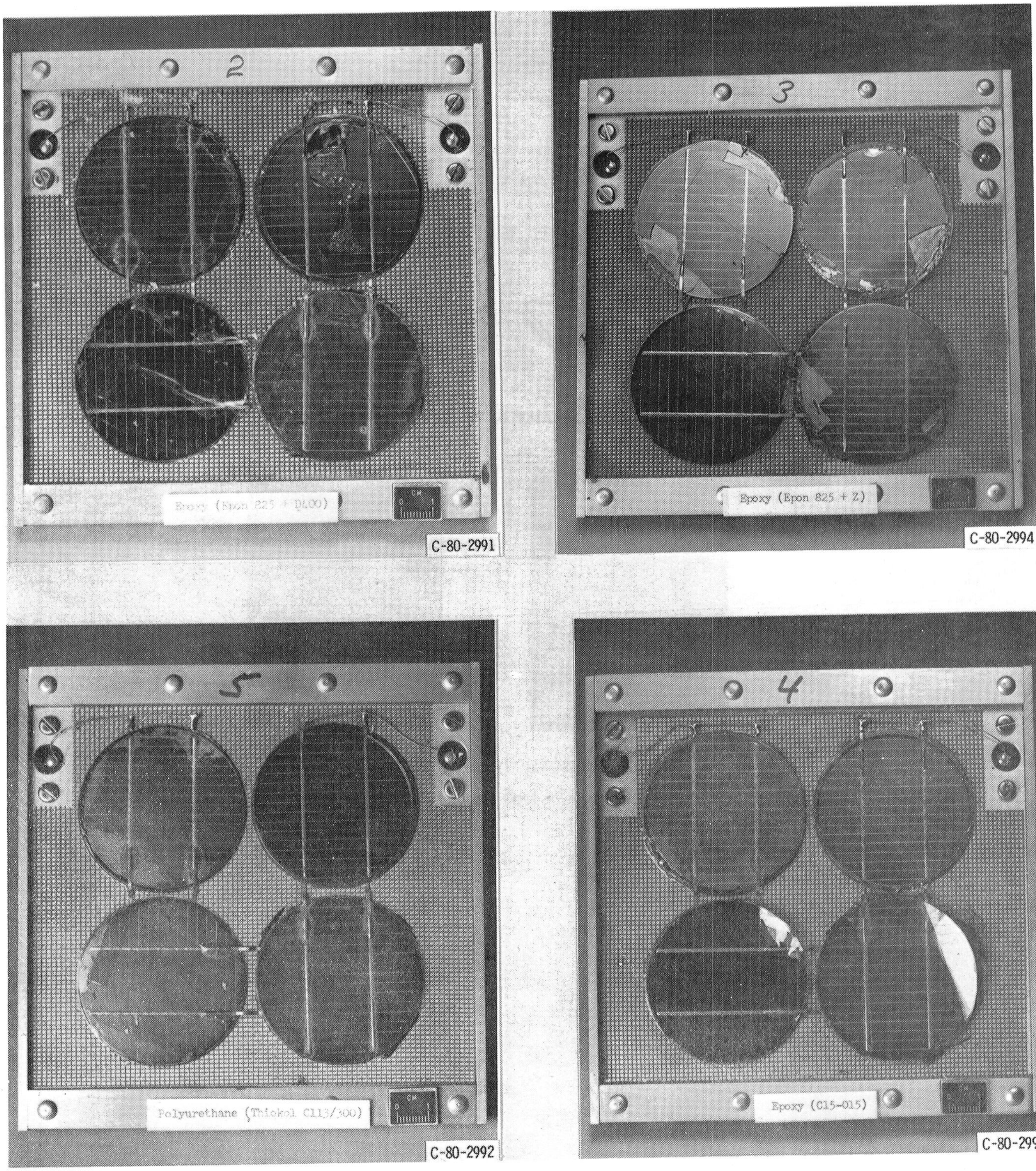
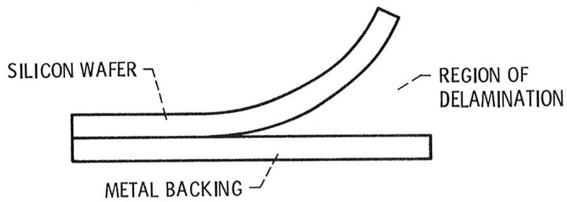
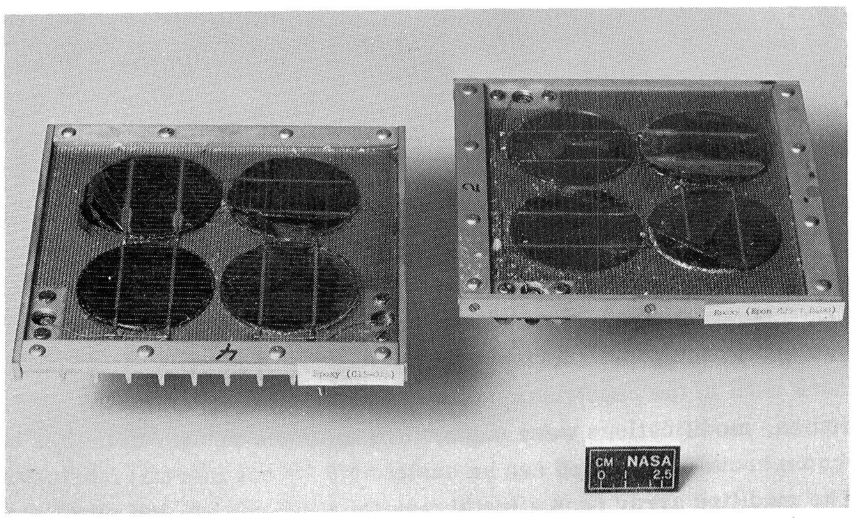


Figure 6. - Cells broken because of uneven expansion of materials during thermal cycling.



SCHEMATIC DIAGRAM SHOWING TYPICAL DELAMINATION



PHOTOGRAPH SHOWING CELL WITH DELAMINATION

Figure 7. - Cell with silicon wafer delaminated from metal backing.

1. Report No. NASA TM-81622	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle COMMERCIAL (TERRESTRIAL) AND MODIFIED SOLAR ARRAY DESIGN STUDIES FOR LOW COST, LOW POWER SPACE APPLICATIONS		5. Report Date January 1981
		6. Performing Organization Code
7. Author(s) Joseph C. Kolecki and Thomas J. Riley		8. Performing Organization Report No. E-632
		10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The Long Duration Exposure Facility/Space Power Experiment (LDEF/SPEX) was designed to demonstrate the use of industrial hardware for possible low cost (< 100 W peak) space applications (ref. 1). Laboratory studies were conducted to determine the suitability of commercial (terrestrial) solar arrays for use in low earth orbit. These studies showed that commercial solar arrays degrade under thermal cycling because of material flexure, and that certain types of silicones used in the construction of these arrays outgas severely. Based on the results of these studies, modifications were made. The modified array retains the essential features of typical commercial arrays and can be easily built by commercial fabrication techniques at low cost. The modified array uses a metal tray for containment, but eliminates the high outgassing potting materials and glass cover sheets. Cells are individually mounted with an adhesive and individually covered with glass cover slips, or clear plastic tape. The modified array was found to withstand severe thermal cycling for long intervals of time.

17. Key Words (Suggested by Author(s)) Low cost solar array; Low power space application; Material and configuration; Commercial and terrestrial solar array evaluation; Modified design for space use		18. Distribution Statement Unclassified - unlimited STAR Category 27	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price*

National Aeronautics and
Space Administration

Washington, D.C.
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