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Evaluation of Adhesive Materials Used on the Long Duration Exposure Facility

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EVALUATION OF ADHESIVE MATERIALS USED ON THE LONG DURATION EXPOSURE FACILITY

FOREWORD

This report describes the results from the testing and analysis of adhesives flown on the Long Duration Exposure Facility. Boeing's activities were supported by the following NASA Langley Research Center (LaRC) contracts; "LDEF Special Investigation Group Support" contracts NAS1-18224, Tasks 12 & 15 (October 1989 through January 1991), NAS1-19247 Tasks 1 & 2 (May 1991 through October 1992), and NAS1-19247 Task 8 (initiated October 1992). Sponsorship for these programs was provided by National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia and The Strategic Defense Initiative Organization, Key Technologies Office, Washington D.C.

Mr. Lou Teichman, NASA LaRC, was the initial NASA Task Technical Monitor. Following Mr. Teichman's retirement, Ms. Joan Funk, NASA LaRC, became Task Technical Monitor. The Materials & Processes Technology organization of the Boeing Defense & Space Group performed the five contract tasks with the following Boeing personnel providing critical support during the program.

Bill Fedor	Program Manager
Sylvester Hill	Task Manager
Harry Dursch	Testing and Analysis, Final Report
Bruce Keough	Testing and Analysis, Collation of Results
Dr. Gary Pippin	Data Analysis

TABLE OF CONTENTS

1.0 INTRODUCTION

A wide variety of adhesives and adhesive-like materials were flown on the Long Duration Exposure Facility (LDEF). The majority of these materials were not part of the experimenter's initial objectives but because of LDEF's extended 69 month mission became valuable experiments in themselves. Therefore, the Materials Special Investigation Group (SIG) and Systems SIG conducted an investigation into the post-flight condition of these materials. The investigation involved documenting what had flown, "inspiring" the experimenters to perform testing of these materials, testing materials at Boeing facilities, and documenting and collating the findings.

The adhesive and adhesive-like materials flown on LDEF included epoxies and silicones (including lap shear specimens), conformal coatings, potting compounds, and several tapes and transfer films. With the exception of the lap shear specimens, these materials were used in the fabrication and assembly of the experiments such as bonding thermal control surfaces to other hardware and holding individual specimens in place, similar to applications on other spacecraft. Typically, the adhesives were not exposed to solar radiation or atomic oxygen. Only one adhesive system was used in a structural application.

This report documents all results of the Materials and Systems SIG investigation into the effect of long term low Earth orbit (LEO) exposure of these materials. Results of this investigation show that if the material was shielded from exposure to LDEF's external environment, the 69 month exposure to LEO had, in most cases, minimal effect on the material.

The results presented in this report were collected from the following sources; 1) visual examinations and/or testing of materials performed by various LDEF experimenters, 2) testing done at Boeing in support of the Materials or Systems SIG investigations, and 3) testing done at Boeing on Boeing hardware flown on LDEF.

2.0 LDEF MISSION PROFILE

LDEF was developed by NASA's Office of Aeronautics and Space Technology and the Langley Research Center to provide a means of exposing a variety of experiments to the LEO environment. LDEF was designed and fabricated at Langley in the late 1970's as a passive satellite which could be reusable for planned repeat missions. LDEF is a 14-ft-diameter by 30-ft-long aluminum structure with the cylindrical cross-section of a 12-sided regular polygon and was designed to be transported into space in the payload bay of the Space Shuttle, free-fly in low Earth orbit (LEO) for an extended time period, and then be retrieved by the Space Shuttle during a later flight. The LDEF was passively stabilized so that each surface maintained a constant orientation with respect to the direction of motion.

LDEF, weighing 21,400 lbs, was deployed by the Shuttle Challenger into a 260 nautical mile nearly circular orbit with a 28.4 degree inclination on April 7, 1984. The planned 10-month to 1-year mission carried 57 experiments. A schematic diagram of the location(s) of each experiment on the LDEF is shown in figure 2-1. Due to schedule changes and the loss of the Space Shuttle Challenger the duration of this flight was extended well beyond the original planned exposure period.

LDEF was retrieved by the Space Shuttle Columbia on January 12, 1990 after spending 69 months in orbit. A photo of the LDEF during retrieval operations is shown in figure 2-2. During these 69 months, LDEF completed 32,422 orbits of the Earth and decreased in altitude to 184 nautical miles, where it was grappled, photographed extensively from the Space Shuttle crew cabin, and then placed in the Space Shuttle payload bay for return to Earth. The levels of exposure to atomic oxygen and solar radiation as functions of position on the LDEF are shown in figure 2-3. The LDEF remained in the payload bay of the Space Shuttle Columbia for the landing at Edwards Air Force Base and during the ferry flight to Kennedy Space Center (KSC). The LDEF was removed from Columbia at KSC and brought to the Spacecraft Assembly and Encapsulation Building (SAEF-2) where the LDEF and its experiments were examined visually and photographed, radiation measurements were conducted, and the experiments removed from the structure tray by tray. Each tray was photographed individually subsequent to removal. System level tests were carried out for particular experiments and support hardware. External surfaces were examined for evidence of impacts, contamination, and other exposure induced materials changes. This process was initiated with the removal of LDEF from the Space Shuttle Columbia on January 27, 1990 and ended 4 months later with the LDEF structure being placed in storage.

The extended duration of the LDEF mission, constant orientation to ram, and the successful retrieval presented a unique opportunity to study the long-term effects of space

ROW \ BAY	A	B	C	
1	A0175	S0001	GRAPPLE	
2	A0178	S0001	A0015, A0187, M0006	
3	A0187	A0138	A0023, A0034, A0114, A0201	TRAILING EDGE
4	A0178	A0054	S0001	
5	S0001	A0178	A0178	P0005
6	S0001	S0001	A0178	P0003
7	A0175	A0178	S0001	
8	A0171	S0001, A0056, A0147	A0178	
9	S0069	S0010, A0134	A0023, A0034 A0114, A0201	LEADING EDGE
10	A0178	S1005	GRAPPLE	
11	A0187	S0001	A0178	
12	S0001	A0201	S0109	

ROW \ BAY	D	E	F
1	A0178	S0001	S0001
2	A0189, A0172 S0001	A0178	P0004, P0006
3	M0003, M0002	A0187, S1002	S0001
4	M0003	S0001	A0178
5	A0178	S0050, A0044, A0135	S0001
6	A0201, S0001	A0023, S1006 S1003, M0002	A0038
7	A0178	S0001	S0001
8	M0003	A0187	M0004
9	M0003, M0002	S0014	A0076
10	A0054	A0178	S0001
11	A0178	S0001	S0001
12	A0023, A0019, A0180	A0038	S1001

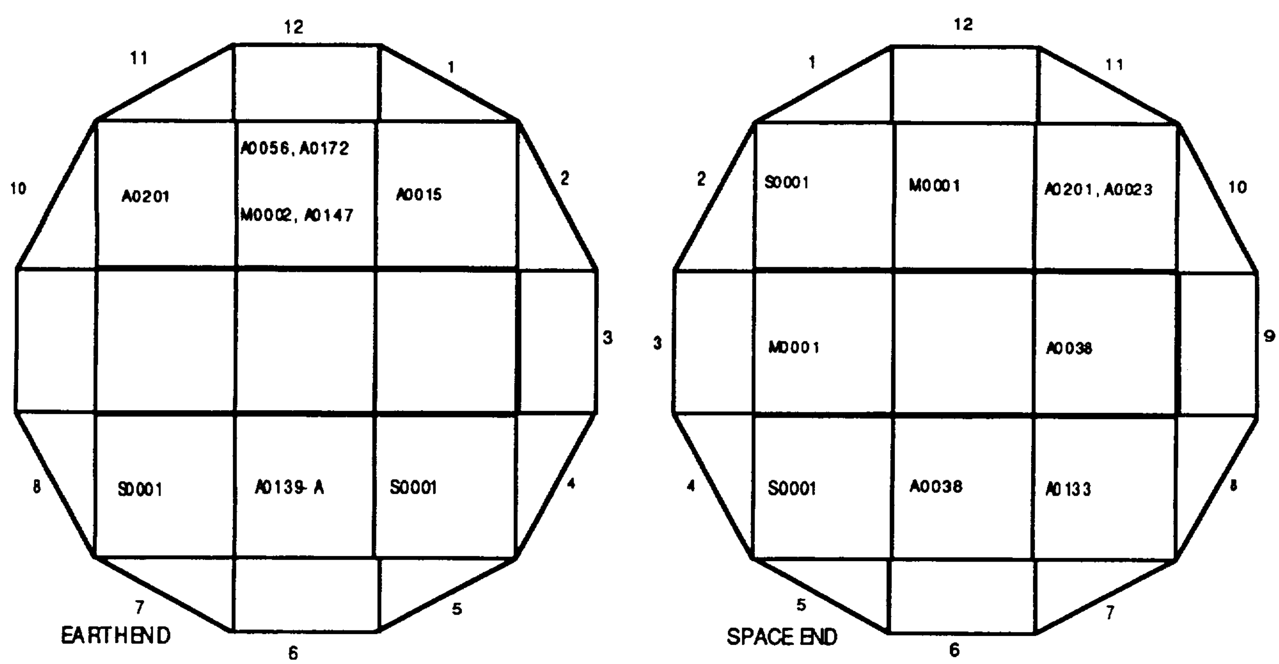


Figure 2-1 Schematic diagram of the location of each LDEF Experiment.

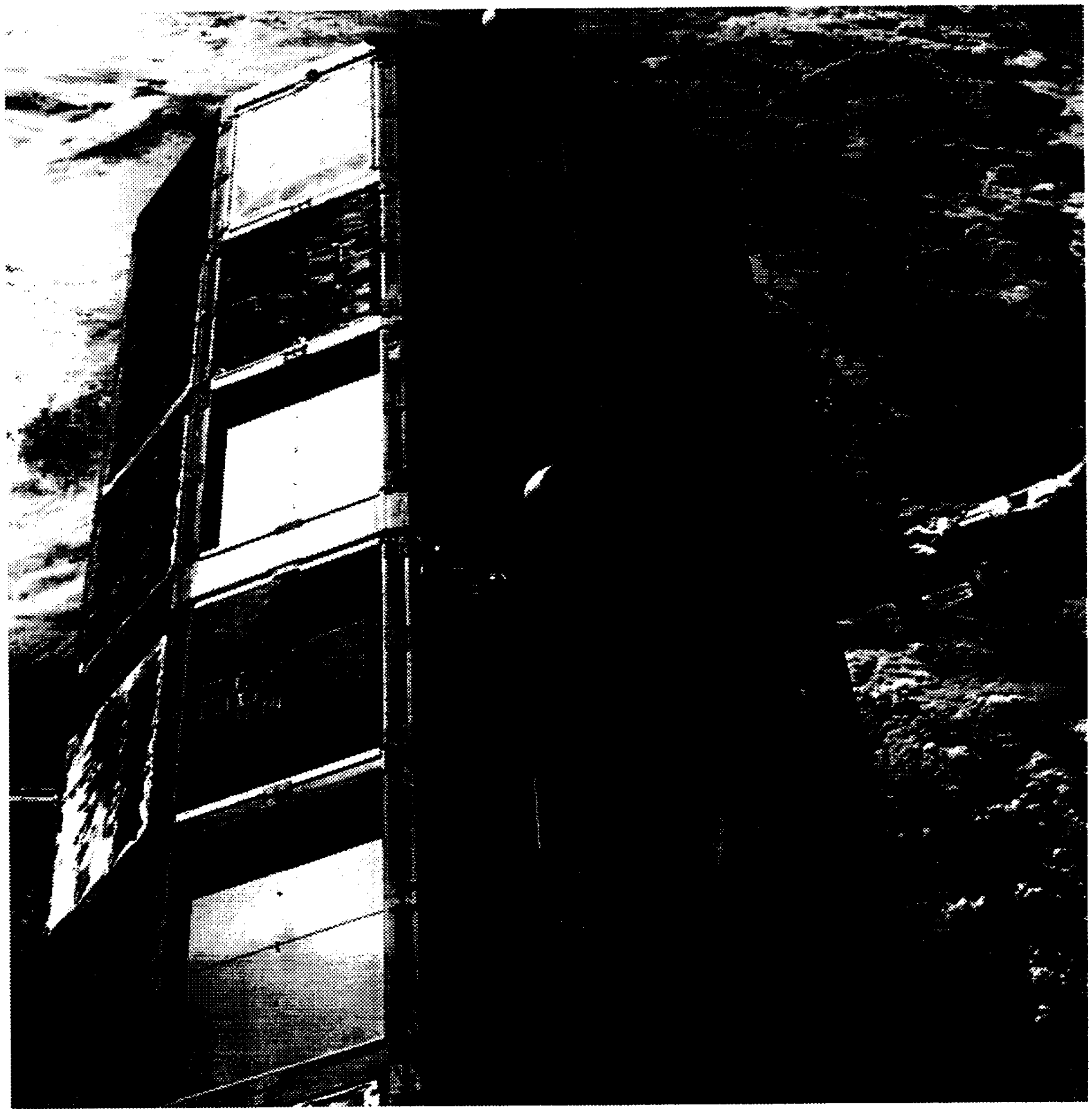
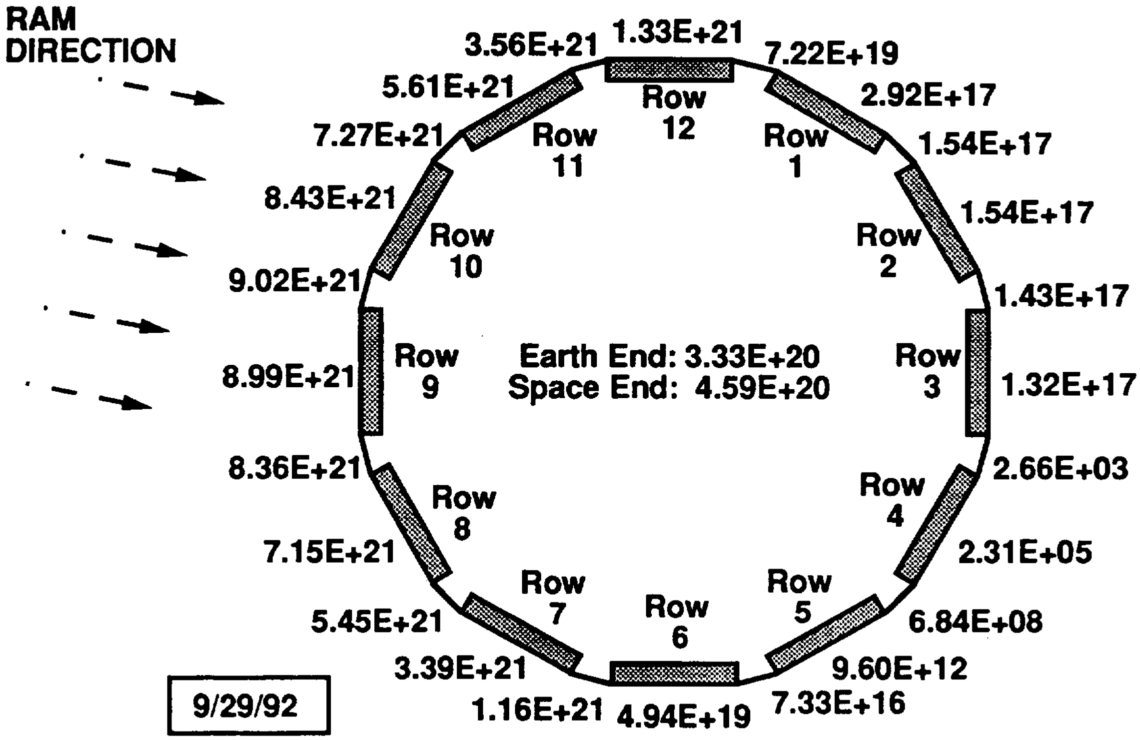
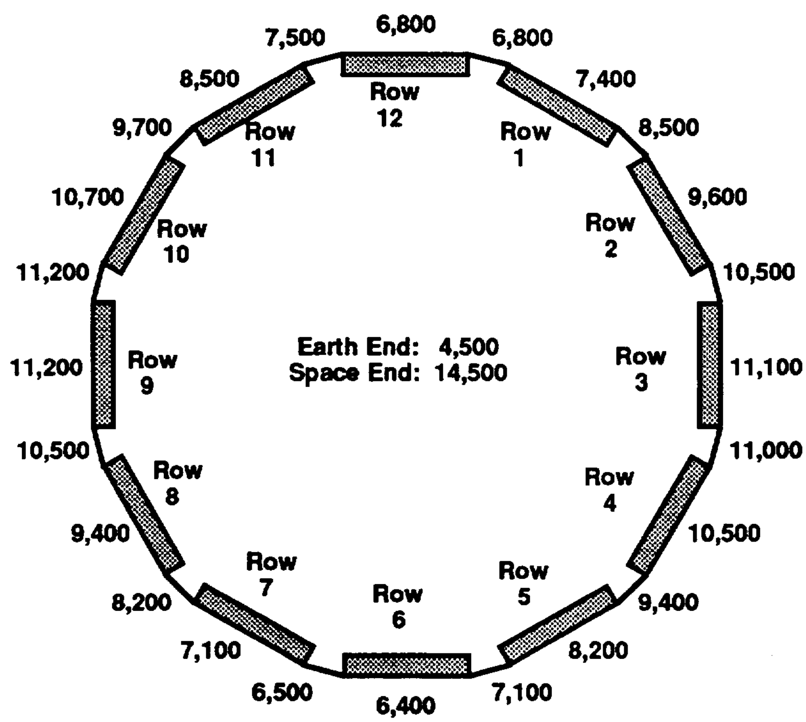


Figure 2-2. On-orbit Photograph of LDEF's Retrieval Showing Row 3 Trailing Edge. (Photo Courtesy of NASA LaRC)



ATOMIC OXYGEN FLUENCES ($ATOMS/CM^2$) AT END OF MISSION, INCLUDING EXPOSURE DURING RETRIEVAL



CUMULATIVE EQUIVALENT SUN HOURS EXPOSURE AT END OF MISSION

Figure 2-3. Mission Atomic Oxygen and Solar Exposures for LDEF exposure on the more than 10,000 specimens carried on the 57 different experiments. Because of the extended mission length, the science and engineering interest extended beyond the original individual experiment objectives. Four Special Investigation Groups were formed by the LDEF Science Office to assist in the deintegration of LDEF and post-flight analysis of hardware. These four SIGs were the Induced Radiation, Material, Systems, and Meteoroid and Debris SIGs. This report documents the results of the Materials and Systems investigation into the performance of the adhesive materials that were used on LDEF.

3.0 ADHESIVES

Adhesive and adhesive-like materials flown on LDEF include epoxies, silicones, tapes and transfer films, conformal coatings, and potting compounds. Six different adhesive systems were evaluated using lap shear specimens exposed to LDEF's exterior environment. All other adhesive related materials were used in assembly of the various experiments flown on LDEF and were typically shielded from exposure to the external spacecraft environment.

With the exception of lap shear specimens, most of the adhesives used on LDEF were of secondary interest to the experimenter and were only investigated by visual examination and a "Did they fail?" criteria. Because of this role, most adhesive applications had only a few specimens, not enough for statistical data generation. Often, no control samples were kept, and documentation of what was used was occasionally sketchy.

With few exceptions, the adhesives performed as expected, that is they held the hardware together. Several experimenters noted that the adhesives had darkened in areas that were exposed to ultraviolet (UV) radiation. The remainder of this report documents the additional information available on the performance of materials that underwent testing and analysis. This report documents all known information available as of December, 1993.

3.1 EPOXY ADHESIVES

Table 3.1-1 lists all known epoxy adhesives used by the various LDEF experimenters. The adhesives are identified as to whether the experimenter has reported the on-orbit performance of the adhesives and whether the adhesive had darkened if exposed to UV. Table 3.1-1 also identifies the adhesives that are discussed in further detail in this section (if any testing was performed, all findings are reported in this section).

<u>Epon 828</u> - One of the LDEF adhesive failures occurred on experiment M0003-8, Space Environment Effects on Spacecraft Materials. Two silicon and two thin film solar cells were bonded to individual aluminum mounting plates using an unfilled low viscosity epoxy adhesive, Shell Epon 828. One silicon cell and one thin film cell each were exposed on both LDEF's leading and trailing edges. On-orbit retrieval photographs showed that all four solar cells were no longer bonded to their mounting plates. As shown in the post-flight photos in figure 3.1-1, only a minimal amount of adhesive remained on the leading edge mounting plates but the original 0.003" to 0.004" thick layer remained on the two trailing edge mounting plates. This indicates that the bond failed at the solar cell interface, and then atomic oxygen eroded the leading edge post-failure exposed adhesive layers.

VENDOR	PRODUCT	EXPERIMENT	COMMENTS
Ciba Ceigy	Araldite AV 100/HV 100	A0056, A0139	4
	Araldite AV 138/HV 998	A0023, A0056, A0138-1, S1002	4
	Araldite AV 138/HW 2951	A0138-1	4
	Araldite AW 136/HY 994	M0002	4
	Araldite AW 2101/HW 2951	A0138-1	4
	Araldite MY 750/HY 956	A0056	4
Crest	3135/7111	A0180	1,2
Emerson & Cuming	Eccobond 55	A0056,A0139	4
		A0147	1
		S1004	1,2
	Eccobond 55 + 10% Ecosil	S1002	4
	Eccobond 56C	A0076,A0171	1
		S0069	1
	Eccobond 56C + Ag powder	S1002	4
	Eccobond 57C	M0003-5	1,3
		A0054	1,3
Epoxy Technology	Epo-Tec 301	A0147	1
		S0014	1
	Epo-Tec 331	M0004	1
Furane	Epi-Bond 104	S0014	1
Hysol	EA 934	A0180	1
		M0004, S1001	1
	EA 956	A0054	1
	EA 9210/109519	M0004	1
	EA 9628	M0003-8	1,2,3
		M0003-9	1,2,3
Micromeasurements	MBond 600	M0003	3
		A0180	3
Narmco	Metlbond 329	A0175	1,3
Rome & Haas	K-14	A0171	1
	N-580	A0171	1
Shell	Epon 828	A0056	4
		A0180	1,2
		P0003	1
		S1001	1
		M0003-8	3
3M	AF-143	M0003-8	1,2,3
	EC 2216	A0076, A0178	4
		A0138	1,2,3
		M0003-8	1,2,3
		S1005	1
		Viscous Damper	1
Varian	Torrseal	M0006	4

Key to Comments- 1: Performed as expected, 2: Discolored where exposed to UV, 3: Results discussed in this report, 4: Not reported but experiment performance was nominal.

Table 3.1-1 Epoxy Adhesives used on LDEF

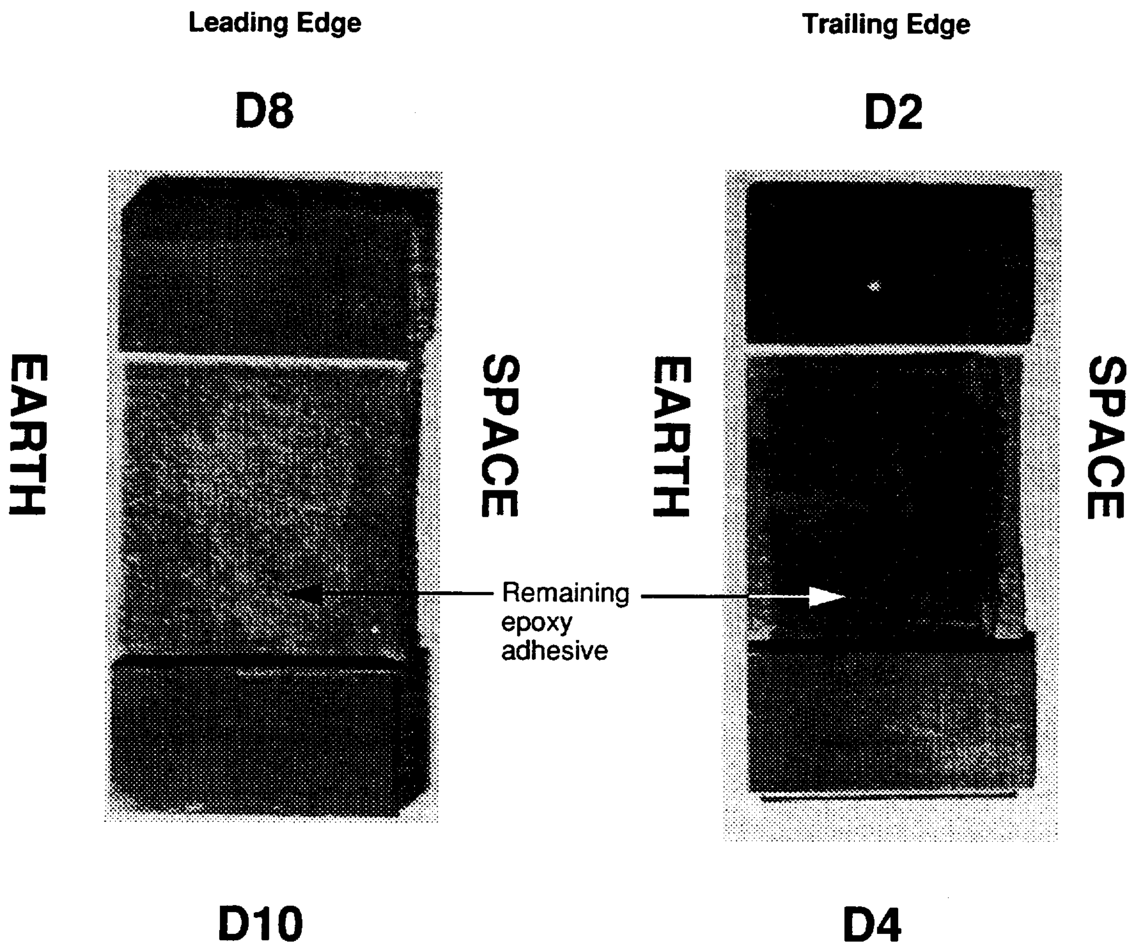


Figure 3.1-1. Solar Cell Mounting Plates Used On Experiment M0003
(Photo Courtesy of Aerospace Corporation)

Using the atomic oxygen fluence vs time calculations contained in reference 1, it was estimated the cells detached from the mounting plate about one year prior to retrieval. This was determined by the fact that the initial bondline was approx 0.004" thick, that minimal amounts of epoxy still remained, and an assumed 1.0 - 1.5×10^{24} atoms/cm^3 recession rate for epoxies. Epon 828 was used successfully on other experiments so no conclusions have been drawn as to the failure mode. Possibilities include 1) poor surface preparation prior to bonding, 2) excessive thermal cycling and high loads due to different thermal expansion coefficients between the solar cells and the aluminum, or 3) excessive loading during takeoff.

Micromeasurements MBond 600 - This epoxy adhesive was used on experiment M0003-9 to bond (cure temperature of 200°F) 40 strain gages to 3.5" long x 0.5" wide x 0.0031 thick strips of metal matrix and organic matrix graphite composites. The strain gages were mounted on the backside of the strips which were mounted on both the leading and trailing edge trays of M0003. Because of this shielded exposure, the gages were not exposed to atomic oxygen or UV radiation. As shown in table 3.1-2, four out of the 40 strain gages debonded. One of the debonded strain gages malfunctioned sometime during the first 14 months of the mission. However, it is not known whether the malfunction was caused by debonding of the strain gage or whether the failure was electrical in nature and the cell debonded later in the mission. The specimens did see 32,422 thermal cycles of - 40 to +176°F. The graphite composite substrates had a rough texture from the bleeder cloth used during specimen fabrication and no sanding was done to smooth the surfaces prior to bonding. It is thought that the failures were due to a combination of thermal cycling and poor surface preparation.

Substrate Material	Specimens strain-gaged (#)	Debonded strain-gages (#)
Graphite-Al with 2024 surface foil	5	0
Graphite-Al with 6061 surface foil	6	0
Graphite-Mg with AZ31B surface foil	5	0
Invar	4	0
Graphite-Epoxy	6	1
Graphite-Polyimide	5	1
Graphite-BMI	2	0
Graphite-Polysulfone	7	2 (both partial)

Table 3.1-2. Number of Debonded Strain Gages Flown on M0003.

Micromeasurements MBond 600 - This adhesive was also used on Experiment A0180, Effect of Space on the Properties of Composite Materials. Sixteen strain gages and thermisters were bonded on composite tubes and panels using MBond 600 epoxy adhesive. All gages were shielded from direct exposure. No debonds occurred and the gages continue to display nominal performance during extensive post-flight testing.

Narmco 329 Metlbond epoxy adhesive - As part of Experiment A0175, Evaluation of Long-Duration Exposure on Composites, Rockwell flew on LDEF's near trailing edge (tray A1) a 12" wide x 36" long bonded honeycomb-sandwich panel. The panel consisted of T300/934 facesheets secondarily bonded to Nomex core with Narmco's 329 Metlbond unsupported 350°F epoxy film adhesive. This honeycomb structure was patterned after the Space Shuttle payload bay door construction. Post-flight ultrasonic inspection revealed no defects, such as delaminations or disbonds, for the honeycomb panel. Pre-flight and post-flight photomicrographs showed no microcracks (figure 3.1-2). Flatwise tension and beam shear testing was performed using both the control and flight panels. Tests results are shown in table 3.1-3a and 3.1-3b.

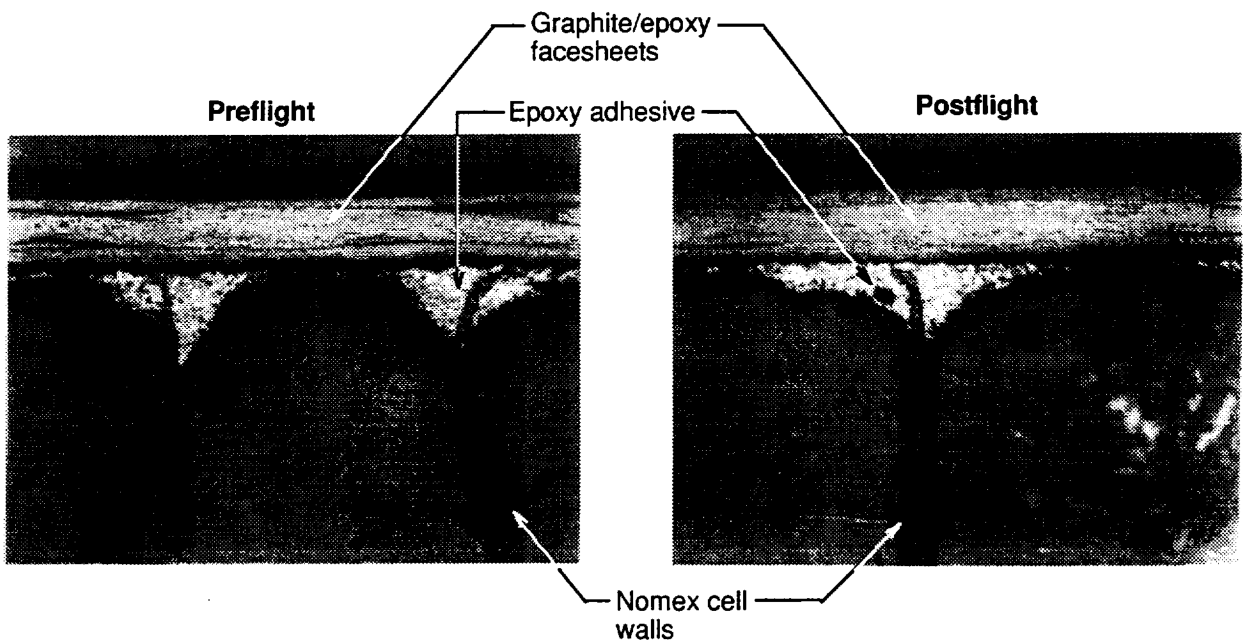


Figure 3.1-2. Polished Cross-Section Of Honeycomb Sandwich Panel (Photo Courtesy of Rockwell International)

There was essentially no difference between control and flight results for the room temperature flatwise tests, while the 350°F results showed a 17% lower value for the flight specimens. The beam shear test yielded the reverse pattern with minimal difference at 350°F and a minimally lower value for the flight specimens at room temperature. In these tests, failure is expected to occur in the core (rather than in the adhesive bondline or the facesheet), and this was, in fact, observed for both the control and flight specimens. In summary the experimenter states that the honeycomb panel exhibited generally comparable mechanical properties between flight and control, indicating no measurable degradation of bondline (329 Metlbond) or honeycomb core strength due to the exposure (ref. 2).

Control 75°F, (psi)	Post-flight 75°F, (psi)	Control 350°F, (psi)	Post-flight 350°F, (psi)
344	358	265	220
338	358	270	240
339	326	265	234
346	342	275	212
346	332	279	221
-	315	-	223
Average = 343	Average = 338	Average = 271	Average = 225

Table 3.1-3a. Flatwise Tension Results from the A0175 Honeycomb Panel

Control 75°F, (psi)	Post-flight 75°F, (psi)	Control 350°F, (psi)	Post-flight 350°F, (psi)
85	74	70	66
86	80	66	67
87	85	67	67
85	83	69	68
86	82	69	69
Average = 86	Average = 81	Average = 68	Average = 67

Table 3.1-3b. Sandwich Beam Core Shear Transverse Strength Results from the A0175 Honeycomb Panel

3M EC 2216 - This adhesive was used to bond the bolts, screws, and velcro strips used on experiment A0138 located on LDEF's trailing edge. EC 2216 was used to adhere approximately 1/8" diameter fasteners to tray components. These bolts were used to fasten together aluminum shields and supports. Although most bonded fasteners were shielded from UV throughout the mission, several were exposed. No failures occurred. The velcro, used to attach the flexible thermal blankets to the structure, was bonded to the supporting metallic structure using EC 2216 adhesive. The mating velcro strips were stitched to the thermal blankets using Nomex thread. Traces of excess adhesive, although cleaned for assembly, reappeared on the rigid structure under long term UV exposure (figure 3.1-3). The adhesive changed color from grey to green. Variations in the glass transition temperature (Tg) depended on the thermal conditions to which they were exposed (ref. 3).

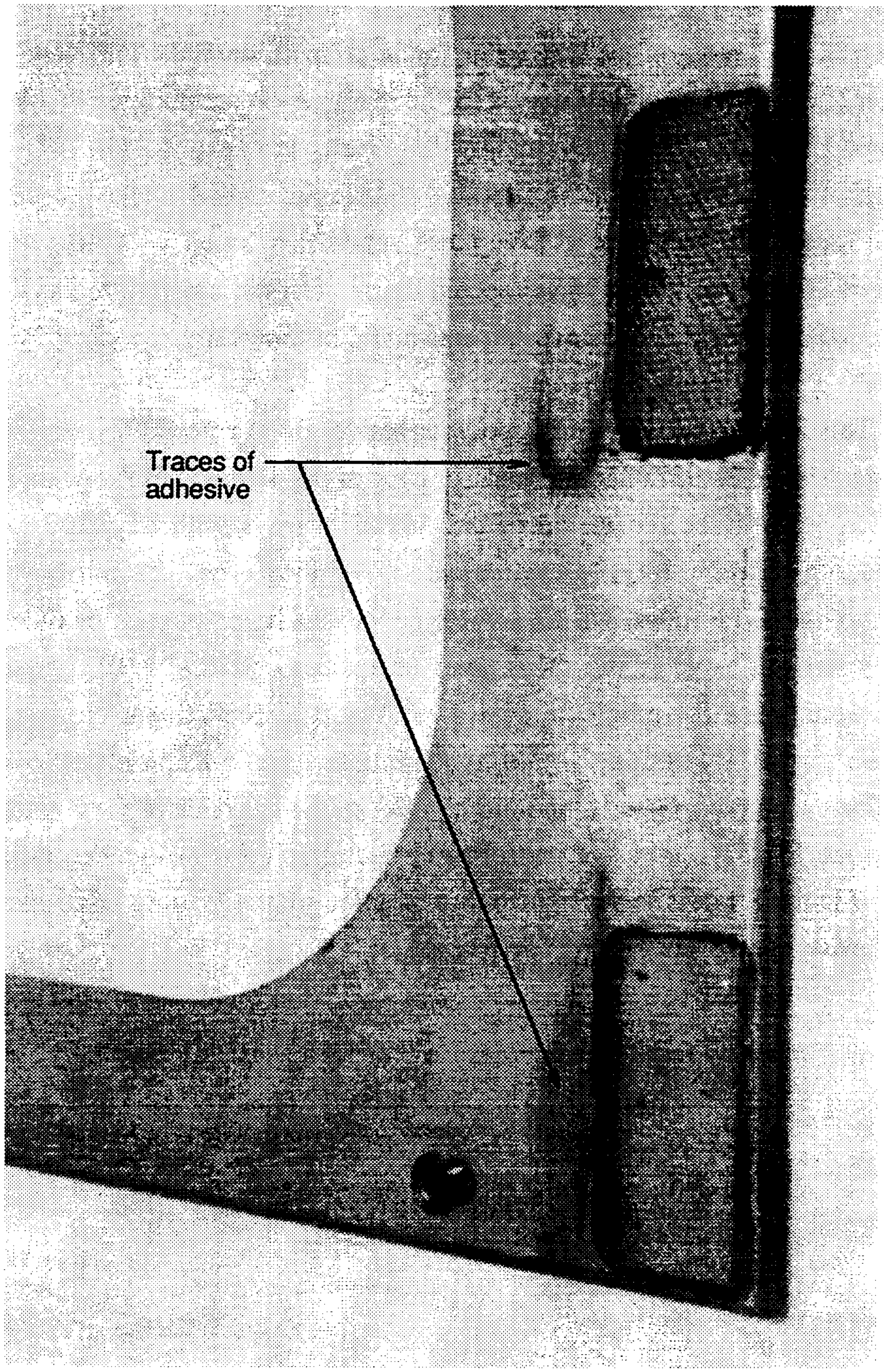


Figure 3.1-3. Velcro Glue Traces (Photo Courtesy of CNES)

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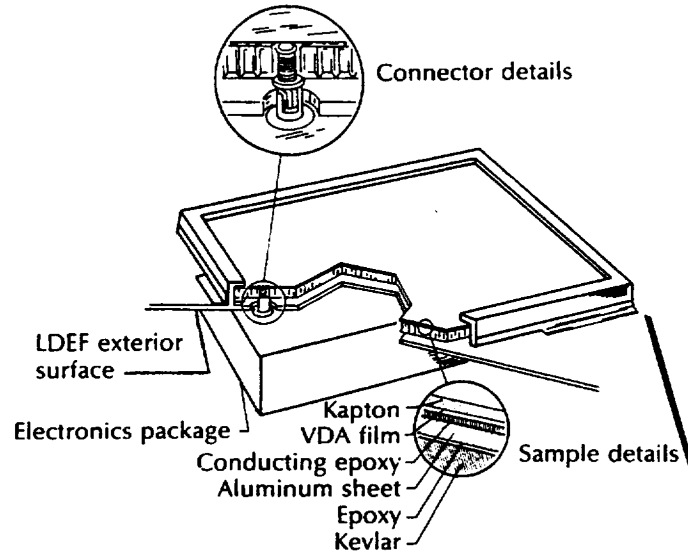
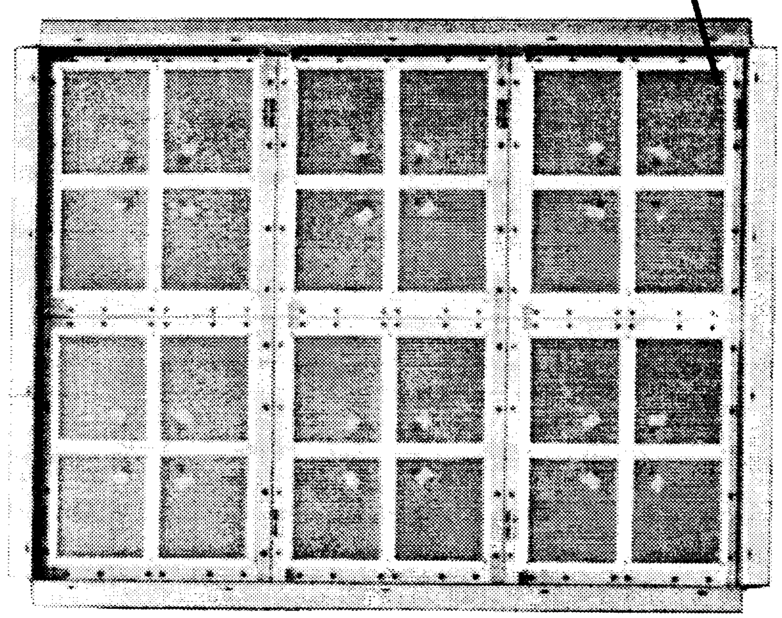
The Nomex thread stitching was exposed to the UV and turned completely yellow but tensile testing showed only a 10% reduction in ultimate strength. Differential Scanning Calorimeter (DSC) analysis showed an increase in transition temperature of 14%, showing that the thread had aged chemically, mainly due to long-term exposure to UV. While both velcro attachment schemes, EC 2216 adhesive and Nomex thread, underwent minor ageing due to the long-term exposure to UV, these schemes worked well in a trailing edge environment. However, due to the expected atomic oxygen erosion, the use of exposed Nomex thread in a leading edge environment should be avoided.

EC 57C - This Emerson & Cuming's epoxy adhesive, filled with 60% silver, was used as conducting adhesive in the dielectric stack for each of the 44 modules flown on Experiment A0054. This experiment consisted of two identical trays with tray B10 located near LDEF's leading edge and tray B4 located near the trailing edge. Each tray contained 22 dielectric modules with figure 3.1-4 showing the various layers of each module. Note that this conducting adhesive is the third layer on each module. No changes (including adhesive) were noted for modules located on tray B4. Significant erosion of Kapton occurred on tray B10 resulting in almost complete loss of Kapton that covered each module. The vacuum deposited aluminum (VDA) on the backside of the Kapton remained adhered to the EC 57C adhesive and prevented atomic oxygen induced erosion of the adhesive. Figure 3.1-5 is post-flight photo of three of the leading edge modules. No further adhesive related analysis was performed.



(a) Dielectric sample construction.



(b) Top view of tray

Figure 3.1-4. Space Plasma High-Voltage Drainage Experiment

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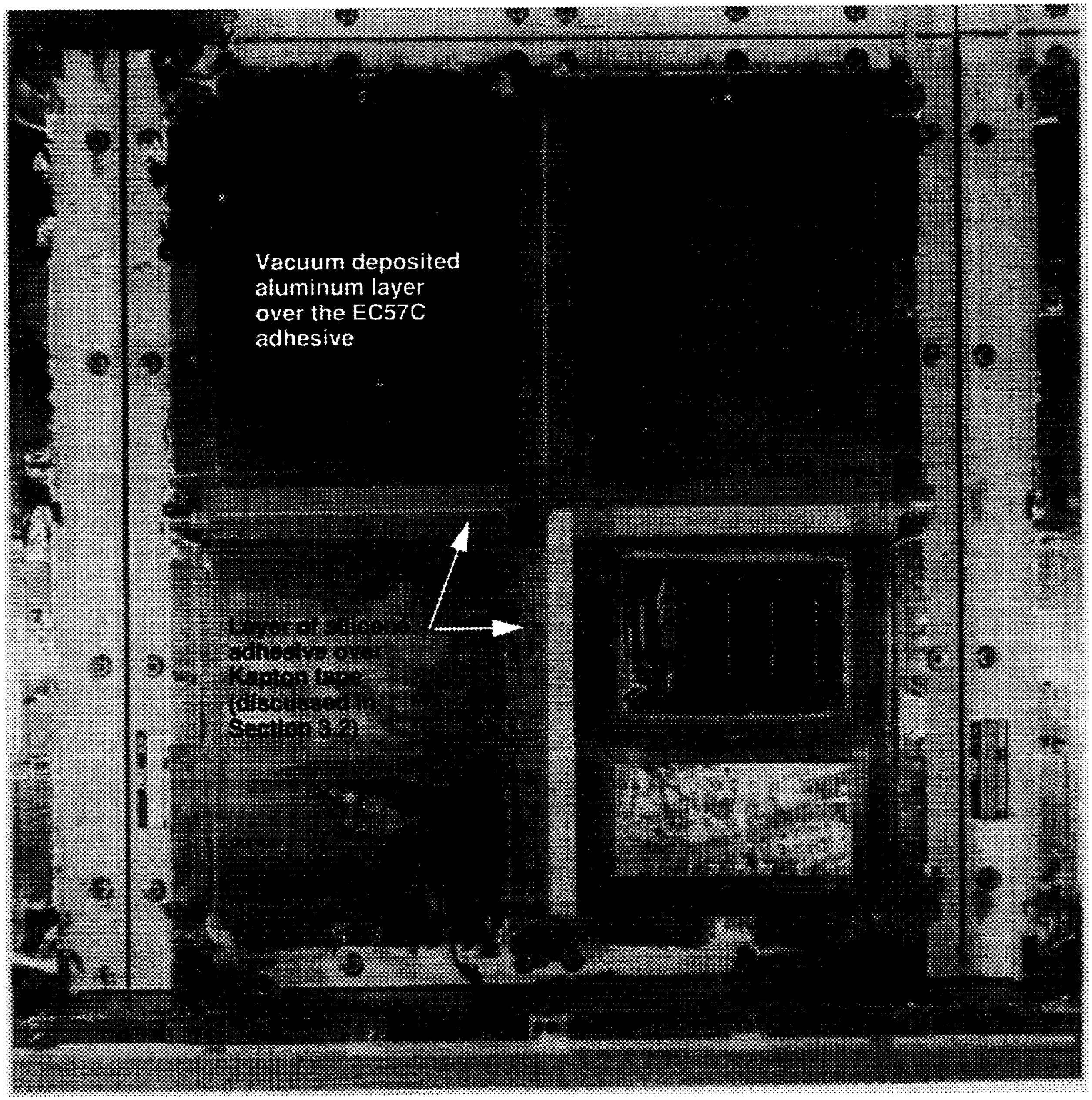

Figure 3.1-5 Three of the Twenty-two Leading Edge Modules from Experiment A0054

3.1.1 Epoxy Lap Shear Specimens

EC 57C - Emerson & Cuming's Eccobond 57C is an epoxy based, room temperature cure, low resistance, conductive adhesive. Two silverized Teflon/EC 57C/aluminized Kapton lap shear specimens (each polymeric strip was 0.005" thick x 6" x 1") were flown on LDEF with one each exposed on the leading and trailing edges. These specimens were part of M0003-5, Thermal Control Materials. The mating surfaces were the Inconel on the backside of the silverized Teflon and the Kapton on the aluminized Kapton. While both strips had torn on-orbit (most likely due to the effects of thermal cycling), the adhesive joint was intact (ref. 4). Lap shear testing on both intact flight and control specimens has not been performed.

3M AF 143 film adhesive - The AF 143, per Boeing Material Specification (BMS) 5-104, 350°F cure film adhesive lap shear specimens using both titanium-composite and composite-composite adherends (composite adherends were T300/934 graphite/epoxy) were exposed on the trailing edge of LDEF as part of Experiment M0003-8. Visual examination of the specimens showed the exposed bondlines to have become dark brown when compared to the shielded bondline on the specimen backsides. Results of post-flight testing are shown in table 3.1-4 (ref. 5). The titanium - composite adherend lap shear strength increased almost 7% and the composite - composite adherend lap shear strength increased over 17% when compared to pre-flight values (tested in 1978). No control specimens exist. Predicted temperature ranges were -20°F to +160°F (ref. 5).

3M EC 2216 - The EC 2216 (BMS 5-92) room temperature epoxy lap shear specimens using both titanium-composite and composite-composite adherends (the composite adherends were T300/934 graphite/epoxy) were exposed on the trailing edge of LDEF also as part of M0003-8. Visual examination of the specimens showed the exposed bondlines to have become dark brown when compared to the shielded bondline on the specimen backsides. The results of post-flight testing is shown in table 3.1-4 (ref. 5). The titanium - composite adherend lap shear strength increased over 19% and the composite-composite adherend lap shear strength increased almost 28% when compared to pre-flight control values. One possibility for the increases in lap shear strengths is continued cure advancement due to the long term exposure to higher temperatures (predicted temperature range was +160°F to -20°F). No control specimens exist (ref. 5).

Adhesive	Adherend	Preflight Shear Stress (psi)	Post Flight Shear Stress (psi)	Average Post Flight Increase (%)	Flight Specimens Tested
AF 143	Titanium - Composite	4515	4820	7	3
AF 143	Composite - Composite	3640	4275	17	2
EC 2216	Titanium - Composite	3750	4480	19	2
EC 2216	Composite - Composite	3145	4020	28	3

Table 3.1-4. AF 143 and EC 2216 Epoxy Lap Shear Test Results

Hysol EA 9628 - Hysol EA 9628 250°F cure epoxy was evaluated on LDEF Experiment M0003-9 using double lap shear specimens consisting of HMF 330/934 graphite fabric reinforced epoxy bonded to 2024 aluminum with Hysol 9628 epoxy film adhesive. Four flight samples each were located in the following four environments; leading edge exposed, leading edge shielded, trailing edge exposed, and trailing edge shielded. Eight non-flight control specimens also existed and were tested at the same time. Table 3.1-5 shows the shear strength test results (ref. 6) and the data is displayed graphically in figure 3.1-6 (the Boeing data is discussed later in this section). Unlike the previous two epoxy systems, a decrease in shear strength is observed for all exposed flight specimens in comparison with the corresponding shielded and control values. The data showed a 6% decrease for leading edge specimens and a 29% decrease for trailing edge specimens compared to post-flight control values. With the exception of the four trailing edge exposed specimens, minimal differences existed between the flight specimens and control specimens.

Figure 3.1-7 shows representative daily temperature profiles that leading and trailing edge lap shear specimens underwent for the first 14 months of the mission (ref. 6). The maximum and minimum temperatures on the leading edge was 180°F and -55°F. The maximum and minimum temperatures on the trailing edge was 170°F and -30°F. Figure 3.1-7 also shows that the differences between temperature extremes for a given orbit was usually greater on the trailing edge. However, these temperature differences are not significant enough to explain the differences between the exposed leading and trailing edge lap shear strengths.

Post-flight Control, (psi)	Leading Edge Exposed, (psi)	Leading Edge Shielded, (psi)	Trailing Edge Exposed, (psi)	Trailing Edge Shielded, (psi)
4020	4290	3960	3240	4130
3910	3780	4250	2910	4230
4210	3270	4190	3280	4170
4260	4040	4020	2190	4100
4060	-	-	-	-
4090	-	-	-	-
4040	-	-	-	-
4040	-	-	-	-
Average = 4080	Average = 3850	Average = 4110	Average = 2910	Average = 4160

Table 3.1-5. Hysol 9628 Epoxy Double Lap Shear Strengths.

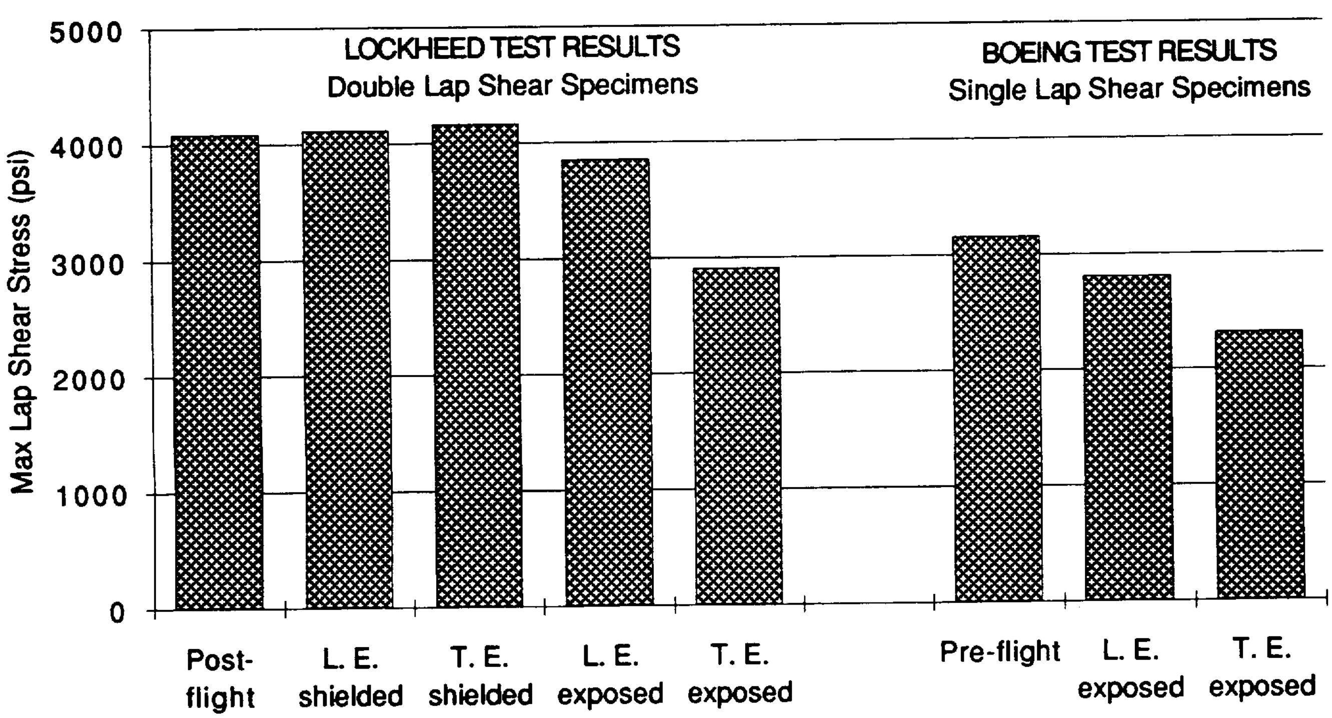

Figure 3.1-6 Hysol 9628 Epoxy Lap Shear Test Results

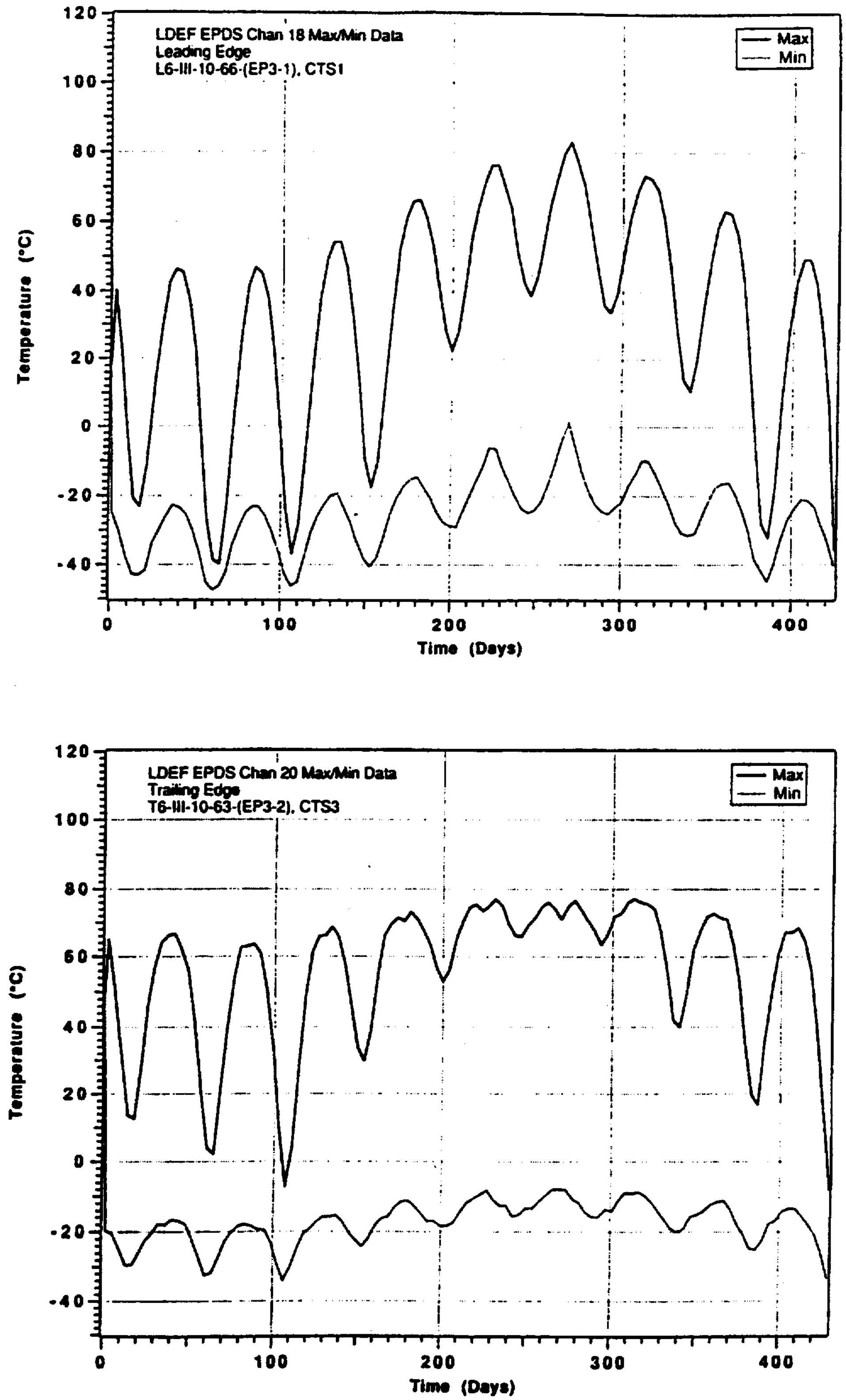

Figure 3.1-7. Maximum and Minimum Temperature Recorded for Each Orbit For T300/934 Samples mounted on the Leading and Trailing Edges of LDEF (Courtesy of The Aerospace Corporation)

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Hysol EA 9628 - Hysol EA 9628 250°F cure epoxy was also evaluated on LDEF Experiment M0003-8 using T300/934 composite lap shear adherends. Three lap shear specimens were flown on the leading edge and three were flown on the trailing edge. Each of the six specimens was mounted so one flat surface was facing toward space. Pre-flight measurements were made in 1978, no control specimens exist. Similar to the previous Hysol EA 9628 specimens flown by Lockheed, the Boeing trailing edge specimens (UV exposure only) show a similar decrease in tensile strength compared to corresponding leading edge specimens (atomic oxygen and UV exposure). These results are shown in table 3.1-6 and also shown graphically in figure 3.1-6. The reason for the difference between leading and trailing edge results is unknown as the vast majority of the adhesive was between the mating surfaces, shielded from the detrimental effects of atomic oxygen and solar UV (ref. 5).

Preflight, (psi)	Post Flight - Leading Edge, (psi)	Post Flight - Trailing Edge, (psi)
3250	3500	2400
3100	2210	2000
2480	2720	2560
3670	-	-
3330	-	-
3090	-	-
Average = 3155	Average = 2810	Average = 2320

Table 3.1-6. EA 9628 Epoxy Lap Shear Strengths.

Prior to determination of shear stresses of the above specimens, the epoxy fillets around the edges of the lap shear joints underwent Fourier transform infrared spectroscopy (FTIR) analysis. This testing was performed to determine if the exposed portion of the adhesive had undergone any physical changes. Comparison of infrared spectra of the shielded Hysol EA 9628 fillets to fillets exposed to UV or UV/atomic oxygen showed the following results. The dicyandiamide catalyst was absent from the six shielded fillets that underwent FTIR. Several of the fillets then had their exterior surface scraped away to expose new, fresh surfaces. These surfaces were then examined using FTIR. Similar results were found with no catalyst identified on these fresh surfaces. The absence of the catalyst is an expected result for thoroughly cured epoxy systems. The dicyandiamide catalyst was observed on almost all exposed leading and trailing edge fillets. Several of these fillets had their exterior surface scraped away with the newly exposed surfaces undergoing FTIR. The catalyst was also found to exist at these surfaces in quantities similar to the original surfaces. The presence of dicyandiamide catalyst on the exposed specimens may be due to chemical bonds being broken by the long term exposure to UV. This could cause the regeneration or reappearance of the catalyst (or a material with a very similar structure).

3.2 SILICONE ADHESIVES

Table 3.2-1 lists all known silicone adhesives used by the various LDEF experimenters. The adhesives are identified as to whether the experimenter has reported the on-orbit performance of the adhesives and whether the adhesive had darkened if exposed to UV radiation. Table 3.2-1 also identifies adhesives that are discussed in further detail in this section.

VENDOR	PRODUCT	EXPERIMENT	COMMENTS
Dennison	Densil Silicone PSA	A0076	1
Dow Corning	6-1104	A0187	
		P0004/A0178	1,2
	43-117	A0171	1
	93-500	A0171	1
		S1002	
		M0003-5	1,2
	RTV 3140	S1001	1
3M	92 ST	A0054	1,2
General Electric	RTV 560 + 12% graphite	M0003-5	2
	RTV 566	A0076	1
		A0171	1
		S0014	1
		S1002	
	RTV 567	A0054	1
	RTV 655	A0171	1
	SR 574	A0171	1,2
	SR 585 PSA	A0076	1

Key to Comments - 1: Performed as expected, 2: Results discussed in this report

Table 3.2-1. Silicone Adhesives used on LDEF

SR574 Silicone Adhesive - Marshall Space Flight Center (MSFC) experiment A0171 included three S-glass composite specimens that were protected by thermal control tape. This tape consisted of 0.002" thick aluminum with 0.002" thick SR574 pressure sensitive silicone adhesive. In addition, three unprotected S-glass composite specimens were exposed along side the three protected specimens. Identical control specimens existed and were tested at the same time as the flight specimens and provided the control values shown in table 3.2-2. The flight specimens were exposed to the exterior environment on row 8 which was 38-degrees from the ram vector. Post-flight visual observations showed no noticeable differences between flight and control specimens. However, because the tape was applied only to the composite surfaces, the edges of the flight specimens showed signs of resin erosion in the composite matrix. Post-flight peel testing showed that the silicone adhesive withstood the rigors of the space environment, with the flight specimens showing an increase in peel strength over the control by a factor of greater than 2 to 1 (see table 3.2-2). The experimenter speculates that the increase is caused by thermal cycling effects. Difficulties were encountered in conducting the flight specimen peel tests due to embrittlement of the tape by the long-term space exposure (ref. 7).

Control specimens - Post-flight testing (lbs/in)	Flight specimens (lbs/in)
1.8	4.6
1.9	4.4
1.9	4.9
Average = 1.9	Average = 4.6

Table 3.2-2. Peel Strength Test Results of SR574 Silicone Adhesive.

Dow Corning 6-1104 Silicone Adhesive - This silicone adhesive was used to bond velcro to the thermal blankets in experiment A0178, A High Resolution Study of Ultra-Heavy Cosmic Ray Nuclei. This experiment consisted of 17 trays located throughout LDEF. Figure 3.2-1 is an on-orbit photo showing one of the 17 trays. These trays are identifiable by the one-piece silverized Teflon thermal control blanket covering the entire tray. The DC6-1104 bond between the velcro and the blanket performed very well with no degradation of the adhesive noted during post-flight examination. The velcro also worked well as an attachment mechanism, with no failures at any of the over 200 attachment locations distributed over 17 trays. As shown in figure 3.2-1, both the DC6-1104 adhesive and the velcro were shielded from exposure to the external spacecraft environment.

In an attempt to determine the effects of the long-term exposure to vacuum on DC6-1104, specimens were tested for outgassing in accordance with NASA SP-R-0022A. The initial total mass loss (TML) and condensible volatile collectable materials (CVCM) testing was performed approximately 28 months after LDEF's return to the Earth atmosphere. Outgassing measurements were also made on velcro specimens from trays B-7 and A-2. For the DC6-1104 outgassing tests, samples were collected both from the bond line at the edge of the velcro and from adhesive underneath the center of the velcro strip. This was an attempt to detect any outgassing differences due to diffusion. However, no significant

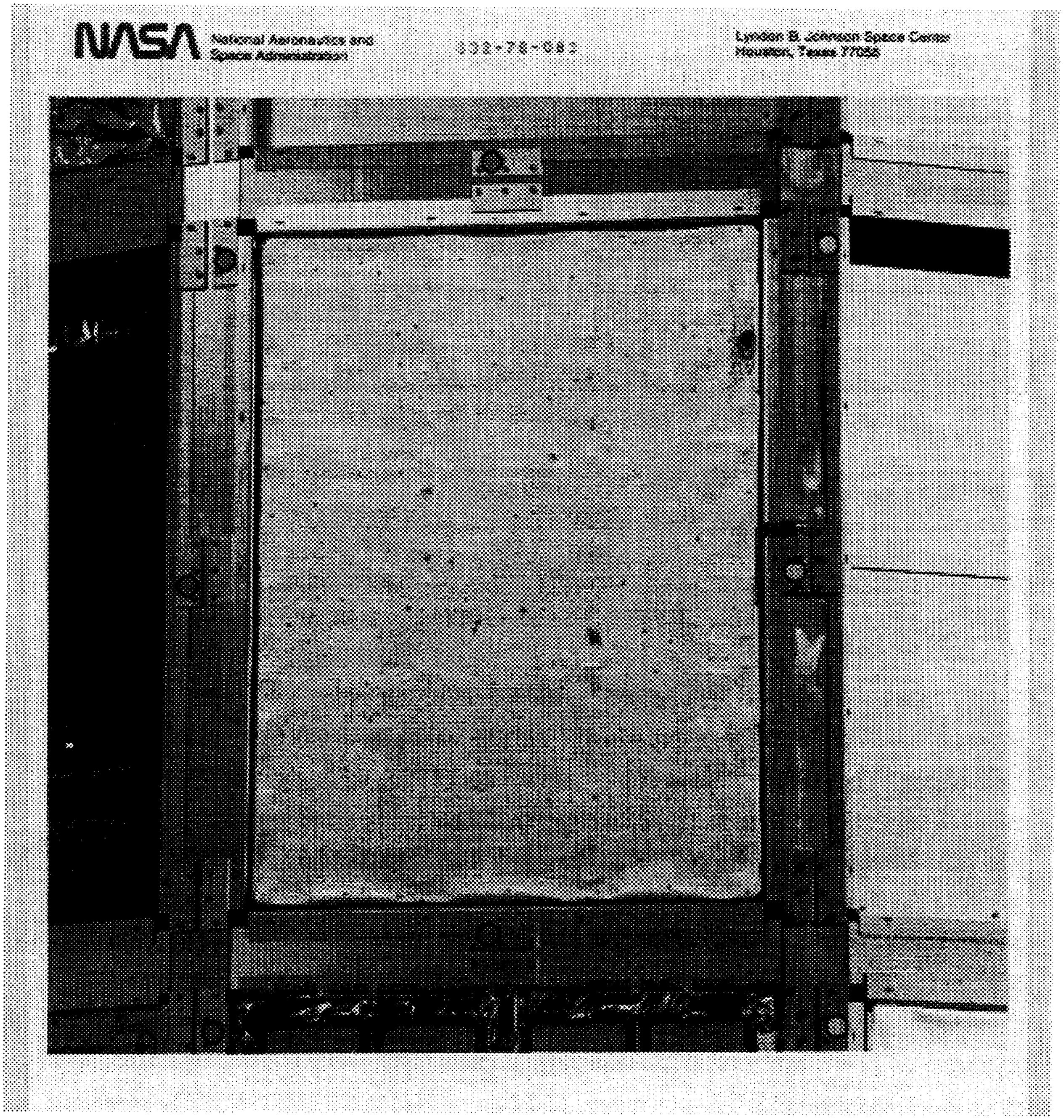

Figure 3.2-1. Silverized Teflon Thermal Control Blanket Used on 17 Trays.

difference existed between samples from the two locations. Outgassing measurements from the DC6-1104 specimens and the velcro are shown in tables 3.2-3 and 3.2-4, respectively. No velcro control data exists.

SAMPLE ID	TML - % (Individual)	CVCM - % (Inidvidual)	TML - % (Average)	CVCM - % (Average)
C-8 - middle	0.28/0.30	0.016/0.019	0.29	0.018
C-8 - edge	0.32/0.26	0.023/0.019	0.29	0.021
B-7 - middle	0.38//0.36	0.011/0.044	0.37	0.028
B-7- edge	0.35	0.029	0.35	0.029
C-6 - edge	0.51/0.50	0.033/0.033	0.51	0.033
B-5 - edge	0.35	0.037/0.026	0.35	0.032
F-2 - middle	0.54	0.081	0.54	0.081
A-2 - edge	0.33/0.32	0.056/0.026	0.33	0.041
A-2 - middle	0.33/0.35	0.032/0.042	0.34	0.037

Table 3.2-3. DC6-1104 Silicone Adhesive Outgassing Data

SAMPLE ID	TML - % (Individual)	CVCM - % (Inidvidual)	TML - % (Average)	CVCM - % (Average)
B-7	0.23/0.21	0.009/0.008	0.22	0.009
A-2	0.24/0.23	0.000/0.001	0.24	0.000

Table 3.2-4. Velcro Outgassing Data

In addition, several meteoroid or space debris impact events occurred in areas of the thermal control blankets on experiment A0178 which had velcro fasteners directly underneath. The surface damage from these events appears to be greater than for impacts in other, unsupported areas of the blankets. The effects on the underlying adhesive holding the velcro to the blankets has not been examined. It is speculated that blanket areas where the adhesive fastened the velcro to the blankets were allowed less freedom of motion than the remainder of the blanket, causing stresses at the interface.

Dow Corning DC 93-500 - Experiment M0003-5, Thermal Control Materials, included the exposure of 32 - 1" x 6" polymeric film strips on both the leading and trailing edges. The ends of all 32 strips were wrapped around and then bonded to the backside of the mounting plates using a clear RTV silicone thought to be Dow Corning DC 93-500. All 64 of these shielded bonds survived the mission intact. No other observations or testing was performed (ref. 4).

3M tape 92 ST - This Kapton tape, with a pressure sensitive silicone adhesive, was used on experiment A0054, Space Plasma High Voltage Drainage. This experiment was comprised of two identical trays with tray B10 located near LDEF's leading edge and tray B4 located near the trailing edge. Each tray consists of 22 dielectric modules (figure 3.1-4 showed the various layers of each module). Two overlapped layers of the 92 ST tape were used to seal the sides of each module. Figures 3.2-2 and 3.2-3 are post-flight photos of these trays showing the condition of each tray. The trailing edge tray remains essentially unchanged, but due to high levels of atomic oxygen exposure, all Kapton on tray B10 was severely eroded. All that remained from the top layer of Kapton tape was the underlying silicone adhesive. However, this silicone layer prevented atomic oxygen induced erosion of the bottom layer of tape. Figure 3.1-5 shows a close up post-flight photo of three modules showing how the bottom layer of Kapton tape remained intact.

To assess the effect of the space environment on the adhesion of the tape, TRW performed the following testing and analysis (the following results are copied from an internal TRW test report). The test procedure was modeled after ASTM Standard No. D1000-82a (Standard Methods of Testing Pressure - Sensitive Adhesive Coated Tapes Used for Electrical Insulation); a 90-degree tape pull test using a hand held, Chatillon DFG-100 Digital Force Gauge in the continuous readout mode.

The 0.787 inch wide Kapton tape, having the silicone-based adhesive, showed essentially no difference between leading and trailing edge materials with the average pull strength being 1.3 lbs. and 1.2 lbs, respectively, which can be compared to a value of 0.9 lbs. for the same test performed on fresh, unaged, unflown material.

RTV 560 + 12% graphite - Six Teflon (FEP)/Ag/Inconel/RTV 560 + 12% graphite/Kapton/Al and two FEP/Ag/Inconel/RTV 560 + 12% graphite/Al/Kapton (same configuration as the previous six specimens except the Kapton/aluminum surface was reversed) lap shear specimens were flown on LDEF as part of M0003-5, Thermal Control Materials. Each of the polymeric strips were 0.005" thick x 1" wide x 6" long. The graphite was added to the RTV to increase conductivity across the bondline. Four specimens were exposed on the leading edge and the other four were exposed on the trailing edge. The on-orbit photo survey showed that all eight lap shear specimens had failed prior to LDEF's retrieval. In all eight specimens, the adhesive remained on the surface of the adherends. Control specimens exist but have not been tested (ref. 4).

Silicone pressure sensitive adhesive - Almost 400 of the individual tray clamps had 1.25" diameter painted (A-276 white thermal control paint) aluminum disks adhesively bonded to their front surface. Figure 3.2-4 is a closeup of a tray clamp showing the A-276 paint disk

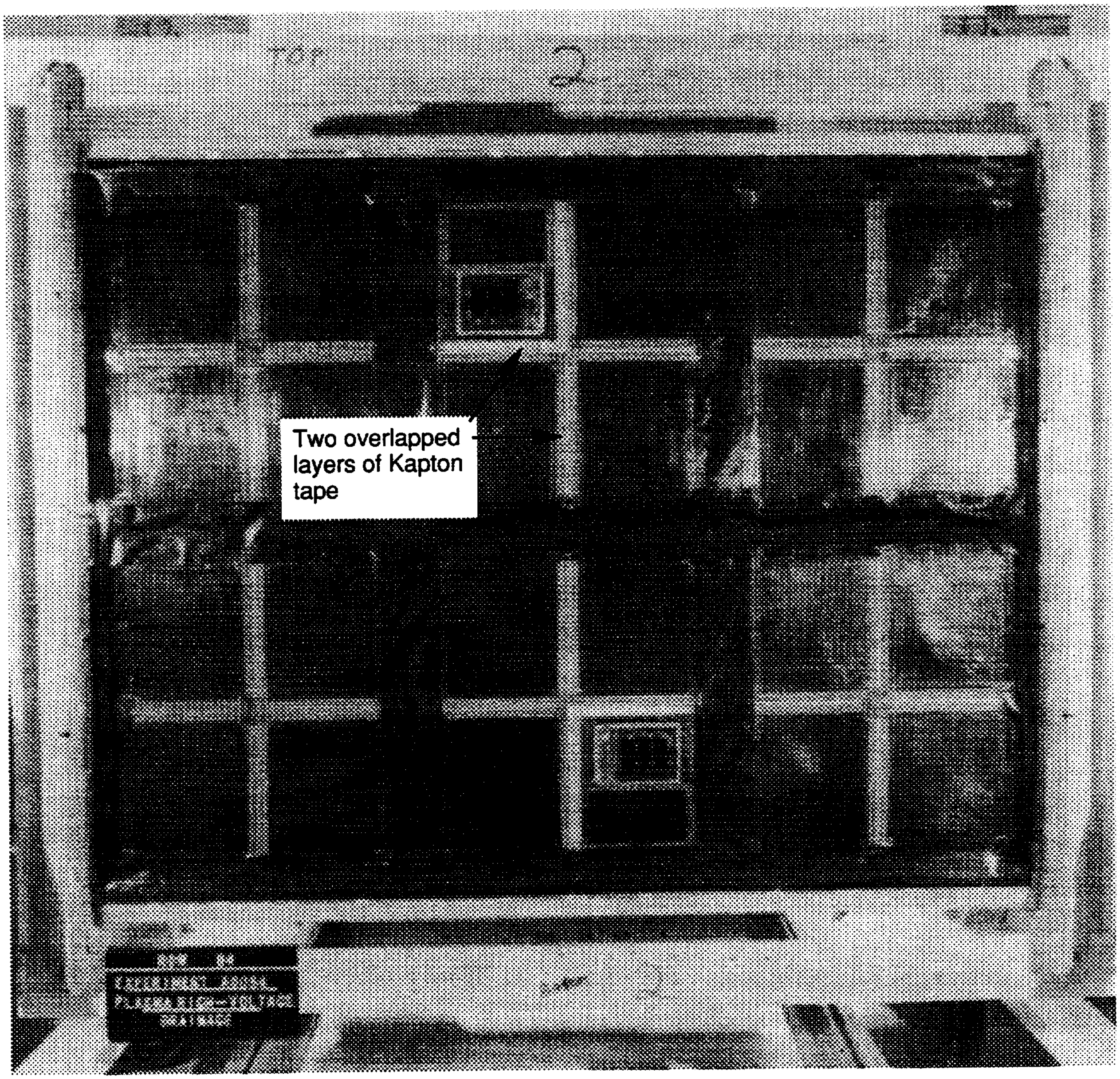

Figure 3.2-2. Experiment A0054, Trailing Edge Tray (Photo Courtesy of NASA LaRC)

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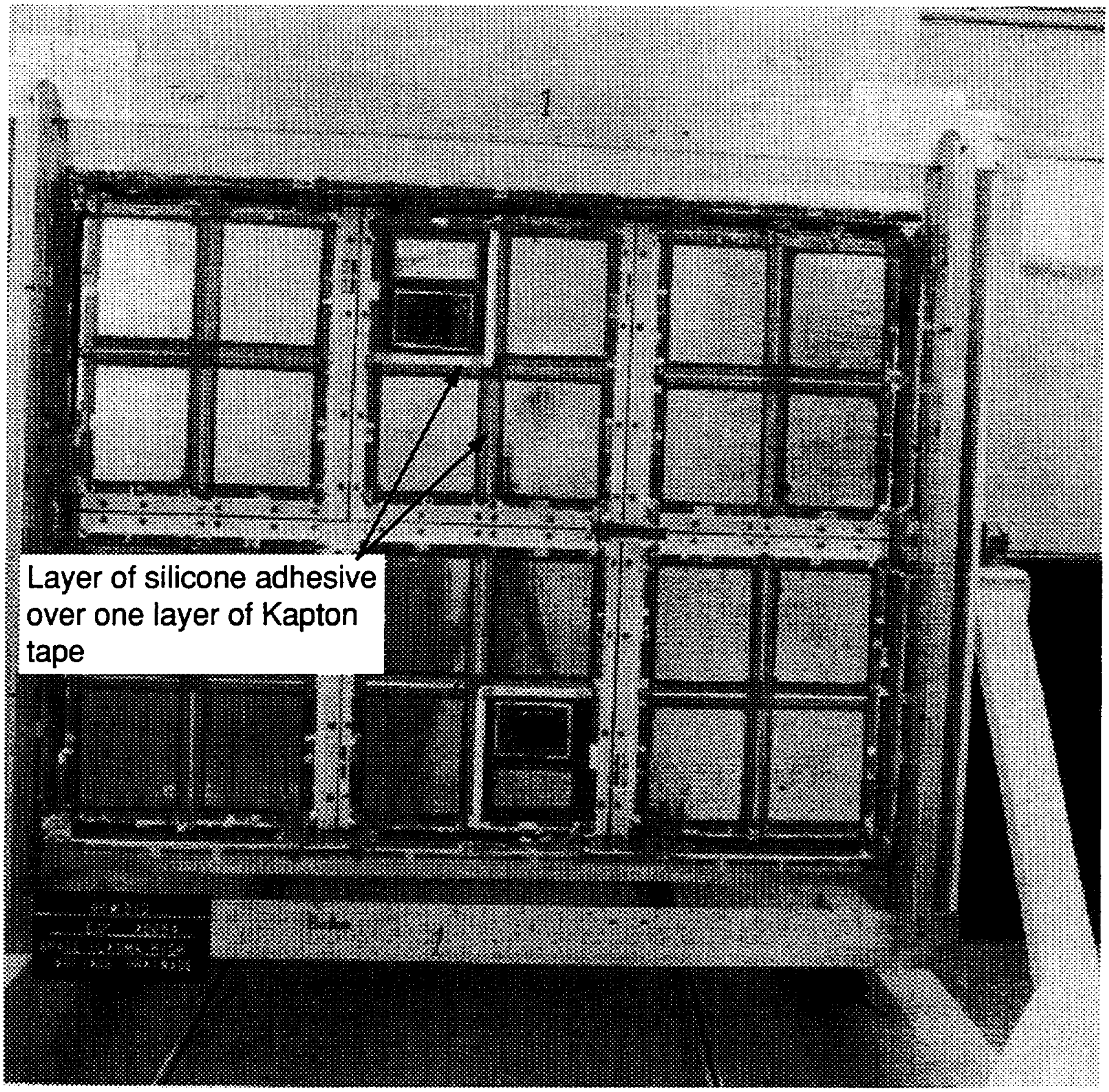

Figure 3.2-3. Experiment A0054, Leading Edge Tray
(Photo Courtesy of NASA LaRC)

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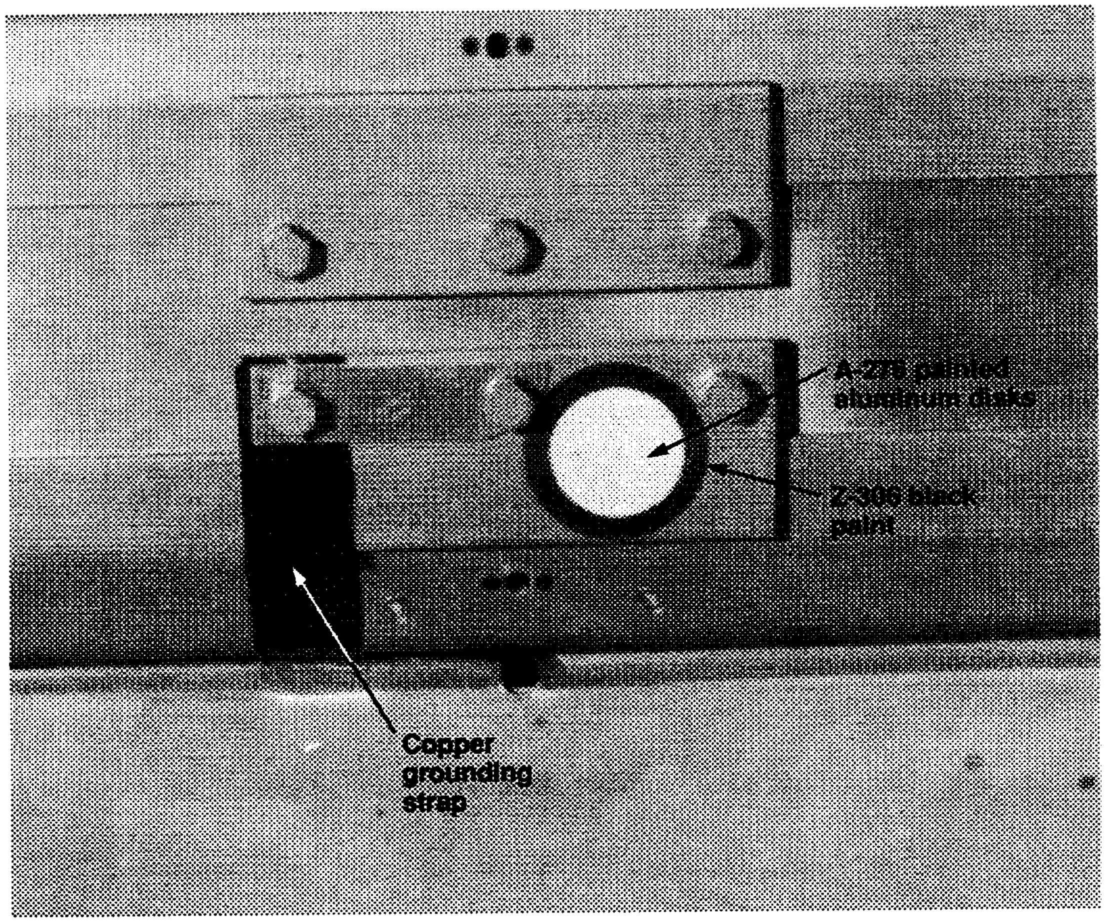
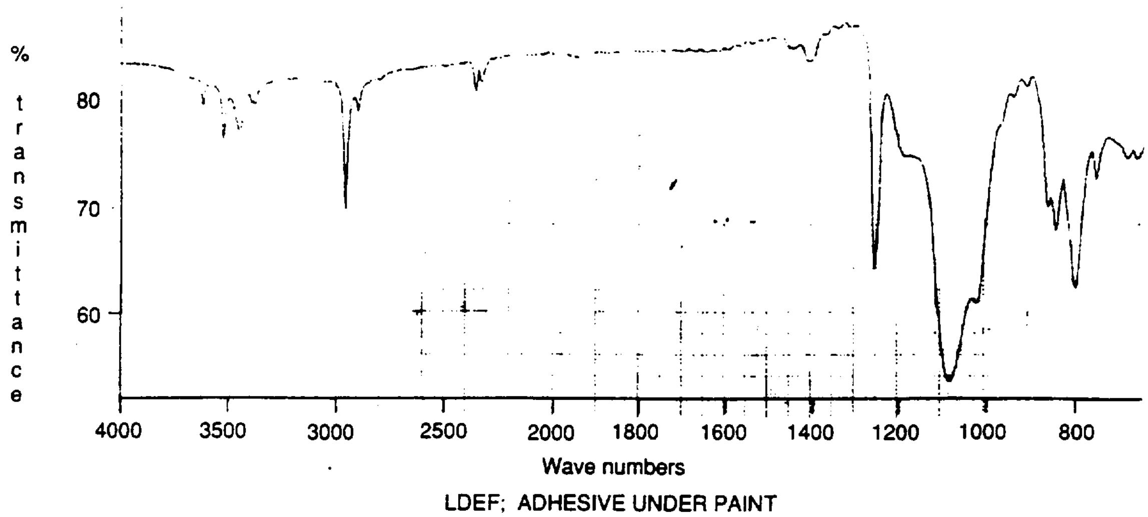


Figure 3.2-4. Chromic Acid Anodized Tray Clamp



The FTIR of the adhesive from a paint disk of LDEF

RTV-90

SILICONE RUBBER

Sp. Gr. 1.47 Visc. 12,000 ps.
Solids 100%
Source: General Electric Company,
Silicone Products Department
Film

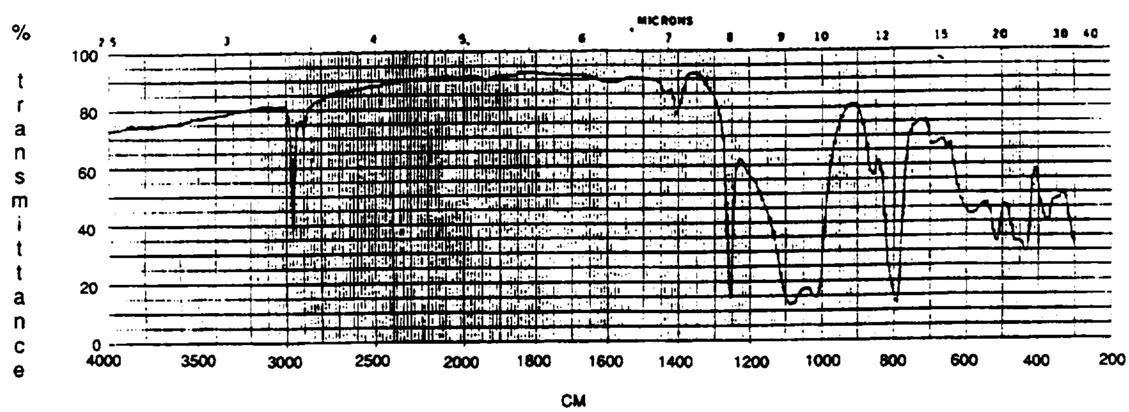
BLOCK

SADTLER RESEARCH LABORATORIES INC.

COMMERCIAL - INFRARED © 1973

MONOMERS AND POLYMERS

GRATING SPECTRA



The IR spectrum of a GE Silicone Rubber

Figrue 3.2-5. FTIR Spectra Used To Identify Adhesive On Backside Of Aluminum Disks bonded to Z306 black paint which had been sprayed onto the chromic acid anodized aluminum tray clamp. Each A-276 disk remained bonded throughout the mission. In an attempt to identify the adhesive, IR spectra was obtained from FTIR analysis of the backside of a painted disk. The results, shown in figure 3.2-5 are typical of silicone compounds. A silicone reference spectrum is also presented for comparison. No further identification was performed.

A calculation was performed to assess the thermal loads on the adhesive due to thermal cycling induced as the LDEF traveled in and out of theEarth's shadow and as the A276 paint changed its solar absorptance. End of mission absorptance and emittance for selected "paint buttons" were used. The results show that the maximum temperature differences between the surface of the paint and the adhesive are only 2 to 4°F, within the uncertainty of the model calculation. Figures 3.2-6 and 3.2-7 show the thermal cycling ranges for adhesives on clamps from row 4 and row 9, respectively. As expected, the higher solar absorptance from the solar-UV altered paint induced higher temperatures in the adhesive on the trailing edge disc. Table 3.2-5 shows the optical properties used to predict the temperature environment seen by the paint buttons, adhesive layer, and tray clamps. In summary, this adhesive experienced approximately 32,422 temperature cycles between approximately 85°F to 140°F (Row 9) and ~90°F and 150°F (Row 4) with no failures of any of the paint disks.

Specimen ID	Exposed side		Shielded side	
	absorptance (%)	emittance (%)	absorptance (%)	emittance (%)
Row 9; A-276	0.32	0.88	-	-
Row 9; Z-306	0.90	0.91	-	-
Row 9; Aluminum	0.34	0.15	0.33	0.16
Row 4; A-276	0.55	0.85	-	-
Row 4; Aluminum	0.35	0.15	0.34	0.16
Space end; Al	0.35	0.16	0.35	0.17
Row 6; A-276	0.42	0.86	-	-
Row 6; Aluminum	0.35	0.16	0.35	0.16

Table 3.2-5. Optical Properties used to Predict Silicone Adhesive Temperatures.

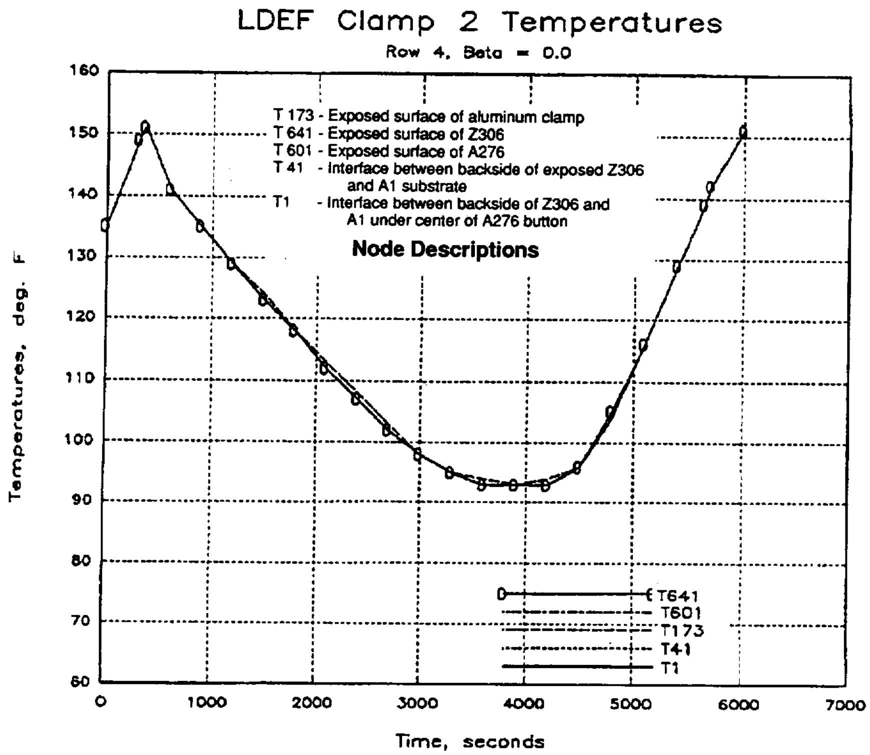


Figure 3.2-6. Trailing Edge Tray Clamp Temperature Profiles

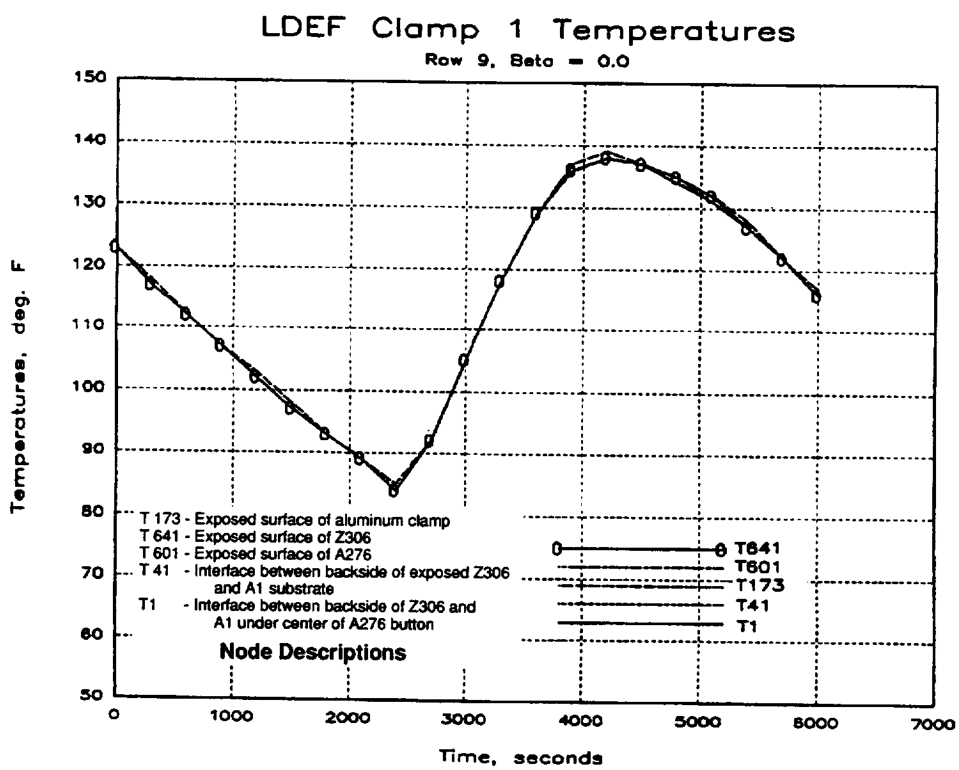


Figure 3.2-7. Leading Edge Tray Clamp Temperature Profiles

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3.3 ACRYLIC ADHESIVES and TAPE

Table 3.3-1 lists the known acrylic adhesives and tapes used on LDEF. The materials are identified as to whether the experimenter has reported the on-orbit performance of the adhesives and identifies materials that are discussed in further detail in Section 3.3.

VENDOR	PRODUCT	EXPERIMENT	COMMENTS
Emerson & Cuming	Eccoshield PST-C	M0003	3
Loctite		A0119, A0138-1	3
Mystic Tapes	7355	M0001 P0003	1 1
3M	5	A0139	3
	56	S0069	1
	74	S0069	1
	433	A0076	1
	X-1181	A0178 M0001	1,2 3
	Y966	A0054 M0003-5 S0069 M0001	1,2 1,2 1,2 2
	Y8437	A0076 Viscous Damper	1 1,2
	Polyester Hot Melt Adhesive	A0133	1,2

Key to Comments - 1: Performed as expected, 2: Results discussed in this report, 3: Not reported but experiment performance was nominal.

Table 3.3-1. Acrylic Adhesives, Tapes and Other Materials

<u>3M tape X-1181</u> - This copper foil tape with a conductive acrylic adhesive, was used as grounding straps for the silver/Teflon blankets (figure 3.2-4 shows a tray clamp with a copper foil grounding strap) on 17 trays located throughout LDEF. The grounding straps were constructed by plying two layers of tape, the adhesives together, with an area of adhesive remaining on each end. A peel test was performed on a sample of the ground strap and compared to a control sample of a freshly constructed strap made from the same roll of tape. All samples had a peel strength of 3.5 to 3.9 pounds per inch. No difference was found between space hardware and ground hardware.

Acrylic adhesive- Two FEP/Ag/Inconel/Acrylic/Kapton specimens were flown with one exposed on each of the leading and trailing edges as part of M0003-5, Thermal Control Materials. Adhesive strips (1" x 6") were used to bond two 1" x 6" strips of silverized Teflon and Kapton together (these specimens were not configured as lap shear specimens). Both strips were intact. No post-flight testing has been performed.

3M Y966 - Two silverized/Y966/aluminized Kapton lap shear specimens were flown on LDEF as part of M0003-5, Thermal Control Materials. Each of the polymeric strips were 0.005" thick x 1" wide x 6" long. One lap shear specimen was exposed on each the leading and trailing edges. While both strips had torn on-orbit (most likely due to the effects of thermal cycling), the adhesive joint was intact. Lap shear testing of the intact flight specimens and control specimens has not been performed.

3M transfer tape with Y966 adhesive - This acrylic transfer tape was used to adhere aluminized Kapton to the aluminum tray flanges on both trays B10 and B4 of TRW's Experiment A0054. Additional layers of Kapton tape with silicone adhesive (92 ST) covered this aluminized Kapton/Y966 layer. As previously described in Section 3.2, the silicone in the 92 ST tape was an effective atomic oxygen barrier. Although the Kapton degraded, the silicone adhesive shielded the underlying Kapton/Y966 layer. To assess the effect of the space environment on the adhesion of the Y966 tape, TRW performed the following testing and analysis (the following results are copied from a TRW test report). The test procedure was modeled after ASTM Standard No. D1000-82a (Standard Methods of Testing Pressure - Sensitive Adhesive Coated Tapes Used for Electrical Insulation); a 90-degree tape pull test using a hand held, Chatillon DFG-100 Digital Force Gauge in the continuous readout mode.

The acrylic adhesive tape formed a bondline, 0.394 inches wide, between the aluminum tray flange and the aluminized side of the intermodular VDA-Kapton. The average force registered during the constant rate 90-degree pull test, was 4.5 lbs. and 3.5 lbs. for the leading and trailing edge trays respectively. Repeating the pull test with unflown material, an average force of 1.4 lbs. was measured. Variation in maintaining and repeating a constant pull rate with the manual force gauge introduces an unknown amount of uncertainty into the measurements, as does the fact that the unflown material was not from the same batch as the flight specimens. It is not clear how much of the difference between the leading and trailing edge specimens is due to space environmental effects and how much is an artifact of the test method, but the difference between these specimens and the unflown material is thought to be significant.

Comparing leading and trailing edge pull tests for the acrylic transfer tape, there was a distinct difference in bondline failure. For the leading edge specimen, approximately 75 percent of the adhesive stuck to the VDA-Kapton with the remaining material adhering to the aluminum tray flange. For the trailing edge specimen, the reverse was true with 85 percent of the adhesive remaining on the tray flange. The bondline failure in the unflown material test most closely resembled that of the trailing edge specimen. The reason for the differing failure modes is unclear. There is insufficient material on the leading edge to repeat the test enough times to build a statistical base. Subjectively however, the adhesive demonstrated adequate bond strength in both tests. Note: In areas where the acrylic adhesive was exposed to atomic oxygen on the leading edge tray, the adhesive was completely eroded from the surface.

<u>3M tape Y966</u> - This adhesive was used on a silverized FEP film substrate which was used to hold the thermal blankets to the tray frame on experiment M0001. The blankets apparently shrunk in flight causing the blankets to detach from the frame. Portions of the tape were attached to both the blanket and to the frame, having failed in tension. The film and Y966 remained pliable. Attempts to fail the tape to frame joint in shear were unsuccessful even though a load of roughly 100 pounds was applied to a piece of tape less than a quarter inch wide. The tape was then tested in peel. The Y966 bonded to the aluminum and to the silver on the film well enough to cause delamination of the silver from the film.

<u>Y966 film adhesive</u> - 3M's Y966 film adhesive was used to adhere 0.002" thick silverized Teflon to the exposed aluminum thermal covers on Experiment S0069, Thermal Control Surfaces Experiment (located on the leading edge). Post-flight observations showed a brownish discoloration of the exposed silverized Teflon material. Figure 3.3-1 is in an on-orbit photograph showing the discoloration. This brownish discoloration varies from light to dark brown. For the regions with a low degree of brown discoloration, the solar absorptance was relatively unchanged at 0.10 compared to a ground reference sample's absorptance of 0.08. The worse case brownish area had an solar absorptance as high as 0.49. The silverized Teflon is composed of an outer Teflon layer, a silver layer deposited on the Teflon, an Inconel protective layer deposited on the silver, and the Y966 acrylic pressure sensitive adhesive. Post-flight testing and analysis showed the technique used to apply silverized Teflon/Y966 adhesive to the aluminum covers excessively stressed the material resulting in cracking of the silver and Inconel layers (figure 3.3-2 shows the a cross section of the various materials during application). This internal damage exposed the underlying Y966 adhesive to UV (Teflon is transparent to UV) causing the

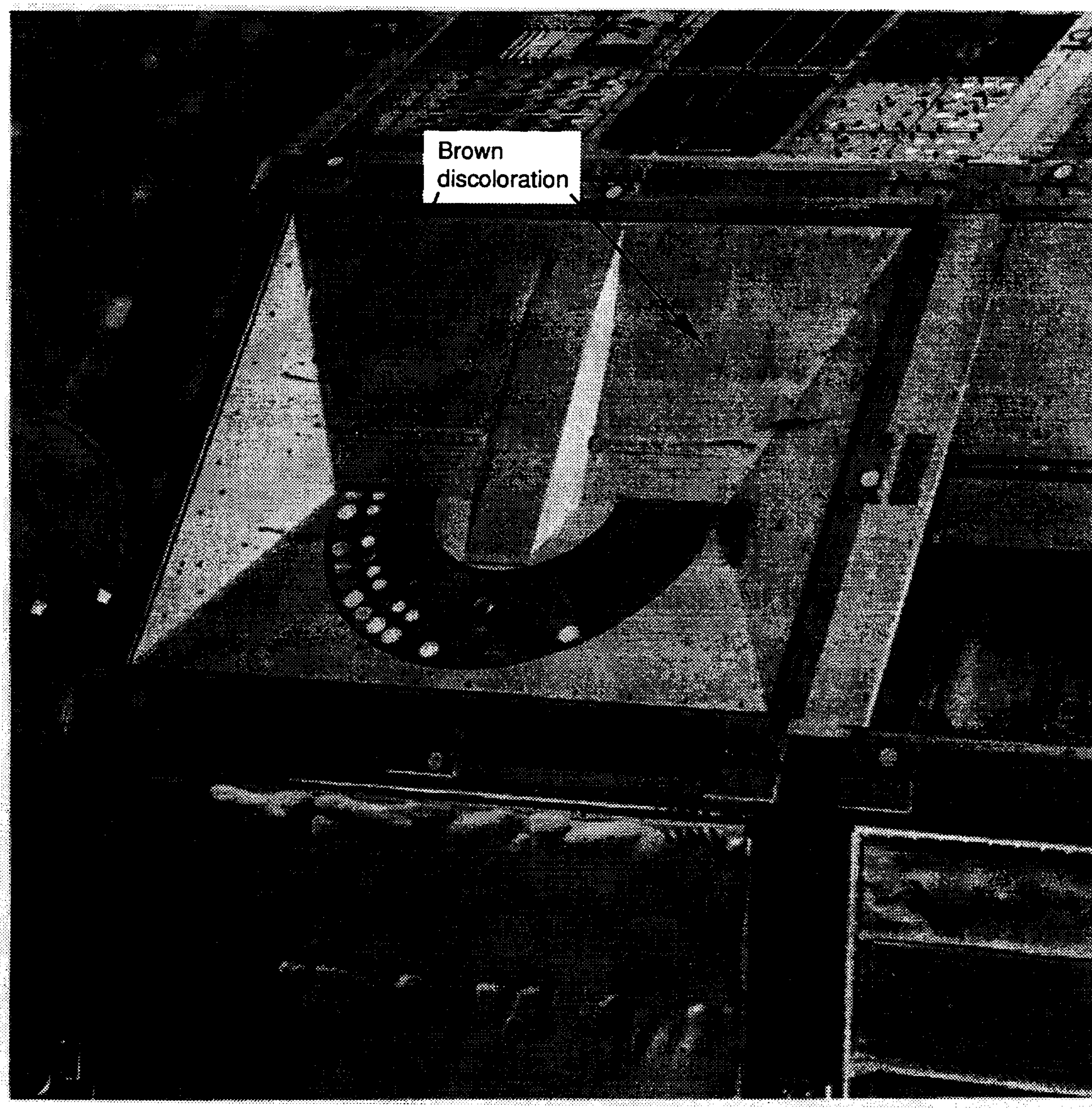

Figure 3.3-1. On-orbit Photograph of Experiment S0069 Showing Areas of Brown Discoloration

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discoloration (ref. 8). Improved application techniques (keeping the Teflon film flat during release paper removal and less squeegee pressure during application of film to substrate) have been developed eliminating damage to silver and Inconel layers.

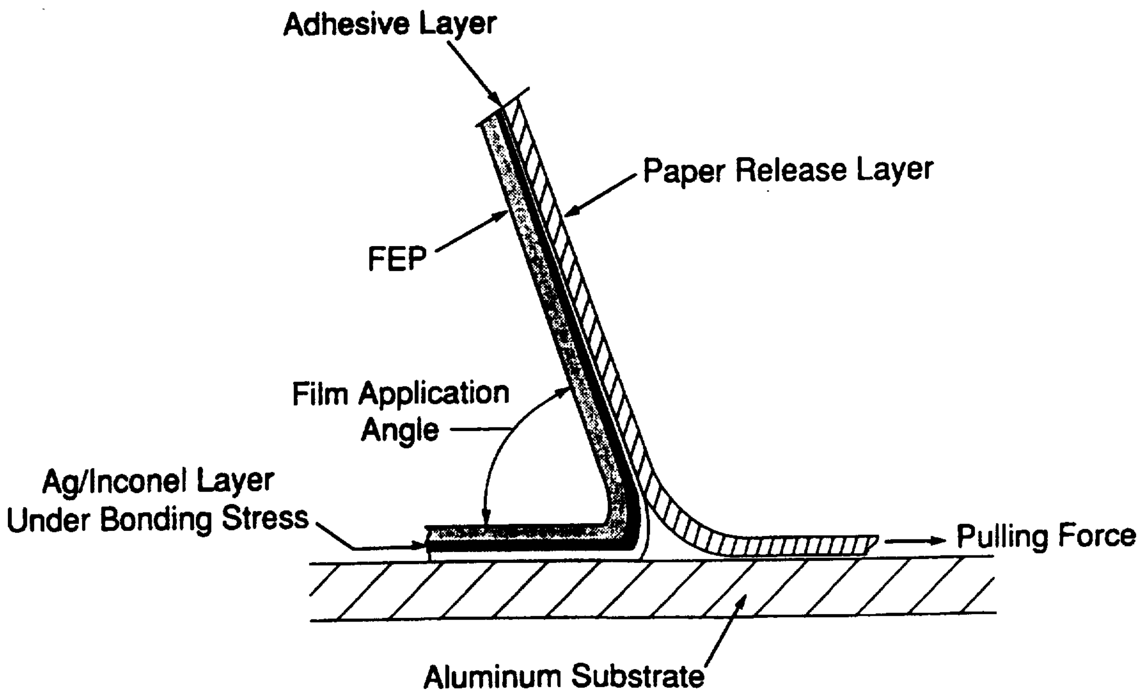

Figure 3.3-2. Schematic Of Silverized Teflon Application Method Used On Experiment S0069 (Figure Courtesy of NASA MSFC)

3M tape Y8437 - This 3M product is a 0.001" thick transparent polyester film with VDA on both sides using a transparent acrylic adhesive. The tape was used as a coating on the viscous damper shroud, a fiberglass epoxy structure located on the interior of LDEF. The tape used on LDEF had an average 90 degree peel strength of 4.5 lbs/in. After the LDEF tape had been removed, a new piece of the same type of tape (different batch and manufacture time) was applied to the shroud. This tape had an average peel strength of less than 1 lb/in. Apparently, the tape adhesive sets up with time to give increased adhesion. Exposure to thermal vacuum cycling in space did not appear to have any adverse effect on the tape. Table 3.3-2 shows the individual test data for the six flight and two control specimen. The actual load curves are shown in Appendix A.

Specimen ID	Peel Strength (lbs)
Control #1	0.75
Control #2	0.5 - 1.0
Flight Specimen #1	4.6
Flight Specimen #2	5.2
Flight Specimen #3	5.0
Flight Specimen #4	3.4
Flight Specimen #5	5.3
Flight Specimen #6	4.2

Table 3.3-2. 3M Y8437 Viscous Damper Tape Peel Strength

Polyester Hot Melt Adhesive - This adhesive was used on Experiment A0133, Effect of Space Environment on Space Based Phased Array Antenna, which was located on the space end of LDEF. Part of the experiment's objectives was to determine the effect of the space environment on dimensional stability of spliced and continuous Kapton. The hot melt polyester adhesive was used to splice the Kapton. No results have been published.

3.4 CONFORMAL COATINGS and POTTING COMPOUNDS

Table 3.4-1 identifies the conformal coatings and potting compounds used on LDEF. All these materials were used in construction and assembly of experiments and were shielded from direct exposure to LDEF's exterior environments. These materials have undergone minimal post-flight inspection and testing. Table 3.4-1 documents the five materials that were reported to have "performed as expected".

VENDOR	PRODUCT	EXPERIMENT	COMMENTS
Conap	CE-1155	A0201 P0005	1 2
Dow Corning	Sylgard 182	S1001	1
	Sylgard 186	S1001	1
Emerson & Cuming	Stycast 1090	A0056	2
	Stycast 2850	P0003	1
	Stycast 3050	S0069	1
General Electric	RTV 411/511	S0014	1
Products Research	PR 1535	A0038	2
	PR 1568	A0201	2
Thiokol	Solithane 112	A0178	2
	Solithane 113	A0038, A0178, A0187-2, S0001, S1001, S1002	2
3M	Scotchcast 280	A0139	2

Key to Comments - 1: Performed as expected, 2: Not reported but experiment performance was nominal.

Table 3.4-1. Conformal Coatings and Potting Compounds.

4.0 CONCLUSIONS

Over 60 different adhesives, tapes, conformal coatings, and potting compounds were used on LDEF. With the exception of the six adhesive systems evaluated using lap shear specimens, all other materials were used in fabrication of experiment hardware, mounting of specimens, or installation of instrumentation. The majority of the materials tested performed equal to or exceeded pre-flight mechanical properties. However, most materials were shielded from exposure to the LEO space environment with the exception of the vacuum component of the LEO environment and the thermal cycling associated with the 32,422 90-minute orbits. In addition, while adhesives are known to be susceptible to particle radiation, the total dosage seen by LDEF during its 69 month 28.4-degree inclination orbit was apparently below the degradation threshold of these materials.

The following three epoxy adhesives were characterized using lap shear specimens;

- 3M's EC 2216, room temperature cure
  - single lap shear specimens exposed on the trailing edge
- Hysol's EA 9628, 250°F cure
  - single lap shear specimens exposed on the leading and trailing edges
  - double lap shear specimens exposed and shielded on both the leading and trailing edges
- 3M's AF 143, 350°F cure
  - single lap shear specimens exposed on the trailing edge

Post flight test results of these three adhesive systems showed that when compared to pre-flight test values, both the EC 2216 and the AF 143 systems exhibited a 7% to 28% increase in lap shear strengths with the composite-to-composite adherends exhibiting a larger increase compared to the titanium-to-composite adherends. However, both the single lap shear (Boeing specimens) and double lap shear (Lockheed specimens) EA 9628 specimens showed a similar decrease in lap shear strengths. The Boeing data showed an 11% decrease for leading edge specimens and a 26% decrease for trailing edge specimens compared to pre-flight values. The Lockheed data showed a 6% decrease for leading edge specimens and a 29% decrease for trailing edge specimens compared to post-flight control values. The significant but similar decrease in trailing edge vs leading specimens vs pre-flight data is surprising. The only exposed portion of the adhesive are the fillets formed around the perimeter of the lap shear joint. Degradation of this small layer should have insignificant effect on the overall strength of the joint. It is unlikely that the temperature differences between leading and trailing edge exposures (as was shown in figure 3.1-6) were significant enough to account for the difference in lap shear strengths.

Why the trailing edge EA 9628 exposed specimens degraded significantly more than the leading edge specimens, why the shielded EA 9628 specimens showed a slight increase in shear strength compared to post-flight control values, and why the EC 2216 RT cure and AF 143 350F cure increased in strength and the exposed EA 9628 250F cure decreased is unknown. The small number of specimens, lack of equivalently aged lab control specimens, and inherent scatter in lap shear testing have made developing conclusions difficult.

Tape peel strengths generally increased for both exterior and shielded exposures. The reason for this increase is uncertain but the long-term exposure to higher than room temperature installation temperatures is thought to play a major role. Maximum temperature seen by the various tapes was dependent upon location but was approximately 150^{o}F. This would result in advancing the cure of the tape adhesives, resulting in higher peel strengths.

Only one experiment used an adhesive (3M's EC 2216) in a structural application. Post-flight condition of the adhesive was nominal and no failures occurred.

LDEF results showed that pre-flight workmanship continues to be one of the most critical aspects to successful on-orbit performance. The correct adhesive selection is also important so that the adhesive is able to exceed required mechanical and thermal properties at both the maximum and minimum service temperatures throughout the entire mission.

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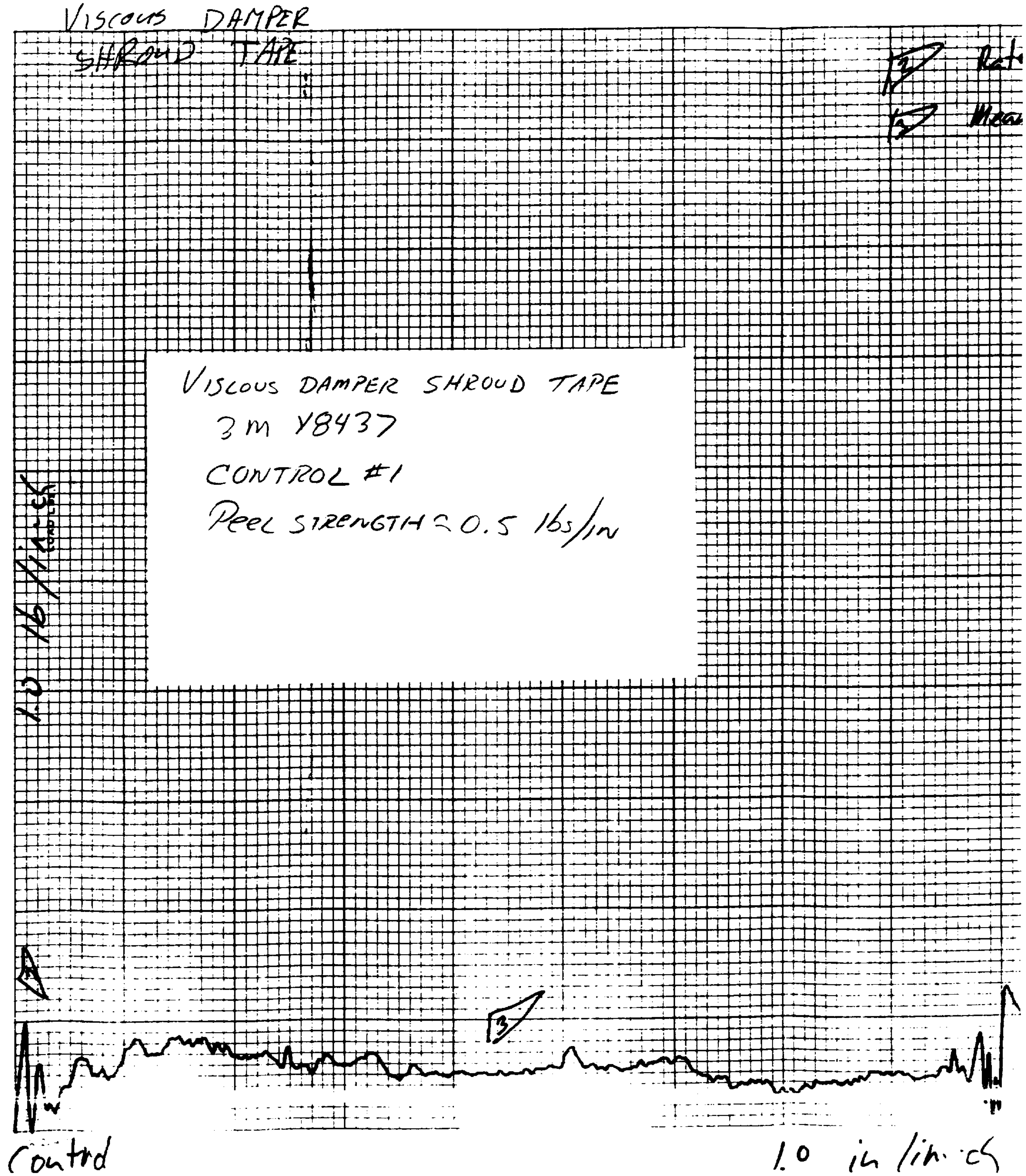
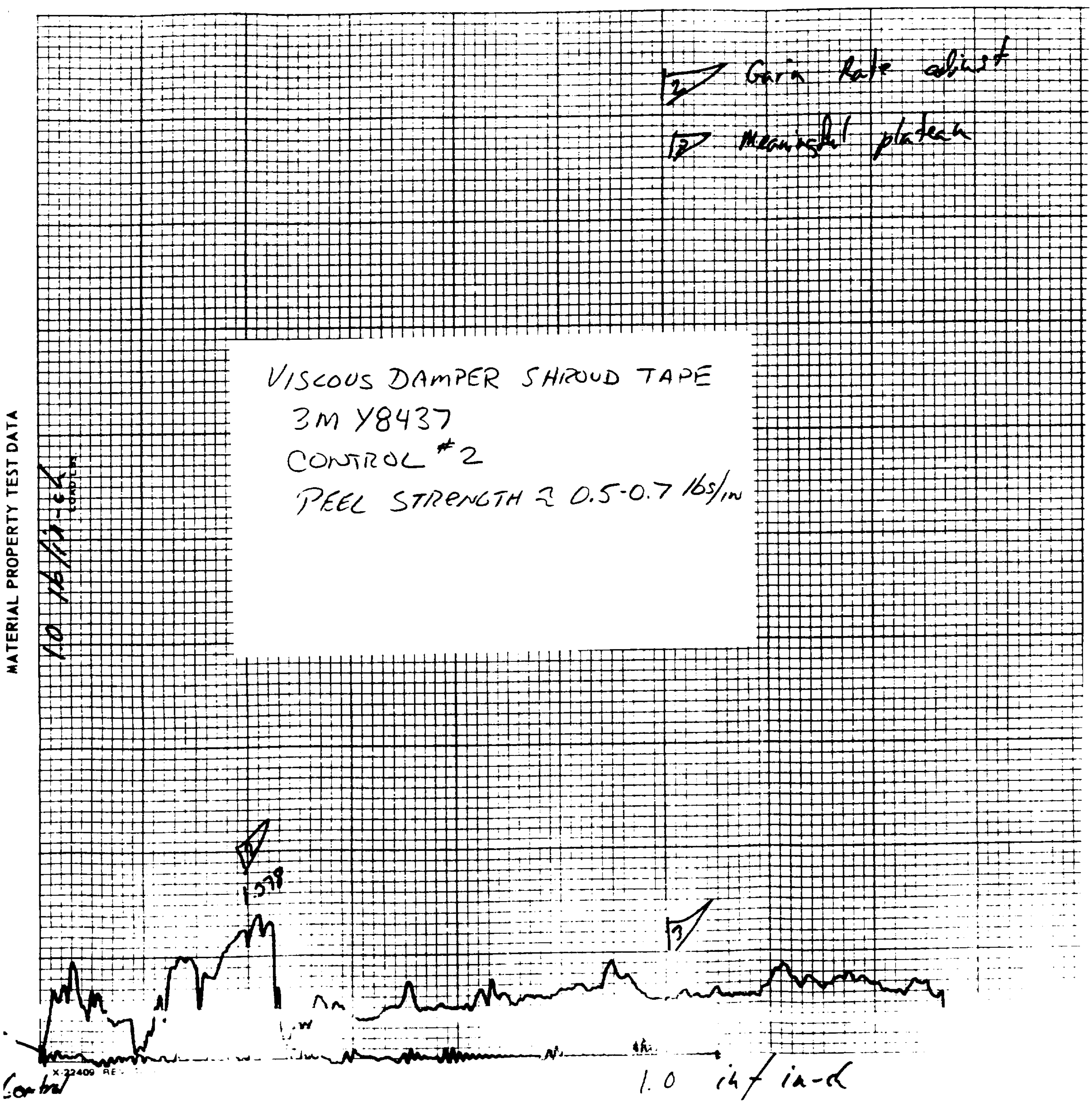
APPENDIX A
VISCOUS DAMPER SHROUD TAPE (3M Y8437) MECHANICAL TESTING DATA

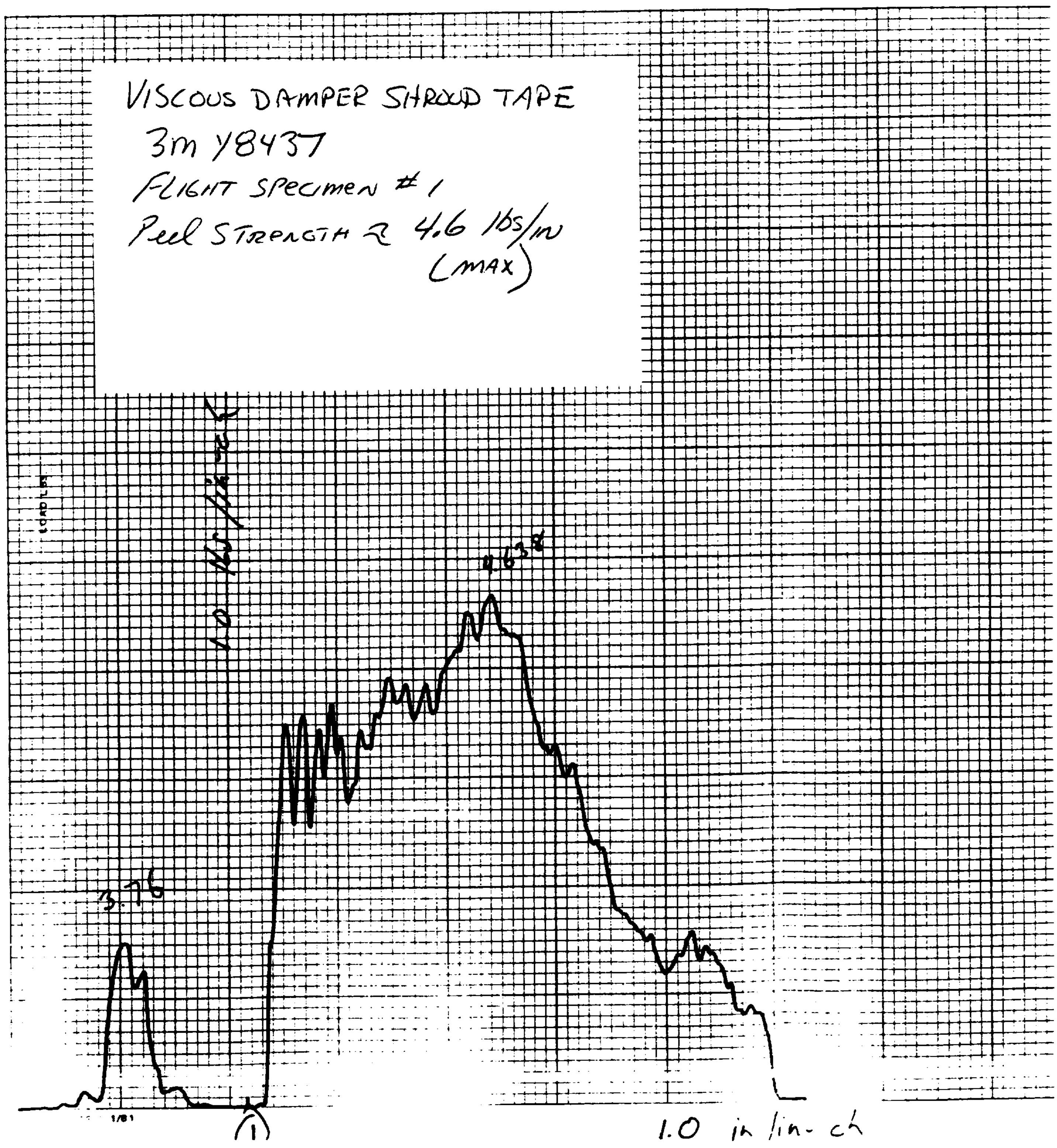
Control #1 - Peel strength = 0.75 lbs
Control #2 - Peel strength = 0.5 - 1.0 lbs
Flight specimen #1 - Peel strength = 4.6 lbs
Flight specimen #2 - Peel strength = 5.2 lbs
Flight specimen #3 - Peel strength = 5.0 lbs
Flight specimen #4 - Peel strength = 3.4 lbs
Flight specimen #5 - Peel strength = 5.3 lbs
Flight specimen #6 - Peel strength = 4.2 lbs

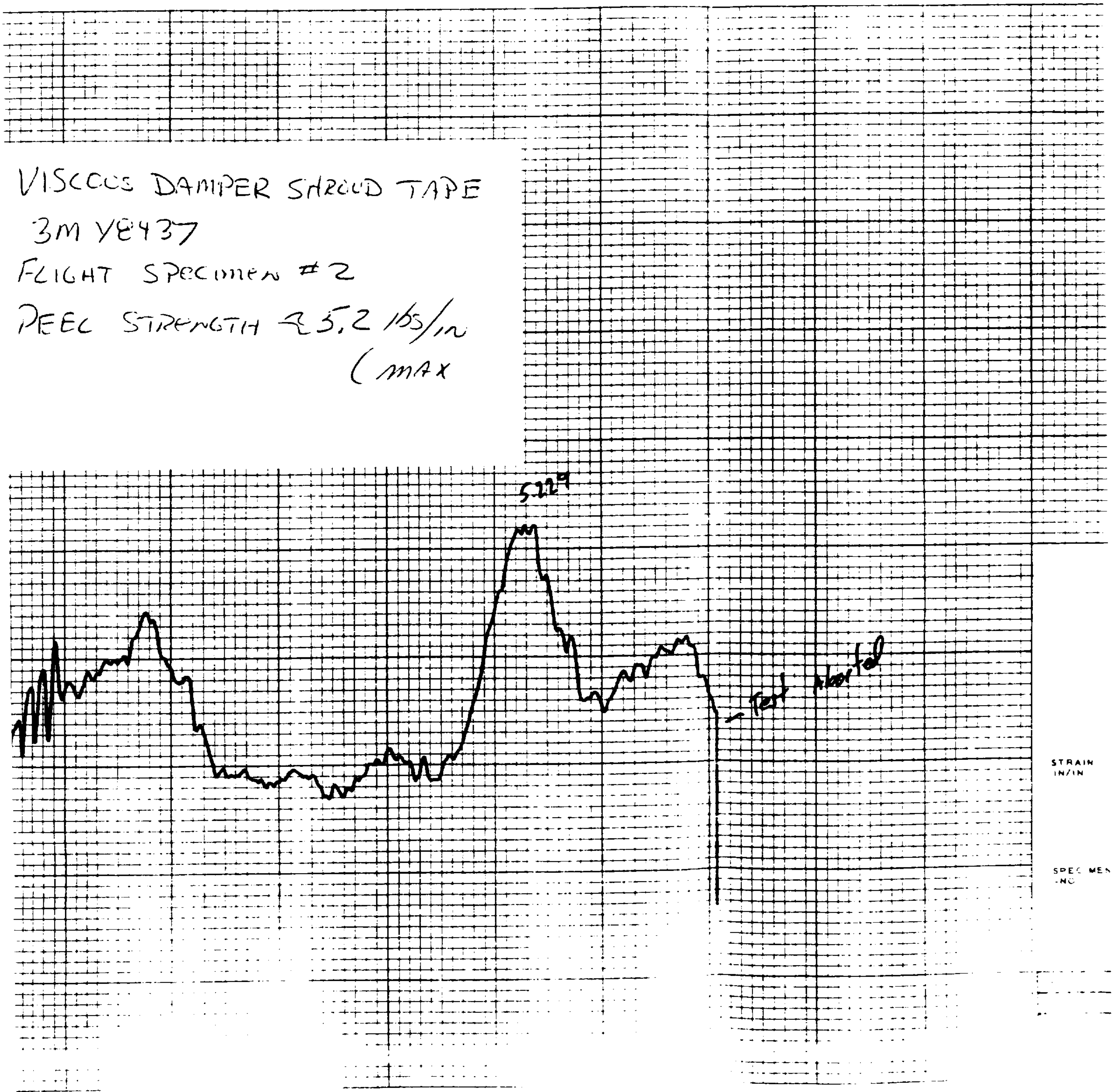
MATERIAL PROPERTY TEST DATA




MATERIAL PROPERTY TEST DATA
LOAD LBS
1.0 lb/in-ch
2 Gain Rate adjust
1 Meaningful plateau
VISCOUS DAMPER SHROUD TAPE
3M Y8437
CONTROL #2
PEEL STRENGTH ≈ 0.5-0.7 lbs/in
1.378
1.0 in/in-d
Control
X-22409

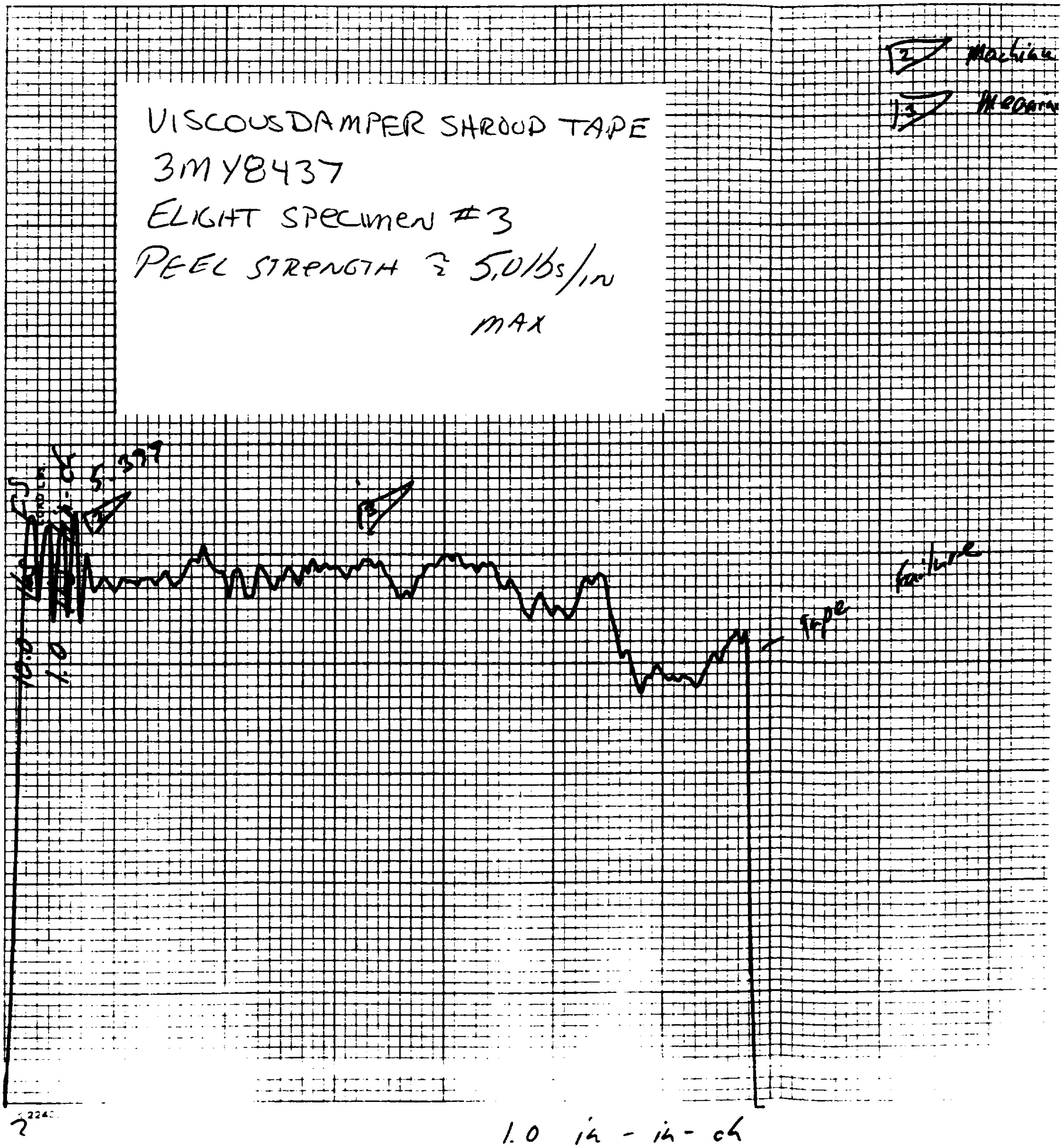
MATERIAL PROPERTY TEST DATA

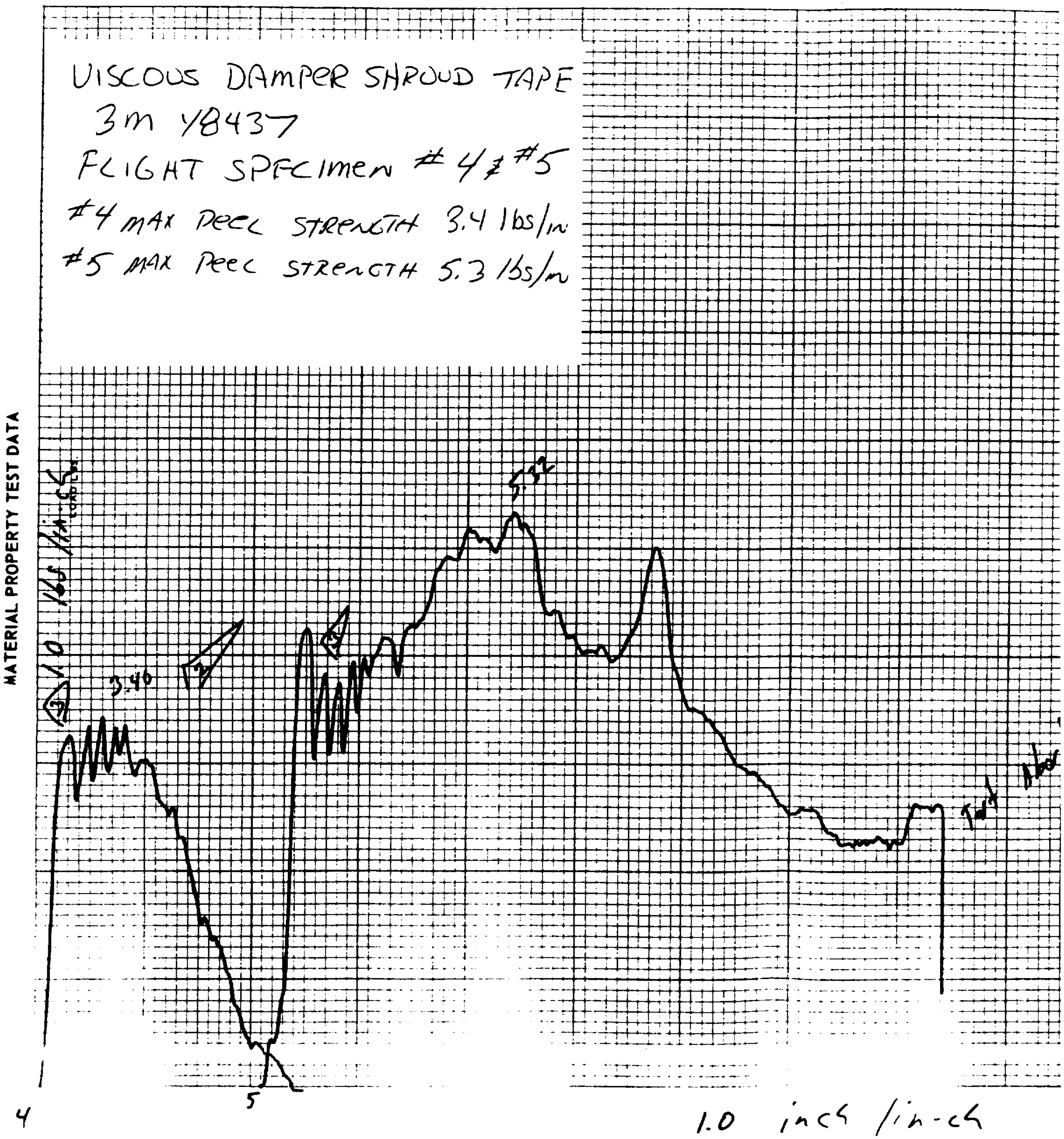



VISCOUS DAMPER SHROUD TAPE
3M Y8437
FLIGHT SPECIMEN #2
PEEL STRENGTH ≈ 5.2 lbs/in
(MAX
5.22
test aborted
STRAIN
IN/IN
SPECIMEN
NO

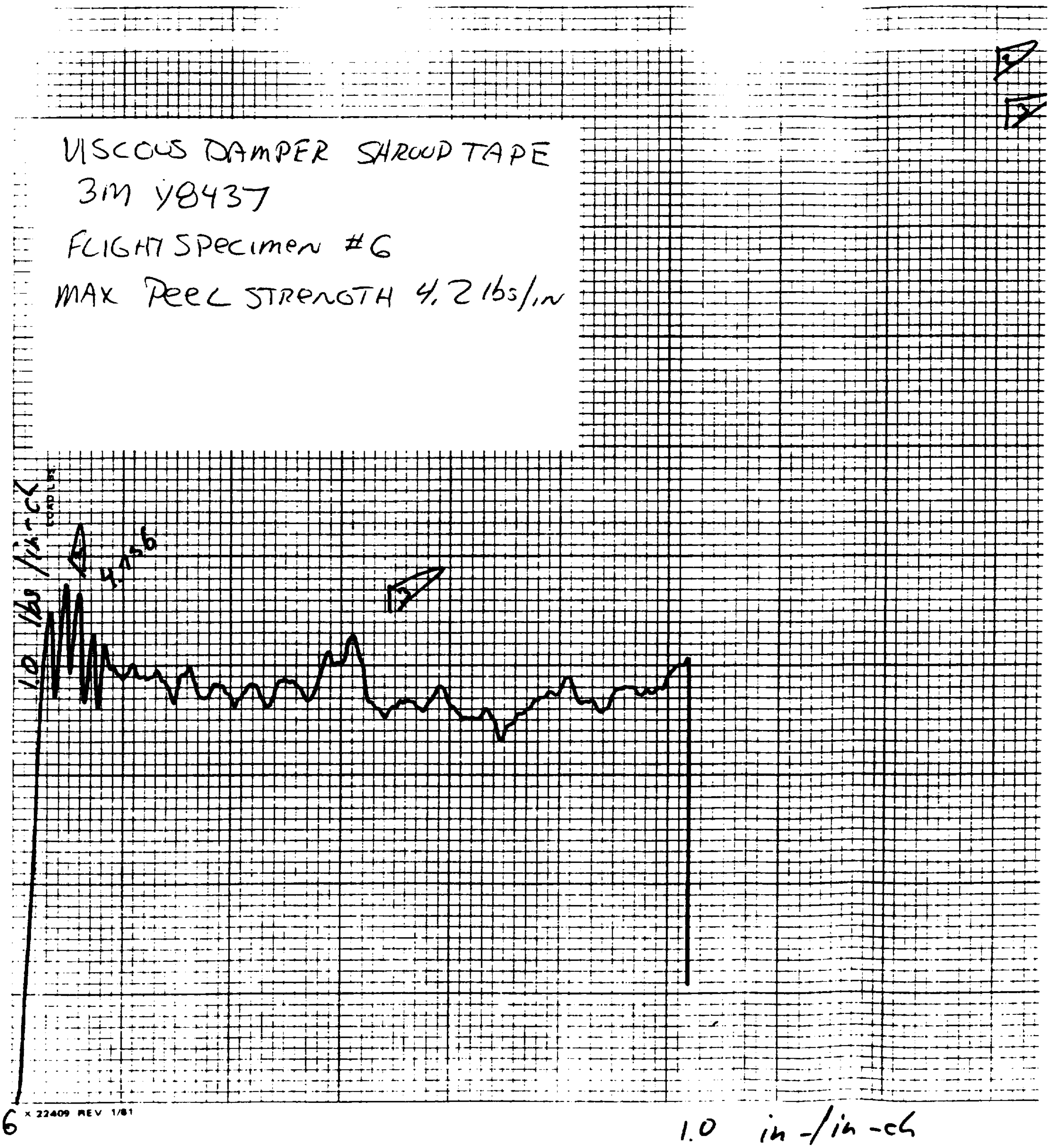
1.0 inch/in-ch

MATERIAL PROPERTY TEST DATA




VISCOUS DAMPER SHROUD TAPE
3M Y8437
FLIGHT SPECIMEN #4 & #5
#4 MAX PEEL STRENGTH 3.4 lbs/in
#5 MAX PEEL STRENGTH 5.3 lbs/in
MATERIAL PROPERTY TEST DATA
1.0 lbs/inch
3.40
5.32
4
5
1.0 inch/inch

MATERIAL PROPERTY TEST DATA



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13. ABSTRACT (Maximum 200 words)

The adhesive and adhesive-like materials flown on LDEF included epoxies and silicones (including lap shear specimens), conformal coatings, potting compounds, and several tapes and transfer films. With the exception of the lap shear specimens, these materials were used in the fabrication and assembly of the experiments such as bonding thermal control surfaces to other hardware and holding individual specimens in place, similar to applications on other spacecraft. Typically, the adhesives were not exposed to solar radiation or atomic oxygen. Only one adhesive system was used in a structural application.

This report documents all results of the Materials and Systems SIG investigation into the effect of long term low Earth orbit (LEO) exposure of these materials. Results of this investigation show that if the material was shielded from exposure to LDEF's external environment, the 69 month exposure to LEO had, in most cases, minimal effect on the material.

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