General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

ROHR CORPORATION, CHULA VISTA, CALIFORNIA

ENGINEERING REPORT
24-1512

FABRICATION AND TEST OF LIGHTWEIGHT HONEYCOMB SANDWICH STRUCTURES

FINAL REPORT

James A. Scholl
Muriel L. Koss
Jack E. Dawson

N69-21050
(ACCESSION NUMBER) 268 (PAGES) (THRU) 1 (CODE) 32 (CATEGORY)
CR 100457 (NASA CR OR TMX OR AD NUMBER)
FACILITY FORM 602

Rohr Contract NAS 7-100
JPL Contract 951612
Issued: 30 January 1969

ROHR CORPORATION, CHULA VISTA, CALIFORNIA

ENGINEERING REPORT
24-1512

FABRICATION AND TEST OF LIGHTWEIGHT HONEYCOMB SANDWICH STRUCTURES

FINAL REPORT

James A. Scholl
Muriel L. Koss
Jack E. Dawson

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Rohr Contract NAS 7-100
JPL Contract 951612
Issued: 30 January 1969

TABLE OF CONTENTS

		Page No.
	LIST OF ABBREVIATIONS	iv
	LIST OF TABLES	v
	LIST OF ILLUSTRATIONS	vi
	SUMMARY	xi
1/	INTRODUCTION	1
2/	PHASE I - REINFORCED PLASTIC HONEYCOMB SANDWICH PANELS	4
	2.1 Initial Selection of Materials and Combinations	4
	2.2 Sandwich Facings	4
	2.3 Honeycomb Core	11
	2.4 Potting Compounds	15
	2.5 Adhesives	19
	2.6 Material and Process Control	20
	2.7 Material Evaluation Procedure	23
	2.8 Material Combination Evaluation	31
	2.9 Test Procedure	60
	2.10 General Results and Conclusions	68
3/	PHASE II - ALUMINUM HONEYCOMB SANDWICH PANELS	108
	3.1 Material Combinations	108
	3.2 Material and Process Control	109
	3.3 Fabrication Procedures and Records	109
	3.4 Initial Fabrication and Problem Areas	112
	3.5 Preliminary Test Program	114
	3.6 Fabrication of 27-Inch by 27-Inch Sandwich Panel	114
	3.7 Test Results and Conclusions	114
4/	PHASE III - SMALL DOUBLY-CURVED AEROSHELLS - REINFORCED PLASTIC	118
	4.1 Material and Process Control	118
	4.2 Fabrication Methods	118
	4.3 Tooling	126
	4.4 Subscale Aeroshells Fabricated	128
	4.5 Ablator Application and Machining	134
5/	PHASE IV - SMALL DOUBLY-CURVED AEROSHELLS - ALUMINUM	137
	5.1 Material Selection	137
	5.2 Tooling	138
	5.3 Forming of Core	138

TABLE OF CONTENTS (Cont)

		Page No.
	5.4 Forming of Aluminum Face Sheets	138
	5.5 Problem Areas	141
6/	PHASE V - 6-1/2-FOOT DIAMETER AEROSHELL	143
	6.1 Detail Design	143
	6.2 Material Used	146
	6.3 Tooling	146
	6.4 Detail Parts Fabrication	149
	6.5 Aft Cone Fabrication	149
	6.6 Major Cone Fabrication	149
	6.7 Final Assembly of the Cones	149
	6.8 Finishing and Maring the Attachment Ring	150
	6.9 Final Assembly and Inspection	153
	6.10 Strain Gage and Thermocouple Application	153
	6.11 Ablator Application and Machining	155
	6.12 Completed Aeroshell and Final Inspection	155
	6.13 Repair Techniques	157
7/	CONCLUSIONS	160
	REFERENCES	164
	GLOSSARY	G-1
	APPENDICES	A-1
	A Standard Fabrication Forms	A-1
	B Rohr Fabrication and Test Procedures	B-1
	C Material Combinations for Flat Honeycomb Sandwhich Fabrication in Phase I	C-1
	D Fabrication Forms for 27-Inch by 27-Inch Panels of Reinforced Plastics Materials	D-1
	E Infrared Spectra of Resin Systems Used to Fabricate 27-Inch by 27-Inch Sandwich Panels	E-1
	F Material Suppliers	F-1

LIST OF ABBREVIATIONS

BDMA	Benzyldimethylamine
BF_3MEA	Boron trifluoride monoethylamine
BzP	Benzoyl peroxide
BONJ	Bond Jig
Curing Agent CL	Shell Chemical's metaphenylene diamine
Curing Agent Z	Shell Chemical's eutectic blend of metaphenylene diamine and methylene dianiline
DCBzP	2,4 - Dichlorobenzoyl peroxide
DDS	Diaminodiphenylsulfone
DEH 50	Dow epoxy hardner 50
HHPA	Hexahydrophthalic anhydride
NMA	Nadic methyl anhydride
O.M.L.	Outside Mold Line
RCR 568	Rohr Casting Resin 568
RCR 576	Rohr Casting Resin 576
RMS	Rohr Material Specification
R.P.S.	Rohr Process Specification
t-BPB	Tertiary butylperbanzoate

LIST OF TABLES

		Page No.
1.	Raw Material Properties of A-Stage Resin Systems	33
2.	Raw Material Properties of B-Stage Resin Systems	34
3.	Working Properties of Resin Systems	35
4.	Raw Material Properties of Core	36
5.	Raw Material Properties of Potting Compounds	36
6.	Raw Material Properties of Adhesives for Fabrication of 27" x 27" Panels	38
7.	Screening Tests - One-Stage Resin Bonded Panels (No Adhesive)	48
8.	Screening Tests - Adhesive Bonded Panels	49
9.	Core Screening Test Data	52
10.	Potting Compound Compatibility Test	53
11.	High-Temperature Resistant Adhesive Screening	61
12.	Principal Properties Test Data of Various Resin Systems	72
13.	Principal Properties Test Data of Nonmetallic Honeycomb Panels	73
14.	Effect of Test Temperature on Principal Properties of Various Resin Systems	76
15.	Effect of Heat Sterilization and Ethylene Oxide Decontamination	77
16.	Effect of Vacuum on the Principal Properties of Composites	78
17.	Core Evaluation	78
18.	Test Data of Spliced Face Sheets and Nonrecessed Doubler	79
19.	Evaluation of Core Splice Techniques	80
20.	Adhesive Bonding Evaluation	115
21.	Effect of Primers Versus No Primer on Lap Shear Strength	116
22.	Aluminum 27" x 27" Test Panel Results	117
23.	Materials Used on 6-1/2-Foot Diameter Aeroshell	147

LIST OF ILLUSTRATIONS

		Page No.
1.	Layout Pattern for Aligned and Staggered Facing Splice . . .	12
2.	Layout Pattern for Inner and Outer Doubler Evaluation. . . .	13
3.	Layout Pattern for Core Overlap and Butt Splices	16
4.	Layout Pattern for Overlap Butt Splices at 20° to Ribbon Direction.	17
5.	Screening Test Specimen Pattern.	24
6.	Layup of Resin Bonded Panel Facing	24
7.	Positioning Honeycomb Core over Resin Bonded Panel Facing. .	25
8.	Application of Upper Facing of Resin Bonded Sandwich Panel .	25
9.	Layout of Four-Ply and Eight-Ply Laminates and Resin Bonded Sandwich Panel, Thermocouples, and Vacuum Probe.	27
10.	Vacuum Bagged Parts for Screening Test Prior to Cure	27
11.	Decision Tools	28
12.	Test Specimen Layout Pattern for 27" x 27" Panels.	30
13.	Eight-Ply Laminate Strength Versus Temperature, Polyesters and Butadine Styrene (170)	39
14.	Flexure Strength for Eight-Ply Laminate Versus Temperature, Epoxies.	41
15.	Flexure Strength for Eight-Ply Laminate Versus Temperature, Epoxy-Novolacs	42
16.	Flexure Strength for Eight-Ply Laminate Versus Temperature, Epoxies.	43
17.	Flexure Strength for Eight-Ply Laminate Versus Temperature, Epoxies.	44
18.	Flexure Strength for Eight-Ply Laminate Versus Temperature, Phenolics.	45
19.	Flexure Strength for Eight-Ply Laminate Versus Temperature, Polyimides	46
20a.	Photomicrograph of Poor Fitting at Top Facing of One-Stage Resin Bonded Sandwich Panel Having DEN 438/NMA/BDMA Facings Showing Flow of Resin Down Core Cell Wall (Mag. 100X). . .	50
20b.	Photomicrograph of Fillet at Bottom Facing-to-Core Junction of One-Stage Resin Bonded Sandwich Panel Having DEN 438/NMA/ BDMA Facings (Mag. 50X).	50

LIST OF ILLUSTRATIONS (Cont)

Page No.

21. Segments of EG-35 Sandwich Panels Prepotted with RCR-576 . 55

22a. Failure of Flatwise Tensile Specimen of EG-35, FM-96U Prepotted RCR-576 and Cured in a One-Stage Operation . . 56

22b. Failure of Flatwise Tensile Specimen DEN 438/NMA/BDMA, FM-96U Sandwich Specimen Prepotted with M-323V and Cured in a One-Stage Operation 56

23a. Photomicrograph of Facing-to-Core Junction Showing HT-424 Paste Adhesive (Mag. 125X) 59

23b. Photomicrograph of Facing-to-Core Junction Showing Epon-901 Adhesive (Mag. 125X) 59

23c. Photomicrograph of Facing-to-Core Junction Showing FM-96U Adhesive Fillet (Mag. 125X). 61

24. Preliminary Adhesive Evaluation. 62

25. Specimen Being Tested for Flatwise Tensile Strength. . . . 64

26. Flatwise Compression Test. 64

27. Tested Specimen Being Removed from Climbing Drum Test Fixture. 65

28. Honeycomb Sandwich Flexure Specimen. 65

29. Failed Laminate Flexure Specimen 67

30. Plate Shear Specimen Ready for Test. 67

31. Edgewise Compression Specimen being Monitored with Compressometers 69

32a. Flat Honeycomb Panel Being Laid Out Into Test Specimens. . 70

32b. Template Being Removed After Lay Out of Flat Honeycomb Panel Specimens. 70

33. Specific Laminate Flexural Strength. 82

34. Flexure Strength For Eight-Ply Laminate Versus Temperature - Glass Finish 83

35. Flexure Strength for Eight-Ply Laminate Versus Temperature - Glass Styles 84

36. Flexural Modulus Versus Temperature ^{o}F. For Eight-Ply Laminates - Epoxy Novolacs 86

37. Flexural Modulus Versus Temperature ^{o}F. For Eight-Ply Laminates - Phenolics. 87

LIST OF ILLUSTRATIONS (Cont)

Page No.

38. Flexural Modulus Versus Temperature °F. For Eight-Ply Laminates - Epoxies 88
39. Flexural Modulus Versus Temperature °F. For Eight-Ply Laminates - Polyesters. 89
40. Flexural Modulus Versus Temperature °F For Eight-Ply Laminates - Polyimides. 90
41. Flexural Modulus Versus Temperature °F. For Eight-Ply Laminates - Fabric Finish 91
42. Flexural Modulus Versus Temperature °F. For Eight-Ply Laminates - Glass Styles. 92
43. Flatwise Tension Versus Temperature 93
44. Flexure Strength Versus Temperature (Parallel to Ribbon Direction). 94
45. Flexure Strength Versus Temperature (Transverse to Ribbon Direction). 95
46. Edgewise Compression Versus Temperature (Parallel to Ribbon Direction). 96
47. Edgewise Compression Versus Temperature (Transverse to Ribbon Direction). 97
48. Flatwise Tension Loading Apparatus Installed in the Vacuum Test Chamber. 100
49. Loading Apparatus Being Calibrated with a Load Cell 100
50. Close Up of Strain Gage Load Cell 101
51. Vacuum Chamber with Bell Jar in Place 101
52. Schematic Valve and Flow Diagram for Type CVE-20. 102
53. Three-Core Splice Techniques using FM-40 Tape, Overlap Core Crush, and FM-96 Adhesive 105
54. Honeycomb Sandwich Thermal Gradient Test. 107
55. Aluminum Honeycomb Panel 27" x 27" x .5". 110
56a. Photomicrograph of Asymmetric Fillet of FM-96U (One Layer) on Aluminum Sandwich Panel (Mag. 50X) 111
56b. Photomicrograph of Fillet of FM-96U (Two Layers) on Aluminum Sandwich Panel. 111
57. Subscale Aeroshell. 119
58. Subscale Aeroshell Facing Lay Up Showing Spliced Ply Segments 121

LIST OF ILLUSTRATIONS (Cont)

Page No.

59. Preforming of Subscale Aeroshell Facing Ply 121
60. Impregnation of Preformed Glass Fabric Facing Plies with A-Stage Resin 122
61. Preforming "Green" Hexcore for a Subscale Aeroshell 124
62. Cured Phenolic Hexcore Segments Spliced with FM-40. 124
63. Prepotting Subscale Aeroshell Core Utilizing Potting Tool . 125
64. Prepotted Honeycomb Core for Subscale Aeroshell 125
65. Inner Section of Subscale Aeroshell, Showing Postpotted Edge and Internal Prepotted Ring. 127
66. Teflon-Coated Aluminum Bond Jig for Subscale Aeroshells . . 127
67. Aeroshell Tooling 129
68. Outer Surface of Subscale Aeroshell, Showing Slight Surface Irregularities and Internal Prepotted Ring. 133
69. Application of Ablator to Aeroshells. 135
70. Modified Dial Indicator Used for Measuring Thickness of Aero-Shell 136
71. Aluminum Forming Dies Used for Forming Inner and Outer Skins 139
72. Forming Tool Used to Fabricate Aluminum Facing for Subscale Aeroshells. 139
73a. Aluminum Honeycomb Core Being Positioned in Plastic Bond Tool. 140
73b. Prepotting of Aluminum Subscale Aeroshell Core, Utilizing a Potting Tool. 140
74a. Formed Aluminum Skin Being Positioned in Plastic Bond Tool. 142
74b. Orange Peel Surface of a Formed Aluminum Aeroshell Skin . . 142
75. Schematic of Aeroshell Design for Mars Probe. 144
76. Beryllium Nose Dome Detail (405 Stainless in Preliminary Model). 145
77. Schematic of Major Tool Assembly. 148
78. Grouping of Detail Parts for 6-1/2-Foot Aeroshell 151
79. Surface of Machined Core of the 6-1/2-Foot Aeroshell. . . . 151
80. Cross Section of Vacuum Bag Lay Up. 152
81. Outer Surface of 6-1/2-Foot Aeroshell with the Stainless Steel Nose Dome in Place. 154

LIST OF ILLUSTRATIONS (Cont)

Page No.

82. Rotating Table. 154

83. Close Up of the 6-1/2-Foot Aeroshell Core, Showing an Area Where the Removed Facing Had Not Bonded to the Core . . . 156

84. Repair of Core with FM-40 Foam Adhesive 156

85a. Damaged Area on the 6-1/2-Foot Aeroshell Where the Outer Facing had Fractured. 158

85b. The Completed Repair of the Fractured Skin of the 6-1/2-Foot Aeroshell 158

86. Face Sheet Repair Technique 159

SUMMARY

Glass reinforced plastics have gained increasing acceptance as engineering materials in the aerospace industry, but their full use has been severely restricted by the lack of design data for lightweight honeycomb sandwich structures. The purpose of this program is to evaluate various combinations of metallic and nonmetallic materials in constructing lightweight bonded honeycomb structures. This includes both the determination of mechanical and physical properties of minimum and other gage material combinations and the establishment of optimum fabrication techniques.

Honeycomb sandwich test panels were fabricated from a potential list of eighty different reinforced plastic material combinations. These included material and configuration variations in the face sheets, honeycomb core, and core-to-face sheet adhesive. Facings of phenolic, epoxy, polyimide, and polyester resin systems were evaluated using various numbers of plies of several styles of fiberglass cloth laid up at different orientations. Face sheet splice and repair methods were also investigated. Hexagonal, flexcore, and dovetail honeycomb core with various cell sizes, densities, and thicknesses were used with a standard face sheet to determine comparative results. Core splice techniques were also evaluated. A comparison was made of resin bonded panels and those utilizing epoxy, epoxy-phenolic, and polyimide adhesives which varied in thickness and form.

The materials were first screened for handling characteristics and critical mechanical properties. Those which showed promise were used to fabricate sandwich panels which were tested for significant mechanical properties. The material combinations showing the most promise were further tested for -150°F. and +350°F. temperature properties, for flatwise tensile strength with one face sheet held for a short time at 600°F. for compatibility with ethylene oxide and dry heat sterilization, and for vacuum stability and strength effects.

Honeycomb sandwich test panels were also fabricated from various lightweight combinations of 5052, 5056, and 2024 aluminum alloys.

Small doubly-curved aeroshell models were fabricated from the best reinforced plastic material combinations. An attempt was also made to fabricate these models using aluminum materials.

A lightweight 6-1/2-foot-diameter honeycomb sandwich aeroshell structure with an elastomeric ablator, which was fabricated as part of a separate extension of this program, is also briefly described. This sphere-cone structure was made primarily from phenolic fiberglass for ease of fabrication and radio frequency transparency, but titanium rings were used as stiffeners at the outer edge. Some conclusions can be derived from this fabrication and test experience summarized above.

1. For this lightweight sandwich construction, the thinnest gage unsupported film adhesive available produced a bond between the face sheet and core as good as or better than thicker unsupported film, any supported films, or paste adhesives. Polyimide and epoxy-phenolic adhesives provided superior elevated temperature (600°F.) strength compared to the lightweight epoxy adhesive evaluated.

2. Selected epoxy, phenolic, and polyimide prepregs exhibited satisfactory mechanical properties, temperature resistance, and processing characteristics for fabrication of aeroshell facings. In the sandwich

configurations evaluated, the face sheet resin contributed only slightly to differences in the composite flexural strength at room temperature. All styles of the glass fabric tested, except 108, provided the same stress characteristics on multi-ply face sheets. Laminates utilizing fabric with Volan "A" finish produced significantly higher mechanical properties than the A1100 Silane or S-935 finishes when using a phenolic resin system.

3. Phenolic and polyimide hexagonal core exhibited the highest strength-to-weight ratios of the various types of plastic core evaluated. Hexagonal shaped core of fiberglass reinforced phenolic formed adequately to doubly-curved surfaces in the partially cured condition.

4. Low density potting compounds which were evaluated for prepotting and postpotting applications were successfully utilized for reinforcing and core edge filling of subscale and 6-1/2-foot diameter aeroshells.

5. Reinforced plastic honeycomb sandwich configurations are lighter in weight, easier to fabricate, and more reproducibly reliable than minimum gage aluminum honeycomb sandwich of similar design.

There is no obvious reason that this same technology cannot be used equally well for 20-foot diameter or larger aeroshells. The techniques are especially adaptable to a large selection of attachment joints, local reinforcements, rings, compound curvatures, etc., with minimum compatibility problems.

The following page tabulates the various configuration combinations in the advanced development program.

Configuration Variations in Advanced Development Program
(From JPL Technical Report 32-1325)

Structural item	Configuration Variations	
	Fiberglass sandwich	Metallic sandwich
Facesheet	Resin: phenolic, epoxy, epoxy novolac, polyester, polyimide Glass type: E-glass, S-glass Glass weave: style 108, 112, 116, 120, and 181 Glass finish: Volan A. A-1100, S-935 Number of plies: 2, 4, 6, 12 Rotation of plies: 45 and 60 deg Ply overlap: aligned, staggered Doubler discontinuities: aligned, staggered	Material: 2024-T4, 5056, 5052 Thickness: 5, 10, and 15 mils
Core	Resin: phenolic, polyimide, nomex Cell shape: hexagonal, flex-core, dovetail Cell size: 3/16 and 1/4 in. Cell density: 3.5, 4.0, and 4.5/ft^3 Thickness: 1/2, 3/4 in. Core splice: film, foam, and 1-in.-crush overlap	Material: 2024-T4, 5056, 5052 Cell shape: hexagonal Cell size: 3/8 and 1/4 in. Cell density: 3.4 and 4.2 lb/ft^3 Thickness: 1/2 in.
Adhesive	Resin: epoxy, epoxy phenolic, polyimide Thickness: 4 to 12 mils Support and unsupported	Resin: epoxy Thickness: 4, 8, and 12 mils Supported and unsupported

1/ INTRODUCTION

The ability of the United States to maintain and extend its position of leadership in aerospace accomplishment depends in a large measure on the ability to design and fabricate strong lightweight aeroshells that will meet the exacting requirements of projected missions at an acceptable cost.

A Mars entry probe, for example, requires new developments in lightweight structures to maximize the science payload delivered to the planet surface without compromising mission reliability. Because of the tenuous Martian atmosphere, a very low vehicle weight per unit area is required, and consideration of the minimum gage in each of the potential shell construction alternates becomes critical.

Preliminary structural configuration studies at Jet Propulsion Laboratory have shown that, except for certain exotic composite materials, honeycomb sandwich configurations appear to show the widest applicability to a variety of potential missions. Monocoque structures and other common alternates appear to be comparatively heavy, and in some cases, less adaptable to such specific mission requirements as atmospheric sampling and radiofrequency transparency.

Because of such requirements, aerospace companies active in the design of future space vehicles have become increasingly interested in the design

possibilities of adhesive bonding and reinforced plastics. They predict that composites will be used in ever increasing amounts and in more critical and demanding areas. However, the lack of reliable test data, proven processes, and fabrication techniques have placed the greatest restraint on more widespread use of adhesive bonding and reinforced plastics for programs being developed at the present time.

The purpose of this program is to establish criteria and develop fabrication techniques that will permit the optimum use of the most promising materials for aeroshell structures.

This program evaluates various combinations of metallic and nonmetallic materials for construction of lightweight bonded honeycomb sandwich structures. It includes both the determination of mechanical and physical properties of the material combinations and the establishment of optimum fabrication techniques. Eighty different reinforced plastic material combinations were considered and honeycomb sandwich test panels were fabricated from 48 of them, as well as from various lightweight combinations of three aluminum alloys, which were used to make a direct comparison of principal properties and weight trade-off to reinforced plastics.

The combinations included material and configuration variations in the face sheets, honeycomb core, and core-to-face sheet adhesive. Minimum and other gage material combinations were included to give the results the widest possible application consistent with the scope of the program.

The program was accomplished in five principal sequential phases:

Phase I was designed to evaluate and test various reinforced plastic materials and adhesives for fabrication techniques for use in honeycomb sandwich panels. A screening procedure was established to eliminate materials which were difficult to process or which were inferior in critical mechanical properties. Initial screening consisted of flexure testing a one-stage laminate of the facing material to determine facing

strength retention at elevated temperatures. Two-stage laminates were tested for flatwise tensile strength. Materials which passed the screening tests were used to fabricate 27-inch-square sandwich panels from which principal mechanical properties were determined.

Phase II was designed to provide appropriate flat aluminum honeycomb sandwich panels for comparison with reinforced plastic panels. A special test program was set up for the aluminum panels, and 27-inch by 27-inch panels of six different material combinations were fabricated.

Phase III involved the construction of small doubly-curved aeroshell models from the best reinforced plastic material combinations selected from Phase I.

Phase IV outlined the procedures taken to fabricate small doubly-curved aeroshell models from the best of the aluminum material combinations chosen from Phase II.

Phase V consisted of applying the data and fabrication technology colligated from the preceding phases to construct a full-sized aeroshell of reinforced plastic honeycomb sandwich structure to meet the requirements of an early Mars mission. This phase resulted in the development of design data which was used in analyzing various structural configurations and design concepts for a large variety of missions under study by Jet Propulsion Laboratory.

2/ PHASE I - REINFORCED PLASTIC HONEYCOMB SANDWICH PANELS

2.1 INITIAL SELECTION OF MATERIALS AND COMBINATIONS

The first phase of the program consisted in selecting materials to be used in various combinations for the fabrication of flat 27-inch by 27-inch honeycomb sandwich panels suitable for further testing in later phases of the program. Initial screening examined properties of materials that could be considered for use as facings, honeycomb core, potting compounds, and adhesives. Material and process controls were established to assure the validity of comparative tests and procedures were set up to verify that raw materials met specifications for pertinent properties. Firally, evaluations were made of the compatibility of material combinations and test procedures were set up to determine the relevant characteristics with the summation of the test results and the conclusions reached.

2.2 SANDWICH FACINGS

Reinforced plastics were selected as the prime candidate materials for evaluation because of the high strength-to-weight ratios attainable and because of the relative ease of fabricating complex configurations.

The temperature range of applications was a determining factor in the selection of materials to be utilized in the reinforced facings. Initially, use temperatures of less than 180^{o}F. maximum under stress were anticipated for the vehicle facings with a possible brief (less than 20 second)

exposure to 600°F. after the period of maximum stress application. The facings also had to resist sterilization temperatures up to 275°F. in dry nitrogen and decontaminate environment of ethylene-oxide/Freon 12 at 122°F.

Chemical resistance to sterilization gases, low vapor absorption, and negligible outgassing under low pressure environments were additional criteria for suitable facings after cure. Radiofrequency transparency was a desirable characteristic.

Pressure application was a limiting feature in the type of cure. Because of the large size of the aeroshell structure originally considered (19-feet diameter), and the unavailability of sufficiently large autoclaves, autoclave curing was not used. The expense of matched metal tools for preliminary fabrication was prohibitive. Although augmented pressure curing was considered, just vacuum pressure curing was selected because the fabrication of projected aeroshells would require larger autoclaves than are available. However, vacuum curing places a limitation on the type of resin system which can be utilized.

Wet lay up or A-stage resins and vacuum grade prepregs were suitable for this type of cure. In general, this pressure limitation requires an initially higher resin content and flow for the laminate than is needed for high-pressure cures. It also prevents the ready attainment of laminates or facings with as little porosity as high-pressure cures permit for resin systems which emit volatiles on curing.

Although A-stage resin systems were evaluated, the use of a prepreg or B-stage instead of a wet lay up or A-stage for the facings was considered to be advantageous on the basis of ease of handling, reproducibility, and reliability of the product. The control of resin content and flow can be established prior to use of a prepreg. Resin content may vary considerably throughout a part (especially one with contours and different thicknesses) when a wet lay up procedure is used. If the system has a relatively short pot life, the viscosity will be changing as impregnation occurs. Also, for a large structure, numerous batches of resin would be required, each

of which should be checked to assure good quality control. Because of the initially high flow during cure of a liquid resin system which has not been B-staged, the use of such a facing system placed directly over honeycomb core can produce inhomogeneity between upper and lower facings.

A wet lay up may offer an advantage over B-staged prepregs in formability, or drape, for complex curvatures and may circumvent the problem of controlled tack requirements for prepregs.

2.2.1 RESINS -- Design values for strength requirements at the operating temperatures were not available initially. However, typical epoxy, phenolic, and polyester resins were considered to offer adequate strength at the exposure temperatures indicated and to exhibit suitable processing characteristics.

Epoxy resins have the advantage of ease of handling, essentially no volatiles, low shrinkage, and excellent adhesion to the glass reinforcement. Although common low-temperature-curing epoxy resin systems have not been noted for strength at elevated temperatures, epoxy systems are available which have excellent strength at temperatures above 350°F.

The phenolic resins are noted for their good temperature resistance, but they are less preferable for low pressure curing when a nonporous structure is desired because they release volatiles upon curing.

Polyester resins, in general, have lower elevated temperature strength than either the phenolics or epoxies. They have a higher shrinkage during cure and somewhat poorer adhesion to glass fabrics. The cure of many polyesters is inhibited by moisture and other impurities. Radiofrequency transparency of polyesters is somewhat superior to that of the epoxy and phenolic resins.

A typical low-dielectric-loss resin, a styrene-butadiene copolymer, was also examined. This type of resin is very sensitive to traces of moisture or other polar impurities for its properties. Its dissipation factor is significantly lower than that of the other resins considered, even when all are impregnated on glass fabric. Styrene-butadiene copolymers have generally poor elevated temperature strength.

Polyimides were evaluated for the event that the 600°F. use temperature should become an important factor in material selection. Polyimides have good mechanical properties and thermal resistance at these higher temperatures. However, very high postcure temperatures are required to obtain good elevated temperature strength. Other problems in using these resins are caused by their moisture sensitivity and generally brittle nature. Also, excessive volatiles are released during cure, particularly on thick laminates. Prepregs of these materials are inclined to have relatively poor tack and drape.

The polysulfones reportedly have good thermal stability, so were considered as possible candidates for evaluation because they are available for use in fabrication.

2.2.2 FABRIC REINFORCEMENT -- Glass fabric reinforcement of the resin systems used for honeycomb sandwich facings was utilized because of the outstanding strength-to-weight ratio attainable. Glass fiber reinforcement also provides high tensile strength, good modulus of elasticity and resilience, and dimensional stability. The use of high modulus graphite reinforcement was also considered for evaluation, but its availability in woven form is limited and its cost is extremely high compared to glass fabric.

2.2.2.1 Glass Formulations -- Fabrics woven from E-glass are standard in the industry for electrical and common mechanical applications. Fabrics woven from E-glass meet military specifications of MIL-F-9084A and MIL-P-8013B. E-glass fabrics were utilized as the standard reinforcement for the

facings. S-glass is a special high-strength fiber for structural applications. It was considered as a possible alternate for evaluation. Also, the low dielectric D-glass was considered. Its evaluation was not advantageous to the program, since E-glass proved to be sufficient for radiofrequency transparency requirements.

2.2.2.2 Weave -- Plain, eight-harness-satin, and crowfoot-satin weaves were evaluated in facings. The plain weave consists of yarns interlaced in an alternating fashion over and under every other yarn. The plain weave provides maximum fabric stability and firmness, and minimum yarn slippage. The thinnest and lightest weight fabrics are achieved by the use of this weave. Since similar strengths can be obtained in warp and fill directions, nearly isotropic properties can be obtained in a laminate by suitable orientation of successive plies of fabric.

The eight-harness-satin weave construction has a warp yarn over seven and under one fill yarn. It is very pliable and is useful for conforming to complex contoured configurations. The satin weave requires more threads per inch to retain stability, so is usually used in heavier fabrics. The crowfoot-satin weave consists of one warp yarn woven over three and under one fill yarn. Fabrics utilizing this weave also conform easily to contoured surfaces.

The different weights and strengths of fabric with a particular weave are achieved by the use of various types of yarns woven at various spacings. Some glass fabrics are woven from single yarns. Literature reveals that any stress in the yarn which could cause processing difficulties is balanced by twisting the filaments and then combining or plying the threads. Greater strength, smoothness, and uniformity should be obtained by twisting and plying the strands. The single yarn, prepared without twisting, eliminates certain crimp and shear factors in the fabric. Fabrics comprised of single strands were evaluated for comparison with correspondingly heavier plied material.

Fabrics woven from the same yarn, but with a different thread count, were also compared. Using yarns having the greatest number of filaments and a finer filament diameter usually increases the fatigue strength of laminates.

2.2.2.3 Finish -- In order to increase compatibility between the fabric and the resin binder and improve properties such as strength, moisture, resistance, or drapeability, various chemical finishes are applied to glass fabrics. Several finishes were evaluated to ascertain the structural effect. Certain finishes were evaluated for use with particular resins because of their limited compatibility.

Volan A is a chrome finish. It is the most widely used treatment for laminating with phenolic, epoxy, and polyester resins. Laminates made with Volan A treated glass cloth will meet the requirements of MIL-P-8013C and MIL-C-9084B. This finish was selected as the standard for preliminary panel fabrication.

A-1100 is an amino silane type finish. It is suitable for use with high-temperature phenolics, silane modified phenolics, epoxies, and polyimides. Laminates using fabrics having an A-1100 finish meet the requirements of Federal specifications MIL-R-9299 and MIL-R-9300A. A-1100 soft provides fabrics with greater drapeability and softer hand than does A-1100.

S-935 is a silane finish which is suitable for use with phenolic resins and high-temperature resistant epoxy resins. Its primary advantages are high mechanical properties, long term wet strength retention, and excellent wet-out and drapeability.

2.2.3 LAY UP CONFIGURATIONS --

2.2.3.1 Ply Orientation -- Because the fabricated aeroshell is axially symmetric, it was desired to obtain isotropic properties in the facings. Design calculations indicated that the most nearly isotropic properties

could be obtained in a four-ply laminate which was constructed of a plain weave fabric by orienting each successive ply with the warp at 45 degrees to the previous one. Therefore, this ply orientation was utilized for most of the standard sandwich panel facings.

During lay up of the aeroshell facings which have compound curvatures, initial orientation of the fabric plies at one radial position from the axis will not necessarily result in the same alignment at other positions around the axis. The necessity for splicing the facing fabric because of the size and forming limitations of the fabric also can result in deviations in the warp orientation. Preforming the fabric to contour by stretching also distorts the weave of the fabric. The effect on the strength of the facings of ply orientation angles other than 45 degrees was consequently of interest.

2.2.3.2 Number of Plies -- The specific strength of the various facing materials and the strength per ply were parameters for determining the material selection and the number of plies required for the aeroshell facing. The number of plies can influence the desired ply orientation.

Since the number of fabric plies can affect the strength per ply as a consequence of processing factors, the effect of ply number on facing strength was evaluated. In addition to the standard facing thickness of four plies which was used for the sandwich panels, six and twelve plies were of particular interest because these thicknesses were utilized for the 6-1/2-foot diameter aeroshell (see Figure 81 and Section 6). Directional effects could be ascertained by the use of two-ply and six-ply facings.

2.2.3.3 Joining -- Since the aeroshell structures could not be completely fabricated of continuous multiple plies of fabric, it was necessary to establish parameters for joining two pieces of fabric which constituted the same fabric ply. Also, where reinforcement was needed in some regions of the facing, an optimum method of including doublers was desired.

In splicing facing plies, the initial procedure was to overlap the junction one-half to one-inch and stagger the overlap region so that overlaps in successive plies did not coincide. Because of the use of fairly large numbers of plies and both circumferential and radial splices in aeroshell structures, it was difficult to avoid coincidence of overlap areas within the facings. Since the overlap regions were often visible, a minimal one-fourth inch wide overlap which was closely controlled in overlap tolerance was desired by Jet Propulsion Laboratory. The integrity of this narrow splice was evaluated by checking sandwich facing flexure strength and edgewise compressive strength (Figure 1). The effectiveness of a staggered overlap compared to one in which the overlap region in successive plies was aligned to reduce possible stress concentration in facings was similarly evaluated.

The reinforcing effect of doublers and the fabrication procedure were checked by testing in flexure sandwich specimens which contained three-inch wide doublers. Successive doubler plies were staggered so that each succeeding ply was one-eighth inch narrower than the preceding ply (Figure 2). Extra layers of adhesive were used to fill in stepped regions of inner doublers at the doubler-to-core junction.

2.3 HONEYCOMB CORE

2.3.1 MATERIALS -- Glass fabric reinforced honeycomb core which contains a phenolic resin impregnant was selected as the standard core for fabricating sandwich panels. This core is suitable for fairly high-temperature applications, is available in low densities (four lbs. per cubic foot or less), and has a strength-to-weight ratio comparable to that of common (5052) aluminum core.

For environmental conditions involving the exposure to higher temperatures (for example, 600°F.), core which utilizes a polyimide resin has a greater potential. Honeycomb core which has a high-temperature nylon-paper reinforcement is tougher and more resilient. Therefore, core constructed of these materials was evaluated.

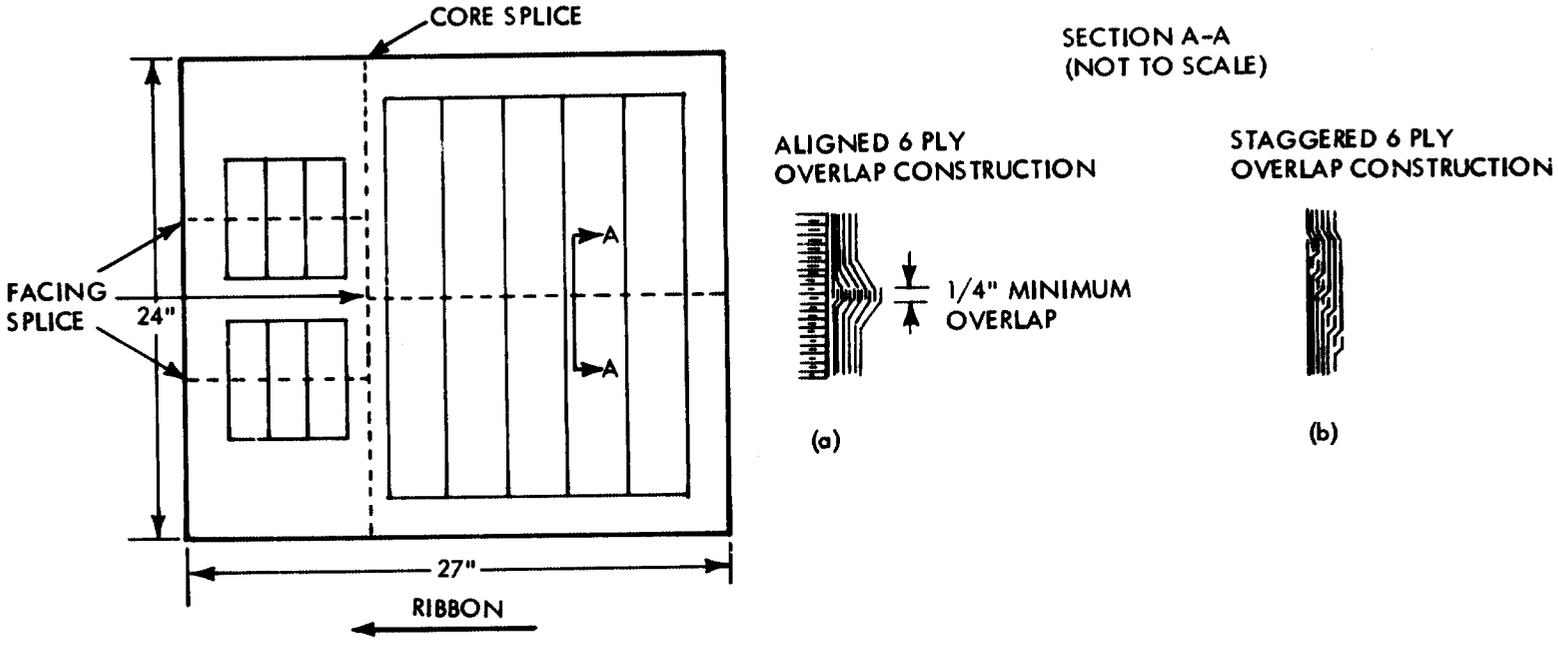


Figure 1. Layout Pattern for Aligned and Staggered Facing Splice.

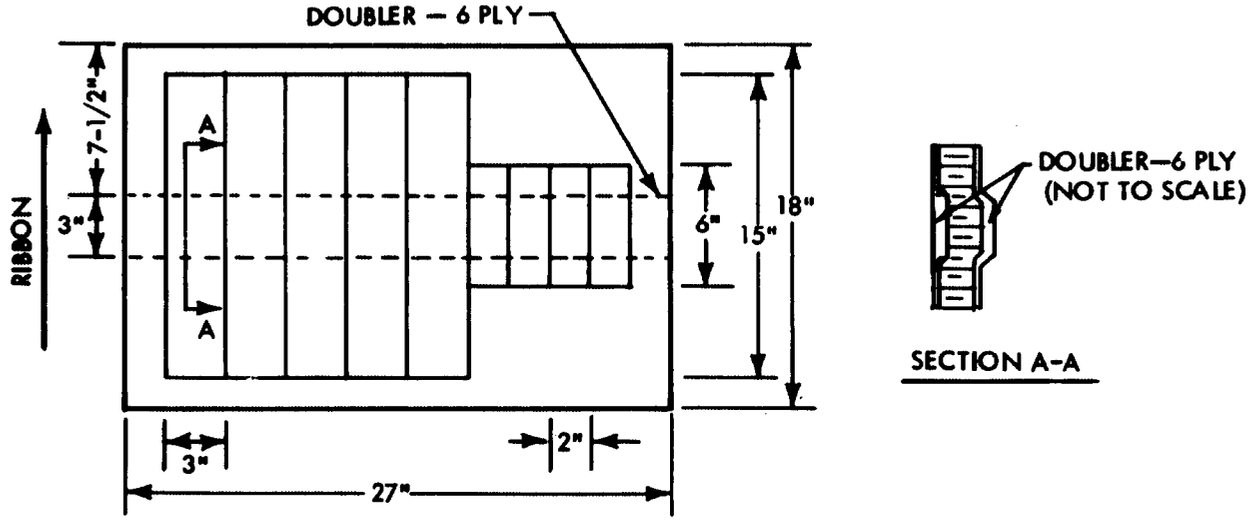


Figure 2. Layout Pattern for Inner and Outer Doubler Evaluation.

2.3.2 DIMENSIONS -- Core strength and density are influenced by the core cell size. Hexagonal core of high-temperature phenolic is available in three-sixteenth, one-fourth, and three-eights cell size, with corresponding decreases in density and strength. This core in the density range of 3.2 lbs. per cubic foot to 4.0 lbs. per cubic foot was considered for evaluation to obtain a minimum weight with adequate structural properties.

Although metal honeycomb strength and density is also influenced by foil thickness, the plastic core is not designated in this manner. The change in density is effected by changing core reinforcement or number of resin dips, although an optimum resin content range prevails for the highest strength-to-weight ratio. A low-temperature curing adhesive is applied to the node bond areas of ribbon fabricated from a prepreg material. Then the prepreg material is stacked with the adhesive node bonds aligned and high pressure is applied at low temperature. Then the block is expanded, dipped in resin, and dried two times prior to postpotting.

The honeycomb sandwich density and rigidity are influenced by the thickness of the core utilized. Although the standard core thickness employed for the panel fabrication was 0.75-inch, 0.5-inch and 1.0-inch thick core were also evaluated.

2.3.3 CORE CONFIGURATIONS -- The normal honeycomb core cell configuration is hexagonal. This was utilized as a standard for fabrication of flat panels and subscale aeroshells. Because of some of the processing problems involved in forming the hexagonal core to the complex curvatures of the aeroshell, other cores which offered a potential for greater ease of fabrication were investigated. Two such core types which form readily in two dimensions are flexcore and dovetail core. Without adequate forming techniques, hexagonal shaped core has an anaclastic effect in a direction transverse to the direction being formed.

2.3.4 JOINING -- Since the large aeroshell structures could not be fabricated from a single continuous piece of honeycomb core, methods of joining the core sections were required. Three methods of core splicing have been investigated:

1. Bonding a butt joint with an adhesive which expands upon curing.
2. Stabilizing with a resin a splice formed by forcing overlapped core segments together.
3. Bonding a butt joint with a standard adhesive film.

The first two gave comparable joint strength and were evaluated in depth. The strength of the splices was determined by testing beam flexure specimens having the splice in the region of maximum shear (Figure 3). The splices were made both parallel and perpendicular to the core ribbon direction. The relative weights of the spliced regions and their appearance were also factors for comparison.

Because the radial joining of core segments in the aeroshell structure resulted in core splices at an angle of approximately 20 degrees to the ribbon direction, additional tests were made to evaluate this condition. Core splices at an angle of 20 degrees to the ribbon direction, consisting of: core sections butted together and bonded with FM-40 adhesive, and core sections with a one to two cell forced overlap were tested in flexure (Figure 4).

2.4 POTTING COMPOUNDS

Low density potting compounds were utilized as a means of reinforcing the honeycomb sandwich struccures. Core was reinforced in regions where fasteners were to be installed in the aeroshell; and hollow, angular edge members and void regions between core fittings were filled in order to maintain structural integrity.

2.4.1 PREPOTTING -- It was desired to incorporate the potting compound into the sandwich structure prior to bonding the second facing, so that no

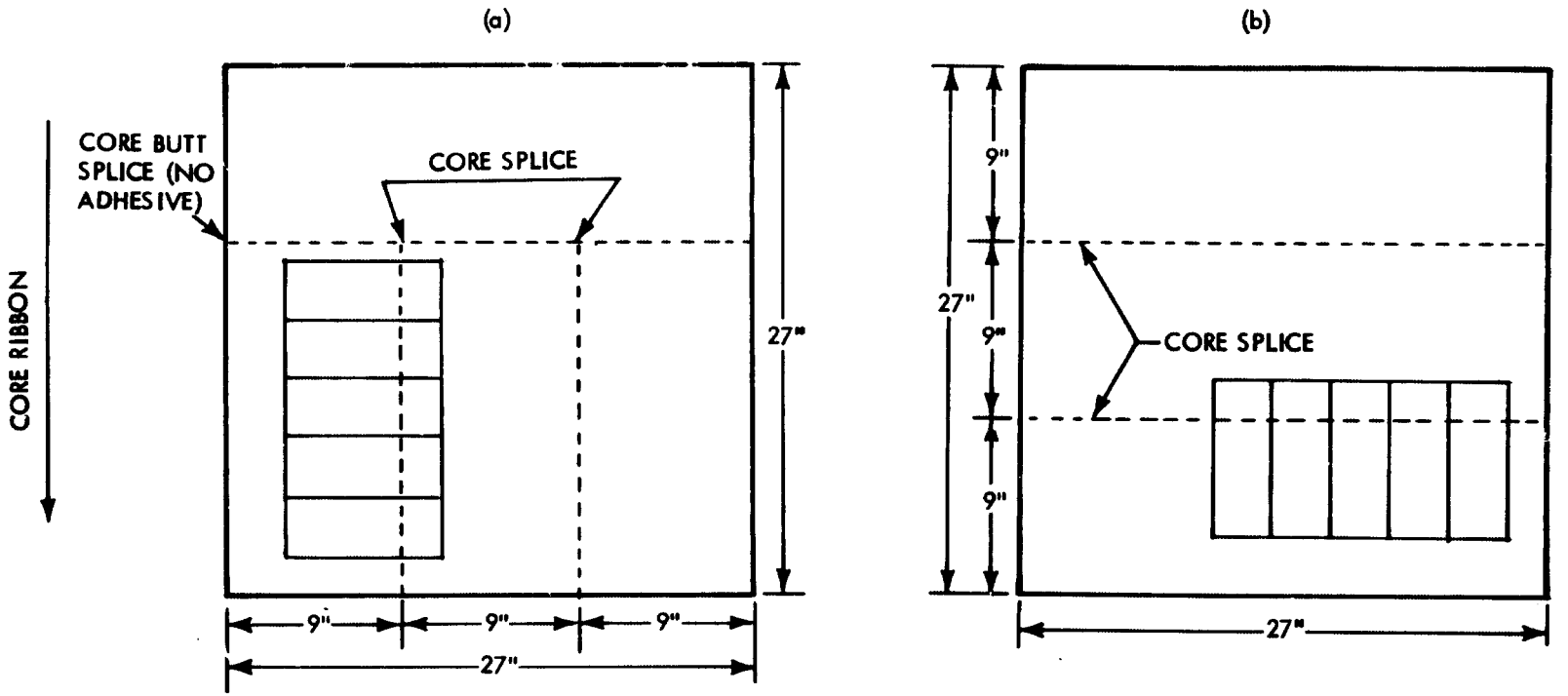


Figure 3. Layout Pattern for Core Overlap and Butt Splices.

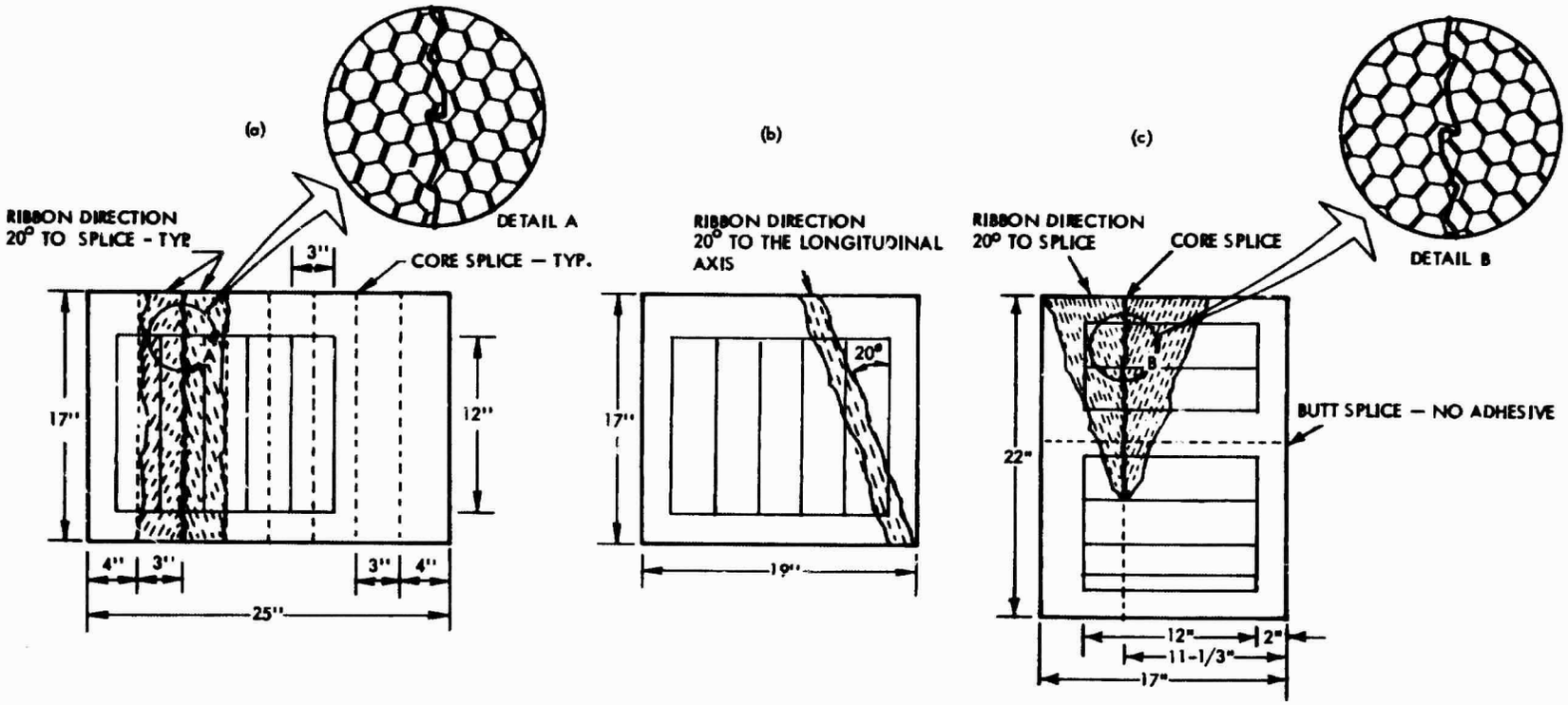


Figure 4. Layout Pattern for Overlap Butt Splices at 20° to Ribbon Direction

perforations would be present in the facings. Therefore, a compound which had a sufficiently long gel time, or which would flow at the cure temperature of the adhesive and/or facing, was needed so that irregularities from the compound would not appear in the surface and mismatched regions would be filled evenly. The compound should cure within the cure schedule of the adhesive or facing. It was also necessary for the compound to have nonslumping characteristics so it could be placed at any position in the contoured aeroshell without flowing and subsequently depleting the region to be filled.

The lowest density consistent with adequate strength was an obvious criterion for a lightweight structure. Two Rohr-developed compounds, syntactic epoxies (RCR-568 and RCR-576), which were suitable for use in prepotting aluminum honeycomb sandwich structures, were selected for evaluation with the plastic core and facings. Because the very high viscosity of the RCR-576 caused some extrusion difficulties, M-323V, a modification with slightly lower viscosity was also used for fabricating aeroshells.

Since the adhesive and/or facing resin are cured simultaneously with the potting compound, compatibility of these materials had to be ascertained. Therefore, sandwich panel samples comprising typical A-stage and B-stage resins and the adhesive selected for fabrication of subscale aeroshells were potted and the assemblies cured. After cure, the samples were examined for physical evidence of incompatibility. Potted flatwise tensile specimens were also evaluated to determine the effect on strength.

Since the prepotting compound has previously been evaluated only with rigid facings, its suitability for use with uncured prepreg or A-stage facings was also of concern because of the possibility of insufficient restraint of the compound during cure.

2.4.2 POSTPOTTING -- For filling the periphery of the core in the subscale aeroshells (reference Section 4.2.4), a low-density compound

which had high thixotropy was required. Since the routing of the aeroshell to size was one of the last operation in its manufacture, a compound which could cure at ambient temperature and thus obviate the need for an additional elevated temperature cycle was preferred. A standard, low-density (0.83 specific gravity), commercial potting compound (Epocast H-1843, Type IV, Grade B), was selected for this operation.

2.5 ADHESIVES

2.5.1 REQUIREMENTS -- In order to bond the facings to the core, an adhesive system was required which would withstand the environmental exposure of the assembly. Similar thermal conditions to those required for the facings, considering a possible insulating contribu tion from the facing, and similar chemical resistance, as described in paragraph 2.1 were involved.

A single adhesive which could bond well to both aluminum and plastic facings and core was preferable for structural comparisons between the two types of sandwich structures. In the event that one-stage facing and adhesives cures were to be utilized with the plastic facings, compatibility between the pertinent facing resins and the adhesive was required. In addition, an adhesive which could cure during the cure cycle of the facing was preferred. The adhesive also had to flow and cure properly under vacuum pressure.

2.5.2 ADHESIVE TYPES -- High-temperature (350°F.) resistant epoxy and epoxy-phenolic adhesives were prime candidates for evaluation. These types have exhibited good strength and processing characteristics in bonded aluminum honeycomb sandwich structures. Polyimide adhesives were considered for use in the event that the 600°F. use temperature became a deciding factor in the adhesive selection.

Since weight was an important factor in material selection, the lowest weight film providing good filleting and bonding was desired. In general,

film adhesives are supported with a lightweight fabric which assists in fabrication, processing, and/or providing improved properties, such as control flow and release of volatiles, particularly for metal to metal bonding. However, because of the added weight, unsupported films or those with the lightest weight fabric were major candidates.

An alternate method of achieving low weight bonds was the use of a paste adhesive which could be applied to the core only in the areas to be bonded, and thus eliminate the portion not contributing to structural function.

In the event that a suitable controlled-flow prepreg system was available, the resin could serve as both facing matrix and adhesive. The extra process of adhesive application could be eliminated and perhaps the total weight of this structure reduced. Therefore, controlled-flow prepregs were of interest as possible adhesive substitutes.

2.6 MATERIAL AND PROCESS CONTROL

In order to assure that comparative tests were not reflecting material variability but represented the parameter being investigated, material reproducibility between batches and between fabricated specimens was necessary. Also, reproducibility was required so that values obtained for material used in test specimens would be representative of properties of corresponding aeroshell structures. Therefore, controls for incoming raw materials and processing controls for fabrication variables were established.

2.6.1 ACCEPTANCE CRITERIA -- Infrared spectra were prepared for each resin and curing agent as a standard for an indication of purity and structural identity between batches and upon extended storage of a single batch. Other pertinent properties of resins and curing agents such as reactive content, specific gravity, viscosity, refractive index, and melting or freezing point with limits, were specified as acceptance criteria.

In addition to specifying reinforcement type and finish for prepregs, resin conformance to appropriate military specifications was required. To provide consistent prepreg properties, resin content, resin flow, and volatile content, values and limits were specified. These values were selected to provide a laminate (facing) which, when cured under vacuum pressure, had a suitable resin content and adequate mechanical properties.

Although controlled resin content, flow, and volatiles provide fairly reproducible properties between different lots of prepreg, the handling characteristics were frequently different because of variations in tack.

Suitable measurements by the vendors for initial tack and/or control for materials which changed in tack upon aging appeared to be lacking. Therefore, handling tack was checked after receipt of the prepreg. Insufficient or excessive tack occasionally resulted in rework of the prepreg by the vendor if it was initially unsuitable, or in eventual material rejection if it could not be altered.

Adhesives were accepted on the basis of minimum strength at ambient and elevated temperatures. Controlled specific film weight was also required of film adhesives because consistency of film thickness is important to assure uniform quality of bond.

Honeycomb core was purchased to pass requirements of MIL-C-8073A, where applicable. Minimum bare compressive strength values were utilized for acceptance tests.

2.6.2 PROCESS CONTROLS -- In order to provide consistency of properties within a given fabricated structure or series of panels, raw material from the same lot was used for a complete series wherever possible. The entire series of panels fabricated from a given material combination for use in comparative tests was cured simultaneously to reduce variability in cure cycles. Standard fabrication procedures and cure schedules, including heat rise rate, pressure, and time-at-temperature, were prepared for each

material. These were utilized to assure reproducible conditions when a single variable in a material combination was changed, so that processing variables would not be reflected when comparing data.

An additional process control utilized was the inclusion of a standard eight-ply laminate composed of the facing material which was cured simultaneously with each series of sandwich panels or aeroshell components. This laminate was tested in flexure at 300°F. and compared with initial values obtained for similar laminates of the same reinforced plastic during material qualification testing.

Originally, a Barcol hardness test was considered for use as a measure of the degree of cure of the facing materials. The facings from cured sandwich panels were stripped and the hardness determined. In order to do this, the adhesive had to be removed, for example, by sanding. Some dimpling of the facings, especially of the outer facing, occurred during fabrication which caused irregularities in the surface. When this surface was sanded smooth, alternately glass- or resin-rich areas were exposed. Barcol hardness readings over the surfaces were quite inconsistent.

In order to circumvent the problem incurred by the dimpling of the facings, separate process control laminates could have been fabricated and cured simultaneously with the sandwich panels. However, because of the need for fabricating relatively thin laminates to simulate the facings, it would have been necessary to stack a number of the thin laminates to obtain a hardness value unaffected by the backing material. Also, the value obtained from stacking is not definite but only indicative of the hardness.

Therefore, flexure strength at elevated temperature was selected as a criterion of process control. For a particular resin system, the degree of cure is reflected in the "hot" flexure strength. Resin content, while influencing room temperature strength, has less effect on elevated temperature strength.

A check of the adhesive bonding was obtained by comparing flatwise tensile strength of specimens from the 27-inch-square honeycomb sandwich specimens with flatwise tensile strength values obtained for the screening tests of each material. Controls for the bonded aeroshell structures consisted of tensile shear or flatwise tensile specimens, as appropriate. Adherends were processed the same as the corresponding structure, and the control specimens accompanied the structure during cure.

2.7 MATERIAL EVALUATION PROCEDURE

2.7.1 MATERIAL ACCEPTANCE -- Raw materials which were to be utilized for fabrication of 27-inch-square honeycomb sandwich test panels were required to satisfy specified acceptance criteria, as indicated in paragraph 2.6.1. Vendor certification to pertinent properties, with spot-checking by Rohr Quality Assurance as considered appropriate, constituted the principal procedure.

Infrared spectra were also prepared for each lot of each resin component, resin system, and adhesive. Infrared spectra of different lots of a material were compared to ascertain any differences in structure or purity.

2.7.2 SCREENING -- Prior to the fabrication of the 27-inch-square honeycomb sandwich panels which would be tested for various mechanical properties, the materials to be evaluated were subjected to a preliminary screening operation. The screening tests were designed to eliminate materials which had unsuitable handling characteristics or noticeably inferior critical mechanical properties. The screening tests also permitted the proving of fabrication and process techniques for each material.

The standard complement of screening tests involved four types of test panels: eight-ply and four-ply laminates, and resin and adhesive bonded sandwich panels as indicated in Figure 5. All of the panels were laid up and cured at the same time. The fabrication sequence for the resin-bonded sandwich panel is shown in Figures 6 through 8. A typical layout of the

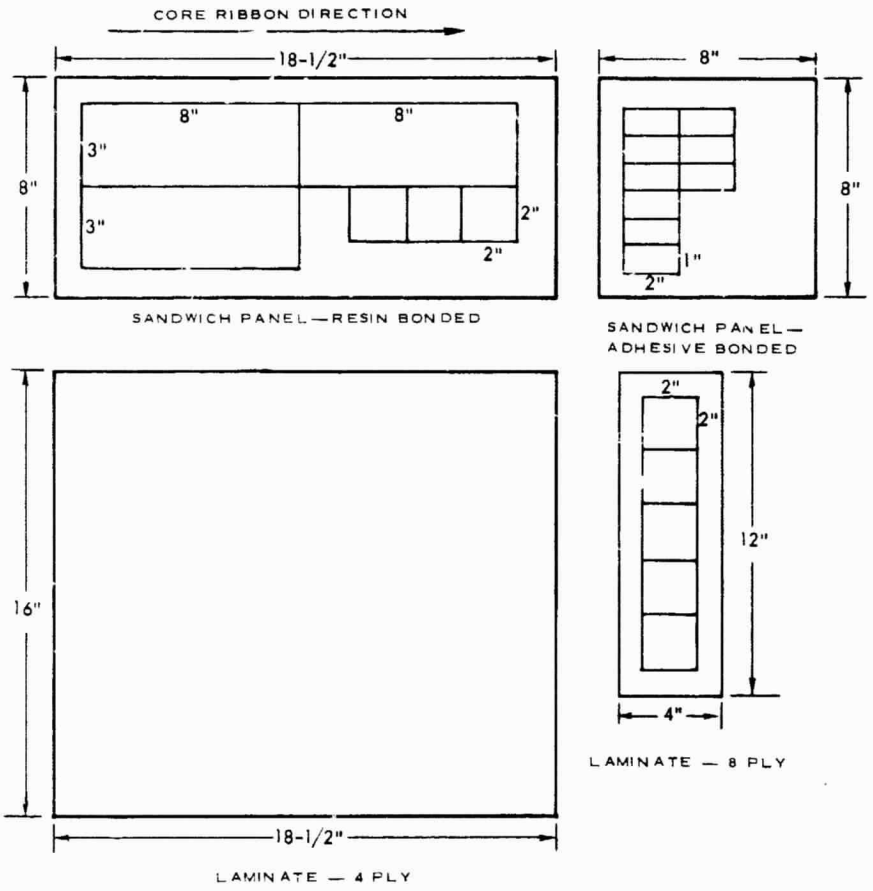


Figure 5. Screening Test Specimen Layout Pattern.

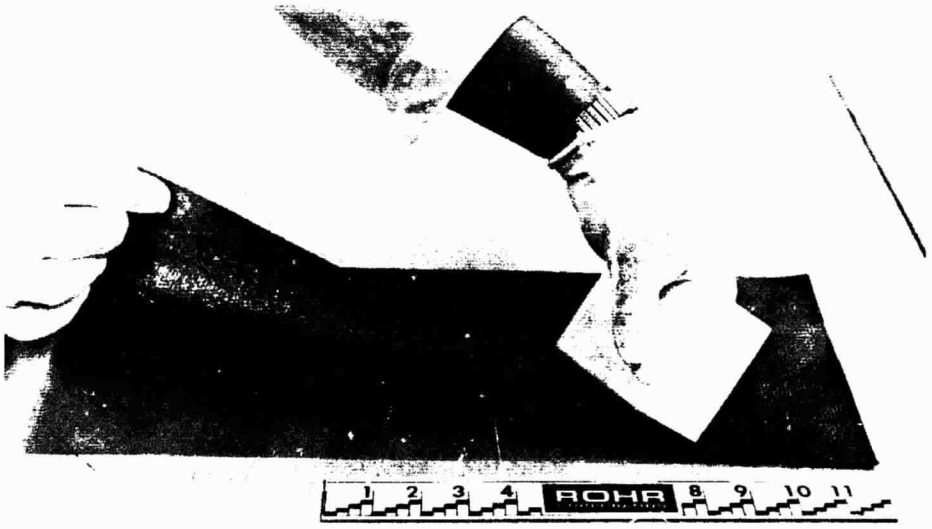


Figure 6. Lay Up of Resin Bonded Panel Facing.

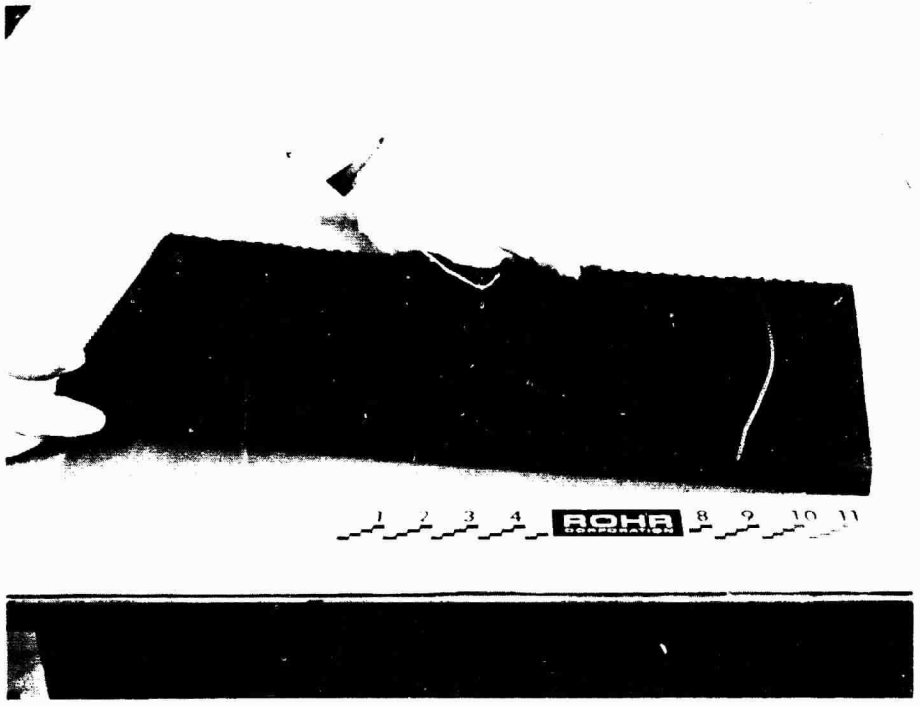


Figure 7. Positioning Honeycomb Core Over Resin Bonded Panel Facing.

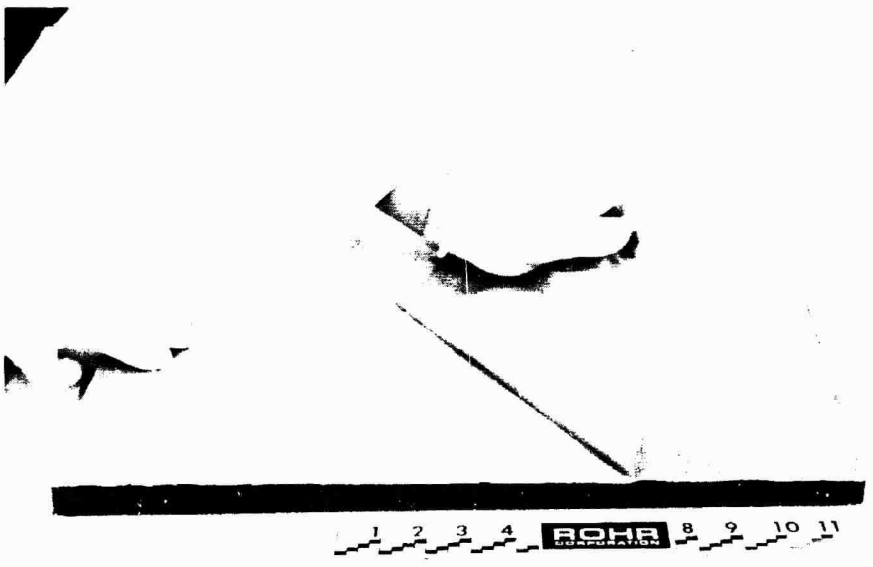


Figure 8. Application of Upper Facing of Resin Bonded Sandwich Panel.

laminates and a sandwich panel on the caul plate (Figure 9) and the bagged parts (Figure 10) are depicted.

Initial screening consisted of flexure testing of the eight-ply laminate of the facing material at room temperature and 300°F. This test was selected to ascertain facing strength retention at elevated temperatures. which is one of the primary environmental requirements. Criteria for continuting testing at 250°F. or 350°F., or elimination of the material from further consideration are included in Figure 11. If 300°F. strength was greater than 50 percent of the room temperature strength, the resin system was considered to be satifactory for further evaluation. If less than 50 percent of the room temperature strength was retained at 300°F., testing was conducted at 250°F. Inadequate strength at 250°F. was a basis for discontinuing further evaluation of the resin system.

In order to determine the capability of a given resin system for serving as both a facing material and bonding agent to the honeycomb core, the facing material was cured in place adjacent to the core. Its bond strength was ascertained on the basis of flexure and flatwise tensile strength. If the test results were poor for the resin-bonded panels, the adhesive bonded flatwise tensile specimens were tested.

A one-stage fabrication procedure, in which the facing and adhesive were cured simultaneously in the assembly, was considered to be desirable for efficiency. A two-stage operation was often preferable for control of quality of the assembly, however. In the event that satisfactory bonding with the resin alone was not achieved, the one-stage adhesive bonded flatwise tension specimens were tested. These specimens were fabricated in the same manner as the resin-bonded specimens, except that a layer of the standard adhesive selected from the adhesive evaluation procedure was included adjacent to the core. If there was evidence of incompatibility between adhesive and resin system as a consequence of the latter test, the 16-inch by 18-1/2-inch laminate was used to fabricate two-stage adhesive bonded specimens (Figure 11). These were tested for

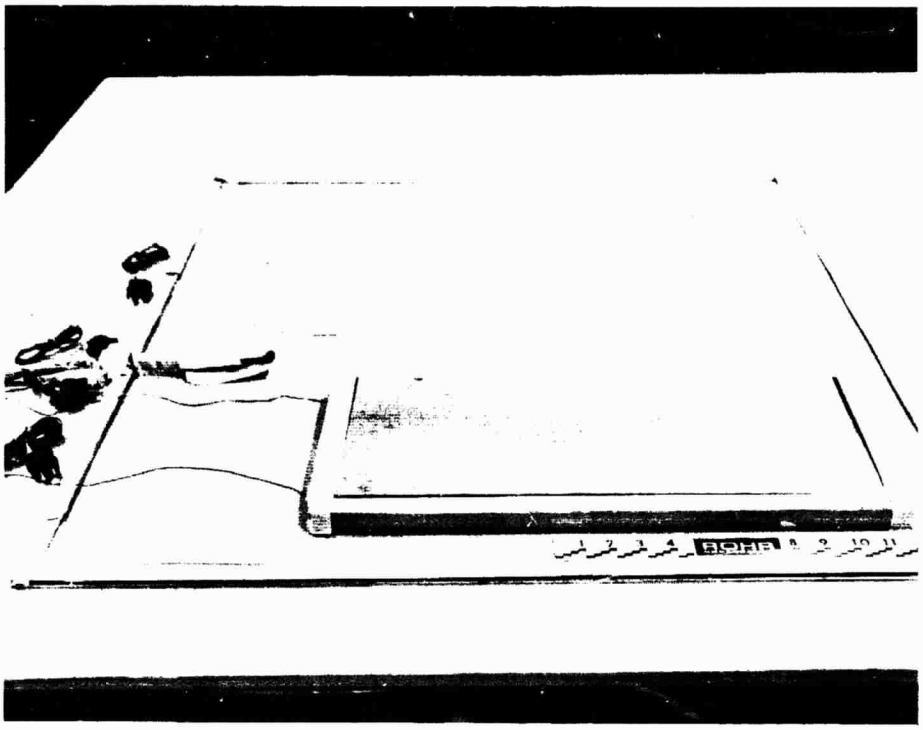


Figure 9. Layout of Four-ply and Eight-ply Laminates and Resin-bonded sandwich Panel on Cowl Plate, Showing Fairing Blocks Around Sandwich Panel, Thermocouples, and Vacuum Probe.

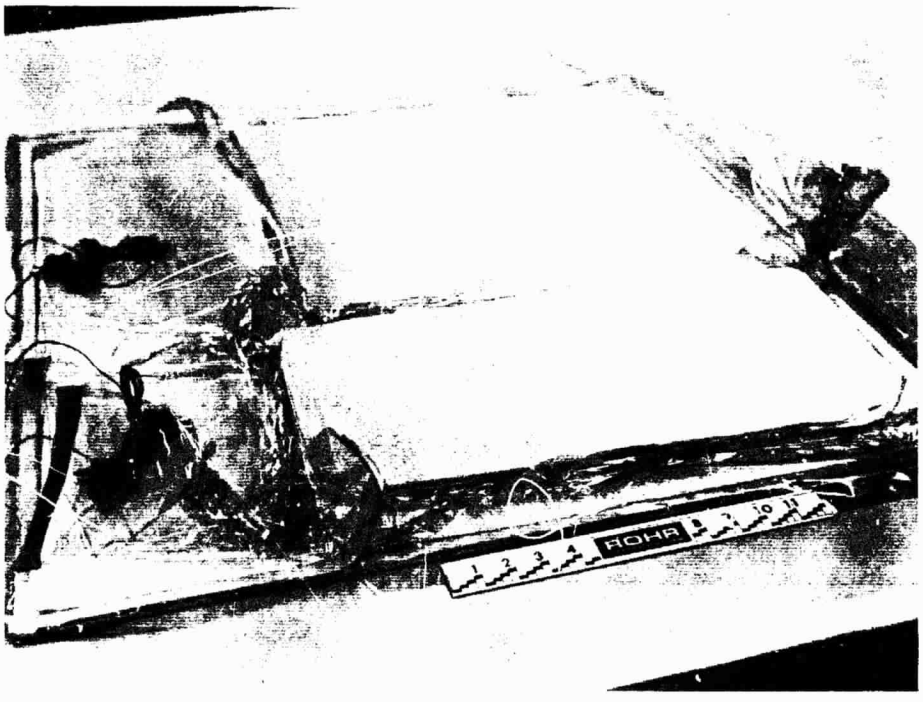
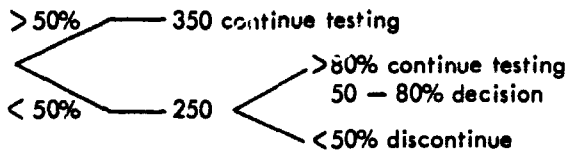


Figure 10. Vacuum-bagged Parts for Screening Test Prior to Cure.

1. Acceptance of materials.
   (a) Material within stated specification

2. 8-ply laminates.
   (a) RT — 300



3. Sample sandwich panel (no adhesive).
   (a) Acceptable flatwise tension
   (b) Acceptable flexure strength

4. Sample sandwich panel (one-stage adhesive bonded).
   (a) Same as 3a

5. Same as 4 (two-stage adhesive bonded).

6. Large (27 x 27) flat sandwich panels.
   (a) Visual approval
   (b) Acceptable initial test series
      (1) Flatwise tension
      (2) Beam flexure, parallel to ribbon
   (c) Acceptable final test series
      (1) Beam flexure, perpendicular to ribbon
      (2) Flatwise compression
      (3) Peel
      (4) Edgewise compression, parallel to ribbon
      (5) Edgewise compression, perpendicular to ribbon
   (d) Failure in flexure below minimum core shear allowable
      (1) Flatwise shear, parallel to ribbon
      (2) Flatwise shear, perpendicular to ribbon

Figure 11. Decision Tools.

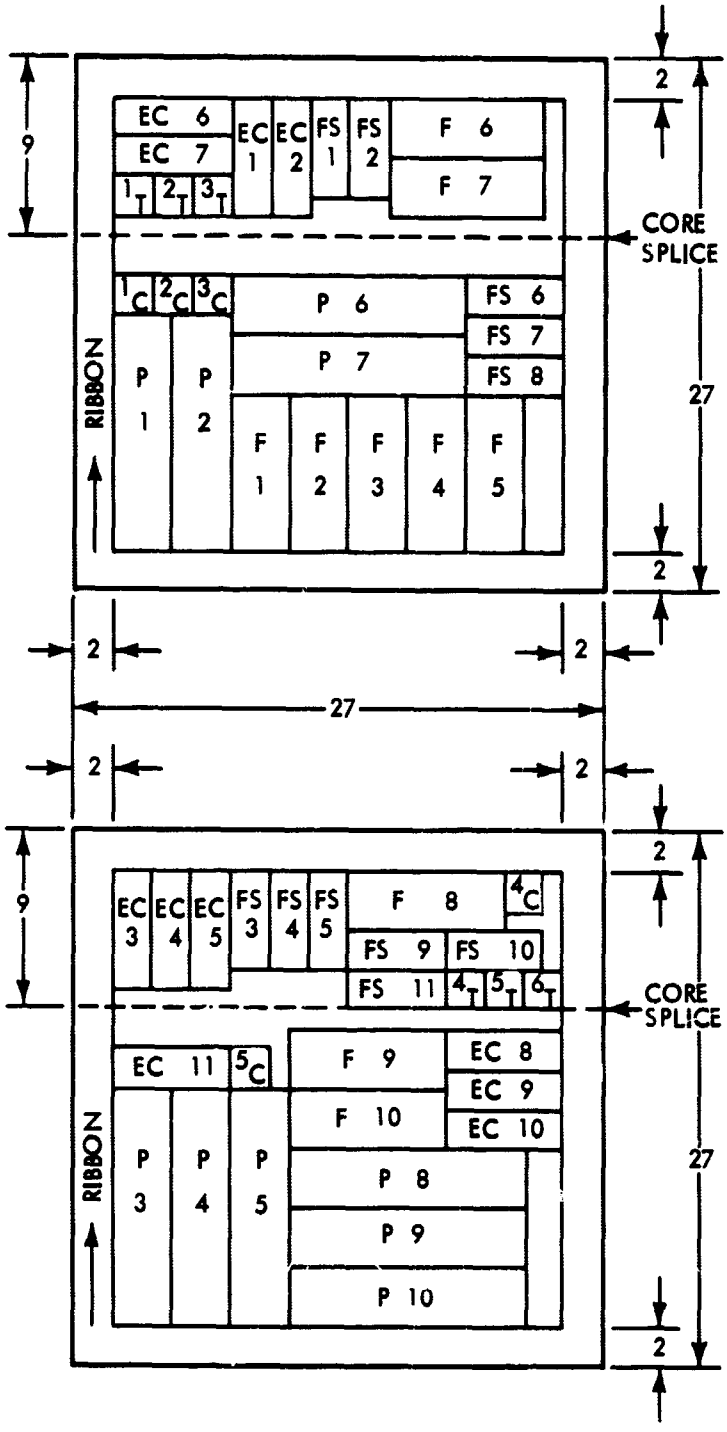
flatwise tensile strength. If the material provided a selected minimum flatwise tensile strength, it remained a candidate material for use in the fabrication of 27-inch-square sandwich panels; otherwise it was eliminated from further consideration.

2.7.3 SANDWICH PANEL FABRICATION AND TEST -- Material combinations which were considered to have promise for use in honeycomb sandwich structures on the basis of handling characteristics and screening test results were further evaluated for mechanical properties which could be utilized for design data. In order to accomplish this, 27-inch-square sandwich panels were fabricated from the various combinations of facing materials, adhesive and core. Test specimens were machined from the sandwich panels according to the layout shown in Figure 12. The two-inch band around the outer periphery was discarded to preclude edge effects. Order of testing and criteria for complete testing of the entire series are indicated in Figure 11.

Material combinations which had suitable processing characteristics and good mechanical properties, as determined from these tests, were selected as candidates for subscale aeroshell fabrication.

Additional tests were performed from selected material combinations to evaluate special fabrication techniques pertinent to the construction of aeroshell structures. Environmental effects such as resistance to ethylene oxide and heat sterilization, high vacuum stability, and strength upon exposure to -150°F. and +350°F. and brief exposure to 600°F. were also determined.

2.7.4 MATERIAL AND PROCESS RECORDS AND PROCEDURES -- In order to provide closely controlled procedures with a minimum of duplication of effort and maintain accurate records, standard forms and fabrication and test procedures were established.



1. FOR PHASE 1, FABRICATE 6 PANELS 27" X 27".
2. TEST SPECIMEN LAYOUT PATTERN SHOWN REPRESENTS 1/3 OF TOTAL REQUIREMENT.
3. LEGEND:
   - P — PEEL: 3" X 12"
   - F — FLEXURE: 3" X 8"
   - FS — FLAT SHEAR: 2" X 5"
   - EC — EDGEWISE COMPRESSION: 2" X 6"
   - T — FLATWISE TENSION: 2" X 2"
   - C — FLAT COMPRESSION: 2" X 2"

Figure 12. Test Specimen Layout Pattern for 27" x 27" Panels.

Six standard forms were prepared, including quality control information, facing fabrication, resin bonded panel fabrication, adhesive bonded panel fabrication, resin mixing details, and test data. Typical forms are illustrated in the Appendix (A) to indicate the type of information included in each.

Where procedures used for property determinations were selected from standard military, ASTM, or Rohr specifications, these are indicated on the appropriate form (Appendix A). Fabrication procedures or property determinations, for which standards were not previously written, were prepared and assigned PS- (Process Specification) numbers. These procedures, which were used for fabrication of the various screening panels and the 27-inch-square sandwich panels, are also indicated by number on the fabrication forms. Copies of the actual procedures, PS-1 through PS-25, are included in Appendix B.

Where departures from the standard procedures were made, these were indicated on the fabrication forms. Problem areas and characteristics of the materials were also noted on these forms.

Cure time, temperature, pressure, and heat rise rate to be used were included on the fabricatic forms. Supporting data to assure conformance to the requested cure conditions were included in the form of cure charts which reflected thermocouple temperature versus time and the vacuum attained.

2.8 MATERIAL COMBINATION EVALUATION

The complete series of 80 material combinations evaluated and their corresponding designations are included in Appendix C. From this list of material combinations, thirty-one combinations were eliminated prior to fabrication of 27-inch-square honeycomb panels. Forty-eight combinations have been evaluated to determine mechanical property design data and select optimum material combinations. The evaluation of "S" glass was scheduled for a later date, due to delay in receiving material.

This evaluation is included in an addendum to this report. Fabrication procedures and cure schedules used for each of the resin systems utilized in preparation of 27-inch-square panels are included in Appendix D.

Details of the material properties, screening results, and mechanical property evaluations are described below.

2.8.1 MATERIAL CHARACTERISTICS --

2.8.1.1 Resins -- The resin systems investigated are listed in Tables 1 and 2, which include typical physical properties of the raw materials for A-stage and B-stage systems, respectively. Reactive content, specific gravity, viscosity, refractive index, and freezing point, where applicable, are indicated for the A-stage systems. Resin content, flow, and volatiles are specified for the prepregs. Properties such as gel time, working life or open time, shelf life, and handling characteristics are included in Table 3. Infrared spectra of the fifteen different resin systems utilized in the fabrication of 27-inch-square honeycomb sandwich panels are included in Appendix E.

2.8.1.2 Honeycomb Core -- Typical compressive strength, shear strength, and density of the five types of honeycomb core evaluated are included in Table 4.

The Honeycomb Products, Inc. HTP - three-sixteenth inch - 4.0 lbs./cubic foot core and Hexcel HRP - three-sixteenth inch - 4.0 lbs./cubic foot core are the same type of core, but are obtained from different manufacturers. Compressive strength of the HTP - three-sixteenth - 4.0 core was generally higher for the same density than the HRP - three-sixteenth - 4.0 core.

2.8.1.3 Potting Compounds -- Typical compressive strength and density of the RCR-568 and RCR-576 potting compounds, which were evaluated for prepotting the plastic sandwich structures, are included in Table 5. The compound RCR-576 satisfies the requirements of Rohr Material Specification

Table 1. Raw Material Properties of A-Stage Resin Systems

Resin or Curing Agent (Mfg. Code)*	Reactive Content**	Spec. Gravity**	Viscosity**, cps	Refr. Index**	M.P.** °C.
A. Epoxy					
Resins					
Epon 815	184 epoxide equiv.	-	600 @ 25°C.	-	-
Epon 826	181 epoxide equiv.	-	9,100 @ 25°C.	-	-
Epon 828	180-195 epoxide equiv.	-	10,000-16,000	-	-
Epon 1031	200-220 epoxide equiv.	-	-	-	-
DEN 431	172-179 epoxide equiv.	-	1,400-2,000 @ 52°C.	-	-
DEN 438	175-182 epoxide equiv.	-	30,000-90,000 @ 125°F.	-	-
Curing Agents					
BF_3MEA***	59% BF_3	-	-	-	95 min.
BDMA***	10.32% ter. nit.	.901 (20°/20°C.)	-	1.4996	-
Curing Agent CL***	Purity 99.97%	-	-	-	62.1
Curing Agent Z***	18 wt % amine nit.	-	3,300 @ 25°C.	-	-
DDS***	>98% (dry basis)	-	-	-	170-180
DEH 50***	-	-	-	-	-
HHPA***		-	-	-	-
NMA***	-	1.205 (20°/20°C.)	180	1.5035	-
B. Polyester					
Resins					
Vibrin 135	-	-	-	-	-
Vibrin 136	-	-	-		-
Curing Agents					
Benzoin	-	-	-	-	-
BZP***	-	-	-	-	-
DCBzP***	-	-	-	-	-
t-BPB***	-	-	-	-	-
C. Polysulfone					
Narmco Polysulfone	-	-	-	-	-
D. Butadiene Styrene					
Eccomold L70	-	-	-	-	-

* See Appendix F. for list of manufacturers of various materials.
** Vendor certified values.

Table 2. Raw Material Properties of B-Stage Resin Systems

Prepreg (Mfg. Code)*	Resin Content,**%	Flow,**%	Volatiles,**%
A. Phenolic			
91 LD	45.0 solids	39.4 15 psi @ 325°F.	14.2 5 min. @ 325°F.
Adlock 851	41.4	24.3 15 psi @ 325°F.	6.5 5 min. @ 325°F.
Adlock 453 PHG (Plyophen 5900)	45 + 3 solids	25.0	7.1
Conolon 506	37.0 solids	13.0	7.0
F502 (SC-1008)	50.1 solids	34.3	9.3
F509 (SC-1013)	55.0	41.2	7.2
B. Epoxy			
Adlock EG-35	55.5 pick up	26.2 15 psi @ 325°F.	.6 5 min. @ 325°F.
Adlock EG 9300	45.0	21.2 @ 325°F.	1.0 @ 325°F.
Adlock EG4B	59.5	41.7 @ 325°F.	1.7 @ 325°F.
BP 908	55.0	-	-
E-740B	50.8 solids	25.6	5.1
E-787	42.2	23.0	7.2
E-792	49.9 solids	26.2	5.3
Narmco 500	38.8	9.2	.7
Narmco 588	37.0 solids	9.0	4.0
C. Polyimide			
Dupont 2501	51.2 dry resin	-	19.0
F170 Imide	54.5 dry	30.0 15 psi @ 450°F.	8.9
Narmco 1832	46.5	28.9	10.5
D. Polyester			
Adlock PG-HTA	46.2	2.7	6.5 @ 275°F.

* See Appendix F for list of manufacturers.
** Vendor certified values.

Table 3. Working Properties of Resin Systems

Resin System	Approx. Gel Time*, Min.	Approx. Working Life at R.T.	Shelf Life**	Handling Characteristics
A-Stage				
DEN 431/DER 50	6 @ 260°F. >90 @ 130°F.	6 hrs.	-	Difficult to handle. Must be heated to approx. 200°F. to dissolve curing agent in resin.
DEN 438	50 @ 200°F.	24 hrs.	-	Preheating to 130°F. needed to simplify impregnation of fabric.
Epon 815/CL	-	6 hrs.	-	Requires heating to dissolve curing agent.
Epon 185/Z	-	6 hrs.	-	Impregnates fabric readily.
Epon 826 HHPA/BDMA	-	24 hrs.	-	Curing agent must be heated to dissolve in resin.
Epon 828/1031 MNA/BDMA	-	1-2 days	4 mo. @ 0°F.	Resins need to be heated together before blending curing agents.
Epon 1031 DDS/BF_3MEA	-	1 week	-	Unsuitable for 100% solids A-Stage system.
Eccomold L70	-	-	-	Impregnates fabric very readily.
Vibrin 136 t-BPB/Benzoin	-	-	-	Resin requires prolonged degassing prior to use.
Vibrin 136 t-BPB/DCBzP	-	-	-	Resin requires prolonged degassing prior to use. Problem in dissolving catalyst.
Vibrin 135/BzP	-	-	-	Good handling characteristics.
B-Stage				
Adlock EG-35	19 @ 250°F.	3 months	9 mo. @ 40°F.	Good handling characteristics.
BP 908	2.5 @ 350°F.	>8 hrs.	6 mo. @ 40°F.	Good handling characteristics. Somewhat tacky.
E-740 B	5.7 @ 320°F	1-2 weeks	4 mo. @ 40°F.	Good handling characteristics.
E-787	-	8 hrs.	3 mo. @ 0°F.	Fairly good handling characteristics.
E-792	5.5 @ 320°F.	1-2 days	4 mo. @ 0°F.	Good handling characteristics.
Adlock EG-4B	>60 @ 200°F.	2 months	2 mo. @ 40°F.	Good handling characteristics.
Adlock EG-9300	4 @ 325°F.	6 weeks	3 mo. @ 40°F.	Good handling characteristics.
Narmco 500	-	72 hrs.	-	Good handling characteristics.
Narmco 588	-	3 months	3 mo.	Initially too tacky. Poor tack after rework.
Adlock 453 PHG	-	-	9 mo. @ 40°F.	Initially tack. Good handling characteristics after rework.
Adlock 851	3 @ 300°F.	3 months	9 mo. @ 40°F.	Good handling characteristics.
Conolon 506	47.5 @ 200°F.	2 weeks	6 mo. @ 40°F.	Good handling characteristics.
91LD	3 @ 300°F. (112) 5 @ 300°F. (116)	3 months	9 mo. @ 40°F.	91LD/116 was wrinkled and had excessive tack, so was difficult to handle.
F 502 (SC-1008)	4 @ 310°F.	1 month	6-12 mo. @ 40°F.	Good handling characteristics.
F 509 (SC-1013)	-	-	-	Good handling characteristics.
F 170 Imide	11 @ 280°F.	>10 hrs.	3 mo. @ 40°F.	Prepreg dry. No drape.
Narmco 1832	-	-	-	Good handling characteristics.
PT 2501	11.5 @ 280°F.	>10 hrs.	-	Prepreg dry. No drape.
Adlock PG-HTA	2.8 @ 300°F.	6 months	12 mo. @ 40°F.	Good handling characteristics.

* Determined according to PS-3 or PS-8, as applicable (see Appendix B. for PS procedures).
** Vendor data.

Table 4. Raw Material Properties of Core

Core*	Bare Compressive Strength**, psi	Shear Strength**, psi	Density** lb./ft.^{3}
		L W	
HRH-10	334	226/141	3.88
HRP-3/16-4.0	362***	-	4.0***
HTP-3/16-4.0	549	-	4.0
HTP-1/4-3.5	512	-	3.6
Flexcore SF50-40	330***	-	4.2***
Dovetail	903	-	5.95

* See Appendix F for list of material suppliers.

** Vendor certified values.

*** Determined by Rohr Q.A. in accordance with MIL-C-7438D.

Table 5. Raw Material Properties of Potting Compounds

Compound	Ultimate Compressive Strength*, psi			Specific Gravity
	R.T.	180°F.	300°F.	350°F.
M323V	6,700	--	4,400	0.67
RCR-568**	9,000	8,000	--	0.80
RCR-576**	6,000	--	3,500	0.56
Epocast H-1843*** Type IV, Grade A	7,300	--	2,250	0.80

* Representative values for specimens 0.5 in. by 0.5 in. by 1.0 in. tested per Fed. Test Method Std. No. 406, Method 1021.

** Compound was cured for 1 hr. at 350°F.

*** Compound was cured for 3 hours at room temperature + 0.5 hour at 170°F. + 1 hour at 250°F.

(RMS) 027, Type VI. It has a specific gravity in the range of 0.52 to 0.58 and cures at temperatures as low as 250°F. within one hour. The RCR-568 is qualified to RMS 027, Type III. It requires a cure temperature of 350°F. to develop the properties specified in RMS 027.

2.8.1.4 Adhesives -- The tensile shear strength, flatwise tensile strength, and specific film weight of the three adhesive candidates used in the fabrication of 27-inch-square panels are included in Table 6. The minimum strength values allowed for material acceptance and the film weight tolerance required are indicated. The FM-34 polyimide and HT-435U epoxy-phenolic adhesives have better elevated temperature strength than FM-96U modified epoxy.

2.8.2 SCREENING --

2.8.2.1 Resin Systems -- Each resin system was evaluated for retention of strength at elevated temperature by checking flexure strength of an eight-ply laminate at ambient temperature, 300°F., and 350°F. (see paragraph 2.6.2 and Figure 11).

The effect of temperatures up to 350°F. on the flexure strength of eight-ply laminates of the resin systems is depicted graphically in Figures 13 through 19. (The broken lines on the graphs indicate that the curve is drawn from past experience with the thermal behavior of these polymers.) The resins were reinforced with 112 glass fabric having each ply oriented at 45 degrees to the preceding ply.

2.8.2.1.1 Polyester and Butadiene Styrene -- As may be observed, the room temperature strength of the polyester resins evaluated is lower than that of the epoxy or phenolic resins. The flexural strength of the polyester resins decreases significantly at temperatures of 300°F. to 350°F. (Figure 13). The flexural strength of the butadiene styrene copolymer, Eccomold L70, was the lowest of the materials evaluated.

Table 6. Raw Material Properties of Adhesives
For Fabrication of 27" x 27" Panels

Adhesive*	Test Temp.	Tensile Shear Strength**, psi		Flatwise Tensile Strength***, psi		Specific Film Wt.****, psf
		Required Min.	Typical****	Required Min.	Typical****	
FM-96U	R.T.	2500	4230	540	772	.03 ± .005
	180°F.	1250	4480	-	-	
FM-34/1070	R.T.	2150	-	-	-	.06 ± .005
	500°F.	1100	-	-	-	
HT-435U	R.T.	2150	2370	-	-	.03 ± .005
	500°F.	1100	1650	-	-	

* See Appendix F for list of material suppliers.

** Specimens were prepared from .063-inch thick, clas 2024-T3 aluminum adherends bonded with a 0.5-inch overlap, using the standard adhesive cure cycle.

*** Average of at least four specimens using HRP-3/16" - 4.0 lb./cu. ft. core.

**** Vendor certified test data.

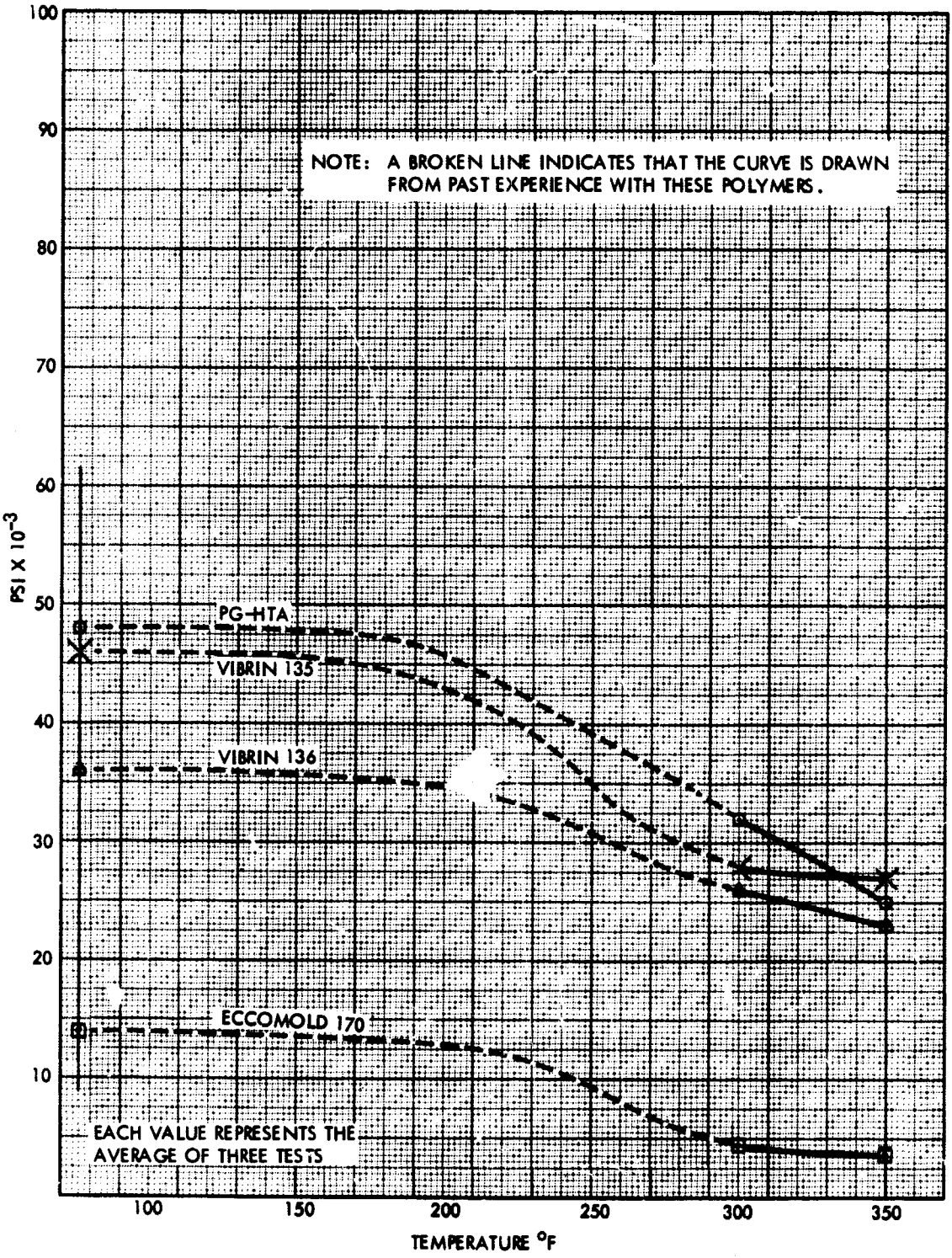


Figure 13. Eight-Ply Laminate Strength Versus Temperature, Polyesters and Butadiene Styrene (170).

2.8.2.1.2 Epoxy -- The A-stage epoxy resins and epoxy novolacs (Figures 14 and 15) cured with common amine and anhydride curing agents (Curing Agents Z, CL, DEH 50, and HHPA) have high room temperature flexural strength, which decreases rapidly with increasing temperature. The elevated temperature strength of the epoxy resins cured with NMA/BDMA exhibit a more gradual decrease in strength with temperature. The NMA/BDMA curing agent system gives comparable results for both the epoxy resin blend of Epon 828/Epon 1031 and the epoxy novolac, DEN 438. The prepreg E-792 (Figure 16), which is based upon an epoxy resin blend cured with NMA/BDMA. exhibits less temperature dependence than the corresponding Epon 828/1031 A-stage system (Figure 14).

The epoxy prepregs EG-9300, EG-35, E-792, E-740B, BP-908, and Narmco 588 exhibit little or moderate decrease in flexural strength with increase in temperature up to 350°F., as may be seen in Figures 16 and 17. The prepregs EG-4P, Narmco 500, and E-787 decrease in flexural strength with increasing temperature to a pronounced degree.

2.8.2.1.3 Phenolic -- The phenolic prepregs as a class are fairly stable with respect to temperature effects on strength in the range of room temperature to 350°F. (Figure 18). The phenyl silane, F509 (SC-1013), appears to have a slightly lower flexural strength than do the other phenolic resins. The strength level of the phenolics is comparable to that of the best high-temperature resistant epoxies.

2.8.2.1.4 Polyimide -- The polyimide resins, Trevarno F170, Narmco 1832, and du Pont 2501 are fairly stable up to 300°F., but decrease somewhat in flexural strength at 350°F. (Figure 19). This is attributed to the use of a maximum cure temperature of 400°F. instead of the recommended higher temperatures required to achieve a complete cure.

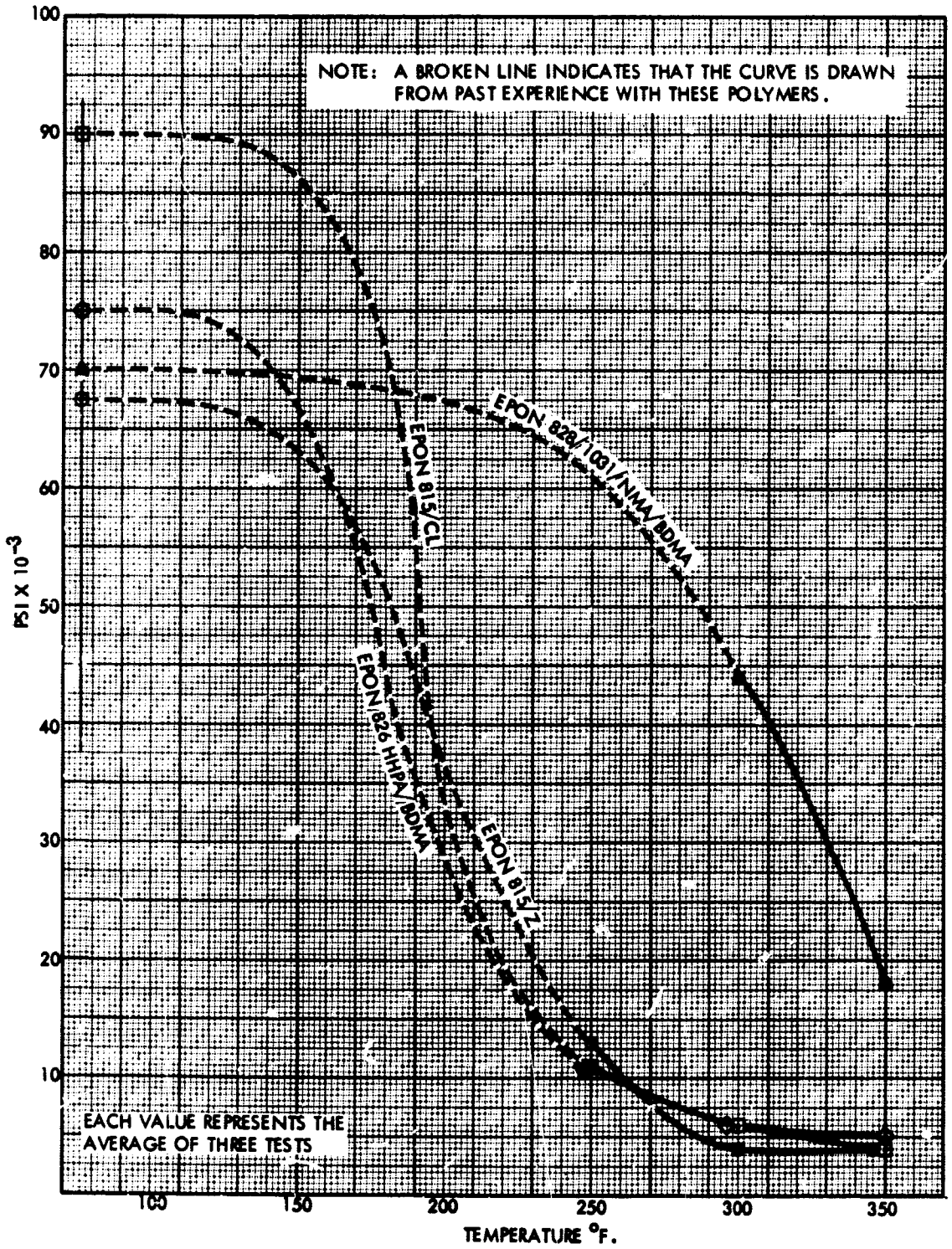


Figure 14. Flexure Strength for Eight-Ply Laminate Versus Temperature, Epoxies.

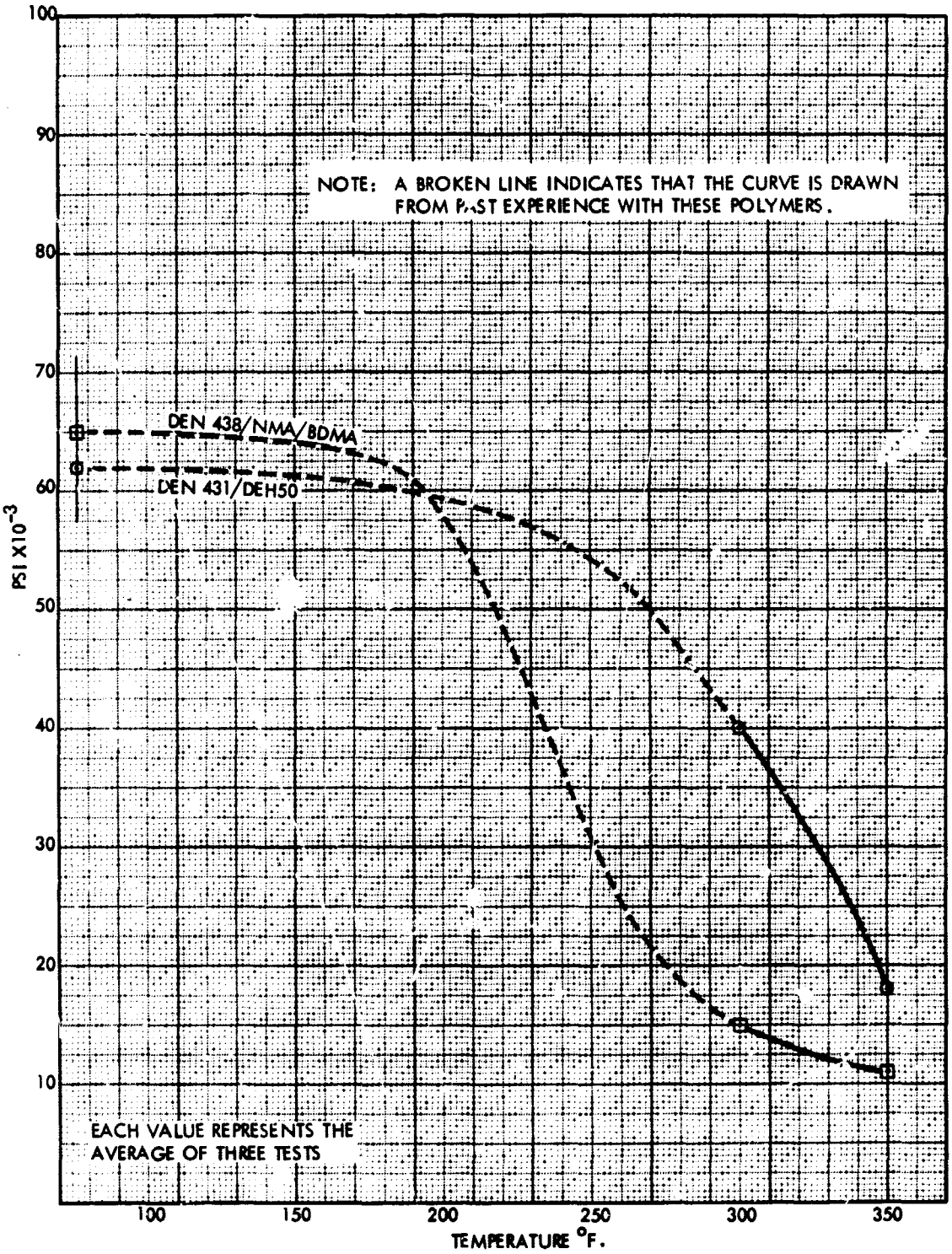


Figure 15. Flexure Strength for Eight-Ply Laminate Versus Temperature, Epoxy-Novolacs.

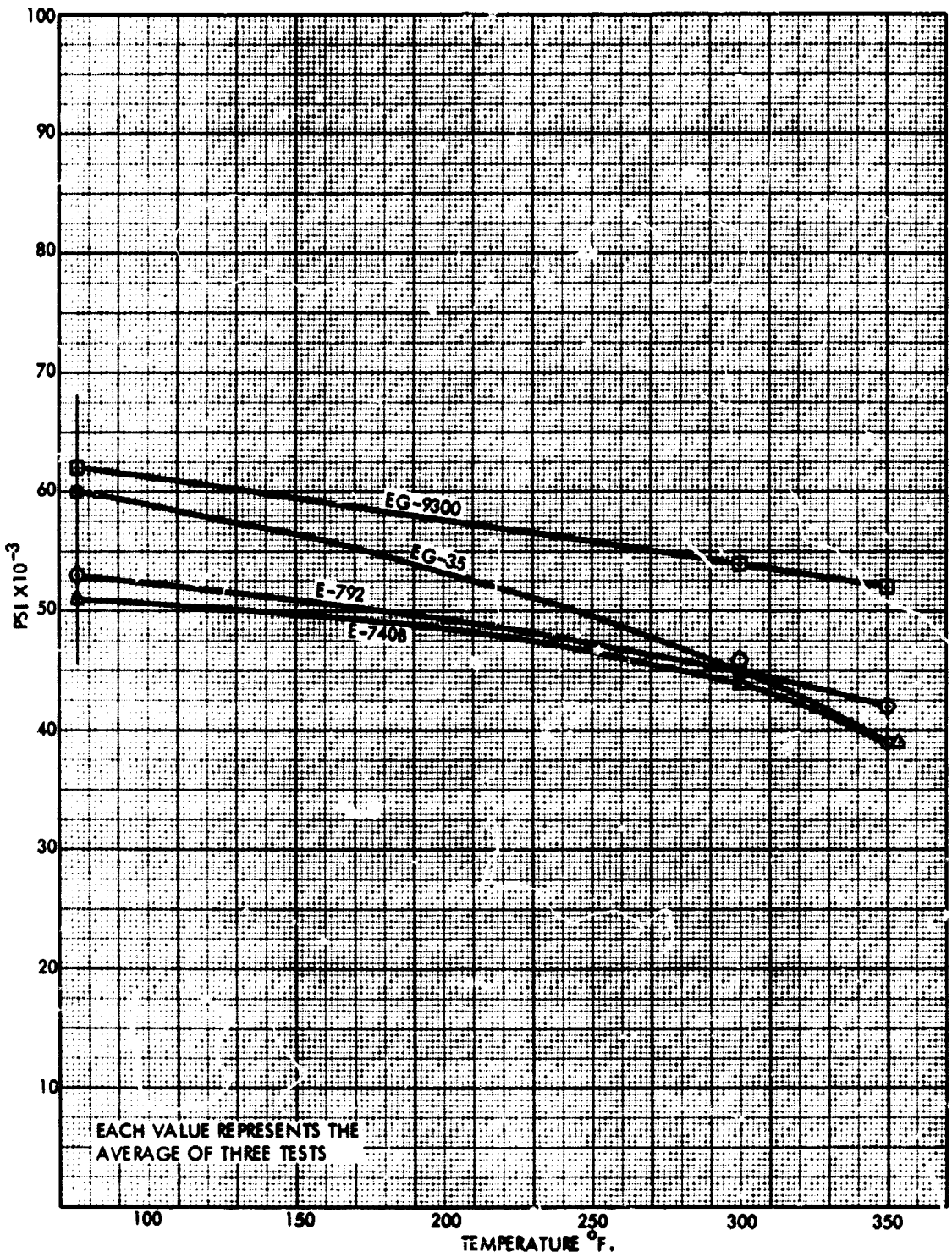


Figure 16. Flexure Strength for Eight-ply Laminate Versus Temperature, Epoxies.

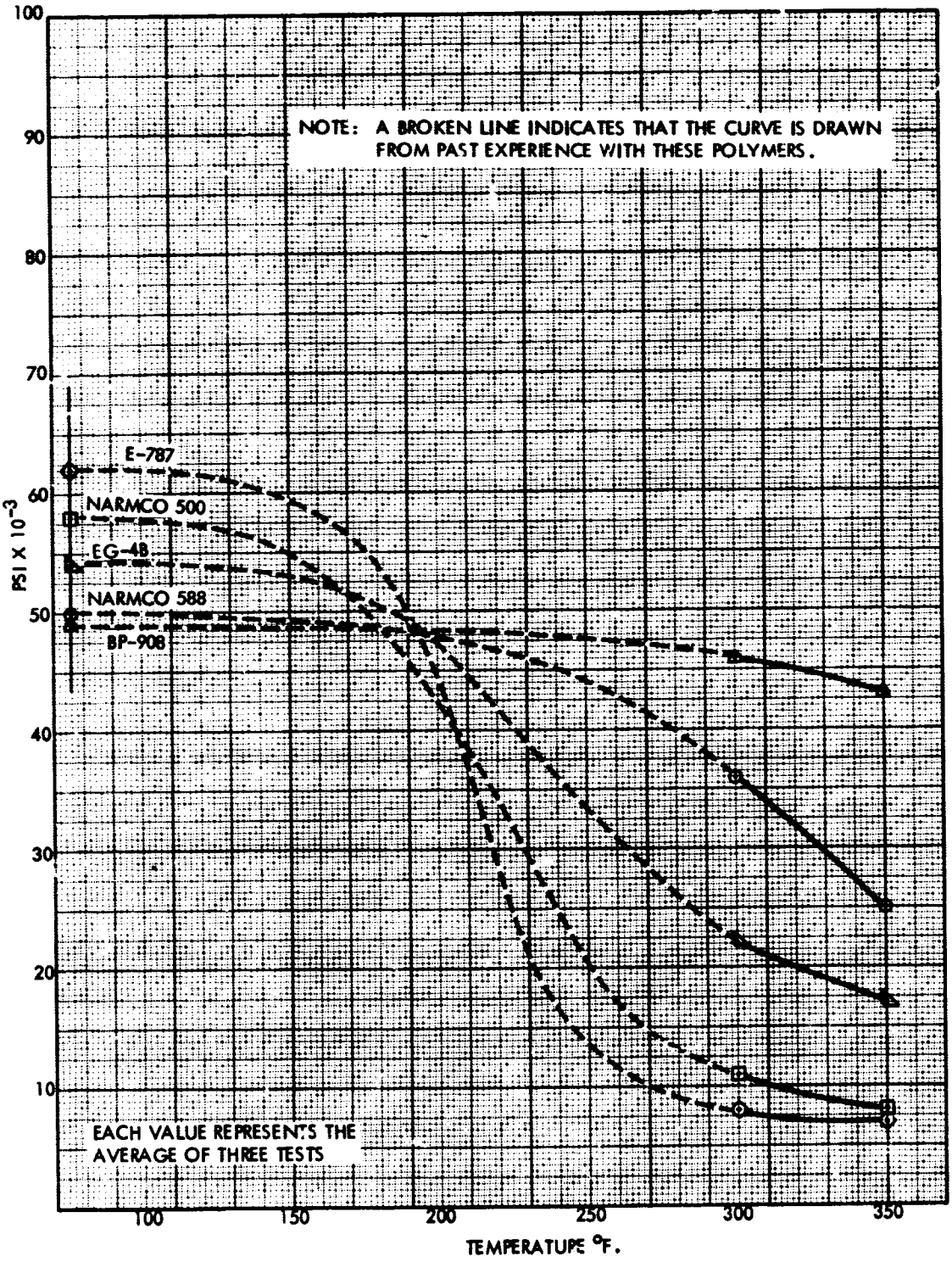


Figure 17. Flexure Strength for Eight-Ply Laminate Versus Temperature, Epoxies.

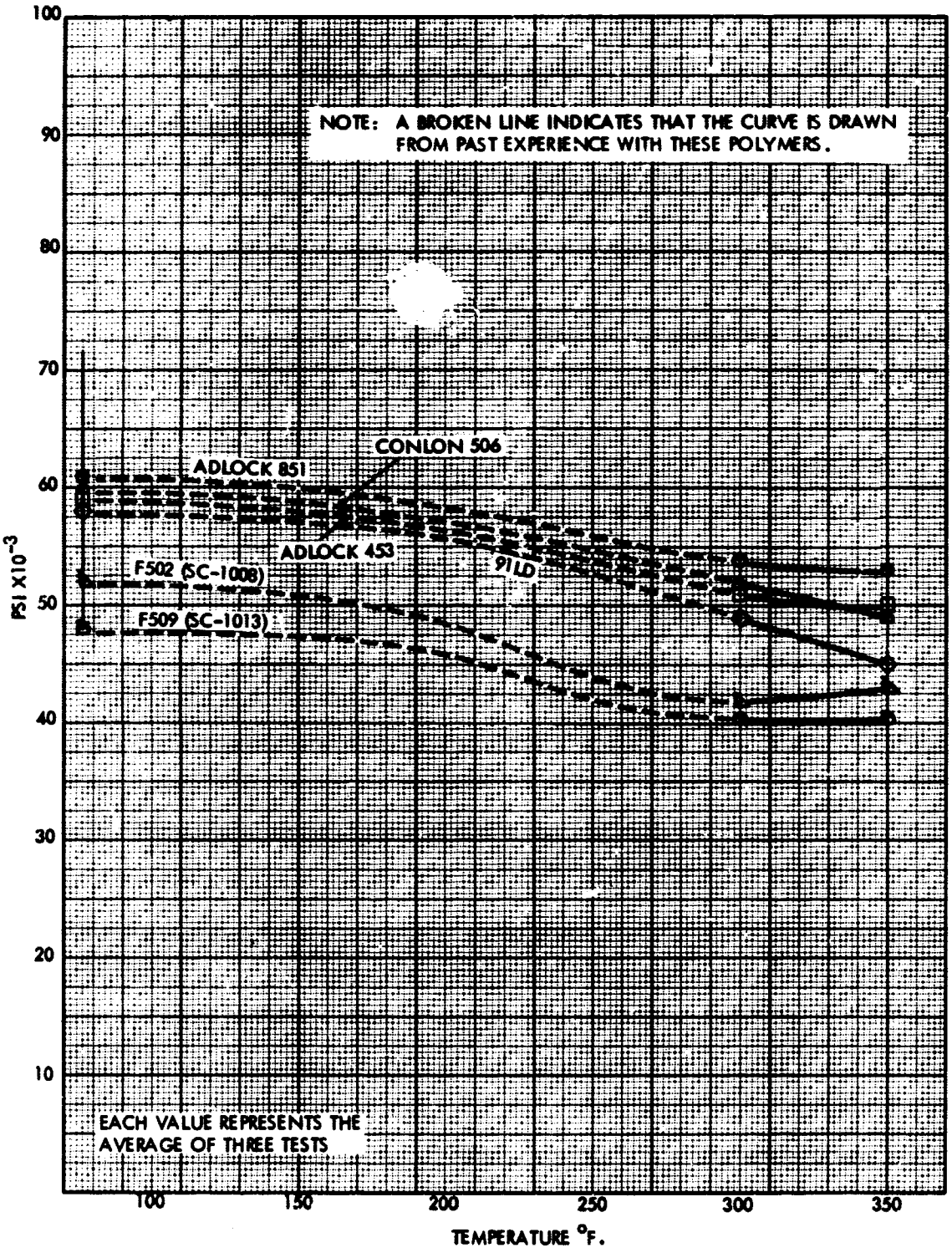


Figure 18. Flexure Strength for Eight-Ply Laminate Versus Temperature, Phenolics.

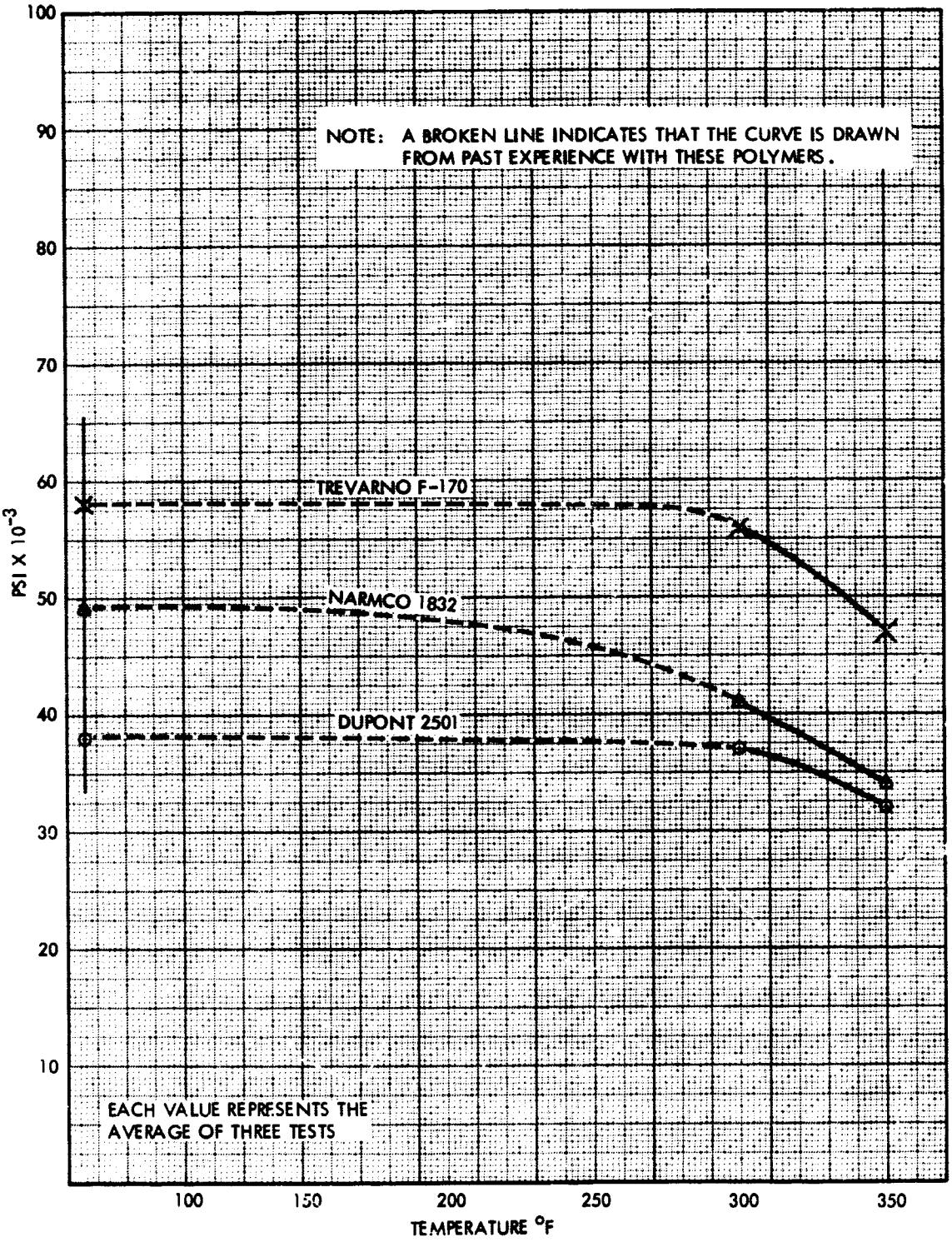


Figure 19. Flexure Strength for Eight-Ply Laminate Versus Temperature, Polyimides.

2.8.2.1.5 Resin Systems Comparison -- All of the A-stage resin systems evaluated, except the DEN 438/NMA/BDMA and Vibrin 135/BzP, were eliminated on the basis of screening tests as a consequence of poor handling characteristics or low elevated temperature strength (see Table 3 and Figures 13, 14, and 15). The Narmco polysulfone, Sunform F1760, and VC 8359 were not evaluated because they were not available.

Three of the nineteen B-stage resin systems, Narmco 500, EG-4B, and E-787, were eliminated prior to fabrication of 27-inch-square panels because of inferior elevated temperature strength (Figure 17). The du Pont 2501 was lacking in tack and could not be formed to contour, and was therefore eliminated from further evaluation.

Two of the prepreg facing materials, NAEMCO 500 and BP-908 were found to be suitable for bonding adequately to the core when cured in position against it without adhesive (Table 7). However, Narmco 500 exhibited low temperature resistant characteristics. The resin content of the BP-908 was too high for it to be competitive on a weight basis with the other resin bonded panels (Table 7). Compared to the adhesive-bonded facings, BP-908 is still heavier than most adhesives and face sheets combined, as may be observed from Tables 7 and 8.

The DEN 438/NMA/BDMA had fairly good flatwise tensile and beam flexure strengths when the facing resin was utilized to bond the sandwich panels in a one-stage operation (Table 7). Failure occurred exclusively at the upper facing. Microscopic examination revealed that the resin had flowed from the upper facing-to-core junction down the core cell walls, leaving a resin-poor region. Good filleting occurred at the junction of the lower facing and core (Figure 20).

Table 7. Screening Tests - One-Stage Resin Bonded Panels (No Adhesive)

Facing Material	Flatwise Tensile Strength*, psi	Facing Weight, psf	Beam Flexure Facing Stress*, psi
A-Stage			
DEN 431/DEH 50	290	.111	21,480
DEN 438/NMA/BDMA	340	.130	22,730
Epon 828/1031 NMA/BDMA	270	.101	16,080
Vibrin 135/BzP	75	.105	7,600
Vibrin 136 Benzoin/t-BPB	180	.107	13,300
Vibrin 136 DCBzP/t-BPB	340	.107	15,600
B-Stage			
91LD	100	.106	19,960
91LD/116	110	.139	16,700
Adlock 453	110	.087	24,600
Adlock 851	90	.096	19,410
BP-908	524	.152	19,870
Conclon 506	150	.096	13,520
E-740B	-	.111	-
E-787	360	.101	17,640
E-792	-	.111	23,200
EG-35	190	.110	18,000
EG-9300	130	.085	13,780
F502 (SC-1008)	230	.109	24,100
F509 (SC-1013)	150	.115	27,200
Narmco 500	300	.099	19,200
	540	.112	22,600
	730	.138	24,300
Narmco 588	180	.116	16,700
Narmco 1832	320	.091	-
PG-HTA	100	.103	17,090
PI 2501	240	.106	20,930
Trevarno F170	180	.122	21,800

* Panels were fabricated using 3/16-inch hexagonal phenolic core, 4.0 lb./ft.^{3} density. Facing reinforcement was 112 glass fabric, except as specified. Each value represents the average of three specimens.

Table 8. Screening Tests - Adhesive Bonded Panels

Facing Material	One Stage Flatwise Tensile Strength, psi*	One Stage Facing plus Adhesive Weight, psf	Two Stage Flatwise Tensile Strength, psi*	Two Stage Facing plus Adhesive Wt., psf
A-Stage				
DEN 431/DEH 50	750	-	-	-
DEN 438/NMA/BDMA	640	.15	-	-
Epon 828/1031 NMA/BDMA	760	-	-	-
Vibrin 135/BzP	184	-	245	-
Vibrin 136 Benzoin/t-BPB	400	-	-	-
Vibrin 136 DCBzP/t-BPB	470	-	-	-
B-Stage				
91LD	-	-	590	-
91LD/116	260	.19	-	-
Adlock 453 PHC	420	-	-	-
Adlock 851	510	.13	-	-
BP-908	-	-	680	.145
Conolon 506	700	.13	-	-
E-740B	540	-	-	-
E-792	590	-	-	-
EG-35	660	.14	-	-
EG-9300	370	-	-	-
F502 (SC-1008)	520	-	-	-
F509 (SC-1013)	520	-	-	-
Narmco 500	580	.12	-	-
Narmco 588	560	-	-	-
Narmco 1832	400	-	-	-
PG-HTA	560	-	-	-
PI 2501	380	-	-	-
Trevarno F170**	600	-	-	-

* Panels were fabricated using FM-96U adhesive and 3/16-inch hexagonal phenolic core, 4.0 lb./ft.^{3} density. Facing reinforcement was 112 glass fabric, except as specified. Each value represents the average of three species.

** Panels were bonded with FM-34/1070 adhesive.



Figure 20a. Photomicrograph of Poor Filleting at Top Facing of One-stage Resin-bonded Sandwich Panel Having DEN438/NMA/BDMA Facings, Showing Flow of Resin Down Core Cell Wall. (Mag. 100x.)

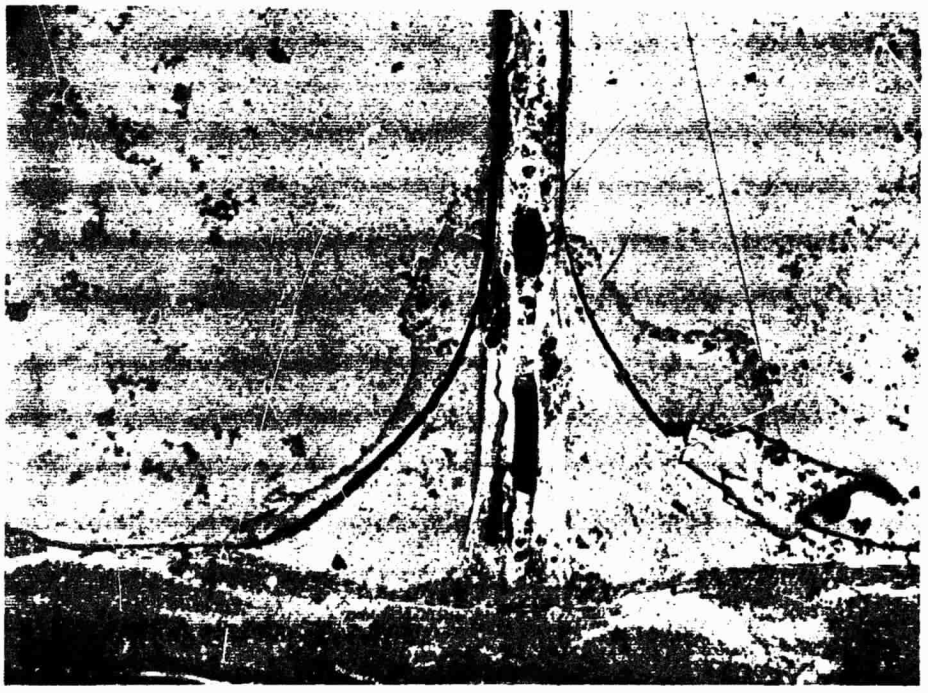


Figure 20b. Photomicrograph of Fillet at Bottom Facing-to-Core Junction of One-stage Resin-bonded Sandwich Panel Having DEN438/NMA/BDMA Facings. (Mag. 50x.)

The flatwise tensile specimens which had failed at the upper facing were retested to check the bond strength of the bottom facing. This was accomplished by bonding the exposed core directly to the test block. The flatwise tensile strength was approximately twice that obtained initially (720 psi compared to 340 psi). Therefore, it was concluded that additional adhesive adjacent to the upper facing would be beneficial to the structural integrity of this system. The one-stage adhesive bonded panels were subsequently tested, and the results verified this assumption (Table 8).

One of the phenolic prepregs, 91LD, and the A-stage polyester resin, Vibrin 135/BzP, were found to be incompatible with the FM-96U adhesive when used in a one-stage bonding operation (Table 8). The Vibrin 135/BzP also had inadequate flatwise tensile strength when cured and bonded in a two-stage operation. Therefore, it was eliminated from further evaluation. The 91LD had satisfactory bond strength wehn the facings were cured and bonded separately (Table 8). Therefore, 27-inch-square sandwich panels employing the latter facing material were fabricated using a two-stage cure and bond operation. The remaining material combinations were found to be satisfactory for one-stage adhesive bonding as a result of screening tests.

2.8.2.2 Honeycomb Core -- Screening test results for flatwise tensile strength and beam flexure strength of adhesive and resin bonded panels using the various types of honeycomb core are presented in Table 9. As may be observed, facing or adhesive failure occurred in each case prior to reaching ultimate properties of the core, with the exception of the HRH-10. This core failed in tension (adhesive bonded specimens) and in shear at sufficiently low values that it was excluded from further evaluation.

2.8.2.3 Potting Compounds --

2.8.2.3.1 Prepotting -- In order to establish processing parameters for potted assemblies, the Rohr compounds, RCR-568 and RCR-576, were evaluated in both one-stage and two-stage curing operations. Preliminary evaluations also included M-323V, a slightly higher density, lower viscosity modifica-

Table 9. Core Screening Test Data

Core Designation	Flatwise Tensile Strength*, psi		Resin Bonded Sandwich Flexure Strength*	
	Resin Bonded	Adhesive Bonded**	Core Shear***, psi	Facing Stress, psi x 10^{-3}
HRH-10	152****	265#	123#	16.5#
HTP-1/4-3.5	90	530	-	-
HRP-3/16-4.0	90	510	146	19.4
HTP-3/16-4.0, extra dip	53	420	100	13.4

* Results for honeycomb sandwich specimens with facings of Adlock 851/112. Each value represents the average of three specimens.

** Specimens were bonded with FM-96U adhesive.

*** Parallel to ribbon direction.

**** Core to facing failure occurred in all cases except where otherwise indicated.

\# Core failure.

Table 10. Potting Compound Compatibility Test

Facing Material	Potting Compound	Flatwise Tensile Strength*, psi
EG-35	None	660
EG-35	RCR-568	1080
EG-35	RCR-576	1170
DEN 438/NMA/BDMA	None	643
DEN 438/NMA/BDMA	M-323v**	870
Adlock 851	None	670
Adlock 851	RCR-568	1130

* Specimens were fabricated from the designated facing resin impregnated on 112 glass fabric, FM-96U adhesive, the potting compound indicated, and 0.75-in. thick 3/16-inch hexagonal phenolic core, 4.0 lb./ft.^{3} density, using a one-stage cure. Testing was conducted in accordance with ASTM C297-61

** Modification of RCR-576 having a slightly higher density.

tion of RCR-576. Uncured epoxy and phenolic resin systems and FM-96U adhesive were utilized in the one-stage cure, and cured phenolic facings with FM-96U were utilized in the two-stage operation.

Screening results indicated that the Rohr compounds were suitable for prepotting the panel when the two-stage fabrication procedure was used. Initial tests for the one-stage cure resulted in a sandwich panel which had a raised area in the potted region of the upper facing because of the slight expansion of the potting compound during cure and the lack of restraint provided by the slow curing prepregs during cure. Further evaluation demonstrated that suitable pottings could be obtained using a one-stage operation by allowing the potted core to remain under normal processing conditions for a minimum of approximately twelve hours prior to cure (Figure 21).

Compatibility of the potting compounds with both B-stage and A-stage epoxy resin facing systems utilizing a one-stage cure, was checked by means of visual examination and flatwise tensile strength. The tensile strength of sandwich panels having EG-35 facings, which were potted with RCR-576, was approximately twice that of the corresponding unpotted panels, as may be seen in Table 10. Since only one-half of the specimen was potted, the comparative strength is actually greater. Failure occurred within the potting compound (Figure 22a), which indicated that compatibility between it, the adhesive, and the facing material are good.

On the contrary, potted specimens having facings of DEN 438/NMA/BDMA exhibited evidence of poor compatibility, although the same adhesive film was used. Flatwise tensile strength of the potted specimens was only slightly greater than the corresponding unpotted specimens (Table 10). Failure occurred in the potting compound just beyond the facing-to-potting compound interface (Figure 22b). The compound was somewhat discolored in the failure region.

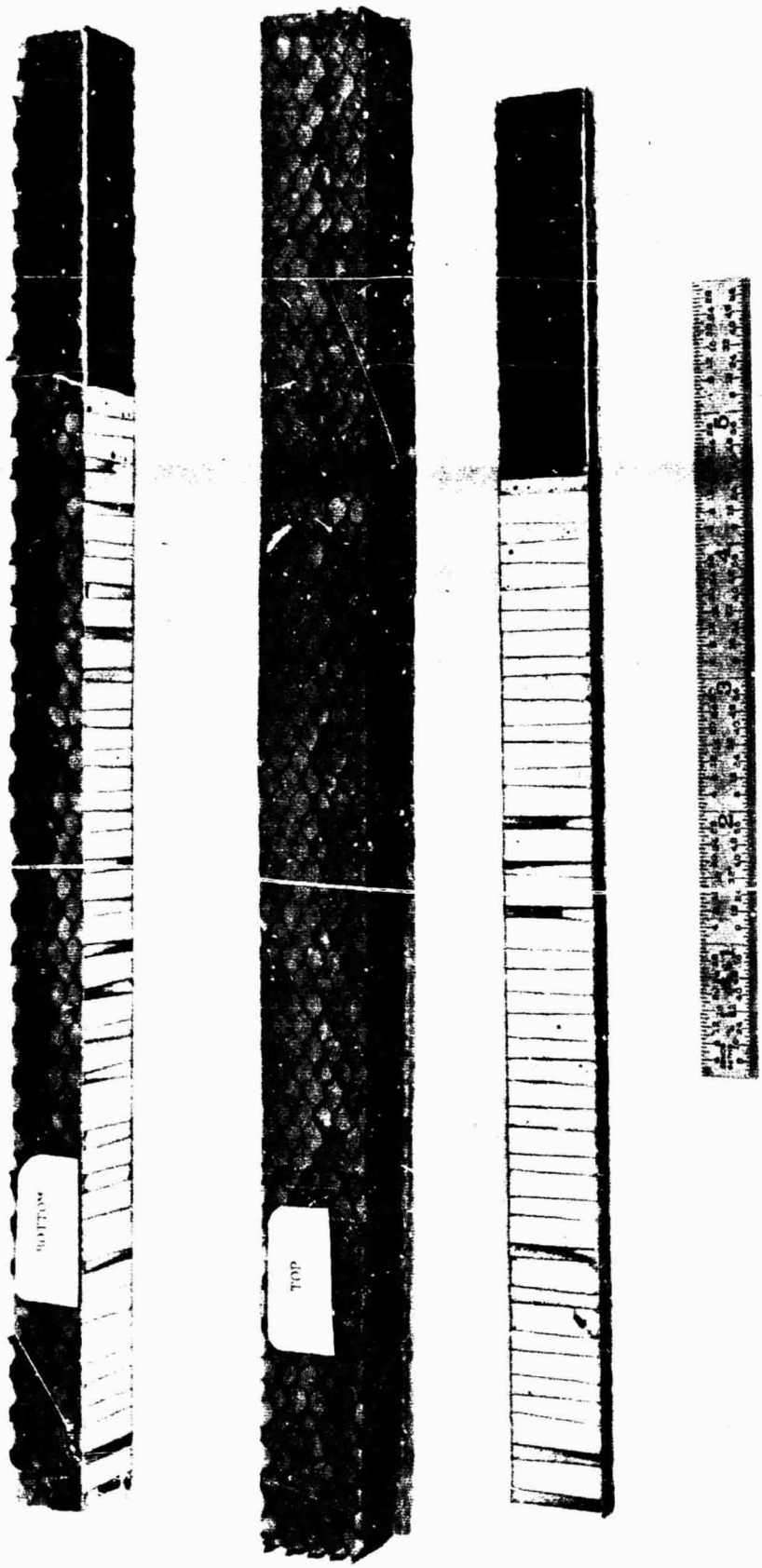


Figure 21. Segments of EG-35 Sandwich Panels Prepotted with RCR-576 Showing Homogeneity of Potted Region.

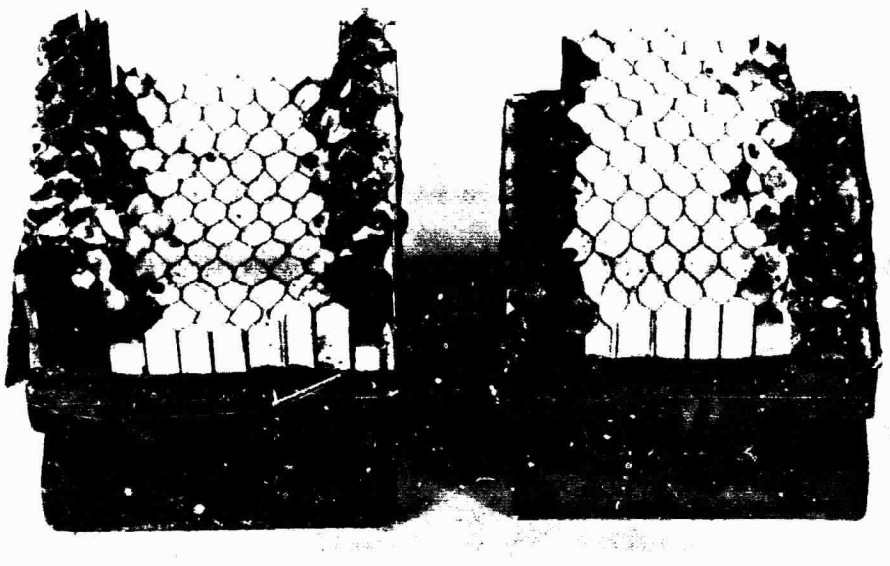


Figure 22a. Failure of Flatwise Tensile Specimen of EG-35, FM-96U Prepotted with RCR-576 and Cured in a One-stage Operation.

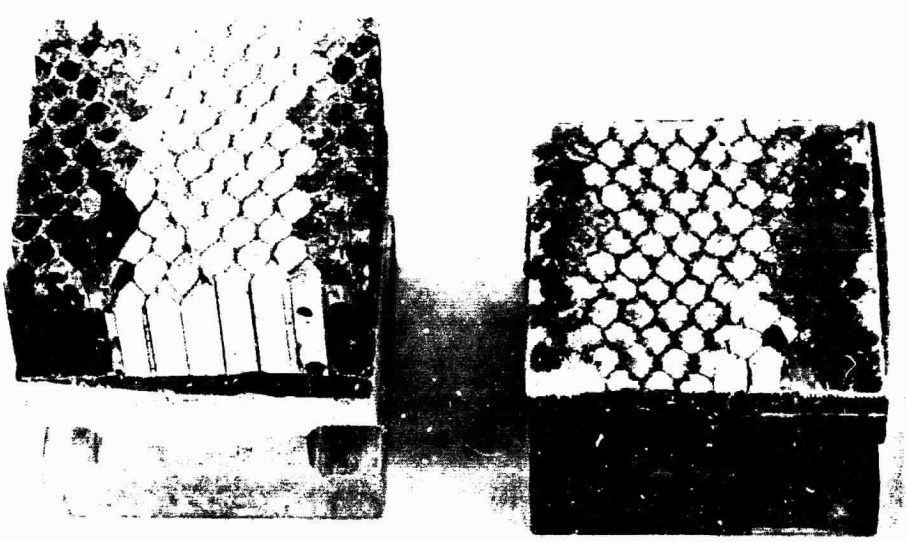


Figure 22b. Failure of Flatwise Tensile Specimen of DEN438/NMA/BDMA, FM-96U Sandwich Specimen Prepotted with M-323V and Cured in a One-stage Operation.

Compatibility of the RCR-568 with the Adlock 851 in a one-stage cure appears to be good, as indicated by the tensile shear strength of the potted panel (Table 10).

Because the RCR-576 has a lower density than the RCR-568 (Table 5), yet appears to provide adequate strength, it was selected as the prime candidate for use in prepotting the subscale aeroshells.

2.8.2.3.2 Postpotting -- The operation of filling the edges of a honeycomb sandwich panel was evaluated using Epocast H-1843, Type IV, Grade B potting compound. In one instance the compound was placed directly into the severed edges of the core, the surface smoothed, and the compound allowed to cure at room temperature. Alternately, the outer row of cells was removed from the panel prior to filling the edge with compound.

In the first case, the edge of the panel was somewhat irregular because of the protruding edge cell walls The potted edge region of the second potted section was smooth and hard after cure of the compound. The latter procedure and the Epocast H-1843 compound were therefore used for filling the edges of the subscale aeroshells.

2.8.2.4 Adhesives --

2.8.2.4.1 Preliminary Screening -- Preliminary screening of adhesive systems was conducted to select a standard adhesive for use in the fabrication of the sandwich panels to permit comparisons of various other parameters of sandwich construction. This adhesive was to provide maximum bond strength and minimum weight.

Four types of adhesives were evaluated initially: Epon 901/B-3 epoxy paste, HT-424F epoxy-phenolic paste, FM-96U (unsupported) epoxy film adhesive, and FM-96 (supported) film adhesive. Honeycomb sandwich panels using standard precured face sheets of 91LD phenolic prepreg and BP-908 modified epoxy prepreg were bonded with the candidate adhesive systems.

These facings were selected to assess any difference in adhesion due to the difference in composition or premeability of the facing. The bonded panels were weighed and dissected into flatwise tension specimens, which were tested according to the standard procedure. Photomicrographs were taken of the fillets at the junction of core and facing.

As may be observed from the photomicrographs in Figure 23, the Epon 901 and HT-424 paste adhesives are porous and/or provide a poor fillet. FM-96U adhesive flowed away from the center of the core hexagon and formed a dense fillet at approximately a 45 degree angle with the cell walls. No significant difference in filleting occurred for the different face sheets.

The preliminary evaluation of the adhesive strength proved to be difficult because of the infiltration of test block adhesive through the porous facing during bonding of flatwise tensile specimens to the text fixture. This secondary adhesive tended to reinforce the test adhesive. The problem was overcome by sealing the sandwich facings with Epon 901/B-1 before bonding the specimens to the test blocks.

The flatwise tension test results are depicted graphically in Figure 24. As may be observed, no significant difference in bonding occurred between the two facings. The FM-96 (.05 psf.) provided the highest strength of the adhesives evaluated. When the specific strength (strength divided by weight) is considered, the superiority of FM-96U (.03 psf.) as a light-weight adhesive is shown. It was consequently utilized as the standard adhesive in fabricating 27-inch-square sandwich panels.

2.8.2.4.2 Screening of High-Temperature Adhesives-- Additional screening of adhesives which had higher elevated temperature strength than FM-96U was conducted according to the standard screening procedure outlined in paragraph 2.7.2, utilizing one-stage bonded flatwise tension specimens. These adhesives were evaluated for use in fabricating specific 27-inch-square panels to determine properties of material combinations having higher temperature capabilities than those fabricated using FM-96U.



Figure 23a. Photomicrograph of Facing-to-Core Junction Showing HT-424 Paste Adhesive. (Mag. 125x.)

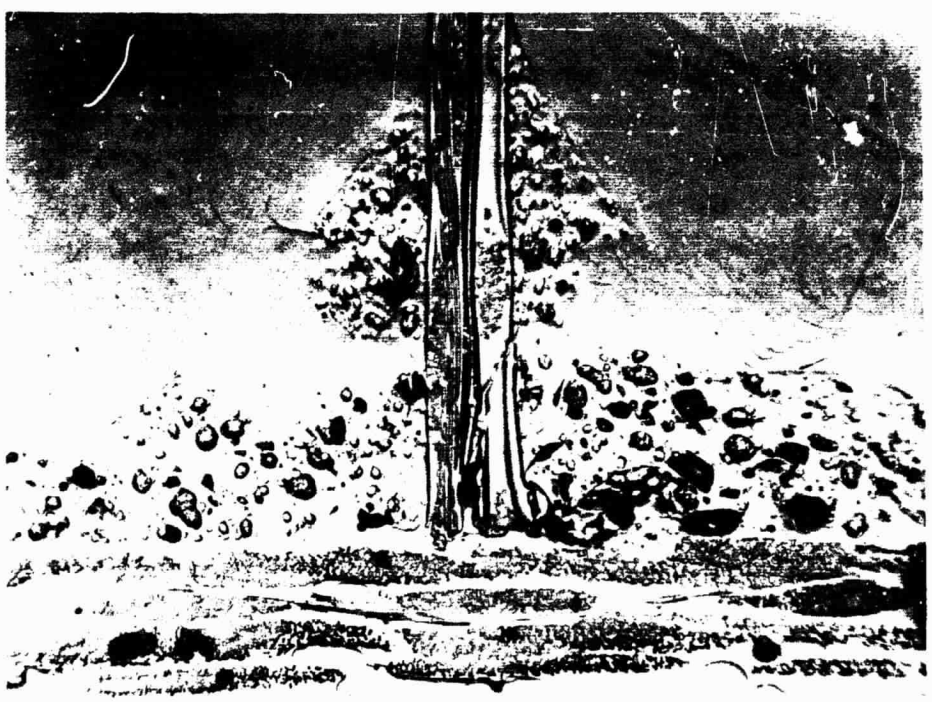


Figure 23b. Photomicrograph of Facing-to-Core Junction Showing Epon 901 Adhesive. (Mag. 125x.)

The adhesives evaluated are listed in Table 11 with flatwise tensile strength test results. Initial evaluation of HT-435/1070 was conducted to assure adequate adhesion, so that this lower density material could be substituted for the heavier standard 0.135 psf. adhesive. As may be observed, flatwise tensile adhesive strength compared favorably with that obtained with FM-96U (Figure 24), hence HT 435/1070 was used in fabricating one set of 27-inch-square panels.

Later, unsupported HT-435 adhesive in two film weights became available for evaluation. Results for flatwise tensile strength of these materials shows that satisfactory bonding can be achieved with use of the HT-435U in 0.03 psf. film weight, and higher strength-to-weight ratios result for it than for the higher weight HT-435U films. Therefore, this adhesive was subsequently evaluated further by employing it in the fabrication of 27-inch-square panels.

The polyimide adhesive FM-34 was considered for evaluation in 27-inch-square panels because of its high-temperature resistance. Since it was also available in a lower density version, FM-34/1070, the two weights of adhesive were compared. As shown in Table 11, the FM-34/1070 is superior on the basis of both strength and weight.

2.9 TEST PROCEDURES

2.9.1 FLATWISE TENSILE STRENGTH -- This test was performed in accordance with ASTM-C-297. A flatwise tensile specimen is shown being tested at room temperature in Figure 25.

Data from this test provided an excellent study on the compatibility of the various adhesive and resin systems, as well as determining optimum bond techniques.

Due to the porosity of the honeycomb phenolic and polyimide laminate facings, their flatwise tensile specimens were first sealed with a room

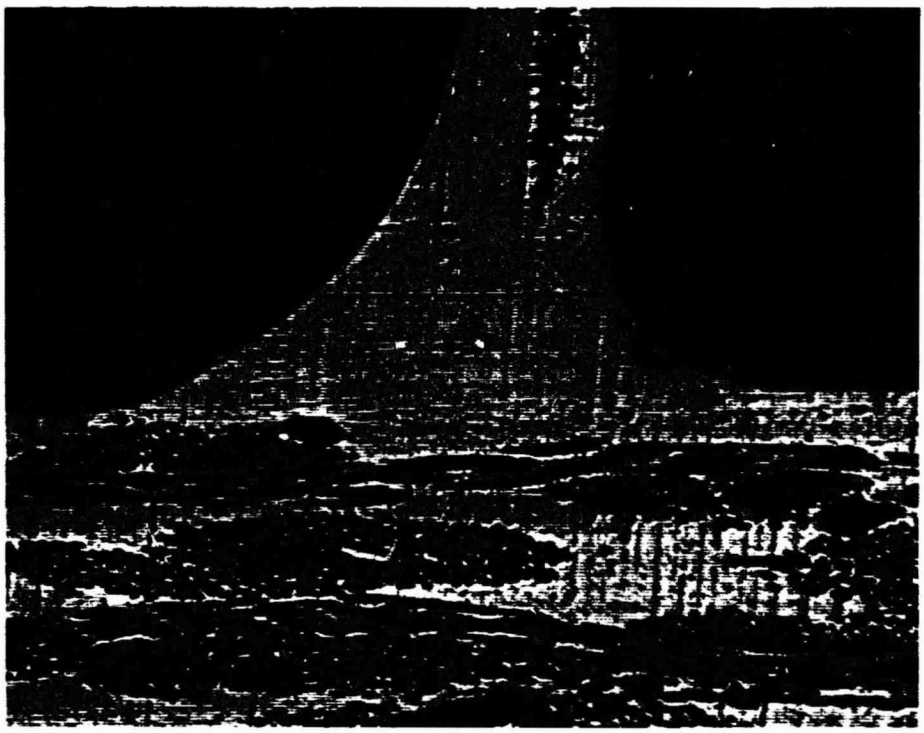


Figure 23c. Photomicrograph of Facing-to-Core Junction Showing FM-96U Adhesive Fillet. (Mag. 125x)

Table 11. High-Temperature Resistant Adhesive Screening

Adhesive	Facing Material	Film Weight, psf	Flatwise Tensile Strength*, psi
HT-435/112	Adlock 851	.135	310
HT-435/1070	Adlock 851	.05	460
HT-435U	Adlock 851	.03	470
HT-435U	Adlock 851	.06	490
FM-34	F170	.135	510
FM-34/1070	F170	.06	600

* Honeycomb sandwich specimens were fabricated using 0.75-inch thick hexagonal phenolic core, 4.0 lb./ft.^{3} density. Facing reinforcement was 112 glass fabric. Testing was conducted in accordance with ASTM C297-61.

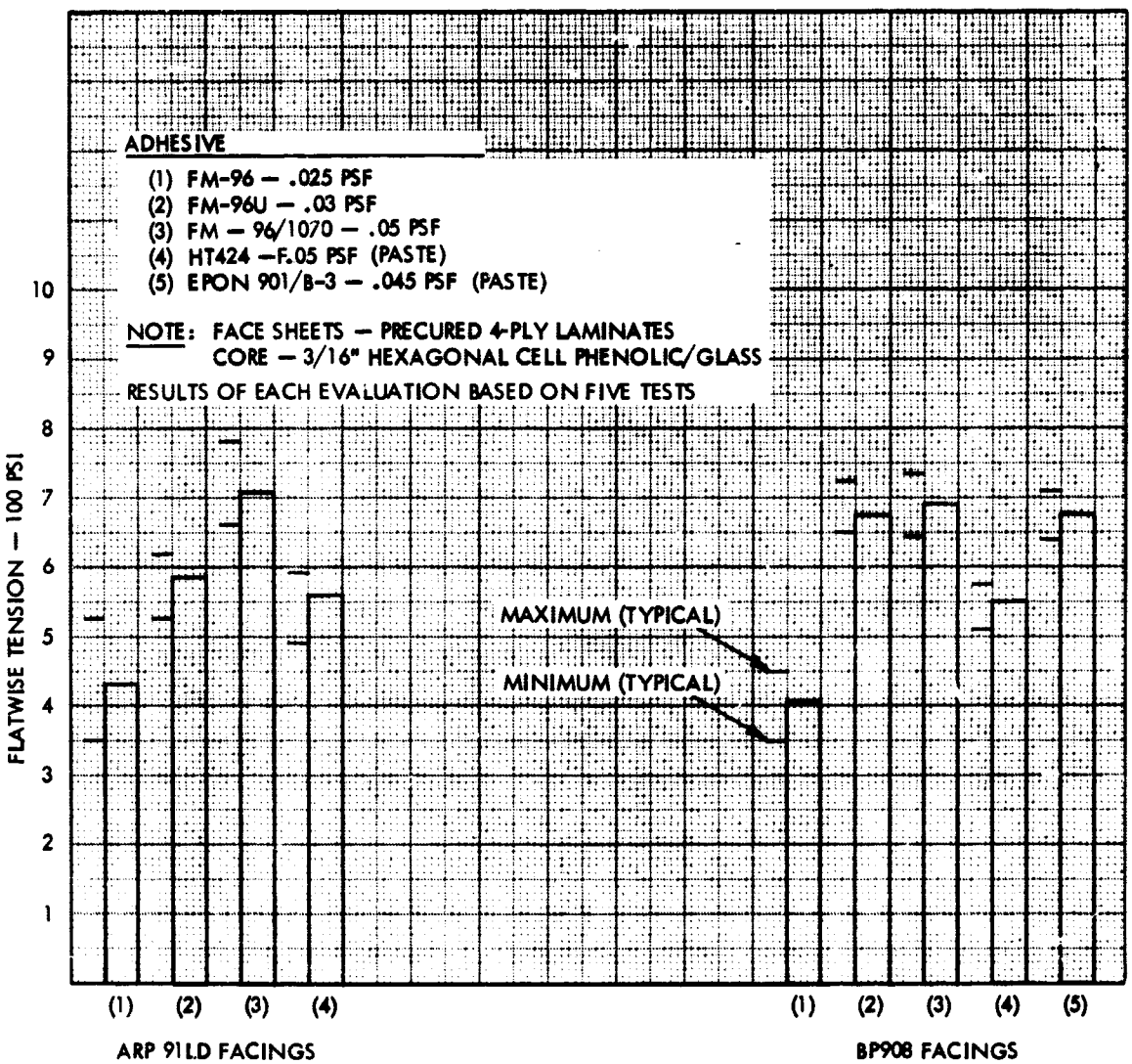


Figure 24. Preliminary Adhesive Evaluation

temperature curing epoxy paste. This alleviated adhesive from bleeding through the face sheet. The surfaces of the specimens were then ground flat and parallel, and bonded under pressure to the loading blocks with a low-temperature curing epoxy adhesive.

2.9.2 FLATWISE COMPRESSION STRENGTH -- The flatwise compressive strength provided excellent data for comparing various core cell sizes and configurations. This test was performed in accordance with ASTM-C-365.

Figure 26 shows a specimen in position for flatwise compression testing.

2.9.3 HONEYCOMB SANDWICH PEEL STRENGTH -- This method of test provided the necessary data to determine the relative ability of honeycomb structure facings to resist peeling action. Tests were conducted in accordance with ASTM-D-1781.

Figure 27 shows a specimen being tested for sandwich peel strength.

2.9.4 HONEYCOMB SANDWICH FLEXURAL STRENGTH -- This test was of primary interest since its data provided an excellent comparison of the performance of the composite structure. The test was performed in accordance with ASTM-C-393. Specimens were simply supported on two points, six inches or ten inches apart, according to the desired mode of failure; and the loads were applied at two third points. Figure 28 shows a specimen in a six-inch span test.

2.9.5 FACING THICKNESS -- Photomicrographs were taken of the honeycomb panel facings. Measurements of the facing thickness were taken at points where the core made contact with the facing and in between these contact points. An average of six measurements were used to determine the facing thickness. Due to the wide variation of measurements that could be obtained on any one panel (depending upon the location used) and the critical role this measurement played in the resulting data, facing stress was calcualted based on two thicknesses. A nominal thickness of .015 inch

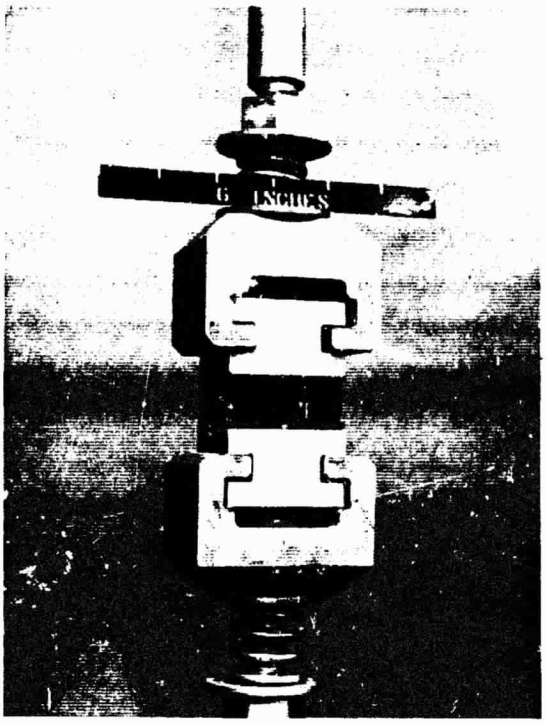


Figure 25. Specimen Being Tested for Flatwise Tensile Strength.

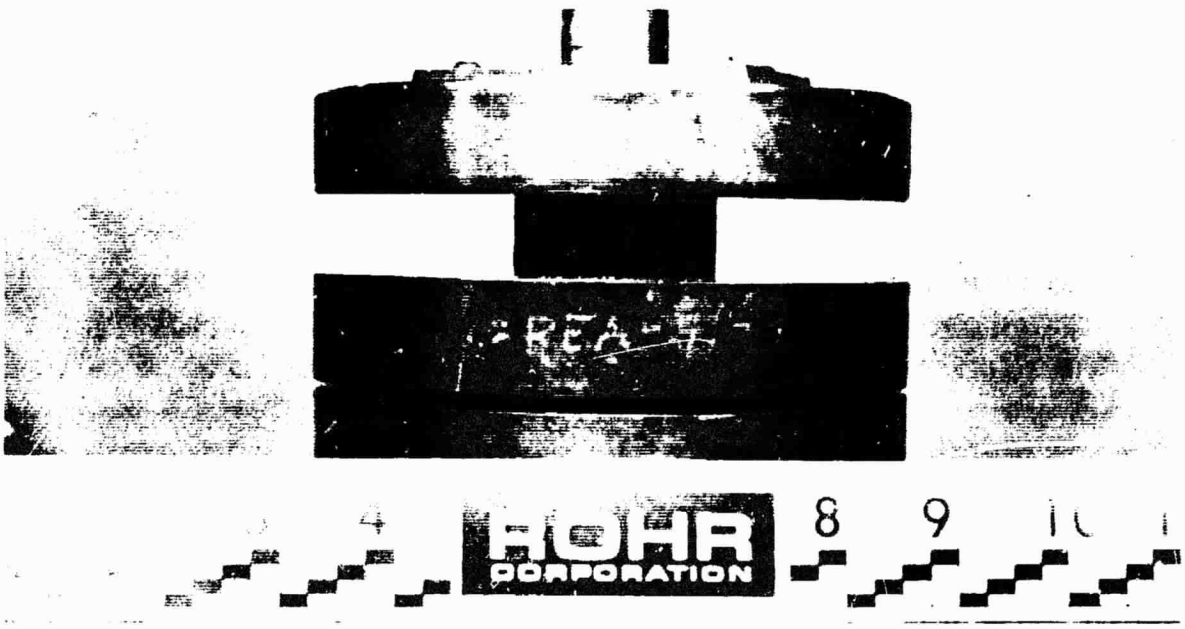


Figure 26. Flatwise Compression Test.

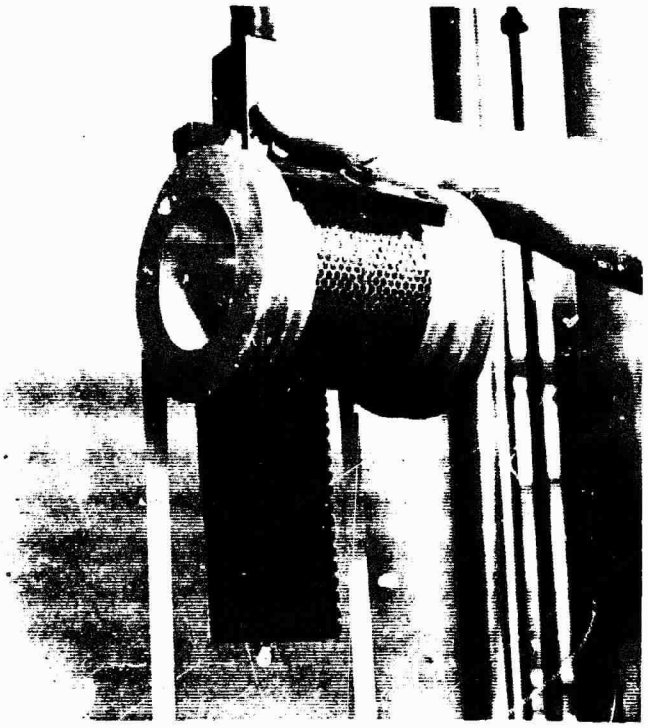


Figure 27. Tested Specimen Being Removed from Climbing Drum Test Fixture.

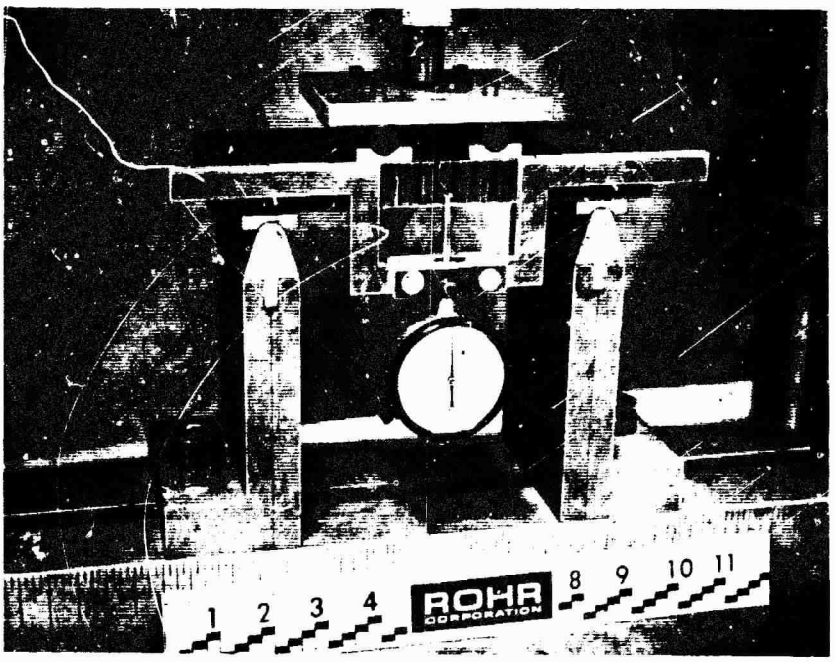


Figure 28. Honeycomb Sandwich Flexure Specimen.

was used for all panels in which the facings were fabricated from four-ply laminates and 112 glass cloth to aid in the evaluation of parameters being tested such as resins, adhesives, core, etc. An additional set of data is reported on flexural stress using the thickness obtained from the photomicrographs.

2.9.6 BENDING OF FACE SHEETS -- This test (per ASTM-C-393) involves bending a face sheet which has been removed from a 27-inch by 27-inch bonded panel. The specimen size would be four inches by eight inches or a given ratio of length to thickness. The thin face sheets involved render the test values immeasurable on the former panel, and would produce impractically small specimens in the latter. Therefore, this test method was replaced by ASTM-D-790 discussed below.

2.9.7 LAMINATE FLEXURAL STRENGTH -- This test was performed in accordance with ASTM-D-790. The specimen was simply supported at five-eights-inch span and loaded under a single point. Results from this test were necessary to determine the optimum curing cycles, the ability of the resins to withstand elevated temperature, and to compare various styles of glass cloth. Eight-ply laminates were measured and weighed after being cured, then machined into one-inch by two-inch test specimens. Flexural strength, flexural modulus, and specific flexural modulus were determined from this test. Figure 29 shows a laminate specimen being tested at room temperature.

2.9.8. CORE SHEAR AND CORE MODULUS -- These data were obtained by testing the core in plate shear in accordance with ASTM-C-273. Results from this test provided excellent data for comparing various core configurations, cell sizes, and resin systems. Honeycomb sandwich specimens two inches by five inches were bonded to the loading plates with a low-temperature curing epoxy adhesive after they had been prepared as in Figure 30, which shows a plate shear specimen in position for testing.

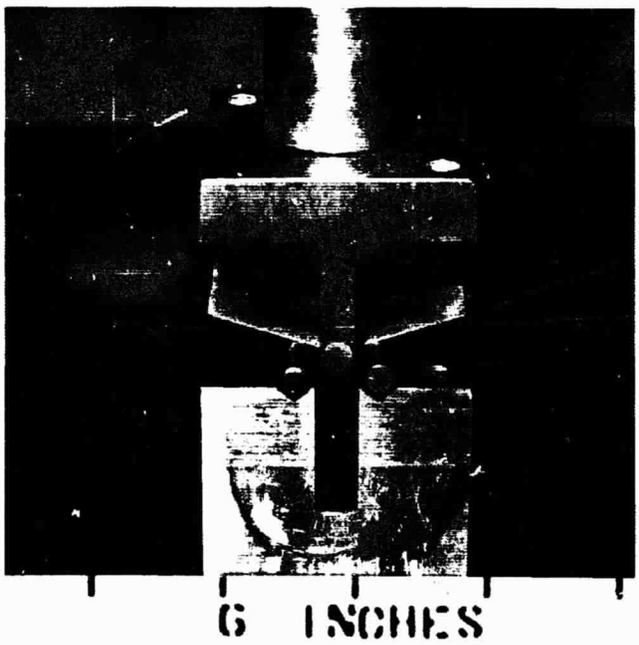


Figure 29. Failed Laminate Flexure Specimen.

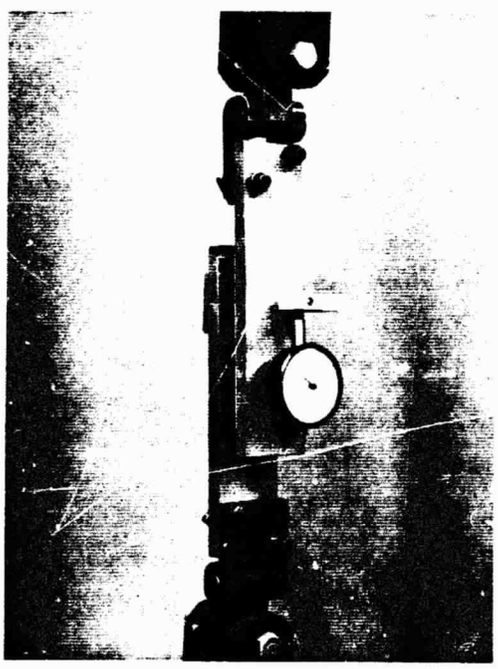


Figure 30. Plate Shear Specimen Ready for Test.

2.9.9 EDGEWISE COMPRESSION -- This test was performed in accordance with ASTM-C-364. Results from this test provided the basis for comparing the load-carrying capacity of the composites.

Edgewise compression specimens were cut from the honeycomb panels and the end potted with a room temperature curing epoxy paste, when necessary to ensure against premature end failures. The ends of the specimens were then machined flat and parallel.

Figure 31 shows an edgewise compression specimen being located in the testing apparatus. Compressometers were used to assist in locating the specimens to ensure uniform loading of the facings.

2.9.10 TEST SPECIMEN PREPARATION -- Two plastic templates were laid out as shown in Figure 12. These templates ensured the accuracy and reproducibility of specimen lay out on the 27-inch by 27-inch composite panels, as well as reducing lay out time to a minimum. Test specimens were cut from the panels with a band saw. Edgewise compression specimens were then prepared as in 2.9.8. Figure 32a and 32b show typical reinforced plastic panels being laid out into test specimens.

2.10 GENERAL RESULTS AND CONCLUSIONS

2.10.1 MATERIAL COMBINATION RESULTS ANC CONCLUSIONS -- Tables 12 and 13 present the screening results for all materials tested, and the 27-inch by 27-inch flat panel test results for materials which passed the screening test. Epon 815/Z, Epon 826, Epon 815/CL, USP E-787, Narmco 500, Adlock EG4B, and DEN 431 systems were dropped due to low laminate flexural strength at 300°F. and 350°F. BP908 was discontinued because the prepreg could not be obtained with a lower resin content than 55%, which adds additional weight without an increase in strength. Epon 828/Epon 1031 was difficulat to handle as an A-stage system. Vibrin 135 and 136 were dropped due to adhesive incompatibility and handling difficulties, respectively. Du Pont 2501 polyimide prepreg was not satisfactory for

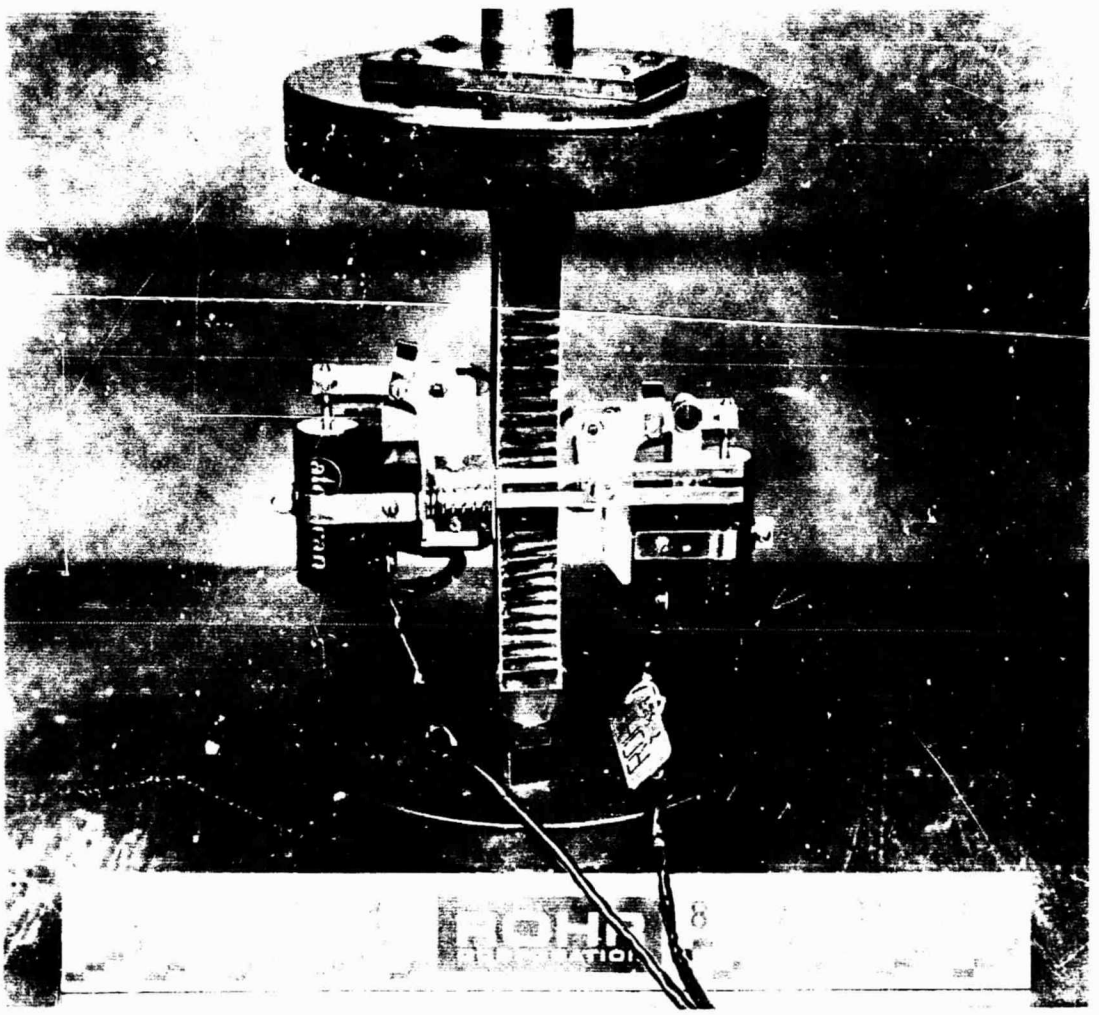


Figure 31. Edgewise Compression Specimen Being Monitored with Compressometers.

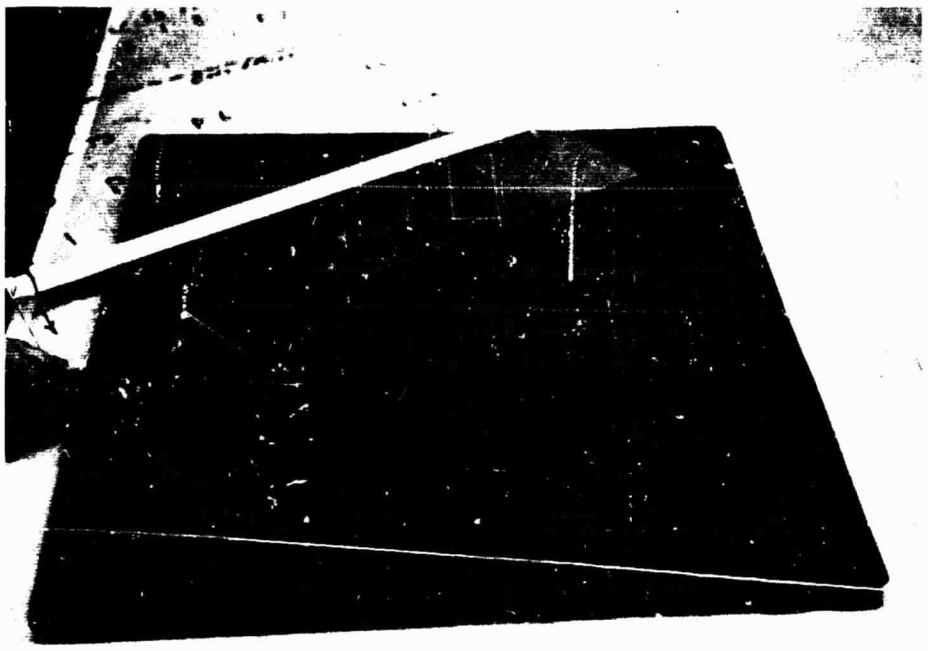


Figure 32a. Flat Honeycomb Panel Being Laid Out Into Test Specimens.

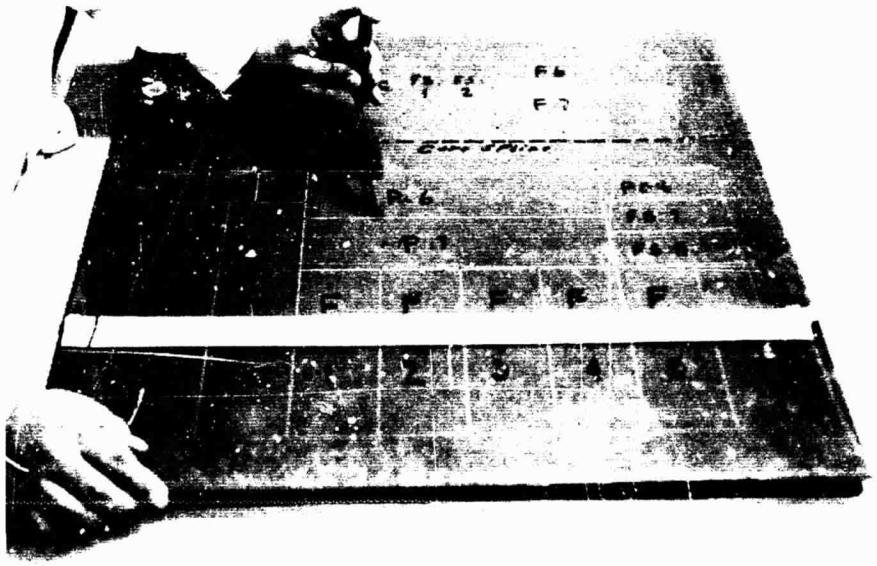


Figure 32b. Flat Honeycomb Panel Being Laid Out Into Test Specimens.

potential aeroshell fabrication because it was dry and brittle and had no tack or drapeability due to short working life.

The flatwise tension properties for each resin system is shown for resin bonded panels and for adhesive bonded panels when they were screened (see paragraph 2.7.2). Flatwise tension, along with laminate flexure, at 300°F. is repeated for the 27-inch by 27-inch panel evaluation. These two tests were used as a quality control check by comparing the results before proceeding with the more costly tests.

The flatwise compression tests were discontinued when the same honeycomb core was used, since the composite has no significant effect on the compression strength of the core.

Delta note △2 of Table 12 refers to the average flexure strength based on measured facing thickness for each face sheet. Due to the large variations in thickness, comparison of these results is not too meaningful for a given number of plies. Therefore, an average face sheet thickness of fifteen mils was used for four-ply face sheets as indicated by delta note △1 in the table. The average, high, and low flexure strength is given when the core ribbon direction is both parallel and transverse to the length of the specimen. When the specimen failed in core shear, additional specimens were lengthened to accommodate a ten-inch span length in order that the facings alone would resist the column forces.

Edgewise compression properties are given using the same constant facing thickness.

Climbing drum sandwich peel test results were taken from the top skin (vacuum bag side) which, because it had less adhesive filleting, had lower strength than the bottom (tool surface side). The values are given in pounds per linear inch width of specimen.

Core shear was calculated from the short beam flexure tests when core shear failure occurred in those tests. When core shear failure did not occur in short beam flexure tests, flatwise core shear tests were conducted.

2.10.1.1 Comparison of Principal Properties -- In Table 13, a comparison of the same principal properties is made when the material combinations of the composite were changed, but the same resin system (Adlock 851) was used. All fabric styles, except 108, produced the same strength characteristics on multi-ply face sheets varying from ten to twenty-two mils in thickness. Flatwise tension values are relatively low for four plies of 108 face sheet and two plies of 181 face sheet specimens. This may be due to the resin in the 108 fabric and two-ply 181 fabric not being readily available to aid the adhesive in producing a stronger fillet to the core.

The single strand 112 fabric yarn produced a very thin four-ply face sheet of only nine mils thick compared to twelve mils for the two twisted-strands fabric yarn. When using the average measured face sheets, the single strands flexure strength is 44,200 psi, while that of the two twisted strands is 36,300 psi. The edgewise compression tests show the same trend. Single strand 112 has the same strength per ply as the two twisted-strands 112 fabric, but produces a more dense laminate.

Volan A fabric finish appeared to exhibit the best properties when used with Adlock 851 phenolic resin. Panels made with 112 fabric Volan A finish produced consistently higher mechanical properties than those made with A-1100 Silane or S935 finishes when used with a phenolic resin system.

Variation of the number of plies did not significantly alter any of the mechanical properties. However, the compression strength of two plies of 112 glass face sheets did drop about 4,000 psi, which was probably due to premature buckling of the extremely thin face sheet of six mils between the core cells.

Facing Resin System*	Screening													
	(5) Flatwise Tension	Cured % Resin Content	"B" Staged % Content	8-Ply Laminate (5) Flexure psi x 10^{-3}				Face Sheet Thickness MILS	Flexure Q.C. 300°F. (6)	Flatwise Tension (6) psi			
				RT	250°F.	300°F.	350°F.			AVG.	HI	LO	A
Phenolics													
Adlock 851	507	36	44	61	--	54	53	12	--	610	710	510	5
Adlock 453	420	37	45	59	--	51	50	16	43	620	720	530	
91LD**	-	--	46	58	--	49	45	16	--	600	730	420	5
Conolon 506	704	34	45	60	--	52	49	14	61	750	840	690	6
SC 1008	518	40	50	52	--	42	43	12	43	430	440	420	5
Phenolic Silicones													
SC 1013	524	38	55	49	--	41	41	12	42	410	500	330	
Epoxies													
EG-35	660	37	56	60	--	45	39	14	--	620	720	440	7
EG-9300	372	--	48	62	--	54	52	12	45	520	610	430	6
E-740B	540	39	51	51	--	44	39	13	--	550	590	500	6
E-792	594	37	50	53	--	45	42	13	--	390	490	340	6
Narmco 588	560	39	56	50	--	36	25	13	31	345	402	292	
Narmco 500	-	44	49	58	13	11	8	16	--	580	600	560	
Epon 815/Z	-	--	--	68	13	4	4	--	--	-	-	-	
Epon 815/CL	-	46	--	90	11	6	4	--	--	-	-	-	
Epon 826	-	45	--	75	11	6	5	--	--	-	-	-	
Epon 828/1031	760	--	--	70	--	44	18	--	--	-	-	-	
EG-4B	-	--	--	54	40	22	17	--	--	-	-	-	
E-787	-	36	43	62	--	8	7	--	--	-	-	-	
BP-908	-	46	55	49	--	46	43	--	--	-	-	-	
Epoxy Novolacs													
DEN 438	640	43	--	62	--	40	18	15	--	660	810	550	6
DEN 431	-	33	--	65	--	15	11	--	--	750	770	730	
Polyesters													
PG-HTA	556	43	45	48	--	32	25	16	36	480	630	400	6
Vibrin 135	-	--	--	46	--	28	27	15	--	250	270	230	
Vibrin 136	-	--	--	36	--	26	23	15	--	400	450	380	
Polyimides													
2501/FM-96U	-	50	51	38	--	37	32	15	--	380	420	320	
Trevarno F170/ FM-34	508	47	55	44	--	42	36	15	40	453	580	345	5
Narmco 1832/FM-34	400	32	47	49	--	41	34	18	43	370	370	360	

(1) Constant Facing Thickness of .015"

(2) Average Flexure Strength Based on Actual Facing Thickness

(3) In all long b failure occur face sheet.

(5) Values represent the average of three tests.

(6) Values represent the average of five tests.

FOLDOUT FRAME

Table 12. Principal Properties Test Data of Various Resin Systems

atwise sion (6) psi		Flatwise Compression (6) psi			Sandwich Flexure (6) psi x 10^{-3}										Edgewise Compression (1)(6) psi x 10^{-3}					
					Parallel (4)				Perpendicular (3)(4)						Parallel (4)			Perpendicular (4)		
					(2) 1 Long Beam				Short Beam											
HI	LO	AVG.	HI	LO	AVG.	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO
710	510	550	590	470	#36.3	29.1	30.6	26.3	26.1	27.6	25.5	17.2	17.3	16.9	20.5	22.9	19.3	19.0	21.1	16.9
720	530	-	-	-	#24.8	-	-	-	#27.7	28.8	26.4	19.9	20.6	19.1	23.5	24.5	22.6	20.6	22.3	18.4
730	420	510	540	480	#24.7	29.6	30.3	28.2	24.7	27.0	21.9	15.5	16.0	14.6	25.1	25.8	24.5	21.0	26.4	16.5
840	690	630	650	620	#24.9	26.6	28.7	25.7	28.0	29.0	26.7	19.9	20.6	19.4	21.0	23.9	19.2	19.4	21.8	17.5
440	420	570	650	534	#31.3	29.3	30.2	28.0	#29.3	31.5	26.0	21.5	22.4	20.6	24.3	25	23.7	21.7	22.1	21.3
500	330	-	-	-	#29.5	23.6	25.1	22.6	21.8	21.9	21.8	18.8	19.7	18.1	18.3	20.4	15.7	17.2	17.8	16.8
720	440	760	780	720	#28.3	26.4	29.8	23.6	#29.4	30.9	27.9	18.8	19.1	17.9	25.0	27.9	20.9	22.3	24.9	18.5
610	430	640	680	600	#32.3	25.8	27.5	23.0	#24.6	27.1	23.1	21.8	22.4	21.3	13.8	13.9	13.5	12.6	13.4	11.7
590	500	600	660	560	#23.9	20.7	21.5	20.1	#24.1	25.8	21.9	19.5	20.0	19.0	12.6	13.6	11.8	11.0	11.4	10.6
490	340	640	660	630	#27.8	24.1	27.6	22.7	#24.3	25.0	23.3	20.0	21.4	18.8	13.2	14.4	12.0	10.8	11.4	10.2
402	292	-	-	-	#30.0	24.0	24.2	23.3	27.6	28.4	26.8	19.4	20.0	18.2	14.3	15.0	13.5	12.5	14.7	10.1
600	560	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
810	550	680	720	640	#28.8	-	-	-	28.8	30.0	27.1	15.5	16.0	14.8	25.5	29.1	21.0	24.6	25.4	23.6
770	730	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
630	400	630	670	560	#22.2	23.7	24.3	23.5	25.8	26.4	23.8	20.7	21.6	19.7	14.1	14.7	13.0	12.5	13.5	12.0
270	230	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
450	380	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
420	320	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
580	345	561	570	550	#26.4	26.4	28.2	24.8	27.2	28.0	25.6	18.7	19.5	17.9	20.5	21.9	19.7	18.2	19.4	16.5
370	360	-	-	-	#23.7	28.5	29.3	27.6	-	-	-	-	-	-	24.7	26.7	23.3	19.6	21.7	18.8

ll long beam tests, (4) ure occurred in the sheet.

Direction of core ribbon relative to longitudinal axis of the specimen.

* Core-Phenolic, HRP 3/16" Cell 4# density 3/4 T
Adhesive-Epoxy, FM-96U .03#/ft.^{2} (except in the polyimide systems)

** Two-S

FOLDOUT FRAME 2

Various Resin Systems

dicular (4)		Edgewise Compression psi x 10^{-3} (1)(6)						Flatwise Shear psi (6)						Honeycomb Sandwich Peel Top Side (6) In-Lb/In.			Panel Weight lb./ft.^{2}
(4)		Parallel (4)			Perpendicular (4)			Parallel (4)			Perpendicular (4)						
am HI	LO	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	
7.3	16.9	20.5	22.9	19.3	19.0	21.1	16.9	225	235	212	134	135	133	2.6	2.8	2.3	.494
0.6	19.1	23.5	24.5	22.6	20.6	22.3	18.4	-	-	-	-	-	-	-	-	-	.493
6.0	14.6	25.1	25.8	24.5	21.0	26.4	16.5	206	219	182	-	-	-	2.3	2.7	2.0	.492
0.6	19.4	21.0	23.9	19.2	19.4	21.8	17.5	-	-	-	-	-	-	3.3	3.7	3.0	.511
2.4	20.6	24.3	25	23.7	21.7	22.1	21.3	-	-	-	-	-	-	1.7	2.0	1.5	.546
9.7	18.1	18.3	20.4	15.7	17.2	17.8	16.8	-	-	-	-	-	-	-	-	-	.558
9.1	17.9	25.0	27.9	20.9	22.3	24.9	18.5	220	232	209	139	143	134	2.4	2.5	2.2	.556
2.4	21.3	13.8	13.9	13.5	12.6	13.4	11.7	184	203	173	160	170	155	2.1	2.5	1.5	.528
0.0	19.0	12.6	13.5	11.8	11.0	11.4	10.6	182	188	173	147	150	142	2.3	2.4	2.2	.531
1.4	18.8	13.2	14.4	12.0	10.8	11.4	10.2	254	260	250	150	161	141	2.6	3.0	2.2	.509
0.0	18.2	14.3	15.0	13.5	12.5	14.7	10.1	-	-	-	-	-	-	-	-	-	.484
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6.0	14.8	25.5	29.1	21.0	24.6	25.4	23.6	216	-	-	-	-	-	4.0	4.2	3.9	.558
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.6	19.7	14.1	14.7	13.0	12.5	13.5	12.0	193	198	179	170	174	164	2.7	3.0	2.3	.535
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9.5	17.9	20.5	21.9	19.7	18.2	19.4	16.5	202	217	192	140	146	135	5.1	6.5	3.9	.604
-	-	24.7	26.7	23.3	19.6	21.7	18.8	-	-	-	-	-	-	-	-	-	.539

-Phenolic, HRP 3/16" Cell
density 3/4 T
sive-Epoxy, FM-96U
03#/ft.^{2} (except in the
lyimide systems)

** Two-Stage Cure

Failure of specimens occurred in the face sheet. All other flexure specimens failure in core shear.

FOLDOUT FRAME 3

Table 13.

	F.T. (Screening) AVG.	"B" Staged Resin Content %	8-Ply Laminate Flexure psi x 10^{-3} RT	250°F.	300°F.	350°F.	Face Sheet Thickness MILS	Flexure Q.C. 300°F. AVG.	Flatwise Tension psi AVG.	HI	LO	Flatwise Compression psi AVG.	HI	LO	Actual Facing Thickness AVG.	10" Span (Parallel) Long Beam AVG.	HI	LO
Fabric Style (4-ply) *																		
108	-	46	48	--	45	46	10	36.7	340	380	300	-	-	-	-	27.0	27.5	26.4
112	507	44	61	--	54	53	12	--	610	710	510	550	590	470	-	36.3	38.3	33.0
116	-	41	--	--	--	--	15	--	560	590	530	540	570	490	-	32.2	33.3	29.6
120	-	45	56	--	47	46	15	57.4	670	730	590	-	-	-	-	35.6	37.1	31.8
181 (2-ply) **(Twisted)	-	35	69	--	59	57	18	48.2	360	410	300	-	-	-	-	34.4	36.1	33.5
880 **(Singles)	413	46	66	--	61	54	22	57.7	534	604	475	-	-	-	-	--	--	--
Fabric Yarn (112 Style)*																		
2 Twisted Strands (Standard)	507	44	61	--	54	53	12	--	610	710	510	550	590	470	#36.3	29.1	30.6	26.3
Single Strand	772	45	39.9	--	46	46	9	46.0	690	790	640	-	-	-	#44.2	26.5	27.7	25.7
Fabric Finish *(4 Ply)																		
Volan A	507	44	61	--	54	53	12	--	610	710	510	550	590	470	#36.3	29.1	30.6	26.3
A-1100	626	46	41	--	45	45	15	32.1	520	580	450	-	-	-	-	--	--	--
S-935	595	45	45	--	45	44	14	36.3	540	580	450	-	-	-	#26.3	24.6	26.4	23.0
Number of Plies of 112 fabric*, (1)																		
2	-	47	--	--	46	--	6	45.4	600	650	530	-	-	-	#33.2	--	--	--
4	507	44	61	--	54	53	12	--	610	710	510	550	590	470	#36.3	36.3	38.3	33.0
6	590	44	59	--	50	48	17	52.2	570	630	500	570	590	550	#30.7	32.7	33.5	30.7
12	-	45	60	--	57	--	34	56.7	600	650	540	-	-	-	#32.2	21.5	22.8	19.8
Rotation of Plies (6)*																		
45°	-	44	59	--	50	48	17	52.2	570	630	500	570	590	550	#32.7	37.1	38.0	34.8
60°	-	47	60	--	52	51	17	51.5	700	750	670	-	-	-	#31.1	35.2	36.3	34.3
Adhesive Material (4 Ply) *Except for Adhesive																		
Epoxy FM-96U .03 lb./ft.^{2}	507	44	61	--	54	53	12	--	610	710	510	550	590	470	#36.3	29.1	30.6	26.3
Epoxy-Phenolic HT-435U .03 lbs./ft.^{2} (6)	461	46	55	--	44	--	15	42.0	379	460	263	-	-	-	-	--	--	--
Polyimide FM-34/1070 .06 lb./ft.^{2}	508	55	58	--	56	46	15	34.0	490	530	450	560	570	550	#26.4	26.4	28.2	24.8
Adhesive Thickness*(4 Ply)																		
4 Mil	507	44	61	--	54	53	12	--	610	710	510	550	590	470	#36.3	29.1	30.6	26.3
8 Mil	-	45	--	--	51	--	12	51.1	600	740	360	-	-	-	#35.7	28.5	29.7	27.3
Core Material (4 Ply) (7)																		
Phenolic *	507	44	61	--	54	53	12	--	610	710	510	550	590	470	#36.3	29.1	30.6	26.3
Nomex-HRH-10 Core 851/112 Skin	265	47	--	--	43	--	--	--	270	270	260	350	360	340	-	--	--	--
Polyimide ***	320	47	49.3	--	41.1	34.4	.5	42.6	370	380	360	560	570	550	#28.5	29.3	29.3	27.6
Core Shape *(4 Ply)																		
Hex	507	44	61	--	54	53	12	--	610	710	510	550	590	470	#36.3	29.1	30.6	26.3
Flex (HRP-SF-50-40)	-	45	--	--	55	--	15	55.4	470	550	430	390	460	350	-	--	--	--
Dovetail (HTP-3/16" 5.5 lbs.	-	-	--	--	-	--	-	--	464	548	395	745	790	718	-	--	--	--
Core Cell Size *(4 Ply)																		
3/16 in.	507	44	61	--	54	53	12	--	610	710	510	550	590	470	#36.3	29.1	30.6	26.3
1/4 in.	320	45	--	--	45	--	15	45.2	310	340	300	390	410	340	-	--	--	--
Core Thickness *(4 Ply)																		
1/2 in.	601	46	63	--	54	53	13	52.6	630	700	480	540	570	510	#28.1	24.4	25.4	22.6
3/4 in.	507	44	61	--	54	53	12	--	610	710	510	550	590	470	#36.3	29.1	30.6	26.3
1 in.	520	46	63	--	54	53	13	42.1	370	410	300	590	630	570	#31.0	26.9	27.7	25.6
Core Dips *(4 Ply)																		
Normal	507	44	61	--	54	53	12	--	610	710	510	550	590	470	#36.3	29.1	30.6	26.3
1 Extra	418	45	--	--	48	--	13	44.3	540	590	495	930	940	910	#30.1	23.3	24.7	22.4

(1) Results based on constant facing thickness of:

2-Ply - 8 mils
4-Ply - 15 mils
6-Ply - 22 mils
12-Ply - 45 mils

Except for fabric style and no. of plies where actual facing thickness

(2) In all long beam tests, failure occurred in the face sheet.

(3) Direction of core ribbon relative to longitudinal axis of specimen.

(4) Values are the average of three tests.

(5) Values are the average of five tests.

(6) (Ref) paragraph 2.8.2.4.

(7) (Ref) paragraph 2.10.2.3.

* Facings - Phenolic, Adlock 851 resin - E glass

Core - Phenolic, HRP 3/16" cell, 4# density

Adhesive - Epoxy, FM-96U .03 #/ft.^{2}

Table 13. Principle Properties Test Data of Nonmetallic Honeycomb Panels

Sandwich Flexure Strength (5)(1) psi x 10^{-3}									Edgewise Compression (1)(5) psi x 10^{-3}						Flatwise Shear Strength (5) psi						Honeycomb Sandwich Peel Strength Top Side (5)		
10" Span (3) (Parallel) (2)			6" Span (3) (Perpendicular)						(3) Parallel			(3) Perpendicular			(3) Parallel			(3) Perpendicular			In.-Lb./In		
Long Beam			Short Beam																				
AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	
27.0	27.5	26.4	#32.4	33.0	31.0	27.7	29.0	26.3	17.5	19.7	15.3	17.0	19.0	14.7	-	-	-	-	-	-	-	-	
36.3	38.3	33.0	32.3	34.2	31.8	21.3	22.0	20.2	25.6	28.6	24.1	23.8	26.3	21.1	225	235	212	128	130	125	2.6	2.8	
32.2	33.3	29.6	29.7	31.8	27.8	17.5	17.9	17.0	24.2	24.7	23.7	24.0	24.7	23.4	252	261	205	135	138	132	2.5	2.8	
35.6	37.1	31.8	27.6	30.6	26.1	18.8	19.7	17.7	24.1	26.7	21.8	21.5	23.4	19.3	207	229	196	141	148	132	-	-	
34.4	36.1	33.5	26.4	27.9	24.5	20.2	20.6	19.6	27.9	28.5	26.7	23.6	25.5	21.5	-	-	-	-	-	-	-	-	
--	--	--	21.8	23.1	19.6	15.5	16.0	14.6	32.2	34.4	27.3	30.1	31.7	28.4	-	-	-	-	-	-	-	-	
29.1	30.6	26.3	26.1	27.6	25.5	17.2	17.3	16.9	20.5	22.9	19.3	19.0	21.1	16.9	225	235	212	128	128	128	2.6	2.8	
26.5	27.7	25.7	--	--	--	22.2	23.1	21.4	24.6	26.9	22.4	21.8	23.5	20.4	-	-	-	-	-	-	-	-	
29.1	30.6	26.3	26.1	27.6	25.5	17.2	17.3	16.9	20.5	22.9	19.3	19.0	21.1	16.9	225	235	212	128	128	128	2.6	2.8	
--	--	--	24.2	24.7	23.1	18.1	17.7	17.7	18.1	20.1	16.7	14.6	16.1	13.3	-	-	-	-	-	-	-	-	
24.6	26.4	23.0	25.6	26.3	24.5	18.6	19.4	17.4	20.3	21.9	18.3	15.0	15.7	13.7	-	-	-	-	-	-	-	-	
--	--	--	#33.2	35.3	32.4	30.3	32.4	28.4	22.5	24.2	20.5	20.8	23.2	19.3	-	-	-	-	-	-	-	-	
36.3	38.3	33.0	32.6	34.5	31.9	21.5	21.9	21.2	25.6	28.6	24.1	23.7	26.4	21.1	225	235	212	128	128	128	2.6	2.8	
32.7	33.5	30.7	25.0	25.7	23.9	17.5	18.5	15.4	25.7	27.8	24.0	25.7	27.2	23.3	213	221	204	143	156	116	-	-	
21.5	22.8	19.8	13.5	14.0	13.1	9.6	9.8	9.3	27.3	29.7	25.3	24.7	25.5	23.8	230	238	223	163	167	159	-	-	
37.1	38.0	34.8	28.4	29.2	27.1	19.8	21.0	17.4	29.1	31.5	27.2	26.2	27.1	24.4	213	221	204	143	156	116	-	-	
35.2	36.3	34.3	29.1	29.3	28.6	20.3	20.9	19.7	26.4	29.0	23.3	23.8	25.2	22.7	218	220	215	163	167	159	-	-	
29.1	30.6	26.3	26.1	27.6	25.5	17.2	17.3	16.9	20.5	22.9	19.3	19.0	21.1	16.9	225	235	212	128	128	128	2.6	2.8	
--	--	--	27.5	30.3	24.6	20.7	21.7	20.9	16.0	18.2	13.6	16.9	25.6	13.6	-	-	-	-	-	-	-	-	
26.4	28.2	24.8	27.2	28.9	25.6	18.7	19.5	17.9	20.5	21.9	19.7	18.2	19.4	16.5	-	-	-	-	-	-	5.1	6.5	
29.1	30.6	26.3	26.1	27.6	25.5	17.2	17.3	16.9	20.5	22.9	19.3	19.0	21.1	16.9	225	235	212	128	128	128	2.6	2.8	
28.5	29.7	27.3	30.0	30.6	28.2	20.9	21.4	20.4	20.4	23.5	16.8	21.2	23.2	20.9	-	-	-	-	-	-	-	-	
29.1	30.6	26.3	26.1	27.6	25.5	17.2	17.3	16.9	20.5	22.9	19.3	19.0	21.0	16.9	225	235	212	128	128	128	2.6	2.8	
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-	-	-	-	-	-	-	-	
29.3	29.3	27.6	--	--	--	--	--	--	24.7	26.7	23.3	19.6	21.7	17.9	200	220	190	110	110	110	-	-	
29.1	30.6	26.3	26.1	27.6	25.5	17.2	17.3	16.9	20.5	22.9	19.3	19.0	21.0	16.9	225	235	212	128	128	128	2.6	2.8	
--	--	--	21.0	22.6	18.8	14.1	15.8	12.4	12.7	14.0	11.8	11.3	12.1	10.1	192	212	178	116	129	102	2.8	3.2	
--	--	--	--	--	--	--	--	--	20.1	22.3	16.4	17.5	18.8	16.0	-	-	-	-	-	-	-	-	
29.1	30.6	26.3	26.1	27.6	25.5	17.2	17.3	16.9	20.5	22.9	19.3	19.0	21.0	16.9	225	235	212	128	128	128	2.6	2.8	
--	--	--	20.1	21.6	17.9	15.2	16.0	14.5	18.5	19.5	17.8	12.8	14.0	11.9	-	-	-	-	-	-	2.4	3.0	
24.4	25.4	22.6	#26.4	27.0	25.6	19.6	20.3	18.6	14.0	14.8	13.2	12.8	13.5	11.8	233	252	209	147	152	139	-	-	
29.1	30.6	26.3	26.1	27.6	25.5	17.2	17.3	16.9	20.5	22.9	19.3	19.0	21.0	16.9	225	235	212	128	128	128	2.6	2.8	
26.9	27.7	25.6	22.0	23.2	19.8	17.1	18.8	15.0	12.7	13.6	12.0	11.1	11.7	10.2	-	-	-	-	-	-	-	-	
29.1	30.6	26.3	26.1	27.6	25.5	17.2	17.3	16.9	20.5	22.9	19.3	19.0	21.0	16.9	225	235	212	128	128	128	2.6	2.8	
23.3	24.7	22.4	26.1	26.5	25.5	23.3	23.6	22.9	20.7	21.5	19.1	19.5	20.1	18.9	270	280	250	180	180	170	-	-	

nolic, Adlock
glass

ic, HRP 3/16"
ity

oxy, FM-96U

** All values based on actual facing thickness.

*** Facing - Polyimide
Adhesive - Polyimide

Failure of specimen occurred in the face sheet. All other flexure specimens failed in core shear.

FOLDOUT FRAME 2

Flatwise Shear Strength (5) psi						Honeycomb Sandwich Peel Strength Top Side (5)			Panel Weight
(3) Parallel			(3) Perpendicular			In.-Lb./in.			lb./ft.^{2}
AVG.	HI	LO	AVG.	HI	LO	AVG.	HI	LO	
-	-	-	-	-	-	-	-	-	.427
225	235	212	128	130	125	2.6	2.8	2.3	.494
252	261	205	135	138	132	2.5	2.8	2.0	.539
207	229	196	141	148	132	-	-	-	.571
-	-	-	-	-	-	-	-	-	.638
-	-	-	-	-	-	-	-	-	.757
225	235	212	128	128	128	2.6	2.8	2.3	.494
-	-	-	-	-	-	-	-	-	.536
225	235	212	128	128	128	2.6	2.8	2.3	.494
-	-	-	-	-	-	-	-	-	.477
-	-	-	-	-	-	-	-	-	.497
-	-	-	-	-	-	-	-	-	.395
225	235	212	128	128	128	2.6	2.8	2.3	.494
213	221	204	143	156	116	-	-	-	.595
230	238	223	163	167	159	-	-	-	.897
213	221	204	143	156	116	-	-	-	.595
218	220	215	163	167	159	-	-	-	.593
225	235	212	128	128	128	2.6	2.8	2.3	.494
-	-	-	-	-	-	-	-	-	.494
-	-	-	-	-	-	5.1	6.5	3.9	.604
225	235	212	128	128	128	2.6	2.8	2.3	.494
-	-	-	-	-	-	-	-	-	.522
225	235	212	128	128	128	2.6	2.8	2.3	.494
-	-	-	-	-	-	-	-	-	-
200	220	190	110	110	110	-	-	-	.539
225	235	212	128	128	128	2.6	2.8	2.3	.494
192	212	178	116	129	102	2.8	3.2	2.5	.490
-	-	-	-	-	-	-	-	-	-
225	235	212	128	128	128	2.6	2.8	2.3	.494
-	-	-	-	-	-	2.4	3.0	1.8	.447
233	252	209	147	152	139	-	-	-	.405
225	235	212	128	128	128	2.6	2.8	2.3	.494
-	-	-	-	-	-	-	-	-	.578
225	235	212	128	128	128	2.6	2.8	2.3	.494
270	280	250	180	180	170	-	-	-	.525

FOLDOUT FRAME 3

Rotation of six plies at 45° or at 60° seemed to have very little effect on the strength of the face sheets.

Comparison of FM-96U, .03 lb./ft.^{2}; HT-435U, .03 lb./ft.^{2}; and FM-34S, .06 lb./ft.^{2} adhesive revealed that FM-96 was consistently stronger than the phenolic or polyimide adhesive, both during the screening test and the test of the large 27-inch-square panel. However, elevated temperature tests discussed later in this report show that FM-96U is inferior to the phenolic and the polyimide adhesives at 350°F. and 600°F. The lightest available FM-34S polyimide adhesive is twice as heavy as either of the other two.

When the FM-96U adhesive is doubled in thickness, no change in mechanical properties of the sandwich composite occurred. This shows that the ultra-lightweight four-mil FM-96U adhesive appears to be optimum when used in conjunction with this resin/glass system. However, as will be seen in the section of aluminum sandwich panels, a heavier adhesive is required.

Separate charts (reference Table 17) show strength comparisons of core configurations, cell sizes, and the effects of an extra coat of resin. The effect of core thickness on sandwich flexural and edgewise compression strength is given in Table 13. The three-fourth-inch thick core produces consistently higher sandwich flexure and edgewise compression strengths than the one-half-inch and one-inch thick core. None of the other mechanical properties would be significantly affected by core thickness variation.

2.10.1.2 Laminate Flexure Strength Versus Temperature -- Figures 13 through 19 depict laminate flexure strength versus temperature for all of the resin systems evaluated. The specimens were conditioned at temperature for ten minutes prior to testing at temperature. These tests were the basis for either continuing the evaluation by fabrication of 27-inch by 27-inch sandwich panels or dropping the system. Notice that EG-9300, EG-35, E-792, E-740B, and BR-908 were the only epoxies that maintained strength

Table 14. Effect of Test Temperature on the Principal Properties of Various Resin Systems

Material Combination*	Test Temp. °F.	Flexural Strength psi x 10^{-3}						Edgewise Compression psi x 10^{-3}						Facing Thickness in.****	Flatwise Tension psi		
		Parallel			Perpendicular			Parallel			Perpendicular						
		Avg.	Hi	Lo	Avg.	Hi	Lo	Avg.	Hi	Lo	Avg.	Hi	Lo		Avg.	Hi	Lo
F-170/112** (Polyimide) 4-ply facing	-150	32.8	33.8	31.9	25.0	26.3	24.5	26.4	26.7	25.1	25.2	27.5	23.3	.015	360	380	330
	R.T.	27.2	28.9	25.6	18.7	19.5	17.9	20.5	21.9	19.7	18.2	19.4	16.5	.015	450	580	350
	+350	20.4	21.1	19.9	16.3	16.8	15.9	14.9	15.6	14.6	13.9	14.8	13.4	.015	270	280	260
Conolon 506/112*** (Phenolic) 4-ply facing	-150	30.1	31.5	28.9	22.5	24.1	21.5	25.8	27.1	24.7	24.1	25.8	22.0	.016	390	430	350
	R.T.	26.2	27.1	24.9	18.7	19.3	15.9	19.7	22.4	18.0	18.2	20.4	16.4	.016	750	840	690
	+350	9.5	10.2	8.8	8.8	9.1	8.3	5.5	6.1	5.1	4.5	5.1	3.8	.016	40	50	30
EG-35/112*** (Epoxy) 4-ply facing	-150	36.9	40.7	35.3	22.6	23.4	20.6	28.8	31.5	25.9	19.4	21.2	17.8	.014	330	370	300
	R.T.	31.5	33.1	29.9	19.8	20.5	19.1	22.3	24.0	21.0	20.6	22.2	19.6	.014	620	720	440
	+350	5.7	6.0	5.3	4.9	5.2	4.6	3.6	3.7	3.4	3.2	3.4	2.9	.014	90	100	80
Adlock 851/112*** (Phenolic) 6-ply facing	-150	30.6	31.5	29.1	20.6	21.4	18.7	33.6	37.7	31.5	30.1	38.2	25.7	.018	450	640	300
	R.T.	24.8	25.7	23.8	16.8	18.3	13.6	27.4	29.1	25.9	25.7	27.2	23.2	.017	570	630	500
	+350	14.5	17.3	11.1	11.0	12.2	9.7	17.4	19.4	13.9	13.5	15.5	10.4	.018	70	80	70

*Phenolic core was used in all combinations, values based on the average of five tests.

**Bonded with FM-34 polyimide adhesive.

***Bonded with FM-96 modified epoxy adhesive.

****Actual facing thickness.

Table 15. Effect of Heat Sterilization and Ethylene Oxide Decontamination

	Flatwise Tension	Flexural Strength psi x 10^{-3}		Edgewise Compression psi x 10^{-3}		Tensile psi x 10^{-3}	Core Shear psi		Core Compr. psi
		Parallel	Trans.	Parallel	Trans.		Parallel	Trans.	
Control	570	25.3	13.0	21.1	19.9	30.5	210	140	570
Sterilized	670	26.7	13.5	19.9	17.9	34.7	210	150	550

Materials: Adlock 851/112 6-ply facings
FM-96U .03#/sq. ft. adhesive
3/16" cell 4.0# density hexagonal core

NOTE: Values represent the average of five tests.
Decontamination temperature 122°F. for 168 hours.
Dry heat sterilization of 275°F. for 552 hours.

Table 16. Effect of Vacuum on the Principal Properties of Composites

Test Condition	Flatwise Tension			Laminate Flexure Modulus psi x 10^{-6}			Laminate Flexure Strength psi x 10^{-3}		
	Avg.	Hi	Lo	Avg.	Hi	Lo	Avg.	Hi	Lo
Control (ambient)	620(1)	710	530	1.5(3)	1.5	1.5	46.3(3)	47.0	45.6
Conditional 12 hrs. at 10^{-6} torr minimum tested in atmosphere	610(1)	740	520	-	-	-	-	-	-
Conditioned 12 hrs. at 10^{-6} torr minimum tested in vacuum	630(2)	690	610	1.5(2)	1.5	1.4	48.6(2)	50.5	47.6

(1) Average of 6 tests

(2) Average of 3 tests

(3) Average of 2 tests

Materials: Adlock 851/112

FM-96U .03#/ft.^{2}

3/16 cell 4# density phenolic hexagonal core

Table 17. Core Evaluation

Cell Size	Configuration	Resin/ Reinforcement	Density	Core Compression psi			Shear Stress psi Parallel			Shear Stress psi Transverse			Shear Modulus psi x 10^{-3} Parallel	Shear Modulus psi x 10^{-3} Transverse
				Avg.	Hi	Lo	Avg.	Hi	Lo	Avg.	Hi	Lo	Avg.	Avg.
3/16	Hexagonal	Phenolic/ Glass	4.0	550	590	470	230	240	210	130	130	130	12.9	5.6
3/16	Hexagonal	Phenolic*/ Glass	4.5	930	940	910	270	280	250	180	180	170	17.9	-
1/4	Hexagonal	Phenolic/ Glass	3.6	390	410	340	190	190	180	130	140	130	13.9	7.7
-	Flexcore	Phenolic/ Glass	4.2	390	460	350	190	200	190	120	130	100	9.2	4.4
3/16	Hexagonal	Polyimide/ Glass	4.0	710	740	670	240	250	230	130	140	130	14.7	6.2
3/16	Hexagonal	Phenolic/ Nylon-Paper (Nomex)	3.9	350	360	340								
	Dovetail	Phenolic/ Glass	6.0	745	790	718	298	311	283	116	121	108	13.0	3.9

NOTE: The values represent the average of five tests for sandwich compression and sandwich plate shear.

* Extra coat of resin.

Table 18. Test Data of Spliced Face Sheets and Nonrecessed Doubler

	Flexural Strength x 10^{-3} psi			Edgewise Compression x 10^{-3} psi		
	Avg.	Hi	Lo	Avg.	Hi	Lo
Aligned Splice	24.3	26.1	22.6	19.1	19.9	17.6
Staggered Splice	23.5	24.0	22.6	20.7	21.3	20.3
No Splice or Doublers	25.3	25.9	23.0	19.9	20.9	18.9
3" Doubler*	27.5	22.5	26.1	-	-	-
3" Doubler**	14.9	15.8	14.7	-	-	-

Materials: Adlock 851/112 6-ply facings
FM-96U Adhesive
3/16" cell, 4# density, 3/4T phenolic honeycomb core

*Tested with internal doubler in tension.

**Tested with internal doubler in compression.

NOTE: Values represent the average of five tests.

Table 19. Evaluation of Core Splice Techniques

Method	Δ Core Shear - psi			
	Ribbon Direction Relative to Specimen Length			
	Parallel	Trans.	20°	70°
No Splice (Control)	210*	150*	180*	-
Overlap core splice located perpendicular to longitudinal axis##	250*@#	190*@#	-	130**
Butt splice with FM-40 located perpendicular to longitudinal axis	260*@	190*@	-	160*
Overlap core splice located through longitudinal axis##	-	-	160ΔΔ	-
Butt splice with FM-40 located through longitudinal axis	-	-	200*	-

Materials: Adlock 851 phenolic facings with 112 glass cloth except where noted
FM-96U adhesive
3/16 cell, 4. # density, 3/4T phenolic honeycomb core
FM-40 splicing adhesive 0.050" thick

NOTES:
- Δ Core splices perpendicular to longitudinal axis are located in maximum shear zone.
- * Core shear failure.
- ΔΔ Skin failed in compression.
- ** Core pulled away from skin.
- @ 181 glass fabric facings.
- # 3/4" overlap splice stabilized with BR-227 Type III pour coat.
- ## One cell minimum, two cell maximum overlap, except where noted.

Values represent the average of five tests.

up to 350°F. The epoxy-novolacs DEN 438 and DEN 431 exhibited most high temperature strength. The phenolics produced a relatively flat curve. All polyesters and butadiene styrenes gave poor results. Trevarno F-170 was the better of the polyimides with high strength from room temperature out to 50°F.

2.10.1.3 Composite Weights -- A very important factor in selecting or comparing composites is the relative difference in their weights. Figure 33 depicts the specific strength (strength divided by weight) of each resin system with 112 glass at both room temperature and 350°F. The specimens were conditioned at 350°F. for ten minutes prior to testing at that temperature. The initial prepreg resin content is very significant in determining the final weight, since very little resin can be bled off during a one-step sandwich cure.

Adlock 851 phenolic and EG-9300 epoxy exhibited the highest specific strengths at room temperature and 350°F. All of the phenolics had satisfactory strengths at room temperature and 350°F., but the other types had specific strengths varying from very poor to satisfactory.

2.10.1.4 Flexure Strength for Various Glass Finishes and Styles -- Figures 34 and 35 show flexure strength for three glass finishes and for five glass styles, respectively, using the same resin system (Adlock 851). Contrary to published data, the Volan A finish produced significantly higher results than A-1100 or S-935 finishes. While this is true of Adlock 851 phenolic resin system, it may not be typical of other phenolics, epoxies, etc. Also, the A-1100 glass finish is known to retain its strength after heat aging for a long time at elevated temperature, which can be observed on the graph for short time exposure. The 181 and 880 glass appear to be the strongest, with the lightweight 112 slightly lower, and the 120 crowfoot-satin weave and 108 substantially lower in strength. The 181 and 880 styles have and eight-harness-satin weave, and the 880 ECG1501/0 is a single yarn. The higher strengths obtained by the 181 and 880 may be attributed to their heavier gage and consequently thicker eight-ply laminate.

tension, the Conolon 506, Adlock 851, and F-170 produce almost the same strengths at -150°F. and room temperature, with EG-35 epoxy system considerably higher. At 350°F. the polyimide again retains a high percentage of its strength while the other systems, particularily the epoxy, lose a high percentage of room temperature strength. Adlock 851 retained about 60% of its room temperature strength at 350°F., which is probably attributable to six-ply face sheets in lieu of four plies. Also, full flexural strength for Adlock 851 is not recorded because the core failed in shear due to the heavier face sheets. Flexure strength with the ribbon direction perpendicular to the length of the specimen, produced similar results at 350°F. At -150°F. and room temperature, the results were almost identical for all systems because the mode of failure was core shear. The edgewise compression test results show Adlock 851 superior at -150°F. and room temperature, and almost the same as F-170 at 350°F. EG-35 epoxy and Conolon 506 drop drastically at 350°F. The same relative trend and strength values are shown when tested with the ribbon direction perpendicular to the length of the specimen.

Table 14 lists the low, high, and average results of the above mechanical property data.

2.10.2 RESULTS AND CONCLUSIONS OF SPECIAL TESTS.

2.10.2.1 Tests after Exposure to Ethylene Oxide and Elevated Temperature -- Honeycomb sandwich panels fabricated from Adlock 851/112 were exposed to ethylene oxide decontamination at a temperature of 122°F. for 168 hours and a dry heat sterilization of 275°F. for 552 hours at Jet Propulsion Laboratory. The long exposure to 275°F. which served to post cure the composite, deepened the color of the resin to a dark red. Most of the mechanical properties of the composite sandwich improved slightly as shown in Table 15. The increase in strength was attributed to a post-curing effect and a normal scatter.

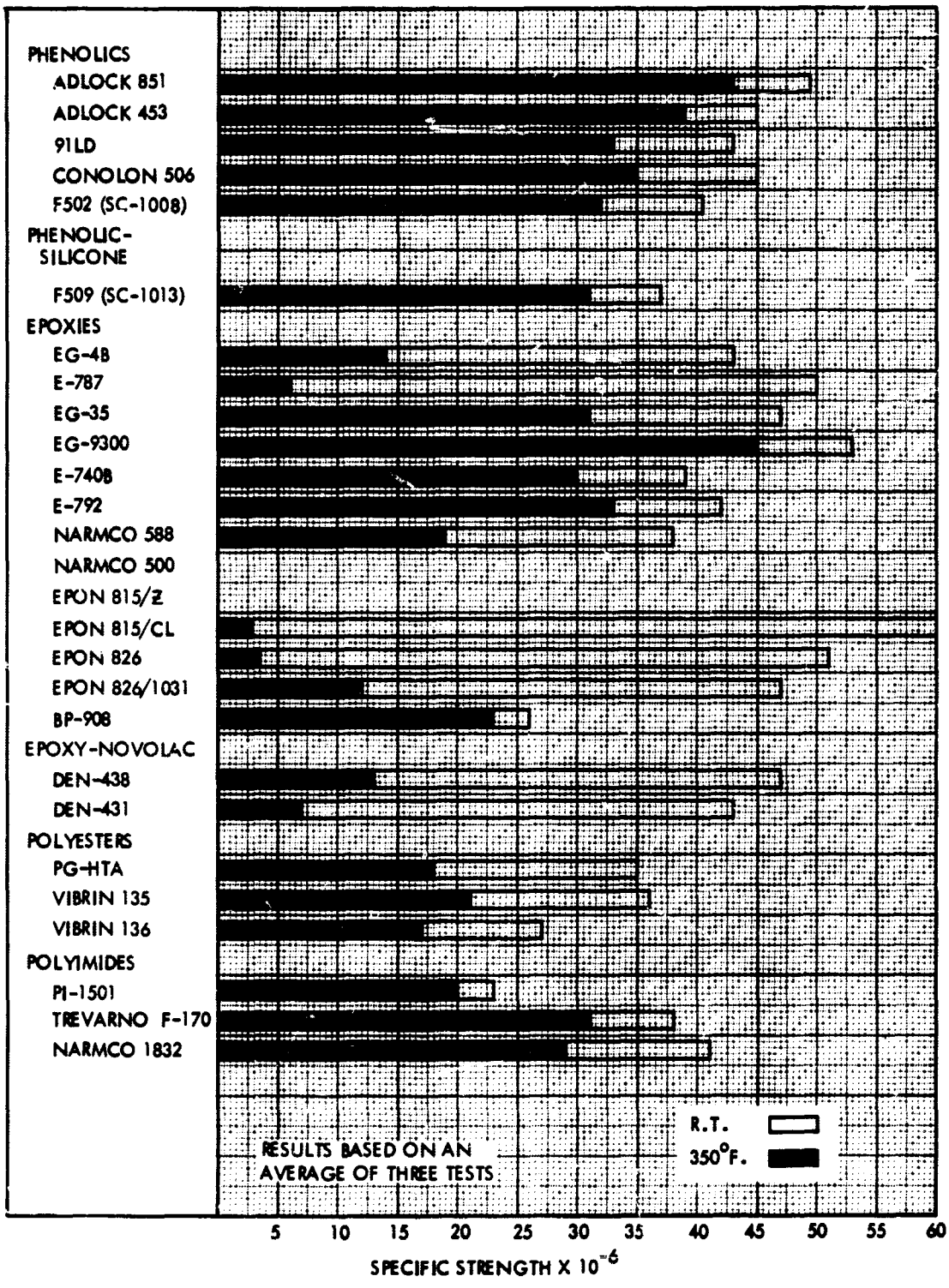


Figure 33. Specific Laminate Flexural Strength.

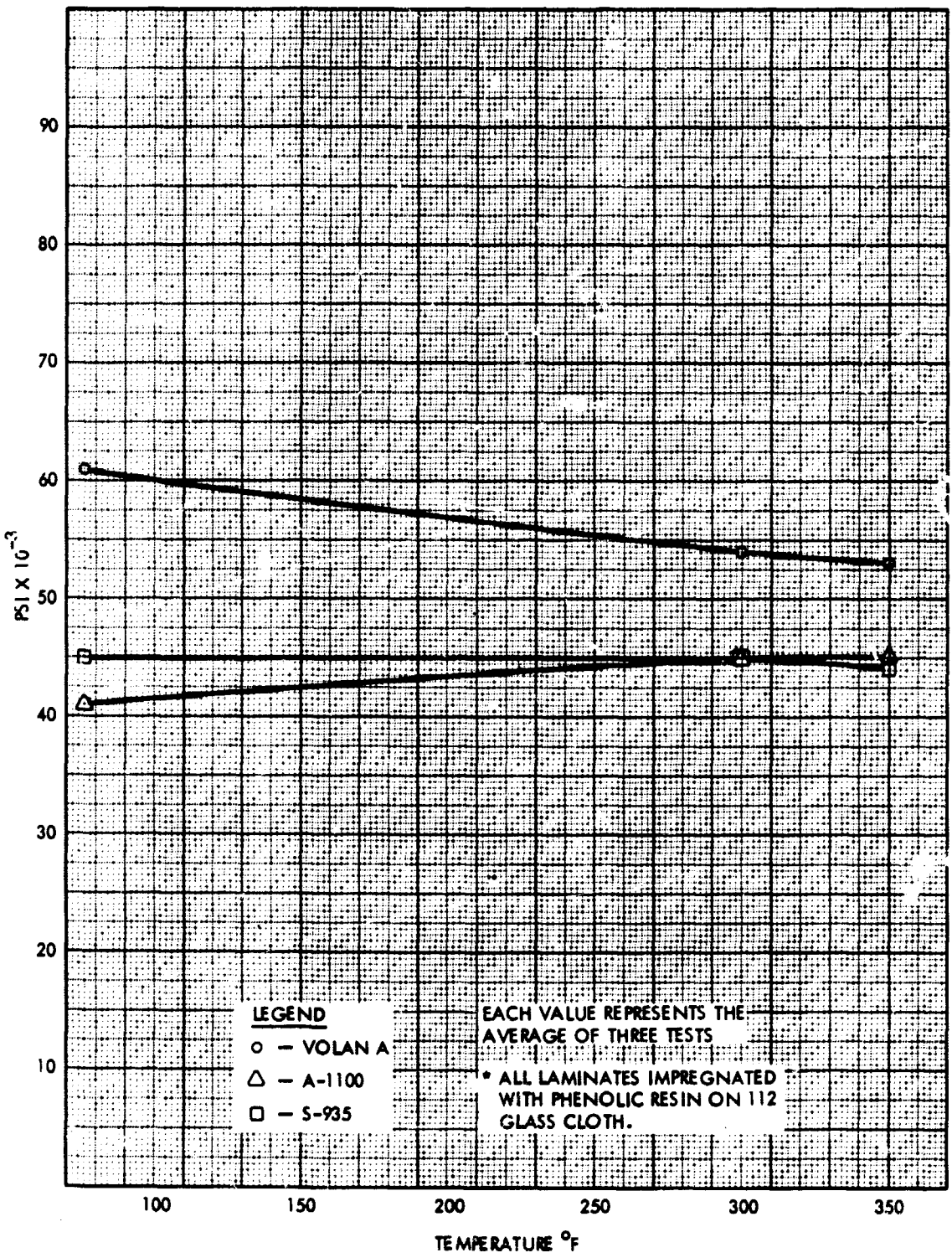


Figure 34. Flexure Strength for Eight-Ply Laminate Versus Temperature, Glass Finish*.

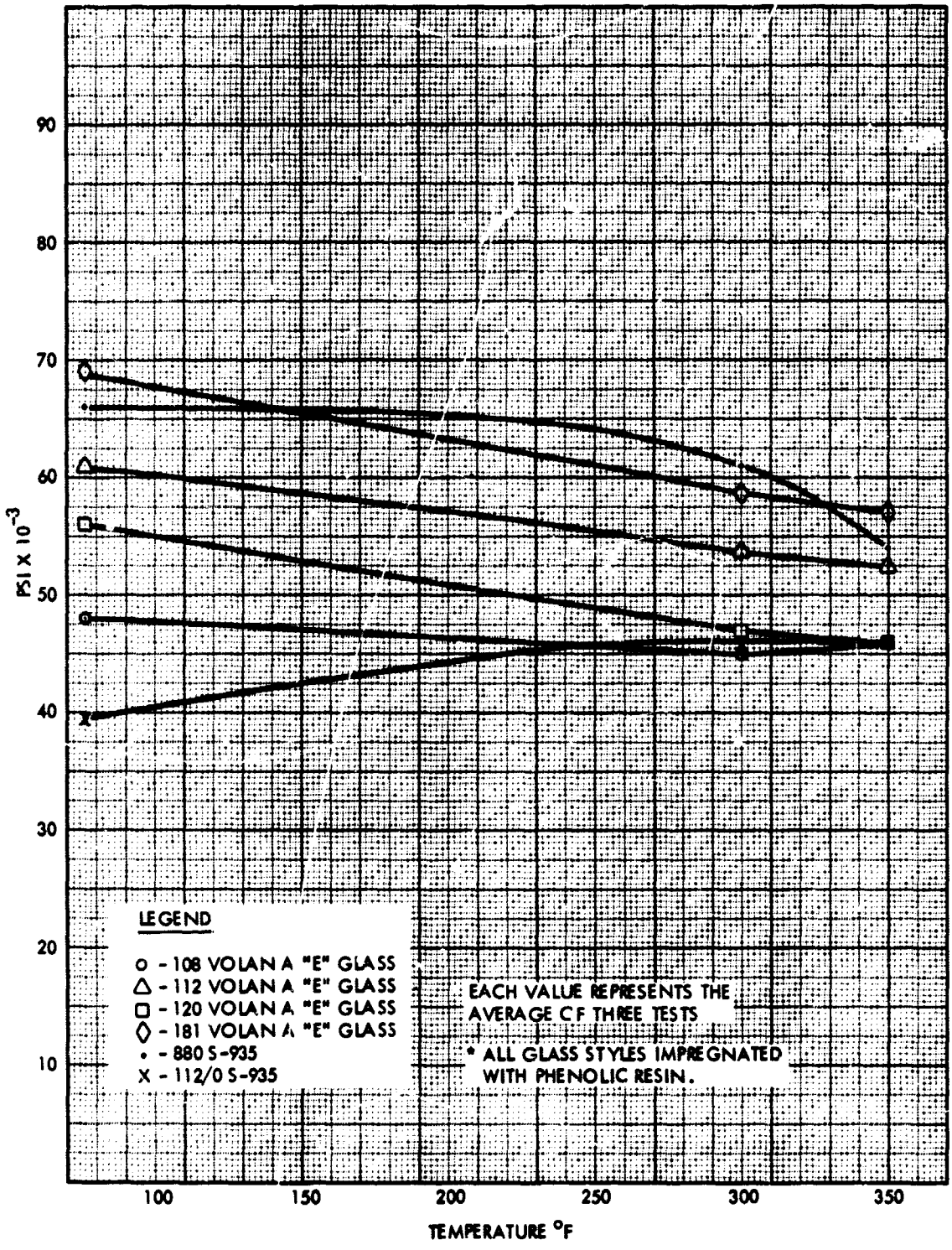


Figure 35. Flexure Strength 8-Ply Laminate Versus Temperature, Glass Styles

The 112 glass has a plain weave and unlike the flimsy 108 glass, it holds its shape and performs satisfactorily.

2.10.1.5 Flexure Modulus Versus Temperature -- In Figures 36 through 40, flexure modulus versus temperature is given for resin systems reinforced with E112 Volan A woven glass cloth. EG-9300 epoxy produced the highest flexural modulus at 300°F. (2.9×10^6). The curves of the phenolic and polyimides are fairly flat as they were for flexure strength versus temperature. Epoxy/Novolac systems gave a high modulus of approximately 3×10^6 psi at room temperature, but dropped down to approximately 1.5×10^6 at 300°F. and 350°F. The modulus of the polyesters was fair at all temperature ranges.

2.10.1.6 Flexure Modulus of Various Glass Finishes and Styles -- Figures 41 and 42 show the relative effect of fabric finish and glass style on flexure modulus at various temperatures. There was no significant difference between A-1100, S-935, or Volan A finishes, although the S-935 curve appeared to flatten out between 300°F. and 350°F., while the others dropped. For the glass systems, 108 had the highest modulus, with 112, 120, 880 and 181 slightly lower in that order. It is interesting to note that the relative flexural strengths of the same glass styles were reversed from this order. (NOTE: Straight lines were drawn through the three points and do not reflect the modulii between points.)

2.10.1.7 High and Low Temperature Effects -- Figures 43 through 47 show principal property test results for sandwich panels fabricated from four material combinations and tested at -150°F. room temperature, and 350°F. The flatwise tension graph shows that all materials tested had satisfactory strength at -150°F. and an increase in strength at room temperature, with Conolon 506 the highest and F-170 polyimide the lowest. However, at 350°F. the all polyimide system retained a much higher percentage of its room temperature strength than the systems comprised of other resins bonded with FM-96U epoxy adhesive. In the sandwich flexural tests where the maximum strength of the adhesive is not measured as it is in flatwise

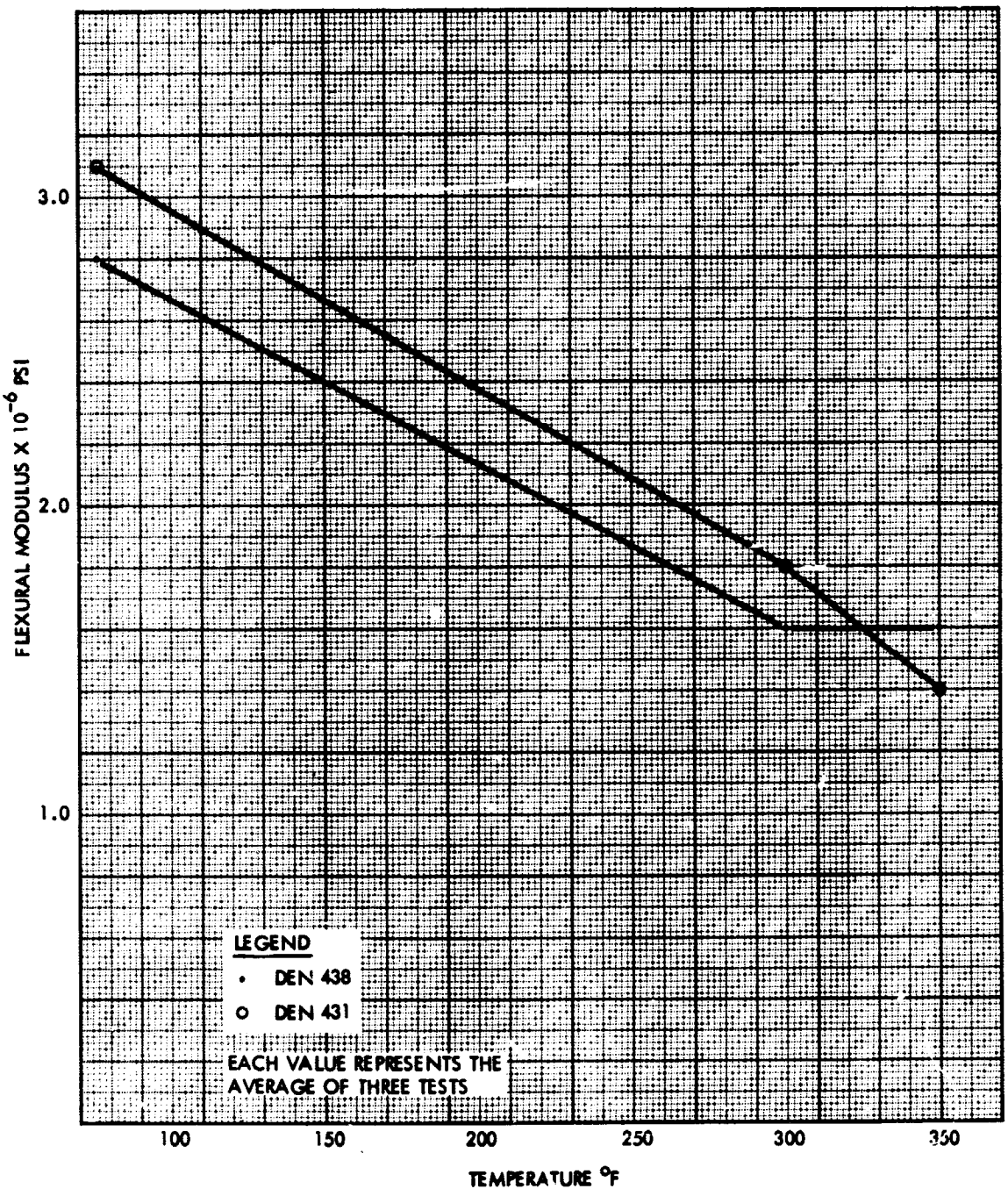


Figure 36. Flexural Modulus Versus Temperature °F. for Eight-Ply Laminates, Epoxy Novolacs.

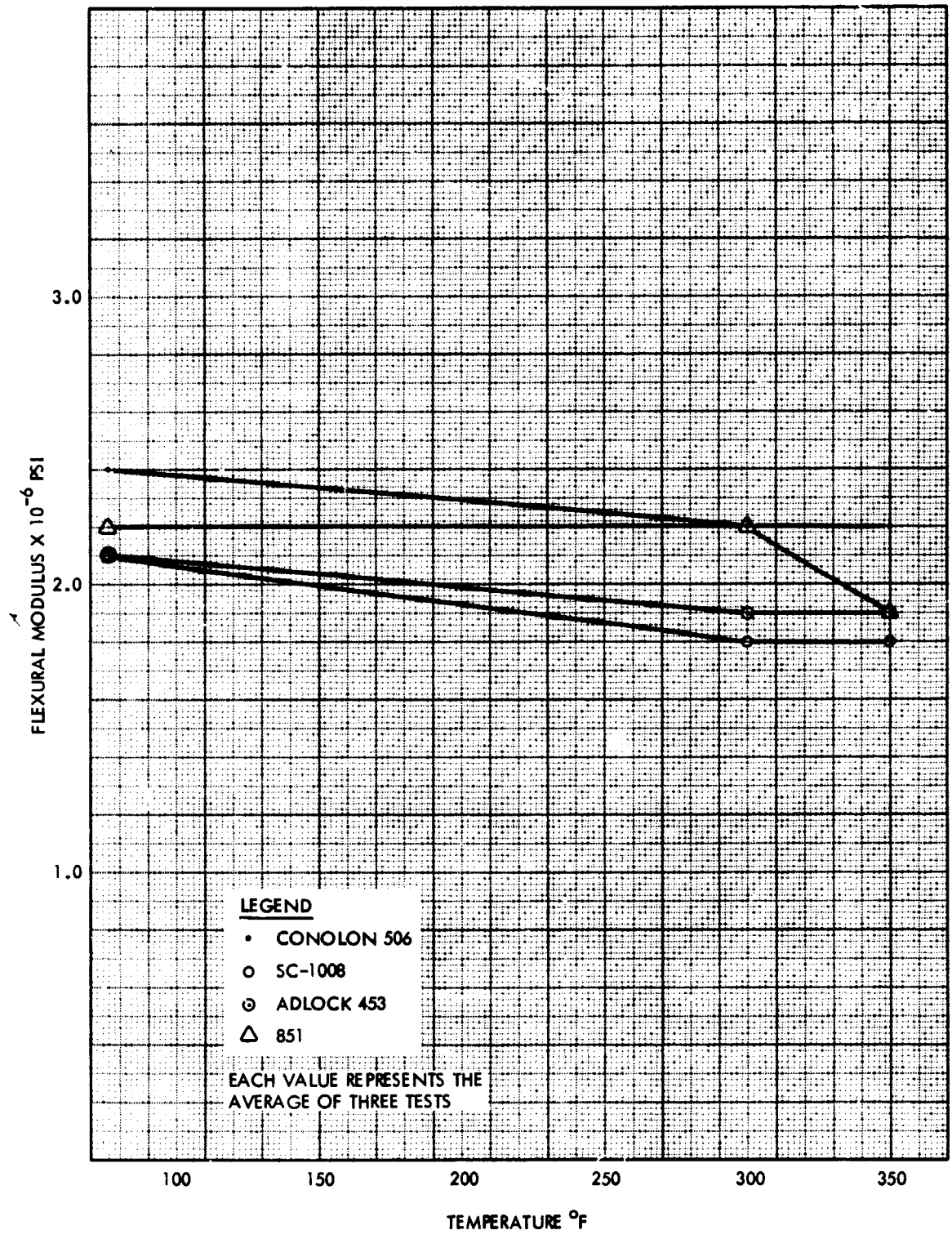


Figure 37. Flexural Modulus Versus Temperature °F. for Eight-ply Laminates, Phenolics.

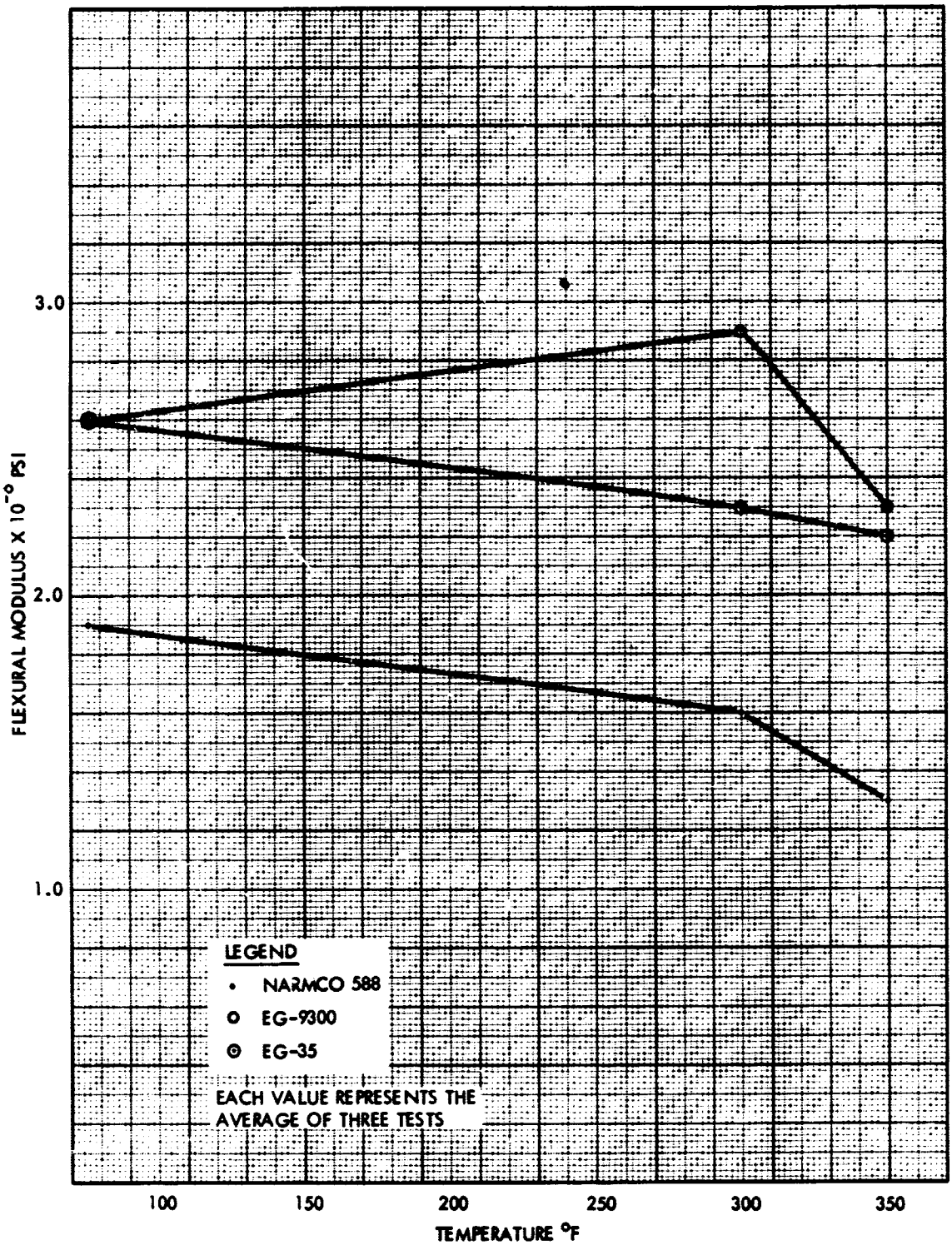


Figure 38. Flexural Modulus Versus Temperature °F. for Eight-ply Laminates, Epoxies.

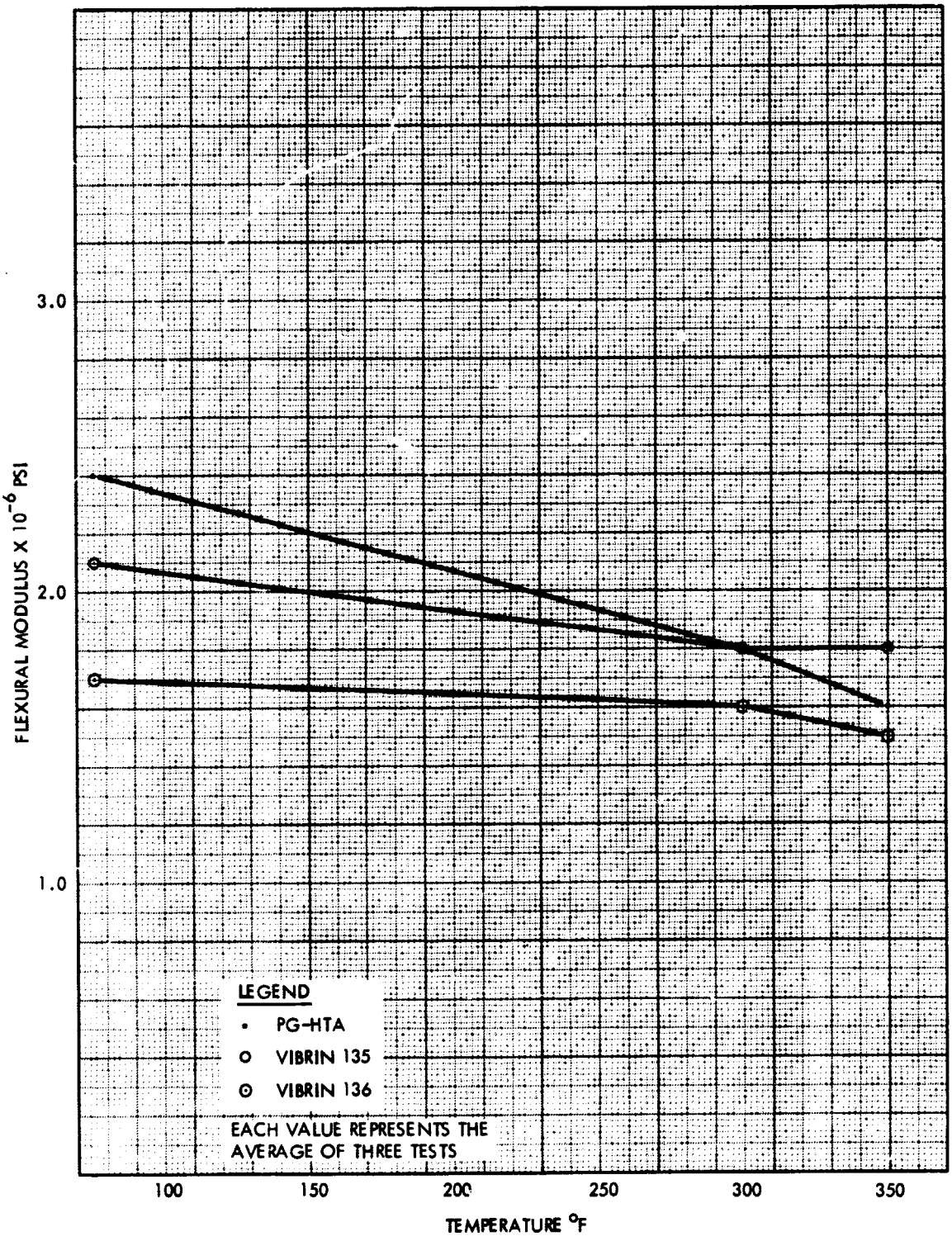


Figure 39. Flexural Modulus Versus Temperature °F. for Eight-ply Laminates, Polyesters.

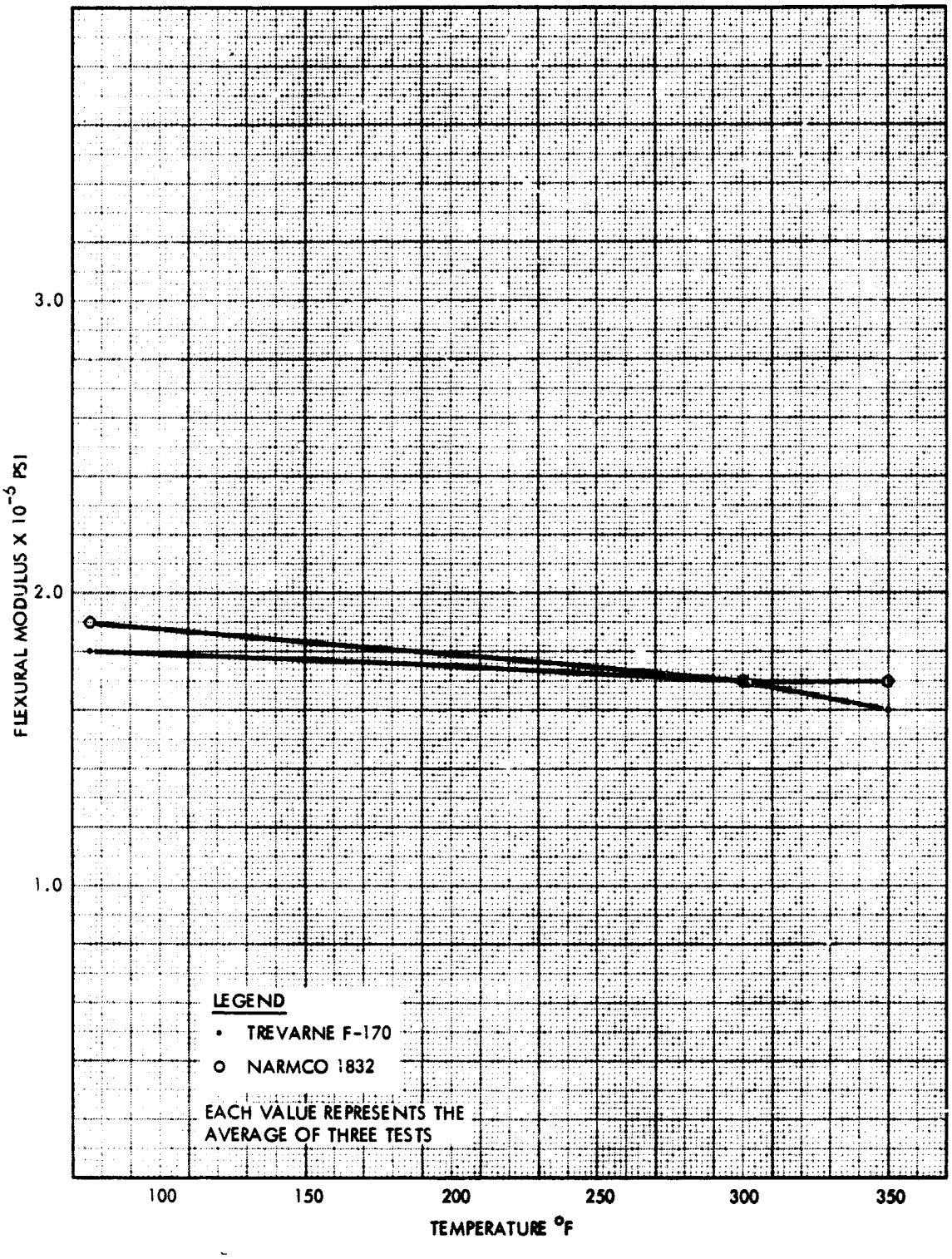


Figure 40. Flexural Modulus Versus Temperature °F. for Eight-ply Laminates, Polimides.

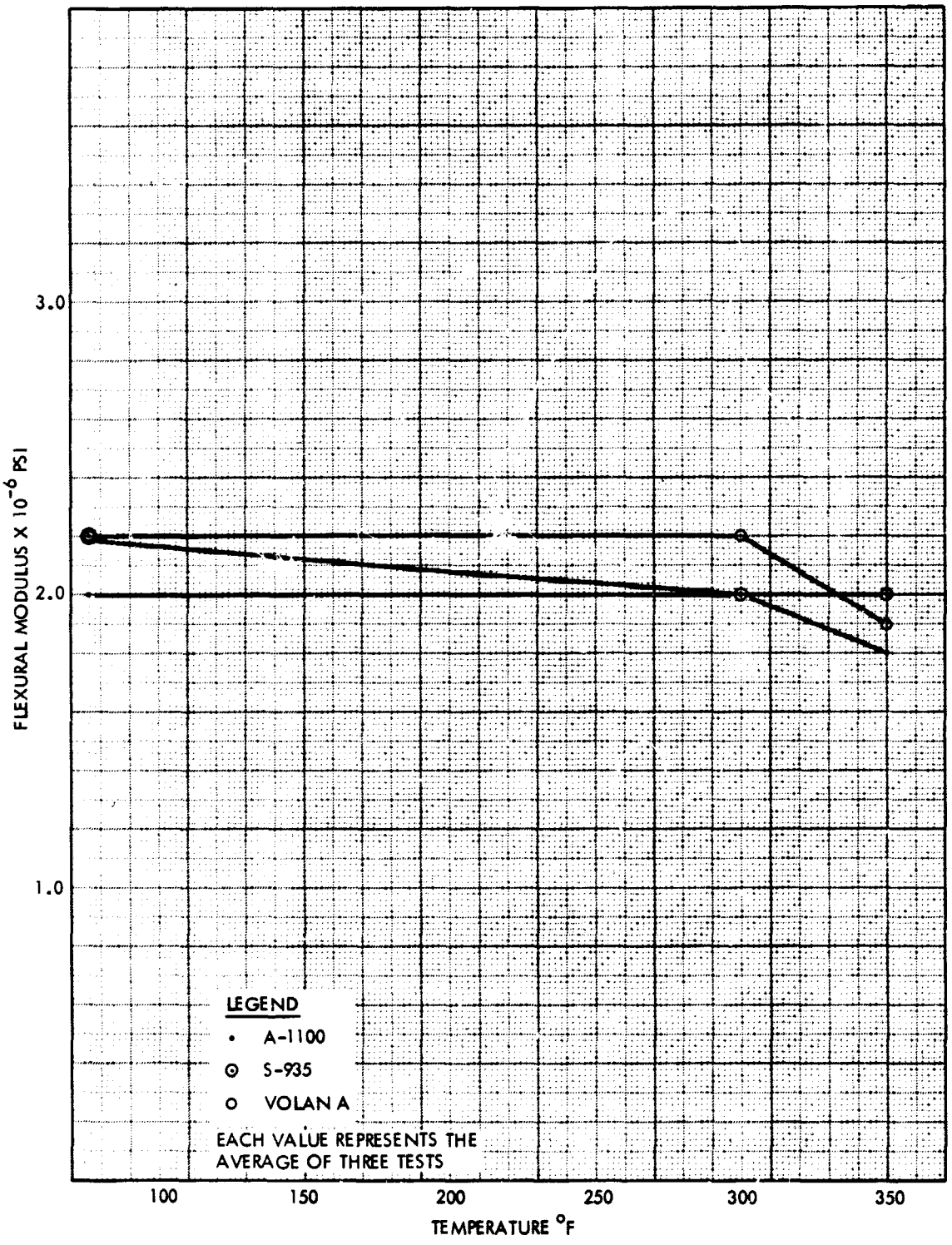


Figure 41. Flexural Modulus Versus Temperature °F. for Eight-ply Laminates, Fabric Finish.

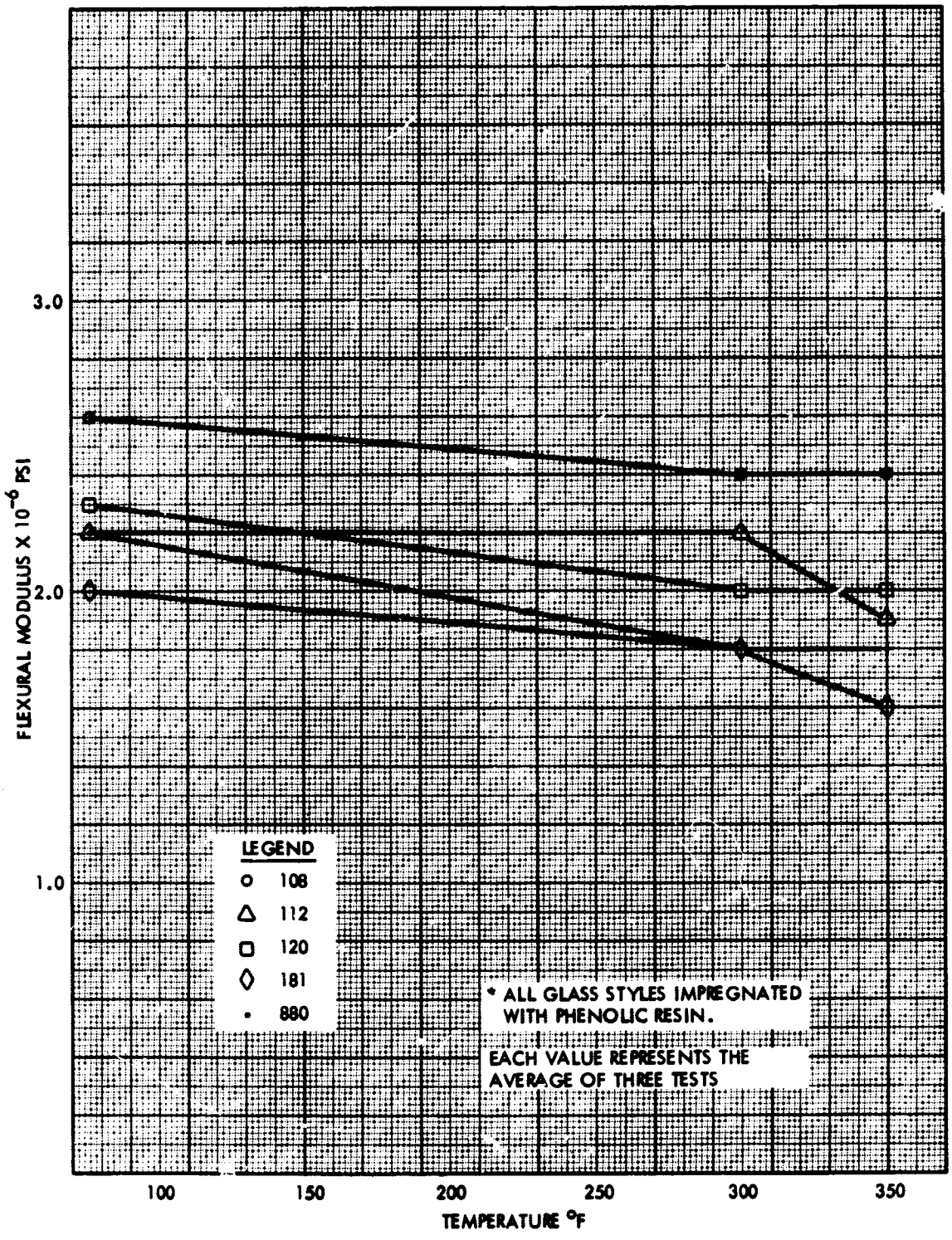


Figure 42. Flexural Modulus Versus Temperature °F. for Eight-Ply Laminates, Glass Styles*.

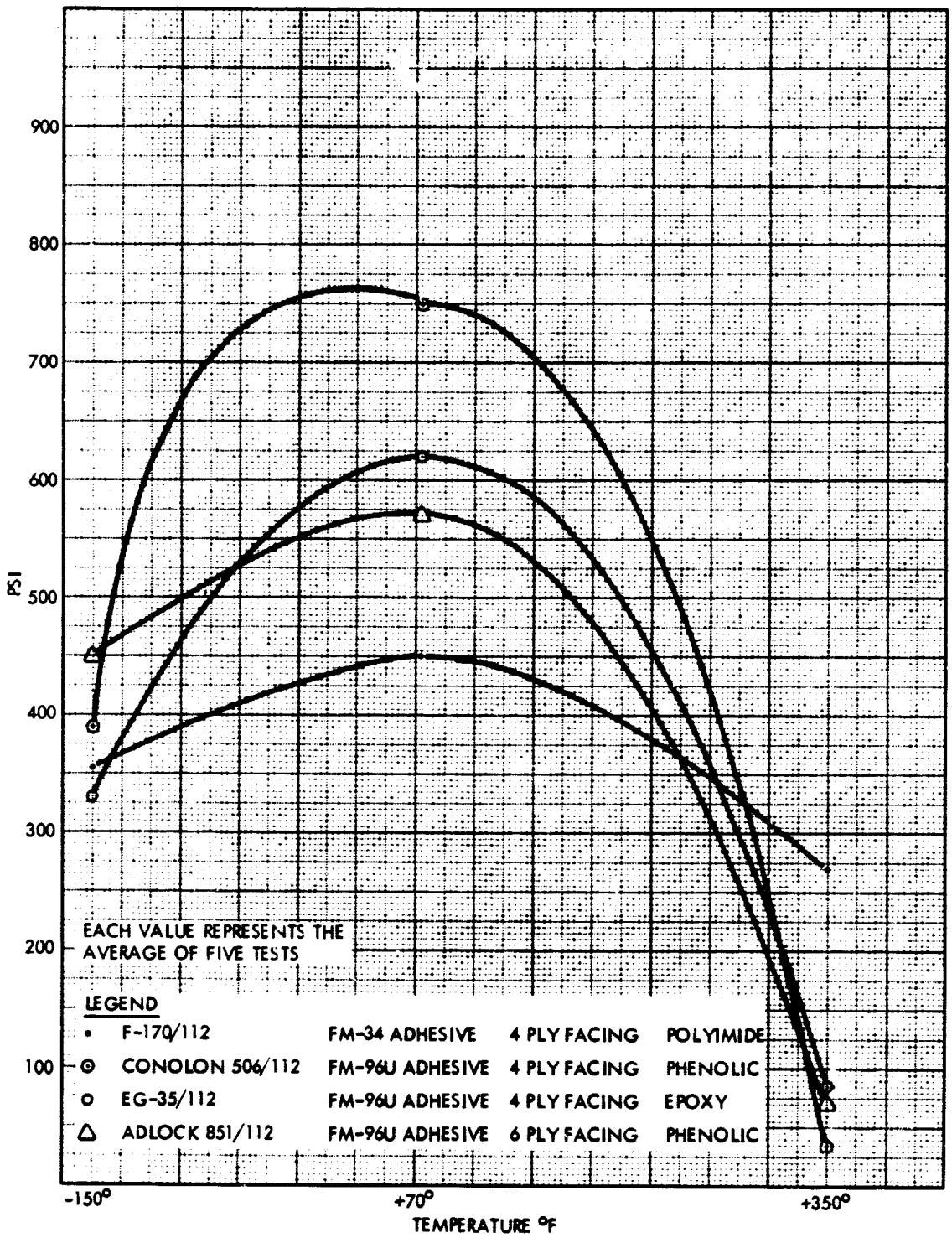


Figure 43, Flatwise Tension Versus Temperature

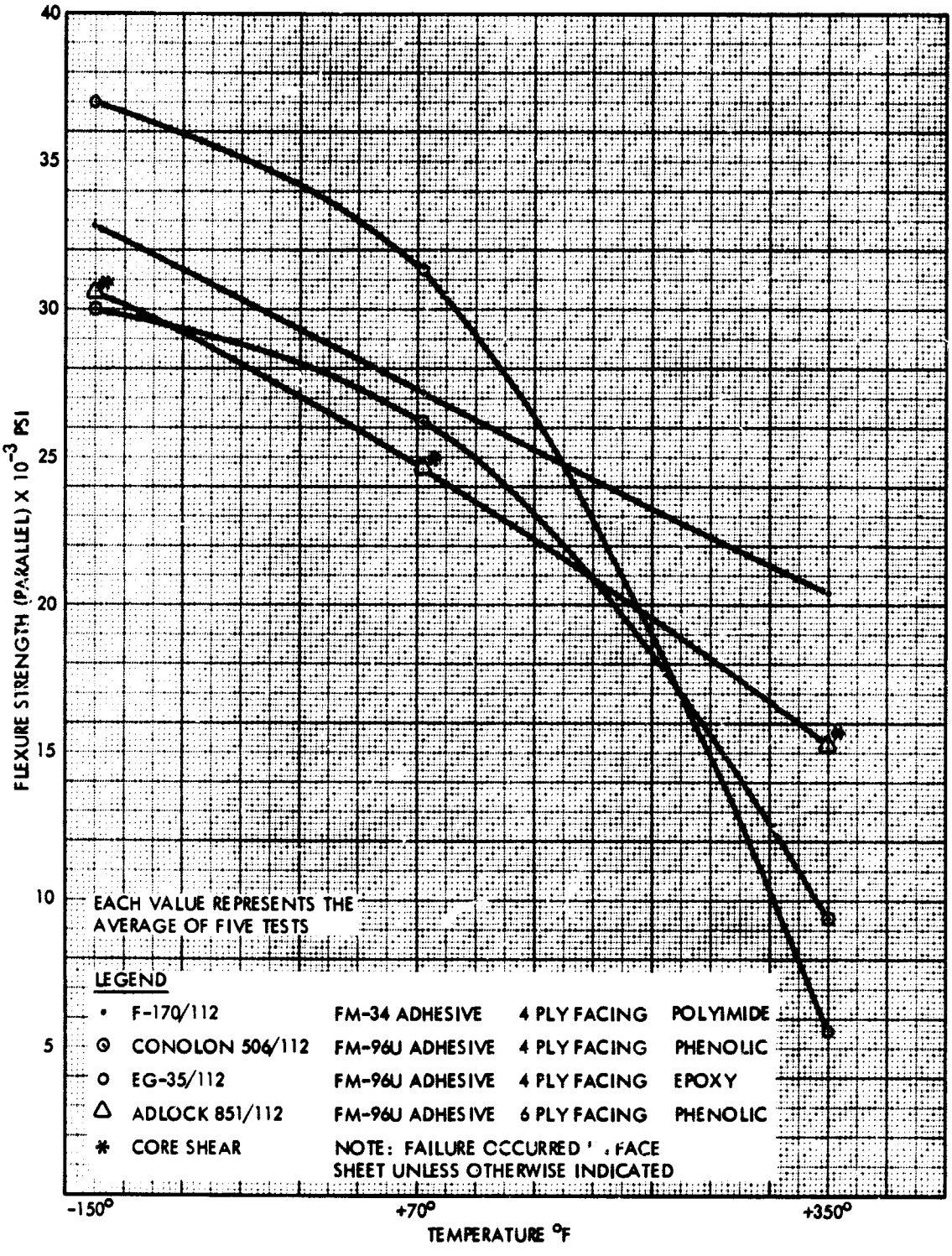


Figure 44. Flexure Strength Versus Temperature (Parallel to Ribbon Direction)

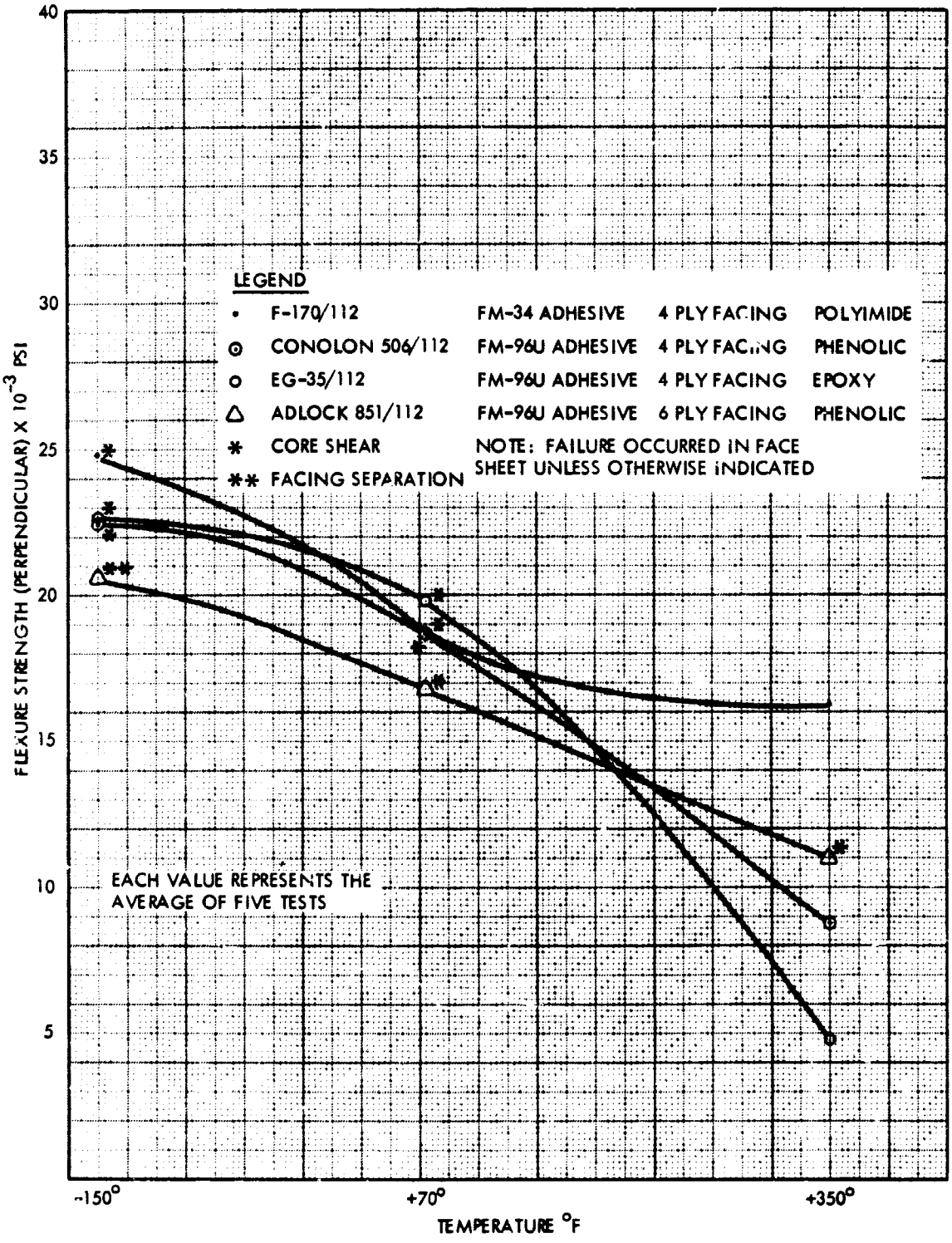


Figure 45. Flexure Strength Versus Temperature (Transverse to Ribbon Direction)

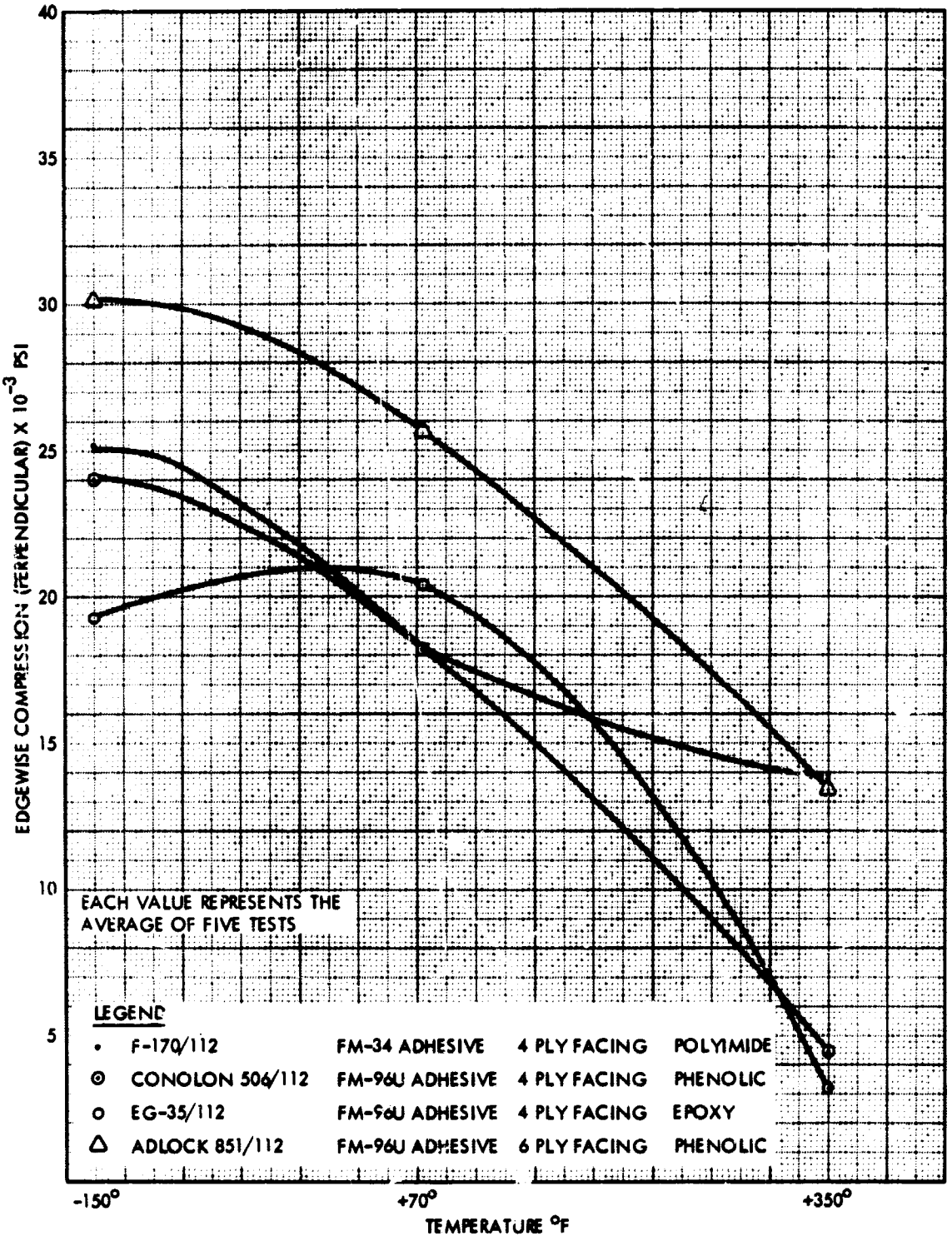


Figure 46. Edgewise Compression Versus Temperature (Parallel to Ribbon Direction)

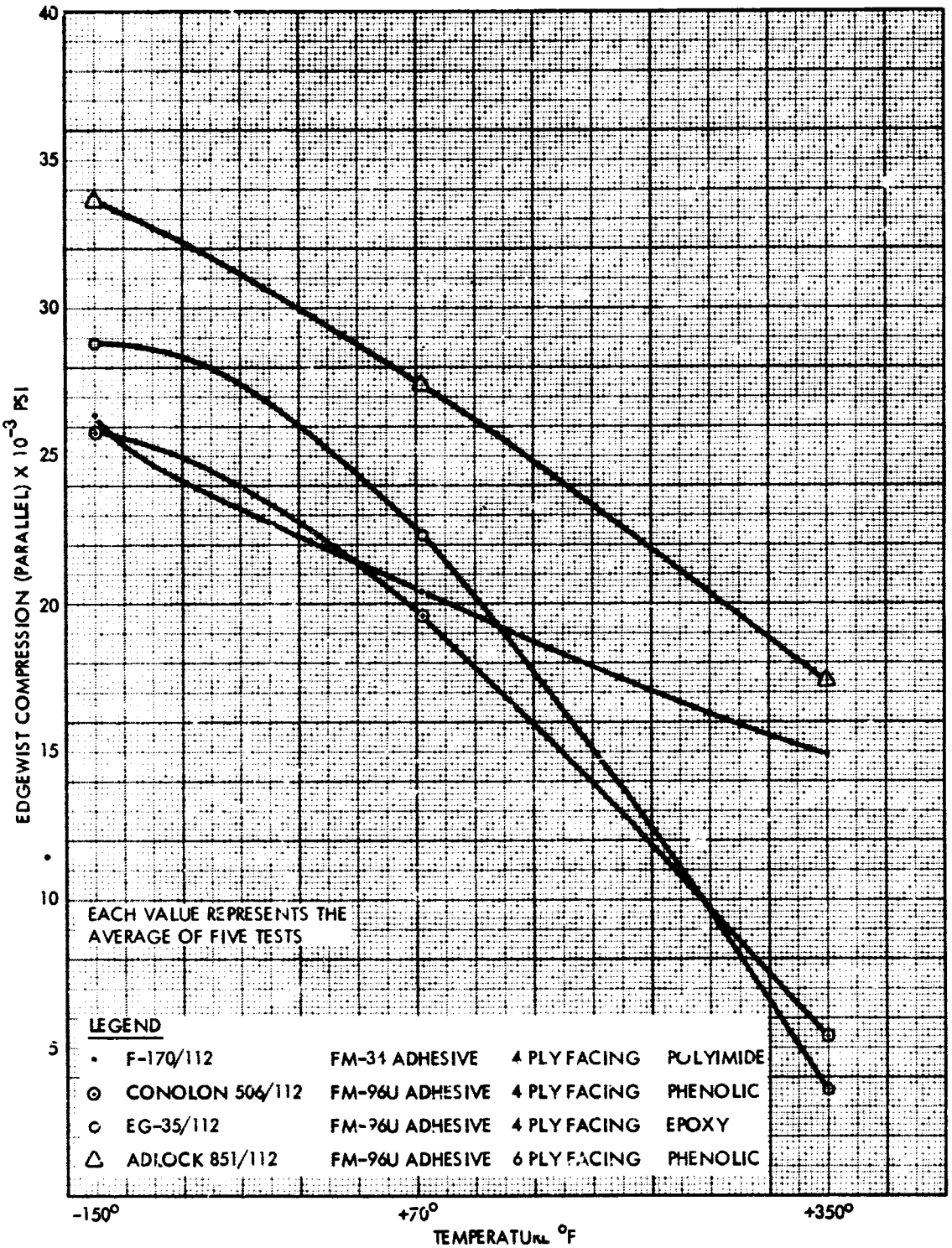


Figure 47. Edgewise Compression Versus Temperature (Transverse to Ribbon Direction).

2.10.2.2 Mechanical Properties in a Vacuum -- The effect of long time exposure of reinforced plastic sandwich panels in a vacuum was considered to be important.

Laminate flexure and flatwise tension tests were performed at pressures between 1×10^{-6} torr and 1×10^{-7} torr. Control specimens from the same batch of material were tested at room temperature for comparative purposes.

2.10.2.2.1 Test Fixtures -- In both tests, load was applied through a small hydraulic ram having one and one-half-inch diameter bore and three-inch stroke. A 0-3000 psi capacity pumping system supplied pressure to the ram for the tension tests, and a small hand-operated pump was used for the laminate flexure tests. A basic stainless steel frame was used for both tests and is shown in Figure 48.

For tension tests, the failing load was determined from ram hydraulic pressure via a transducer and X-Y plotter readout. The system was calibrated against a Tinium Olsen test machine.

For laminate flexure, the ram was relocated (Figure 49) and the specimen loaded against a 0-50 lb. capacity strain gage load cell which had been calibrated using dead weights (Figure 50). Specimen center deflections were determined from a dial gage mounted between the cylinder and the ram, and the gage is also shown in Figures 49 and 50. The frame was mounted on the bell jar base plate of a Consolidated Vacuum Corporation Vacuum Chanber (Figure 51).

Figure 52 is a diagram showing the layout and pump-down sequence. Hydraulic inputs and strain gage outputs utilized three of the fitted "feed throughs." In each case the unpressurized side of the ram was evacuated to atmosphere and a correction made for the true barometric pressure of the laboratory.

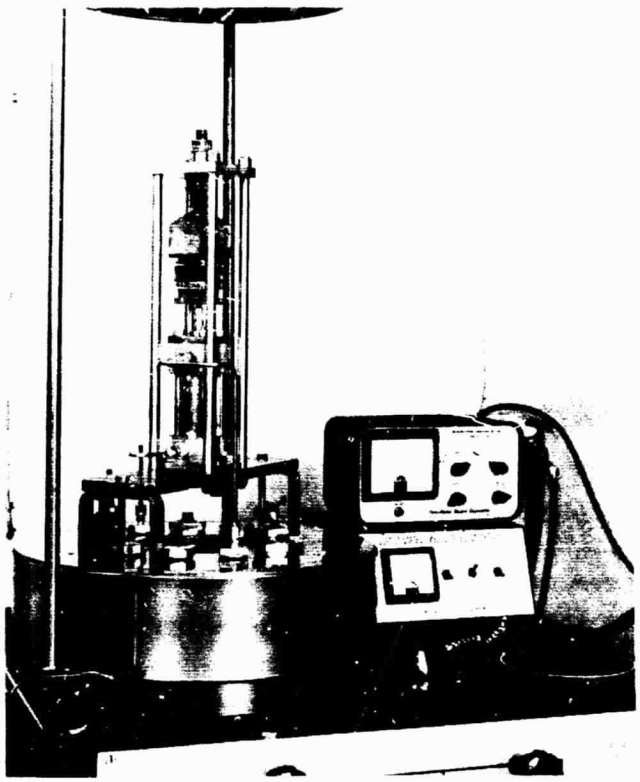


Figure 48. Flatwise Tension Loading Apparatus Installed in the Vacuum Test Chamber.

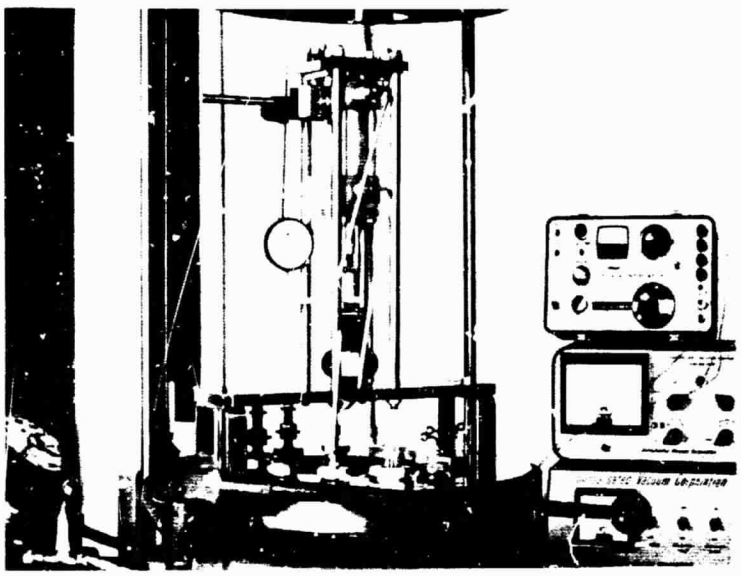


Figure 49. Loading Apparatus Being Calibrated with a Load Cell.



Figure 50. Close Up of Strain Gage Load Cell.

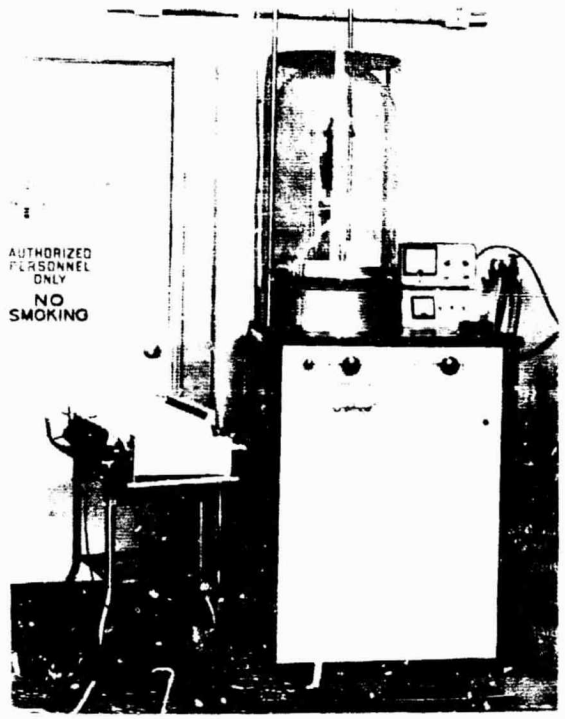
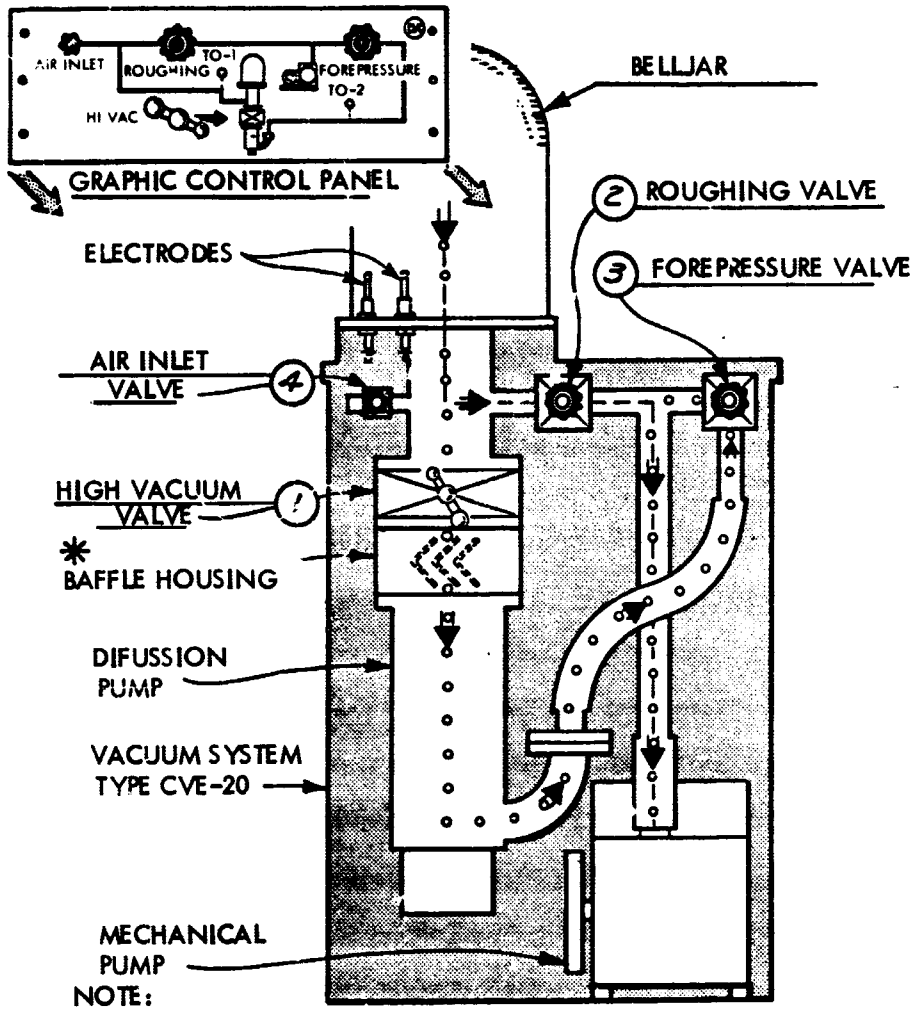


Figure 51. Vacuum Test Chamber With Bell Jar In Place.



		VALVE NUMBERS							
SYM.	PHASE	VALVES CLOSED				VALVES OPEN			
— — —	ROUGHING	1		3	4		2		
o o o	FINE PRESSURE		2		4	1		3	
	OPEN BELLJAR	1	2					3	4

Figure 52. Schematic Value and Flow Diagram for Type CVE-20

2.10.2.2.2 Procedure -- The loading fixture, specimen, and bell jar inner surface were thoroughly cleaned with acetone prior to test. The bell jar pressure was reduced to 1×10^{-6} torr and the specimen soaked for twelve hours, during which the pressure usually continued to drop to 3×10^{-7} torr. Tension specimens were loaded at 700 lb./min. to failure and the maximum tension stress determined. Laminate flexure specimens were loaded incrementally to failure and the maximum facing stress determined. The center deflection was noted.

2.10.2.2.3 Results -- Table 16 lists flatwise tension and laminate test data for specimens tested at atmospheric pressure, after specimens conditioned for twelve hours at 10^{-6} torr minimum at atmospheric pressure, and specimens at 10^{-6} torr minimum after being conditioned in the same vacuum. The results show that 10^{-6} torr vacuum for twelve hours has no effect on the mechanical properties of the materials tested.

2.10.2.3 Core Strength Comparison -- Table 17 presents mechanical properties and density of different core configurations and sizes. The larger one-fourth-inch cell size hexagonal shapped phenolic core is slightly lighter in weight but substantially lower in strength than the three-sixteenth-inch cell size hexagonal shaped phenolic core. When the three-sixteenth-inch cell core is coated with additional resin and cured, a slight increase in weight is experienced with 70% increase in core compression and a large increase in shear and shear modulus.

Flexcore that was available had about the same mechanical properties as the one-fourth-inch hexagonal core, but was .6 lbs./ft.^{3} heavier. The three-sixteenth-inch hexagonal polyimide core is only 4 lbs./ft.^{3} and produces excellent strength and shear modulus. Nylon-paper (Nomex) core was discontinued after testing for core compression due to its low strength-to-weight ratio. Dovetail core was much heavier than the other core configurations, but produced higher strengths except for transverse shear which was low.

2.10.2.4 Face Sheet Splicing and Nonrecessed Doublers -- Table 18 lists flexural and edgewise compression strength of two methods of splicing face sheets compared to no splice and flexural strength of a three-inch wide nonrecessed doubler (see paragraph 2.2.3.3 for configuration). In the sandwich flexure test, the splices and doublers were located in the shear zone of the specimen to determine if the same load can be carried through the interrupted plane as in a sandwich with no discontinuities.

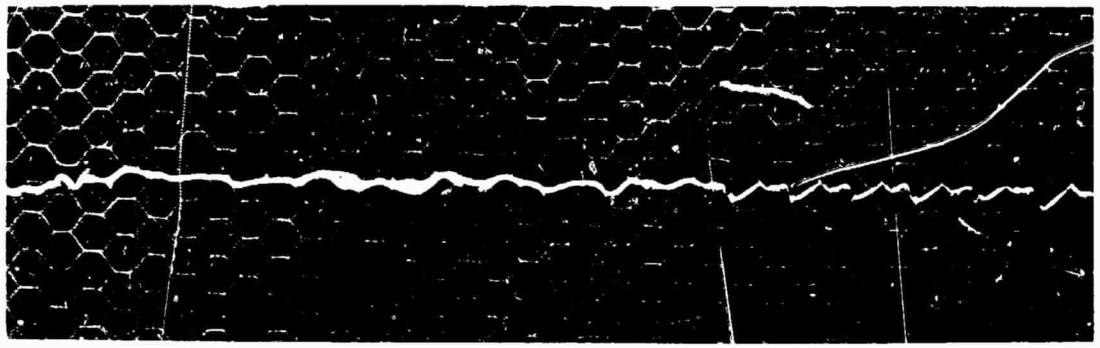
The table shows that the flexural or edgewise compression strength is not affected for either the aligned or staggered splice compared to the control panel (splices were on the upper, or compression, face).

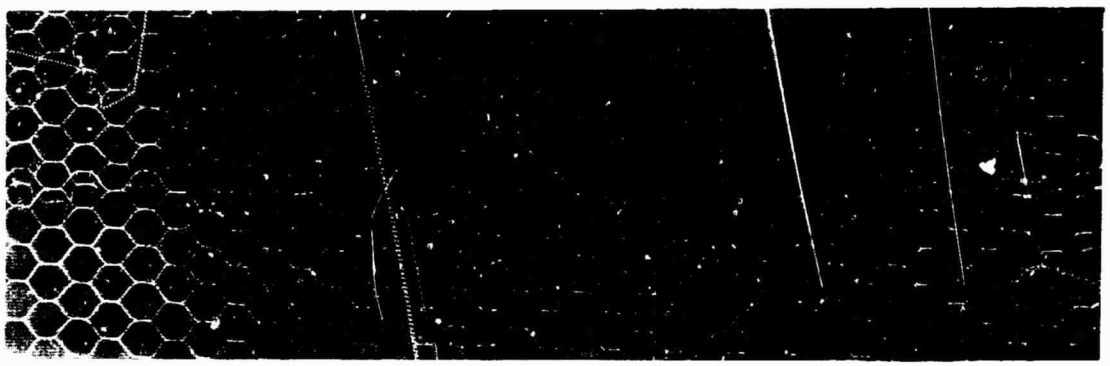
When the three-inch wide nonrecessed doubler was positioned on the bottom (tension side), the specimen exhibited comparable flexural strength to the control panel. However, when the doubler was placed on the top (compression side), a considerable decrease in strength resulted. The mode of failure was buckling of the skin at the six-ply doubler step. The six-ply doublers were stepped down gradually and extra strips of adhesive added. Additional tests were not required.

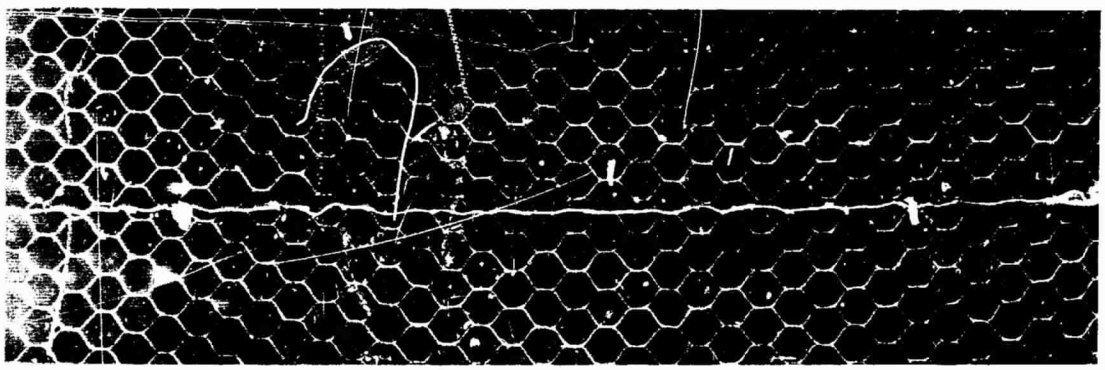
2.10.2.5 Evaluation of Core Splice Techniques -- Table 19 depicts the core shear strength for various methods of splicing hexagonal phenolic core. Typical splices are included in Figure 55. Controlled (no splice) specimens were used with the ribbon direction parallel, perpendicular, and 20° to the longitudinal axis of the specimen.

Refer to paragraph 2.3.4 for core splicing methods and detail configurations.

Overlap core splices (three-fourths-inch overlap stabilized with a pour coat of BR-227 primer) located perpendicualr to the longitudinal axis of the specimen produced optimum core shear strengths. However, at 70° to the longitudinal axis, the core pulled away from the face sheet prior to the anticipated average core shear strength. Since 70° is almost transverse (90°), the shear value should have been about 160 psi (slightly more







[illegible] Pre-Splice Techniques Using K-60 Tape, Overlap Core Mesh, and EM-96 Adhesive

than 150 psi). Observation of the failed panel revealed that the crush overlapping of the core was not completely flush, and a gap prevented full adhesion of the core to face sheet.

Core splicing using a butt joint with FM-40 tape adhesive located perpendicular to the longitudinal axis produced optimum core shear strength.

Overlap and butt splices located through the longitudinal axis were also evaluated, but with the ribbon direction at 20° to the length of the specimen. The overlap core splice did not fail, but the thin four-ply skin with 112 fabric failed in compression just prior to the required core shear failure. The butt splice with FM-40 carried an adequate shear stress of 200 psi during a similar test.

2.10.2.6 Honeycomb Sandwich Thermal Gradient Tests -- The maximum temperature that an aeroshell structure will experience during a mission is approximately 600°F. at the heat shield-structure bond-line (outer surface of sandwich). A flatwise tension test was therefore developed to simulate short time 600°F. performance on the outer face of the sandwich structure while maintaining close to room temperature on the other surface. Calrods imbedded in a copper support block were used to heat one side rapidly to 600°F. as shown in Figure 54. The test temperature was reached in four minutes, and the specimens were loaded at a rate of 600 lbs. per minute just before reaching 600°F. The results for each of two specimens were as follows:

Adhesive	R.T.	600°F. + 20	Time Under Load
FM-96U (.03#/ft.^{2}-4 mil)	610 psi	10 psi	3 sec.
HT 435/1070 (.06#/ft.^{2}-7 mil)	600 psi	180 psi	65 sec.

Jet Propulsion Laboratory mission studies indicate that time to heat-up to 600°F. and duration at that temperature would be less than 60 seconds. The results show that HT 435/1070 which was developed especially for the advanced development program performs quite adequately. Moreover, as

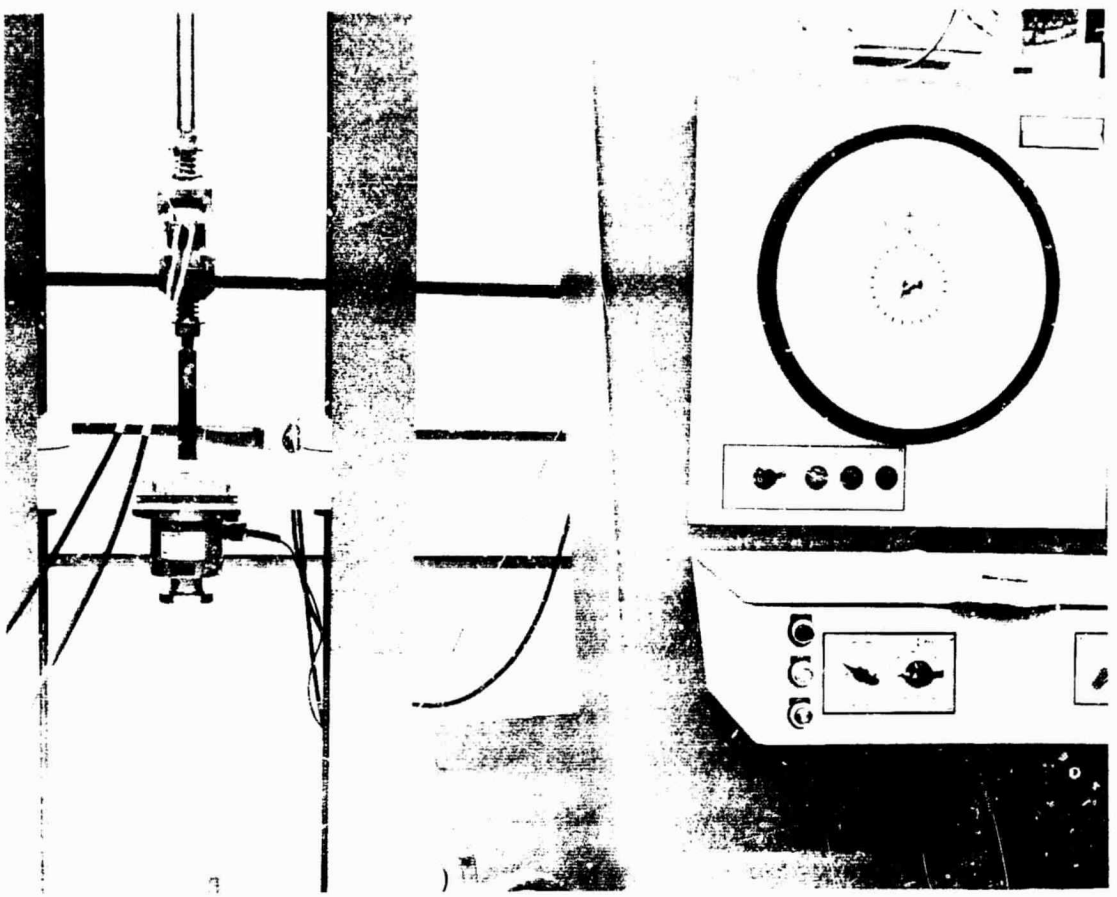


Figure 54. Honeycomb Sandwich Thermal Gradient Test.

3/ PHASE II - ALUMINUM HONEYCOMB SANDWICH PANELS

Flat, 27-inch by 27-inch aluminum honeycomb sandwich panels were fabricated to make a direct comparison of principal properties and weight trade-off to reinforced plastic honeycomb sandwich panels.

3.1. MATERIAL COMBINATIONS

To make this comparison, face sheet thickness and core densities were selected to be comparable to the strength and density of the reinforced plastic materials previously evaluated.

The following is an initial list of materials selected to fabricate panels from six different material combinations:

			Hexagonal Alum. Honeycomb Cores - 2024			
Designation	Material	Thickness	Cell Size & Shape Inches	Thickness Inches	Density, $lbs./ft.^3$	Adhesive System
A1-1-11	2024-T6	.005	1/4	0.5	3.4	FM-96U (.06 psf)
-12	2024-T6	.010	1/4	0.5	3.4	
-13	2024-T6	.015	1/4	0.5	3.4	
-21	2024-T6	.005	3/8	0.5	4.2	
-22	2024-T6	.010	3/8	0.5	4.2	
-23	2024-T6	.015	3/8	0.5	4.2	

3.2 MATERIAL AND PROCESS CONTROL

To assure reproducibility and provide comparative test data, it was necessary to provide controls for incoming material and for fabrication processes.

3.2.1 ACCEPTANCE CRITERIA -- Aluminum sheet material for facings had to conform to alloy and heat treat condition and thickness within specified tolerances. Acceptance testing involved the determination of ultimate tensile strength, yield and elongation, and checking of thickness when appropriate. The presence and thickness of cladding was checked by microscopic examination of etched cross sections of the facing material.

The aluminum honeycomb core was specified according to alloy, heat treat condition, foil thickness, and density. Mechanical properties satisfied requirements of MIL-C-7438C. Acceptance criteria included bare core compressive strength and density. Both vendor certification of the required properties and laboratory testing of compressive strength and density of the core constituted material control procedures.

The adhesive was accepted on the basis of minimum strength at room temperature and elevated temperature and specific film weight.

3.2.2 PROCESS CONTROLS -- To provide consistent properties for comparison, the entire series of panels fabricated from a given material combination was prepared from a single lot of material and cured simultaneously. A standard fabrication procedure and cure schedule, including heat rise rate, pressure, and time-at-temperature, were used for each material combination. In this manner, processing variables were minimized in comparing material combinations.

3.3 FABRICATION PROCEDURES AND RECORDS

The aluminum sandwich panels were fabricated in a one-stage operation, in which both facings were bonded to the core simultaneously. The

facings and the core were cleaned in accordance with RPS 17.23 and RPS 15.11, respectively. The panel assembling and bagging were conducted according to PS-15 and PS-16, respectively. The FM-96U adhesive was cured for one hour at 350° ± 10°F. under a vacuum of 24 inches of mercury, utilizing a heat rise rate of five to seven degrees per minute. Procedures, cure conditions, and fabrication problems and results were recorded on the standard adhesive-bonded panel forms (Appendix A).

3.4 INITIAL FABRICATION AND PROBLEM AREAS

Material combination A1-1-11 was fabricated as a preliminary test panel (see Figure 55). Flatwise tension tests showed an average of 416 psi, and additional 27-inch-square panels were built. However, subsequent panels tested had less than 200 psi flatwise tension. Although the outer periphery of the 27-inch-square panels appeared to be suitably filleted, examination of the sectioned panels revealed inconsistent filleting; and all panels exhibited poor facing-to-core contact in their internal sections (see Figure 56a).

Further testing of these panels was suspended pending results of the special test program described below.

3.5 SPECIAL TEST PROGRAM

A special test program was initiated to find a solution to the above problems. Full size 27-inch by 27-inch panels were fabricated as outlined in Table 20. Since the adhesive appeared to be adhering to the outer edge of each cell, as shown in Figure 56a, the lay up procedure was altered to determine if there was an excess volatile problem. Prior to application of the FM-96U adhesive, the aluminum skins were heated in an oven at 120°F. for fifteen minutes. The face sheet alloy was 2024, but the core alloy was either 2024 or 5052. The first group of panels used a single layer of the lightweight adhesive and subsequent panels used two layers of the same adhesive.

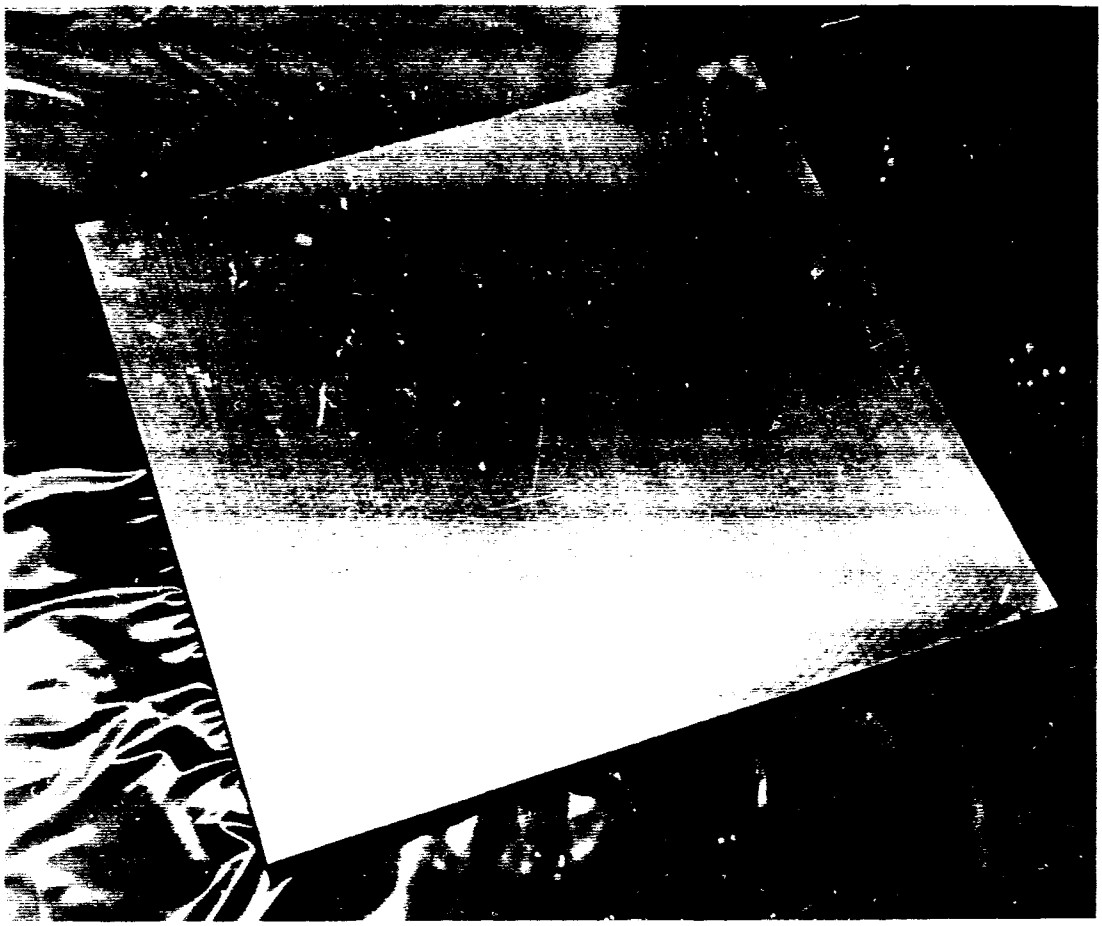


Figure 55. Aluminum Honeycomb Panel, 27" x 27" x .5".

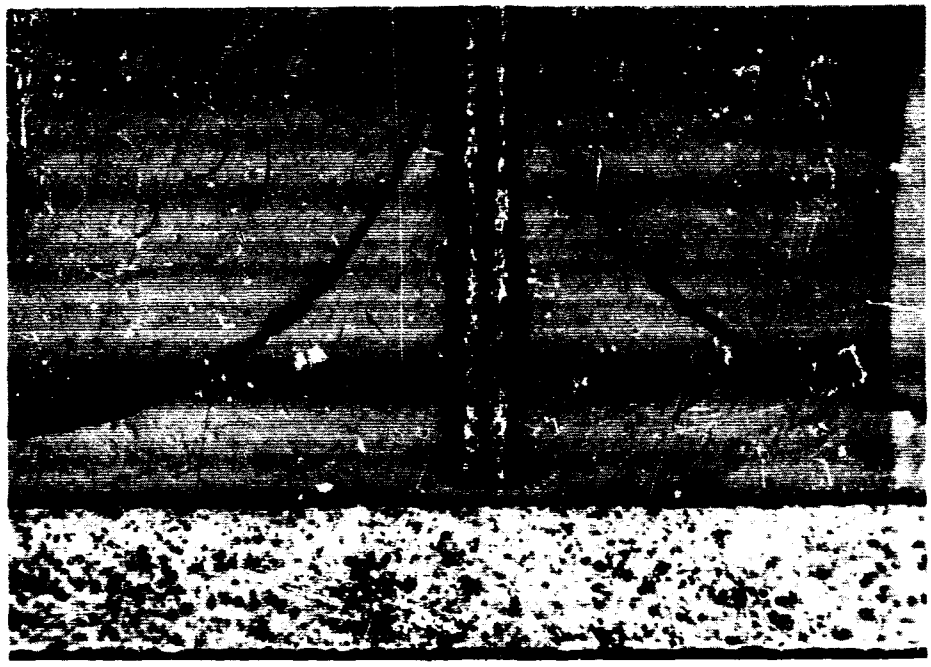


Figure 56a. Photomicrograph of .lle of FM-96U (2 layers) on Aluminum Sandwich Panel. (Ma.. ..)

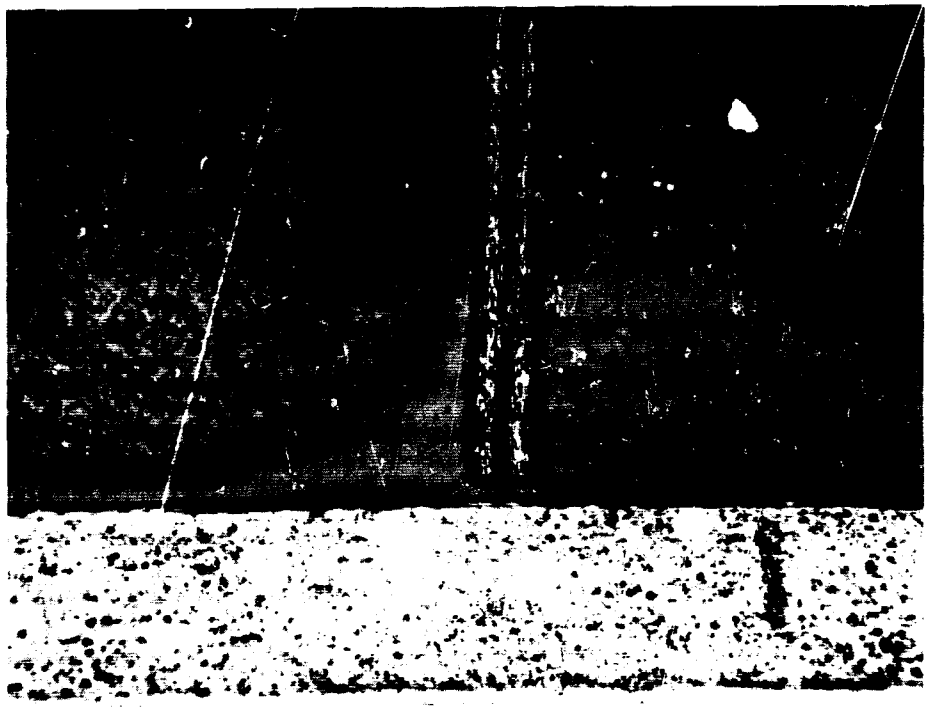


Figure 56b. Photomicrograph of Asymetric Fillet of FM-96U on Aluminum Sandwich Panel. (Mag. 50x.)

Aluminum lap shear test panels were layed up with seven different adhesive batch numbers to determine if the adhesive varied from batch to batch. Also, BR-227 primer, BR-227A primer, a combination of the two primers, and no primer were used for each batch number.

3.5.1 RESULTS AND CONCLUSION OF SPECIAL TEST PROGRAM -- Table 20 presents the flatwise tension, flexure, and beam flexural strength of eight combinations of aluminum sandwich. When using 2024 alloy honeycomb core, the cells repel the adhesive and poor filleting is indicated in the Table. When 5052 alloy core is used with .03 psf FM-96U adhesive, the amount of adhesive is not sufficient to consistently produce a quality bond. In both cases, the adhesive failed in tension and the face sheets buckled prematurely when tested for sandwich flexure. The .06 psi adhesive produced a satisfactcry bond when using 5052 core.

Table 21 shows a relative comparison of 2024 aluminum lap shear results when using seven different batches of FM-96U adhesive and primers versus no primer. Note the consistency of shear results between batch numbers for each variable.

The conclusions drawn from this evaluation are as follows:

1. Aluminum 2024 core is not recommended due to inconsistent quality of the material, poor wetting of the adhesive to core, and unsatisfactory results experienced by the aircraft industry using this material.
2. Aluminum 5052 or 5056 core should be substituted for 2024.
3. Unsupported adhesive (.03#/ft.^{2}) is not adequate for aluminum sandwich bonding if 100% quality panels are to be fabricated and reproduced.
4. Adhesive film (.06#/ft.^{2}) is recommended for this program.
5. Primer is not necessary if the parts are treated and stored per specification.
6. If primer is required due to open-time limitations, BR-227 primer must be used.

3.6 FABRICATION OF 27-INCH BY 27-INCH SANDWICH PANELS

After the test results from the preliminary test program were analyzed, six panels each of the six different material combinations were fabricated with two material changes. The 2024 honeycomb core was changed to 5052 and the adhesive was changed from .03 psf to .06 psf. Prior to the application of the FM-96U (.06 psf) adhesive, the aluminum skins were heated in an oven at 120°F. for fifteen minutes. The assembly was vacuum bagged and cured at 350°F. for one hour. (Reference Process Specifications listed in Appendix B and paragraph 3.3.)

3.7 TEST RESULTS AND CONCLUSIONS

The aluminum panels were cut into test specimens as shown in Figure 12, and testing was performed the same as in paragraph 2.8.

Table 22 presents the test results on the new panels that were fabricated with 5052 core and .06 psf adhesive, and Figure 56b shows a satisfactory fillet. When the smaller cell (one-fourth inch) core is used, the flatwise tension strength is doubled and flexural strength and peel strength is considerably higher. In tension and peel, the smaller cell provides more bonding area. Also, the small cells provide continuous support for the facings, allowing the facing to be worked up to or above their yield strength without crimping or buckling. Note that when the six-inch span flexural test produced core shear failure with the heavier skins, the test was rerun using a ten-inch span length. The panel must be loaded as a column so that the faces alone resist the column forces, while the core stabilizes the facings to prevent buckling. It appears that three-eights-inch cell size is too large to stabilize the extremely thin .005-inch thick skin. Also, there is a noticeable difference in the ability of the three-eights-inch cell to stabilize any of the skin gages when the core ribbon direction is transverse. When the sandwich is loaded in edgewise compression, the three-eights-inch and one-fourth-inch cell core seem to support the skins equally well.

Table 20. Adhesive Bonding Evaluation

Skins	Core	Adhesive	△ Flatwise Tensile Strength, psi	△△ Beam Flexural Strength Parallel Ribbon, psi x 10^{-3}
2024-T3 .010"	2024-T81 3/8" - .002N	(.03U FM-96)	160	31.9
2024-T3 .012"	2024-T81 3/8" - .002N	(.03U FM-96)	210	27.4
2024-T81 .010"	5052-H39 3/8" - .002N	(.03U FM-96)	140	26.9
2024-T3 .010"	5052-H39 3/8" - .002N	(.03U FM-96)	240	-
2024-T81 .010"	5052-H39 3/8" - .002N	(.06S FM-96)	560	41.6
2024-T81 .010"	2024-T81 3/8" - .002N	(.06S FM-96	420	43.2
2024-T3 .016"	5052-H39 3/8" - .002N	(.06U FM-96)	640	-
2024-T3 .016"	5052-H39 3/8" - .002N	(.06U FM-96/BR-227A Primer)	700	-

△ Based on the average result of three tests.
△△ Based on the average result of five tests.
Aluminum was preheated to 120°F. for fifteen minutes.

When comparing the face sheet allowables of aluminum to that of reinforced plastics in Phase I, we find that aluminum is much superior in strength. Recognizing that aluminum is heavier than reinforced plastic, a comparison of specific strength should be made. The .016-inch thick face sheet in the aluminum sandwich using one-fourth-inch cell aluminum core develops 67,300 psi facing stress. Adlock 851/112 (four-ply) face sheets supported by three-sixteenth-inch cell fiberglass core produces only 36,300 psi facing stress (reference Table 12). However, when comparing .0145 lbs./ft.^{2}/mil thickness and .0094 lbs./ft.^{2}/mil thickness for the aluminum and reinforced plactic face sheets respectively, we arrive at 4640 specific strength for aluminum and 3862 specific strength for re inforced plastic. If the fiberglass face sheets were laminated by themselves, rather than with the core, significantly higher face sheet allowables would be achieved.

Table 21. Effect of Primers Vs. No Primer on Lap Shear Strength

Batch No.	1492	1492	1492	1504	1504	1504	1504
Roll No.	3303	3304	3305	3337	3338	3339	3340
Lap Shear St. *	psi	psi	psi	psi	psi	psi	psi
BR-227 Primer	2970	3210	3280	3490	3160	2850	3530
BR-227A Primer	1910	-	1650	1490	1480	1650	1850
BR-227/BR-227A	1580	1490	1700	1340	1510	1400	1670
No Primer	3030	3990	2900	3140	3250	3140	3270

Materials: 2024-T3 aluminum (chromic acid anodized)
FM-96U adhesive

* Average of five specimens tested at room temperature.

Table 22. Aluminum 27" x 27" Test Panel Results

Skin Thick in.	Core Cell Size in.	Core Foil	Flatwise Tension psi	Flexural Strength x 10^{-3} psi ⚠ Parallel 10" Span	⚠ Parallel 6" Span	Core Shear psi 6" Span	⚠ Transverse 6" Span	⚠ Transverse Core Shear psi	Edgewise Compression psi x 10^{-3} ⚠ Para.	⚠ Trans.	Panel Weight #/ft.^{2}	Core Compr. psi	Peel Strength #/in.
.010	1/4	5056	780	-	63.1*	450	45.4**	230	42.2	42.2	.670	690	2.8
.010	3/8	5052	410	54.6*	47.2**	240	22.1	110	43.1	41.8	.581	320	2.0
.016	1/4	5056	1150	67.3*	58.3**	470	30.0**	240	58.8	56.5	.764	610	3.3
.016	3/8	5052	530	54.5*	25.7**	210	13.8	110	53.1	47.8	-	280	2.7
.005	1/4	5056	620	-	60.2*	200	58.5*	150	25.1	16.8	.434	670	2.7
.005	3/8	5052	310	-	43.2*	140	37.6*	90	24.9	14.5	.346	270	2.0

*Bond Failure

**Core Shear

Core Foil Thickness .002"N, Core Depth .500 Inches.

Each value represents the average of five tests.

⚠ Direction of core ribbon relative to the longitudinal axis of the specimen.

4/ PHASE III - SMALL DOUBLY-CURVED AEROSHELLS - REINFORCED PLASTIC

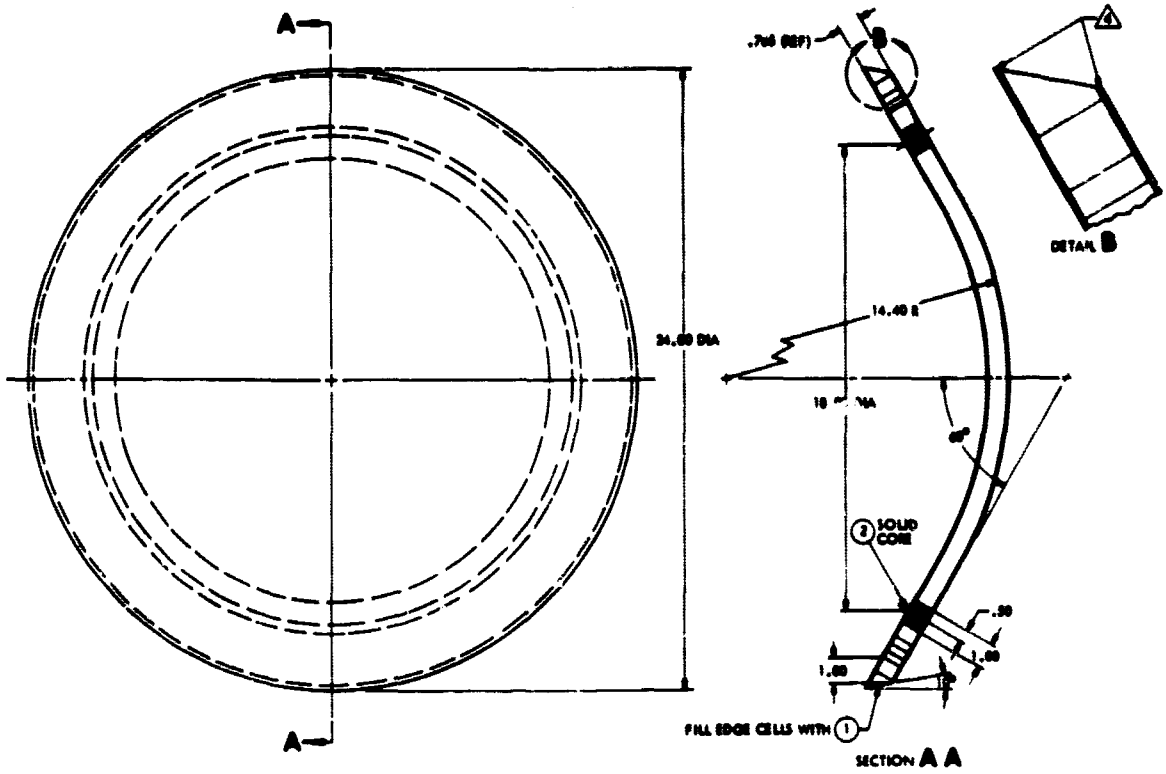
Subscale aeroshells were fabricated to prove out the fabrication procedures, which were established on flat panels and curved sandwich structures, and to provide Jet Propulsion Laboratory with test assemblies for use in environmental exposure evaluations. Eleven subscale aeroshells have been fabricated according to Jet Propulsion Laboratory Model 1 drawing (Figure 57), using eight different material combinations and are described in detail in paragraph 4.4. These material combinations were selected on the basis of processing and handling characteristics and mechanical property values obtained from 27-inch-square flat honeycomb sandwich panels.

4.1 MATERIAL AND PROCESS CONTROL

Material and process control procedures for the subscale aeroshells are as described in paragraph 2.4.

4.2 FABRICATIONS METHODS

4.2.1 FACINGS -- A two-stage bond and cure operation has the advantage of better control of the facing appearance and density, and can result in a fabricated structure with a lower density than a one-stage bond and cure operation as indicated in Table 8. It is also necessary for facing materials and adhesives which exhibit incompatibility in a one-stage cure.



5. ALL FABRICATION SHALL BE DONE WITH AN EMPHASIS ON QUALITY OF WORKMANSHIP AND REPRODUCIBILITY

4 THE WARP DIRECTION OF EACH SUCCEEDING PLY SHALL BE ORIENTED 45° CW TO THAT OF EACH PRECEDING PLY

3. ALL FABRICATION SHALL BE MADE USING VACUUM BAG PRESSURE TECHNIQUES

2. ITEM (2) AVAILABLE FROM ROHR CORP, P.O. BOX 878, CHULA VISTA, CALIF

1. ITEM (1) AVAILABLE FROM FURANE PLASTICS, INC, 4516 BRAZIL ST, LOS ANGELES, CALIF 90039

NOTES: UNLESS OTHERWISE SPECIFIED

QTY REQD	ITEM NO.	REF DES	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	SPECIFICATION	MATERIAL OR NOTE
AS REQD	5			ADHESIVE		
AS REQD	4		RCR-576	CORE POTTING COMPOUND	BMS-027	EPOXY .55 SP. GR.
AS REQD	3		H-1843 TYPE IV, GRADE B	EDGE POTTING COMPOUND		EPOXY
AS REQD	2			FACE SKINS	MIL-R-4099	
AS REQD	1			CORE, HONEYCOMB		FIBREGLASS

Figure 57. Subscale Aeroshell.

However, a one-stage fabrication procedure has the advantage of simplicity and time reduction. A disadvantage of two-stage bonding is that expensive close tolerance tooling would be needed to fabricate the inner facing separately, because an adequate fit could not be obtained for bonding the precured inner facing to the core using the tooling available. Therefore, this limited the fabrication and bonding of the subscale aeroshell inner facings to a one-stage operation.

To evaluate both procedures, facings for some of the aeroshells were fabricated individually and subsequently bonded to the honeycomb core; others were fabricated utilizing a one-stage lay up and cure of the entire assembly.

Initially, the facing plies were prepared in segments, as indicated in Figure 58. The segments were spliced using overlap widths of one-half to one inch. Joints of consecutive plies were arranged so that they did not coincide. Later, as additional tooling became available and improved techniques were developed, each facing ply was preformed in a single piece, thus eliminating the need for splicing (Figure 59).

The facing fabric influenced the ease of preforming, as did the condition of the resin in a prepreg. The 112 glass fabric formed more easily than did the 116 fabric. Glass fabric (112) was formed readily prior to impregnation, and subsequently impregnated with an A-stage resin system (Figure 60).

4.2.2 HONEYCOMB CORE -- The practicability of utilizing fully-cured, hexagonal honeycomb core for contoured parts was investigated in fabricating initial subscale aeroshells. The advantages of "green," partially-cured hexagonal core over the cured core were determined in subsequent aeroshells. The ease of forming flexcore was also evaluated, although it was established from 27-inch-square sandwich panel tests that its specific shear and compressive strength was inferior to that of hexcore (paragraph 2.10.2.3).

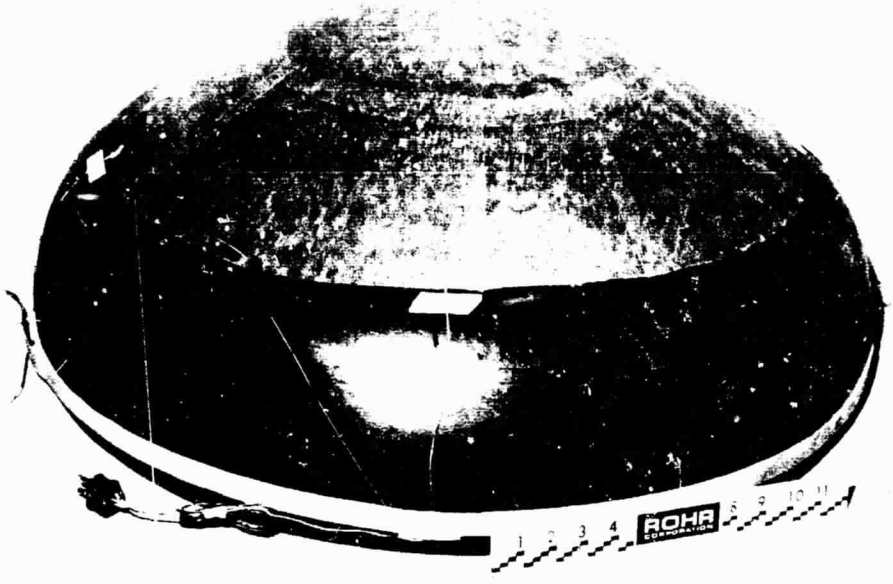
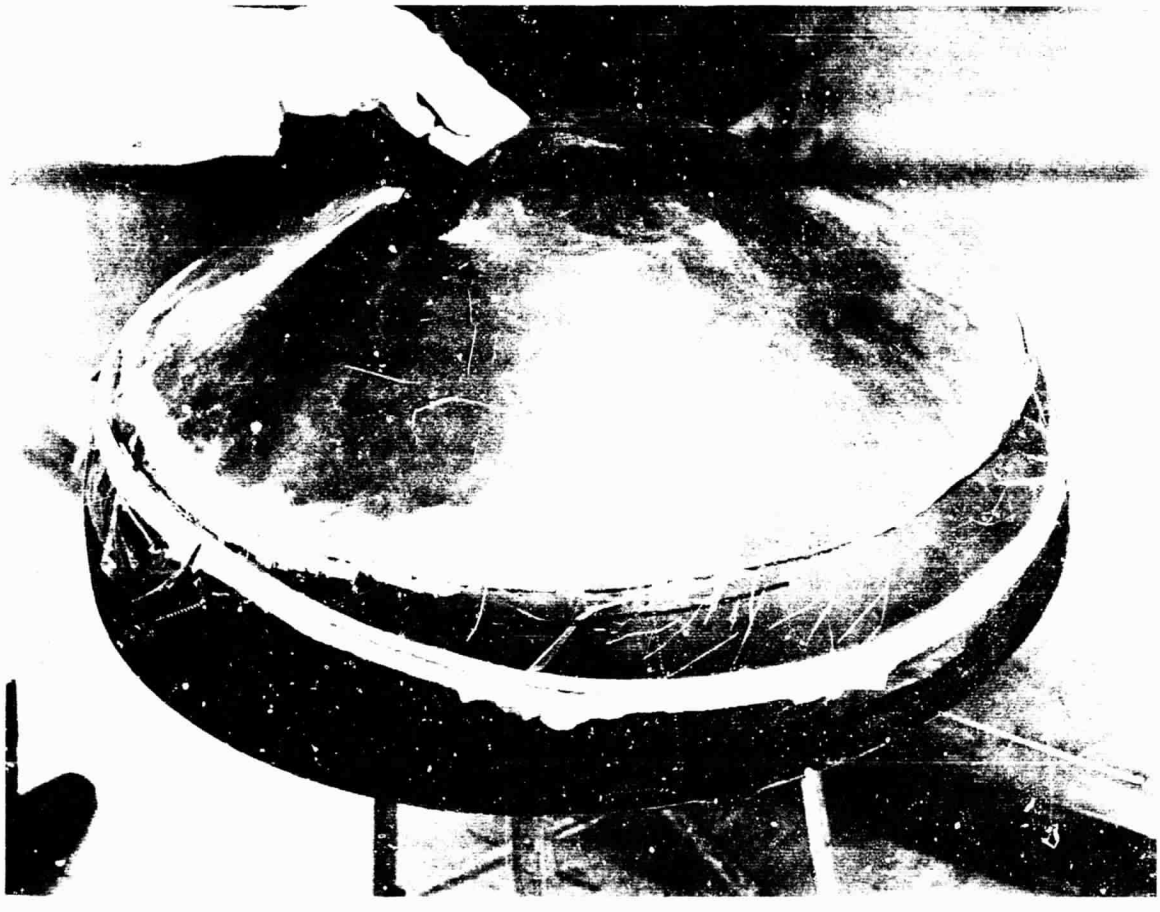


Figure 58. Subscale Aeroshell Facing Lay Up Showing Spliced Ply Segments.



Figure 59. Preforming of Subscale Aeroshell Facing Ply.



The flexcore and the green hexcore could be formed sufficiently well to contour so that a single piece could be used to fabricate a complete subscale aeroshell (Figure 61). However, it was initially necessary to form the cured hexcore in segments and splice the sections. Both forced core tie splices and adhesive-bonded butt splices were utilized. A typical FM-40 adhesive spliced core section is illustrated in Figure 62.

4.2.3 ADHESIVE -- A film adhesive, FM-96U, was utilized in the fabrication of each of the eleven subscale aeroshells. Depending upon the flexibility of the particular lot of adhesive used, forming of the film could be accomplished to limited degrees. In general, it was necessary to splice the adhesive film. This was accomplished by means of butt splices, permitting no overlap and a maximum of one-thirty-second-inch gaps.

4.2.4 POTTING -- Potting of the ring section of the core was conducted utilizing a potting tool (Figure 63). The preformed, precured core was potted in the ring section with the RCR-576 compound. The potting compound was allowed to remain at room temperature overnight prior to placing the potted core in the assembly and curing (Figure 64). Curing of the potting compound was accomplished simultaneously with curing the aeroshell facing and/or adhesive.

The edges of the completed aeroshells, which had been routed to size, were filled with Epocast H-1843, Type IV, Grade B potting compound after removal of one row of core cells around the periphery of the aeroshell (Figure 65). The compound was allowed to cure at room temperature.

4.2.5 RECORDS AND PROCEDURES -- Since, in general, minor departures in fabrication procedures were utilized in each of the initial subscale aeroshells, standard fabrication procedures PS-17 and PS-18, were used only as a guideline in the fabrication of the aeroshells; and appropriate modifications were made for each model. Later, a standard procedure, PS-25, was utilized for one-stage fabrication of adhesive-bonded aero-



Figure 67. Preforming "Green" Mixture for a Subscale Aeroshell.

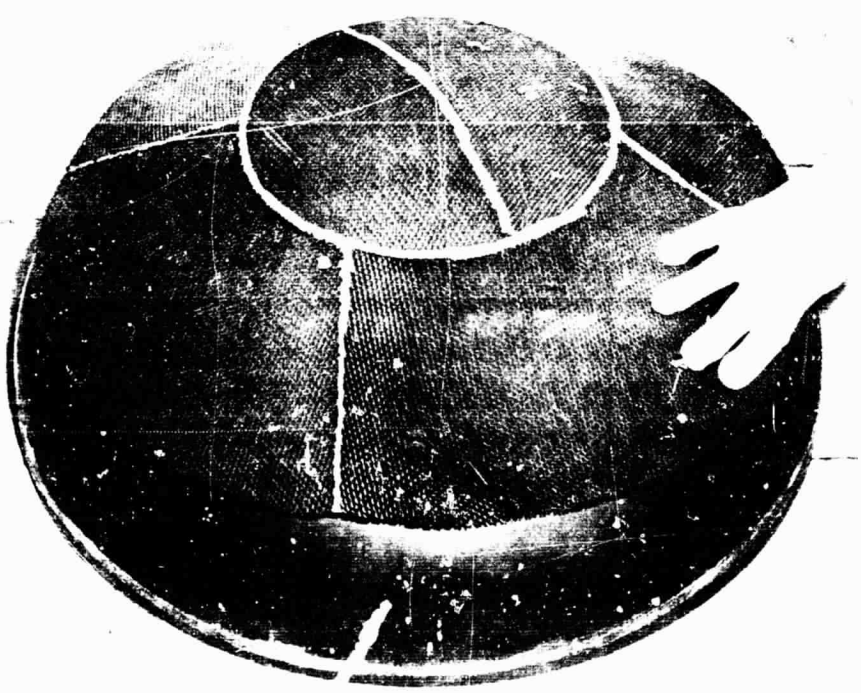


Figure 68. Cured Subscale Aeroshell Prior to Machining.



Fig. 1 Prepotting Pin [illegible] Milling Potting Tool.



Fig. 2 [illegible] Aerosheli.

shells (Appendix 10.2). Procedures and conditions for each aeroshell were recorded on standard fabrication forms as indicated in paragraph 2.7.4.

4.3 TOOLING

The tooling and fixturing was designed to utilize minimum cost consistent with the quality requirements.

4.3.1 BOND FIXTURE -- The BONJ (bond jig) was fabricated by constructing a wooden male plug identical to the OML of the aeroshell shown on Jet Propulsion Laboratory drawing J4210048. This plug was used to spin a 6061 aluminum shell with one-eighth-inch minimum wall thickness. This shell was mounted in a welded egg crate support structure as shown in Figure 66. Construction of this type assures a minimum of combined mass for both the bonding fixture and the assembled honeycomb panel, permitting bonding and aging temperature to be elevated and lowered very rapidly. Vacuum source and measuring parts were installed and net trim lines were added.

4.3.2 LAY UP TOOLS -- Using the bond fixture as a DIEP (die pattern), the contour of the inner skin was swept (allowing for the three-fourths-inch core thickness). From this surface, a reinforced plastic male tool was cast and used for forming and laying up the inner plies of the aeroshells (reference Figure 59).

4.3.3 ROUTING FIXTURE AND CORE POTTING TOOL -- The aeroshell routing fixture and core potting tool are combined into one tool as shown in Figure 63. This tool was made from casts taken off of the BONJ. A standard one-half-inch router guide is used.

4.3.4 TOOL MODIFICATION -- The aluminum spun BONJ was irregular and out-of-round. The family of tools that were made from this spun aluminum shell were also irregular. Even though the tools were within specified drawing tolerances, some tools were rebuilt because of aeroshell fabrication problems.



[illegible] Dentition of [illegible] Showing Distinct Dentition and Distinct Lustrous Edge to Internal Proportion Ring

4.3.4.1 Bond Fixture -- The procedure for BONJ fabrication is shown in Figure 67 and is outlined as follows:

1. Sweep plaster reference tool No. 1 per Jet Propulsion Laboratory Drawing.
2. Laminate high-temperature plastic shell from reference pattern No. 1.
3. Remove existing aluminum shell from egg crate structure and replace with reinforced plastic shell.

4.3.4.2 Lay Up Tool -- DIEP No. 2 was made from reference pattern No 1. A reinforced plastic male tool was molded from the DIEP to be used for forming and laying up the outer plies of the aeroshell.

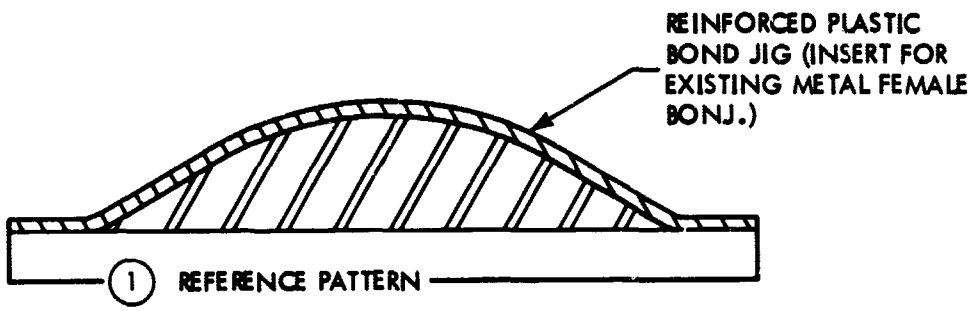
4.3.4.3 Routing Fixture and Core Potting Tool -- This combination jig was reworked to conform to the new BONJ configuration.

4.4 SUBSCALE AEROSHELLS FABRICATED

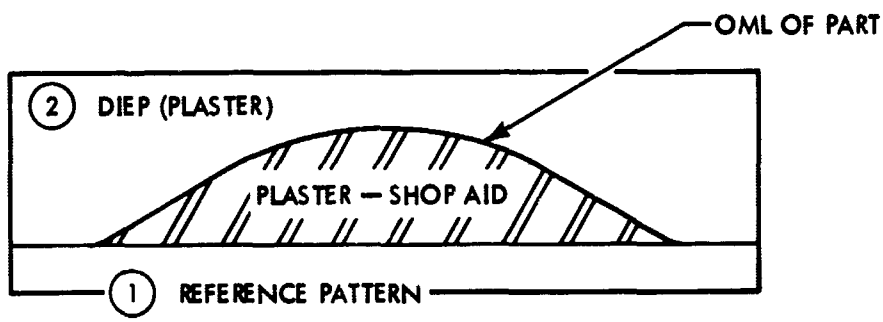
Details of the type of fabrication procedure, materials used, problem areas, and appearance of the aeroshells fabricated are included below.

4.4.1 AEROSHELL MODEL 1-1 -- This aeroshell was fabricated from four-ply phenolic facings of Adlock 851/112, precured hexcore which was spliced with a formed tie splice and FM-96U adhesive. The outer facing segments were spliced, and the facing was cured in the female tool. The core sections were forced and spliced, then the core assembled in the tool over the facing. The inner facing was laid up on the male tool and transferred to the female tool in position over the core. It was cured and bonded to the core simultaneously with the adhesive bonding of the outer facing to the core.

After cure of the assembly, the inner facing was wrinkled as a consequence of problems encountered in transferreing it from the male tool into position in the female tool. The outer skin was smooth, but some void areas were



(a) LAMINATED BOND JIG SHELL



(b) PLASTER DIEP FOR MOLDING OF
MALE PLASTIC TOOL

Figure 67. Aeroshell Tooling.

present between the core and outer facing, primarily in the dome region, apparently as a result of the poor fit of the core.

4.4.2 AEROSHELL MODEL 1-2 -- This aeroshell was fabricated from four-ply phenolic facings of Adlock 851/116, precured hexcore which was butt-spliced with FM-40 adhesive and FM-96U adhesive. The inner and outer facings were spliced and precured on the male and female tools, respectively. Leakage through the plastic male tool occurred causing difficulty in maintaining vacuum.

The outer facing was bonded to the core in the female tool. After cure of the adhesive, the core surface was ground smooth, then the cured inner facing was bonded to the core with FM-96U.

After cure, the outer and inner facings were smooth except for one wrinkle in the inner facing, apparently as a consequence of mismatch of the male and female tools. A void area was present between the core and inner facing at the region of transition between the spherical and conical contours.

4.4.3 AEROSHELL MODEL 1-3 -- This aeroshell was fabricated from four-ply epoxy facings of Adlock EG-35/116, precured hexcore which was butt-spliced with FM-40 adhesive (PS-22 and PS-23) and FM-96U adhesive. The outer facing was applied, then cured and bonded to the preformed core in one step. The applied inner facing and adhesive were placed against the core inner surface and cured and bonded to the core in one operation after minor necessary smoothing of the core inner surface.

Problems were encountered in laying the adhesive and prepreg for the inner facing directly onto the core. The adhesive lacked sufficient tack to adhere it to the core, while the prepreg had sufficient tack to adhere to itself. Therefore, lifting of the adhesive plus prepreg from the core occurred during lay up, particularly when prepreg sections had to be moved from their original position in the lay up.

After cure, the inner facing was smooth and well wet. The preformed core appeared to deform further during the second cure cycle, causing irregular cell configurations, particularly in the spherical section. Small, raised, wrinkled areas and dry regions were present on the surface of the outer facing. These were attributed to the rough female tool surface.

4.4.4 AEROSHELL MODEL 1-4 -- This aeroshell was fabricated using an epoxy-novolac A-stage resin system, DEN 438/NMA/BDMA, which was impregnated into 112 glass fabric to constitute the four-ply facings. The fabric was preformed over the male tool for both inner and outer facings; facing splices were not necessary. The outer facing was impregnated, laid up, and partially cured in the female tool. Green hexcore was preformed in a single piece and cured (PS-24). The ring cells were prepotted with M-323v. The potted core was assembled in the female tool over the outer facing and adhesive. The inner facing, which was impregnated on the male tool, was transferred to the assembly in the female tool, where adhesive bonding to the core and cure of the inner facing and potting compound were accomplished simultaneously. After cure, the aeroshell was routed to size and the edge was sealed with potting compound.

The outer surface of the cured aeroshell was smooth except for a few small, raised areas, which resulted from imperfections in the tool release film. Slight wrinkling occurred in the inner facing. Good contact was obtained between core and facings. The core cells were irregular in a few regions. The potted region was smooth and undistorted.

4.4.5 AEROSHELL MODEL 1-5 -- This aeroshell was fabricated from four-ply epoxy facings of EG-35/112 which were preformed without splices, preformed green (partially cured) hexcore, and FM-96U adhesive. The individual plies of the outer and inner facings were preformed over the large and small male tools, respectively. The outer facing lay up was transferred to the female tool, and adhesive applied. The cured core, which was prepotted with RCR-576 was then placed in the tool. Adhesive was applied over the core and the inner facing transferred from the male tool to the assembly.

The assembly was cured and bonded in one stage. After cure, the aeroshell was routed to size and the edge filled with potting compound. (See PS-25 for detailed fabrication procedures.)

The outer surface of the cured aeroshell was smooth except for a few slightly rough areas, primarily in the transition and dome regions (Figure 68). The inner facing was smooth and free of wrinkles. The surface of the potted area was undistorted, but a few node bonds had been broken within the potted region. Some of the core cells were irregular in configuration as a consequence of the forming operation.

4.4.6 AEROSHELL MODEL 1-6 -- This aeroshell was fabricated from six-ply epoxy facings of Adlock EG-9300/112, HRP-SF50 flexcore, and FM-96U adhesive. The individual plies of the prepreg were preformed over the male tool and cut to size. The outer facing lay up was transferred to the female tool and the adhesive applied. The flexcore was pressed into position in the tool and the facing cured and bonded simultaneously. After cure, the core was prepotted with RCR-576. Adhesive was then applied over the core and the inner facing lay up transferred from the male tool to the assembly. The assembly was then cured, routed to size, and the edge potted.

The cured aeroshell was smooth except for a small wrinkle on the inner facing.

4.4.7 AEROSHELL MODEL 1-7 -- This aeroshell was fabricated from six-ply preformed facings of Adlock 851/112, preformed green hexcore, and FM-96U adhesive. It was cured (facing and potting compound) and bonded in a one-stage operation, as described for Aeroshell 1-5 (PS-25). The inner facing of the completed aeroshell was somewhat wrinkled.

4.4.8 AEROSHELL MODEL 1-8 -- This aeroshell was fabricated from four-ply, preformed facings of Conolon 506/112 (phenolic), preformed green hexcore, and FM-96U adhesive. It was cured (facing and potting compound) and bonded in a one-stage operation, as described for Aeroshell 1-5.



Figure [illegible]. Outer Surface of Subscale Aeroshell Showing Slight Surface Irregularities and Internal Prepotted Ring.

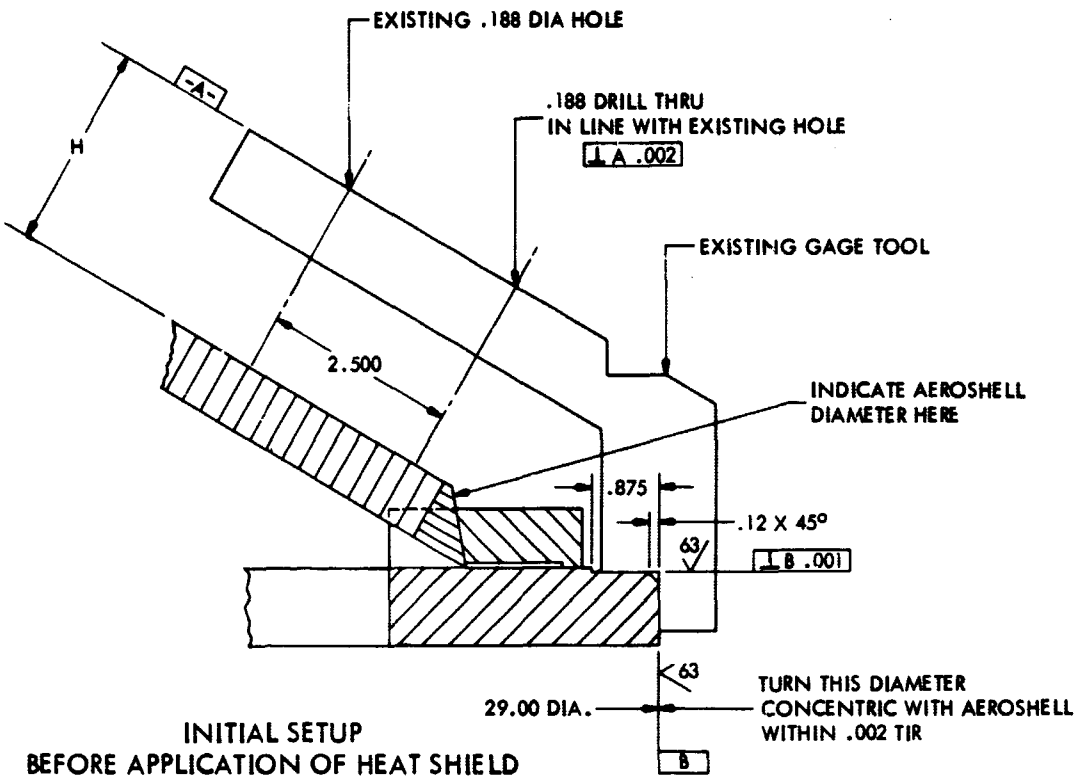
4.4.9 AEROSHELL MODEL 1-9 -- This aeroshell was the same as Aeroshell Model 1-7. This one, however, was smooth and wrinkle-free.

4.4.10 AEROSHELL MODEL 1-10 -- This aeroshell was the same as Aeroshell Model 1-8 except that the facings were fabricated from a differerent lot of prepreg, which was somewhat more tacky. Therefore, difficulty was encountered in removing the preformed facing lay up from the male tool. This problem was alleviated by covering the plastic male tool with Teflon tape to enhance release of the prepreg.

4.4.11 AEROSHELL MODEL 1-11 -- This aeroshell was the same as Aeroshell Model 1-10. It was damaged in the center of the outer facing during the routing operation. The facing was repaired using standard techniques described in paragraph 6.13.

4.5 ABLATOR APPLICATION AND MACHINING

Ablator heat shield was applied to Aeroshell No. 1-6 by AVCO Corporation, Space Systems Division, in Lowell, Massachusetts. The aeroshell was located on an inspection fixture shown in Figure 69, and the outer diameter and surface were indicated from the existing gage tool. The gage tool was then removed, and the micarta clamp ring was bolted down as shown in Figure 69b. Approximately .650 inches of Avco MOD 7 Ablator (silicon elastomer with phenolic microballoons and glass fiber) was applied in a semifluid state by roller coating. The unit was then vacuum bagged and cured. Several rough machine cuts were taken with a pencil cutter on a vertical Bullard boring mill. After each machine cut, measurements were taken with the gage tool to assure alignment and to inspect the assembly for warpage. Final machining of the ablator heat shield was performed by a numerical tape-controlled operation to the aeroshell contour. Gage tool measurements showed a total deviation within 10 mils. The aeroshell was removed from the tool and inspected. To check the gage measurements, local depth of the heat shield was measured with a dial indicator adapted for ablator penetration (see Figure 70). The dial indicator extension penetrates the



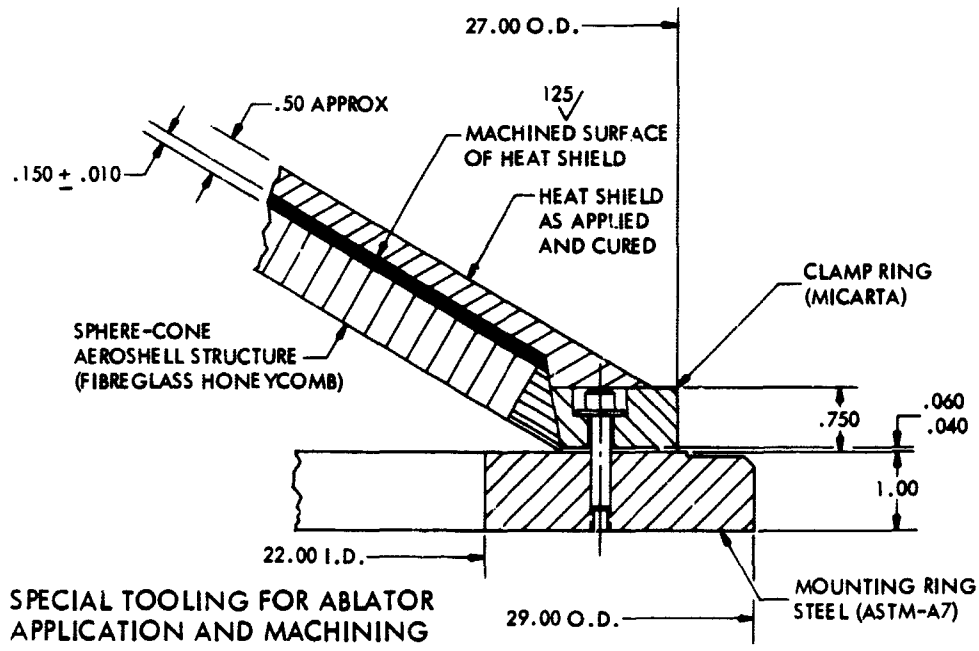
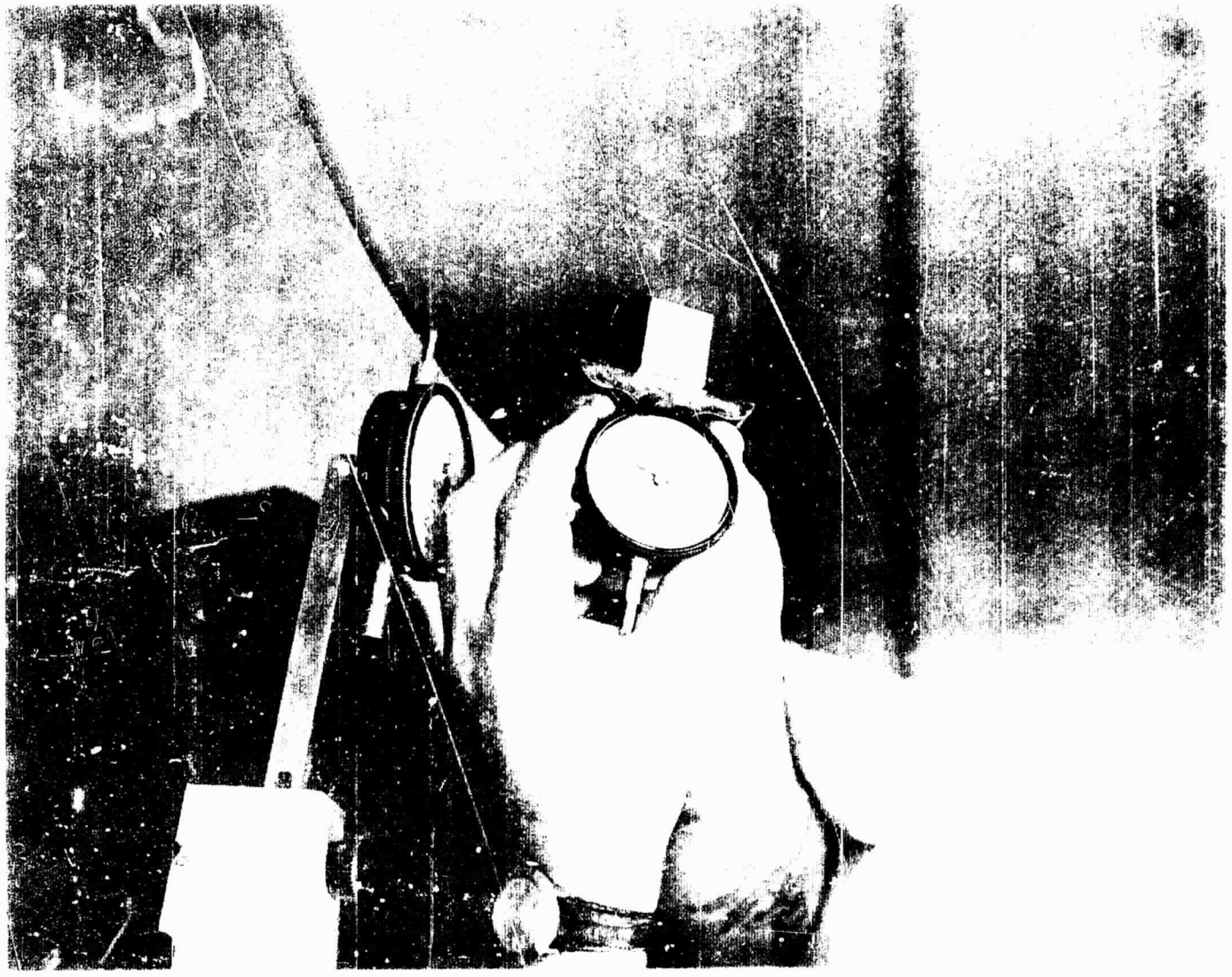


Figure 69. Application of Ablator to Aeroshells.



5/ PHASE IV - SMALL DOUBLY-CURVED AEROSHELLS - ALUMINUM

This phase of the program involved the fabrication of two sphere-cone all-aluminum test models conforming to Jet Propulsion Laboratory drawing No. J4210047 (shown in Appendix G). The objective is to compare the fabricability and structural reliability of aluminum aeroshells to the reinforced plastic aeroshells. The design of the aluminum aeroshell is very similar to that shown in Figure 57. The only configuration change is that the thickness of the core is .50 inch in lieu of .75 inch. The OML of the outer skin was maintained, while the inside skin moved outward one-fourth inch.

5.1 MATERIAL SELECTION

Because of its high strength and good high-temperature properties, 2024-T6 aluminum alloy was selected for both the honeycomb core and the face sheet material. The thickness of the face sheet was .010 inch and the core was .50-inch thick, one-fourth-inch cell, 3.4 psf density to match as closely as possible the gages of the reinforced plastic aeroshells. Two layers of FM-96U, .03 psf adhesive, were chosen from the results of the flat panel evaluation (paragraph 3.5.1).

5.1.1 MATERIALS CONTROL -- Certification by the vendor to specific material types was required to control raw materials. Heat treating of the 2024-0 aluminum was conducted in accordance with Specification MIL-H-60880.

5.2 TOOLING

The same BONJ as was used in bonding the reinforced plastic aeroshells was used for bonding the aluminum aeroshells. In addition, form dies were built to form the inner and outer aluminum skins to contour (see Figure 71). The dies were machined from an aluminum billet with a tracer template that was coordinated with the template to make the plaster reference pattern shown on Figure 72. The surface was polished and Teflon coated. Number 60 holes were drilled in the center to relieve entrapped air during skin forming. Two one-half-inch thick aluminum plates were laminated together. These plates were positioned over the form die and holes were drilled on diameter at the outer edges. The holes in the form die were tapped, and the holes in the plate were drilled out to accommodate the hold-down bolts. An air pressure gage was installed in the plate along with a hoist apparatus.

5.3 FORMING OF CORE

The aluminum honeycomb core shown in Figure 73a had sufficient flexibility to nest in the tool without adverse cell distortion or any delamination. Finger pressure and heat tack of the adhesive held it in place. In Figure 73b, the core is being potted with a Semco pneumatic gun with the shop aid installed.

5.4 FORMING OF ALUMINUM FACE SHEETS

The 2024-0 aluminum face sheets were heat treated to 2024-W condition and formed prior to reaching 2024-T4 condition. A picture of the forming tool is shown in Figure 72. The aluminum sheet was placed over the tool and clamped down by bolting a plywood ring and an aluminum plate to the tool. Eighty psi of air pressure was applied to the top of the aluminum. The aluminum sheet slipped more than it stretched, and radial wrinkles occurred. Additional torque was applied to the bolts on the next attempt and eighty psi was applied. This time the sheet ruptured in the spherical section due to excessive elongation. After several more attempts, one face sheet was formed by keeping the tool in dry ice to prevent the aluminum from advancing

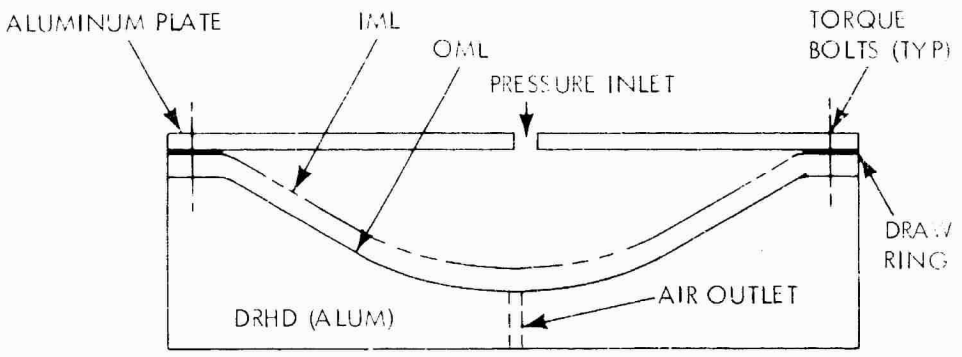


Figure 71. Aluminum Forming Die For Inner and Outer Skin Forming.

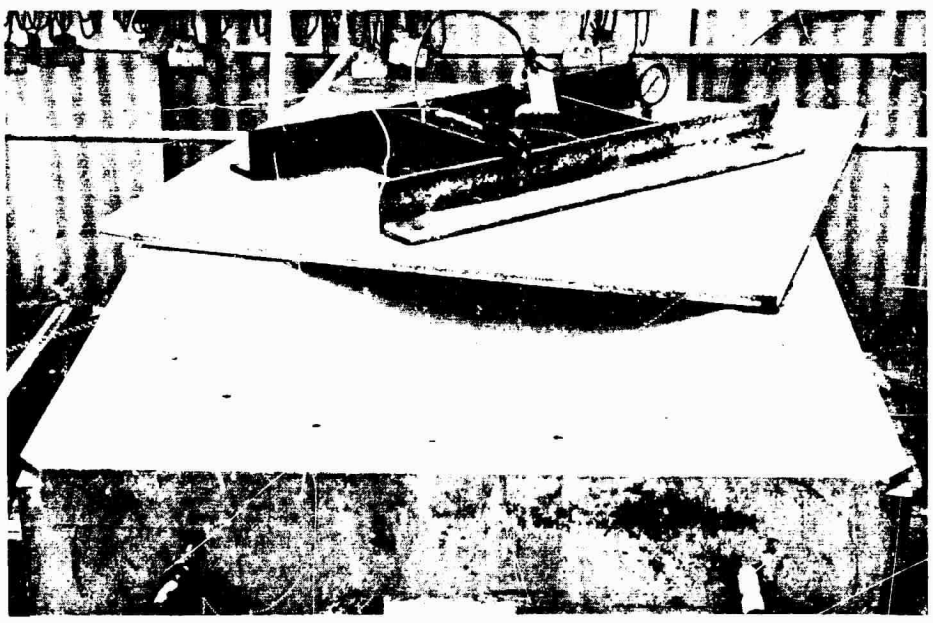
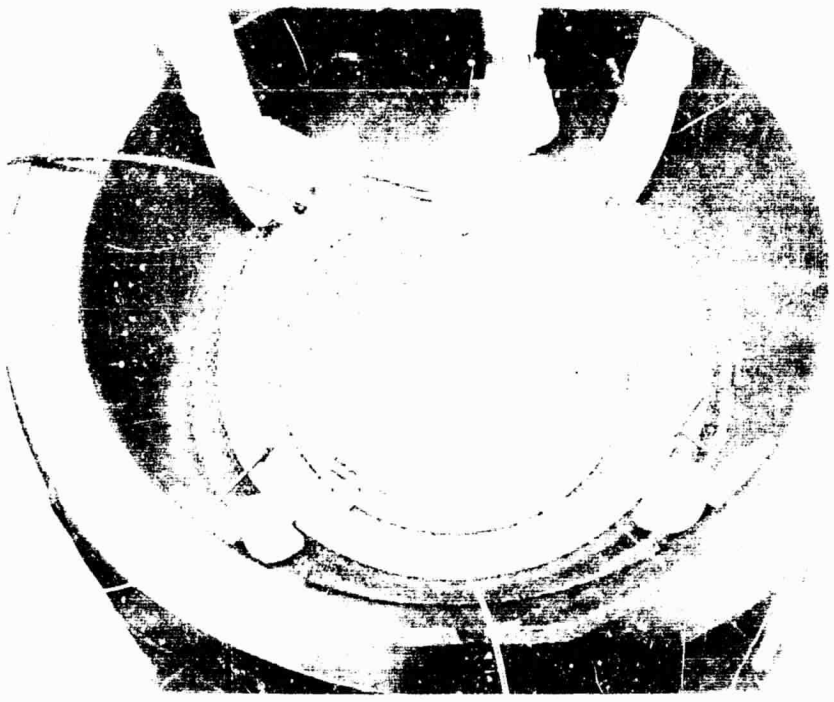


Figure 72. Forming Tool Used to Fabricate Aluminum Facing For Sub-Scale Aerospoils.





to T4 condition. Superficial stretch marks were apparent and the metal thinned a maximum of 15%. The skin is shown being positioned in the hand tool in Figure 74a. Additional tries were made, but were all unsuccessful. The 2024-0 aluminum sheet was then tried six different times, and one skin was formed. Its appearance was the same except for an orange-peel effect on the surface (Figure 74b).

5.5 PROBLEM AREAS

Forming the aluminum to the aeroshell configuration stretches the material to its average elongation of 18% (in two inches) for T4 condition. When using 2024 annealed material, the elongation is still only 20%. Even if annealed aluminum could be formed, there would be a problem in heat treating the part without expensive heat treating fixtures. Since 20% elongation is borderline for forming to the aeroshell configuration, a material with a considerably higher percent elongation is required. Aluminum alloys 1060, 1100, 3003, and 5056 have an elongation of 30%-43% in the annealed condition. Additional work using this material is in progress and will be discussed in an addendum.



Figure [illegible] Formed Aluminum Skin Before Install[illegible]

6/ PHASE V - 6-1/2-FOOT-DIAMETER AEROSHELL

The preceding extensive advanced development program provided sufficient principal property data and fabrication techniques to develop and fabricate a full-size 6-1/2-foot-diameter aeroshell. Minimum gage fabrication of honeycomb snadwich was defined, material systems were optimized, reproducible methods of manufacture in both flat and doubly-curved samples were established, and design data was provided which was used in analyzing various structural configurations and design concepts for the large variety of missions under study at Jet Propulsion Laboratory.

This section summarizes the development and fabrication of a lightweight 6-1/2-foot-diameter reinforced plastic honeycomb sandwich structure for an early Mars mission. Jet Propulsion Laboratory Technical Report No. TR 32-1325, Reference 1, presents a detailed documentation of the development and construction of this full-size aeroshell.

6.1 DETAIL DESIGN

The 6-1/2-foot-diameter aeroshell shown in Figures 75 and 76 was designed structurally using a computer program for unsymmetrically loaded thin shells of revolution (Reference 2). In this program, the honeycomb sandwich is treated as a thin shell with an equivalent, or effective modulus. The payload attachment ring, splice doublers, skin splice, and core splice designs were developed and tested in the development phase mentioned earlier.

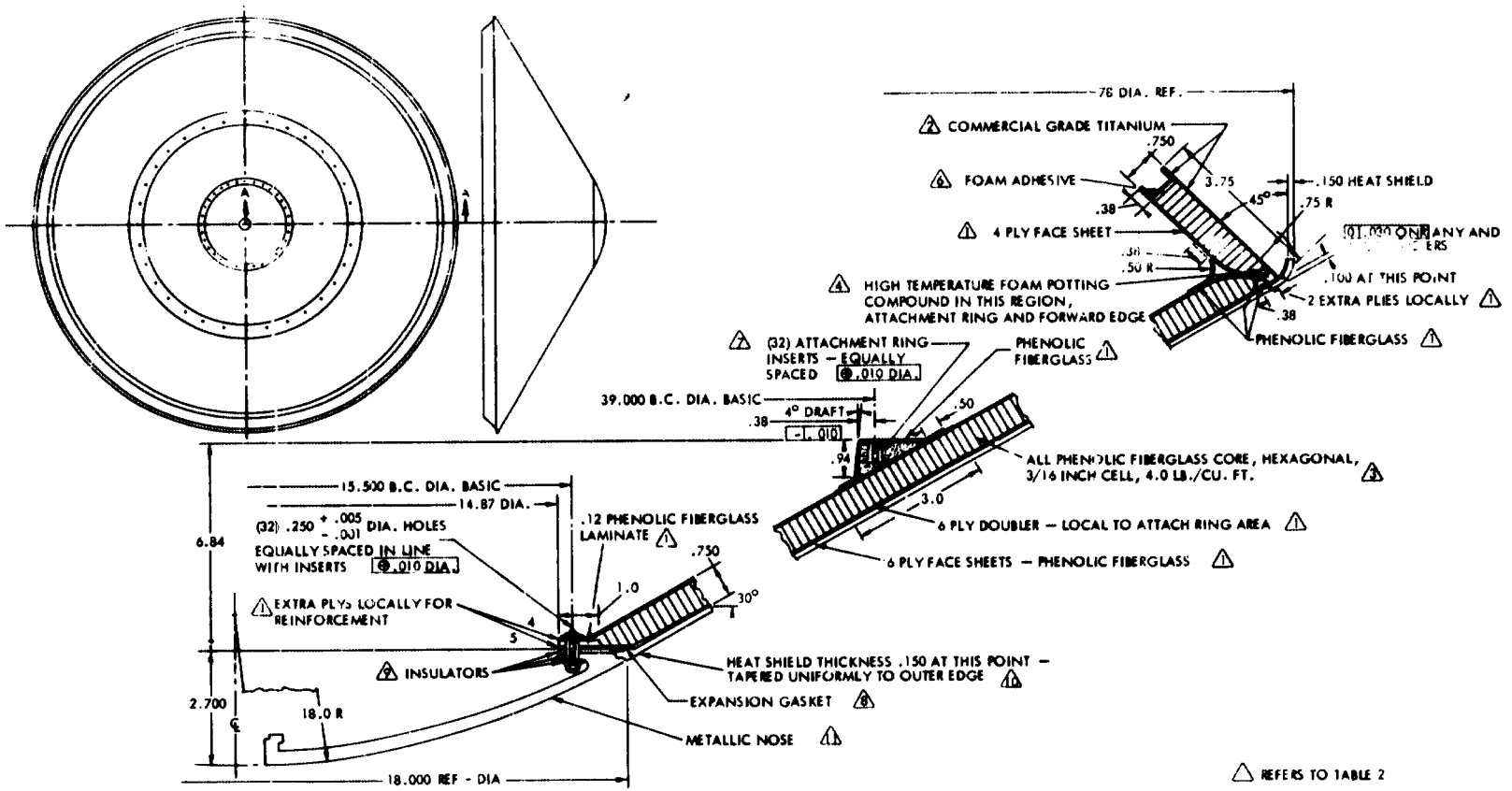


Figure 75. Schematic of Aeroshell Design for Mars Probe.

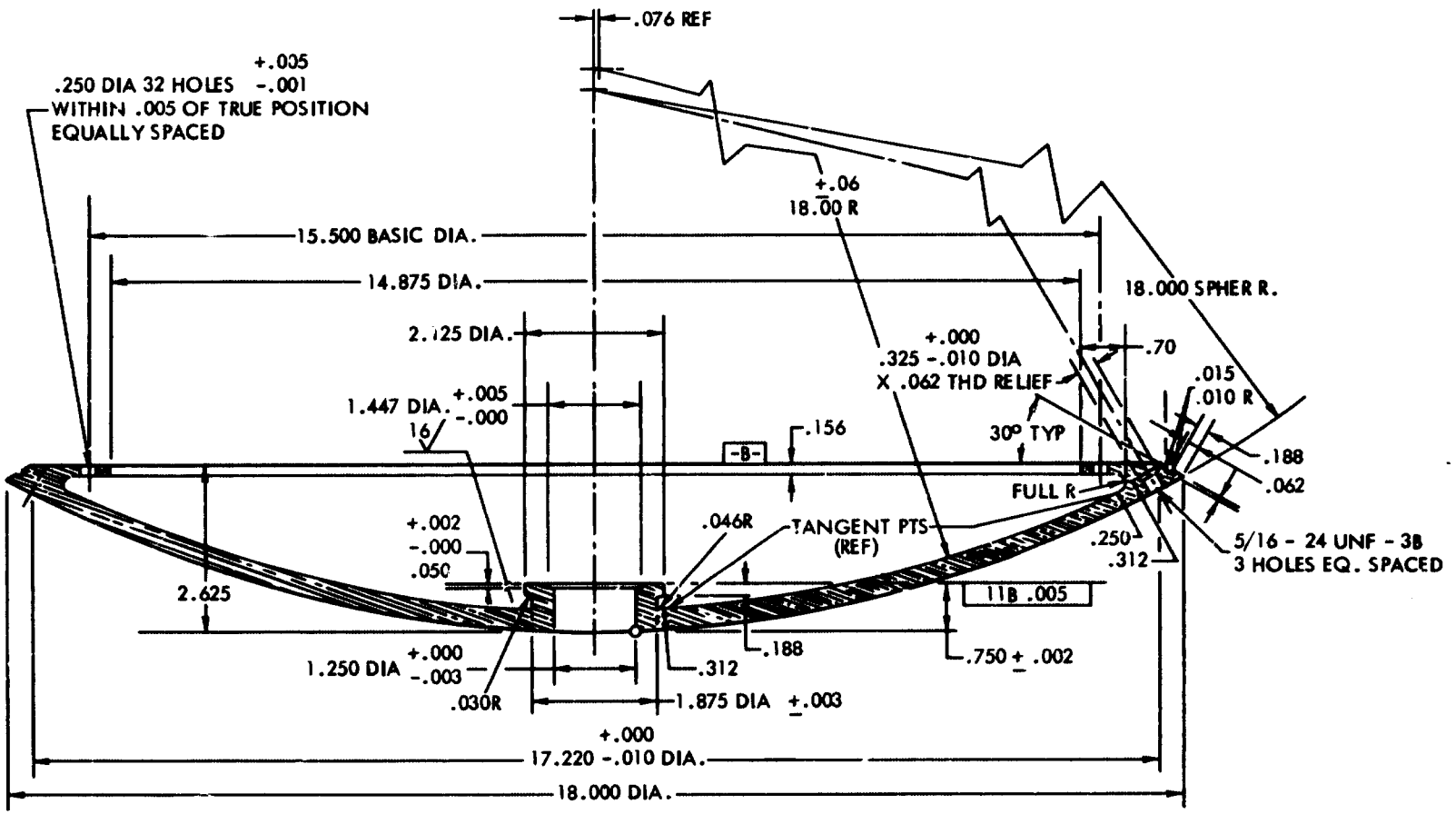


Figure 76. Beryllium Nose Dome Detail. (405 Stainless in Preliminary Model.)

6.2 MATERIALS USED

The specific materials used in the fabrication are outlined in Table 23. These materials are not necessarily optimum, since they were chosen prior to the completion of the development phase discussed earlier. However, their physical and mechanical properties are sufficient to comply with the design requirements and the anticipated environmental tests for a Mars mission.

6.3 TOOLING

The dimensional tolerance called out in the design drawing are more stringent than normally required on reinforced plastic structures.

Some of the locational size tolerances are 10 mils in diameter. To minimize shrinkage and resultant adverse tolerance conditions, the tools were fabricated from 405 stainless steel to one-third the drawing tolerance. The 405 stainless steel has about the closest thermal expansion coefficient to reinforced plastic of any metallic material suitable for tools (6.0 in./in./^{o}F. x 10^{-6} versus 5.5 in./in./^{o}F. x 10^{-6} for phenolic fiberglass).

A schematic of the two conical bond jigs for the fore and aft cones and the central spider to locate the payload attachment ring is shown in Figure 77. These major tools are made of approximately one-inch thick 405 plate, and are stiffened by welded circumferential plates and egg-crated radial plates (3194-47, 3087-3). Numerous templates were made for cutting and locating the facing plies and the core. Routing tools were made for routing the nose of the forward cone and the honeycomb core. A plaster cone was constructed both as a welding fixture in making the major bond jig and as a core-forming tool. A break-forming and a stretch-forming die were made to form the titanium into a channel and then stretch form it to the 45 degree U-angle.

Table 23. Materials Used on 6/1/2-Foot-Diameter Aeroshell

(1) Face Sheets and Reinforcement Rings - American Reinforced Plastic's Adlock 851 Phenolic Resin impregnated on E glass cloth with a Volan A Finish - resin content 45% ± 3%.

A. Individual face sheets are locally 4 to 12 plies of Style 112 cloth (4 mils each).

B. Three-edge reinforcement rings are seven plies of Style 112 cloth.

C. Attachment ring skin has two outer plies of Style 112 cloth and five inner plies of Style 181 cloth (50 mils total nested).

D. Forward reinforcement laminate 15 plies of Style 183 cloth.

(2) Aft Cone Face Sheets and U-Ring - Commercially pure titanium, MIL-T-9046 Class 7, 15 mil face sheet, 20 mil U-ring.

(3) Core - Honeycomb Products, Inc. HTP Hexagonal Core, three-sixteenth inch cell, three-fourths inch thick, 4.0 lb./cu. ft. density, phenolic impregnated Style 112 E glass.

(4) Foam Potting Compound - Rohr Corporation M323 V high temperature, epoxy foam, 31.2 lb./cu. ft. density.

(5) Film Adhesive - Bloomingdale Rubber Co. FM96U unsupported epoxy film, .03 lb./ft.^{2}, and FM96 supported epoxy film on Style 112 E glass cloth.

(6) Foam Adhesive - Bloomingdale Rubber Co. FM40 epoxy foam adhesive film.

(7) Inserts - Shur-Lok Corp. SL601-3-4C.

(8) Fore Expansion Gasket - Teflon (TFE).

(9) Fore Joint Insulators - sintered silica foam of 25 lb./ft.^{3} density on flight model, phenolic fiberglass stock laminate on demonstration model.

(10) Heat Shield - Avco Corporation MOD 7 silicone elastomer syntatic foam.

(11) Metal Nose - Beryllium on flight model, 405 stainless steel on demonstration model for better thermal expansion match and reduced cost.

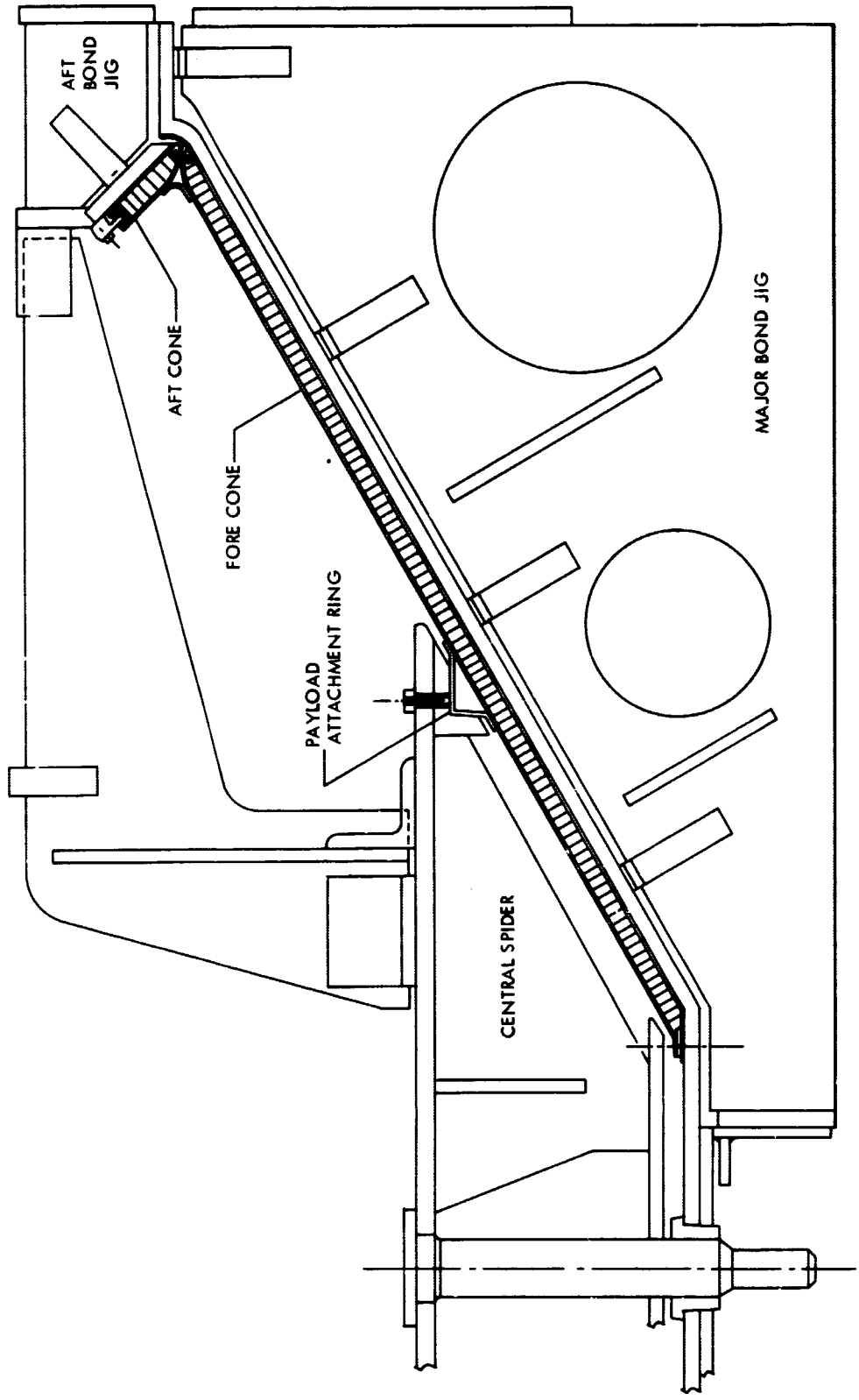


Figure 77. Schematic of Major Tool Assembly.

6.4 DETAIL PARTS FABRICATION

A grouping of sections of all the major detail parts is shown in Figure 78. The titanium U-ring is shown at the top. One fiberglass reinforced plastic V-ring and C-ring are shown in the center with the V-ring already potted. The reinforced plastic attachment ring is shown with the metal inserts installed. A reinforced plastic disk lies in the foreground.

The titanium parts are welded into completed details. Reinforced plastic parts are laid up with Adlock 851 preimpregnated glass fabric and autoclave cured. The V-rings are fabricated in halves and prepotted, and the C-ring is also in two halves. Since the diameter and roundness of the attachment ring is very critical, it was made in one piece.

6.5 AFT CONE FABRICATION

The aft cone is laid up by fitting the outer titanium face sheet to the tool surface and applying two layers of FM-96U adhesive to the entire surface. The titanium U-ring and phenolic honeycomb core are butted together with FM-40 foam adhesive and positioned in the tool on top of the titanium skin. This assembly is then vacuum bagged and cured one hour at 350°F. After the subassembly is inspected, the core is machined to contour, and the edges sealed. The reinforced plastic V-ring is installed with potting compound and one layer of FM-96U adhesive is applied over the assembly, followed by four plies of the Adlock 851/112 prepreg. The entire aft cone is vacuum bagged and cured a half hour at 300°F. and two hours at 350°F.

6.6 MAJOR CONE FABRICATION

The outer face sheet of the major cone is laid up in the major bond jig using six plies of Adlock 851/112 prepreg with the warp direction of each ply rotated 45 degrees from the previous ply. Doublers and spacers are positioned per drawing and the unit is vacuum bagged and cured. The outer skin laminate is removed from the tool and inspected in a free-standing position.

The honeycomb core is formed in the partially cured condition in gore segments on a male plaster tool. The gore segments are overlap spliced with a minimum of one cell and a maximum of two cell overlap. After the core is routed, FM-96U adhesive and the core are positioned on top of the outer face sheet in the bond tool. The subassembly is vacuum bagged and cured one hour at 350°F. The bond between the core and the outer face sheet is inspected. The bond tool with the part in it is placed on a vertical lathe and the core is machined using a coordinated profile template. The surface of the machined core is shown in the bond jig (Figure 79).

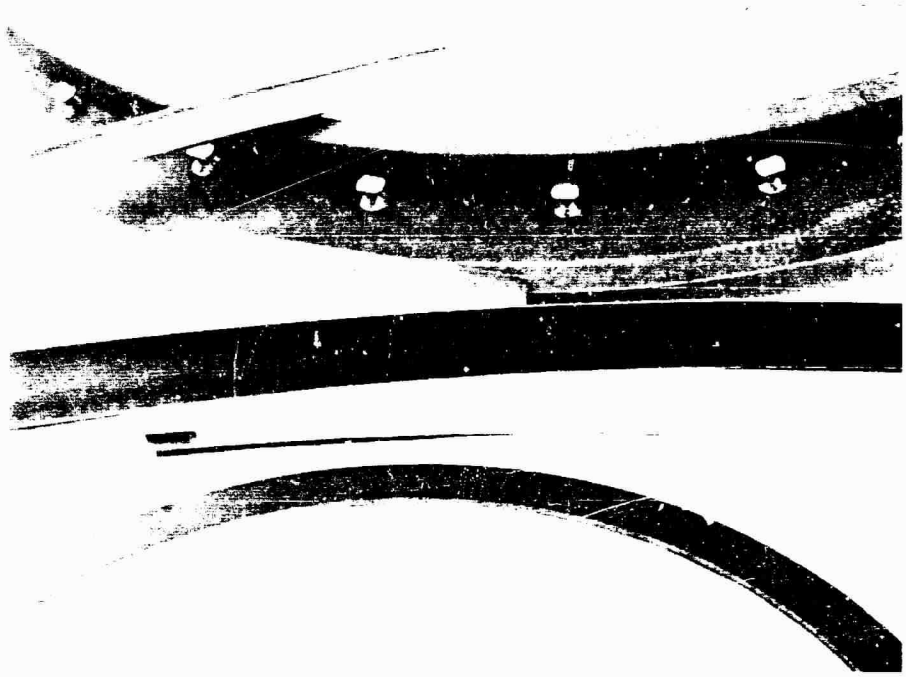
Prepotted V-ring halves are positioned at the aft edge, spliced with one-inch doublers, and faired in with potting compound. FM-96U film adhesive is then applied, followed by six plies of Adlock 851/112 prepreg laid up in the same manner as the outer face sheet, including required doublers. The completed aft cone is used as a pressure tool so that any bumps or discontinuities in the faying surface due to the original cure are transferred in mirror image to the major cone faying surface. A release film is used between the two subassemblies to preclude bonding. A cross section showing the detail lay up as vacuum bagged is illustrated in Figure 80. After cure, the assembly is removed and inspected.

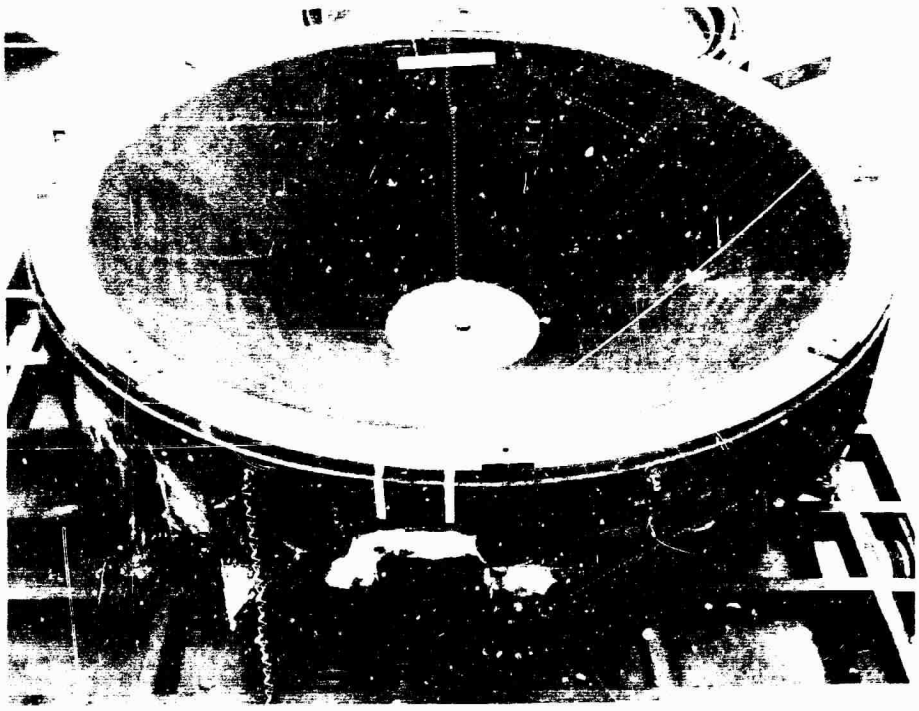
6.7 FINAL ASSEMBLY OF THE CONES

With the two cones complete, the cones and their tools are assembled and the gap between the mating surfaces is measured with a feeler gage. The parts are again separated and the appropriate amount of supported FM-96 adhesive is applied. After the tools and cones are reassembled, potting compound is applied to the mating groove between cones and trammeled to contour. The C-ring halves are then installed with adhesive and splice doublers. This assembly is vacuum bagged and cured for one hour at 350°F.

6.8 FINISHINC AND MATING THE ATTACHMENT RING

The predrilled attachment ring is laid in the center bond tool and the 32 inserts are screwed in place with adhesive washers. These inserts are





cured in place to prevent insert misalignment and adhesive flow through the threaded inserts during application and cure of the potting compound.

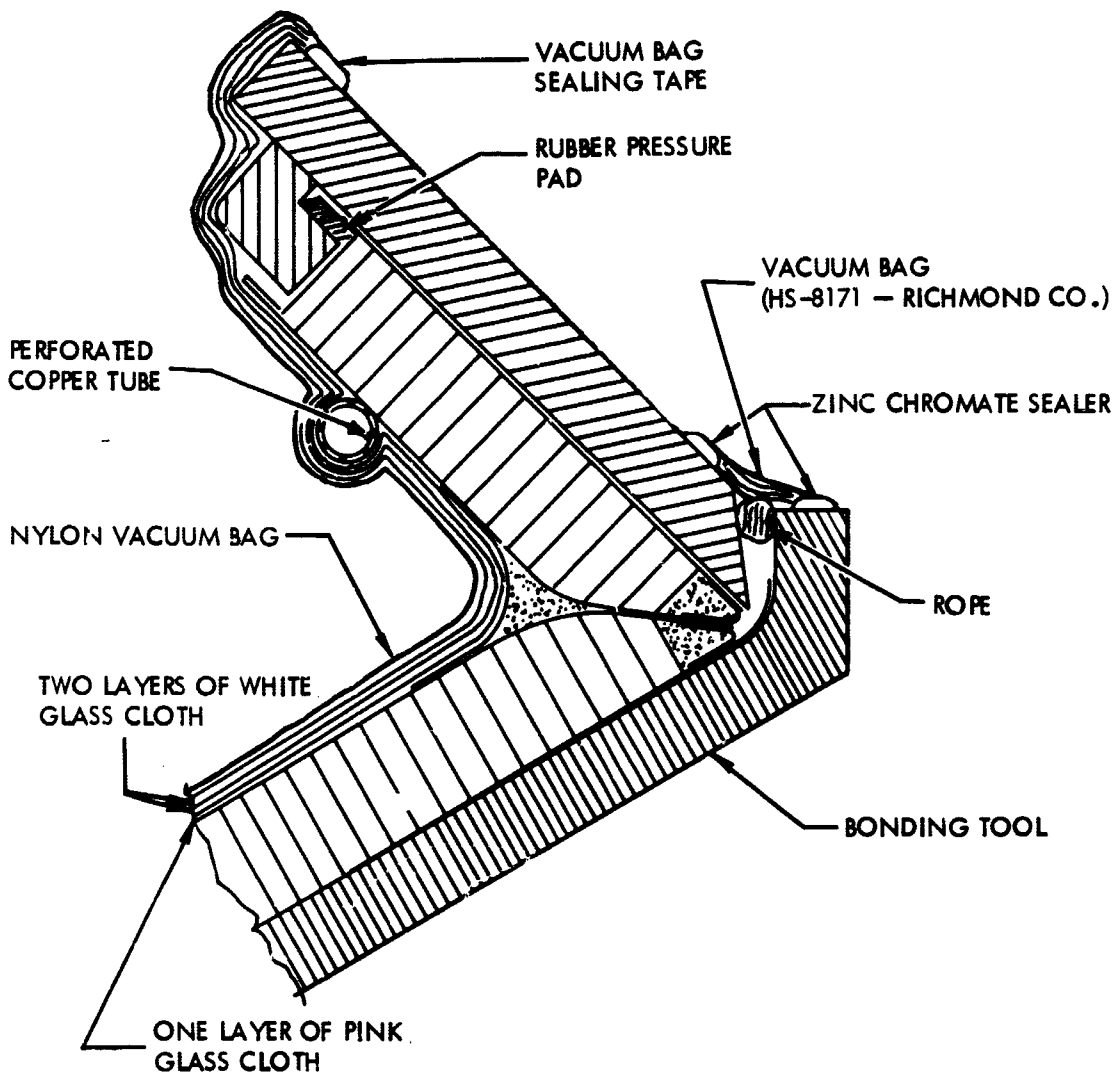


Figure 80. Cross Section of Vacuum Bag Lay Up.

This potting compound is then applied to the attachment ring and trammeled. Supported FM-96 adhesive is applied to the faying surface of the main cone. The center bond tool with the attachment ring in place is lowered onto the main conical surface and cured at 350°F. for one hour under mechanical pressure.

6.9 FINAL ASSEMBLY AND INSPECTION

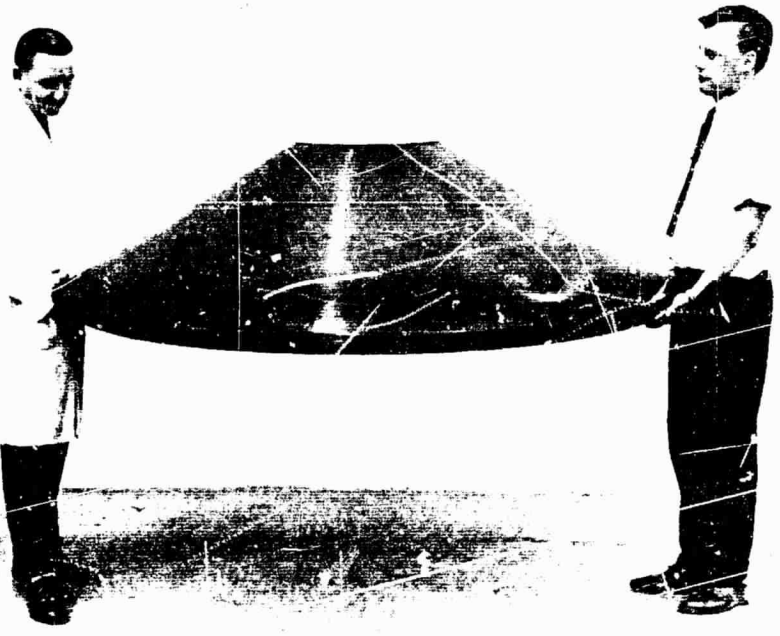
The forward section of the aeroshell is routed and drilled to accommodate the stainless steel nose dome. The outside surface of the aeroshell, with the nose dome in position, is shown in Figure 81.

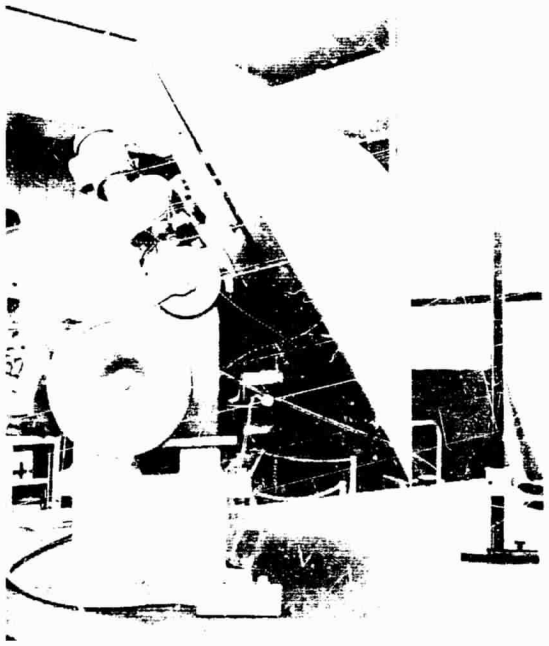
Inspection at any point in the entire fabrication procedure was primarily visual. Quality Control panels were run for each cure cycle. Any bond imperfections or poor workmanship were repaired or replaced. The bond between the face sheets and core was inspected by coin tapping. Other nondestructive test methods were unsuitable, either because of unacceptable contamination from necessary coupling liquid or because of expense or availability.

Dimensional tolerances were inspected on a large Niles lathe using dial indicators. The 39-inch bolt circle on the attachment ring was within four mils of true positional tolerance on diameter. The nose dome attachment hole pattern was located within eight mils of true position with the attachment ring bolt circle. The attachment ring flatness and major cone flatness and roundness were all within drawing tolerance.

6.10 STRAIN GAGE AND THERMOCOUPLE APPLICATION

Strain gages and thermocouples were bonded to outer surface on one subscale aeroshell and one 6-1/2-foot aeroshell. On the 6-1/2-foot aeroshell, twenty-seven WK-06-250-BG-350 (single element temperature compensated) gages were applied, while a total of eight (one WK-06-250-BG-350 and seven ES-624-KZTS stacked rosette) gages were applied to the subscale aeroshell. Adhesive, solder, lead wires, and strain gages that would stand a maximum temperature of 600°F. were required.





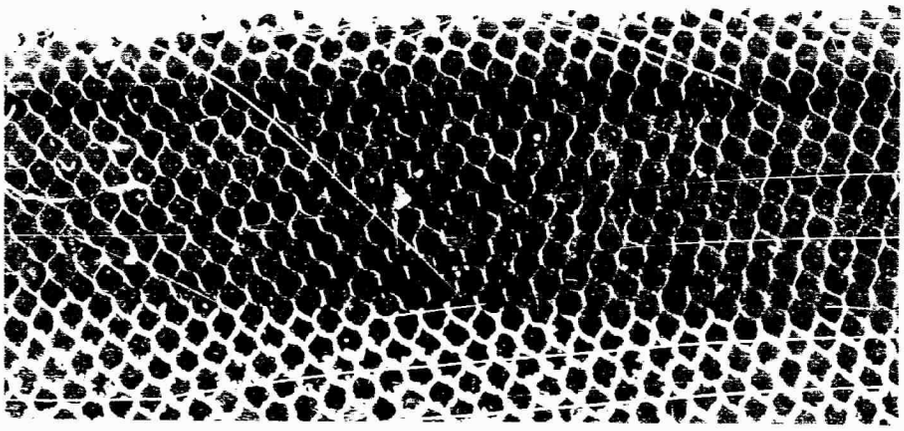
6.11 ABLATOR APPLICATION AND MACHINING

The ablator was applied by AVCO Corporation, Space Systems Division in Lowell, Massachusetts. The aeroshell structure was placed on a coating fixture furnished by Rohr. Silicone elastomer AVCO Model 7 ablator material is applied in a semifluid state by roller coating. The unit is then vacuum bagged and cured, producing a thick nonfriable buildup. After the aeroshell is transferred to a Rohr-furnished machining fixture, it is mounted on a tape-controlled Bullard lathe. The mating surface for the nose dome at the forward end is machined first, extreme care being taken to center on the same line as the cone centerline and to be at the proper height relative to the mounting surface. Circumferential machining of the ablator under tape control was accomplished to produce a .100 to .150 inches taper.

6.12 COMPLETED AEROSHELL AND FINAL INSPECTION

The completed aeroshell with the ablator, but without the nose dome, weighed fifty-five pounds; the structure thirty-nine pounds and the ablator sixteen pounds. A beryllium nose dome for a flight capsule would weigh only about six pounds, but the stainless steel nose dome made for this unit weighed twenty-two pounds.

Final inspection was accomplished on a lathe in a similar manner to that done earlier on the reinforced plastic structure. These measurements showed similar concentricity to the earlier measurements taken on the structure. As a precautionary measure, the aeroshell was also inspected on a rotating table at Jet Propulsion Laboratory (Figure 82). On-the-average surface of the structural cone was within .05 inches of the design surface, which is considered excellent for a reinforced plastic structure. Local depth of the heat shield was measured with a modified dial indicator which penetrates the ablator with less than ten pounds force but stops at the reinforced plastic surface.




ROHR

6.13 REPAIR TECHNIQUES

Reinforced plastic structure can generally be repaired to maintain its original or better structural integrity. The inner face sheet of the second aeroshell was not bonded to the core at the major cone outer curvature due to vacuum bag bridging. This face sheet was entirely removed without difficulty. The bonded and unbonded areas of the honeycomb core are shown in Figure 83. A new six-ply face sheet was applied and cured to the assembly. In fact, test samples going through the identical repair procedure showed an increase of 65% in flatwise tension properties. The increase in strength was due to the original adhesive, which was still bonded to the core, giving the second bond more area to which to bond. The resultant increase in weight was very slight.

One section of the honeycomb core along the outer periphery of the major cone buckled laterally due to insufficient precautions during vacuum bagging. The damaged core was carefully cut out and new core was spliced in place with foam adhesive as shown in Figure 84.

The first 6-1/2-foot diameter aeroshell was damaged when it was removed from the final assembly bond jig. Figure 85a shows the outer skin buckled and fractured. The six-ply outer skin was carefully removed and the plies were stepped around the outer edge of the repair area similar to that shown in Figure 86. New plies were carefully added and the entire assembly was vacuum bagged and cured. The repaired area is shown in Figure 85b.

The structural effects of face sheet overlaps and various methods of core splicing are reported in paragraph 2.9.



Figure 85a. Damaged Area on the 6-1/2 Foot Aeroshell Where the Outer Facing Had Fractured.

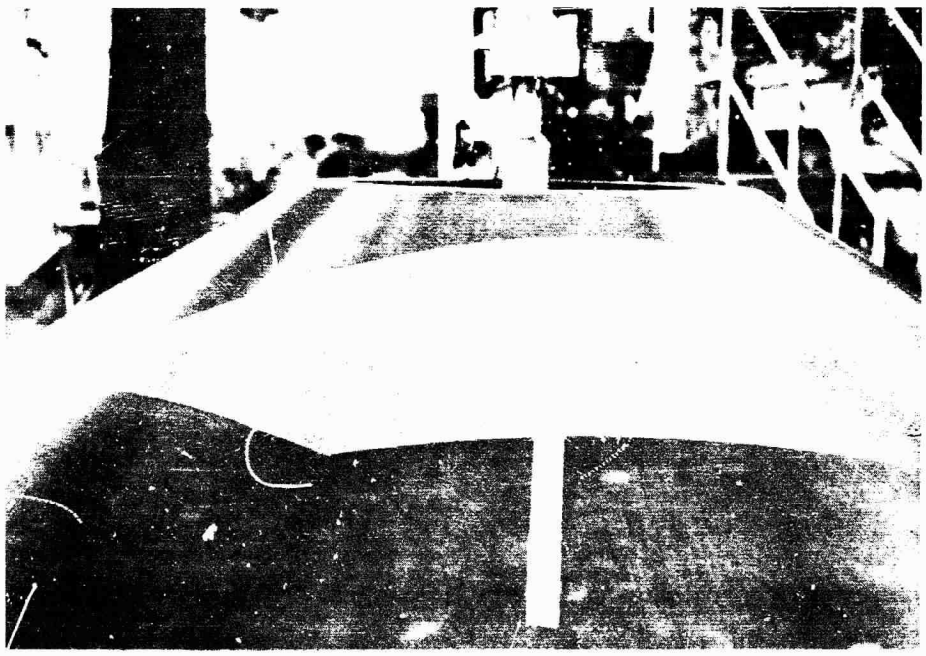


Figure 85b. The Completed Repair of the Fractured Skin of the 6-1/2 Foot Aeroshell.

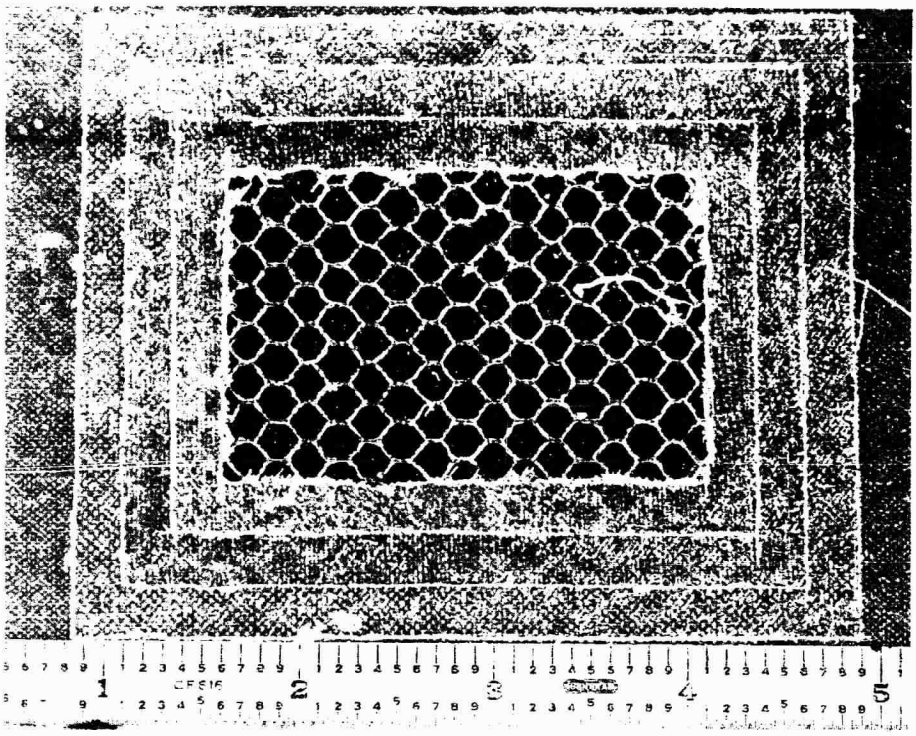


Figure 86. Face Sheet Repair Technique.

7/ CONCLUSIONS

Principal property values for design of honeycomb sandwich structures have been determined for various combinations of facing, adhesive, and honeycomb core for both reinforced plastics and aluminum materials. Epoxy, phenolic, and polyimide prepregs exhibited satisfactory mechanical properties, temperature resistance, and processing characteristics for fabrication of aeroshell facings which will withstand the environmental exposure conditions anticipated.

In these sandwich configurations, the face sheet resin contributes only slightly to differences in the overall composite flexure strength at room temperature, providing other parameters (adhesive, core, etc.) in the configuration are not changed and the particular resin used is one of the best of its generic class.[1] Therefore, resin selection is more dependent upon high and low temperature effects, sterilization, and vacuum compatibility. Phenolic and polyimide composites appear to be superior in this respect, with the phenolic slightly easier to fabricate.

All styles of glass cloth tested, except 108, produced the same stress characteristics on multi-ply face sheets varying from 10 to 22 mils in thickness. Fabricability did not change particularly, except that the eight-harness-satin-weave of the style 181 cloth was more readily formed around sharp radii.

---

[1] Jet Propulsion Laboratory Technical Report 32-1325

Laminates utilizing fabric with Volan A finish produced significantly higher mechanical properties than those fabricated with A-1100 Silane or S-935 finished fabric when using a phenolic resin system. Four plies of preimpregnated 112 style fiberglass at 45 degree rotations produced a reasonable isotropic minimum gage face sheet. Six plies of 112 glass fabric at 45° ply rotation provides identical bidirectional strength as at 60° ply rotation. Two plies are feasible as reasonable isotropic face sheets if special care is taken in cloth selection and composite fabrication. Two-ply laminates are more critical when loaded in compression, due to minor imperfections causing premature buckling of the extremely thin face sheet between the core cells. Face sheets composed of six and twelve plies of 112 fabric and two plies of 181 also exhibited satisfactory properties when compared to four plies. However, since the purpose of this advanced development program was to develop fabrication techniques to utilize minimum gage material combinations with reproducible quality, four and six plies were selected for structural lightweight honeycomb structures.

Adhesives which provide high strength-to-weight ratios and which will resist thermal exposure to 350°F. were selected. The thinnest gage unsupported film adhesive available (.03 lb./ft.^{2}) produced a sufficient and often better bond between the face sheet and core than thicker unsupported film, supported films, or paste adhesives. Polyimide and epoxy-phenolic adhesives provided superior elevated temperature (600°F.) strength compared to the epoxy adhesive candidate. Supported adhesive film controls the bond line thickness requirements on metallic substrates, but acts as a nonuseful heavy filler in reinforced plastic application.

Low density epoxy potting compounds which were evaluated for prepotting and postpotting applications were successfully utilized in fabricating subscale and 6-1/2-foot diameter aeroshells. Higher temperature potting compounds should be evaluated for future activities to meet a 600°F. short time use criteria.

Phenolic and polyimide hexagonal honeycomb core exhibited the highest strength-to-weight ratios of the various types of plastic core evaluated. The strength-to-weight ratio of three-sixteenth-inch hexagonal phenolic core was greater than one-fourth-inch cell core. Although the standard cured hexagonal core is difficult to form to contour and requires splicing, the phenolic core is available in a semicured condition which enables it to be preformed to curvature prior to complete curing. A direct comparison between plastic and aluminum core could not be made because of the different cell sizes evaluated for the two types of materials. However, the aluminum core had excellent mechanical properties and could be formed. The strength-to-weight ratio of three-sixteenth-inch hexagonal core, which was the highest of those tested, was further increased by having the material supplier apply an extra dip of resin. The extra coat of resin added .5 $lb./ft.^3$ of core which is a 12.5% increase in weight. However, a 50% to 80% increase in core shear, flatwise compression, and peel strength resulted without affecting other properties. This technique could be used advantageously in local areas of high stress concentration.

Although the strength-to-weight ratios for principal sandwich panel properties such as flexural strength and edgewise compressive strength for specific flat aluminum honeycomb panel configurations evaluated were generally superior to those for the reinforced plastic sandwich panels, the processability of the reinforced plastic materials was generally superior and more economical. Doubly-curved-contoured subscale aeroshells were successfully fabricated from the plastic facings and honeycomb core using a single-cure cycle. If the face sheets were laminated by themselves using matched close tolerance tooling, significantly higher mechanical properties could be achieved. Because of the problems encountered in fabricating contoured 2024 aluminum facings, methods of producing contoured subscale aluminum aeroshells are still under investigation.

Fabrication procedures and joining techniques were developed, and the structural integrity of panels utilizing these methods were assured by appropriate mechanical property testing. In the three-sixteenth-inch

hexagonal cell size, the lighter weight, one-cell crush overlap core splices were inequivalent in strength to foam adhesive spliced core or overlap spliced core stabilized with a pour coat. Both aligned and staggered facing splices gave sandwich flexural and edgewise compressive strengths equivalent to panels with no splice.

It was also demonstrated that the fabrication procedures and techniques developed on subscale reinforced plastic aeroshell configurations can be successfully adapted to large (6-1/2-foot diameter) aeroshell construction and there is no obvious reason that this same technology cannot be used equally well for twenty-foot diameter or larger aeroshells. The techniques are especially suitable to a large selection of attachment, local reinforcements, rings, etc., with minimum compatibility problems.

Two 6-1/2-foot diameter aeroshells were fabricated utilizing a multistage fabrication sequence, moderate cure temperature (350^{o}F.), and vacuum pressure only.

REFERENCES

1. Nagler, R.; Boundy, R.; Scholl, J. A.; Dawson, J.; "A Lightweight 6-1/2-Foot Aeroshell for an Early Mars Probe Mission," Jet Propulsion Laboratory Technical Report No. TR 32-1325, September 15, 1968.

2. Rung, Robert; Mason, Phillip; and Rosenbaum, Jacob; "Unsymmetrical Analysis of Shells of Revolution," Grumman Aircraft Engineering Corporation Report No. ADR 02-11-65.3, December 1965.

GLOSSARY

A-STAGE. An early stage in the reaction of a thermosetting resin in which the material is still soluble and fusible.

B-STAGE. An intermediate stage in the reaction of a thermosetting resin in which the material softens when heated and swells in contact with certain solvents, but does not entirely fuse or dissolve. Materials are usually cured to this stage to facilitate handling and processing.

COEFFICIENT OF THERMAL EXPANSION (α). The change in volume per unit volume produced by a one degree rise in temperature.

$$\alpha = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P = \left(\frac{\partial \ln V}{\partial T}\right)_P$$

units: degrees^{-1}

CRIMP. The waviness of a fiber. It determines the capacity of fibers to cohere under light pressure. Measured either by

(1) number of crimps or waves per unit length, or

(2) the percent increase in extent of the fiber on removal of the crimp.

FABRIC. A material constructed of interlaced yarns, fibers, or filaments; usually a planar structure. Nonwovens are sometimes included in this classification.

FIBER. A single homogeneous strand of material having a length of at least 5 mm which can be spun into a yarn or roving or made into a fabric by interlacing in a variety of methods.

FILAMENT. A variety of fiber characterized by extreme length. Filaments can be formed into yarn without twist or with very low twist. Used in filament winding processes, which require long continuous strands.

FINISH. A material, with which glass fibers are treated, which contains a coupling agent to improve the bond between the glass surface and the resin matrix in a laminate or other composite material. In addition, finishes often contain ingredients which provide lubricity to the glass surface, preventing abrasive damage during handling, and a binder which promotes strand integrity and facilitates packing of the filaments.

ISOTROPIC. Having uniform properties in all directions. The measured properties of an isotropic material are independent of the axis of testing.

MOLD RELEASE AGENT. A lubricant applied to mold surfaces to facilitate release of the molded article.

PLAIN WEAVE. The simplest of the fundamental weaves. Each filling yarn passes alternately under and over each warp.

POLYMER. A material composed of long molecular chains consisting or repeating chemical units held together by covalent bonds; also referred to as a plastic, a fiber, an elastomer, or a resin.

PREPREG. A combination of mat, fabric, nonwoven material, or roving with resin, usually cured to the B-stage, ready for molding.

RESIN. A solid organic material with indefinite and usually high molecular weight and no sharp melting point. Seldom water soluble or crystalline. The term "resin" is sometimes used synonymously with "plastic."

SCRIM. A low cost, nonwoven open-weave reinforcing fabric made from continuous filament yarn in an open mesh construction.

STRAND. A primary bundle of continuous filaments combined in a single compact unit without twist.

STRESS (σ). Most comonnly defined as "engineering stress", the ratio of the applied load P to the original cross-sectional area A_o.

$$\sigma = \frac{P}{A_o}$$

units: psi

STRESS CONCENTRATION. The magnification of the level of an applied stress in the region of a notch, void or inclusion.

THERMOSETTING RESIN. A resin which undergoes corsslinking and becomes infusible on heating; e.g. phenol-formaldehyde, polyester, and epoxy resins.

VACUUM BAG MOLDING. A hand lay up process in which the lay up is cured under pressure generated by drawing a vacuum in the space between the lay up and a flexible sheet placed over it and sealed at the edges.

VISCOSITY (η). The property of resistance to flow exhibited within the body of a material. Calculated as the ratio of the tangential frictional force per unit area to the velocity gradient perpendicular to the direction of flow of a liquid; the ratio of the shearing stress in a moving liquid to the time rate of shearing strain.

units: poise

WARP - TEXTILES. The threads or fibers which run lengthwise in a fabric.

WETTING. The spontaneous spreading of one phase over the surface of another.

YARN. Generic term for strands of fibers or filaments in a form suitable for weaving or otherwise intertwining to form a fabric.

APPENDIX A

STANDARD FABRICATION FORMS

LIST OF FORMS	PAGE NO.
1. Quality Control Form	A-2
2. Resin Mixing Form	A-3
3. Facing Fabrication	A-4
4. Resin Bonded Panel Fabrication Form	A-5
5. Adhesive Bonded Panel Form	A-6
6. Test Data Form	A-7

QUALITY CONTROL FORM

Project JPL Contract No. 951612 W.O. 402- No. OC

Designation _____ Mfg. Date _____

Vendor _____ Expiration Date _____

Vendor Certification _____ Batch No. _____

Property _____ Lot No. _____

IR Spectrum PS-21 Flow PS-1

Viscosity _____ Reinforcement Type _____

Reactive Content RMS-008, Epoxy Fabric Finish _____

Specific Gravity ASTM D 1475-60 (liquids) Solid Content _____

Volatile Content SPPS-2005, Methods I & II Quantity or Dimensions _____

Resin Content SPPS-2006, Method I Weight/Area _____

AVERAGE MECHANICAL PROPERTIES	Test Data Sheet
Flatwise Flexure (ASTM D-790) _____	_____
Lap Shear ASTM D 1002-64	_____
Barcol Hardness PS-2	_____
Core Compressi... MIL-C-7438	_____

STORAGE CONDITIONS

Temp. _____ _____

_____

_____

REMARKS

_____

_____

_____

_____

_____

_____

_____

Abbreviations:
N.A. - Not applicable

ROHR CORPORATION

RESIN MIXING FORM

Project JPL Contract No. 951612 W.O. 402- No. RM-

COMPONENTS	Q.C. NO.		Q.C. NO.
Resin		Resin	
Curing Agent			

MIXING

Ratio _____ Weight _____

Balance _____ Pot Life _____ Type of Mixer _____

TECHNIQUE

Preparation of Components _____

Order of Addition/Time _____

Blending Procedure _____

Mix Time _____

REMARKS

ROHR CORPORATION

FACING FABRICATION FORM

Project JPL Contract No. 951612 W.O. 402- No. FF-

Code _____ Resin Mixing Form _____

No. of Plies ____ Ply Orientation ____ Fabric/Finish _____ Q.C. No. ___

Impregnation Technique PS-4, PS-12

Lay-up Method PS-5

Bagging Procedure PS-6, PS-7

CURING PROCESS (charts attached) Gel Time PS-3, PS-8

Heat-up Rate Pressure/Vac. Time Temperature

Post Cure _____

PROPERTIES Dimensions _____

Resin Content SPPS-2006, Method I Specific Gravity ASTM D792-64

Barcol PS-2

Screening Test Flatwise Flexure, ASTM D 790-66

Remarks _____

Disposition _____

RESIN BONDED PANEL FABRICATION FORM

Project JPL Contract No. 951612 W.O. 402- No. RP-

Code _____ Resin Mixing Form _____

No. of Plies _____ Ply Orientation _____

Fabric Q.C. No. _____ Core Q.C. No. _____

Impregnation Technique PS-4

Lay-up Method PS-9, PS-10, PS-19, PS-20

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time PS-3, PS-8

Heat-up Rate	Pressure/Vac.	Time	Temperature

Post Cure _____

PROPERTIES (specimen diagram attached) Panel Dimensions ____ Weight ____

Resin Content SPPS-2006, Method I Specific Gravity ASTM D 792-64T

Barcol PS-2 Core Thickness _____

Screening Tests ASTM C 393-62 Sandwich Flexure, ASTM C 297-61 Flatwise Sandwich Tension

Remarks _____

_____ Disposition _____

ROHR CORPORATION

ADHESIVE BONDED PANEL FORM

Project JPL Contract No. 951612 W.O. 402- No. AP-

Code _____

Component	Code No.	Record No.	Component	Code No.	Record No.
Facing (top)			Facing (bottom)		
Core			Adhesive		

CLEANING PROCEDURE

Facings RPS 17.23 (A1), PS-14

Core RPS 15.11 (A1), PS-13

Primer/Adhesive Application RPS 17.20 ¶'s 6.5 and 6.6 (film, primer), PS-15, PS-18

Assembly PS-15, PS-16, PS-18

CURING PROCESS (charts attached)

Heat-up Rate _____ Cure Temp. _____ Cure Time _____

Cure Pressure/Vacuum _____ Equipment _____

CONTROL DATA Lap Shear ASTM D 1002-64 psi Data Sheet No. _____

PANEL CHARACTERISTICS Dimensions _____ Core Thickness _____

Warpage _____ Appearance _____

Remarks _____

_____ Disposition _____

ROHR CORPORATION

TEST DATA FORM

Project JPL Contract No. 951612 W.O. _____ Serial No. _____

PANEL NO. _____ TEST TYPE _____

SPECIMEN IDENTITIES (see diagram) TEST TEMPERATURE _____

ADHESIVE _____ AMBIENT CONDITIONS _____

PRIMER _____ DATE _____

FACING CODE NO. _____ TEST METHOD ASTM-C-297, ASTM C-365,

CORE _____ ASTM-D-1781, ASTM-C-393, ASTM-C-273,

ASTM-C-364

Spec. Ident.	Length	Width	Depth	Area Sq. Inch	Ultimate Load (lb)	psi	Remarks

COMMENTS: _____

TEST FIXTURE

Tested By _____

Forwarded To _____

Date _____

ROHR CORPORATION

APPENDIX B

ROHR FABRICATION AND TEST PROCEDURES

LIST OF PROCEDURES		PAGE NO.
PS-1	Resin Flow - Prepreg Materials	B-2
PS-2	Barcol Hardness Test - For Glass Fiber Reinforced Laminates	B-3
PS-3	Gel Time of Resin - Prepreg Materials	B-4
PS-4	Liquid Epoxy Resin Impregnation Technique	B-5
PS-5	Lay Up Method for Prepregs	B-6
PS-6	Bagging Procedure for Prepregs	B-7
PS-7	Bagging Procedure for Wet Lay Up	B-8
PS-8	Gel Time of Resin	B-9
PS-9	Prepreg Lay Up Procedure for Resin Bonded Panel	B-10
PS-10	Wet Lay Up Method for Resin Bonded Panel	B-11
PS-11	Resin Bonded Panel Bagging Procedure	B-12
PS-12	Liquid Epoxy Resin Impregnation and Lay Up	B-13
PS-13	Cleaning and Storage Procedure for HRP Core	B-14
PS-14	Cleaning Procedure for Cured Laminates Prior to Bonding	B-15
PS-15	Lay Up Procedure for sive Bonded Panel (Film Adhesive)	B-16
PS-16	Adhesive Bonded Panel Bagging Procedure	B-17
PS-17	Fabrication of Contoured Facings from Prepregs	B-18
PS-18	Assembly of Adhesive Bonded Sphere-Cone Models (Film Adhesive)	B-20
PS-19	Wet Lay Up Method for Resin Bonded Panel	B-22
PS-20	Prepreg Lay Up Procedure for One-Stage Adhesive Bonded Panel	B-23
PS-21	Infrared Analysis of Resin Systems	B-24
PS-22	Forming Cured Phenolic Honeycomb Core	B-28
PS-23	Core Splicing with Adhesive (FM-40)	B-29
PS-24	Forming and Curing HTP Green Core	B-30
PS-25	One-Stage Fabrication of Sphere-Cone Models from Prepregs (Film Adhesive)	B-31

RESIN FLOW - PREPREG MATERIALS

1. Cut and stack four 5-inch square pieces and place a 4-inch by 4-inch template on the unpressed laminate with template edges parallel to laminate edges. Cut laminate to template.

2. Weigh the 4-inch by 4-inch sample to the nearest 0.001 gram and record.

3. Place laminate between two sheets of nylon or other suitable film.

4. Place laminate between heated press platens stabilized for a minimum of 15 minutes before running the test. Immediately close press and apply 15 psi pressure. (The gage used to measure ram pressure shall be graduated so that it can be read accurately to 1 psi.) Press shall be closed and full pressure applied in not more than 30 seconds from the time the sample is placed on the platen.

5. Curing conditions shall be as follows:

   Time - 10 minutes, or until completely gelled.

Type	Temperature, °F.
Phenolic	325 ± 5°F.
Epoxy	325 ± 5°F.
Polyester	225 ± 5°F.

6. Remove the cured sample from the press. Remove the separator film and cool to room temperature.

7. Remove the resin beyond the edges of the laminate, being careful not to remove any of the original carrier fabric.

8. Weigh the trimmed sample to the nearest 0.001 gram.

9. Calculate the resin flow to 0.1% as follows:

$$\text{Resin flow, \%} = \frac{(W_1 - W_2)}{(W_1)} \times 100$$

   W_1 = Original weight of sample

   W_2 = Weight of cured sample after flash removal.

10. Report the results of the resin flow to 0.1%.

BARCOL HARDNESS TEST - FOR GLASS FIBER REINFORCED LAMINATES

1. Test specimens shall be at least 0.25-inch in thickness, unless it has been shown that identical results are obtained on specimens 0.125-inch or greater in thickness, in which case the latter specimens may be used. Thinner samples may be stacked to obtain these thicknesses, but hardness determinations made on such specimens shall be considered only indicative and not definite. No hardness determination shall be made within 0.5-inch of the edge of the specimen, unless it has been shown that this factor does not affect the results.

2. A Barcol Impressor, Model No. GY2J-934-I, shall be used. Each instrument shall be supplied with a Barber-Coleman standard; and prior to each set of readings, the Barcol Impressor shall be checked against the standard.

3. Place the laminate or part on a solid table.

4. Apply pressure directly over the Barcol Impressor, firmly and at a uniform rate. Avoid starved areas, voids, and uneven areas.

5. Record the highest point reached by the indicator needle for five readings. Disregard all readings less than twenty-five.

6. Report the average of all readings over twenty-five as the average Barcol hardness.

GEL TIME OF RESIN - PREPREG MATERIALS

1. Cut, across the roll width, sufficient 2-inch by 2-inch pieces to make a sample approximately 0.20-inch thick.

2. Place the sample between sheets of nylon or other suitable film. Insert between the platens of a press at the lowest temperature specified for cure. The press platen temperature shall be stabilized for at least 15 minutes before running the test.

3. Apply sufficient pressure to form a bead of resin around the specimen. Start time as soon as pressure is applied.

4. The resin bead shall be probed at intervals with a wire. Gelling will be preceded by the appearance of long strands of resin referred to as "stringiness." These long strands of resin will eventually disappear. The probing shall be continued until the disappearance of these long strands and actual gelation takes place. Gelation in this case is defined as the absence of strands of resin. To further confirm that gelation has occurred, the sample shall be removed immediately from the press and inspected. In many cases the gel time cannot be distinguished as a sharp, definite point and a range shall be reported; for example, between 3.5 and 4.0 minutes.

5. Report as the gel time, the time range or the time elapsed.

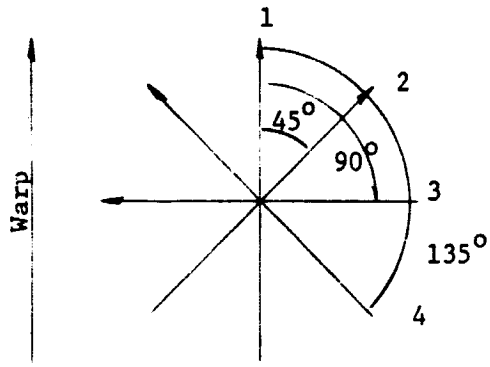
LIQUID EPOXY RESIN IMPREGNATION TECHNIQUE

NOTE: Clean white gloves must be worn when handling the fabric during trimming and lay-up procedures.

1. Cut fabric, oriented to warp as indicated below, and weigh plies.

2. The fabric will be saturated with a preweighed quantity of degassed, blended resin sufficient for an initial resin content of 45 percent.

3. Apply a portion of the resin mix to the prepared form and lay one ply of fabric over it. Each of the plies of fabric shall be oriented at 45^{o} to the preceding ply, or as indicated on the Facing Fabrication Form. Compact with a squeegee or roller as each ply is laid up. Do not apply resin over surface of last ply.



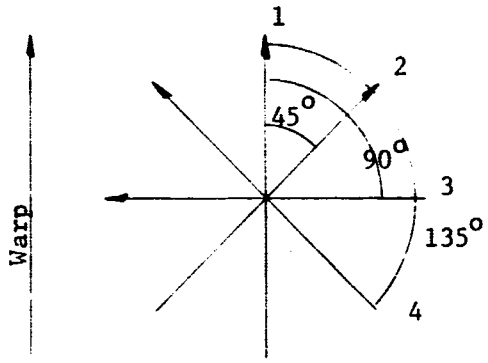
LAY UP METHOD FOR PREPREGS

NOTE: Clean white gloves must be worn when handling the prepreg during trimming and lay-up operations.

1. Apply one sheet of parting film, such as cellophane, and one sheet of Armalon to caul plate.

2. Cut prepreg with fabric oriented to warp as indicated below.

3. Apply the plies of prepreg, each one oriented at 45° to the preceding ply, or as indicated on Facing Fabrication Form. Compact and smooth out each ply as it is laid up.



BAGGING PROCEDURE FOR PREPREGS

1. Apply one sheet of Armalon over the prepreg lay up.

2. Apply one layer of Osnaburg cloth and two layers of 181 glass fabric bleeder over the Armalon. Edge bleeder shall consist of the equivalent of four layers of cloth.

3. Install a thermocouple between the laminate plies approximately one-half inch from the edge.

4. Apply high temperature sealer around the sheet and imbed thermocouple, vacuum probe, and vacuum source line in the sealer.

5. Bag with 2 mil nylon vacuum blanket or equivalent.

6. Apply a partial vacuum and adjust bag wrinkles to eliminate bridging.

7. Apply full vacuum and check for leaks. A minimum of 24-inches of mercury shall be obtained.

BAGGING PROCEDURE FOR WET LAY UP

1. Place bleeders (four layers of Osnaburg cloth, or equivalent) around the edges of the part.

2. Install a thermocouple between the laminate plies, approximately one-half inch from the edge.

3. Apply high temperature sealer around the sheet and imbed thermocouple, vacuum probe, and vacuum source line in the sealer.

4. Bag with a transparent film of polyvinyl alcohol, or equivalent.

5. Apply a partial vacuum and adjust bag wrinkles to eliminate bridging.

6. Apply full vacuum. After the bag has been drawn against the part as tightly as possible and impregnation is completed, air and excess resin shall be swept out of the part by using squeegees or rollers.

7. Check for leaks. A minimum of 24-inches of mercury shall be obtained.

GEL TIME OF RESIN

1. Impregnate #181 glass fabric with the resin mixture.

2. Prepare a sufficient number of two-inch by two-inch pieces to make a sample approximately 0.20-inch thick.

3. Place the sample between sheets of nylon or other suitable film.

4. Insert between the platens of a press at the lowest temperature specified for cure. The press platen temperature shall be stabilized for at least 15 minutes before running the test.

5. Apply contact pressure. Start time as soon as pressure is applied.

6. Probe the resin at intervals with a wire. Gelling will be preceded by the appearance of long strands of resin referred to as "stringiness." These long strands of resin will eventually disappear. The probing shall be continued until the disappearance of these long strands and actual gelation takes place. Gelation, in this case, is defined as the absence of strands of resin. To further confirm that gelation has occurred, the sample shall be removed immediately from the press and inspected. In many cases the gel time cannot be distinguished as a sharp, definite point and a range shall be reported; for example, between 3.5 and 4.0 minutes.

7. Report as the gel time, the time range or the time elapsed.

PREPREG LAY UP PROCEDURE FOR RESIN BONDED PANEL

NOTE: Clean white gloves must be worn when handling the prepreg during trimming and lay-up operations.

1. Apply one sheet of parting film such as cellophane and one sheet of Armalon to caul plate.

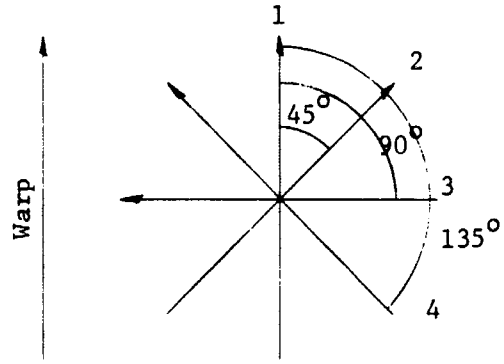
2. Cut prepreg with fabric oriented to warp as indicated below.

3. Assemble the plies of prepreg for each facing, with each ply oriented at 45° to the preceding ply, or as indicated on Facing Fabrication Form. Compact and smooth out each ply as it is laid up.

4. One facing shall be placed in contact with the Armalon.

5. Center the core over the facing and press into position.

6. Place the second facing over the core. Smooth into place, being careful not to damage the core.



WET LAY UP METHOD FOR RESIN BONDED PANEL

1. Impregnate fabric per indicated procedure for each facing.
2. Apply one sheet of parting film, such as celleophane, and one sheet of Armalon to the caul plate.
3. Place one facing over the Armalon.
4. Center the core over the facing and press into position.
5. Place the second facing over the core. Smooth into place, being careful not to damage the core.

RESIN BONDED PANEL BAGGING PROCEDURE

1. Install thermocuples between the laminate plies of each facing, approximately one-half inch from the edge.

2. Place bleeders around the edges of the lay up. Edge bleeders shall make contact with the edges of the lay up, but shall not be placed closer than one-half inch to the part net-trim line. Bleeder strips may be of Osnaburg cloth or any other suitable noncontaminating material which serves as direct connection to the vacuum line.

3. Cover the resin-impregnated fabric lay-up with one sheet of Armalon. The film must partially overlap the edge bleeder.

4. Place one layer of Osnaburg cloth and two layers of #181 glass fabric bleeder over the Armalon. The bleeder should extend beyond and contact the edge bleeder and the bleeder cloth which serves as a direct connection to the vacuum line.

5. Apply high temperature sealer around the lay up and imbed thermocouples, vacuum probe, and vacuum source line in the sealer.

6. Bag with 2 mil nylon vacuum blanket or equivalent.

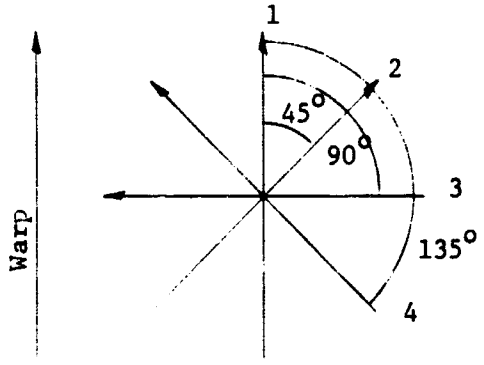
7. Apply a partial vacuum and adjust bag to eliminate bridging, keeping wrinkles to a minimum. Avoid wrinkling of the bag on the part. Wrinkling of the surface bleeder shall not be allowed.

8. Apply full vacuum and check for leaks. A minimum of 24-inches of mercury shall be obtained.

LIQUID EPOXY RESIN IMPREGNATION AND LAY UP

NOTE: Clean white gloves must be worn when handling the fabric during trimming and lay-up operations.

1. Cut the fabric, oriented to warp as indicated below, and weigh plies.
2. Apply one sheet of parting film, such as cellophane, to the caul plate.
3. Stack the fabric plies with each one oriented at 45° to the preceding ply, or as indicated on the Facing Fabrication Form.
4. Place a preweighed quantity of degassed, blended resin sufficient for an initial resin content of 45-50 percent in the center of the glass fabric lay up.
5. Cover the lay up with one layer of cellophane, or equivalent.



CLEANING AND STORAGE PROCEDURE FOR HRP CORE

1. Core shall be stored wrapped in clean, wax-free paper after removal from closed container in which shipped.

2. Core supplied by the vendor is usually in a clean condition ready for adhesive bonding. If dust from core cutting or handling is observed on the core, it shall be blown off with clean, pressurized air. (Plant air shall be run through a suitable filter to remove any entrapped oil and water.) This cleaning shall be done while core is suspended in an area where no bonding or lay-up work is performed. (Caution: Wear respirator.)

3. If the core should get contaminated during improper handling, clean it by washing in acetone or MEK. (Caution: Flammable Solvents.) The solvent shall be poured over the core and allowed to run off and evaporate for 10 minutes followed by a drying period of one hour at 150°F. After cooling to R.T., the core is ready for bonding or storage.

CLEANING PROCEDURE FOR CURED LAMINATES PRIOR TO BONDING

1. Handle the laminates with white cotton gloves and protect in wax-free Kraft paper or equivalent during any storage period exceeding 30 minutes.

2. Pour a small amount of acetone or MEK on clean, lint free, white, cotton cloth. (Don't use solvent fountains because of danger of secondary contamination.) Wipe the faying surface of the laminate with the moistened cloth. If the cloth becomes discolored, use a clean section or new cloth. Allow the solvent to evaporate.

3. Lightly sand the faying surface of the laminate to remove glossy areas of the laminate. Use emery cloth of 80 or finer grit with a wooden block. Avoid damage to the glass fibers of the laminate.

4. Wipe the laminate with a cloth moistened with MEK or acetone (use clean sections of cloth as it becomes discolored).

5. Allow laminate to dry at R.T. for 10 minutes and at 150°F. for 20 minutes. Cool laminate to R.T. and wrap it in wax-free, clean paper prior to storing.

LAY UP PROCEDURE FOR ADHESIVE BONDED PANEL (FILM ADHESIVE)

NOTE: Clean white gloves must be worn when handling the laminate, adhesive, and core.

1. Apply one sheet of parting film such as cellophane, and one sheet of Armalon to tool surface. Tape these release layers to the tool, if necessary, to prevent them from moving.

2. After laminate has been cleaned for bonding, place it on the release layers.

3. Cut adhesive to a pattern the size of the facing. Apply carefully to the faying surface of the facing to avoid wrinkling. Squeeze or roll the adhesive against the laminate to remove large air pockets. Splices shall be butt spliced if necessary. Overlap of adhesive along splice line shall not be allowed. Gaps along the splice line shall be limited to a maximum of one thirty-second inch.

4. Apply thermocouple between adhesive and laminate, approximately one-half inch from the edge.

5. Place the core over the adhesive and press into position lightly.

6. Cut adhesive and apply to the faying surface of the second facing as described in paragraph 3.

7. Place second facing on the core and apply thermocouple between adhesive and facing. Lightly press the skin on the core.

8. Apply fairing blocks around assembly where necessary to prevent lateral crushing of the honeycomb core.

9. Identify panel and top bond line in area shown on attached sketch.

ADHESIVE BONDED PANEL BAGGING PROCEDURE

1. Apply high temperature sealer about one- to two-inches from the part line. Embed thermocouples in sealer tape.

2. Place bleeders around the edges of the lay-up. Edge bleeders shall make contact with the edges of the lay-up, but shall not be placed closer than one-half inch to the part net-trim line. Bleeder strips may be on Osnaburg cloth or any other suitable noncontaminating material which serves as direct connection to the vacuum line.

3. Cover the assembly with one sheet of Armalon. The film must partially overlap the edge bleeder.

4. Place two layers of Osnaburg cloth over the Armalon. The bleeder should extend beyond and contact the edge bleeder and the bleeder cloth which serves as a direct connection to the vacuum line.

5. Imbed vacuum probe and vacuum source line in the sealer.

6. Bag with 2 mil nylon vacuum blanket or equivalent.

7. Apply a partial vacuum and adjust bag to eliminate bridging, keeping wrinkles to a minimum. Avoid wrinkling of the bag on the part. Wrinkling of the surface bleeder shall not be allowed.

8. Apply full vacuum and check for leaks. A minimum of 24-inches of mercury shall be obtained.

FABRICATION OF CONTOURED FACINGS FROM PREPREGS

A. Tool Preparation

1. Tools coated with a permanent release film shall be inspected to assure that there are no breaks or cracks in the parting film, and that the molding surfaces are smooth and free from pits, gouges, or other irregularities.

   1.1 Coated tools with such defects shall be repaired and recoated.

2. Uncoated tools shall be prepared as follows:

   2.1 The molding surfaces shall be smooth and free from pits, gouges, or other irregularities.

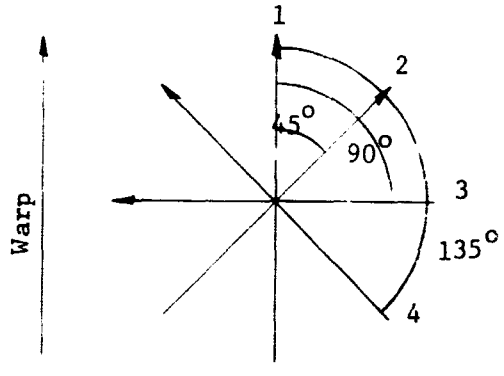
   2.2 If the molding surfaces are porous, a suitable sealant shall be applied.

   2.3 A suitable parting agent shall be applied to the clean, dust free molding surfaces of the tool. Runs or sags are not permitted in sprayed release films. Wax films shall be polished with a clean, soft, dry cloth.

B. Fabric Preparation

1. Clean, white gloves shall be worn when handling fabric.

2. Cut fabric to the required size. Fabric may be cut into definite patterns where applicable. Fabric patterns shall be cut in a manner to ensure that fabric warp direction is in accordance with requirements as specified.



C. Lay Up

1. Lay each pattern or ply on the released tool so there shall be a minimum of gores. Each successive ply shall be oriented with the warp at 45° to the preceding ply, or as indicated on Facing Fabrication Form.

FABRICATION OF CONTOURED FACINGS FROM PREPREGS (CONT.)

2. Stagger cuts and seams of consecutive plies so that joints in contacting plies shall not coincide. Maintain lap widths of one-half to one-inch for fabric pieces in any one given ply. The number of laps shall be kept to a minimum.

3. Apply succeeding plies and carefully work down so as to obtain a smooth, tight laminate free from air pockets and wrinkles.

D. Bagging

1. Apply high temperature sealer external to the part line. Do not remove upper covering.

2. Install a thermocouple between the plies of the laminate, approximately one-half inch from the edge.

3. Place bleeders around the edges of the lay up. Edge bleeders shall make contact with the edges of the lay up, but shall not be placed closer than one-half inch to the part net-trim line. Bleeder strips may be of Osnaburg cloth or any other suitable noncontaminating material which serves as direct connection to the vacuum line.

4. Cover the resin-impregnated fabric lay up with one sheet of Armalon. The film must partially overlap the edge bleeder.

5. Place one layer of Osnaburg cloth and two layers of 181 glass fabric bleeder over the Armalon. The bleeder should extend beyond and contact the edge bleeder and the bleeder cloth which serves as a direct connection to the vacuum line.

6. Remove covering from the sealer and imbed thermocouple, vacuum probe, and vacuum source line in sealer, where applicable.

7. Bag with a 2 mil nylon vacuum blanket or equivalent.

8. Apply a partial vacuum and adjust bag to eliminate bridging, keeping wrinkles on the part to a minimum. Wrinkling of the surface bleeder shall not be allowed.

9. Apply full vacuum and check for leaks. A minimum of 24-inches of mercury shall be obtained.

E. Removal from Tools

1. Remove bagging.

2. Carefully lift or pry the part from the form.

3. Remove all parting media from the part.

ASSEMBLY OF ADHESIVE BONDED SPHERE-CONE MODELS (FILM ADHESIVE)

NOTE: Clean white gloves must be worn when handling the laminate, adhesive, and core.

A. Lay Up

1. Tool coated with a permanent release film shall be inspected to assure that there are no breaks or cracks in the parting film, and that the molding surfaces are smooth. Coated tools with defects shall be repaired and recoated.

2. After the facing has been cleaned for bonding, place it onto the released tool surface.

3. Cut adhesive to a suitable pattern to cover the facing. Apply carefully to the faying surface of the facing to avoid wrinkling. Squeegee or roll the adhesive against the laminate to remove large air pockets. Seams shall be butt spliced. Overlap of adhesive along the splice line shall not be allowed. Gaps along the splice line shall be limited to a maximum of one thirty-second inch.

4. Apply thermocouple between adhesive and laminate approximately one-half inch from the edge.

5. Place the core over the adhesive and press into position lightly. Core segments may be interlocked prior to locating in mold. The ply under the core may be heated with a hot air gun, then the core pressed against the bond ply until the resin has cooled to room temperature in order to attain positive location of the core. No slashing of the core to facilitate forming shall be permitted.

6. Cut adhesive and apply to the faying surface of the second skin as described in paragraph 3.

7. Place the second facing on the core and apply a thermocouple between the adhesive and facing. Lightly press the skin on the core.

8. Apply fairing blocks around assembly where necessary to prevent lateral crushing of the honeycomb core.

B. Bagging

1. Apply high temperature sealer external to the part line. Imbed thermocouples in sealer tape.

ASSEMBLY OF ADHESIVE BONDED SPHERE-CONE MODELS

(FILM ADHESIVE)(CONT.)

2. Place bleeders around the edges of the lay up. Edge bleeders shall make contact with the edges of the lay up, but shall not be placed closer than one-half inch to the part net-trim line. Bleeder strips may be of Osnaburg cloth or any other suitable noncontaminating material which serves as direct connection to the vacuum line.

3. Cover the assembly with one sheet of Armalon. The film must partially overlap the edge bleeder.

4. Place two layers of Osnaburg cloth over the Armalon. The bleeder should extend beyond and contact the edge bleeder and the bleeder cloth which serves as a direct connection to the vacuum line.

5. Bag with a 2 mil nylon vacuum blanket or equivalent.

6. Apply a partial vacuum and adjust bag to eliminate bridging, keeping wrinkles on the part to a minimum. Wrinkling of the surface bleeder shall not be allowed.

7. Apply full vacuum and check for leaks. A minimum of 24-inches of mercury shall be obtained.

C. Removal from Tool

1. Remove bagging.

2. Carefully lift or pry the part from the form.

WET LAY UP METHOD FOR RESIN BONDED PANEL

1. Impregnate fabric per indicated procedure for each facing.
2. Apply one sheet of parting film, such as cellophane, to the caul plate.
3. Place one facing over the film.
4. Center the core over the facing and press into position.
5. Place the second facing over the core. Smooth into place, being careful not to damage the core.
6. Apply one sheet of parting film, such as cellophane, over the second facing.

PREPREG LAY UP PROCEDURE FOR ONE-STAGE ADHESIVE BONDED PANEL

NOTE: Clean white gloves must be worn when handling the prepreg during trimming and lay up operations.

1. Apply one sheet of parting film such as cellophane, and one sheet of Armalon to caul plate.

2. Cut prepreg with fabric oriented to warp as indicated below.

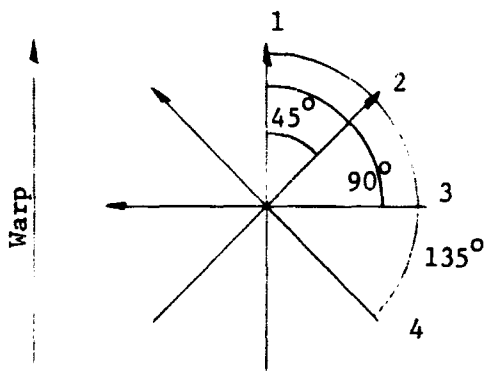
3. Assemble the plies of prepreg for each facing, with each ply oriented at 45° to the preceding ply, or as indicated on Adhesive/Resin Bonded Panel Form. Compact and smooth out each ply as it is laid up.

4. Cut the adhesive to cover the prepreg facing and squeegee or roll it on to remove air pockets.

5. One facing shall be placed with the prepreg side in contact with the Armalon.

6. Center the core over the facing and press into position against the adhesive.

7. Place the second facing over the core with the adhesive side against the core. Smooth into place, being careful not to damage the core.



INFRARED ANALYSIS OF RESIN SYSTEMS

A. The pure resins, curing agents, and the resins extracted from preimpregnated fabric shall be analyzed by infrared spectroscopy for each lot of material. The infrared scan should cover the wavelength from 2 to 15 microns, utilizing a double beam infrared spectrophotometer. Solvent solutions of resins or components shall be conducted using matched, sealed sodium chloride cells of 0.20 mm path length. The following instrument setting shall prevail.

1. Slit width . . . . . 1.5X standard
2. Single beam: double beam ratio. 1:1
3. Speed. . . . . 0.2 micron/min.
4. Period 2

B. Infrared Spectrographic Analysis of Impregnated Resins.

1. Solution.

1.1. Obtain a representative sample and weigh 3.25 to 6.0 grams of prepreg, determined by dividing 191 by the reported resin solids content. Dissolve in 36 milliliters of spectro grade solvent as follows:

Phenolic	Acetone
Epoxy	Acetone or Dichloroethane
Polyester	Chloroform
Polyimide	Acetone or N-methylpyrrolidinone

Extract for a minimum of 10 minutes.

1.2. Filter extract through S and S 589 blue ribbon filter paper. (Flute the paper for faster filtration.)

1.3. Rinse reference and sample cell three times with spectro grade solvent of the type used in paragraph 1.1. Flush each cell with dry nitrogen. Load reference cell with the type of spectro grade solvent used to dissolve the sample. Load sample cell with extract.

1.4. Balance the spectrophotometer. Insert sample and reference cells. Set spectrophotometer at wavelength of maximum absorbing peak, or as follows:

Phenolic	7.9 microns
Epoxy (Bisphenol A or Novalac)	8.0 microns
Polyester	5.8 microns

Transmittance at wavelength of maximum absorbing peak, or as specified above, shall be between 17 and 20 percent. If

INFRARED ANALYSIS OF RESIN SYSTEMS (CONT.)

transmittance is less than the minimum value indicated, adjust the concentration of the remaining solution by the addition of the appropriate spectro grade solvent. If the transmittance is greater than the indicated maximum value, evaporate in a vacuum desiccator, or equivalent, at room temperature.

1.5. Scan the spectrum from 2.0 to 15.0 microns.

1.6. Mark the chart with material designation and code, lot number, solvent, instrument settings, date, and operator's initials.

1.7. Compare spectrum obtained with standard spectrum for presence of foreign absorption peaks or other irregularities.

2. Smear.

2.1. Using the resin solution obtained from the procedure in paragraphs 1.1 and 1.2, deposit a film of resin (approximately 0.5 to 1.0 mil thick) on a salt plate by using approximately 1 milliliter of solution. Allow the solvent to evaporate at room temperature for 30 minutes minimum. Use a vacuum desiccator, if necessary, to remove solvent peaks. Use a salt plate for the reference cell, which is equal in thickness to that used for the sample cell.

2.2. Balance the spectrophotometer. Insert sample and reference cells. Set instrument at the wavelength of the maximum absorbing peak, as follows:

Phenolic	7.9 microns
Epoxy (Bisphenol A or Novolac)	8.0 microns
Polyester	5.8 microns

Transmittance at the wavelength of the maximum absorbing peak, or as specified above, shall be between 17 and 20 percent.

2.3. Scan the spectrum from 2.0 to 15.0 microns.

2.4. Mark the chart with material designation and code, lot number, solvent, instrument settings, date, and operator's initials.

2.5. Compare the spectrum obtained with a standard spectrum for the presence of foreign absorption peaks or other irregularities.

C. Infrared Spectrographic Analysis of Solid or Liquid Resins.

1. Solution.

INFRARED ANALYSIS OF RESIN SYSTEMS (CONT.)

1.1. Obtain a representative sample. Dissolve 1.8 grams of solid or 1.8 milliliters of liquid resin in 36 milliliters of spectro grade solvent as indicated below:

Epoxy	Acetone or Dichloroethane
Polyester	Chloroform

1.2. Rinse reference and sample cell three times with the spectro grade solvent used in paragraph 1.1. Flush each cell with dry nitrogen. Load reference cell with spectro grade solvent of the type used to dissolve the sample. Load sample cell with the resin solution.

1.3. Balance the spectrophotometer. Insert sample and reference cells. Set spectrophotometer at wavelength of maximum absorbing peak, or as follows:

Epoxy (Bisphenol A or Novolac)	8.0 microns
Polyester	5.8 microns

Transmittance at wavelength of maximum absorbing peak, or as specified above, shall be between 17 and 20 percent. If transmittance is less than the minimum value indicated, adjust the concentration of the remaining solution by the addition of the appropriate spectro grade solvent. If the transmittance is greater than the indicated maximum value, evaporate the solution in a vacuum desiccator, or equivalent, at room temperature.

1.4. Scan the spectrum from 2.0 to 15.0 microns.

1.5. Mark the chart with material designation and code, lot number, solvent, instrument settings, date, and operator's initials.

1.6. Compare spectrum obtained with standard spectrum for presence of foreign absorption peaks or other irregularities.

2. Smear.

2.1. Using the resin solution obtained from paragraph 1.1, or a liquid resin, deposit a film of resin (approximately 0.5 to 1.0 mil thick) on a salt plate. Allow the solvent to evaporate at room temperature for 30 minutes minimum, where applicable. Use a vacuum desiccator, if necessary, to remove solvent peaks. Use a salt plate for the reference cell, which is equal in thickness to that used for the sample cell.

INFRARED ANALYSIS OF RESIN SYSTEMS (CONT.)

2.2. Balance the spectrophotometer. Insert sample and reference cells. Set instrument at the wavelength of the maximum absorbing peak, or as follows:

Epoxy (Bisphenol A or Novolac)	8.0 microns
Polyester	5.8 microns

Transmittance at wavelength of maximum absorbing peak, or as specified above, shall be between 17 and 20 percent. If transmittance for the liquid resin is less than the minimum value indicated, remove excess resin by wiping with the edge of a spatula or equivalent. If the transmittance is greater than the maximum indicated value, deposit additional resin on the salt plate and spread evenly.

2.3. Scan the spectrum from 2.0 to 15.0 microns.

2.4. Mark the chart with material designation and code, lot number, solvent, instrument settings, date, and operator's initials.

2.5. Compare the spectrum obtained with a standard spectrum for presence of foreign absorption peaks or other irregularities.

FORMING CURED PHENOLIC HONEYCOMB CORE

1. Cut a minimum of core sections to fit the contoured male tool.

2. Heat core sections to 550° to 600°F. for 15 to 20 seconds or to 500°F. for 30 seconds using an oven or other appropriate method.

3. Place on tool and form to contour by hand within 3 to 5 seconds from removal from oven. Hold in position until cool.

CORE SPLICING WITH ADHESIVE (FM-40)

1. Apply splicing tape (.050-inch thick) to one of the abutting edges of the core and press edges of core sections together. A heat gun may be used to soften the splicing tape, but over-heating exhibited by bubbling of the adhesive should be avoided. Tape all splices with adhesive and assemble on the male tool.

2. Cover core with two layers of Osnaburg cloth. Use a rubber hose, or equivalent, as an edge member. Bag with 2 mil nylon vacuum blanket or equivalent.

3. Cure at 340° to 350°F. for one hour under vacuum.

4. Cool to 150°F. and remove bagging.

5. Remove from tool and inspect for broken node bonds.

6. Place core on tool and grind off all high spots on the faying surface. Clean core by blowing with clean, dry air and wiping with a clean cloth moistened with methyl ethyl ketone.

7. Dry core in an oven at 150°F. for 15 minutes.

8. Apply extra core splice material to any large depressions in the core.

FORMING AND CURING HTP GREEN CORE

1. Heat core to 500°F. for 20-25 seconds, using an oven or other equivalent method.

2. Remove from oven and place on male tool.

3. Using PVC film, apply pressure over the core to form it to contour. Hold until core cools.

4. Place core in the female tool. Cover with two layers of 181 glass fabric. Use a support ring at the edges of the assembly to prevent lateral crushing of the core. Bag with a 2 mil nylon vacuum blanket, or equivalent.

5. Preheat oven or autoclave to 400°F.

6. Place the bagged assembly under full vacuum in the oven or autoclave and cure for two hours at 375°F.

7. Cool part to 150°F. before releasing vacuum.

8. Remove bagging.

ONE-STAGE FABRICATION OF SPHERE-CONE MODELS FROM PREPREGS (FILM ADHESIVE)

A. Tool Preparation.

1. Tools coated with a permanent release film shall be inspected to assure that there are no breaks or cracks in the parting film and that the molding surfaces are smooth and free from pits, gouges, or other irregularities.

1.1. Coated tools with such defects shall be repaired and recoated.

1.2. For facings which are not to be coated, a fluorocarbon spray film (four coats) shall be applied to the tool and polished with a clean, soft, dry cloth.

2. Uncoated tools shall be prepared as follows:

2.1. The molding surfaces shall be smooth and free from pits, gouges, or other irregularities.

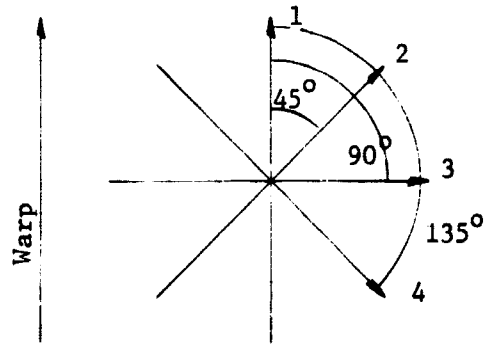
2.2. If the molding surfaces are porous, a suitable sealant shall be applied.

2.3. A suitable parting agent shall be applied to the clean, dust-free molding surfaces of the tool. Runs or sags are not permitted in sprayed release films. Wax films shall be polished with a clean, soft, dry cloth. For facings which may be coated or bonded, a noncontaminating release film (four coats of FreKote 33) shall be applied. Bake at 250°F. for 30 minutes.

B. Fabric Preparation.

1. Clean, white gloves shall be worn when handling fabric.

2. Cut fabric to the required size. Fabric may be cut into definite patterns where applicable. Fabric patterns shall be cut and marked in a manner to ensure that fabric warp direction is in accordance with requirements specified below:



ONE-STAGE FABRICATION OF SPHERE-CONE MODELS FROM PREPREGS (FILM ADHESIVE)(CONT.)

3. Preform fabric over male tool.

C. Lay-up and Potting.

1. Lay each pattern or ply on the large male tool so that each successive ply is oriented with the warp at 45° to the preceding ply, or as indicated on Facing Fabrication form. Trim to size (30-inch diameter).

2. Apply succeeding plies and carefully work down so as to obtain a smooth, tight laminate free from air pockets and wrinkles.

3. Transfer to the released female tool.

4. Cut adhesive to a suitable pattern to cover the facing. Squeegee or roll the adhesive against the prepreg to remove air pockets. Seams shall be butt spliced. Gaps along the splice line shall be limited to a maximum of one thirty-second inch.

5. Place preformed, precured core in the potting tool. Prepot ring and edge cells in 1-inch sections per Aeroshell Model 1 drawing. Allow the potted core to remain overnight before assembly.

6. Place the core over the lay up in the female tool and press into position lightly. The ply under the core may be heated with a hot air gun, then the core pressed against the bond ply until the resin has cooled to room temperature in order to attain positive location of the core. No slashing of the core to facilitate forming shall be permitted.

7. Cut adhesive to a suitable pattern to cover the core surface. Press the adhesive against the core, being careful not to damage the core. Adhesive may be heat tacked to assure positive location. Seams shall be butt spliced. Gaps along the splice line shall be limited to a maximum of one thirty-second inch.

8. Lay each preformed pattern or ply of prepreg on the small male tool so that each successive ply is oriented with the warp at 45° to the preceding ply. Trim to size.

9. Apply succeeding plies and carefully work down so as to obtain a smooth, tight laminate free from air pockets and wrinkles.

10. Transfer to the female tool and position over the adhesive layer. Work out any wrinkles.

ONE-STAGE FABRICATION OF SPHERE-CONE MODELS FROM PREPREGS (FILM ADHESIVE)(CONT.)

D. Bagging.

1. Apply high temperature sealer external to the part line. Do not remove upper covering.

2. Install three thermocouples between the plies of the laminate, approximately one-half inch from the edge.

3. Place bleeders around the edges of the lay up. Edge bleeders shall make contact with the edges of the lay up, but shall not be placed closer than one-half inch to the part net-trim line. Bleeder strips may be of Osnaburg cloth or any other suitable noncontaminating material which serves as direct connection to the vacuum line.

4. Cover the outer edge of the core and the prepreg lay up with Armalon. The film must partially overlap the edge bleeder.

5. Place one layer of Osnaburg cloth and two layers of 181 glass fabric bleeder over the Armalon. The bleeder should extend beyond and contact the edge bleeder and bleeder cloth which serves as a direct connection to the vacuum line.

6. Remove covering from the sealer and imbed thermocouples in sealer.

7. Bag with a 2 mil vacuum blanket or equivalent.

8. Apply a partial vacuum and adjust bag to eliminate bridging, keeping wrinkles on the part to a minimum. Wrinkling of the surface bleeder shall not be allowed.

9. Apply full vacuum and check for leaks. A minimum of 24-inches of mercury shall be obtained.

E. Removal from Tools.

1. Remove bagging.

2. Carefully lift or pry the part from the tool.

3. Remove all parting media from the part.

F. Finishing.

1. Rout to the required diameter.

2. Remove one row of cells along the periphery of the aeroshell.

3. Seal with edge-filling compound, being careful to assure a smooth finished surface.

APPENDIX C

MATERIAL COMBINATIONS FOR FLAT HONEYCOMB SANDWICH FABRICATION IN PHASE I

Material Combinations for Flat Honeycomb Fabrications in Phase I

	Face Sheets				Hexagonal Honeycomb Core					
	Resin and Cure	Fabric Style and Finish	Fabric Plies	Nom. Thick. Inches	Material	Cell Size Inches	Density $lbs./ft.^3$	Thickness Inches	Adhesive	Remarks
1.	Epon 851/20PHR of "Z" (A Stage) -2 hrs. @ 200°F. and 1 hr. @ 400°F.	E116/Volan A	4	0.018	HRP	3/16	4.0	0.75	FM-96U	Inferior 300°F. strength (cancelled)
2.	Epon 815/20PHR of "Z" (A Stage) -2 hrs. @ 200°F. and 1 hr. @ 400°F.	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Inferior 300°F. strength (cancelled)
3.	Epon 826/75PHR hexahydrophthalic anhydride and 0.5 benzyldimethylamine -2 hrs. @ 250°F. + 2 hrs. @ 400°F.	E116/Volan A	4	0.018	HRP	3/16	4.0	0.75	FM-96U	Inferior 300°F. strength (cancelled)
4.	Epon 826/75PHR hexahydrophthalic anhydride and 0.5 benzyldimethylamine -2 hrs. @ 250°F. + 2 hrs. @ 400°F.	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Inferior 300°F. strength (cancelled)
5.	Epon 815/12.5 PHR "CL" (A stage) -2 hrs. @ 200°F. and 1 hr. @ 400°F.	E116/Volan A	4	0.018	HRP	3/16	4.0	0.75	FM-96U	Inferior 300°F. strength (cancelled)
6.	Epon 815/12.5 PHR "CL" (A stage) -2 hrs. @ 200°F. and 1 hr. @ 400°F.	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Inferior 300°F. strength (cancelled)
7.	DEN 438/87.5 PHR Nadic Methyl Anhydride and 1.5 PHR benzyldimethylamine -2 hrs. @ 200°F. and 4 hrs. @ 330°F.	E116/Volan A	4	0.018	HRP	3/16	4.0	0.75	FM-96U	Satisfactory Mechanical properties except at 350°F. (completed)
8.	DEN 438/87.5 PHR Nadic Methyl Anhydride and 1.5 PHR benzyldimethyleamine (A stage) -2 hrs. @ 200°F. and 4 hrs. @ 330°F.	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Good mechanical properties except at 350°F. (completed)
9.	DEN 431/26 PHR DEH 50 (A stage) -16 hrs. @ 130°F., 2 hrs. @ 260°F., and 2 hrs. @ 350°F.	E116/Volan A	4	0.018	HRP	3/16	4.0	0.75	FM-96U	Short working life and poor reproducibility (cancelled)
10.	DEN 431/26 PHR DEH 50 (A stage) -16 hrs. @ 130°F., 2 hrs. @ 260°F., and 2 hrs. @ 350°F.	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Short working life and poor reproducibility (cancelled)
11.	ARP91-LD (B stage) -1/2 hr. @ 300°F. plus 1 hr. @ 350°F. followed by a post cure for 6 hrs. @ 300°F.	E116/Volan A	4	0.018	HRP	3/16	4.0	0.75	FM-96U	Satisfactory (completed)
12.	ARP91LD (B stage) -1/ hr. @ 300°F. plus 1 hr. @ 350°F. followed by a post cure for 2 hrs. @ 350°F.	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Satisfactory (completed)
13.	Adlock EG-35 (B stage) -1/2 hr. @ 200°F., 1/2 hr. @ 250°F., 1/2 hr. @ 300°F., and 1/2 hr. @ 325°F. followed by a post cure for 2 hrs. @ 350°F.	E116/Volan A	4	0.018	HRP	3/16	4.0	0.75	FM-96U	Satisfactory (completed)
14.	Adlock EG-35 (B stage) -1/2 hr. @ 200°F., 1/2 hr. @ 250°F., 1/2 hr. @ 300°F., and 1/2 hr. @ 325°F. followed by a post cure for 2 hrs. @ 350°F.	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Satisfactory (completed)
15.	Adlock 851 (B stage) -1/2 hr. @ 300°F. and 2 hrs. @ 350°F.	E116/Volan A	4	0.018	HRP	3/16	4.0	0.75	FM-96U	Satisfactory (completed)

Material Combinations for Flat Honeycomb Fabrications in Phase I

	Face Sheets				Hexagonal Honeycomb Core					
	Resin and Cure	Fabric Style and Finish	Fabric Plies	Nom. Thick. Inches	Material	Cell Size Inches	Density $lbs./ft.^3$	Thickness Inches	Adhesive	Remarks
16.	Adlock 851 (B stage) -1/2 hr. @ 300°F. and 2 hrs. @ 350°F.	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Satisfactory (completed)
17.	U.S. Polymeric E-787 (B stage) -3 hrs. @ 300 to 320°F.	E116/Volan A	4	0.018	HRP	3/16	4.0	0.75	FM-96U	Inferior 300°F. strength (cancelled)
18.	U.S. Polymeric E-787 (B stage) -3 hrs. @ 300 to 320°F.	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Inferior 300°F. strength (cancelled)
19.	Narmco 500 (B stage)	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Inferior 300°F. strength (cancelled)
20.	BP 908 (B stage)	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Resin Content too high (cancelled)
21.	Narmco Conolon 506	E112/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Satisfactory (completed)
22.	DuPont 2501	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Poor tack and drapability (cancelled)
23.	Epon 1031/10PHR Diamirodiphenyl Sulfone + 1 PHR BF_3 Monoethylamine	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Unsuitable as A-stage system
24.	Epon 1031/20PHR Diaminodiphenyl Sulfone + 1 PHR BF_3Monothylamine	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Unsuitable as A-stage system
25.	Epon 828-Epon 1031(1:1)/90 PHR Nadic Methyl Anhydride + 2 PHR Benzyl Dimethylamine	E112/Volan A	4	0.015	HPP	3/16	4.0	0.75	FM-96U	Handling difficulties as A-stage system
26.	Adlock EG9300	E112/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Satisfactory
27.	Adlock EG4B	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Inferior 300°F. strength
28.	Adlock PG-HTA	E112/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Satisfactory
29.	Vibrin 135/1.5% BZP	E112/Volan	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Adhesive incompatibility
30.	Vibrin 136/.5 PHR t-Butylperbenzoate + .1-.25 PHR Benzoin	E112/Volan A	4	0.015	HRP	3/16	4.0	0.74	FM-96U	Handling difficulties
31.	Vibrin 136/.1-.3 t-Butylperbenzoate + 2, 4 Dichlorobenzoylperoxide (1:1)	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Handling difficulties
32.	Narmco Polysulfone	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Experimental material
33.	Same as Combination 16, except HRP-SF 50-40 flexcore	E112/Volan A	4	0.015	Flex Core	3/16	4.0	0.75	FM-96U	Core configuration evaluation
34.	Same as Combination 16, except 6 plies in each face sheet	E112/Volan A	6	0.022	HTP	3/16	4.0	0.75	FM-96U	No. of plies evaluation
35.	Same Combination 16, except 12 plies in each face sheet	E112/Volan A	12	0.044	HTP	3/16	4.0	0.75	FM-96U	No. of plies evaluation
36.	U.S. Polymeric E740B	E112/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Satisfactory
37.	Trevarno F170 Imide	E112/1100	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Satisfactory
38.	Same as Combination 26, except S glass in style 120/Volan A finish	S120/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Not available
39.	U.S. Polymeric E792	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Satisfactory

Material Combinations for Flat Honeycomb Fabrications in Phase I

	Face Sheets				Hexagonal Honeycomb Core					
	Resin and Cure	Fabric Style and Finish	Fabric Plies	Nom. Thick. Inches	Material	Cell Size Inches	Density $lbs./ft.^3$	Thickness Inches	Adhesive	Remarks
40.	Same as Combination 16, except use 1/4 HRP Hexcore -3.5 density	E112/Volan A	4	0.015	HTP	1/4/4	3.5	0.75	FM-96U	Core configuration evaluation
41.	U.S. Polymeric F502	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Incompatible with FM-96U
42.	Same as Combination 16, except use E120/Volan A glass	E120/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Glass style evaluation
43.	Adlock 851/181 glass having a forced overlap core splice joint (overlap 3/4") and pour coat with BR-227 primer	E112/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Core splice evaluation
44.	Adlock 851/181 butt splice joint with an FM-40 Adhesive Bond	E112/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Core splice evaluation
45.	Adlock 851/112 glass, ± temp.	E112/Volan A	6	0.022	HTP	3/16	4.0	0.75	FM-96U	$-150^{\circ}F.$ and $+350^{\circ}F.$ tests
46.	Same as Combination 45, except add 3" wide nonrecessed doublers	E112/Volan A	6	0.022	HTP	3/16	4.0	0.75	FM-96U	Simulate attachment ring support
47.	Same as Combination 45 having a min. 1/4" wide face sheet overlap construction parallel to the ribbon direction on both inner and outer face sheets	E112/Volan A	6	0.022	HTP	3/16	4.0	0.75	FM-96U	Skin splice evaluation
48.	Same as Combination 16 except use HRH-10.	E112/Volan A	4	0.015	Nomex	3/16	4.0	0.75	FM-96U	Core evaluation
49.	Narmco 588/112 glass	E112/Volan A	5	0.015	HTP	3/16	4.0	0.75	FM-96U	Satisfactory
50.	Same as Combination 16, except use 1/2" thick HRP core	E112/Volan A	4	0.015	HTP	3/16	4.0	0.50	FM-96U	Core evaluation
51.	Same as Combination 16, except use 1" thick core	E112/Volan A	4	0.015	HTP	3/16	4.0	1.00	FM-96U	Core evaluation
52.	Adlock 851/112 glass, butt splice joint with FM-40 adhesive bond at 20° angle	E112/Volan A	6	0.022	HRP	3/16	4.0	0.75	FM-96	Core splice evaluation
53.	Adlock 851/112 glass with the warp of successive plies oriented at 60° clockwise intervals	E112/Volan A	6	0.022	HRP	3/16	4.0	0.75	FM-96U	Ply orientation evaluation
54.	Adlock 851/112 glass, 2-ply	E112/Volan A	2	0.008	HRP	3/16	4.0	0.75	FM-96U	No. of plies evaluation
55.	Adlock 851/112 glass oriented at 45°	E112/S935	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Ply orientation & glass finish eval.
56.	Adlock 851/112 E glass oriented at 45°	E112/A1100	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Ply orientation & glass finish eval.
57	Adlock 851/108 glass oriented at 45°	E108/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Glass style evaluation
58.	Adlock 851/112 and using HT-435, 0.05#/ $ft.^2$ as the face sheet-to-core adhesive	E112/Volan A	4	0.015	HTP	3/16	4.0	0.75	HT-435	Adhesive evaluation

Material Combinations for Flat Honeycomb Fabrications in Phase I

	Face Sheets				Hexagonal Honeycomb Core					
	Resin and Cure	Fabric Style and Finish	Fabric Plies	Nom. Thick. Inches	Material	Cell Size Inches	Density $lbs./ft.^3$	Thickness Inches	Adhesive	Remarks
59.	Eccomold L70/112 glass	E112/Volan A	4	0.015	HRP	3/16	4.0	0.75	FM-96U	Poor laminate flex.
60.	U.S. Polymeric F509	E112/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Satisfactory
61.	Adlock 453 PHG/112 glass	E112/A1100	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Satisfactory
62.	Trevarno F-170/112 glass	E112/A1100	4	0.015	API	3/16	4.0	0.75	FM-34	Satisfactory
63.	Trevarno F-170/112 glass	E112/A1100	4	0.015	HRH-324	3/16	4.0	0.75	FM-34	Satisfactory
64.	Trevarno F-170/112 glass	E112/A1100	4	0.015	HRH	3/16	4.0	0.75	Metlbond 840	Metlbond 840 not available in lightweight
65.	Narmco 1832/112 glass	E112/A1100	4	0.015	API	3/16	4.0	0.75	FM-34	Satisfactory
66.	Sunform F-1760/112 glass	E112/Volan A	4	0.015		3/16	4.0	0.75	FM-96U	Not available
67.	Carbon Cloth/Phenolic Dip	-	4	0.015		3/16	4.0	0.75	FM-96U	Not available in high modulus
68.	Adlock 851/112 (Dove tail type core)	E112/Volan A	4	0.015			4.0	0.75	FM-96U	Core configuration evaluation
69.	SC 1013/112 glass	E112/Silane	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Glass finish evaluation
70.	VC 8359/112 glass	E112 Silane	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Not available
71.	VC 8359/112 glass	E112/Volane A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Not available
72.	Adlock 851/120 S glass	S120/Volan A	4	0.015	HTP	3/16	4.0		FM-96U	Glass composition evaluation
73.	Adlock 851/880 glass/8H satin weave single yarn	E880/S935	4	0.015	HTP	3/16	4.0		FM-96U	Glass style and weave evaluation
74.	Adlock 851/112 glass - one extra dip core	112/Volan A	4	0.015	HTP	3/16	4.0		FM-96U	Core material evaluation
75.	Carbon cloth/all polyimide dip	-	4	0.015	HTP	3/16	4.0	0.75	Metlbond 840 or FM-34	Not available in high modulus
76.	Adlock 851/112 D glass	D112/Volan A	4	0.015	HTP	3/16	4.0	0.75	FM-96U	Glass composition evaluation
77.	Adlock 851/112 E glass/plain weave - single yarn	E112/S935	4	0.015	HTP	3/16	4.0		FM-96U	Glass style and weave evaluation
78.	Adlock 851/112 with (2) layers of FM-96U adhesive	112/Volan A	4	0.015	HTP	3/16	4.0		FM-96U	Multilayer adhesive evaluation
79.	Adlock 851/112 with HT 435U .03 psf adhesive	112/Volan A	4	0.015	HTP	3/16	4.0			Adhesive evaluation
80.	Adlock 851/181 - phenolic core - 45° orientation	181/Volan A	2	0.018	HTP	3/16	4.0		FM-96U	Glass style evaluation

NOTE: All resin systems were cured using vacuum pressure only.

APPENDIX D

FABRICATION FORMS FOR 27-INCH BY 27-INCH PANELS OF REINFORCED PLASTICS MATERIALS

FABRICATION FORMS	PAGE NO.
Adhesive Resin Bonded Panel	D-2, D-3, D-4, D-5, D-7, D-8 D-9, D-10, D-11, D-12, D-13, D-14, D-16, D-17
Facing Fabrication Form	D-6
Adhesive Bonded Panel Form	D-15

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-73

Code 36(E740B/112) FM-96U Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 78 Adhesive Q.C. No. 75 Core Q.C. No. 55

Lay-up Method PS-20

Butt splice core (no adhesive) according to attached diagram.

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up kate	Pressure/Vac	Time	Temperature
5-7°F./min.	27" Hg	3 hrs.	320°F.

Cool to 150°F. before release vacuum.

Post Cure

PROPERTIES (specimen diagram attached) 6 ea. Panel Dimensions 27" x 27"

Weight Resin Content Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests FF-76 to be laid up on same caul plate.

Remarks

Disposition

10/11/67

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-124

Code 37 (F-170 Imide, FM-34/1070) Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 84 Adhesive Q.C. No. 91 Core Q.C. No. 54

Allow prepreg and adhesive to come to R.T. in dry box before opening package. Return sealed roll of material to freezer immediately after use.

Lay-up Method PS-20

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
5°/min.	27" Hg.	--	280°F.
0.2°/min.	"	--	310°F.
2°/min.	"	90 min.	350°F.

Post Cure 2 hrs. at 400°F. Cool to 125°F. before releasing vacuum.

PROPERTIES (specimen diagram attached) 6 ea. Panel Dimensions 27" x 27"

Weight 1387.6 gm. Resin Content 50.8% Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests .604 #/ft.^{2}

Remarks FF-138 to be laid up on same caul plate.

Humidity 47% at start of cutting patterns. 10-11-67

Humidity 40% at start of cutting patterns. 10-12-67

Disposition

ROHR CORPORATION

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-74

Code 39 (E792/112) FM-96U Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 77 Adhesive Q.C. No. 75 Core Q.C. No. 55

Lay-up Method PS-20

Butt splice core (no adhesive) according to attached diagram.

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
5-7°F./min.	27" Hg	3 hrs.	320°F.

Post Cure 3 hrs. @ 400°F. Cool to 150°F. before releasing vacuum.

PROPERTIES (specimen diagram attached) 5 ea. Panel Dimensions 27" x 27"

Weight _____ Resin Content _____ Specific Gravity _____

Barcol _____ Core Thickness 0.75"

Screening Tests _____

Remarks FF-77 to be laid up on same caul plate.

_____ Disposition _____

ROHR CORPORATION

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-86

Code 41 F502 (SC-1008) Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 80 Adhesive Q.C. No. 75 Core Q.C. No. 55

Lay-up Method PS-20

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
2-3°/min.	27 in. Hg.	1 hr.	310°F.

Cool to 150°F. before releasing vacuum.

Post Cure

PROPERTIES (specimen diagram attached) 6 ea. Panel Dimensions 27" x 27"

Weight 1253.5 gm. Resin Content 46.6% Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests

Remarks FF-89 to be laid up on same caul plate.

Good tack, easy to handle. Roll had slight wrinkling prior to lay up; no problems.

Complete 7/14/67 Disposition

1/12/67

FACING FABRICATION FORM

Project JPL Contract No. 951612 W.O. 402-21-0 No. FF-48

Code 1PH12-E1-P1 (91LD) Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric/Finish 112/Volan A Q.C. No. 29

Impregnation Technique N/A

Lay-up Method PS-5

Bagging Procedure PS-6

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac.	Time	Temperature
2-3°/min.	27 in. Hg	30 min.	300°F.
2-3°/min.	27 in. Hg	1 hr.	350°F.

Post Cure 6 hr. @ 300°F. Cool to 150°F. before releasing vacuum.

PROPERTIES Dimensions 12 ea. 27" x 27"

Resin Content 33.7% (calc.) Weight Barcol

Screening Test

Remarks 1st run - six face sheets postcured under vacuum identified (c). Autoclave.

2nd run - Space Products turn key oven.

Disposition

ROHR CORPORATION

3/22/68

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-159

Code 49, Narmco 588/112, FM-96U Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 124 Adhesive Q.C. No. 118 Core Q.C. No. 130

Lay-up Method PS-20 Butt splice core (no adhesive) according to attached diagram

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
4-5°/min.	27" Hg	60 min.	350°F.

Cool to 150°F. before releasing vacuum.

Post Cure

PROPERTIES (specimen diagram attached) 6 ea. Panel Dimensions 27" x 27"

Weight 1107 gm. Resin Content 33.0 Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests

Remarks FF-184 to be laid up on same caul plate.

Disposition

ROHR CORPORATION

5/13/68

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-176

Code 60 (F509/112) FM-96U Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 137 Adhesive Q.C. No. 118 Core Q.C. No. 136

Lay-up Method PS-20

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
3-5°/min.	27" Hg	10 min.	275°F.
3-5°/min.	"	30 min.	350°F.

Cool to 150°F. before releasing vacuum.

Post Cure 8 hrs. @ 350° + 8 hrs. @ 375° + 4 hrs. @ 400°F.

PROPERTIES (specimen diagram attached) 6 ea. Panel Dimensions 27" x 27"

Weight _____ Resin Content _____ Specific Gravity _____

Barcol _____ Core Thickness _____

Screening Tests _____

Remarks FF-198 to be laid up on same caul plate.

_____ Disposition _____

ROHR CORPORATION

5/17/67

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-181

Code 61 (Adlock 453 PHG/112) FM-96U Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 138 Adhesive Q.C. No. 118 Core Q.C. No. 130

Lay-up Method PS-20

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
3-4°/min.	27" Hg	30 min.	300°F.
3-4°/min.	"	2 hrs.	350°F.

Cool to 150°F. before releasing vacuum.

Post Cure

PROPERTIES (specimen diagram attached) 2 ea. Panel Dimensions 27" x 27"

Weight Resin Content Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests

Remarks To be laid up on same caul sheet as FF-203.

Disposition

7/3/68

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-28-0 No. RP-184

Code 65, Narmco 1832/112, FM-34/1070, API Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 134 Adhesive Q.C. No. 129 Core Q.C. No. 117

Allow material to come to R.T. in dry box before opening the package.

Return sealed roll of material to freezer immediately after use.

Lay-up Method PS-20

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
4-6°/min.	27" Hg	30 min.	270°F.
2-4°/min.	"	2 hrs.	350°F.

Cool to 125°F. before releasing vacuum.

Post Cure 2 hrs. @ 400°F.

PROPERTIES (specimen diagram attached) 2 ea. Panel Dimensions 27" x 27"

Weight Resin Content Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests

Remarks Perform long beam flexure tests.

Disposition

ROHR CORPORATION

12/30/67

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-33

Code (DEN 438) 1EN12-E1-P1/FM-96U Resin Mixing Form 9

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 7 Adhesive Q.C. No. 40 Core Q.C. No. 45

Impregnation Technique PS-4

Lay-up Method PS-19, except also assemble one layer of FM-96U on each facing, with adhesive side to be placed against core.

Bagging Procedure PS-11, except omit paragraph 4.

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
5-7°/min.	27 in. Hg	2 hr.	200°F.
"	"	4 hr.	330°F.

Post Cure 3 hrs. at 400°F. Cool to 150°F. before releasing vacuum.

PROPERTIES (specimen diagram attached) 6 ea. Panel Dimensions 27" x 27"

Weight 1281.6 gm. Resin Content 54.0 (Calc.) Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests

Remarks Wt. of 8-ply glass, 27" x 27", prior to impregnation 269 grams. #2 vacuum loss to 5 in. Hg. trying to post cure, so reduced heat to 150°F., debagged, then post cured. Specimens became darkened. Panel warped.

Disposition

12/19/66

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-25

Code (EG-35) 4EP12-E1-P1/FM-96U Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 31 Adhesive Q.C. No. 40 Core Q.C. No. 35

Lay-up Method PS-20

Butt splice core (no adhesive) according to attached diagram.

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
5-7°/min.	27 in. Hg	30 min.	200°F.
"	"	"	250°F.
"	"	"	300°F.
"	"	"	325°F.

Post Cure 2 hr. @ 350°F.

PROPERTIES (specimen diagram attached) 6 ea. Panel Dimensions 27" x 27"

Weight 1276 gm. Resin Content 56.3% (Calc.) Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests

Remarks No problems during lay up. Good drape; material tacky but easy to work with. Appearance good. Panels warped because of warped caul plates.

Disposition

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-64

Code 11EP12-E1-P1 (EG-9300) Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 71 Adhesive Q.C. No. 70 Core Q.C. No. 55

Lay-up Method PS-20

Butt splice core (no adhesive) according to attached diagram.

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
5-7°F./min.	25" Hg	1 hr.	325°F.
"	"	2 hrs.	375°F.
Post Cure 5-7°F./min.	25" Hg	4 hrs.	400°F.

(Cool to 150°F. before releasing vacuum)

PROPERTIES (specimen diagram attached) 6 ea. Panel Dimensions 27" x 27"

Weight Resin Content Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests FF-69 to be laid up on same caul plate.

Remarks

Disposition

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-63

Code 1PE12-E1-P1 (Adlock PG-HTA) Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 72 Adhesive Q.C. No. 70 Core Q.C. No. 55

Lay-up Method PS-20

Butt splice core (no adhesive) according to attached diagram.

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
5-7°F./min.	25" Hg	1 hr.	300°F.
Post Cure 5-7°F./min.	25" Hg	1 hr.	350°F.

(Cool to 150°F. before releasing vacuum)

PROPERTIES (specimen diagram attached) 6 ea. Panel Dimensions 27" x 27"

Weight Resin Content Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests

Remarks FF-68 to be laid up on same caul plate.

Disposition

1/12/67

ADHESIVE BONDED PANEL FORM

Project JPL Contract No. 951612 W.O. 402-21-0 No. AP-17

Code 1PH12-E1-P1 (91LD)

Component	Code No.	Record No.	Component	Code No.	Record No.
Facing (top)	1PH12	FF-48	Facing (bottom)	1PH12	FF-48
Core	HRP	OC-35	Adhesive	FM-96U	OC-40

CLEANING PROCEDURE

Facings PS-14

Core PS-13

Primer/Adhesive Application PS-15

Assembly PS-15, PS-16

CURING PROCESS (charts attached)

Heat-up Rate 5-7°/min. Cure Temp. 350± 10°F. Cure Time 60 min.

Cure Pressure/Vacuum 24 in. Hg. Equipment

CONTROL DATA Lap Shear psi Data Sheet No.

PANEL CHARACTERISTICS 6 ea. Dimensions 27" x 27"

Core Thickness 0.75" Warpage Appearance

Remarks Panel Wt. 1129 gm.

Disposition

ROHR CORPORATION

3/27/67

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-49

Code (Conolon 506) 3PH12-E1/FM-96U Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 8 Adhesive Q.C. No. 50 Core Q.C. No. 55

Lay-up Method PS-20

Butt splice core (no adhesive) according to attached diagram.

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
Preheat oven to 150°F 2-3°/min.	27 in. Hg	30 min.	200°F.
"	"	"	250°F.
"	"	"	300°F.
"	"	2 hrs.	350°F.

Post Cure Cool to 150°F. before releasing vacuum.

PROPERTIES (specimen diagram attached) 6 ea. Panel Dimensions 27" x 27"

Weight 1172.8 gr. Resin Content 42.7% Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests FF-58 to be laid up on same caul plate.

Remarks Adhesive dry - no problems during lay up. Appearance good.

Disposition

12/19/66

ADHESIVE RESIN BONDED PANEL

Project JPL Contract No. 951612 W. O. 402-21-0 No. RP-26

Code (Adlock 851) 2PH12-EL-P1/FM-96U Resin Mixing Form N/A

No. of Plies 4 Ply Orientation 45°

Fabric Q.C. No. 33 Adhesive Q.C. No. 40 Core Q.C. No. 35

Lay-up Method PS-20

Butt splice core (no adhesive) according to attached diagram.

Bagging Procedure PS-11

CURING PROCESS (charts attached) Gel Time

Heat-up Rate	Pressure/Vac	Time	Temperature
3 - 4°/Min.	27" Hg.	30 min.	300°F.
" "	"	2 hr.	350°F.

Cool to 150°F. before releasing vacuum.

Post Cure

PROPERTIES (specimen diagram attached) 3 ea. Panel Dimensions 27" x 27"

Weight 2 - 6 lbs. Resin Content 43.5% Calc. Specific Gravity

Barcol Core Thickness 0.75"

Screening Tests

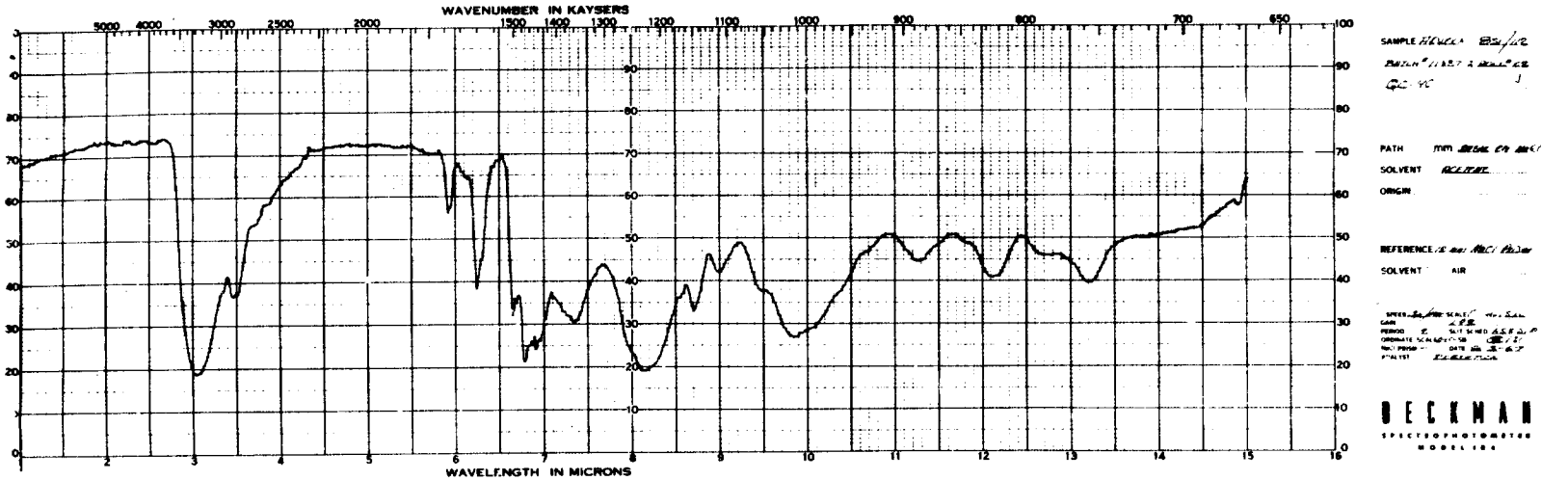
Remarks Only enough prepreg of QC-33 remained to permit fabrication of three 27" x 27" panels.

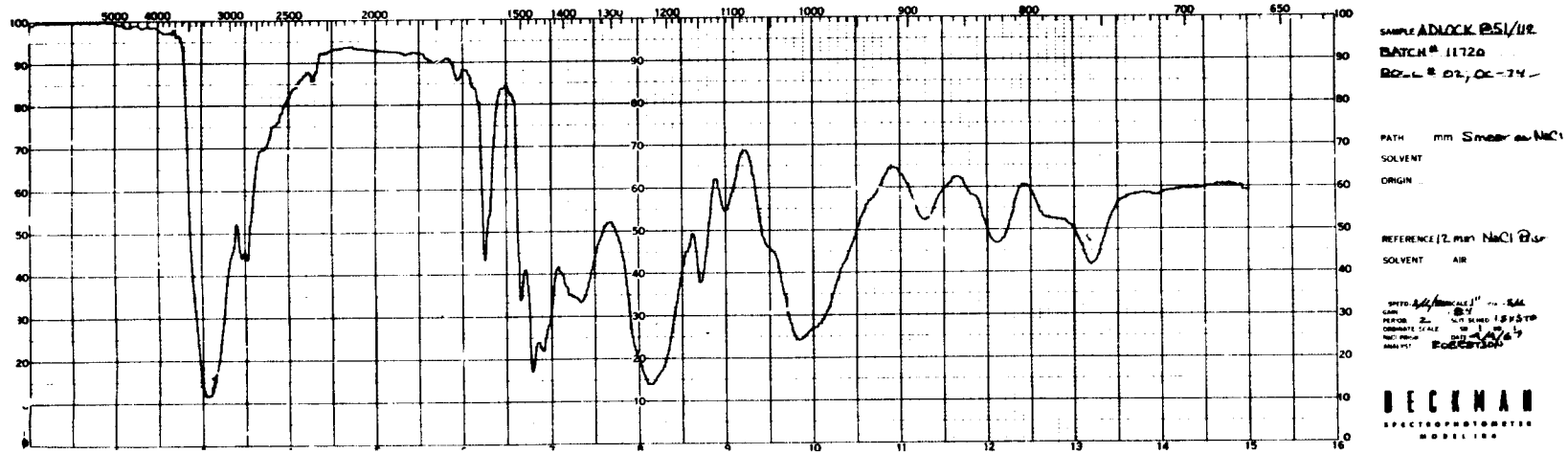
Refer to RP-54 for remaining three panels.

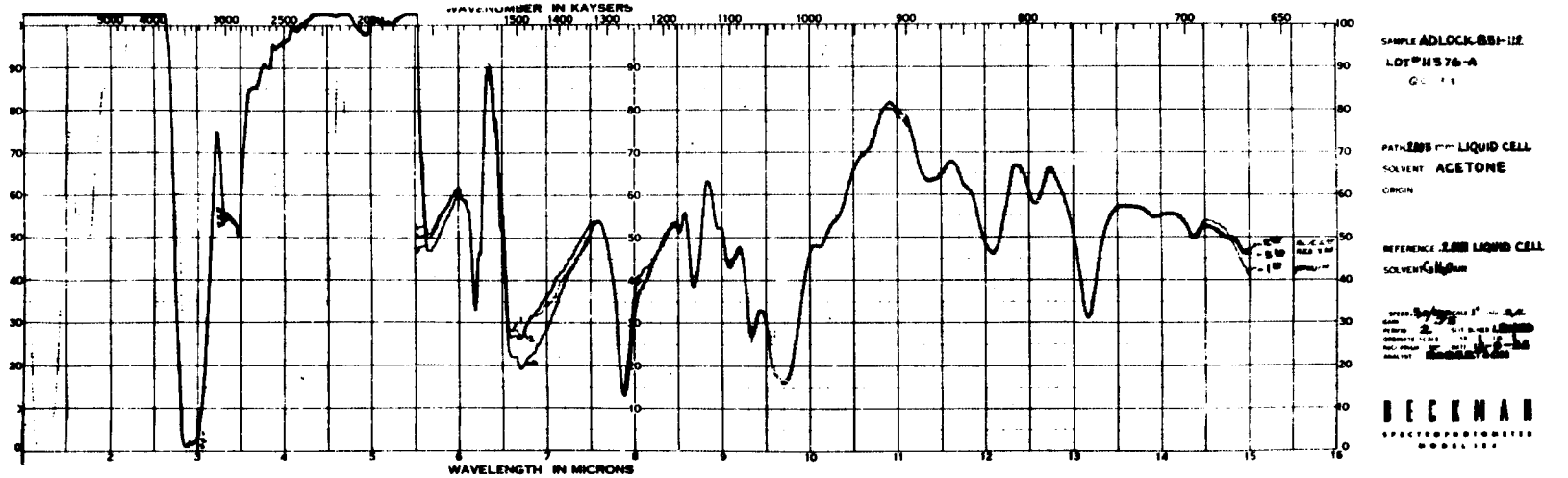
Disposition

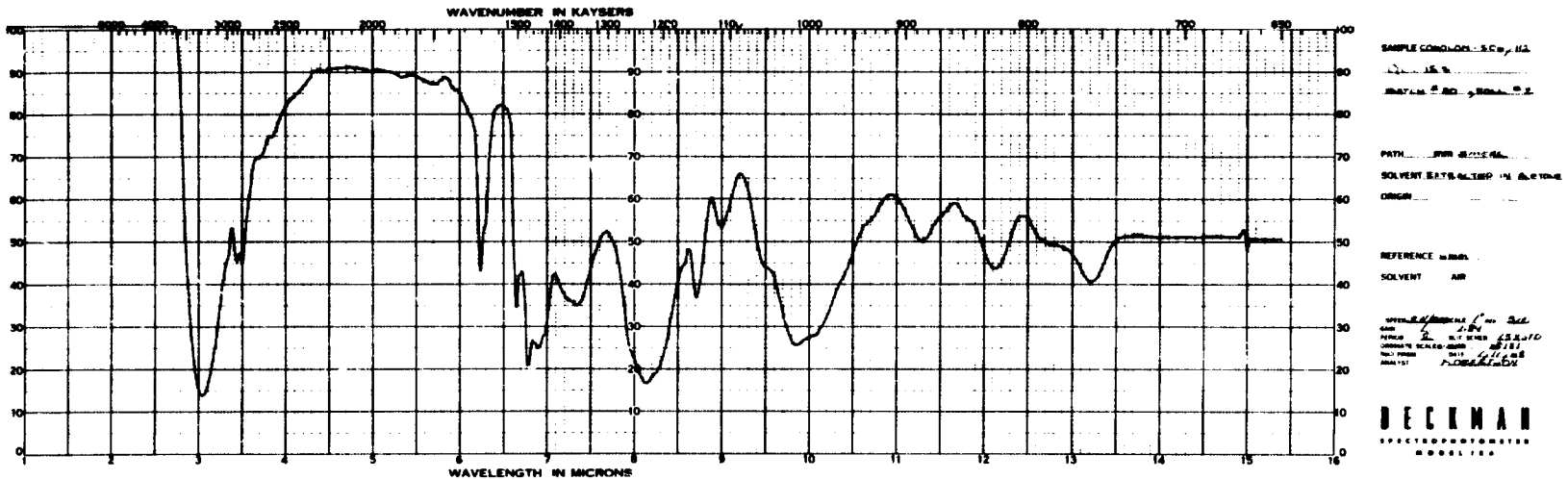
APPENDIX E

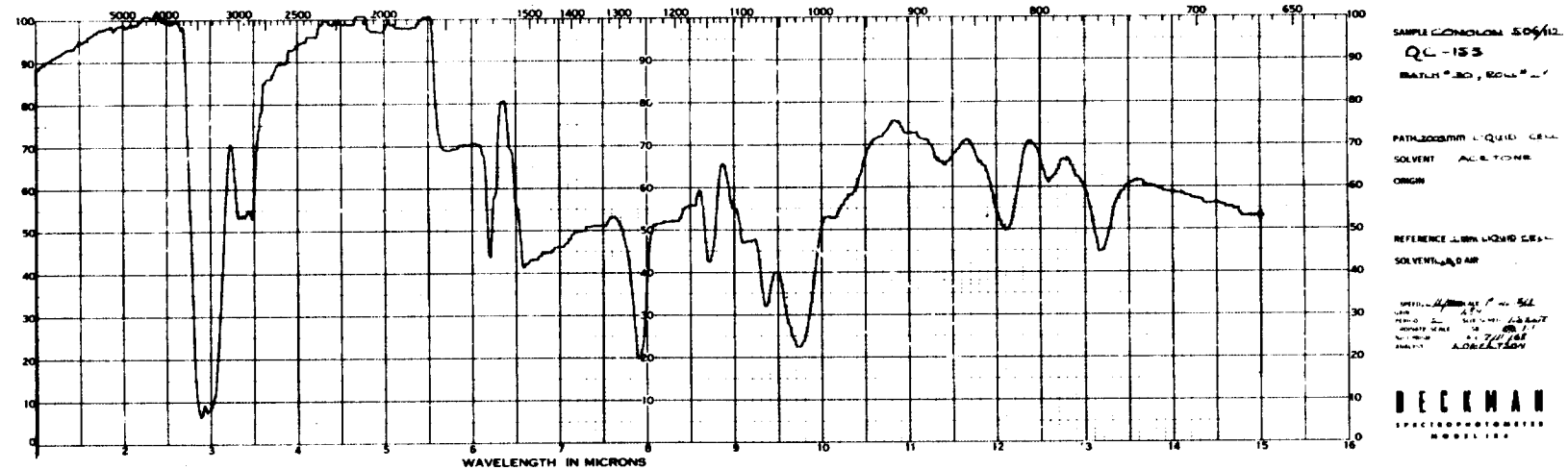
INFRARED SPECTRA OF RESIN SYSTEMS USED TO FABRICATE 27-INCH BY 27-INCH SANDWICH PANELS

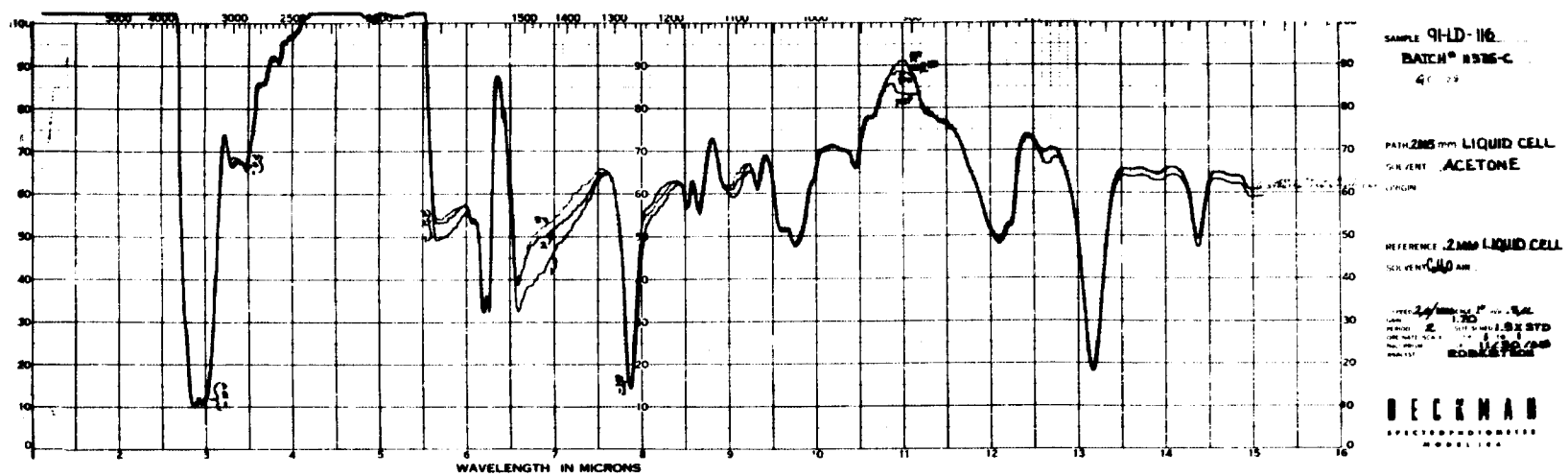

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
SAMPLE ADLOCK PSI/UR
PATH mm
SOLVENT
ORIGIN
REFERENCE
SOLVENT AIR
BECKMAN
SPECTROPHOTOMETER

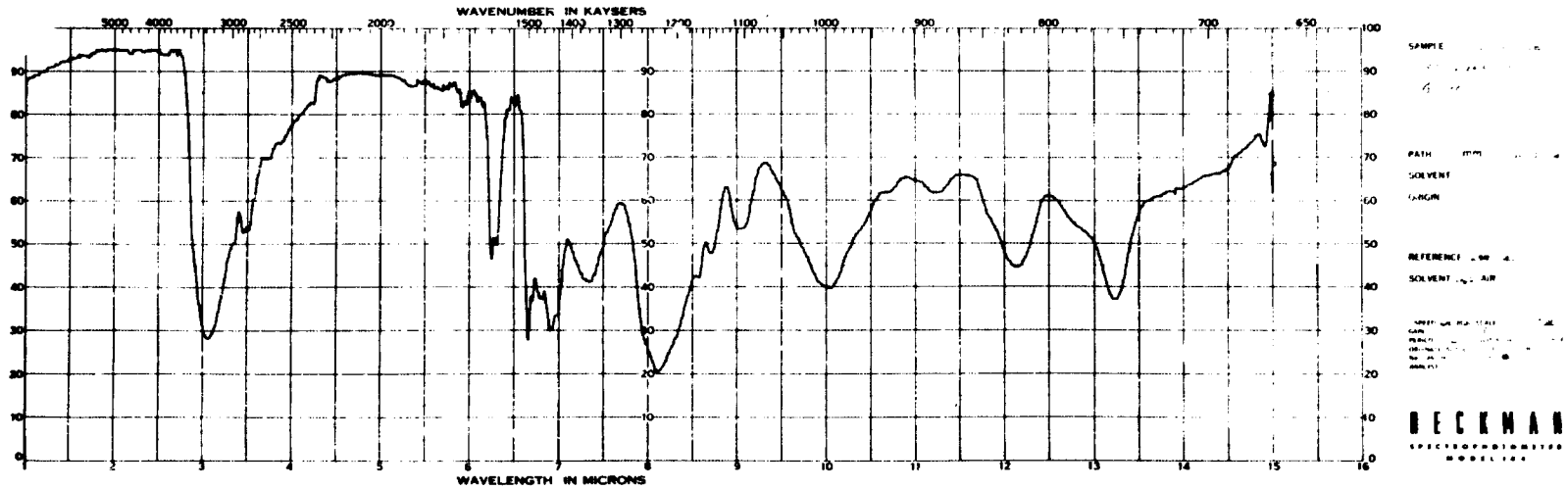

SAMPLE ADLOCK PSI/UR
BATCH # 11720
ROLL # 02, OC-74
PATH mm Smear on NaCl
SOLVENT
ORIGIN
REFERENCE 2 mm NaCl Blank
SOLVENT AIR
BECKMAN
SPECTROPHOTOMETER

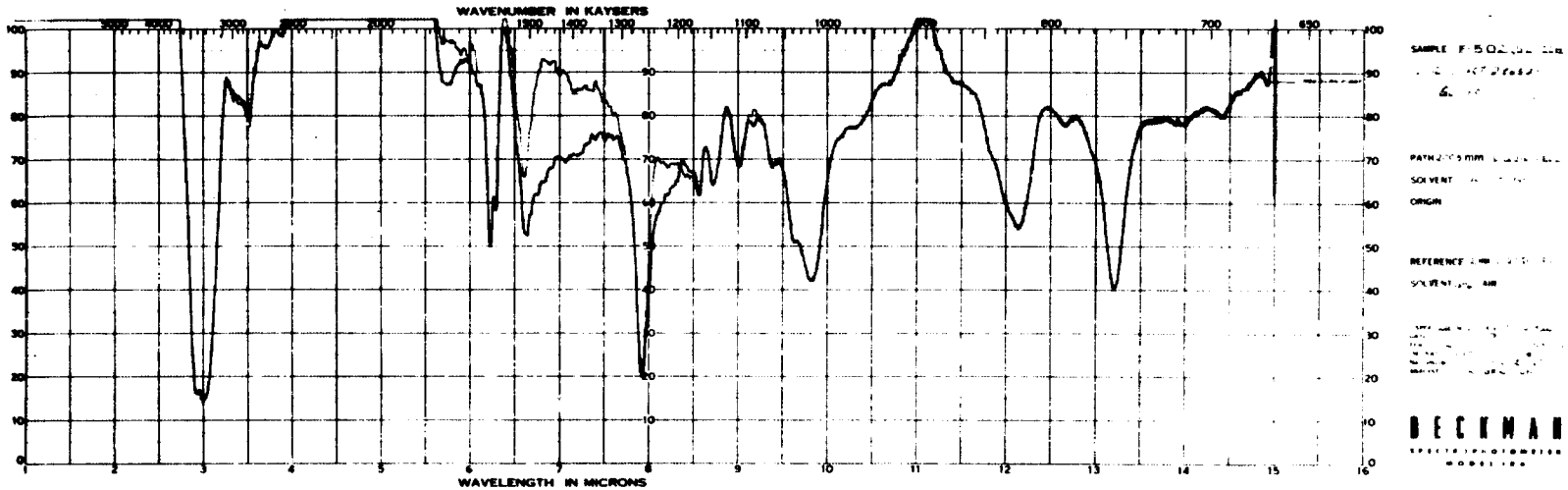

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
SAMPLE ADLOCK-BBI-112
LOT# H576-A
PATH LIQUID CELL
SOLVENT ACETONE
REFERENCE LIQUID CELL
BECKMAN

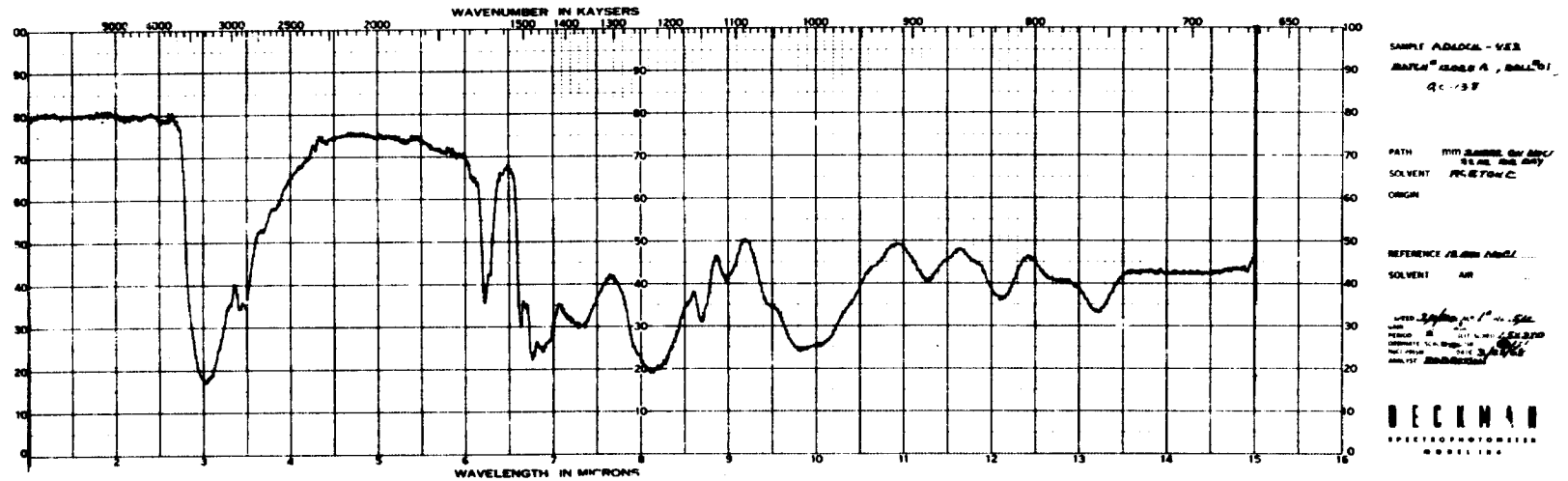

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
SOLVENT AIR
BECKMAN

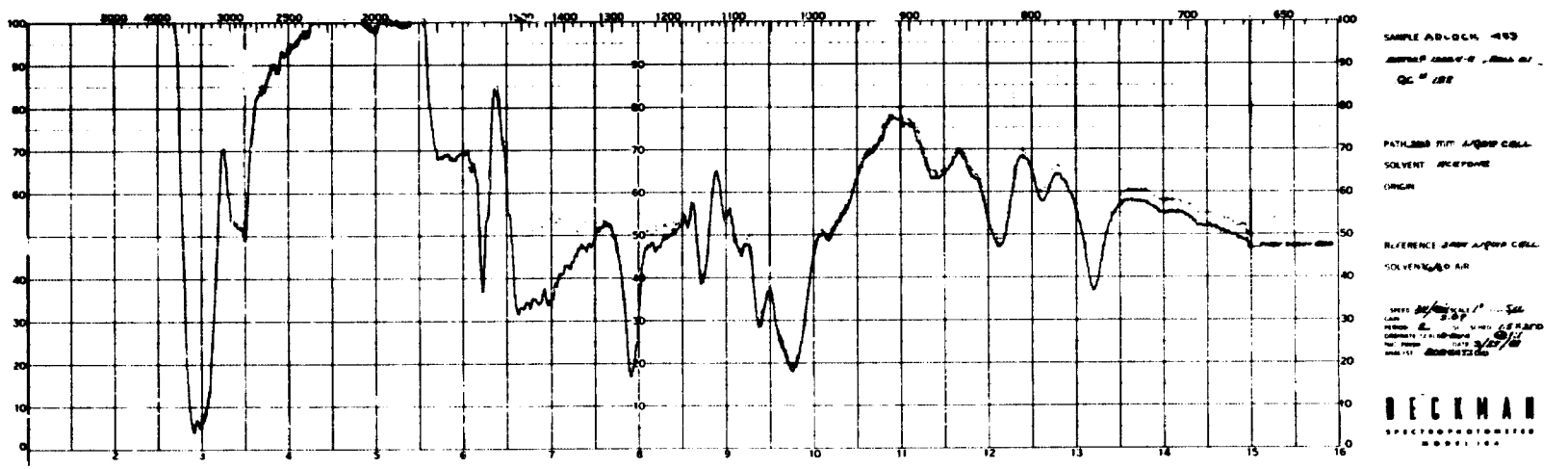

WAVELENGTH IN MICRONS
SAMPLE CONOLON 506/12
QC-153
PATH 200mm LIQUID CELL
SOLVENT ACETONE
ORIGIN
REFERENCE
SOLVENT
BECKMAN

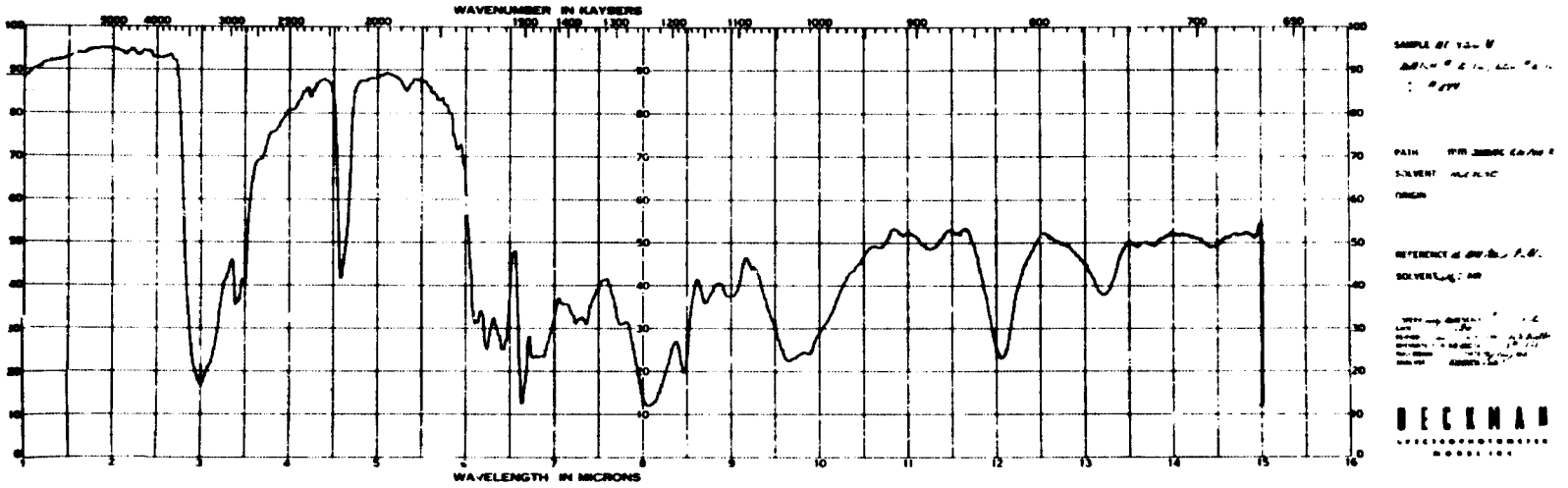

WAVELENGTH IN MICRONS
SAMPLE 91-LD-116
BATCH 8376-C
PATH 2mm LIQUID CELL
SOLVENT ACETONE
REFERENCE .2mm LIQUID CELL
SOLVENT
BECKMAN

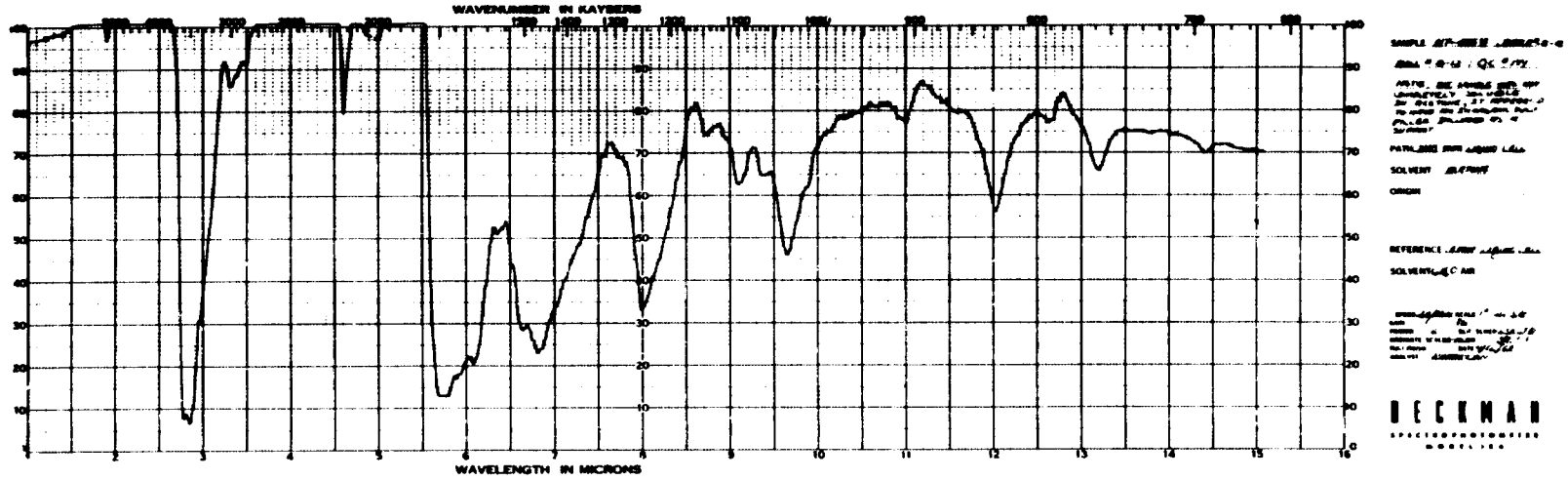

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
BECKMAN

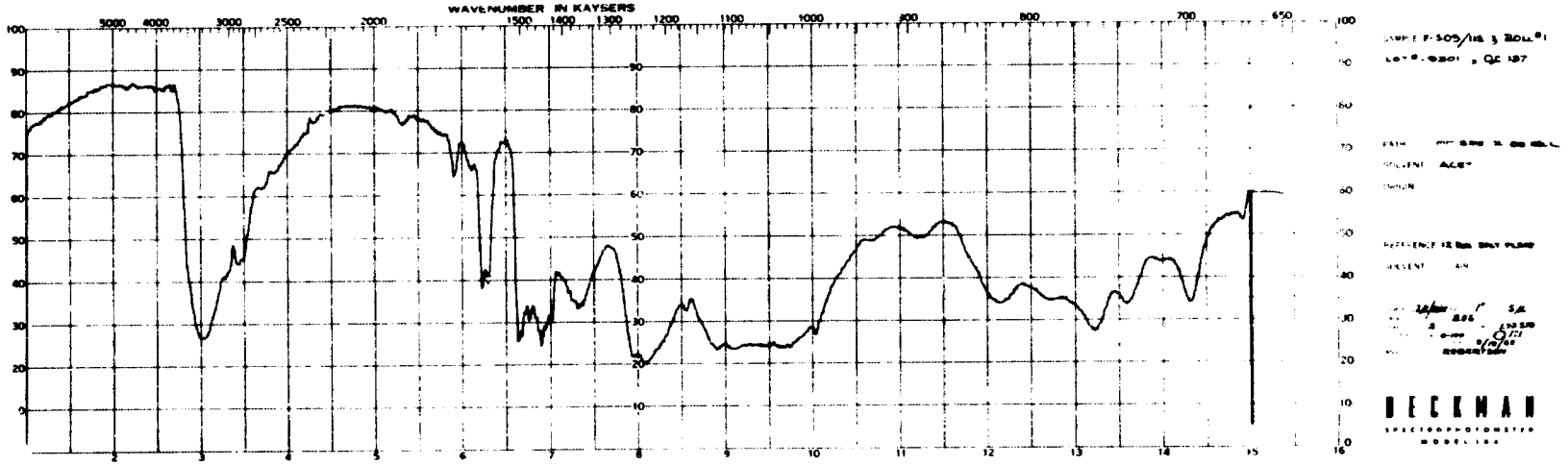

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
BECKMAN

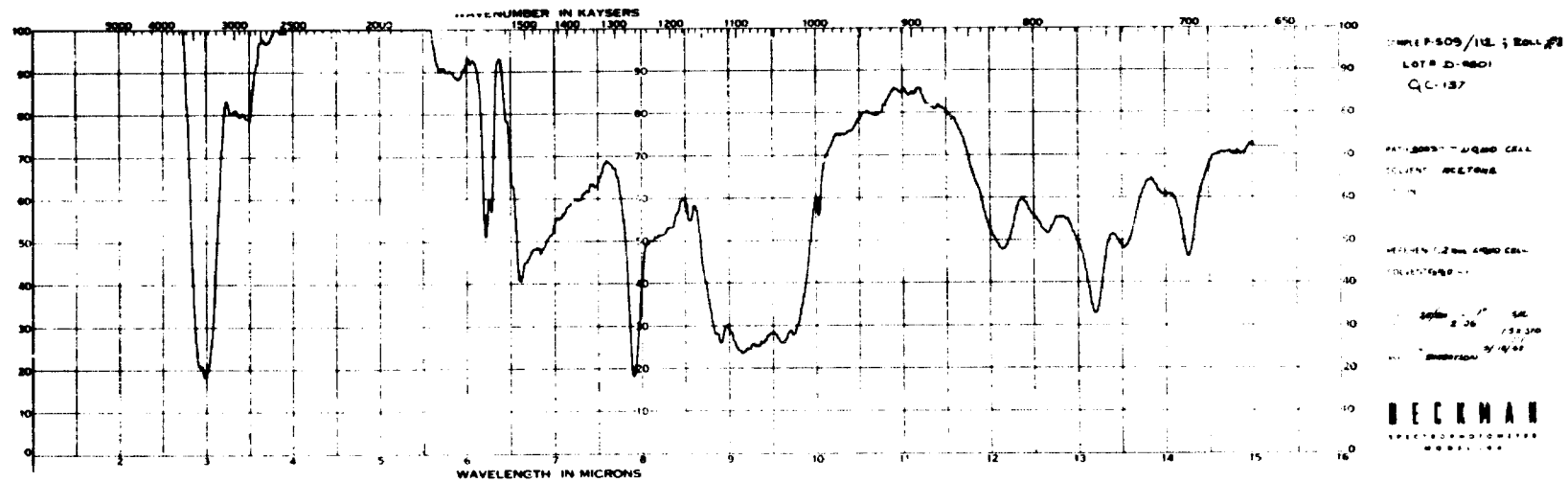

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
BECKMAN

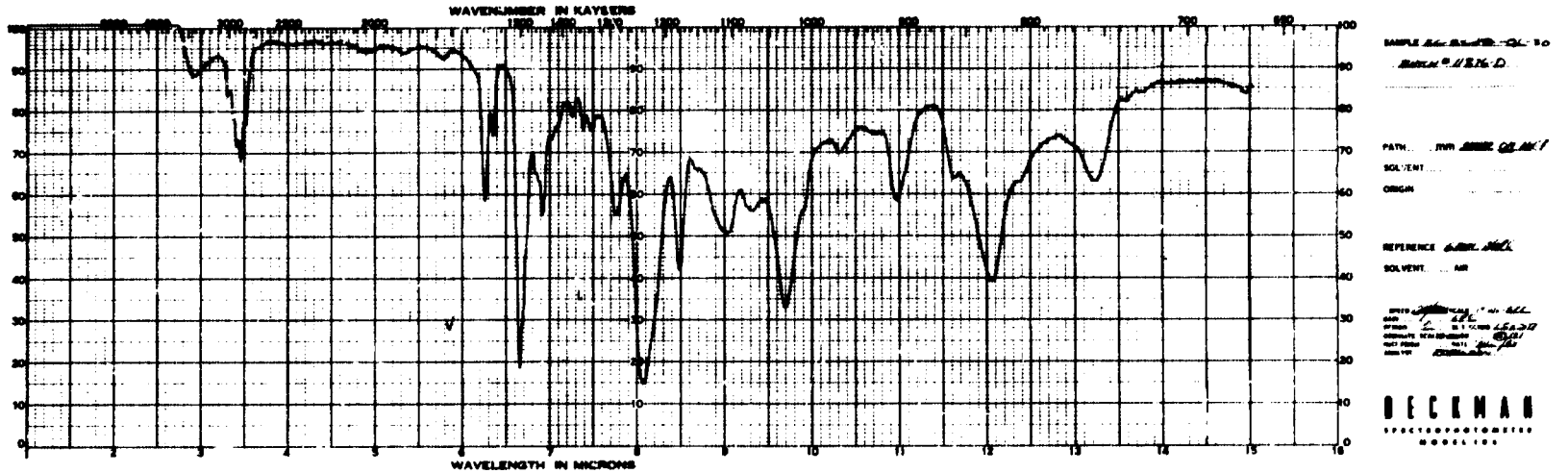

BECKMAN

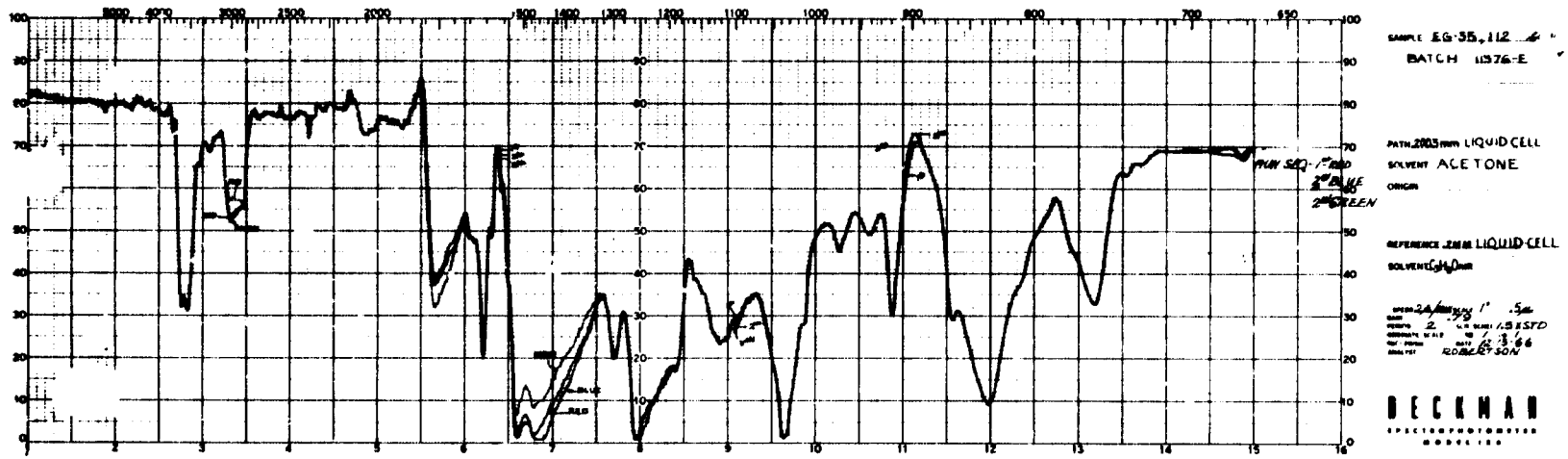

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
BECKMAN

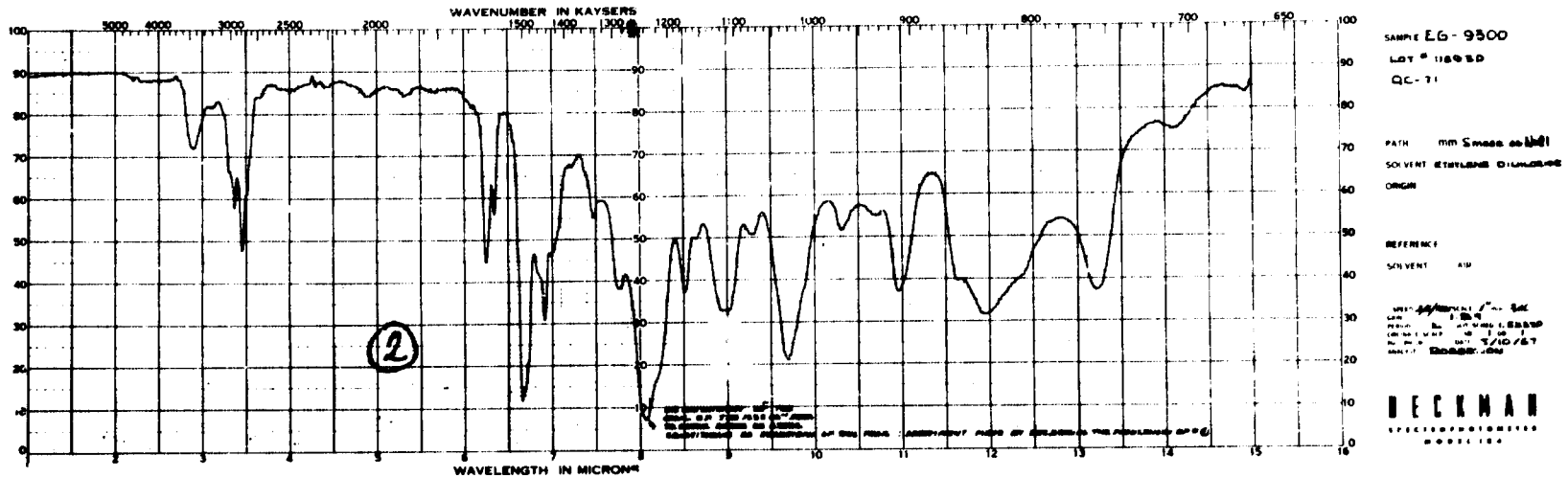

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
BECKMAN

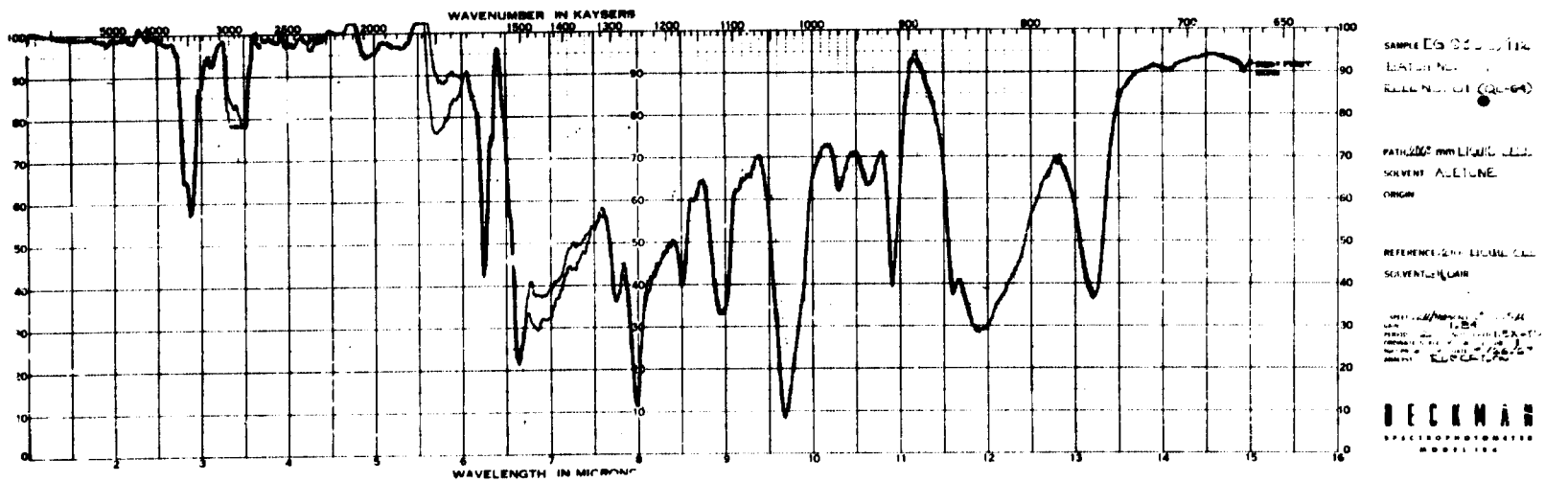

WAVENUMBER IN KAYSERS
5000 4000 3000 2500 2000 1500 1400 1300 1200 1100 1000 900 800 700 650
100 90 80 70 60 50 40 30 20 10 0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
BECKMAN

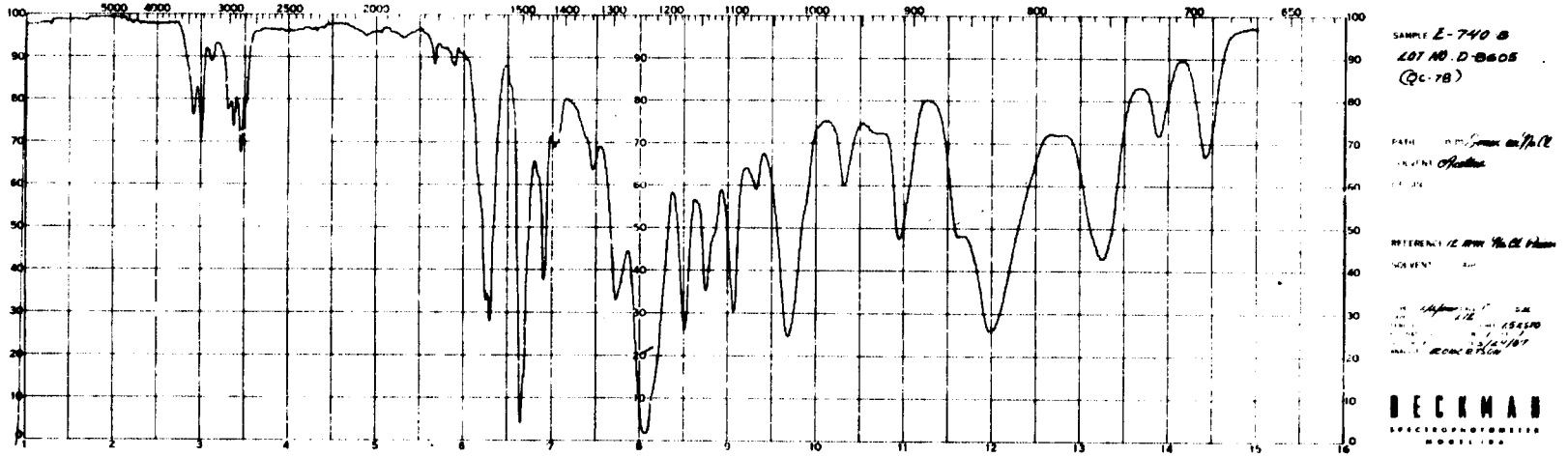

WAVENUMBER IN KAYSERS
5000 4000 3000 2500 2000 1500 1400 1300 1200 1100 1000 900 800 700 650
100 90 80 70 60 50 40 30 20 10 0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
WAVELENGTH IN MICRONS
BECKMAN

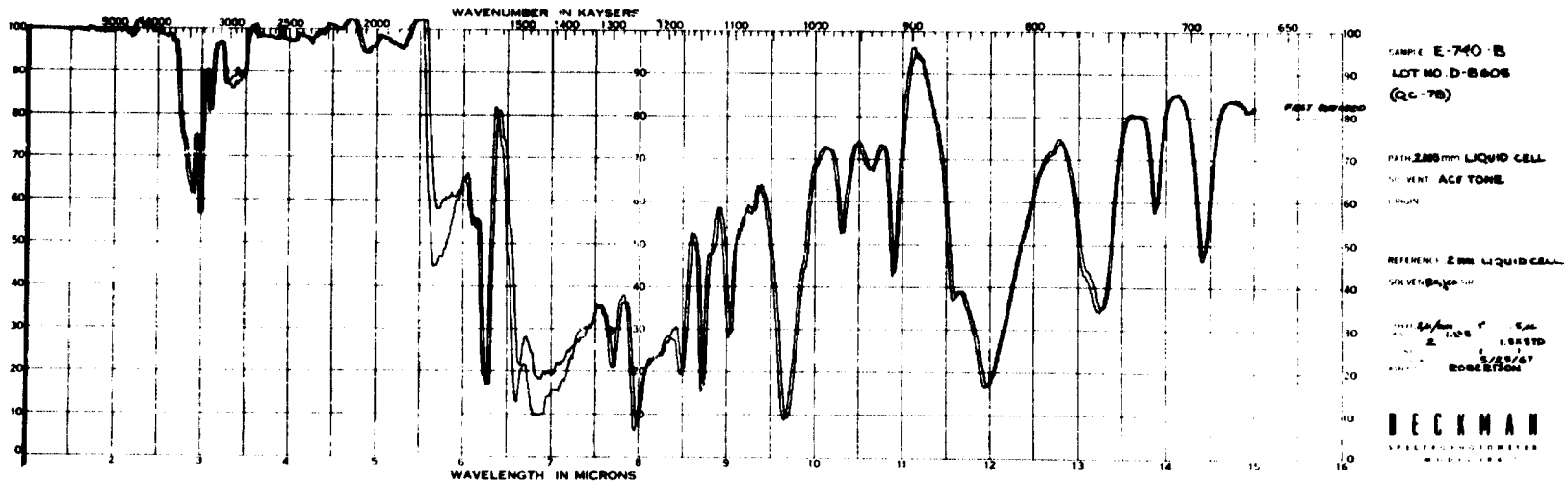

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
DECKMAN
SPECTROPHOTOMETER
MODEL 150

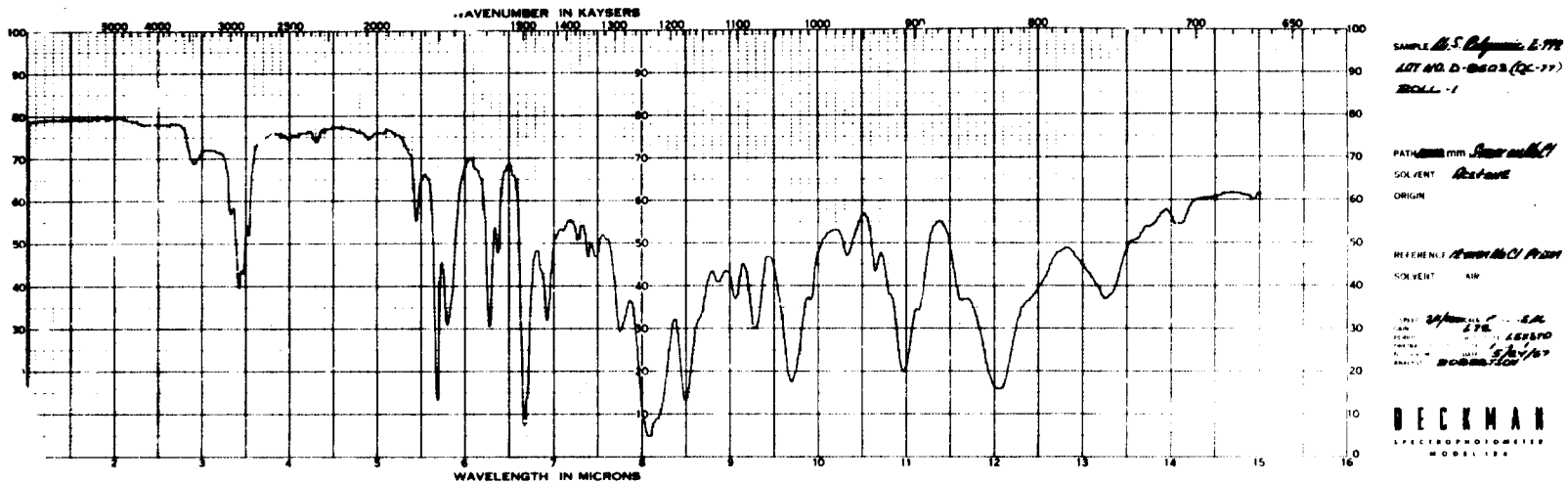

SAMPLE EG-55,112
BATCH 1576-E
PATH 2005mm LIQUID CELL
SOLVENT ACETONE
REFERENCE 2mm LIQUID CELL
DECKMAN
SPECTROPHOTOMETER
MODEL 150

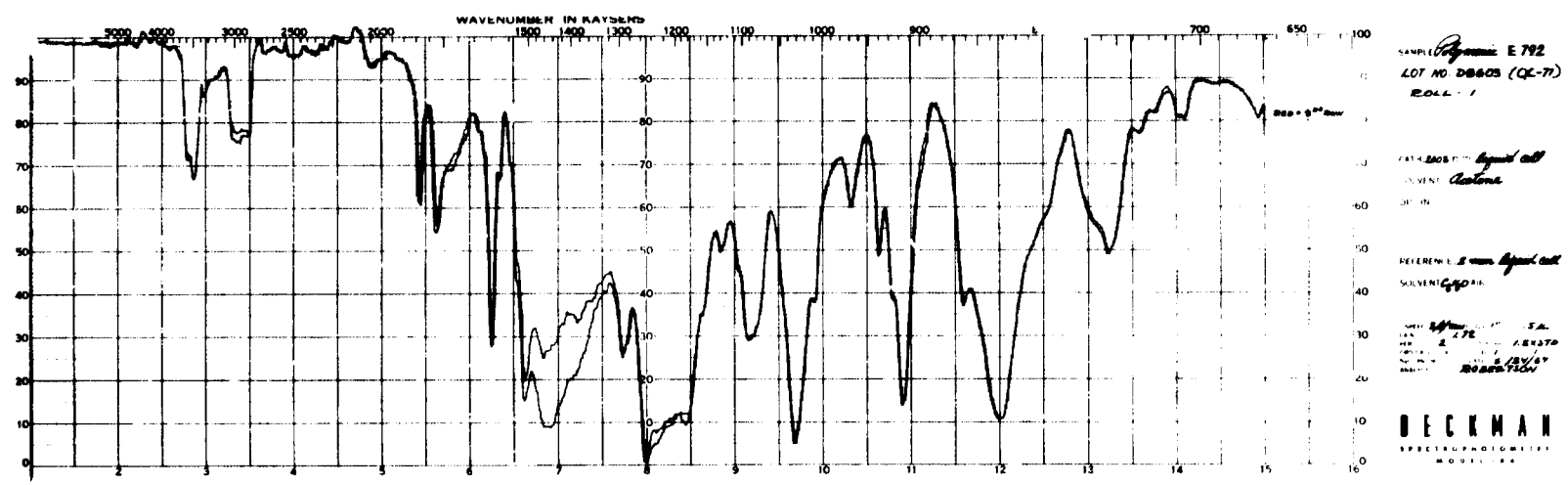

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
SAMPLE EG-9500
QC-71
DECKMAN

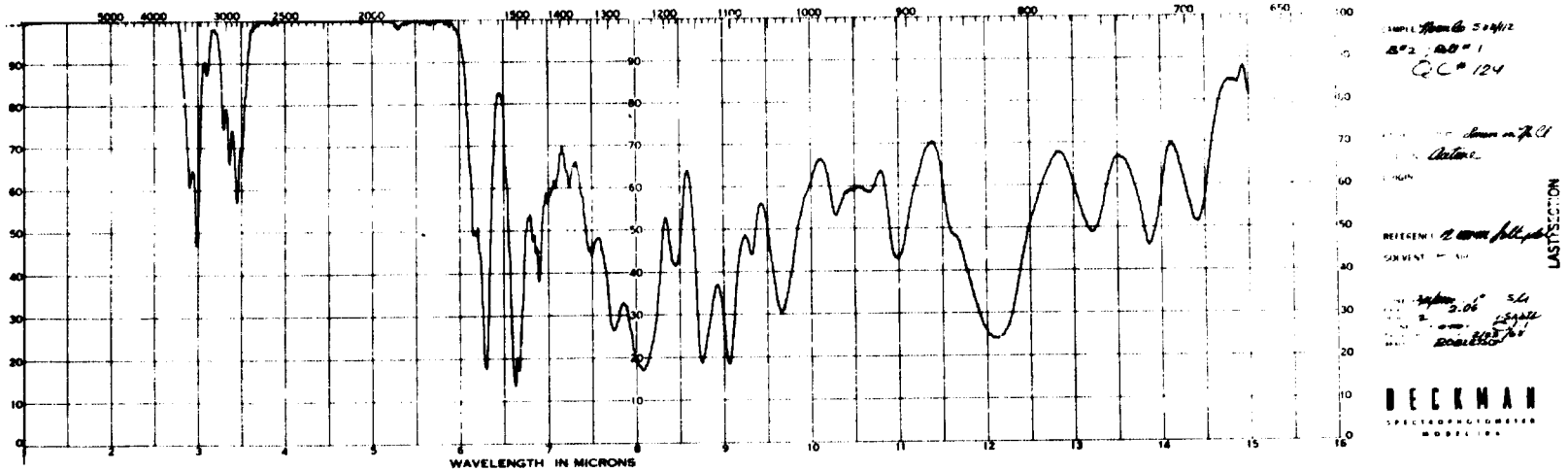

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
SOLVENT ACETONE
DECKMAN

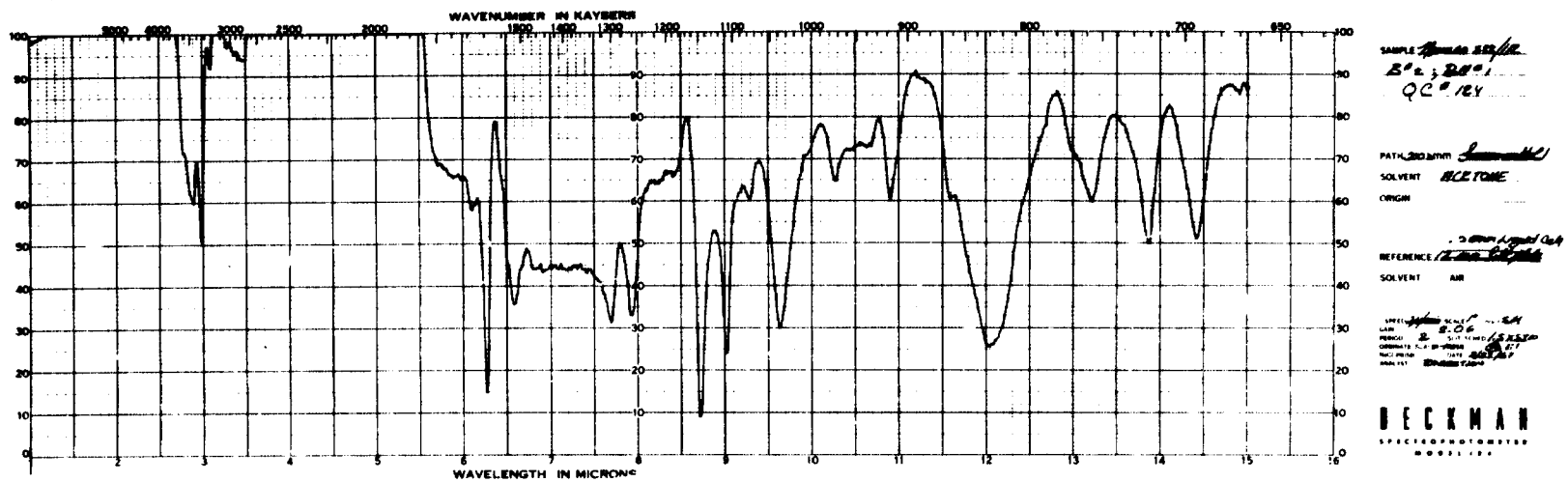

SAMPLE E-740 B
LOT NO. D-8605
(QC-78)
BECKMAN

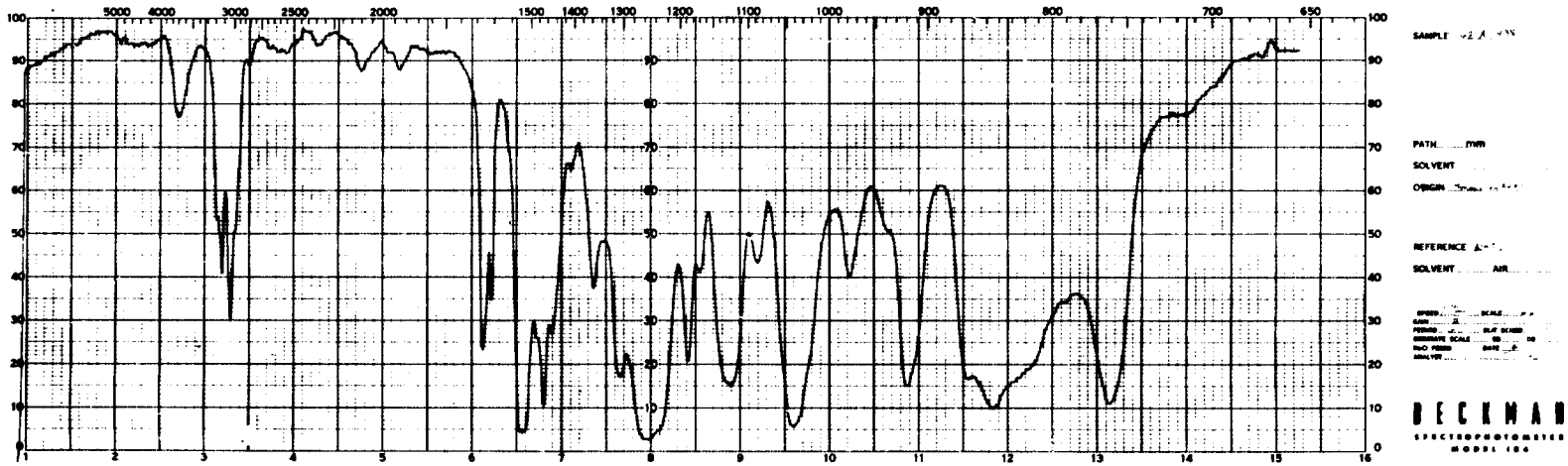

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
SAMPLE E-740 B
LOT NO. D-8605
(QC-78)
PATH 2.85mm LIQUID CELL
SOLVENT ACETONE
BECKMAN

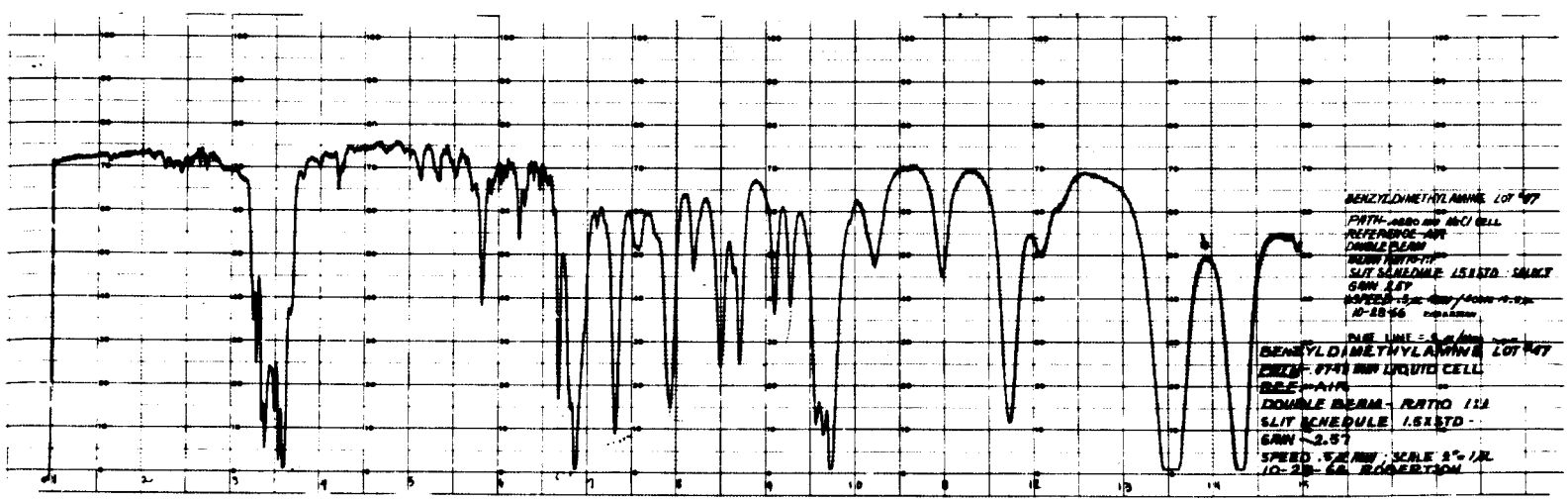

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
DECKMAN

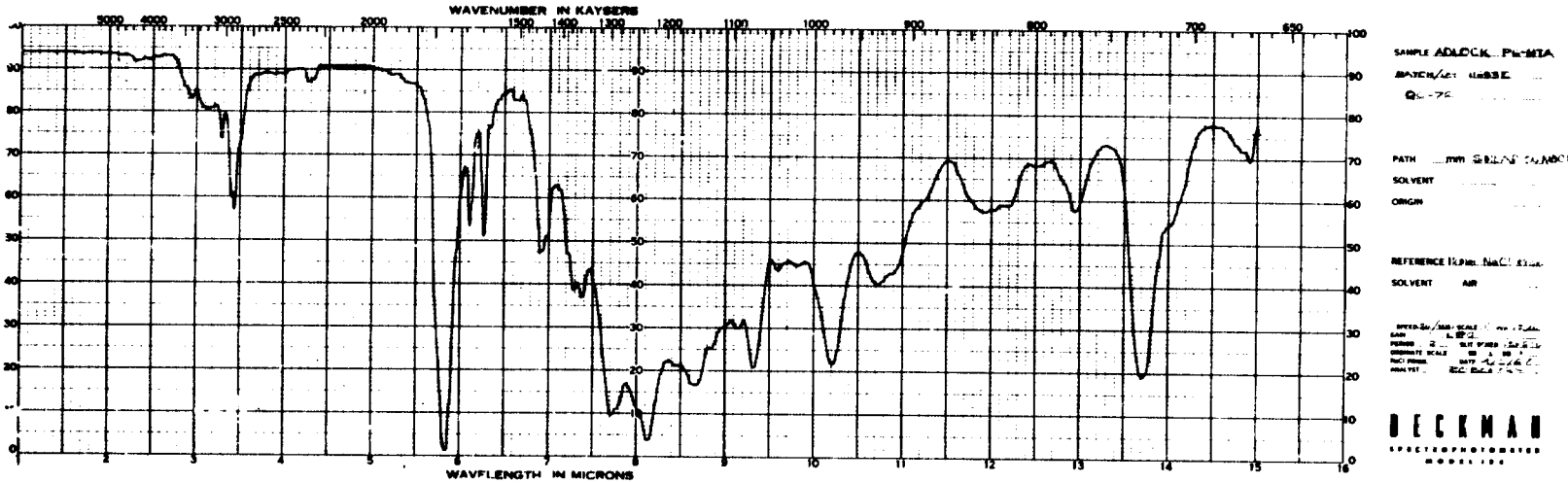

WAVENUMBER IN KAYSERS
DECKMAN

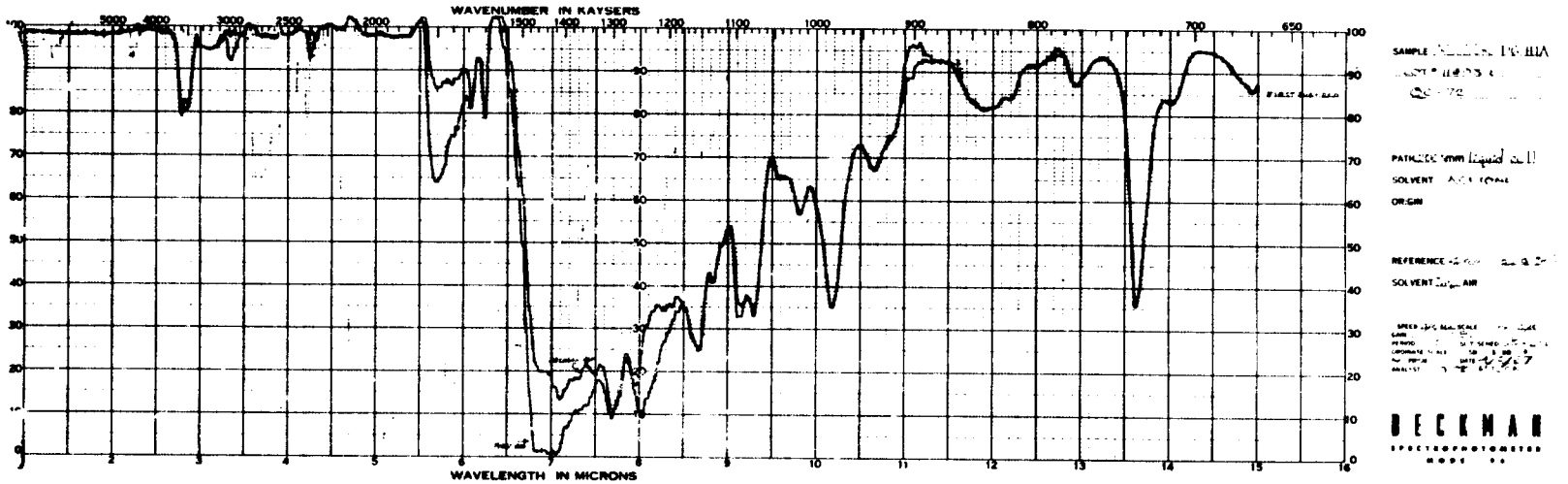

WAVELENGTH IN MICRONS
LAST SECTION
BECKMAN

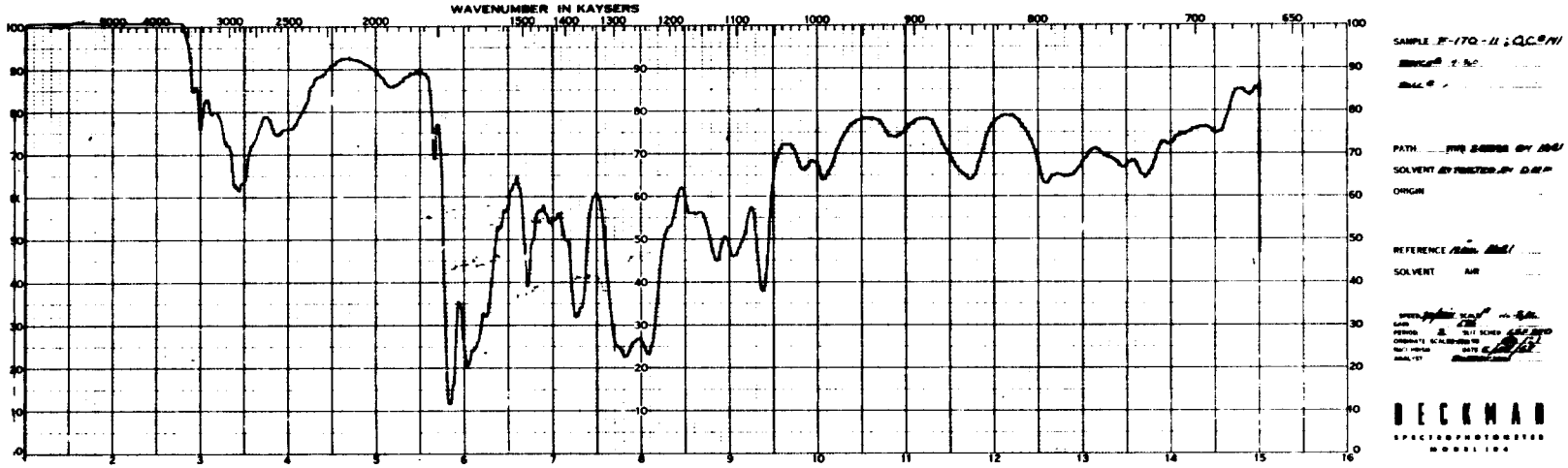

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
SOLVENT ACETONE
SOLVENT AIR
BECKMAN

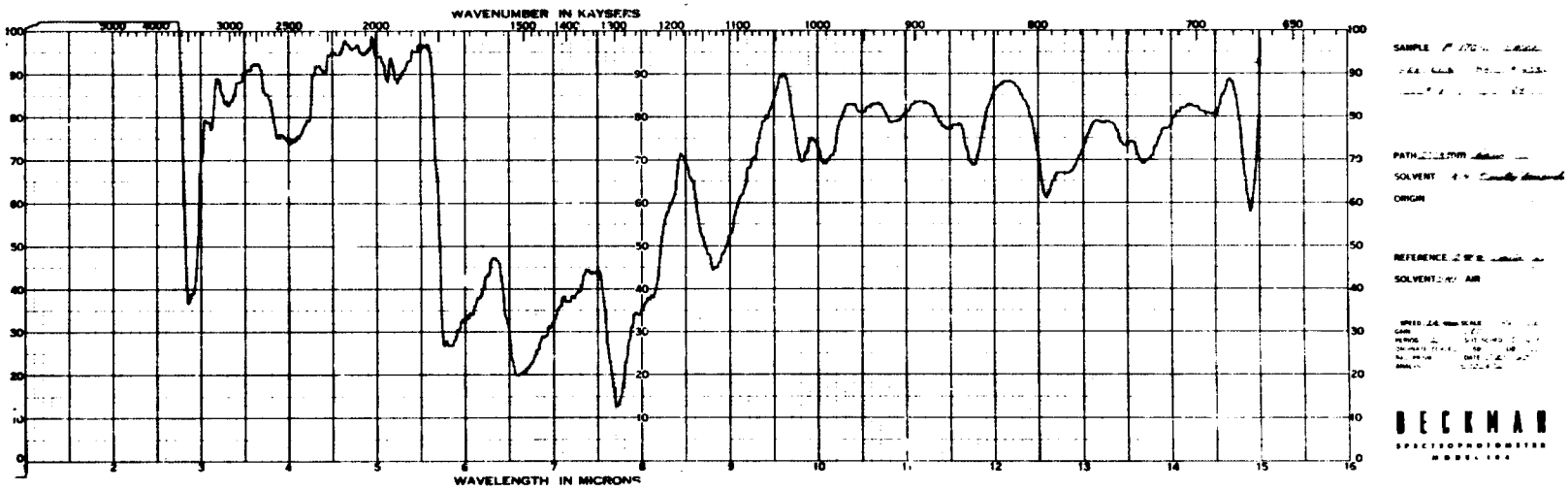

5000 4000 3000 2500 2000 1500 1400 1300 1200 1100 1000 900 800 700 650
SAMPLE
PATH mm
SOLVENT
REFERENCE AIR
SOLVENT AIR
BECKMAN
SPECTROPHOTOMETER
MODEL 1R4

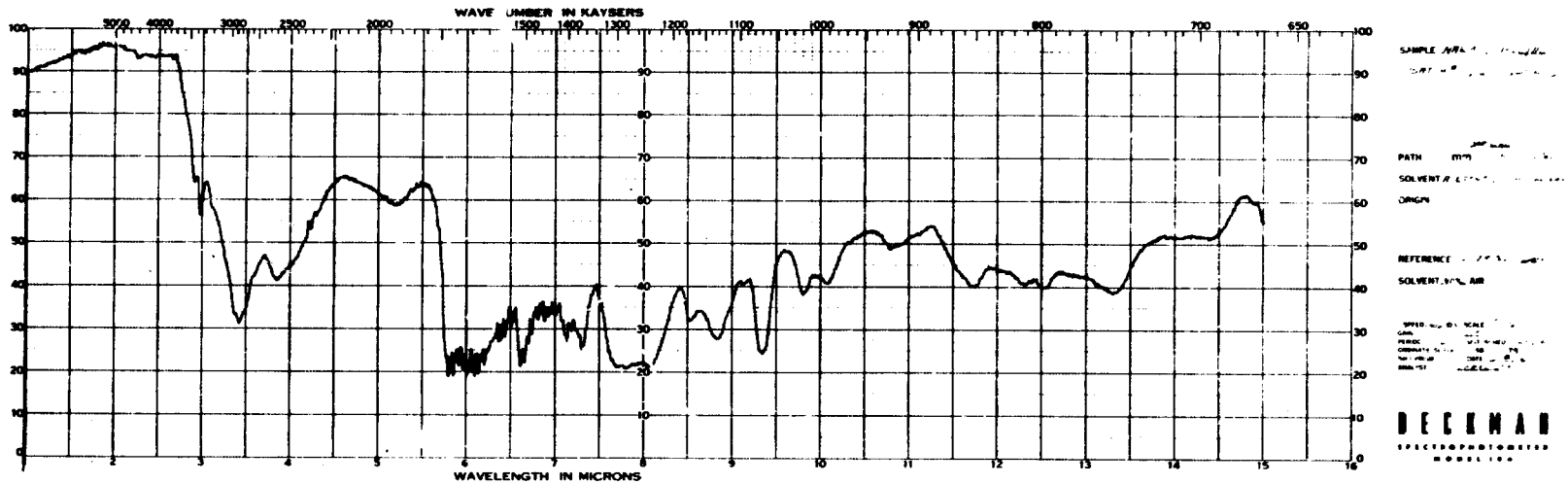

BENZYLDIMETHYLAMINE LOT #97
PATH-.480 mm NaCl CELL
REFERENCE-AIR
DOUBLE BEAM
SLIT SCHEDULE 1.5 STD
GAIN 2.57
BENZYLDIMETHYLAMINE LOT #97
PATH - .0743 mm LIQUID CELL
REF - AIR
DOUBLE BEAM - RATIO 1:1
SLIT SCHEDULE 1.5 STD -
GAIN - 2.57
SPEED .5 AU/MIN , SCALE 5% / IN.

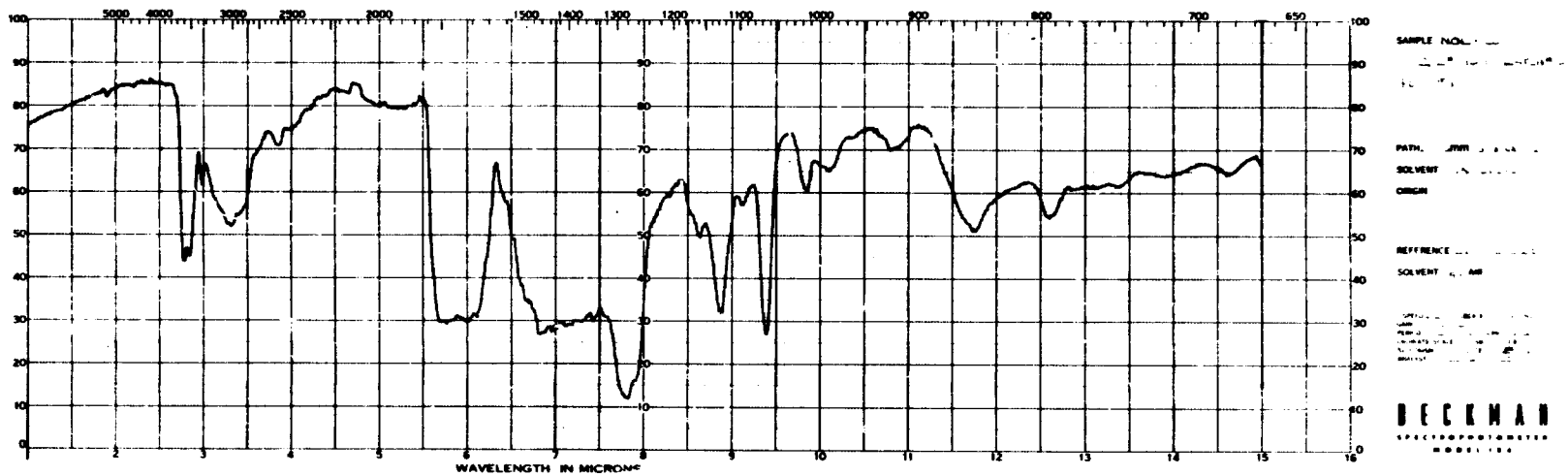

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
BECKMAN

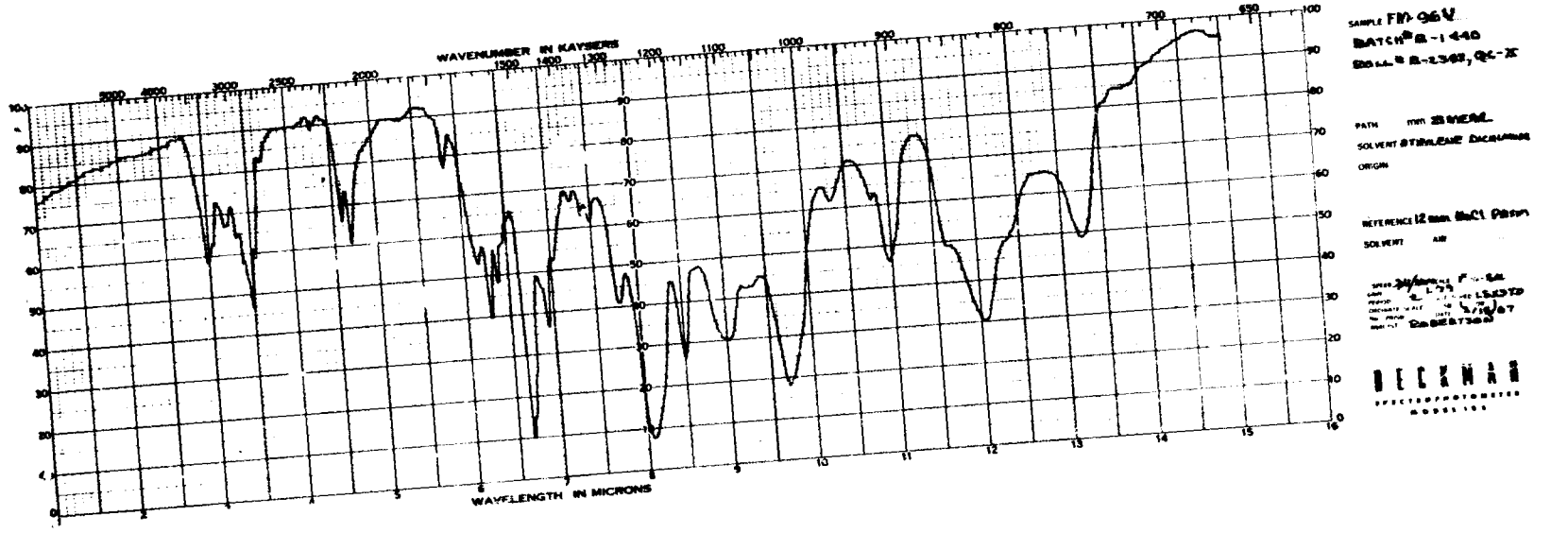

WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
BECKMAN

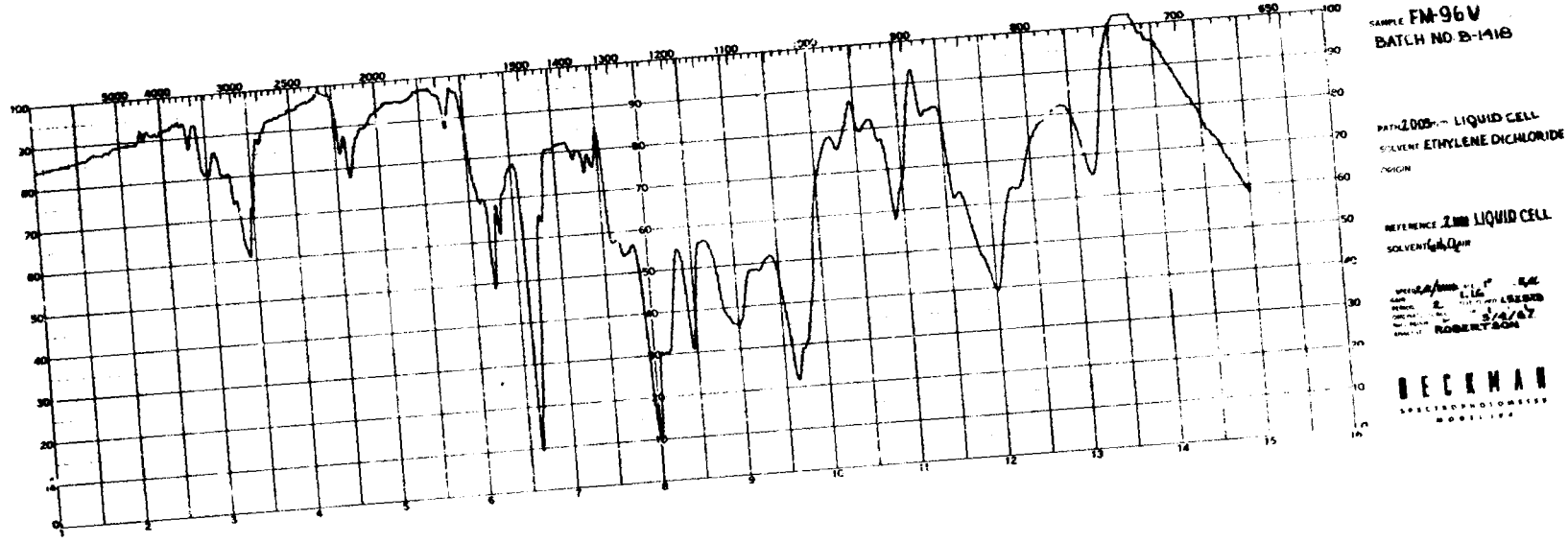

WAVENUMBER IN KAYSERS
4000 3000 2500 2000 1500 1400 1300 1200 1100 1000 900 800 700 650
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
SAMPLE
PATH
SOLVENT
ORIGIN
REFERENCE
SOLVENT AIR
BECKMAN
SPECTROPHOTOMETER

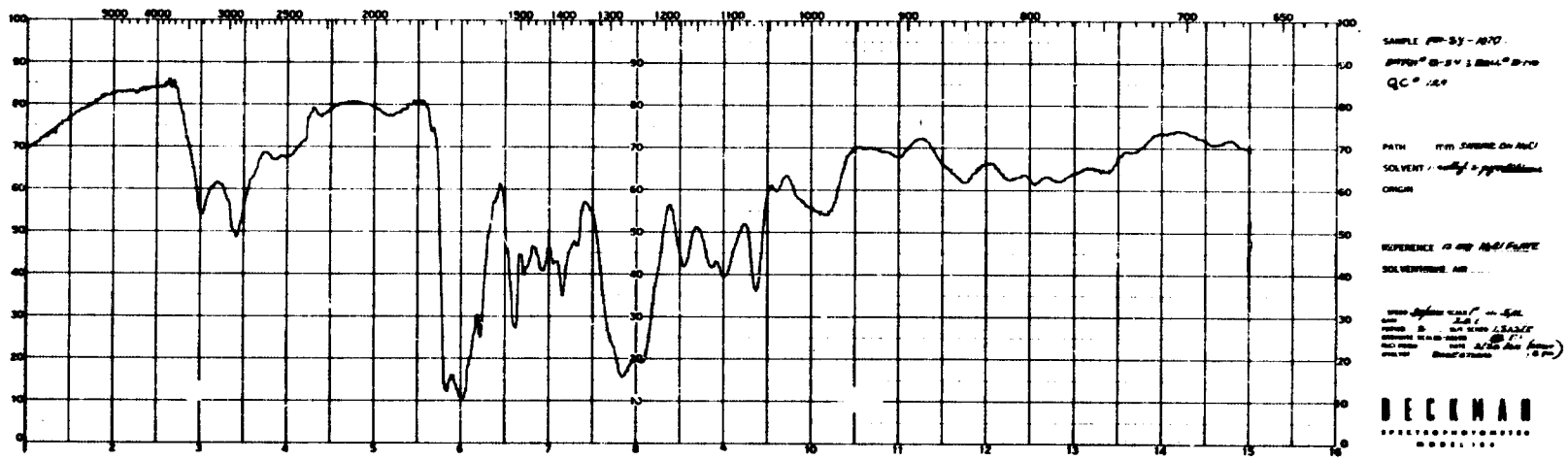

WAVENUMBER IN KAYSERS
4000 3000 2500 2000 1500 1400 1300 1200 1100 1000 900 800 700 650
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
WAVELENGTH IN MICRONS
SAMPLE
PATH
SOLVENT
ORIGIN
REFERENCE
SOLVENT AIR
BECKMAN
SPECTROPHOTOMETER

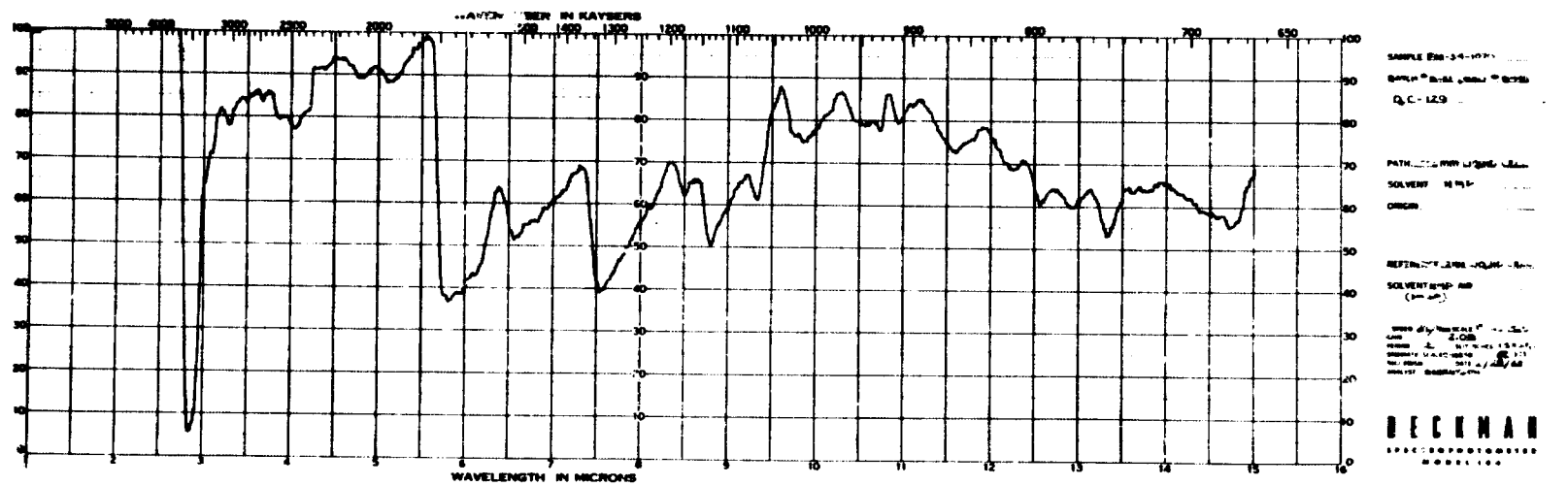

WAVE NUMBER IN KAYSERS
WAVELENGTH IN MICRONS
BECKMAN

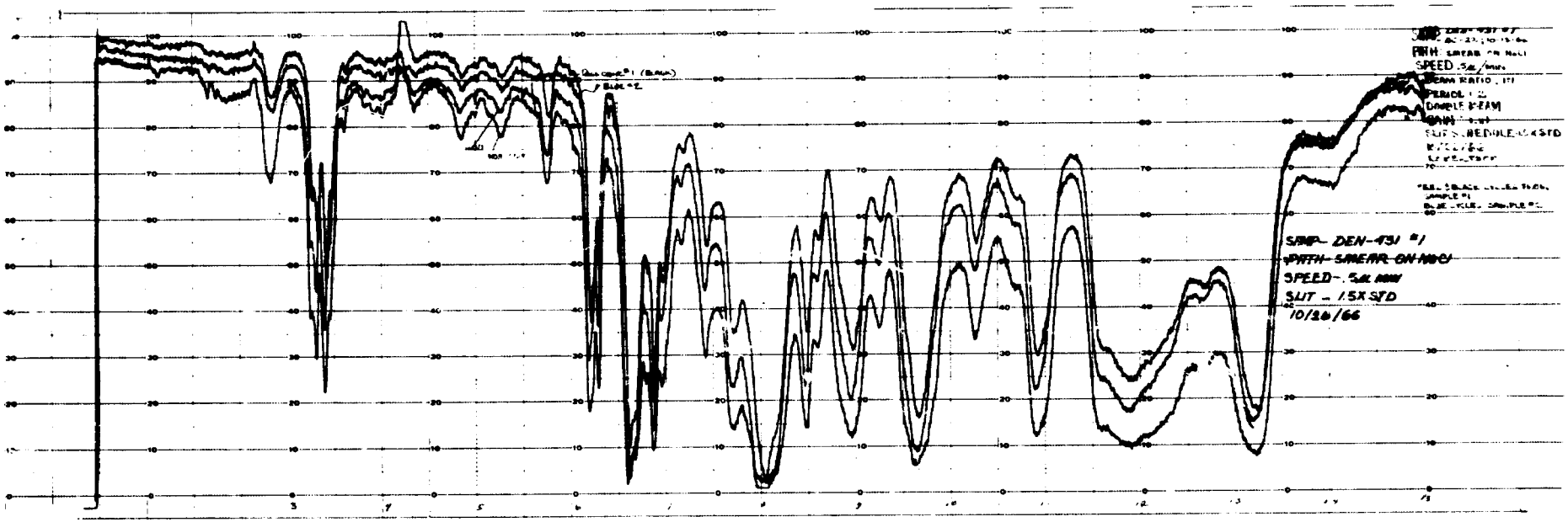

WAVELENGTH IN MICRONS
BECKMAN


WAVENUMBER IN KAYSERS
WAVELENGTH IN MICRONS
SAMPLE FM-96V
BATCH B-1440
PATH mm
SOLVENT ETHYLENE DICHLORIDE
ORIGIN
REFERENCE mm NaCl Plate
SOLVENT AIR
BECKMAN
SPECTROPHOTOMETER


SAMPLE FM-96V
BATCH NO. B-1418
PATH 2.005mm LIQUID CELL
SOLVENT ETHYLENE DICHLORIDE
ORIGIN
REFERENCE 2mm LIQUID CELL
SOLVENT
BECKMAN
SPECTROPHOTOMETER




WAVELENGTH IN MICRONS


SAMP- DEN-431 #/
WITH- SMEAR ON NOC/
SPEED- .5 MM
SLIT - 1.5X STD
10/26/66

APPENDIX F

MATERIAL SUPPLIERS

MATERIAL SUPPLIERS

Material	Type	Supplier
91LD	Phenolic resin prepreg	American Reinforced Plastics
112 E glass fabric	Plain weave glass fabric	Thalco
116 E glass fabric	Plain weave glass fabric	Thalco
120 S glass fabric	Crowfoot satin weave glass fabric	Owens-Corning Fiberglass Corp.
Adlock 453 PHG	Phenolic resin prepreg	American Reinforced Plastics
Adlock 851	Phenolic resin prepreg	American Reinforced Plastics
Adlock EG-4B	Epoxy resin prepreg	American Reinforced Plastics
Adlock EG-35	Epoxy resin prepreg	American Reinforced Plastics
Adlock EG-9300	Epoxy resin prepreg	American Reinforced Plastics
Adlock PG-HTA	Polyester resin prepreg	American Reinforced Plastics
BDMA	Epoxy resin accelerator	Miles Chemical Corporation
Benzoin	Polyester resin accelerator	Ram Chemicals
BF_3MEA	Epoxy resin accelerator	Allied Chemical Corporation General Chemical Division
BP 908	Epoxy resin prepreg	American Cyanamid Bloomingdale Division
BZP	Polyester resin accelerator	Ram Chemicals

MATERIAL SUPPLIERS

Material	Type	Supplier
Conolon 506	Phenolic resin prepreg	Whittaker Corporation Narmco Materials Division
Curing Agent B-1	Epoxy adhesive curing agent	Shell Chemical Company
Curing Agent B-3	Epoxy adhesive curing agent	Shell Chemical Company
Epon 1031	Epoxy resin	Shell Chemical Company
F170 Imide	Polyimide resin prepreg	Coast Mfg. and Supply Company
F502	Phenolic resin prepreg	U.S. Polymeric
F509	Silane-phenolic resin prepreg	U.S. Polymeric
Flexcore SF50-40	Phenolic core	Hexcel Products, Incorporated
FM-34/1070	Polyimide adhesive	American Cyanamid Bloomingdale Division
FM-96U	Epoxy adhesive	American Cyanamid Bloomingdale Division
HHPA	Epoxy resin curing agent	E. V. Roberts and Associates
HRH-10	Nomex phenolic core	Hexcel Products, Incorporated
HRP	Phenolic core	Hexcel Products, Incorporated
HT-424F	Epoxy-phenolic adhesive	American Cyanamid Bloomingdale Division

MATERIAL SUPPLIERS

Material	Type	Supplier
HT-435U	Epoxy-phenolic adhesive	American Cyanamid Bloomingdale Division
HTP	Phenolic core	Honeycomb Products, Incorporated
NMA	Epoxy resin curing agent	E. V. Roberts and Associates
Narmco 500	Epoxy resin prepreg	Whittaker Corporation Narmco Materials Division
Curing Agent CL	Epoxy resin curing agent	Shell Chemical Company
Curing Agent Z	Epoxy resin curing agent	Shell Chemical Company
DCBzP	Polyester resin accelerator	Ram Chemicals
DDS (Eporal)	Epoxy resin curing agent	Ciba Products Company
DEH 50	Epoxy resin curing agent	Dow Chemical Company
DEN 431	Epoxy novolac resin	Dow Chemical Company
DEN 438	Epoxy novolac resin	Dow Chemical Company
Dovetail core	Phenolic core	Honeycomb Products, Incorporated
DuPont 2501	Polyimide resin prepreg	E.E. du Pont de Nemours
E740B	Epoxy resin prepreg	U.S. Polymeric
E787	Epoxy resin prepreg	U.S. Polymeric

MATERIAL SUPPLIERS

Material	Type	Supplier
E792	Epoxy resin prepreg	U.S. Polymeric
Eccomold L70	Butadiene-styrene resin	Emerson and Cuming
Epocast H-1843	Epoxy resin potting compound	Furane Plastics
Epon 815	Epoxy resin	Shell Chemical Company
Epon 826	Epoxy resin	Shell Chemical Company
Epon 828	Epoxy resin	Shell Chemical Company
Epon 901	Epoxy adhesive	Shell Chemical Company
Narmco 588	Epoxy resin prepreg	Whittaker Corporation Narmco Materials Division
Narmco 1832	Polyimide resin prepreg	Whittaker Corporation Narmco Materials Division
Narmco Polysulfone	Polysulfone resin	Whittaker Corporation Narmco Materials Division
RCR-568	Potting compound	Rohr Corporation
RCR-576	Potting compound	Rohr Corporation
t-BPB	Polyester resin accelerator	Ram Chemicals
Vibrin 135	Polyester resin	Marco Chemical Corporation Division W. R. Grace and Co.
Vibrin 136	Polyester resin	Marco Chemical Corporation Division W. R. Grace and Co.