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# Development of Sheet Metal Parabolic Trough Reflector Panels

Albert W. Biester
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Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-76DP00789

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# Development of Sheet Metal Parabolic Trough Reflector Panels

Albert W. Biester
The Budd Company Technical Center
Fort Washington, PA 19034

Under Contract No. 13-8721

## Abstract

This report describes the effort undertaken to develop accurate, durable, and mass producible sheet metal parabolic trough solar collectors and the associated support for the collectors.

## ACKNOWLEDGMENTS

The cooperation and guidance of Messrs. R. Champion and S. Thunborg of the Solar Energy Products Division of Sandia National Laboratories, Albuquerque, NM, during the performance of this contract are gratefully acknowledged.

Also, the assistance and contributions of The Budd Company Technical Center personnel Mr. V. Grasso in the adhesive development phase of the program and Mr. W. Eggert for the design concept are acknowledged.

Work on the development of the sheet metal parabolic trough reflectors was performed under contract for Sandia National Laboratories, Contract Number 13-8721.

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## 1.0 OBJECTIVE

The objective of this project performed by The Budd Company Technical Center for Sandia National Laboratories, under Contract Number 13-8721, was the development of an accurate, durable, and mass producible line focus parabolic trough solar collector panel. Included in the project was the development of tooling and the production of prototype panel modules for testing at Sandia Laboratories.

The requirement for tooling developed on the project was that it be quasi-production type tooling. This type of tooling is designed to meet limited production requirements but is representative of the type of tooling and processes which can be used in high production.

The scope of the project was subsequently increased to include the development of a torque tube assembly for mounting the solar collector panels, the design and fabrication of the tooling required to produce the torque tube assemblies, and the production of initial prototype torque tube assemblies for testing at Sandia Laboratories.

## 2.0 INTRODUCTION

The search for a line focus parabolic trough reflector structure which will be efficient, low cost, durable, and suited to mass production has produced many designs of reflector structures fabricated of various materials. The automobile industry, which is considered the model for high production of structural shapes, has long used sheet metal stampings to provide low cost structures. This report will describe how automobile production technology has been adapted to the development and prototype production of sheet metal parabolic trough reflector structures.

### 2.1 The Budd Company Involvement.

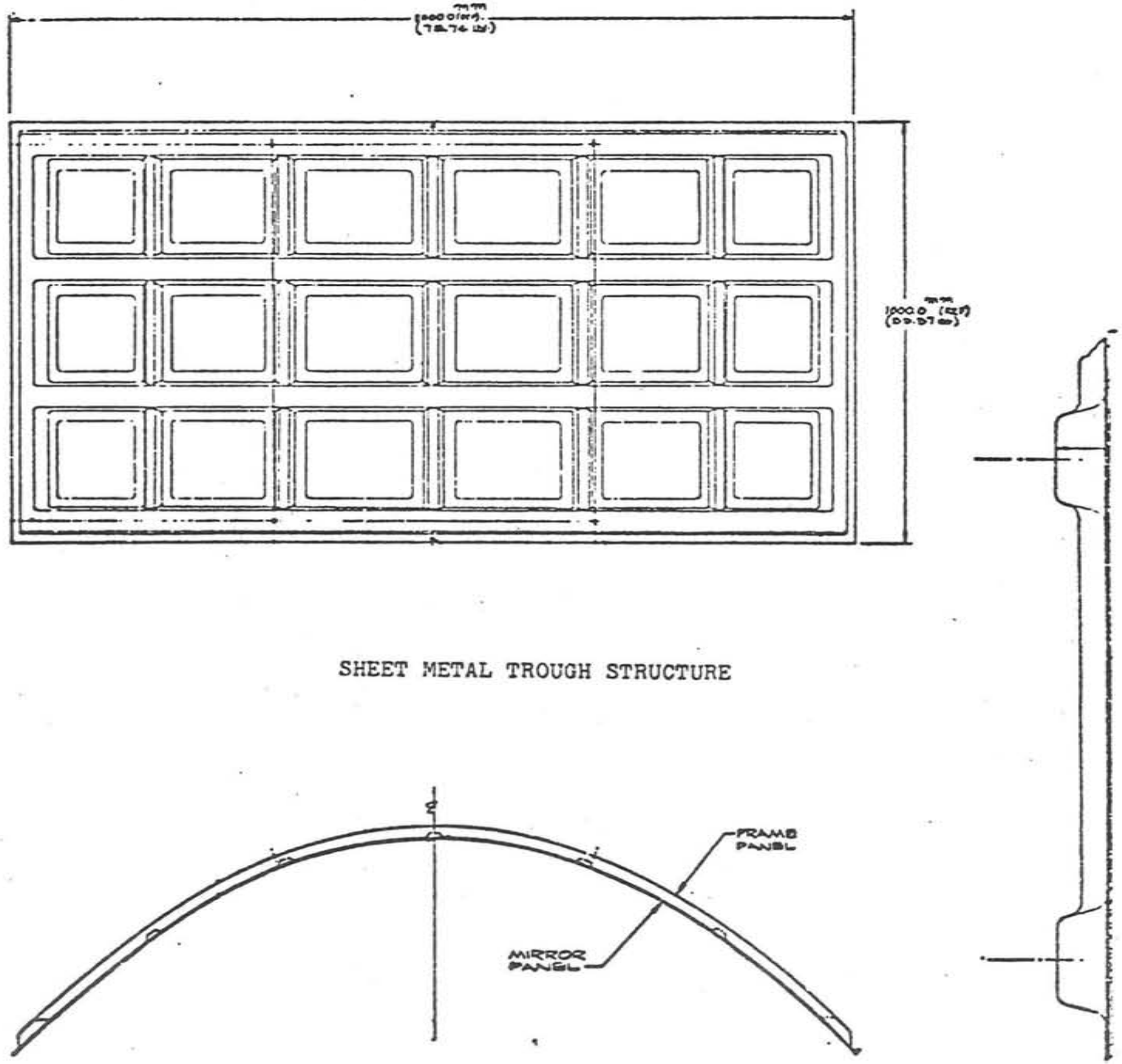
A brief description of The Budd Company experience in automotive production and involvement in this task is appropriate. Most people, if they are familiar with Budd, relate the company with passenger rail cars or highway trailers. What is not generally known is that Budd is the largest independent producer of automotive components in the country. Included in the automotive components produced by Budd are automobile frames and body panels which are mass produced for all of the domestic automobile manufacturers. In addition, Budd technology is utilized by various other automobile producers throughout the world.

Budd has years of experience and the required skilled personnel for the development of prototype structures. In addition, Budd possesses tremendous mass production capacity at its various stamping plants. Included in this capability for mass production is that of also being able to produce the tooling required for a high production effort.

## 2.2 Design Concept.

The Budd experience in the development and production of automobile parts, in discussions with Sandia Laboratories, led to the design concept which was developed on this program. The original design was essentially a two piece sheet metal structure consisting of a formed steel frame or stiffening panel and a smooth contoured steel mirror panel. The two pieces can be bonded or spotwelded to form a rigid structure as shown in Figure 2.2-1. An automobile panel analagous to this structure is a hood panel, which also consists of a formed stiffener and a smooth contoured skin. The reflective surface to be applied to the steel structure can be film, glass mirror, or any of the presently utilized materials.

The stamped steel frame panel also permits a wide latitude in design configurations. The two piece steel structure permits the use of the various reflective surfaces. If chemically strengthened glass is used as the reflective surface, the intermediate steel mirror panel can be eliminated,




SHEET METAL TROUGH STRUCTURE

Figure 2.2-1

with the stamped frame panel bonded directly to the glass mirror. The steel frame panel can also be produced with or without cut-outs with no change in strength characteristics.

2.3 Development Efforts.

The effort performed by The Budd Company Technical Center in this development program encompassed the following areas:

a. Material Selection

b. Adhesive Testing

c. Tool Design and Fabrication

d. Prototype Panel Production

e. Design and Development of Torque Tube Assemblies

This report will cover the results obtained during the program, conclusions reached as a result of the data obtained and recommendations for further effort in the development of this phase of the alternate energy source program.

## 3.0 RESULTS - DEVELOPMENT CONSIDERATIONS AND SEQUENCE

The effort on this program was initiated in September 1979 with the formulation of plans and tooling concepts for performing the required tasks. The plans and tooling concepts were presented to Sandia at a meeting in Albuquerque, NM on October 1, 1979. At this meeting, an increase in scope of the project to require Budd to install the reflective glass mirror surfaces was also discussed and later was implemented.

To determine the materials to be used, studies of available metals and of various adhesives were conducted. Tooling was designed and fabricated or procured. Upon completion of tooling, prototype panels of various configurations as requested by Sandia were produced and furnished to Sandia for test and evaluation.

In accordance with an additional change in scope on the program, a trough support, to be welded to a torque tube, was developed, designed, and procured. An assembly welding fixture for producing torque tube assemblies was designed and fabricated and one (1) full length and one (1) short length torque tube assemblies were produced and furnished to Sandia for testing and evaluation.

The activities required to perform the tasks noted above are discussed herein.

## 3.1 Material Selection.

The material to be used in fabricating the structures must be low cost, formable, durable, particularly in corrosion resistance, and for the prototypes must be available from warehouse stocks. The material choices for mass production are much broader than for prototypes since most materials are available in mill run quantities.

Various sheet metal materials were considered for use. Aluminum and stainless steel are not low cost materials. Cold rolled steel is lowest in cost and formable but its corrosion resistance is poor. Aluminized steel is corrosion resistant and reasonable in cost but it is not recommended for severe forming operations and it is not readily available in the sheet sizes required for forming the frame panels. Hot dip galvanized steel is low in cost and possesses the corrosion resistance and forming characteristics required but the spangled surface is not suitable for use with a film reflector and it requires supplemental surface treatment for paint adherence. It is also not readily available in the sheet sizes required. Galvannealed steel is a hot dip galvanized steel which is heat treated after coating providing a smooth, spangle free surface of iron-zinc alloy suitable for forming and painting. However, it also is not readily available in the sheet sizes required. Zincrometal is a cold rolled steel with a two part coating of Dacromet and

Zincromet produced by various steel companies under license from Diamond Shamrock Corporation. This material is widely used in the automobile industry and possesses the required characteristics. However, in the thickness and sheet sizes required it is only available in mill run quantities.

Finally, it was determined that electrogalvanized steel was available in the thickness and sheet sizes required. This material has excellent surface finish, is formable and corrosion resistant and is reasonable in cost. It also has a phosphate coating which permits painting without further surface treatment. Therefore, electrogalvanized steel was selected for the sheet metal structures.

3.2 Adhesive Testing and Selection.

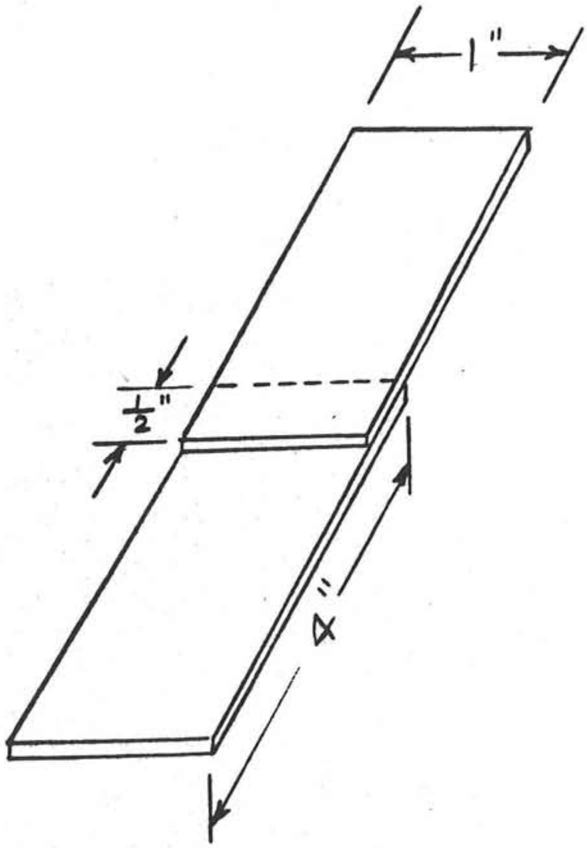
As the first step in the selection of a suitable adhesive for bonding the structure panels, a study was performed to obtain data on various available adhesives. The results of this study are shown in Appendix A to this report. The study indicated that urethane adhesives were most suitable for use in bonding the structures. Of these adhesives,the Goodyear Pliogrip 6000 series adhesives exhibited the most desireable characteristics. However, without automatic mixing and dispensing equipment, the short working life of the Pliogrip adhesive made it impractical for use on the prototype panels.

It was decided that 3M Structural Adhesive EC-3549B/A, with a working life of one hour, would be most suitable for use. It was also decided that automatic adhesive mixing and dispensing equipment should be procured to permit use of the Pliogrip system. After receipt of the equipment, the adhesive used was changed to the Goodyear Pliogrip 6000 series.

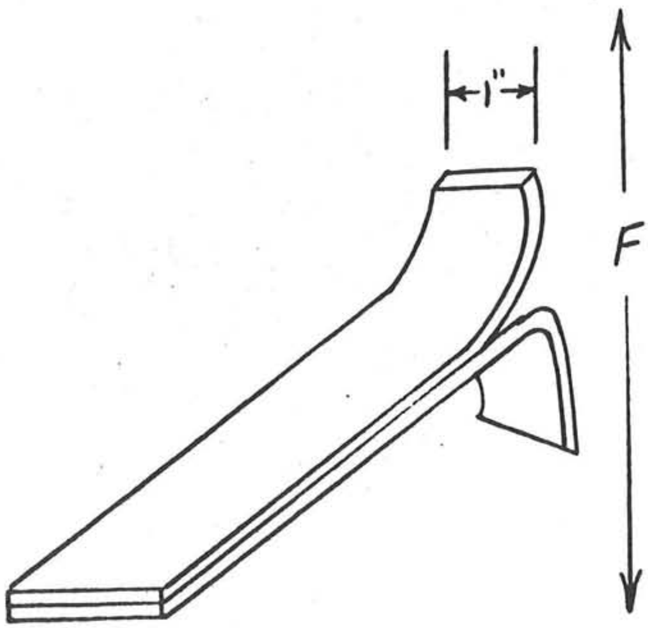
To obtain further information pertinent to this project, bonding tests were completed using galvannealed and electrogalvanized steel and 3M Adhesive 3549B/A. Lap shear tests and peel tests were conducted on control specimens with no environmental exposures and on specimens immersed in water for periods of seven days and twenty-eight days and on specimens exposed to a temperature of 150°F for periods of seven days and twenty-eight days. Configuration of the test specimens is shown in Figure 3.2-1 and the results of the tests are shown in Table 3.2-1. The tests indicated that best results are obtained by a light Scotchbrite abrasion of the bonded surfaces prior to priming. Results after solvent wiping only were unsatisfactory and this method is not considered a viable one.

It was mutually decided between Budd and Sandia that Epon 828 epoxy resin with Versamid 140 polymid should be used for bonding mirrored glass to the steel structures. In the meantime, Sandia requested that aluminized steel be used for

## BONDING TEST SPECIMENS




SHEAR TEST SPECIMEN




PEEL TEST SPECIMEN

FIGURE 3.2-1

Table 3.2-1

## BONDING TEST RESULTS

DESIGNATIONS:

A - Galvannealed steel (.034 inch thick)

B - Electrogalvanized steel (.034 inch thick)

P - Primed - Corogard 9

Pl - Scotchbrite abraded and primed - Corogard 9

| Designation | Control | 7 Days $H_2O$ | 28 Days $H_2O$ | 7 Days 150°F | 28 Days 150°F |
|---|---|---|---|---|---|
| | | Shear Tests (psi) | | | |
| AP | 1393 | 173 | 307 | 2347 | 2307 |
| BP | 1360 | 257 | 293 | 1820 | 1787 |
| A/BP | 1707 | 80 | 217 | 2120 | 2453 |
| BPI | 1800 | 1050 | 320 | — | — |
| | | Peel Tests (lbs/in width) | | | |
| AP | 26 | 19.3 | 32 | 37 | 55 |
| BP | 23 | 24 | 20 | 36 | 35 |
| A/BP | 26 | 18 | 17 | 36 | 55 |
| BPI | 33 | 25 | 20 | — | — |

NOTES: 1. Results shown are average of three (3) specimens
2. Adhesive - 3 M EC3549 B/A

the mirror panel of the steel structure. Aluminized steel of the sheet size required for the mirror panel was available. To determine the bonding characteristics and procedures to be used with aluminized steel, tests were conducted on aluminized steel specimens bonded with epoxy polyamid adhesive. A description of the tests is shown in Appendix B to this report. The results indicated that, in contrast to electrogalvanized steel substrate, the bonding surface of aluminized steel should be solvent wiped only, with no abrading, prior to priming and bonding.

Since some of the steel structures were to consist of aluminized steel bonded to electrogalvanized steel, additional adhesive bonding tests of specimens prepared from these two materials were conducted. The surface preparation for the materials as determined in the previous tests were used. The results of these tests are presented in Appendix C to this report. The results indicated that no problems are presented in bonding these materials.

At the request of Sandia, test specimens were prepared for Sandia for evaluation of adhesives for bonding glass to steel in the flat, prior to forming to the parabolic curve. To prepare satisfactory test specimens, it was necessary to determine an adhesive which would provide a bond between the bare side of the glass and steel which would be stronger than the expected bond strength of the adhesive to be used for bonding the painted back of the mirror to steel. Tests were conducted for this determination and the description and results of the tests are presented in Appendix D to this report. Hughson Chemicals Versilok 204 acrylic adhesive was determined to be satisfactory for this purpose.

The adhesive utilized for bonding chemically strengthened glass sheets to a sheet of steel in the flat had to be strong enough to withstand the stresses induced from bending and from service conditions. Since the steel and glass to be used in producing the laminate were relatively thick, the adhesive also had to be compliant enough to allow some relative movement between the two materials to permit bending of the flat laminate to a parabolic curve. To determine a suitable adhesive for this purpose, test specimens were prepared using various urethane adhesive systems. The test specimens prepared and sent to Sandia for testing are listed in Table 3.2-2. It was decided that the Essex U-82618 adhesive system was most suitable for use in bonding the glass to the steel in the flat.

Considerable effort was expended on the project for adhesive evaluation and testing. Although not specified in the contract, this was considered necessary since the correct adhesive is such an important factor in the accuracy and durability characteristics of the reflectors and in the longer range production plans.

Table 3.2-2

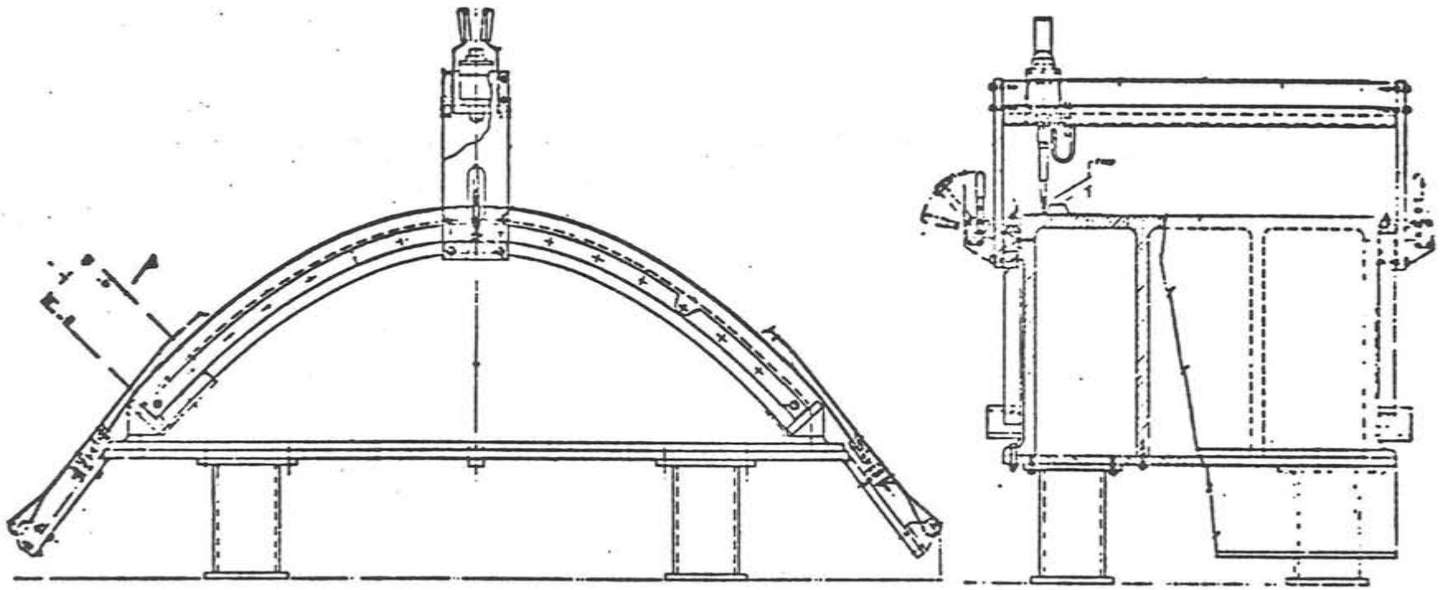
Flat Bonding Test Specimens

| Specimen | Quantity | Specimen Materials | Primer | Adhesive Base Component | Adhesive Curative Component |
|---|---|---|---|---|---|
| 1" Lap Shear | 50 | .038"Aluminiz.Stl .058"Glass Mirror | Essex 43534 | Essex U-82618 | Essex 55100 |
| 1" Lap Shear | 50 | .038"Aluminiz.Stl .058"Glass Mirror | 3M Corogard 9 | 3M 1XA-3504A | 3M 1XA-3504B |
| 1" Lap Shear | 50 | .038"Aluminiz.Stl .058"Glass Mirror | Goodyear 6031/6032 | Goodyear AX37J110-40 | Goodyear AX37J110-57 |
| Flat Panel 10" x 24" | 9 | .038"Aluminiz.Stl .058"Glass Mirror | 3M Corogard 9 | 3M 1XA-3504A | 3M 1XA-3504B |
| Flat Panel 10" x 24" | 10 | .038"Aluminiz.Stl .058"Glass Mirror | Goodyear 6031/6032 | Goodyear 6000 | Goodyear 6027 |
| 1" Lap Shear | 50 | .038"Aluminiz.Stl .058"Glass Mirror | Goodyear 6031/6032 | Goodyear 6000 | Goodyear 6027 |
| Flat Panel 10" x 24" | 8 | .038"Aluminiz.Stl .058"Glass Mirror | Essex 43534 | Essex U-82618 | Essex 55100 |
| Flat Panel 10" x 24" | 10 | .038"Aluminiz.Stl .058"Glass Mirror | Goodyear 6031/6032 | Goodyear AX37J110-40 | Goodyear AX37J110-45 |
| Flat Panel 10" x 24" | 4 | .038"Aluminiz.Stl .058"Glass Mirror | Goodyear 6031/6032 | Goodyear 6000 | Goodyear AX37J110-85 |

### 3.3 Tool Design and Fabrication.

In producing the dies for forming the frame panels, normal automotive prototype production procedures were utilized. The dies were made of zinc alloy and were relatively inexpensive when compared with hard steel forming dies. To produce this type of die, a wood or plaster model is made and is used to produce a sand casting of the zinc alloy material. When the requirement for the die has ended, the zinc alloy is melted down for re-use in another tool. This tooling procedure reduces the material cost for the tooling. The cutouts, trimming and drilling of the panels was performed manually, using a template. In production, these operations would be performed in a blank and pierce die. The smooth mirrored panel was not pre-formed but obtained its contour on the assembly fixture.

To maintain the accuracy of the parabolic surface, it was recognized that the assembly fixture would be the most important tool. A fixture suitable for bonding or spotwelding the assemblies was designed and fabricated. The concept is represented in Figure 3.3-1. For economy, the major portion of the fixture was made from an iron casting. A model of the casting was made of styrofoam and sand was packed around the styrofoam forming the mold. When the molten metal was poured into the mold, the styrofoam burned off leaving the iron casting. The fixture incorporates provision for vacuum hold down of the mirror panel for intimate contact with the parabolic surface. The accurately machined parabolic surface of the cast ing was produced with a one-eighth inch offset to permit



**BONDING AND SPOTWELDING FIXTURE**

Figure 3.3-1

the use of one-eighth inch thick sheet of copper as the bottom electrode for spotwelding. In the event of possible damage to the copper sheet from spotwelding, an alternate aluminum sheet of the same one-eighth inch thickness was provided for the bonding operation. Both the copper and aluminum sheets included holes for the vacuum hold-down and the copper (or aluminum) sheet is tension pulled over the iron casting for intimate contact. A bridge mounted on a parabolic track and incorporating a spotwelding head was provided. The panels are located on the fixture by two pins at the vertex on the datum line and pressure was applied to the formed structure panel by four straps over the longitudinal channels. Initially, steel packing type straps were utilized but were later changed to webbed cargo straps utilizing torque wrench actuated buckles to provide for uniform pressure application. The design and construction of the assembly fixture proved to be versatile when later in the project, it was decided to bond the glass mirrors to the structure. To provide the proper parabolic surface for the glass it was only necessary to replace the one-eighth inch thick copper sheet with a one-sixteenth inch thick plastic sheet, thus accounting for the fifty to sixty thousandths of an inch thickness of the glass.

3.4 Prototype Panel Production.

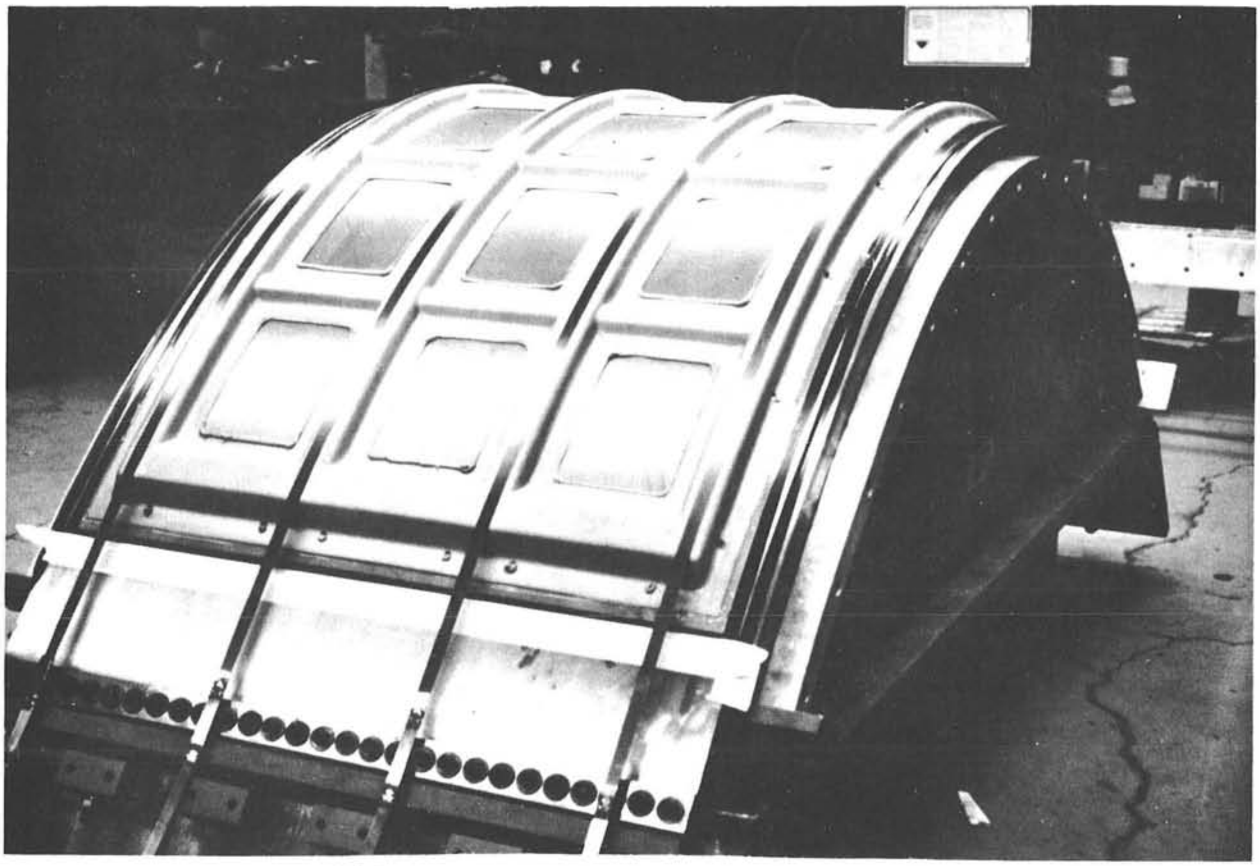
Upon completion of the first stamped panels but prior to completion of the assembly fixture, two structural test units were prepared. These units were assembled using the same methods as planned for the prototype units except that they were assembled on a wooden fixture as shown in Figure 3.4-1. The inside surfaces were prime painted and the smooth steel mirror panel was placed on the fixture. Adhesive was applied to the flanges of the formed panel and it was positioned on the mirror panel and strapped in place for curing of the adhesive. The assemblies were shipped to Sandia for structural testing which proved to be successful.

After completion of the assembly fixture, two structure assemblies were completed for accuracy evaluation. One unit was bonded and the other was spotwelded. The bonded unit was produced first, using the same procedures utilized in the first structural test units. The bonding set-up on the fixture is shown in Figure 3.4-2. After completion of the bonded unit, sample spotwelding coupons were produced at various locations on the fixture and then tested. The fixture was then loaded with the smooth steel mirror panel and the stamped frame panel and the assembly was spotwelded, with welds on all flanges at two inch centers. The spotwelding set-up on the fixture is shown in Figure 3.4-3 and the detail of the spotwelding head mounted on the bridge is shown in Figure 3.4-4.

Upon completion of the bonded and spotwelded reflector modules, they were dimensionally measured by Budd on a three dimensional measuring machine. Measurements were made at one

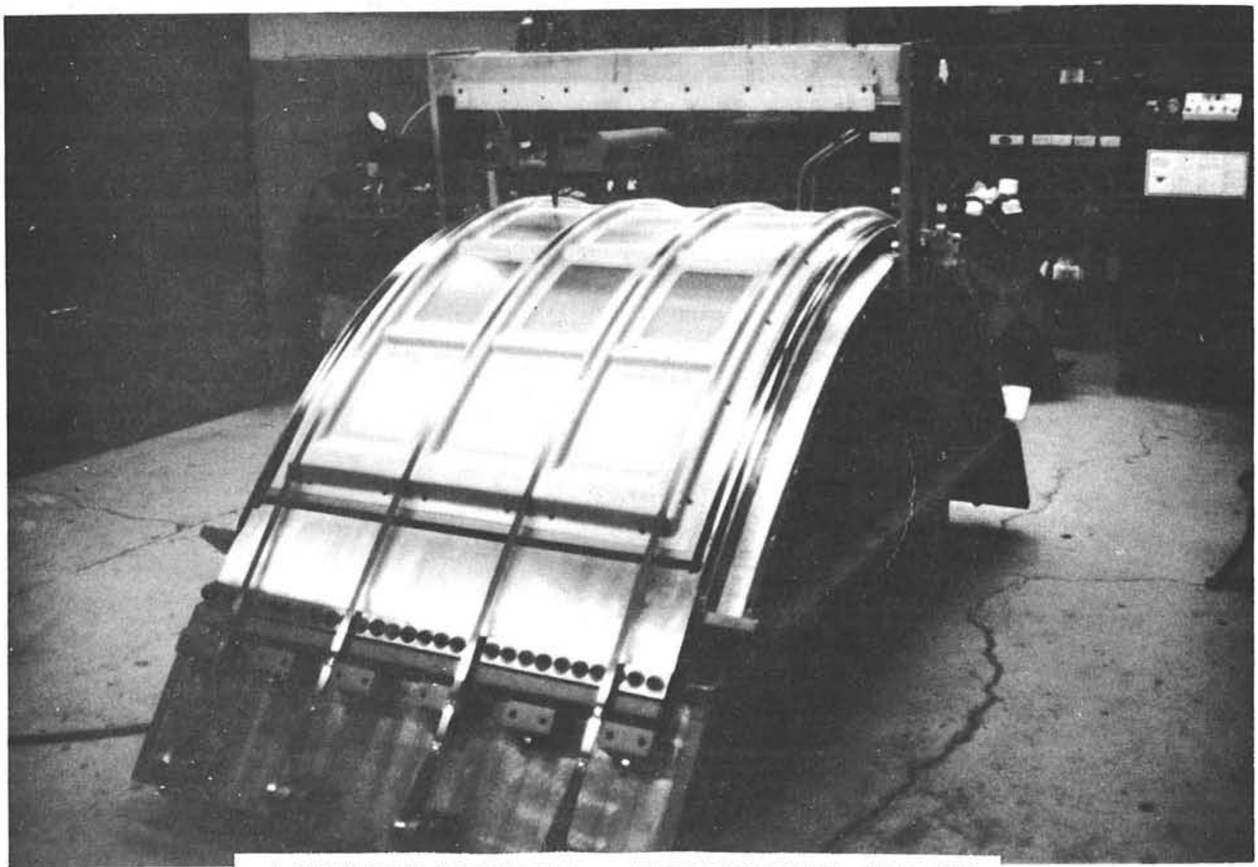
WOOD BONDING FIXTURE

Figure 3.4-1



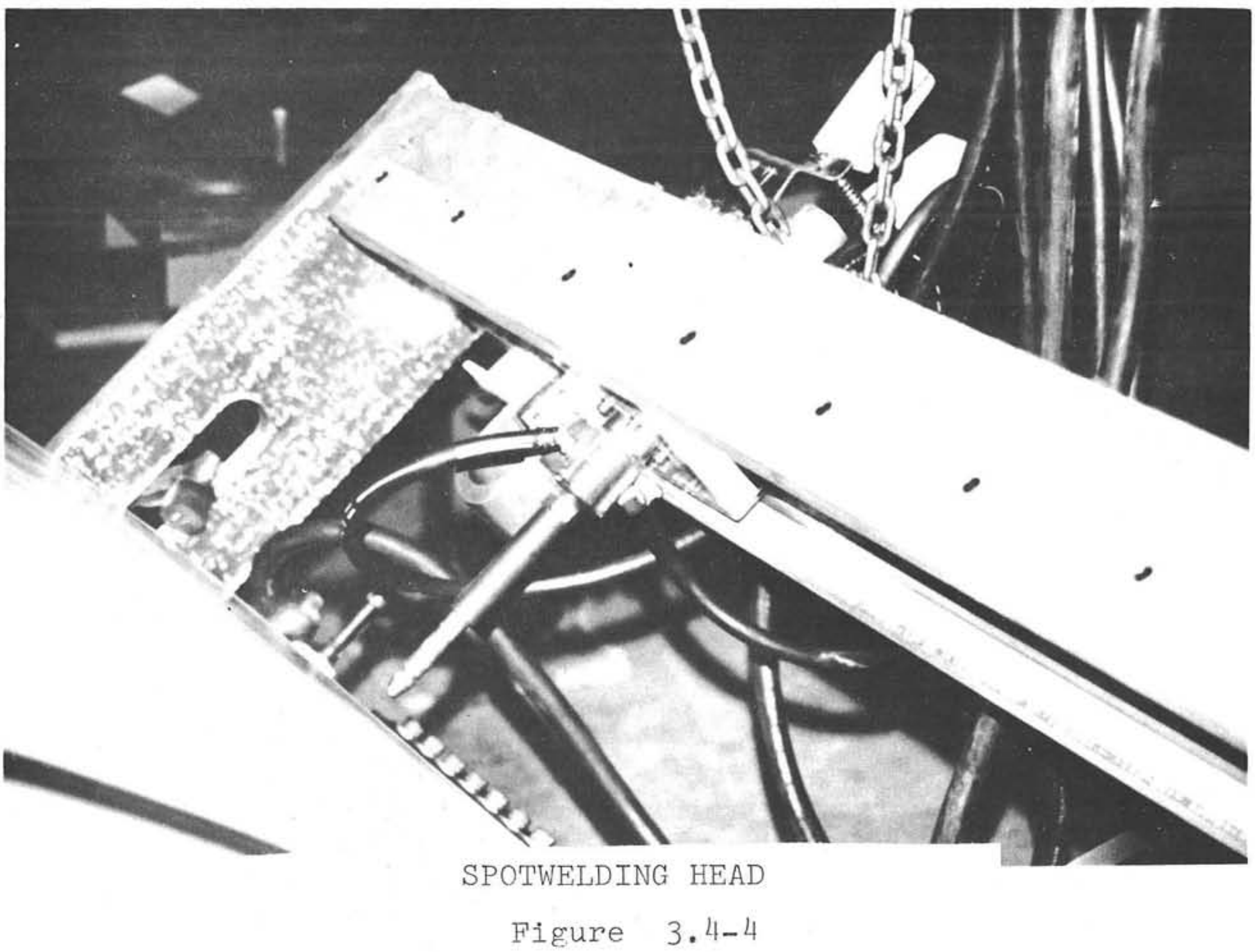
ASSEMBLY FIXTURE - BONDING SET-UP

Figure 3.4-2



ASSEMBLY FIXTURE - SPOTWELDING SET-UP

Figure 3.4-3



SPOTWELDING HEAD

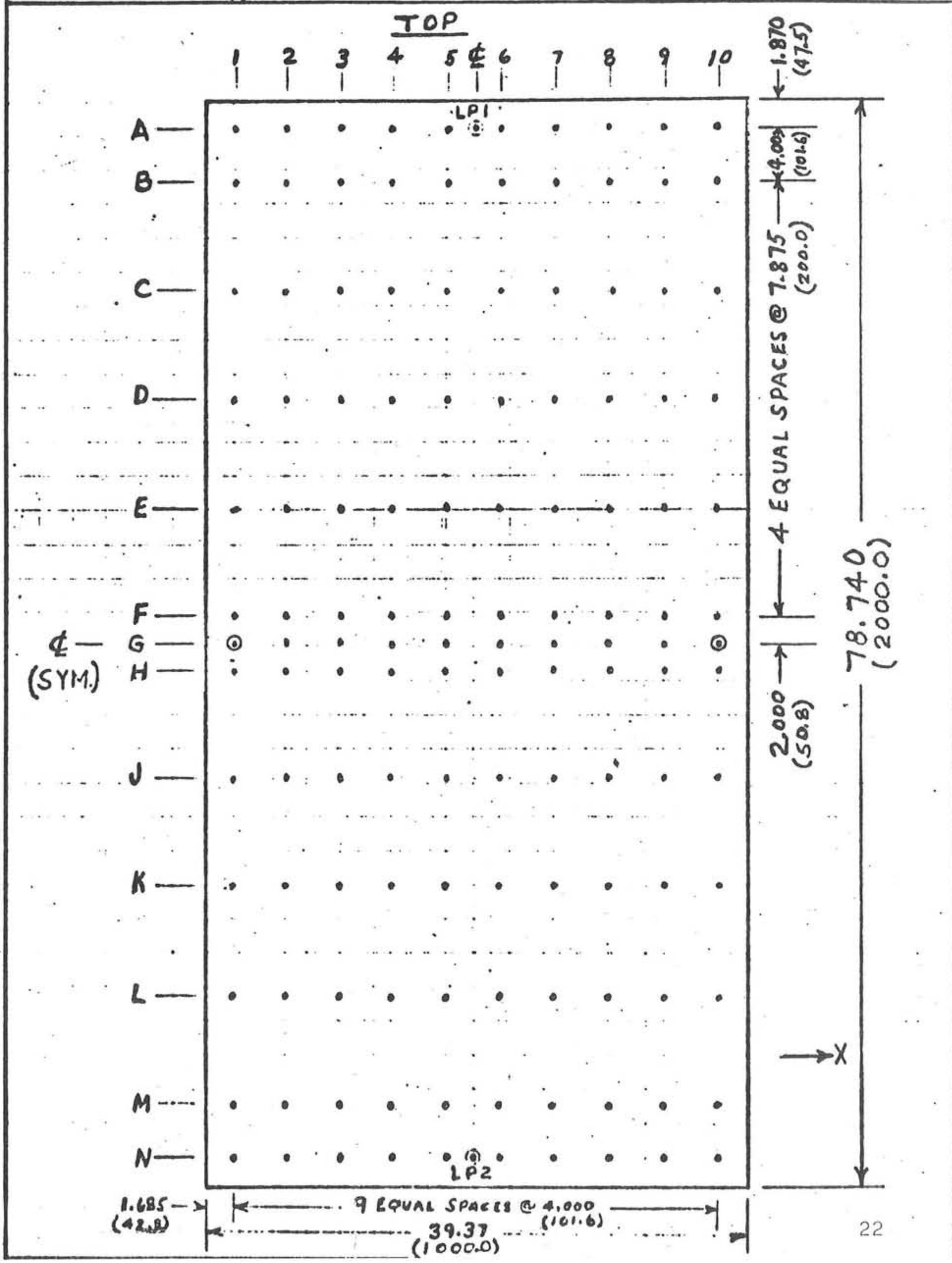
Figure 3.4-4

hundred and thirty points as shown in Figure 3.4-5. The calculated X-Y dimensions at the measurement points are shown in Table 3.4-1. The deviations from the theoretical curve for the two units are shown in Tables 3.4-2 and 3.4-3. From these physical measurements it was possible to determine the modifications to procedures and tooling to further improve the accuracy of the reflector modules. After the physical measurements by Budd, the two reflector modules were subjected to laser ray tracing by Sandia to determine the RMS slope error values. The laser ray tracing revealed that the units were within the target RMS slope error of 2.5 milliradians.

Upon successful completion of the initial steel structures, the contract was amended to enlarge the scope of the Budd effort to include production of prototype reflector modules incorporating the mirrored glass reflecting surfaces. As mentioned previously, the only tooling change required to attach the glass to the steel structures was the replacement of the one eighth inch thick copper sheet with a one sixteenth inch thick plastic sheet. The set-up for bonding glass to the steel structures is shown in Figure 3.4-6.

Figure 3.4-5

| | | |
|---|---|---|
| PREPARED BY: A.W.B. | Budd Company TECHNICAL CENTER | PAGE NO. OF |
| CHECKED BY: | | REPORT NO. |
| DATE: 7-2-80 | PANEL MEASUREMENT LOCATIONS | 940X-011-0[illegible] PROJECT NO. |
| | (VIEW FACING CONCAVE SURFACE) | |

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| PREPARED BY: A.W.B. | The Budd Company TECHNICAL CENTER | PAGE NO. OF |
|---|---|---|
| CHECKED BY: | | REPORT NO. |
| DATE: 7-2-80 | CALCULATED Y-DIM. AT GRID LOCATIONS | PROJECT NO. 940X-011- |

| GRID LOC. | | X | Y |
|---|---|---|---|
| A | in | 37.5000 | 18.4936 |
| | mm | 952.50 | 469.74 |
| B | in | 33.5000 | 14.7537 |
| | mm | 850.90 | 374.87 |
| C | in | 25.6250 | 8.6355 |
| | mm | 650.88 | 219.34 |
| D | in | 17.7500 | 4.1434 |
| | mm | 450.85 | 105.24 |
| E | in | 9.8750 | 1.2824 |
| | mm | 250.83 | 32.57 |
| F | in | 2.0000 | 0.0526 |
| | mm | 50.80 | 1.34 |
| G | in | 0.0000 | 0.0000 |
| | mm | 0.00 | 0.00 |
| H | in | 2.0000 | 0.0526 |
| | mm | 50.80 | 1.34 |
| J | in | 9.8750 | 1.2824 |
| | mm | 250.83 | 32.57 |
| K | in | 17.7500 | 4.1434 |
| | mm | 450.85 | 105.24 |
| L | in | 25.6250 | 8.6355 |
| | mm | 650.88 | 219.34 |
| M | in | 33.5000 | 14.7587 |
| | mm | 850.90 | 374.87 |
| N | in | 37.5000 | 18.4936 |
| | mm | 952.50 | 469.74 |

$$Y = \frac{X^2}{4f} \qquad f = 19.01 \text{ in. } (482.854 \text{ mm})$$

Table 3.4-1



FORM 2310-1 8/67

| PREPARED BY: A.W.B. | Budd Company<br>TECHNICAL CENTER | PAGE NO OF |
|---|---|---|
| CHECKED BY: | | REPORT NO. |
| DATE: 7-2-80 | MEASUREMENT RECORD - PANEL No. 1 | 94CX-0?1-[illegible]7<br>PROJECT NO |
| | (DEVIATION FROM THEORETICAL CURVE) | |

## ADHESIVE BONDED

| GRID | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | in | -.119 | -.105 | -.097 | -.085 | -.073 | -.065 | -.062 | -.058 | -.053 | -.052 |
| | mm | -3.02 | -2.67 | -2.46 | -2.16 | -1.85 | -1.65 | -1.57 | -1.47 | -1.35 | -1.32 |
| B | in | -.093 | -.070 | -.057 | -.056 | -.035 | -.030 | -.033 | -.023 | -.020 | -.037 |
| | mm | -2.36 | -1.78 | -1.45 | -1.42 | -.89 | -.76 | -.84 | -.58 | -.51 | -.94 |
| C | in | -.049 | -.040 | -.035 | -.030 | -.025 | -.019 | -.018 | -.013 | -.012 | -.017 |
| | mm | -1.24 | -1.02 | -.89 | -.76 | -.64 | -.48 | -.46 | -.33 | -.30 | -.43 |
| D | in | -.041 | -.033 | -.036 | -.032 | -.029 | -.025 | -.026 | -.020 | -.018 | -.017 |
| | mm | -1.04 | -.84 | -.91 | -.81 | -.74 | -.64 | -.66 | -.51 | -.46 | -.43 |
| E | in | -.021 | -.016 | -.016 | -.015 | -.010 | -.008 | -.008 | -.005 | .000 | -.004 |
| | mm | -.53 | -.41 | -.41 | -.38 | -.25 | -.20 | -.20 | -.13 | .00 | -.10 |
| F | in | -.005 | -.001 | +.001 | +.001 | +.003 | +.004 | +.005 | +.007 | +.009 | +.007 |
| | mm | -.13 | -.03 | +.03 | +.03 | +.08 | +.10 | +.13 | +.18 | +.23 | +.18 |
| G | in | +.008 | +.002 | .000 | .000 | +.004 | +.004 | +.002 | +.005 | +.004 | .000 |
| | mm | +.20 | +.05 | .00 | .00 | +.10 | +.10 | +.05 | +.13 | +.10 | .00 |
| H | in | -.005 | .000 | .000 | +.001 | +.002 | +.004 | +.005 | +.006 | +.009 | +.006 |
| | mm | -.13 | .00 | .00 | +.03 | +.05 | +.10 | +.13 | +.15 | +.23 | +.15 |
| J | in | -.009 | +.002 | .000 | -.002 | +.002 | +.004 | +.002 | +.005 | +.007 | +.001 |
| | mm | -.23 | +.05 | .00 | -.05 | +.05 | +.10 | +.05 | +.13 | +.18 | +.03 |
| K | in | -.014 | -.008 | -.012 | -.009 | -.011 | -.010 | -.008 | -.012 | -.008 | -.013 |
| | mm | -.36 | -.20 | -.30 | -.23 | -.28 | -.25 | -.20 | -.30 | -.20 | -.33 |
| L | in | -.032 | -.028 | -.030 | -.032 | -.028 | -.029 | -.030 | -.030 | -.031 | -.038 |
| | mm | -.81 | -.71 | -.76 | -.81 | -.71 | -.74 | -.76 | -.76 | -.79 | -.97 |
| M | in | -.054 | -.041 | -.037 | -.041 | -.029 | -.028 | -.047 | -.044 | -.056 | -.075 |
| | mm | -1.37 | -1.04 | -.94 | -1.04 | -.74 | -.71 | -1.19 | -1.12 | -1.42 | -1.91 |
| N | in | -.064 | -.068 | -.066 | -.062 | -.065 | -.065 | -.069 | -.082 | -.089 | -.098 |
| | mm | -1.63 | -1.73 | -1.68 | -1.57 | -1.65 | -1.65 | -1.75 | -2.08 | -2.26 | -2.49 |

Table 3.4-2

NOTE: PLUS (+) DIMENSION INDICATES INCREASE IN Y-DIM. - TOWARD FOCAL POINT PLANE. MINUS (-) DIMENSION INDICATES DECREASE IN Y-DIM. - AWAY FROM FOCAL POINT PLANE.

| PREPARED BY: A.W.B. | Bell<br>TECHNICAL CENTER | PAGE NO OF |
|---|---|---|
| CHECKED BY: | | REPORT NO |
| DATE: 7-2-80 | MEASUREMENT RECORD - PANEL No. 2<br>(DEVIATION FROM THEORETICAL CURVE) | 94CX-0[illegible]1-[illegible]67<br>PROJECT NO |

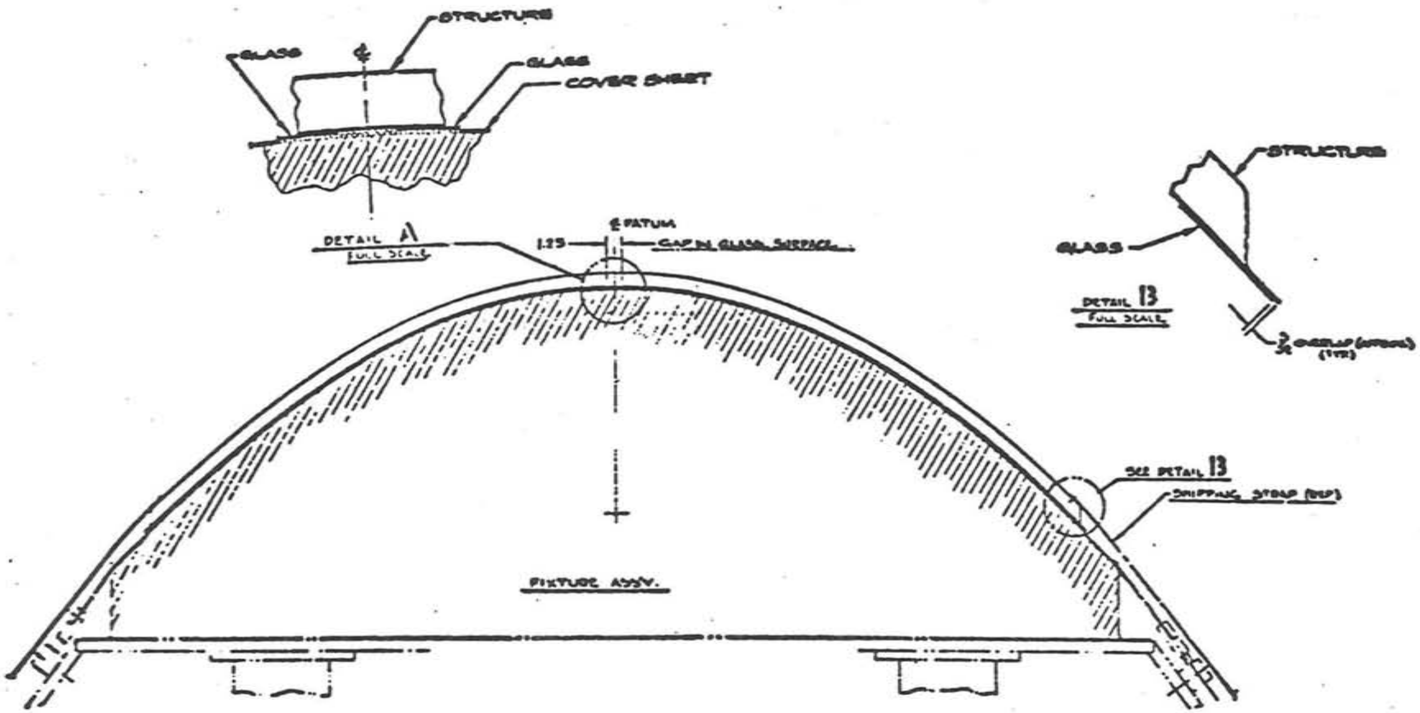
## SPOTWELDED

| GRID | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | in | +.006 | +.010 | +.016 | +.013 | +.016 | +.018 | .000 | -.004 | -.009 | -.012 |
| | mm | +.15 | +.25 | +.41 | +.33 | +.41 | +.46 | .00 | -.10 | -.23 | -.30 |
| B | in | +.003 | +.010 | +.014 | +.008 | +.010 | +.013 | +.008 | +.023 | +.026 | -.002 |
| | mm | +.08 | +.25 | +.36 | +.20 | +.25 | +.33 | +.20 | +.58 | +.66 | -.05 |
| C | in | -.011 | -.006 | -.004 | -.007 | -.004 | -.003 | -.009 | -.004 | -.002 | -.010 |
| | mm | -.28 | -.15 | -.10 | -.18 | -.10 | -.08 | -.23 | -.10 | -.05 | -.25 |
| D | in | -.009 | -.004 | -.007 | -.006 | -.004 | -.002 | -.001 | -.002 | .000 | -.001 |
| | mm | -.23 | -.10 | -.18 | -.15 | -.10 | -.05 | -.03 | -.05 | .00 | -.03 |
| E | in | -.014 | -.012 | -.012 | -.010 | -.006 | -.007 | -.006 | -.005 | -.002 | -.007 |
| | mm | -.36 | -.30 | -.30 | -.25 | -.15 | -.18 | -.15 | -.13 | -.05 | -.18 |
| F | in | .000 | .000 | +.002 | -.002 | +.001 | +.001 | .000 | +.003 | .000 | +.001 |
| | mm | .00 | .00 | +.05 | -.05 | +.03 | +.03 | .00 | +.08 | .00 | +.03 |
| G | in | .000 | -.006 | -.006 | .000 | -.002 | -.002 | -.002 | -.002 | -.005 | .000 |
| | mm | .00 | -.15 | -.15 | .00 | -.05 | -.05 | -.05 | -.05 | -.13 | .00 |
| H | in | .000 | .000 | .000 | -.005 | -.002 | .000 | -.008 | .000 | .000 | -.005 |
| | mm | .00 | .00 | .00 | -.13 | -.05 | .00 | -.20 | .00 | .00 | -.13 |
| J | in | .000 | .000 | -.002 | -.010 | -.010 | -.013 | -.020 | -.024 | -.027 | -.029 |
| | mm | .00 | .00 | -.05 | -.25 | -.25 | -.33 | -.51 | -.61 | -.69 | -.74 |
| K | in | -.008 | -.012 | -.017 | -.019 | -.025 | -.030 | -.035 | -.043 | -.042 | -.050 |
| | mm | -.20 | -.30 | -.43 | -.48 | -.64 | -.76 | -.89 | -1.09 | -1.07 | -1.27 |
| L | in | -.002 | -.002 | -.007 | -.019 | -.021 | -.027 | -.042 | -.046 | -.051 | -.060 |
| | mm | -.05 | -.05 | -.18 | -.48 | -.53 | -.69 | -1.07 | -1.17 | -1.30 | -1.52 |
| M | in | +.028 | +.031 | +.020 | .000 | -.007 | -.019 | -.022 | -.039 | -.036 | -.048 |
| | mm | +.71 | +.79 | +.51 | .00 | -.18 | -.48 | -.56 | -.99 | -.91 | -1.22 |
| N | in | +.049 | +.028 | +.014 | +.014 | +.017 | +.012 | -.005 | -.014 | -.032 | -.040 |
| | mm | +1.24 | +.71 | +.36 | +.36 | +.43 | +.30 | -.13 | -.36 | -.81 | -1.02 |

Table 3.4-3

NOTE: PLUS (+) DIMENSION INDICATES INCREASE IN Y-DIM. - TOWARD FOCAL POINT PLANE. MINUS (-) DIMENSION INDICATES DECREASE IN Y-DIM. - AWAY FROM FOCAL POINT PLANE.

FORM 3310-1 9/67




GLASS BONDING SET-UP

Figure 3.4-6

Sixteen reflector modules were produced to varying configurations as listed in Table 3.4-4. Both spotwelded and bonded steel structures were utilized. The spotwelded structures exhibited excellent accuracy characteristics during laser ray tracing of the structures. However, the spotwelded units did present some local deformation due to the welding pressures and the tolerance differentials in the panels. Also, the lack of corrosion protection between the spotwelded mating steel surfaces provided a source for corrosion when considering life expectancy. In the bonded structures, the adhesive thickness accounted for tolerance differentials between the panels and the adhesive on the mating surfaces provided an excellent seal against corrosion on these surfaces.

To provide the reflective surfaces, both sagged glass pre-formed to the parabolic curve and chemically strengthened flat glass were utilized. The sagged glass provided extremely accurate readings when laser ray traced. Since the glass panels were pre-formed, the sagged glass had no tendency to chord at the ends when pulled down on the fixture by the vacuum. Reports from Sandia indicated however, that the sagged glass had a tendency to crack after a period of time. The chemically strengthened flat glass produced a slight chording at the vertex and rim when held to the fixture by vaccum.

TABLE 3.4-4

Prototype Reflector Module Configurations

| Sandia Identification | Quantity | Configuration |
|---|---|---|
| S29861-000 | 2 | Spotwelded steel assembly - no mirror |
| S29861-100 | 2 | Steel Assembly bonded with 3M-3549 B/A urethane adhesive - no mirror |
| S29861-200 | 2 | Chemcor glass laminated to steel sheet in flat using Essex urethane adhesive. Laminate bonded to steel frame panel using Goodyear Pliogrip urethane adhesive. |
| S29861-300 | 1 | Chemcor glass bonded to spotwelded steel assembly using Epon 828 epoxy adhesive. |
| S29861-400 | 4 | Chemcor glass bonded directly to steel frame panel using Goodyear Pliogrip urethane adhesive - no steel mirror sheet |
| S29861-401 | 1 | Chemcor glass bonded directly to steel frame panel using Goodyear Pliogrip urethane adhesive-no steel mirror sheet & no cutouts in frame panel. |
| S29861-500 | 1 | Sagged glass bonded to spotwelded steel assembly using Epon 828 epoxy adhesive. |
| S29861-600 | 1 | Steel assembly bonded with Goodyear Pliogrip urethane adhesive. Sagged glass bonded to steel assembly using Epon 828 epoxy adhesive |
| S29861-701 | 2 | Steel assembly bonded with Goodyear Pliogrip urethane adhesive. Chemcor glass bonded to steel assy. using Goodyear Pliogrip urethane adhesive. |

The chording at the vertex could be eliminated if glass large enough to cover the entire surface in one piece were available. Even with the chording, the laser ray tracing indicated a high degree of accuracy on the modules utilizing chemically strengthened glass. The strengthened glass is more resistant to cracking and damage than the sagged glass.

In the configurations in which the glass was bonded to either a spotwelded or bonded structure, epoxy adhesive was applied to the smooth steel mirror panel on the structure and spread with a serrated doctor blade. The structure was then placed over the glass on the fixture and strapped down for curing of the adhesive. Two modules, identified as S29861-701, were produced using this procedure except that Goodyear Pliogrip urethane adhesive was used to replace the epoxy adhesive. In order to use the urethane adhesive for this purpose, it was necessary to use a thinner catalyst to permit spreading of the adhesive. The change in catalyst had no effect on the properties of the adhesive but merely provided suitable working characteristics.

Two modules, identified as S29861-200, were produced by bonding chemically strengthened glass panels to a steel sheet in the flat and then forming the glass/steel laminate over the assembly fixture for bonding to the steel frame panel. To produce the laminated panels, it was necessary to fabricate a fixture to permit application of pressure by vacuum bagging. The fixture consisted of a thick aluminum bottom plate with a ground surface and incorporating vacuum grooves and a lighter aluminum top plate, also with a ground surface. The glass panels were placed on the bottom plate, the compliant Essex urethane adhesive was spread on the back of the glass panels using a plastic doctor blade, the steel panel was placed on top and covered with the top aluminum plate. Sheet plastic was sealed around the edges and vacuum applied to provide the bonding pressure. It was not possible to obtain a thin steel sheet material for the lamination. As a result, the 0.030 inch thick steel mated to the 0.050 thick glass provided a relatively stiff laminated sheet. The vacuum hold down of the assembly fixture was not sufficient to prevent chording of the laminate when bonding to the frame panel. With thinner materials, it appeared that this would be a viable process and configuration.

To produce the modules identified as S29861-400 and -401, it was necessary to first bond a narrow bridging strip across the open channel at the vertex of the frame panel. By replacing the full size steel mirror panel with the narrow bridging strip, it was possible to bond the steel frame panel directly to the chemically strengthened glass panels, thereby reducing weight and cost. The S29861-400 configuration incorporated frame panels with rectangular cutouts. In the S29861-401 configuration, the cutouts were eliminated in the frame panel.

All of the various types of reflector modules discussed above were delivered to Sandia for testing and evaluation. It was reported that all configurations exhibited satisfactory results.

3.5 Design and Development of Torque Tube Assemblies.

The contract was further amended to require The Budd Co. Technical Center to design and develop and to build a prototype torque tube assembly. The reflector panels are mounted on the torque tube assemblies which are in turn mounted on pylons in an operating collector system. The use of a tube design was required so it was necessary to develop a support for the troughs which could be attached to a tube. Various concepts were developed and submitted to Sandia for review. Due to the requirement to mount to a tube, most of the concepts were a two part design - a saddle which would be attached to the tube and a support to be attached to the saddle. However, one concept which was originally intended as a mass produced design proved most interesting. Although the trough support was difficult to produce in prototype tooling, it was decided to proceed with this design since it would be most representative of a final configuration. The design selected was a one piece stamping which would induce minimum distortion in attachment to the tube since the welds are on opposite sides of the tube. The concept is shown in Figure 3.5-1. Each support, except the end supports, holds one side of two reflector panels. A complete torque tube assembly is shown in Figure 3.5-2.

To maintain accuracy in a collector string, precise alignment of each torque tube and its panels is a necessity. The alignment accuracy was provided in the design and construction of the torque tube assembly fixture. Locating blocks for the attaching pads on the trough supports were provided. The blocks were optically set during construction. Two datum holes were provided in each end flange for alignment and these holes were drilled and reamed in the assembly fixture. The drill bushings for the datum holes were also aligned optically. To maintain the correct relationship of the receiver tube to the collector panels, the mounting holes for the receiver were also drilled in the assembly fixture. The completed torque tube assembly fixture, with trough supports loaded on their mounting blocks, is shown in Figure 3.5-3. One complete twenty-foot long torque tube assembly and one short torque tube assembly to hold two reflector panels were completed and furnished to Sandia for testing. Corrosion protection for the torque tube assembly and for the rear surfaces of the reflector panels was increased by painting all surfaces with an epoxy primer and a white urethane finish paint. A completed torque tube assembly is shown in Figure 3.5-4.

TROUGH SUPPORT

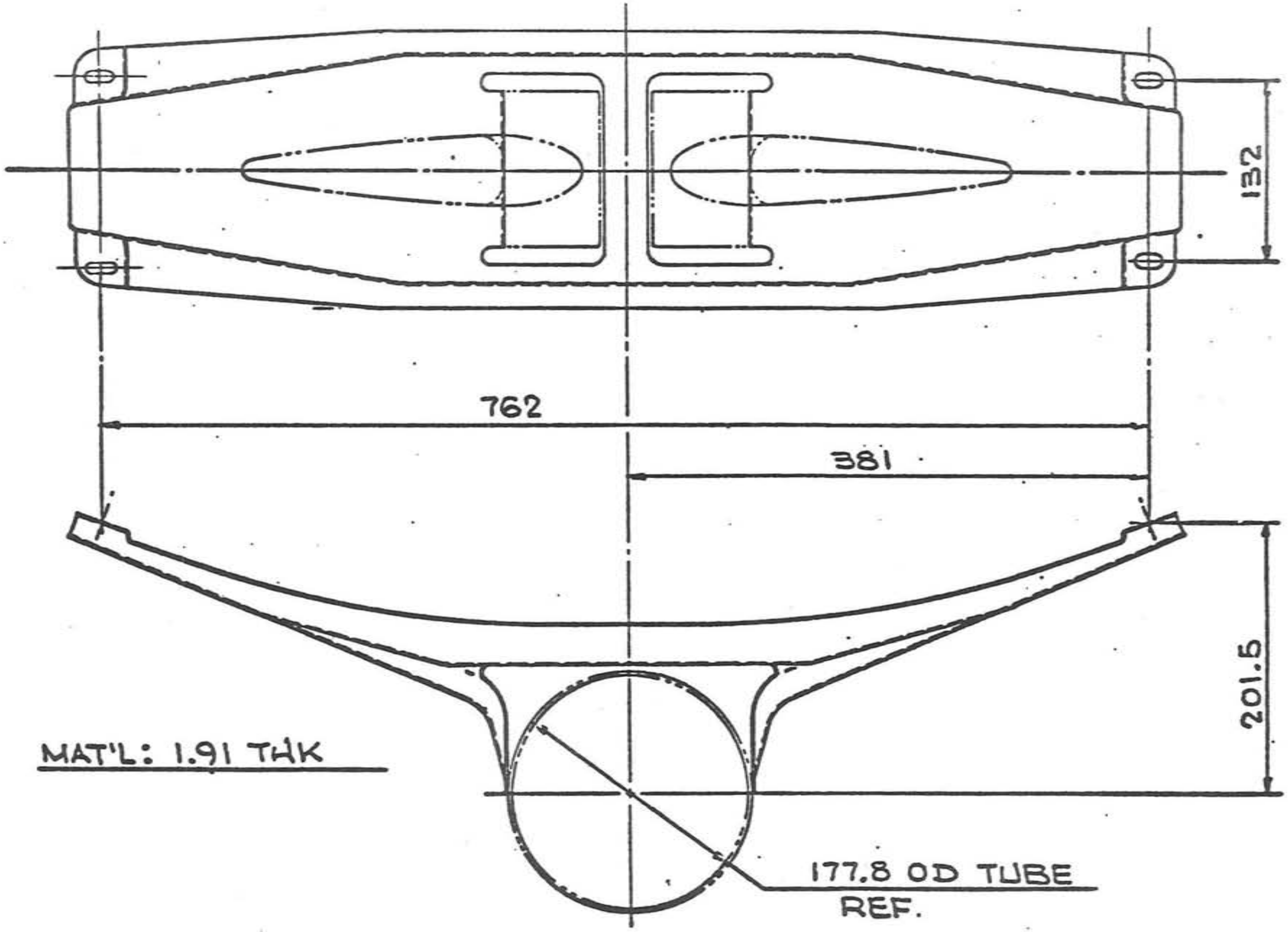



Figure 3.5-1

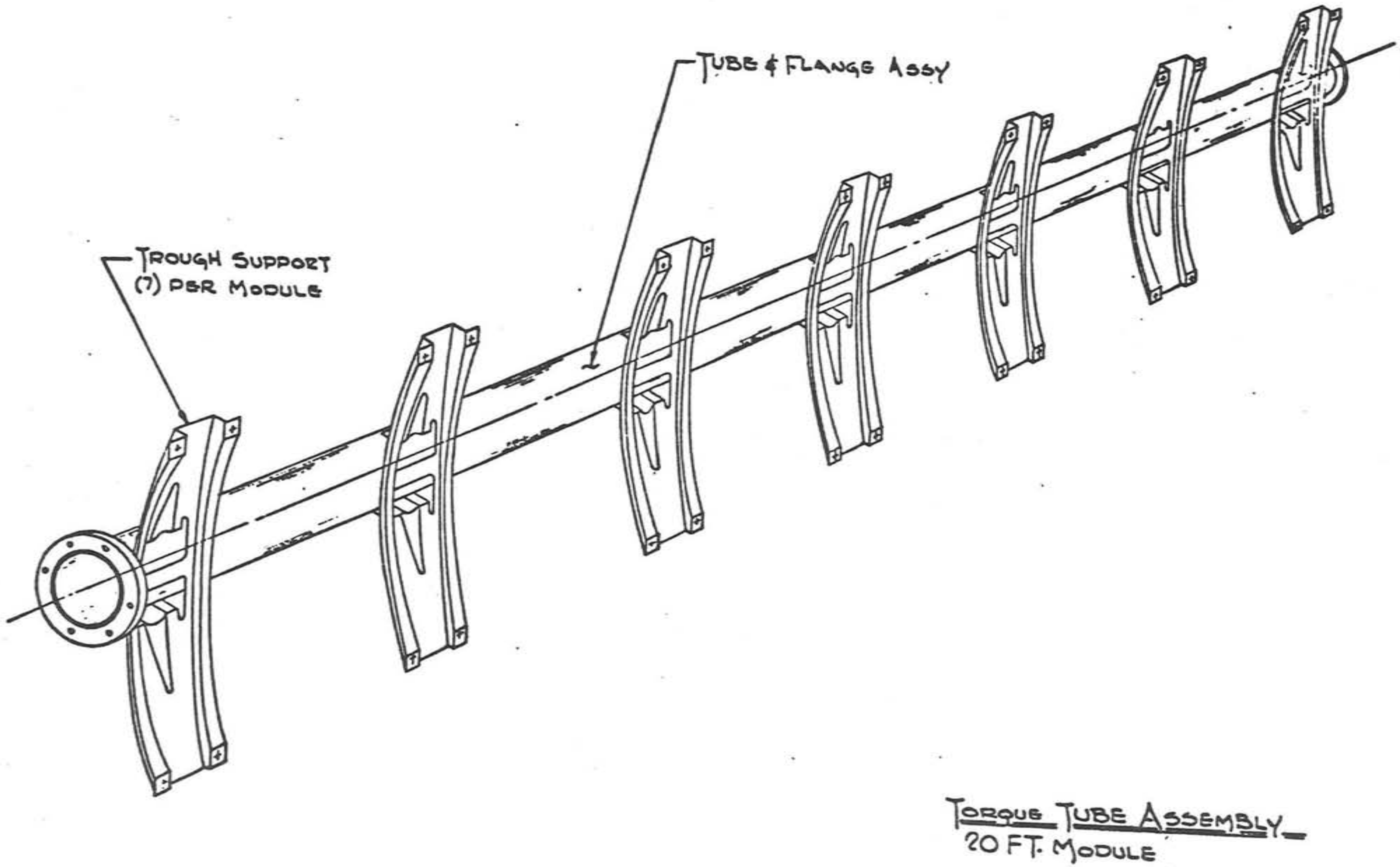
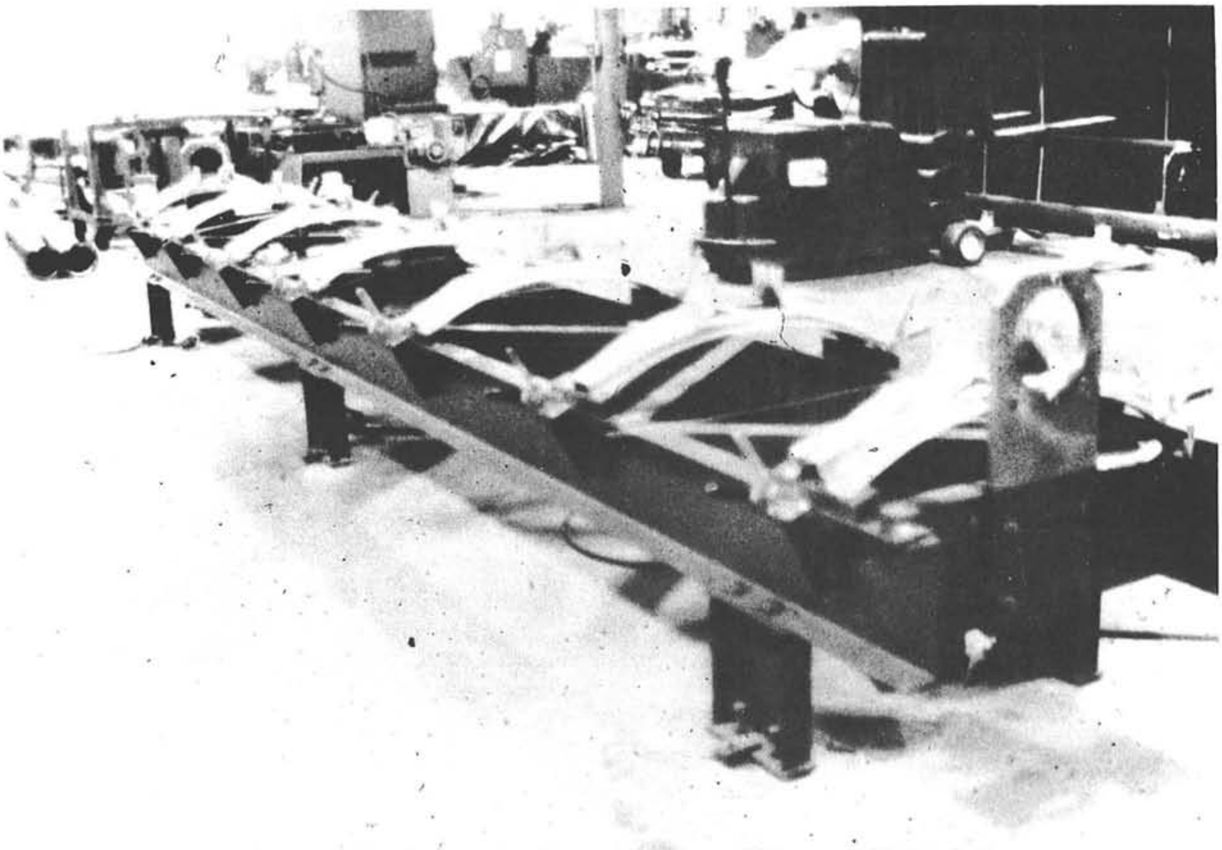
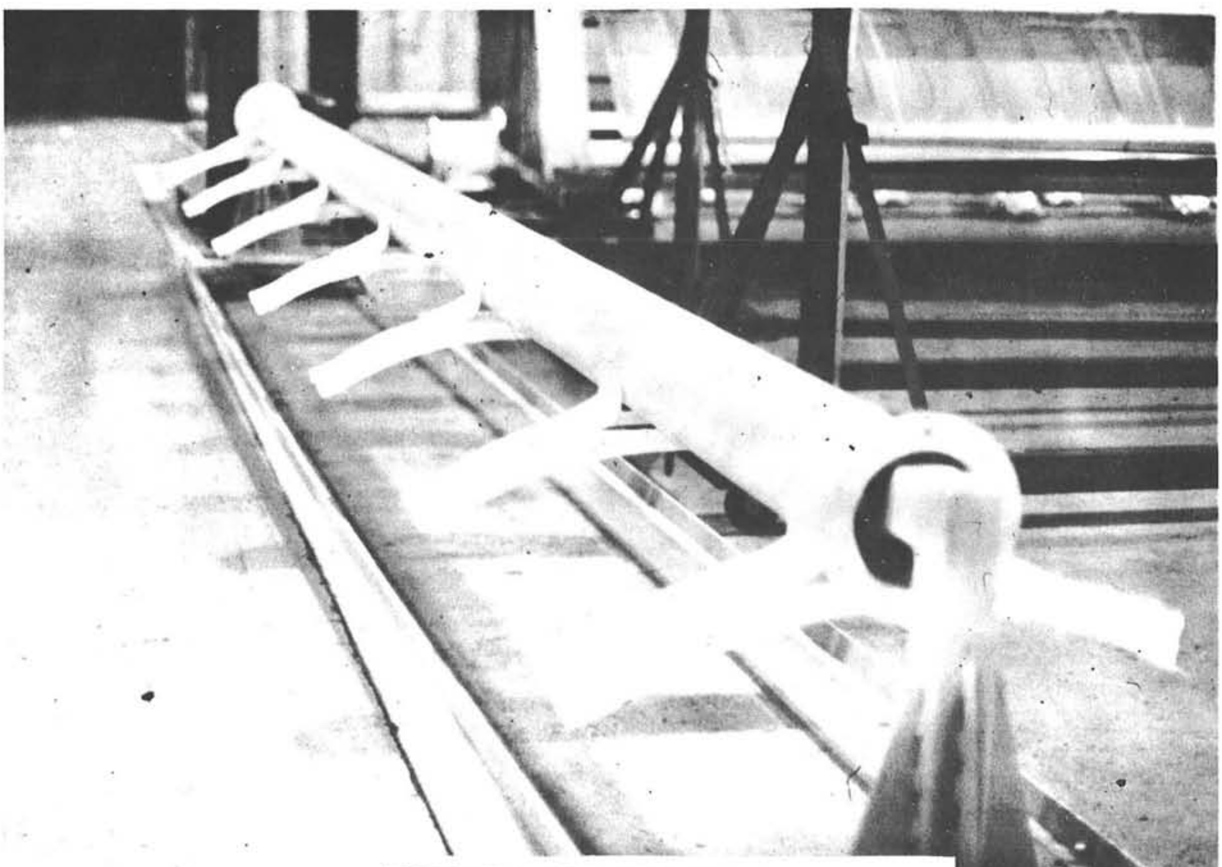

TUBE & FLANGE ASSY
TROUGH SUPPORT
(7) PER MODULE
TORQUE TUBE ASSEMBLY
20 FT. MODULE

Figure 3.5-2



TORQUE TUBE ASSEMBLY FIXTURE

Figure 3.5-3



TORQUE TUBE ASSEMBLY

Figure 3.5-4

## 4.0 CONCLUSIONS

The objective of this project was the development of an accurate, durable, mass-producible solar collector panel. All of the manufacturing processes and tooling used in the fabrication of the prototype units are adaptable to high production. The forming operations are similar to those used for automobile panels which are produced at extremely high rates. Assembly techniques included spotwelding and bonding with adhesives. Spotwelding could be automated for production using gang welders or robots. Fast acting adhesives are available and could be used with automated mixing and dispensing systems for the structural adhesives. Automated handling techniques can also be developed for application of the reflector surfaces.

A variety of sheet metal panels were produced, all of which were based on a single stamped sheet metal structural member which is very similar to structural stampings commonly used in the automobile industry. The construction of the reflector panels is defined in Section 3.4 of this report. The panels included two piece steel assemblies, both bonded and spotwelded, with sagged or chemically strengthened glass reflectors secondarily bonded to the steel panel assembly, and a single stamped steel panel with chemically strengthened glass mirrors bonded directly to the steel panel to serve as both reflector and structural member. The unusual strength characteristics of the chemically strengthened glass made possible this dual functional capability. Use of the strengthened glass permitted elimination of one full size steel sheet with attendant elimination of weight and a major bonding operation.

Another version of the reflector panel utilized a flat glass/steel laminate as the front structural member. The laminate was bonded to the stamped structural panel. The laminate holds some promise for future applications in making use of thin, unstrengthened glass as the reflector. Considerable additional development is necessary if this concept is to be pursued.

A late addition to the contract required development of tooling and processes and fabrication of a prototype six (6) meter torque tube assembly for use with any one of three types of 1m x 2m reflector panels. A stamped trough support was designed, tooling fabricated, and parts produced for welding to a steel tube with end flanges to complete the assembly. Accurate rotational alignment of the torque tube assembly in its next assembly required tight tolerance on the hole pattern in the two end flanges. The torque tube assembly developed could also be easily adapted for low cost production using automated methods, particularly in welding and drilling.

The prototype units have established that high volume technology can be used to produce accurate and structurally sound reflector panels. Their functional performance and durability as a solar collector remain to be established. Evaluation of the prototype panels by Sandia provided information for selection of one version for production of a quantity to be installed in an eighty (80) foot long drive string of trough collectors for actual performance testing. Sandia has selected one particular configuration (the S29861-400 configuration of Table 3.4-4) for fabrication of a suitable quantity for use in performance testing.

## 5.0 RECOMMENDATIONS

The prototype reflector panels fabricated under this contract have clearly established the feasiblity of producing quality panels with production type tooling and processes. The transition to mass production technology will require additional development. Specific recommendations include investigation of factors such as thinner sheet stock in the stamped panel and more effective use of material in the torque tube assembly. Methods are available to produce lighter, stiffer, and more efficient structures for mounting reflector panels. Attachment methods can be simplified to decrease labor requirements and maintain required accuracy. An alternative strongback is a specific area where gains can be accomplished. Similarly, materials (particularly adhesives) must be adapted to provide minimum cure times required for mass production.

The collector components developed on this contract represent a simple design concept which requires a high degree of accuracy and repeatability. Such simple design concepts lend themselves well to highly automated fabrication techniques where consistency is maintained by machines and human error variations are minimized or eliminated. Automatic technique development should be pursued for production of solar collectors.

# APPENDIX - A

## ADHESIVE BONDING STUDY

Extracted from Monthly Progress Report No. 2

November, 1979

1.0 Adhesive Bonding Study

A study was initiated to obtain data on various adhesives suitable for bonding the structure panels. Included in the study was a review of data available from the manufacturers, results of tests conducted by The Budd Company Plastic Research and Development Center, Troy, Michigan, and results of tests conducted at The Budd Company Technical Center. The types of adhesive covered were two-part urethane adhesives and two-part acrylic adhesives. Of interest in the study were lap shear strengths, the effect of environmental factors and application data applicable to this program.

2.0 Manufacturer's Data

Data on urethane structural adhesive was obtained from Goodyear and from 3M. Most of the data available pertains to plastic bonding but some data for steel bonding is included and other data is applicable to either type material.

The Goodyear heat resistant structural adhesive is Pliogrip 6040. The 6040 prepolymer is the base material and the gel time is controlled by the use of various curatives. The range of gel times is indicated in Table 2.0.

Table 2.0

| Adhesive/Curative | Gel Time at 75°F. (min.) |
|---|---|
| Pliogrip 6040/6041 | 4-6 |
| Pliogrip 6040/6042 | 2-4 |
| Pliogrip 6040/6043 | 1-2 |
| Pliogrip 6040/6044 | 10 |

The Goodyear information included results of the effect of elevated temperatures on steel to steel bonds. The material used for testing was steel which had been primed with Pliogrip 6025 with a bond line of 0.030" thick and a one square inch bonded surface. The specimens were exposed to temperatures of 375°F. and 400°F. for various periods and then tested at room temperature and at 200°F. The results of the tests are shown in Figures 2.0 and 2.1. The metal lap shears exposed to 375°F. for 90 minutes show little loss of strength. However, at 400°F. exposure for 30 minutes, the adhesive begins to weaken and then weakens quite rapidly after 30 minutes at 400°F.

The 3M impact resistant structural adhesive is EC-3549 B/A. The EC-3549B is the base material and EC-3549A is the accelerator. The worklife of this material at 72°F. (100 grams mixed) is 60 minutes.

The data from 3M included results of typical values of steel overlap shear bonds at three temperatures. Although 3M recommends priming of metal surfaces prior to adhesive bonding, the test specimens were not primed as were the Goodyear specimens. The 3M tests were conducted on 1 inch wide by ½ inch overlap specimens cut from 0.059 inch thick cold rolled steel which had been washed with chlorethane and abraded with Scotchbrite before bonding. The bond line thickness was 0.035 inches and the cure time was 48 hours at 75°F. The specimens were pulled at 1"/minute with an

FIGURE 2.0 — LAP SHEAR STRENGTH
VS. TIME AT 375°F. (STEEL TO STEEL)

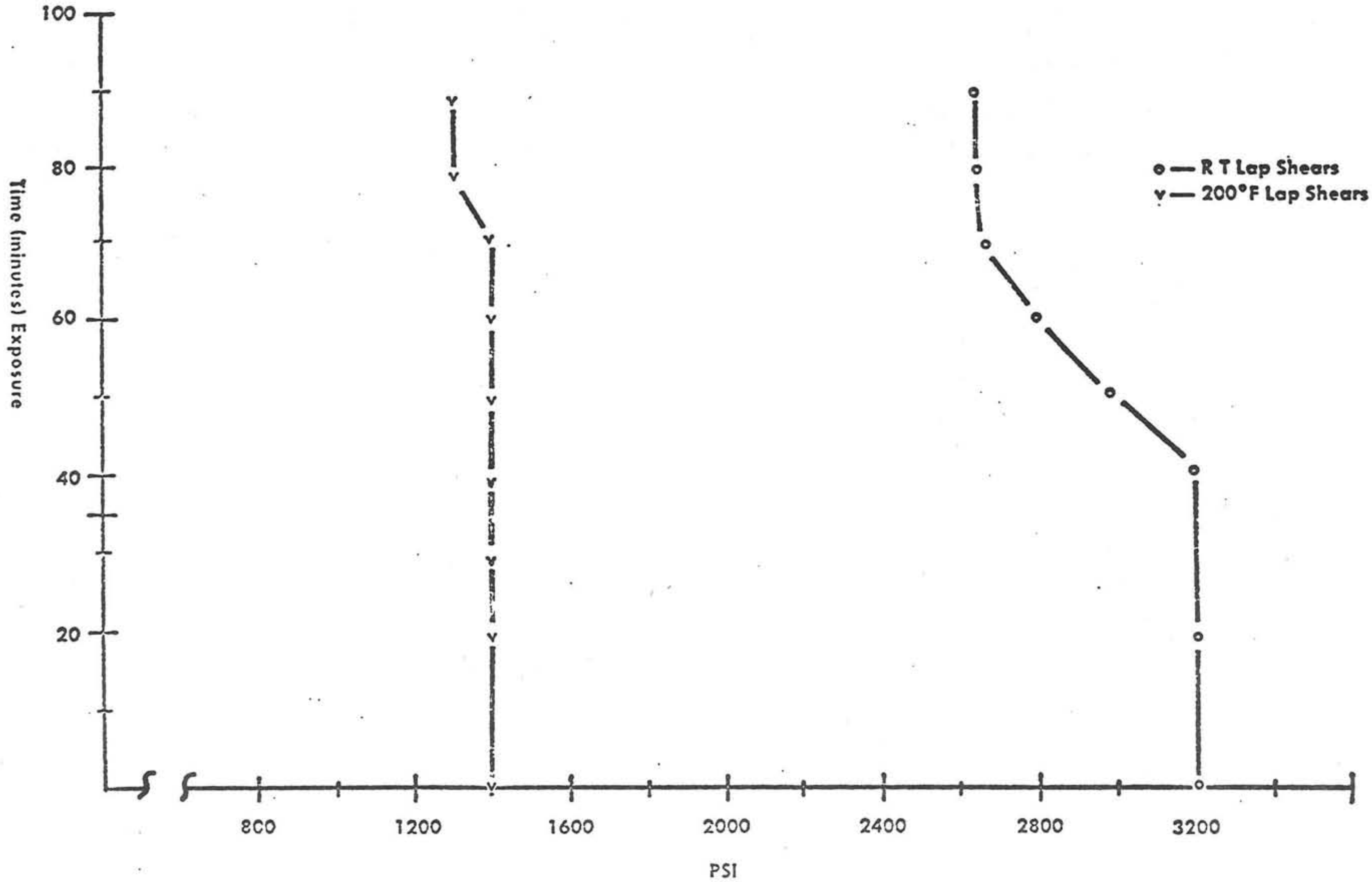
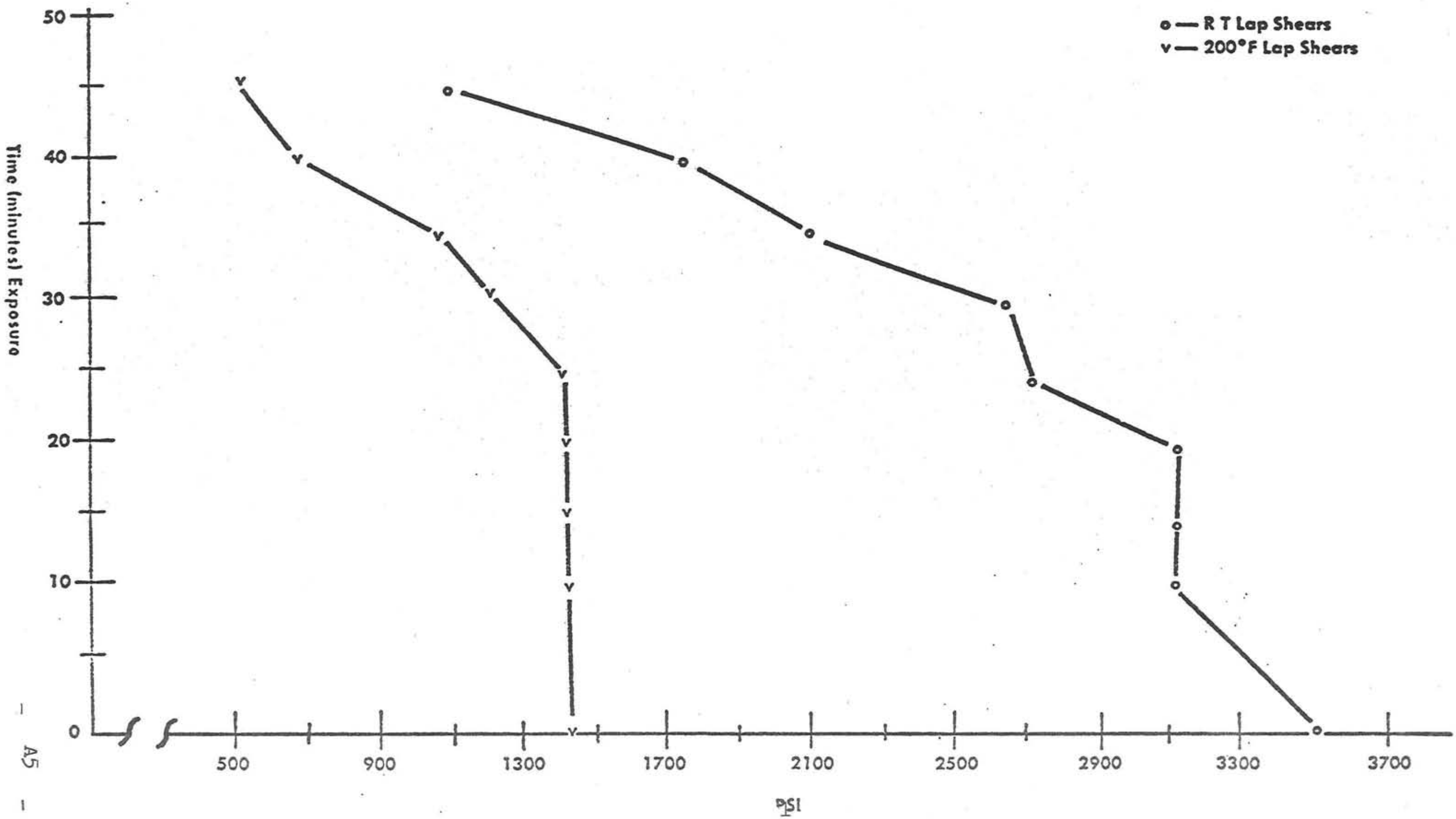


FIGURE 2.1 — LAP SHEAR STRENGTH VS. TIME AT 400°F. (STEEL TO STEEL)



Instron testing machine. The results of the 3M tests are shown in Table 2.1.

Table 2.1

| Test Temperature | Overlap Shear Strength |
|---|---|
| $-40^{o}F.$ | 2500 psi |
| RT | 1400 psi |
| $180^{o}F.$ | 180 psi |

The results shown indicate that, with the unprimed specimens, the shear strength of the adhesive drops severly at elevated temperatures. Other results of plastic to metal bonds indicated that primed specimens, while still weak at elevated temperatures, are higher than that shown above.

3.0 Budd Company Plastic R. & D. Center Data

The Budd Company Plastic Research and Development Center performed a study to evaluate commercially available adhesives for bonding graphite/glass composites. Although no metal to metal bonds were considered in this study, and all tests were conducted using composite material specimens, the effects of various parameters on the lap shear strength are indicative of their comparable performance in metal to metal bonds.

All tests were conducted by the single lap shear test method, ASTM Test No. D-1002. Coupons 4" x 1" were cut from composite materials and specimens were bonded together with an overlap of one inch. The specimens were pulled at a rate of 0.2 inches per minute.

Various adhesives were evaluated, including two-part urethane, two and one-part epoxies, epoxy tape and two-part acrylic. The urethane and acrylic adhesives are pertinent to the reflector module project and the results will be delineated herein. The pertinent adhesives included in the study are shown in Table 3.0.

Table 3.0

| Adhesive Type | Designation | Supplier |
|---|---|---|
| Two part urethane | EC-3549B/A | 3M |
| Two part urethane | Pliogrip 6000/6027 | Goodyear |
| Two part urethane | Pliogrip 6040/6045 | Goodyear |
| Two part acrylic | XA 3585/3678 | 3M |
| Two part acrylic | EA 9446 B/A | Hysol |
| Two part acrylic | Li 259/260 | Loctite |
| Two part acrylic | Lo 524 | Loctite |

The parameters studied for their effects on lap shear strength were bond thickness, surface treatment and temperature. The results obtained from the tests are shown in the following tables.

Table 3.1

Effect of Bond Thickness on Lap Shear Strength (psi)

| Adhesive | Bond Thickness | |
|---|---|---|
| | 0.010" | 0.039" |
| EC-3549B/A | 2610 | 1740 |
| PG 6000/6027 | 1595 | 1450 |
| PG 6040/6045 | 2030 | 1740 |
| Li 259/260 | 3045 | 2175 |
| Lo 524 | 1885 | 1885 |

Table 3.2

Effect of Surface Treatment on Lap Shear Strength (psi)

| Urethane Adhesive | Surface Treatment Scuff Sand | Solvent Wash | Primer Wipe (Pliogrip 6036) |
|---|---|---|---|
| EC-3549 B/A | 1740 | 1305 | - - |
| PG 6000/6027 | 1305 | 1160 | 1740 |
| PG 6040/6045 | 2030 | 1740 | 2030 |

Table 3.3

Effect of Surface Treatment on Lap Shear Strength (psi)

| Acrylic Adhesive | Surface Treatment (primer wipe on all) Scuff Sand | No Treatment |
|---|---|---|
| XA-3585/3678 | 1015 | 580 |
| EA-9446 | 1595 | 1595 |
| Li 259/260 | 2755 | 3190 |
| Lo 524 | 1885 | 1160 |

The urethane adhesive PG 6040/6045 and the acrylic adhesive Li 259/260 were further tested by immersion in distilled water at 180°F. The bond thickness on these specimens was 0.020 inches and cure time was 2 days at room temperature. Results of the water immersion test are shown in Table 3.4.

Table 3.4

Effect of Water Immersion on Lap Shear Strength (psi)

| Duration of Exposure, Days | Adhesive Li 259/260 | PG 6040/6043 |
|---|---|---|
| 0 | 1595 | 1160 |
| 2 | 1740 | 1740 |
| 4 | 1740 | 2030 |
| 6 | 1740 | 1740 |
| 14 | 1450 | 1740 |

In summary, these tests indicate that no significant decrease in lap shear strength is encountered in bond thicknesses up to 0.039 inches (1mm). Both the urethane and the acrylic adhesives should be used with a primer. The adhesives do lose some of their bond strength at elevated temperatures. Room temperature curing is suitable for these adhesives. The lap shear strength was minimally effected by soaking in distilled water at 180°F. for 14 days.

## 4.0 Budd Company Technical Center Data

Tests on various adhesives have been performed at The Budd Company Technical Center. Included herein are results of some of the tests conducted on urethane and acrylic adhesives.

The urethane adhesives tested were 3M adhesive EC-3549 B/A and Goodyear Pliogrip 6040/6045. Coupons were cut from 0.060 inch thick cold rolled steel and were primed with Pliogrip 6031/6032. The specimens were bonded with the urethane adhesives and pull tested. The results of the tests are shown in Table 4.0.

Table 4.0

Lap Shear Strength of Urethane Adhesives

| Adhesive | Lap Shear Strength (psi) | Type of Failure |
|---|---|---|
| EC-3549 B/A | 1800 | All failures Were cohesive failures |
| " | 2000 | |
| " | 1900 | |
| PG 6040/6045 | 2300 | Failures were 50% cohesive and 50% adhesive |
| " | 2400 | |
| " | 2600 | |

Tests were conducted on acrylic adhesives to determine the effects of two parameters on the strength of the bond — immersion in salt solution and bond thickness. Acrylic adhesives can be pre-mixed and applied like the urethane adhesives but for the purposes of these tests, the base resin was placed on one surface and the activator on the other surface. Specimen material was aluminum and no primer was used.

For the salt immersion tests, the specimens were cut from 0.032 inch thick aluminum and were slightly abraded with Scotchbrite. The adhesive used was Hughson Rd-3327-6, which has a worklife of 10 minutes maximum. A one inch lap was used and the assembly of the specimen was accomplished within five minutes after application of the base material. Control specimens, which were not exposed to the salt solution, were tested and the test specimens were immersed for 500 hours in a 3½% Na Cl solution.

Two types of tests were conducted on the specimens. For the first test, the specimens were pulled to determine the lap shear strength. On the pull test, the control specimen failed at 2800 psi and the specimen exposed to the salt solution failed at 1800 psi. The second test was a cyclic axial tension fatigue test in which the specimens were subjected to a cyclic tension of 50 pounds minimum to 500 pounds maximum for a specified number of cycles. In this test, the control specimen failed after 660,000 cycles with the failure being in the aluminum. The specimen exposed to the salt solution reached one million cycles without failure.

Test were also conducted to determine the effect of bond thickness on the strength of acrylic adhesives. These tests also varied the placement of the adhesive components to determine how this would effect the strength. For these tests, the adhesive used was the Ren Acrylic System Structural Adhesive DA-561-2. The specimens were cut from 0.041 inch thick 5052-H291 aluminum (Budd Trailer Stock) and the overlap was one inch. Spacers were used to control the glue line and sufficient pressure was used at assembly to insure proper spacer contact. The substrate material was solvent wiped or sanded and the catalyst was placed on one or both surfaces with the resin placed on one surface. After designated times, the specimens were tested for lap shear strength. The results of these tests are shown in Table 4.1.

The results of these tests indicate that bond lines greater than 0.020 inches require the catalyst to be placed on both surfaces to be bonded. Bond lines greater than 0.040 inches do not develop good strength even with the catalyst on both surfaces.

The Technical Center has conducted tests on weldbonding also. However, all of the tests were conducted using vinyl plastisol and epoxy adhesives requiring elevated temperature cures. This is not desirable for the reflector structures. In weldbonding, the pressure exerted by the electrodes displaces the adhesive at that point to permit a metal to metal contact. Therefore, the adhesive must have enough flow to

## Table 4.1

## Effect of Bond Thickness on Lap Shear Strength

| Specimen No. | Surface Prep. | Catalyst Placement | Glue Line Thickness | Elapsed Time | Strength psi |
|---|---|---|---|---|---|
| 1. | Methylene Chloride | 1 side | .020 | 5 min. | 35 |
| 2. | " | " | " | 10 min. | 50 |
| 3. | " | 2 sides | " | 10 min. | 300 |
| 4. | " | 1 side | " | 15 min. | 150 |
| 5. | " | 2 sides | .020 | 15 min. | 400 |
| 6. | " | 1 side | " | 30 min. | 165 |
| 7. | " | " | " | 1 hour | 600 |
| 8. | " | " | " | 2 hours | 900 |
| 9. | " | " | " | 24 hours | 950 |
| 10. | Sanded & Methylene Chloride Wipe | " | " | 24 hours | 1200 lbs aluminum broke, exceeded strength of al. |
| 11. | Methylene Chloride | 1 side | .040 | 2 hours | No strength |
| 12. | " | 2 sides | .040 | 2 hours | 170 |
| 13. | " | 1 side | .040 | 24 hours | 30 |
| 14. | " | 2 sides | .040 | 24 hours | 475 |
| 15. | " | 1 side | .100 | 4 hours | 0 |
| 16. | " | 2 sides | .100 | 4 hours | 150 |
| 17. | " | 1 side | .100 | 72 hours | 0 |
| 18. | " | 2 sides | .100 | 72 hours | 250 |

Adhesive - Ren Acrylic System DA-561-2

permit this action. Primed surfaces would also not be conducive to spotwelding since the primer would act as an insulator and prevent current flow. It would be necessary to mask the primer in the welding area.

The design of the assembly fixture being prepared for the reflector structure modules will enable a weldbonding operation to be performed since it is a bonding and welding fixture. Further investigation of this process would be required to determine if the weldbond assembly would be feasible for the modules. It would be necessary to determine if the adhesive and surface preparation were compatible with the welding operation. At a future date, it may be desirable to put a line of welds at each end of the bonded structures.

5.0 Conclusion - Adhesive Bonding

The acrylic adhesives, from the data obtained in the study, exhibit excellent characteristics. However, in general their working time is relatively short and they are sensitive to the thickness of the bond line. Therefore, they are not considered suitable for use on the initial reflector structure modules. At a later time if production quantities are produced, and more consistently uniform parts are produced from hard tooling together with more sophisticated assembly methods and tooling, the acrylic adhesives should be reconsidered for use.

Of the urethane adhesives, the data indicates that the Goodyear heat resistant structural adhesive Pliogrip 6040/6045 is the best. However, the relatively short working time with this material makes its use impractical on the prototype structures. Adhesive dispensing equipment which mixes the two components at the dispensing head, could aid in using this material but the equipment is not available to us at the present time. At such time as this type of dispensing equipment becomes available, the Goodyear adhesive would be utilized.

Although the 3M impact resistant structural adhesive EC-3549 B/A does not fully match the Goodyear Pliogrip 6040/6045 in bond strength, it is more than adequate for use on the prototype reflector structures. Its working life of one hour makes its use more advantageous at this point. Therefore, it is planned to use the EC-3549 B/A and primer for bonding the panels on this project.

## Appendix B

## Adhesive Bonding Test Report

(Extracted from Monthly Progress Report #14)

November 1980

# ADHESIVE BONDING OF ALUMINIZED STEEL WITH EPOXY POLYAMID ADHESIVE

MATERIAL: .030" Aluminized Steel, Type I coating, 1" x 6"

ADHESIVE: Epon 828 Epoxy Resin

Versamid 140 Polyamid

Cabosil — Flocculated silica thixotropic agent

PROCEDURE:

1.0 SURFACE PREPARATION

The surfaces of the aluminized steel were prepared in various ways to determine the effect of surface preparation on the adhesive strength when tested at 72°F, 120°F and 150°F. Surfaces were prepared in the following manner:

a. The surfaces were abraded with Scotch-brite followed by methylene chloride wipe. A pad was made of the Scotch-brite and the surfaces were abraded using an air tool.

b. The surfaces were wiped using methylene chloride, then abraded with Scotch-brite using an air tool and then solvent wiped again with methylene chloride.

c. The surfaces were solvent wiped only using methylene chloride.

d. The surfaces were wiped using methylene chloride, then hand abraded with Scotch-brite and then solvent wiped again with methylene chloride.

2.0 ADHESIVE

Epon 828 was degassed at 28 inches of Hg for ten minutes. Versamid 140 was also degassed in the same manner. Sixty (60) grams of Epon 828 was mixed with forty (40) grams of Versamid

140 and the mixture was then degassed at 28 inches of Hg for ten minutes. Two (2) grams of flocculated silica was then added slowly and carefully to the mixed adhesive.

## 3.0 SPECIMEN ASSEMBLY

Thirty-six (36) specimens were prepared — three specimens for testing at each of the three temperatures with the four different surface preparations. Adhesive was placed on the prepared surfaces and the coupons were assembled to provide 1/2 inch lap shear specimens. The specimens were also allowed to cure for 72 hours before testing.

## 4.0 TESTING

Testing was performed on an Instron Tensile Testing Machine. A thermocouple was attached to the specimen at the bond line. Heat was provided by infra-red lamps. When the temperatures of the specimen at the bond line reached the desired test temperature (72°F - 120°F - 150°F), the specimen was pull tested.

## 5.0 RESULTS

The results of the tests are shown in Table 1. The results shown are the average values obtained on three specimens.

## 6.0 CONCLUSIONS

Based on the test data, when bonding aluminized steel using Epon 828 epoxy resin and Versamid 140 polyamide, the highest strengths are achieved when the surface is solvent wiped only. This is especially true when tested at ambient temperature. At elevated temperatures, the strength differential is less pronounced.

Epoxy polyamide systems lose strength rapidly at temperatures in excess of 120°F.

When using aluminized steel as the metal substrate in the solar panel modules and an epoxy polyamide adhesive system, the surface of the aluminized steel should be prepared by wiping with methylene chloride with no abrading.

TABLE 1

LAP SHEAR TEST RESULTS

ALUMINIZED STEEL BONDED WITH EPON 828 & VERSAMID 140

| Surface Preparation | Ave. Shear Strength (psi) at Temperature | | |
|---|---|---|---|
| | 72°F | 120°F | 150°F |
| MeCl Wipe Only | 1785 | 862 | 412 |
| MeCl Wipe<br>Scotch-brite (air tool)<br>Me Cl Wipe | 755 | 813 | 364 |
| Scotch-brite (air tool)<br>MeCl Wipe | 725 | 757 | 271 |
| MeCl Wipe<br>Scotch-brite (hand)<br>MeCl Wipe | 1477 | 797 | 267 |

APPENDIX C

Adhesive Bonding of Electrogalvanized
Steel to Aluminized Steel

Extracted From Monthly Progress Report No. 15

December, 1980

## Adhesive Bonding of Electrogalvanized Steel to Aluminized Steel

1.0 Materials

1.1 Steel Specimens

.030" electrogalvanized steel, 1" x 5"

.038" aluminized steel, Type 1, 1" x 5"

1.2 Adhesive

Base - Goodyear Pliogrip 6000

Curative - Goodyear Pliogrip 6027G

1.3 Primer

Goodyear 6031/6032

2.0 Surface Preparation

2.1 Electrogalvanized Steel

The surfaces were solvent wiped with methylene chloride, lightly abraded with 3M Scotch-brite and solvent wiped again with methylene chloride three times using clean cloths each time.

2.2 Aluminized Steel

The surfaces were solvent wiped several times with methylene chloride until clean. Clean cloths were used for each wiping.

2.3 Primer

The mating surfaces of each piece were primed with Goodyear 6031/6032 primer. The primer was allowed to stand for one hour after mixing (1 to 1 by volume mix) before application. The primed parts were force dried in an oven at 150°F for ten minutes. (optional drying is 8 hours at 72°F)

## 3.0 Procedure

One inch overlap shear specimens were prepared using one piece of each material for each specimen. The adhesive was dispensed from the IRC Adhesive Mixer-Dispenser used in building the prototype panels. The specimens were allowed to cure for 72 hours and were then pulled on an Instron Tensile Testing Machine.

## 4.0 Results

The results of the lap shear strength tests are shown in Table 1. The average of the test results obtained was 1287 psi shear strength.

The typical failure mode of the specimens is depicted in Figure 1.0. It is interesting to note that the electrogalvanized material started to yield and neck down just above the bonded joint. This occurrence probably contributed to the primer failure at the electrogalvanized surface by producing a peeling effect.

## 5.0 Conclusions

From these tests it may be concluded that no problems will be encountered in bonding aluminized steel to electrogalvanized steel using the Goodyear Pliogrip adhesive.

TABLE 1.0

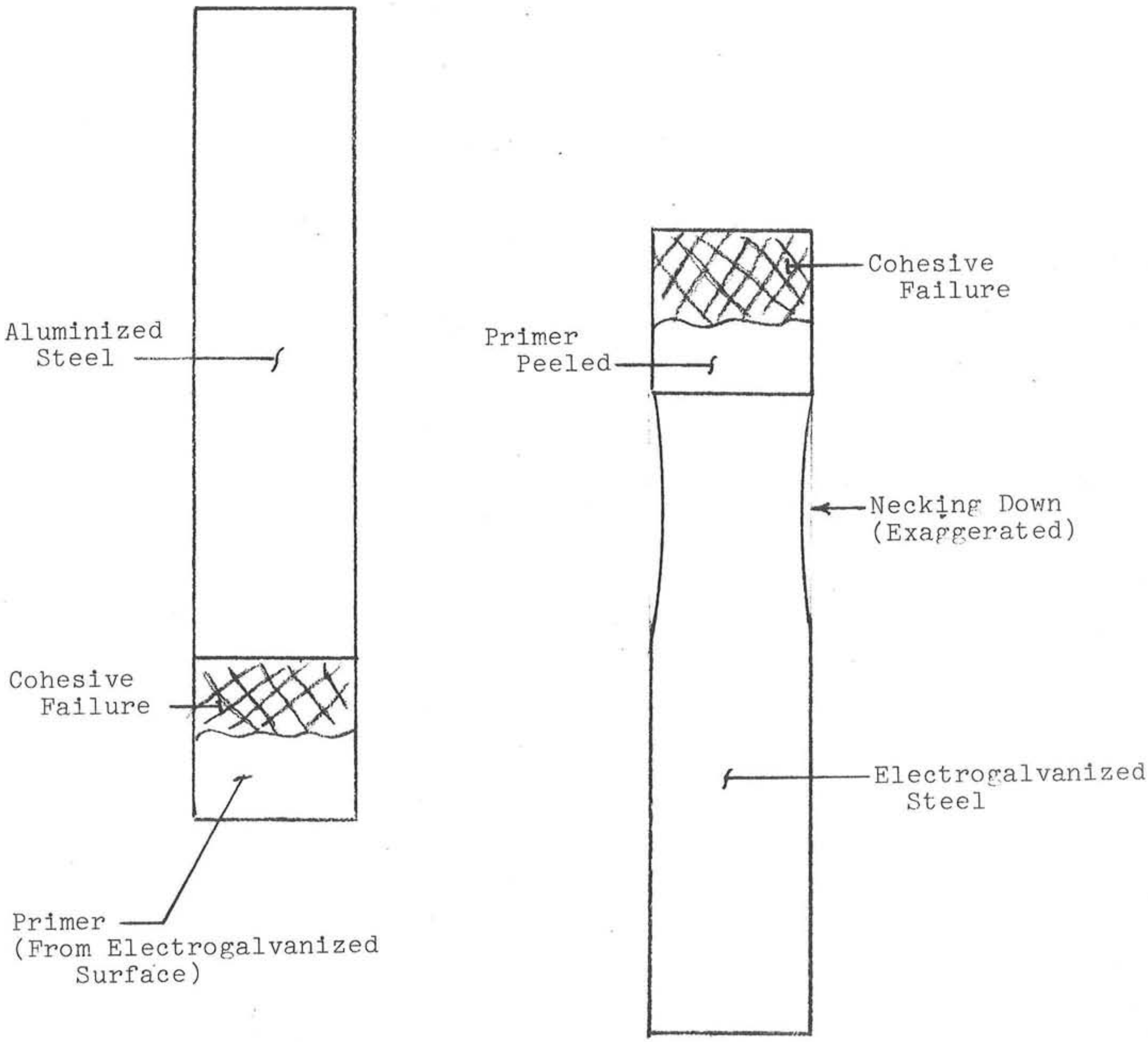
Lap Shear Strength Test Results

| Specimen | Lap Shear Strength (psi) |
|---|---|
| 1 | 1300 |
| 2 | 1340 |
| 3 | 1200 |
| 4 | 1320 |
| 5 | 1240 |
| 6 | 1320 |
| AVE. | 1287 |

See Figure 1.0 for typical failure mode

FIGURE 1.0

TEST FAILURE MODE



# APPENDIX D

## Adhesive Bonding of Mirrored Glass to Aluminized Steel

Extracted From Monthly Progress Report No. 15

December, 1980

# Adhesive Bonding of Mirrored Glass to Aluminized Steel

## 1.0 Purpose

Test specimens are to be prepared to evaluate adhesives to be used for bonding mirrored glass to steel sheets in the flat, prior to bending to a parabolic contour. In order to prepare suitable specimens, it was necessary to select an adhesive for bonding the bare surface of the glass to a metal substrate. This adhesive must produce a bond stronger than that used for bonding the coated side of the mirror to the substrate so that the test adhesives may be evaluated.

## 2.0 Procedure

These tests were conducted in two stages. An adhesive was selected and in order to determine the strength of this adhesive, metal to metal bonded specimens were prepared and tested. Satisfactory results from these tests then led to preparation of representative specimens of mirrored glass bonded to metal substrates. The procedures used in preparing the specimens follow.

## 3.0 Metal to Metal Specimen Preparation and Testing

### 3.1 Materials

Aluminized steel, Type 1, .038" x 5"

Versilok 204 (Hughson Chemical)

Accelerator #5 (Hughson Chemical)

3.2 Preparation

The adhesive selected is an acrylic adhesive with a six minute pot life. This adhesive attacks mirror backing paint so it is not a candidate for bonding the mirrored glass to the steel sheet. However, it was considered an excellent candidate for bonding the bare glass to the metal substrate.

The aluminized material was solvent wiped with methylene chloride until clean, using clean cloths for each wipe. One inch overlap specimens were prepared using the acrylic adhesive. The specimens were then pull tested on an Instron Tensile Testing Machine.

3.3 Test Results

The test results of the lap shear strength of the adhesive on the metal to metal bonded specimens are shown in Table 1.0. The results showed an average lap shear strength of 1882 psi. This indicated that the adhesive was sufficiently strong for specimen preparation.

4.0 Metal to Glass to Metal Specimen Preparation and Testing

4.1 Materials

Aluminized Steel, Type 1, .038" x 6"

Mirrored glass, float, .058" x 1" x 1"

Versilok 204 (Hughson Chemical)

Accelerator #5 (Hughson Chemical)

Epon 828 (Shell)

Versamid 140 (General Mills)

Cabosil (flocculated silica)

TABLE 1.0

Lap Shear Strength Tests
Aluminized Steel to Aluminized Steel Using
Versilok 204 Adhesive

| Specimen | Lap Shear Strength psi | Comments |
|---|---|---|
| 1 | 1900 | Substrate yielding causing some peeling. Failure was cohesive until peeling occurred. |
| 2 | 1860 | |
| 3 | 1880 | |
| 4 | 1890 | |
| 5 | 1910 | |
| 6 | 1850 | |
| Ave. | 1882 | |

4.2 Preparation

One inch square pieces were cut from .058" mirrored glass. The bare glass surface was lightly abraded to provide better adhesion. The aluminized steel was solvent wiped with methylene chloride until clean, using a clean cloth for each wipe. The bare glass surface was bonded to the aluminized steel using Versilok 204 adhesive. The other piece of aluminized steel was solvent wiped with methylene chloride until clean and the paint backing of the mirrored glass was wiped with methyl alcohol and the aluminized steel was bonded to the paint backing of the glass with adhesive mixed in the following proportions:

Epon 828 - 50 pts/wt

Versamid 140 - 40 pts/wt

Cabosil - 2 pts/wt

The specimen configuration is shown in Figure 1.0. After a 72 hour curing period, the specimens were pull tested on an Instron Tensile Testing Machine. To provide proper alignment when pull testing, a spacer was used as shown in Figure 2.0.

4.3 Test Results

The lap shear strength test results are shown in Table 2.0. The average shear strength obtained in the tests was 761 psi. In all cases, the failure was a cohesive failure of the mirror backing paint.

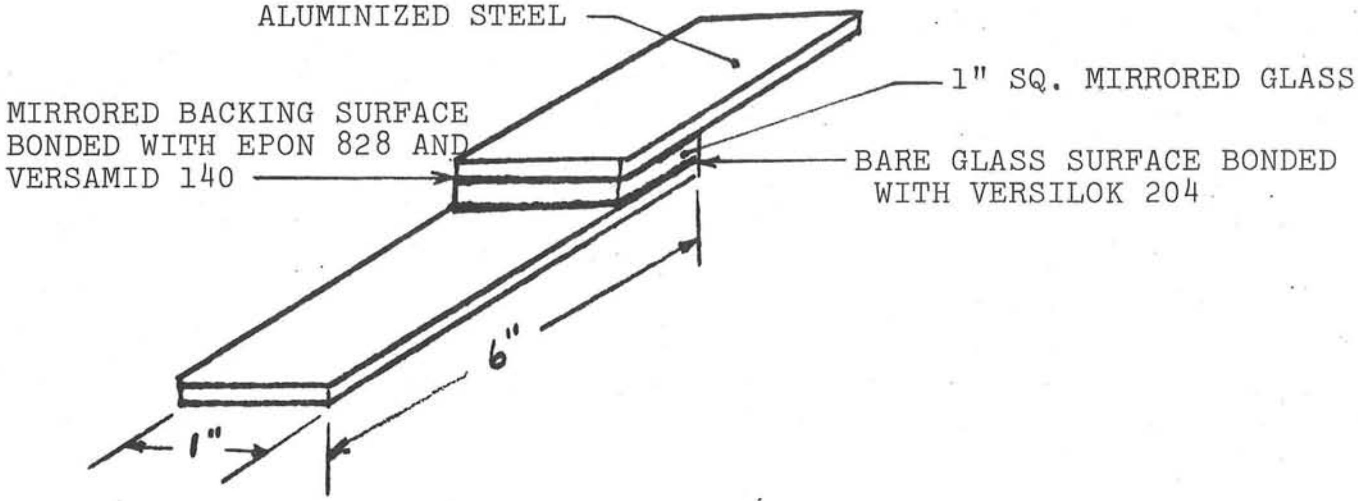



FIGURE 1.0

TEST SPECIMEN

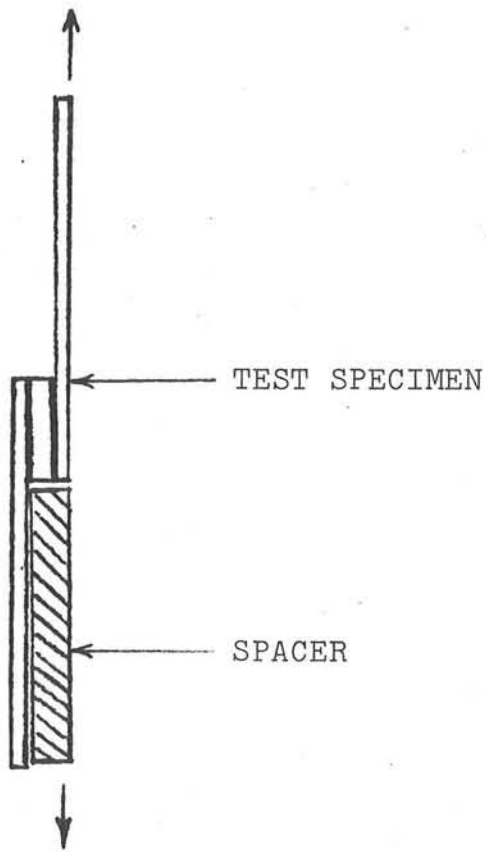



FIGURE 2.0

PULL TEST SET-UP

TABLE 2.0

Lap Shear Strength Tests

Aluminized Steel/Mirrored Glass/Aluminized Steel

| Specimen | Lap Shear Strength psi | Comments |
|---|---|---|
| 1 | 700 | All failures were cohesive failures of the mirror backing paint. |
| 2 | 750 | |
| 3 | 800 | |
| 4 | 850 | |
| 5 | 775 | |
| 6 | 700 | |
| 7 | 750 | |
| Ave. | 761 | |

5.0 Conclusions

The test results indicate that the Versilok 204 system is adequate for bonding bare glass to aluminized steel for the test specimens to be furnished to Sandia.

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