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FINAL REPORT
ON
LOW-COST ABLATIVE HEAT SHIELD
FOR
SPACE SHUTTLES

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Contract NAS1-9943

Prepared by

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FOREWORD

Submittal of this document, Final Report on Low-Cost Ablative Heat Shields for Space Shuttles, is a contractual requirement of the program performed for the National Aeronautics and Space Administration at Langley Research Center (NASA/LRC) under Contract NAS1-9943. The program was conducted by the Production Engineering and Development Department at the Space Division of North American Rockwell Corporation, Downey, California, between April and November 1970. Mr. C.M. Pittman of the Structures Research Division, Langley Research Center, Hampton, Virginia, was the technical representative for the project. With this report, all contract requirements have been completed.

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ABSTRACT

Four ablative material compositions were used to fabricate four flat and four curved 2-foot by 4-foot by 2-inch-thick panels. The panels consisted of a honeycomb matrix bonded to a face sheet and filled with ablation material. Production methods were developed for fabricating the panels, and cost data were compiled. Among the unique fabrication processes used were vacuum bagging the panel to the final required thickness (thus eliminating surface machining) and making curved panels by filling the honeycomb matrix with ablator in the flat and curing to the curved shape. Cost estimates are included for production lots of 1, 10, and 100 panels in various sizes and shapes.

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FINAL REPORT ON LOW-COST ABLATIVE HEAT SHIELDS FOR SPACE SHUTTLES

By Production Engineering and
Development Department, Space Shuttle
Manufacturing, Space Division
North American Rockwell Corporation

SUMMARY

The objective of the program was three-fold, namely:

1. To develop low-cost methods of producing ablative heat shields for Space Shuttles.

2. To fabricate and deliver four flat and four curved panels (2 inches by 2 feet by 4 feet); of the following material compositions: 67-percent elastomer, 33-percent microballoons; 80-percent microballoons, 20-percent elastomer; 50-percent nylon, 50-percent phenolic; 70-percent microballoons, 15-percent nylon, 15-percent phenolic.

3. To establish effective cost-estimating data for production quantities of 1, 10, or 100 shipment sets of ablative heat shields.

Program activities primarily consisted of two parts—the development of fabrication processes and then full-size panel fabrication. Considerable more development effort was required than was anticipated. The greatest effort was concentrated initially in satisfying the contractual density requirements. Of the four ablative compositions, all, except the 67-percent elastomer and 33-percent microballoons, presented difficulties in obtaining the minimum density requirement of 13 lb/ft^3 for the low-density material and 25 lb/ft^3 for the high-density material.

Test specimens were fabricated, using the four specified ablative compounds (two elastomer and two phenolic-nylon mixtures), to develop the required density values, honeycomb core-to-face sheet bonding, filler

compacting procedures, and curing parameters. The specified 10-percent elastomer and 90-percent microballoon mixture was found to be low in density; and by mutual agreement with NASA/LRC, the contract was amended to 20-percent elastomer and 80-percent microballoon mixture, which met the required density. The first 6- by 6-inch test panels filled with 50-percent nylon and 50-percent phenolic were below the minimum acceptable density. This condition prompted the development of a unique compaction method that used uncured rubber sealant mounted on a soft Ensolite blanket to compress the powdery material into the panel, which was held in a flat position. This method was successfully used to achieve the required panel densities on the full-size panels.

During fabrication of the deliverable panels, several situations occurred that required expeditious measures to maintain progress. The spliced over-expanded (OX) honeycomb core blankets for the curved panels were received with wide porous splices and varying nonuniform cell sizes. Two-thirds of this core was found to be of low density and of questionable strength, and cell crushing during compaction resulted unless extreme caution was exercised. The development of additional core splicing and bonding procedures was necessary.

The full-size flat and curved panels of low-density compositions had densities ranging from 14.4 to 14.6 lb/ft^3, while those of high-density compositions had densities ranging from 25.2 to 29.35 lb/ft^3. The ablative compound system that showed the most consistent density was the elastometric system. The only exception was when incomplete filling of core cells occurred.

Quality Control maintained inspection of all fabrication sequences and conducted nondestructive tests (NDT) on all flat panels. The liquid crystal (NDT) concept showed good potential in defining the effectiveness of core-to-face sheet bonding and in detecting face sheet-filler voids. Radiographic inspection was used on test specimens to establish void detection feasibility.

Flat panel prices were estimated to be approximately $332.00, $136.00, and $99.00 per square foot for 1, 10, and 100 units, respectively. As the panels increase in size from 2 by 4 feet to 4 by 6 feet, the price per square foot decreases by approximately 36 percent for 1, 10, or 100 units. Because of the tooling cost, the cost per square foot for 100 units is approximately 70 percent lower than for 1 unit.

Curved panel cost per square foot is nearly double the cost of a flat panel for 1 unit, whereas the cost for 100 units is approximately one third more. In estimating the compound curved panel costs, a complexity factor of 2 over the 3- by 5-foot flat panels was used, and these estimates were approximately $1300.00, $474.00, and $330.00 per square foot for 1, 10, and 100 units, respectively.

Although much knowledge and experience were gained from the program, cost and time would not permit a comprehensive investigation of potentially applicable materials, equipment, and processes that conceivably would advance quality and further reduce costs. The report includes recommended follow-on activities pertinent to future production quantities of low-cost ablative heat shields for Space Shuttles.

INTRODUCTION

The Space Shuttle and Booster vehicles destined for the 1970's have imposed many manufacturing problems because of their massive size and projected flight reusability. With the objective of producing integrated airframe and space vehicles capable of up to 100 missions, one of the critical problems is to devise effective thermal protection systems that will provide the essential degree of functionality during the atmospheric reentry heat phase.

Although several thermal protection concepts are undergoing evaluation at this time, the replaceable ablative heat shield concept unquestionably offers several advantages, provided however, that low-cost methods can be established for production quantities for each flight refurbishment. The advantages are low-cost tooling (amortized), material availability, quick fabrication methods, and short lead time because of the state-of-the-art. Additionally, the reliability aspects of ablative heat shields have been proven, and low-density ablatives could also save weight over that of the reusable metallic heat shield concepts.

The Apollo heat shields proved the ability of the ablative principle but were very costly because each cell of the honeycomb matrix was individually filled and compacted by hand. What is now desired is a fast method of filling and compacting the ablative material into the honeycomb substrate that would drastically reduce production costs. To develop such a method was sufficient reason for starting this program, and it presented a challenge to the talents of the involved plastics engineers.

Early in the program, it was determined that more development would be necessary than was anticipated. That it was successfully completed is credited to the program personnel and the cooperation of NASA/LRC personnel who were informed of any task variance when it occurred. Subsequently, it was also determined that a follow-on program would be extremely advisable to further devaluate producibility costs and restraints still existing.

Before the notice of contract award, small specimens were prepared by plastics engineers to determine preliminary baselines and requirements. This effort was accomplished with material already on hand—some of it samples, the rest stock items used in other plastics development operations. Figure 1 shows part of the laboratory where the major portion of all program activities took place.

Upon notice of contract award, various materials were ordered and received for fabrication of the test specimens. At the same time, materials were ordered for the flat and curved deliverable panels to ensure delivery before the scheduled in-work dates. A preliminary detailed schedule was prepared for test specimen fabrication and for the assembly procedures required for the four flat and four curved panels. This schedule is contained in the Technical Letter Progress Report in Appendix B of this report. Very little deviation from this schedule occurred during the first half of the program due to its logical sequence of events.

The two major activities of this ablative heat shield program centered on development and deliverable panel fabrication. The development effort was necessary in order to gain the following objectives:

1. To determine mixing parameters of the four compounds.
2. To achieve core-fill and compaction techniques.
3. To define flat and curved panel fabrication differentials.
4. To devise hole and plug cutting methods.
5. To meet specified density values.

To accomplish the preceding objectives, several test specimens were made of each composition, some of which are shown in figure 2. Early in the program, it was learned that the 10-percent elastomer, 90-percent microballoon compound would not meet the required density value. Appendix A contains the amendment issued by NASA/LRC that changed the percentage values of this mixture to 20-percent elastomer and 80-percent microballoons, which did meet the required density. A test specimen of this material is shown in figure 3.

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Figure 1. - Plastics Laboratory Area

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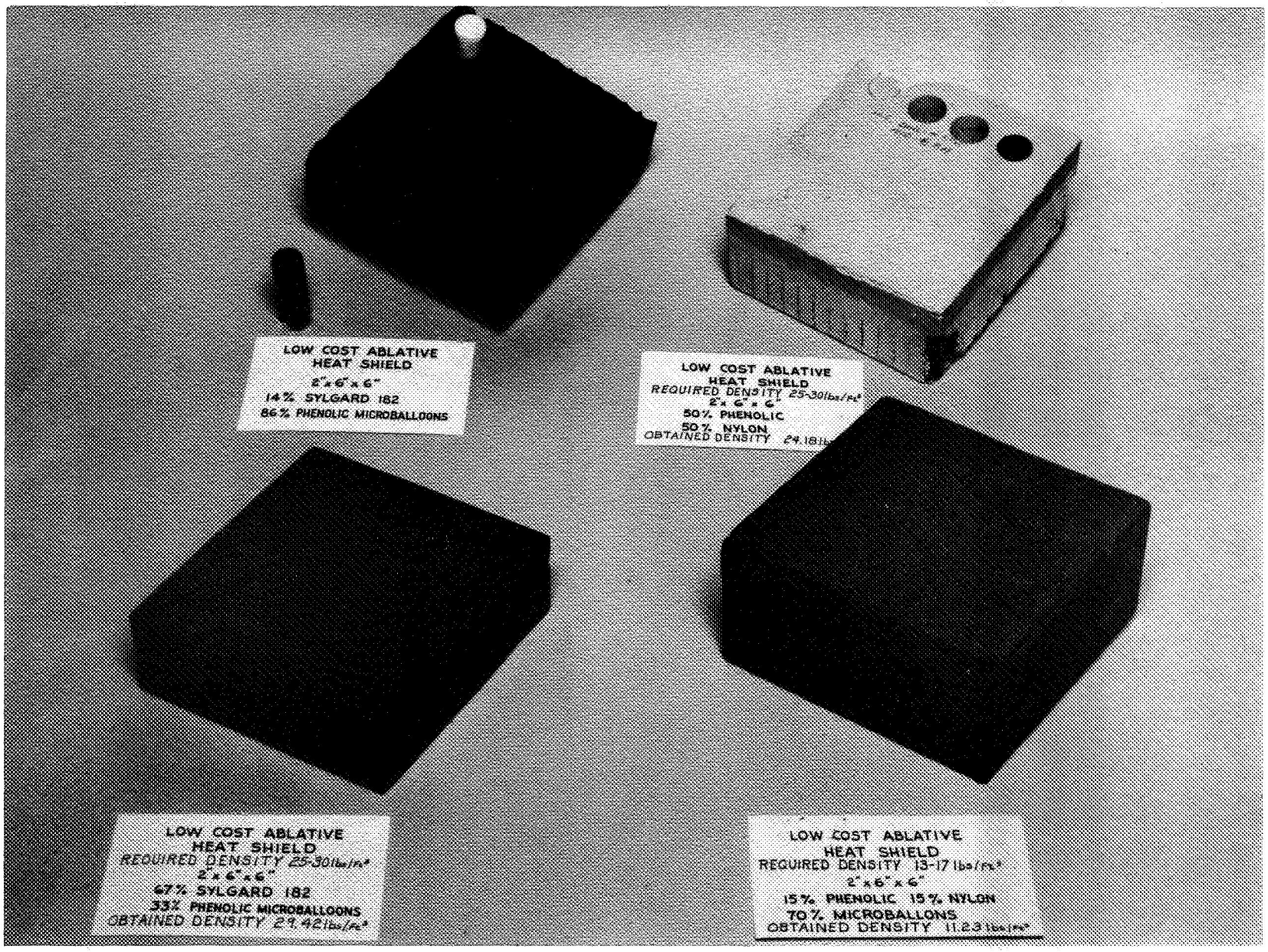


Figure 2. - Test Specimens

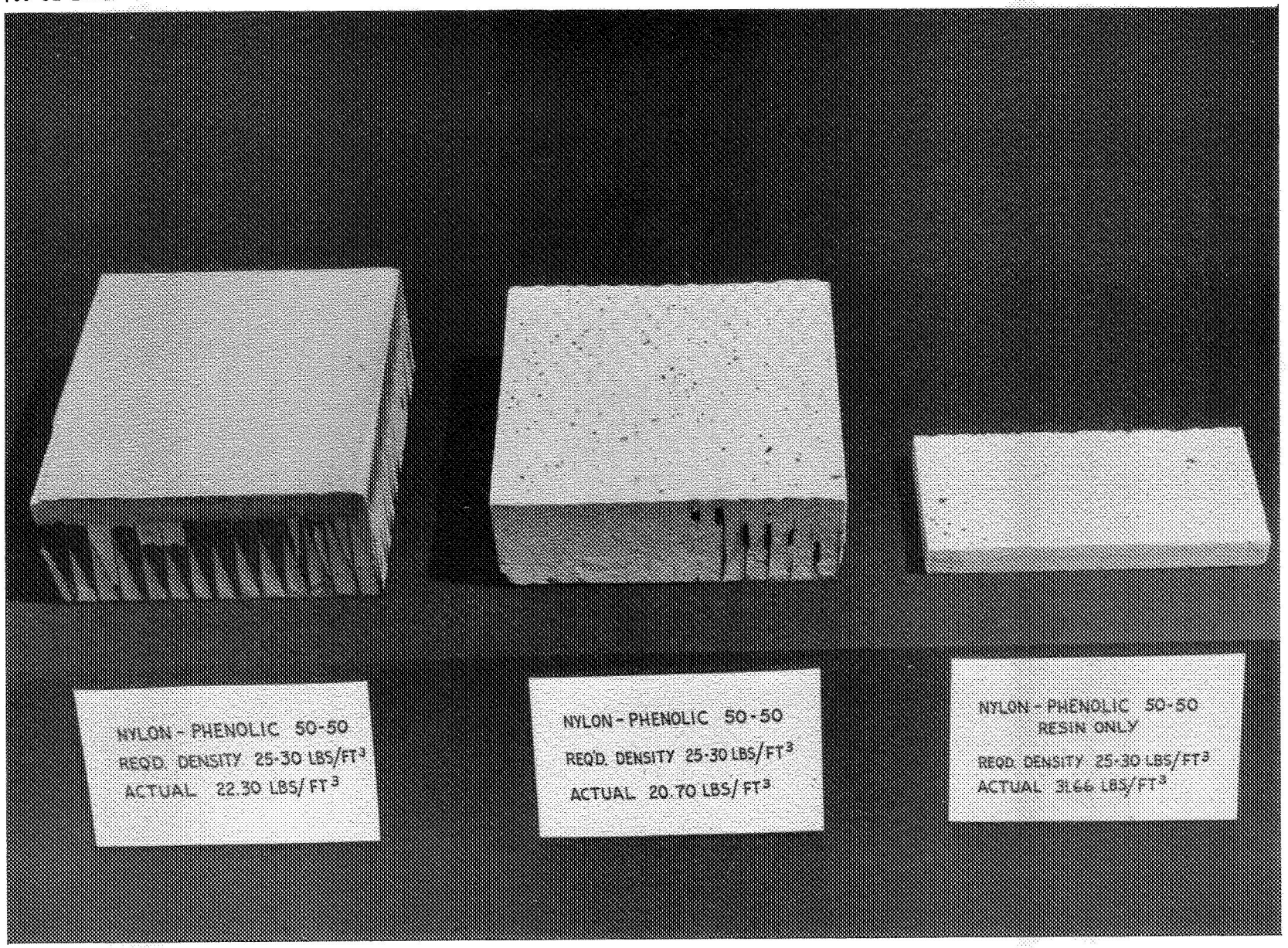


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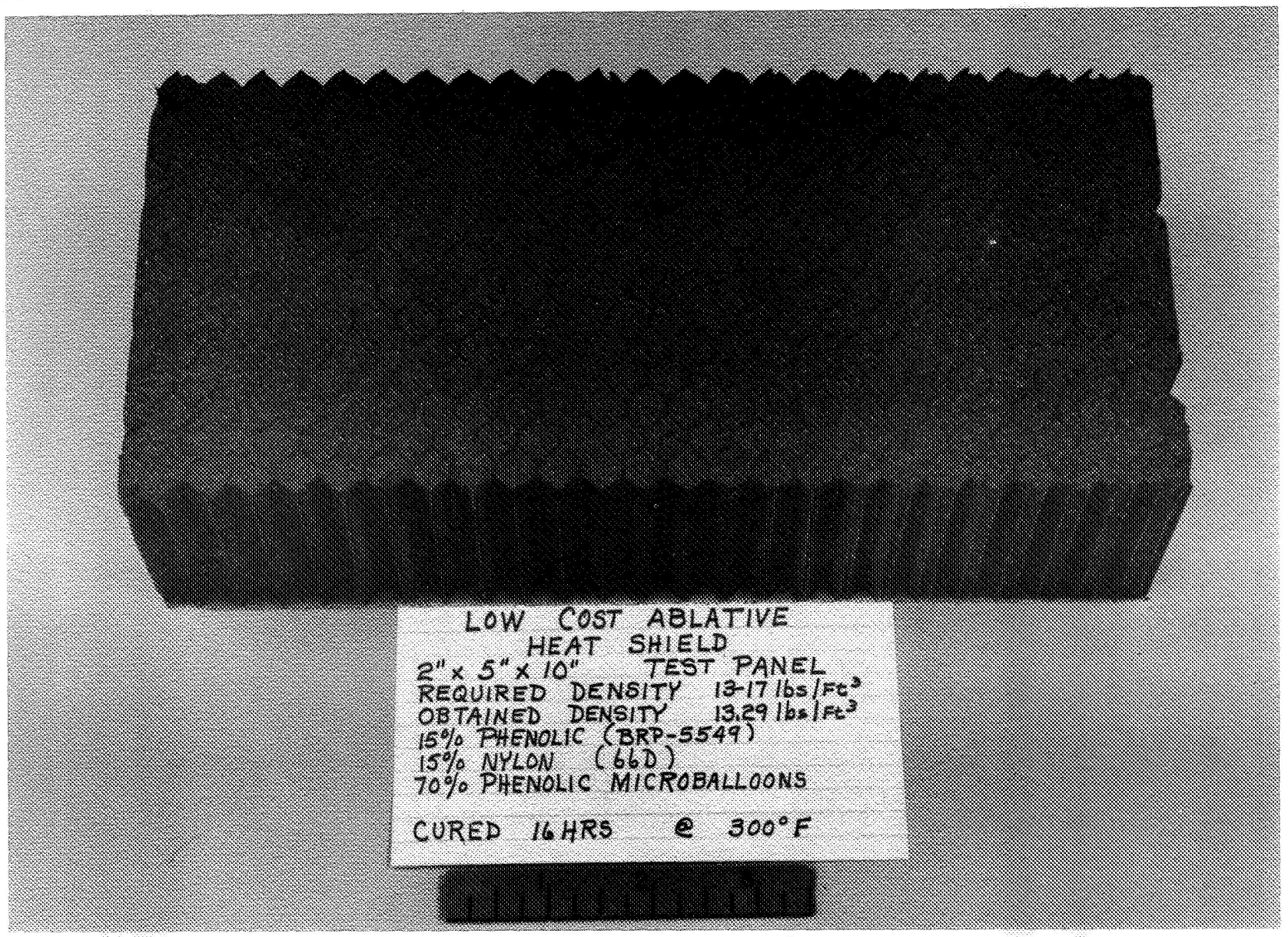


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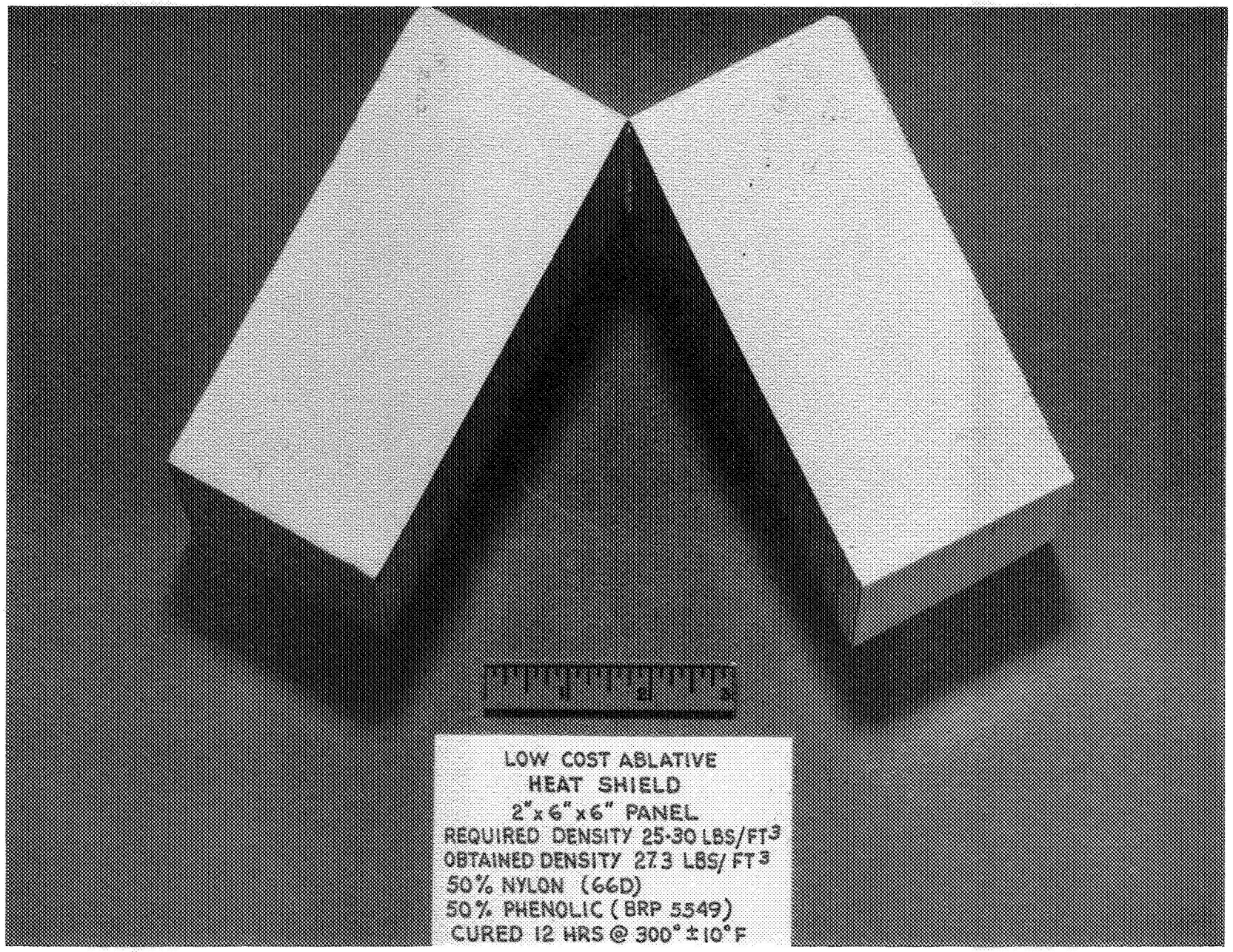


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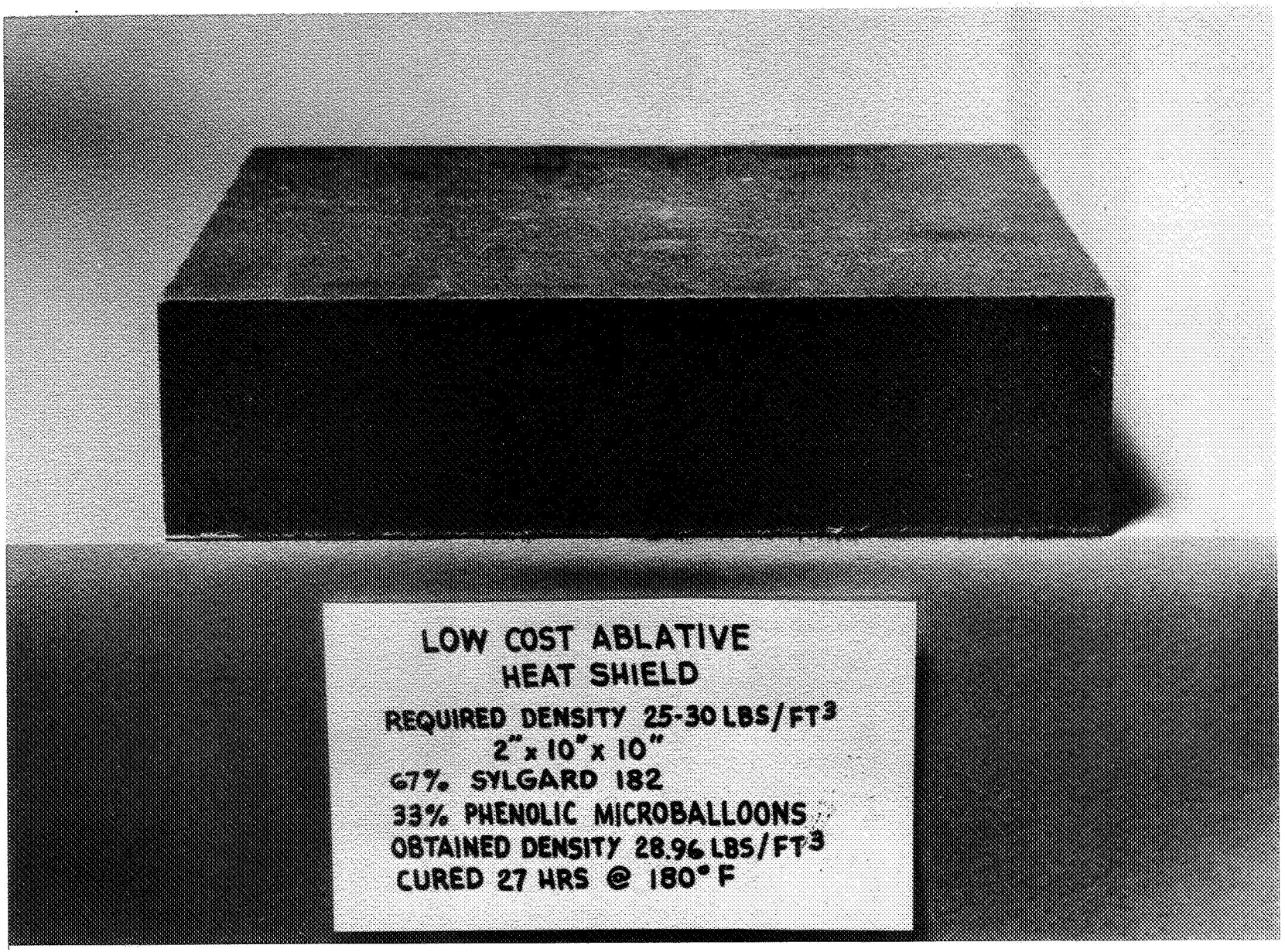
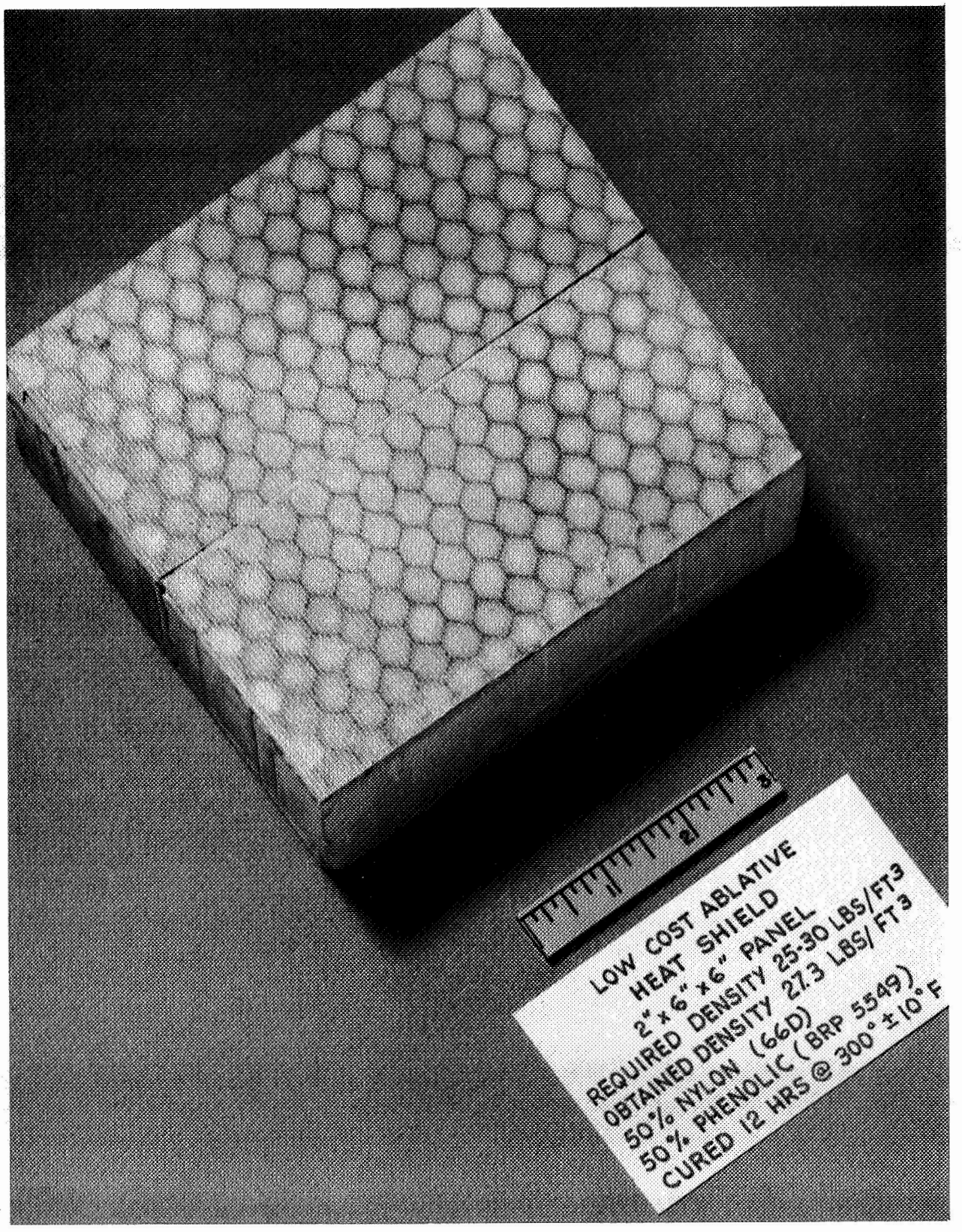


Figure 2. - Continued



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Figure 2. - Concluded

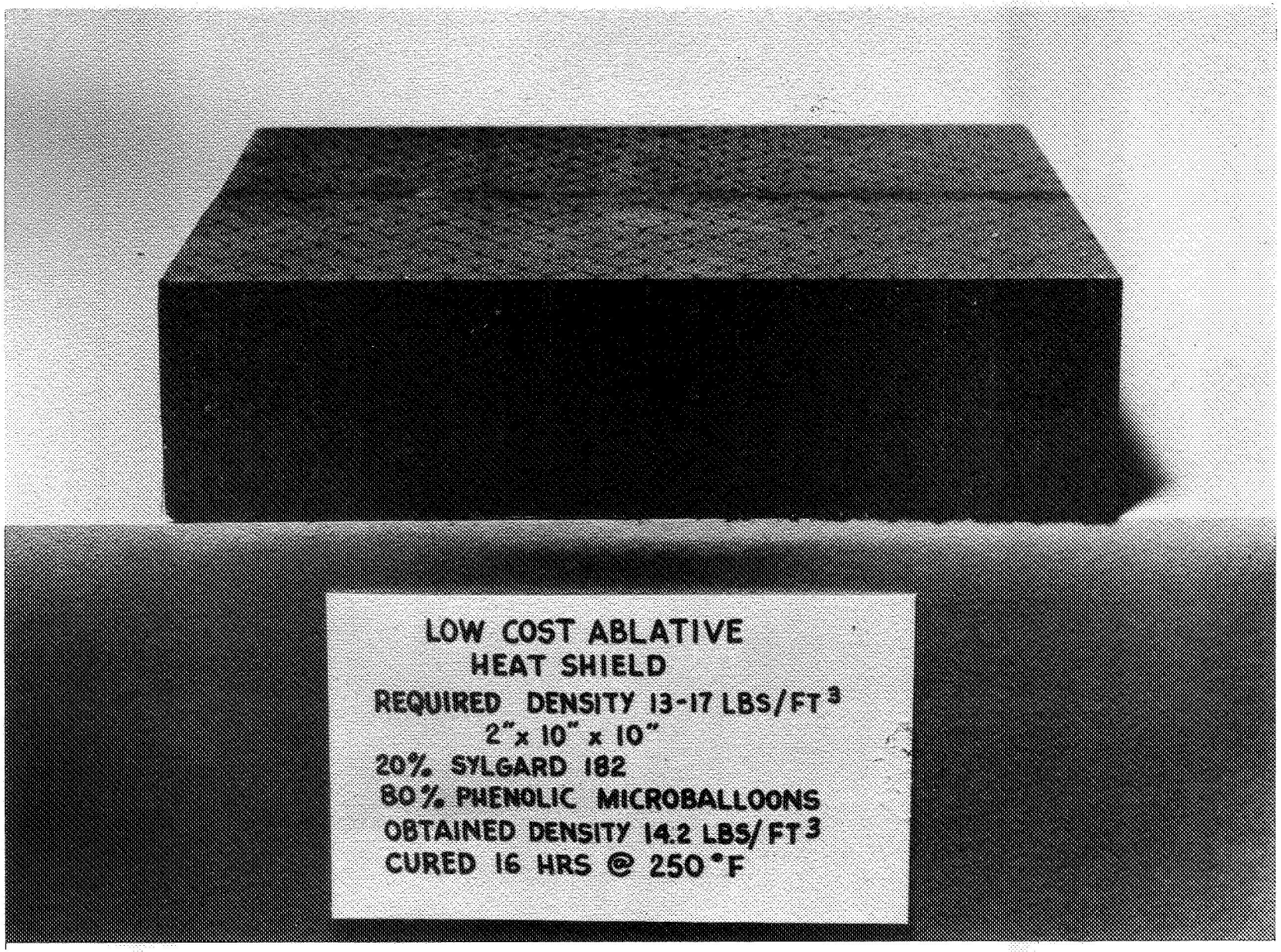


Figure 3. - Test Specimen, Modified Elastomeric Compound

PROGRAM APPROACH

The program effort was directed more at developing and advancing fabrication procedures and techniques than at any other aspect of the program. Once these were established, the learning curve for fabrication of the deliverable panels gradually acquired a more horizontal status. As a result, Space Division Manufacturing has achieved a production capability for large ablative panels.

In order to evaluate pre-program wisdom and establish feasible sequential operations, Planning prepared planning tickets based on Manufacturing projections and a schedule (fig. 4) that detailed operations and milestones to be accomplished within allotted time-spans. During the program, because of procedural changes required in the formulations, and in order to contend with inferior honeycomb material, deviations in the schedule and planning tickets were necessary. By the end of the program, fabrication procedures had been revised and, as shown later in the report, reflect the "best-effort" philosophy used in the fabrication of the deliverable panels.

Plastics engineers and specialists with many years of experience were able to accomplish the contractual requirements in an effective and timely manner. The resulting capabilities will enable Manufacturing to implement similar programs with lower labor grade personnel and with minimal supervision.

MANUFACTURING SCHEDULE
LOW-COST ABLATIVE HEAT SHIELD PANELS

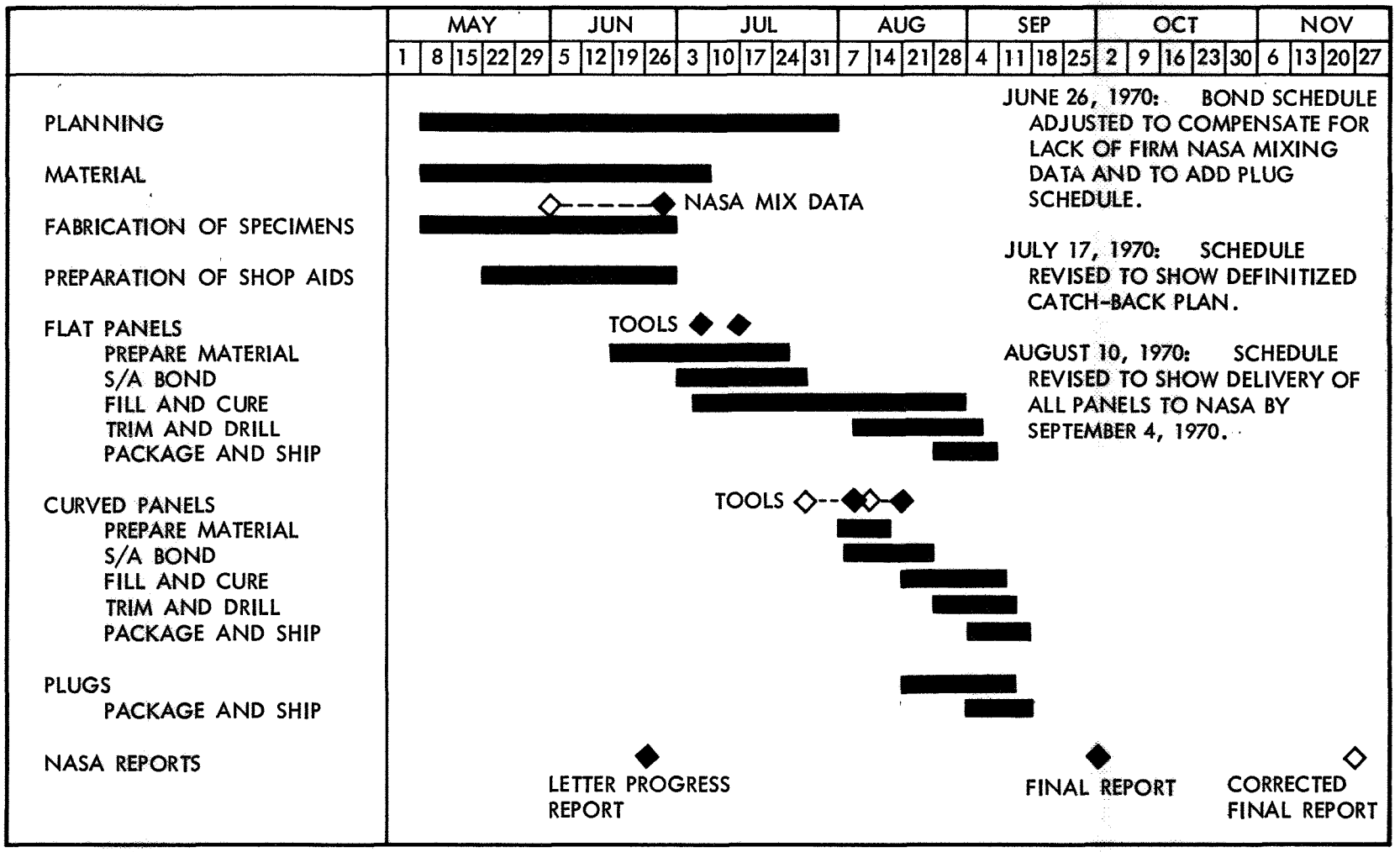


Figure 4. - Condensed Schedule

DEVELOPMENT

Sub-Scale Verification Program

During the inception of the program, it was anticipated that a minimum amount of development effort would be required to verify the proposed fabrication methods. The main items for verification were the formulations, cure cycles, and pressure to fulfill the density requirements. After establishing these parameters, the next item of importance was to demonstrate the technique of filling in the flat, followed by the contouring or curving operation. Secondary operations, such as bonding of face plies, machining holes, and trimming, were also planned as part of this preliminary phase.

While the development tasks were being performed (approximately three months), it became evident that the austere approach would require further augmentation for the manufacture of deliverable panels to meet the contract requirements. Operations, such as mixing, curing, and compaction methods, were heretofore considered as minimal problem areas but later required extensive concentration of efforts for final solution of the problem.

Initial evaluations were based on the fabrication of panels, 6 by 6 by 2 inches thick, with and without the honeycomb/facing sheet or sheets in place. The final analysis was based on reproducing the smaller specimens to a larger size panel, 10 by 10 by 2 inches thick, with honeycomb/facing sheet or sheets in place.

Experimental Tooling

The design and material selection of the full-scale tooling was dependent on the accumulation of information attained from the various types of tooling and shop aids developed in the manufacture of the 6- by 6- by 2- and 10- by 10- by 2-inch-thick panels. Secondary processing aids, such as release agents, sealant compounds, and bleeder and release fabrics were also evaluated to determine compatibility with the tools and ablator materials. These items, as shown in figure 5, are as follows:

1. Three-hole (diameter) molding tool (2)
2. Female mold tool 10 by 10 inches
3. Female mold tool 6 by 6 inches (2)
4. Flexible mold tool 12 by 12 inches
5. Flour shaker
6. Vacuum plate
7. Shaker screen box

8. Vertical fill fixture
9. Hand vibrator
10. Tubular steel bore die*
11. Sub-scale curved tool*
12. Hole saw*

According to the planned schedule, the experimental tooling and test panel phase was due to be completed in three months. However, approximately 50 percent of this effort was conducted concurrently during the fabrication of the full-scale panel.

Test Results

Bulk density factors and compound mixing. - Two-inch-diameter specimens were fabricated to solve the mixing and formulation-density problems of the elastomeric compounds. A three-cavity tool was fabricated in order that three specimens could be fabricated at one time (fig. 5 and 6).

Table 1 presents the data obtained from specimens for the evaluation of the mixing methods with corresponding densities on the low-density elastomeric compounds. It should be noted that only the 80/20 formulation exceeded a density of 12 lb/cu. ft., which was considered minimum to achieve a panel density of 13 to 17 lb/cu. ft.

Tests were conducted on larger specimens to evaluate the use of thinning and wetting agents to further enhance the ease of mixing the low-density elastomeric system. Although solvents such as heptane were considered satisfactory, it was subsequently found more economical to use a mixer with a higher degree of blending action, eliminating the need for the solvent and the risk involved in removing the solvent during cure.

One test specimen 2 by 6 by 6 inches was made using a formulation of 14-percent elastomer — 86-percent phenolic microballoons. (Ten parts of DC 1330 thinner were added to the elastomer mix.) This specimen was fabricated to evaluate the use of Teflon plugs inserted in the core prior to filling, to exclude subsequent hole drilling operation after cure and, at the same time, to evaluate density control. The Dow Corning Co. was contacted for a recommendation in regard to the thinning agent for Sylgard 182 to increase the wetability of the mix. The recommendation was to add no more than 10 parts of DC 1330 since excess thinner would reduce the quality of Sylgard 182.

*Not shown in figure 5.

TABLE 1. - LOW-DENSITY ELASTOMERIC SPECIMENS (2.26-INCH DIAMETER)

No.	Formulation	Cure Cycle	Pressure Type (Vacuum)	Density Goal	Thickness Goal (in.)	Grams of Elastomer	Grams of Microballoons	Thickness Obtained (in.)	Density Obtained
1	10% Sylgard 90% Micro	250°F for 16 hr	1 atmos	13.6 lb/ft^3	1	1.435	12.912	1.153	10.69 lb/ft^3
2	14% Sylgard 86% Micro	250°F for 16 hr	1 atmos	13.6 lb/ft^3	1	1.998	12.349	1.077	11.453 lb/ft^3
3	18% Sylgard 82% Micro	250°F for 16 hr	1 atmos	13.6 lb/ft^3	1	2.588	11.759	1.027	12 lb/ft^3
4	10% Sylgard 90% Micro	250°F for 16 hr	1 atmos	17 lb/ft^3	0.875	1.544	14.119	1.259	10.85 lb/ft^3
5	14% Sylgard 86% Micro	250°F for 16 hr	1 atmos	17 lb/ft^3	0.875	2.179	13.484	1.262	11.278 lb/ft^3
6	18% Sylgard 82% Micro	250°F for 16 hr	1 atmos	17 lb/ft^3	0.875	2.815	12.848	1.240	11.860 lb/ft^3
7	10% Sylgard 90% Micro	250°F for 16 hr	1 atmos	13.6 lb/ft^3	1	1.435	12.912	1.280	10.88 lb/ft^3
8	10% Sylgard 90% Micro	250°F for 16 hr	1 atmos	13.6 lb/ft^3	1	1.435	12.912	1.2	10.89 lb/ft^3
9	10% Sylgard 90% Micro	250°F for 16 hr	1 atmos	13.6 lb/ft^3	1	1.435	12.912	1.275	10.55 lb/ft^3
10	20% Sylgard 80% Micro	250°F for 16 hr	1 atmos	14 lb/ft^3	1	2.95	11.8	1.075	12.199 lb/ft^3
11	20% Sylgard 80% Micro	250°F for 16 hr	1 atmos	14 lb/ft^3	1	2.95	11.8	1.070	12.256 lb/ft^3
12	20% Sylgard 80% Micro	250°F for 16 hr	1 atmos	14 lb/ft^3	1	2.95	11.8	1.075	12.199 lb/ft^3

No.	Formulation	Cure Cycle	Pressure	Density Goal	Thickness Goal (in.)	Grams of Elastomer	Grams of Microballoons	Thickness Obtained (in.)	Density Obtained
	14% Sylgard 86% Micro	250°F for 16 hr	1 atmos	14 lb/ft^3	2	28	172	2.153	12.324 lb/ft^3

No.	Formulation	Cure Cycle	Pressure	Density Goal	Thickness Goal (in.)	Grams of Elastomer	Grams of Microballoons	Thickness Obtained (in.)	Density Obtained
	20% Elastomer 80% Micro 20% Heptane	RT for 72 hr then 250°F for 16 hr	1 atmos	15 lb/ft^3	2.040	46.624	186.494	2.125	14.395 lb/ft^3

Listed below are the results on this panel:

Formulation	Cure Cycle	Pressure	Density Goal	Thickness Goal (in.)	Grams of Elast.	Grams of Microballoons	Thickness Obtained (in.)	Density Obtained
14% Sylgard 86% Micro	250°F for 16 hrs	1 Atmos	14 lb/ft^3	2	28	172	2.153	12.324 lb/ft^3

One test specimen 2 by 6 by 6 inches was made with a formulation of 10 percent elastomer, 90 percent phenolic microballoons, and 10 percent heptane. This had been a NASA-LRC recommendation. This test specimen was made minus face sheet and core. Specimen density was 10.612 lb/ft^3, well below the specified density.

Another test specimen 2 by 6 by 6 inches was made with a formulation of 20 percent elastomer and 80 percent phenolic microballoons. After the mixing, the required quantity of mixed material was weighed out, i.e., 233.18 grams. Then 46.624 grams of heptane (20 percent of the mixed weight) was added to the mixture. The results are shown below:

Formulation	Cure Cycle	Pressure	Density Goal	Thickness Goal (in.)	Grams of Elast.	Grams of Microballoons	Thickness Obtained (in.)	Density Obtained
20% Elastomer 80% Micro 20% Heptane	RT for 72 hrs then 250°F for 16 hrs	1 Atmos	15 lb/ft^3	2.040	46.624	186.494	2.125	14.395 lb/ft^3

As a result of these experimentations, a request was made to NASA-LRC to change the 10-percent Sylgard-90-percent phenolic microballoons to at least 18-percent Sylgard-82-percent phenolic microballoons. It was mutually agreed that 20-percent Sylgard-80-percent microballoons would be preferred and was used (Appendix A). Figure 7 shows one of the first specimens produced having an acceptable density.

Since density limits were predicted to be attainable, limited tests were conducted on the 67-percent Sylgard to 33-percent phenolic microballoon formulation. Obtaining the required density in the 2-ft by 4-ft panels was not considered to be a problem at this time. See table 2 for results.

Specimens 2 by 6 by 6 inches were made using the 15-percent phenolic, 15-percent nylon, and 70-percent microballoons. Table 3 gives the results.

Various specimens were made using the 50-percent phenolic resin and 50-percent nylon powder formulation. In the preliminary phase of development, only one specimen 6 by 6 inches was completed. Results are listed in table 4.

A specimen made using the improved pre-compaction is shown in figure 8.

Mixing. - Mixing of the material, especially the elastomer system, was a problem with existing equipment. The two elastomer formulations were tried by hand, in a Hobart mixer, a modified Hobart (flexible paddles attached to the rotating blade), a ribbon blade mixer, and a sigma blade mixer. Also solvents or wetting agents such as toluene, heptane, and Sylgard primer were used to increase the dispersion of the Sylgard, especially in the 10-percent Sylgard - 90-percent phenolic microballoon formula.

Final decision for the elastomer formulas was to hand-mix the Sylgard resin and catalyst, then hand-mix this catalyzed resin with the required amount of phenolic microballoons, and finally to mix in an Atlantic Research Model 8CV vertical helicone mixer for a designated time.

Face sheet prepreg evaluation. - Three types of face sheet material (prepregs) were tried to see which had the most suitable qualities. This was determined by making core-face flatwise tension tests as listed in table 5.

Core priming procedures. - Six types of primers were tried for ease of application and to evaluate the quality of one versus the other. No test other than visual means and hand peeling were used to decide on the primer to be used. Listed below are the types of primers evaluated:

1.	Dow Corning	1200	Silicone
2.	Dow Corning	4004	Silicone
3.	Dow Corning	1203	Silicone

TABLE 2. - HIGH-DENSITY ELASTOMERIC SPECIMENS*

No.	Formulation	Core Cycle	Pressure and Type	Density Goal	Thickness Goal (in.)	Grams of Elasomer	Grams of Microballoons	Thickness Obtained (in.)	Density Obtained	Mixing Equipment	Size (in.)
1	67% Sylgard 33% Micro	250°F for 16 hr	1 atmos	30	2.250	365	180	2.175	29.418 lb/ft^3	Hobart	2x6x6
2 **	67% Sylgard 33% Micro	250°F for 16 hr	1 atmos	27	2	1209	595	Average 2.062	23.084 lb/ft^3	Hobart	2x12x12 Curved
3	67% Sylgard 33% Micro	250°F for 16 hr	1 atmos	27	2	1222	602	2.187	30.41 lb/ft^3	Hobart	2x12x12
4	67% Sylgard 33% Micro	250°F for 16 hr	1 atmos	30	1.5	30.15	14.85	1.540	27.899 lb/ft^3	Ribbon Blade	2.225 dia by 1.5

*See figure 9.
**This specimen was tamped into a mold (upright) with a wooden block (fig. 5)

TABLE 3. - LOW-DENSITY NYLON-PHENOLIC SPECIMENS

No.	Formulation	Core Cycle	Pressure and Type	Density Goal	Thickness Goal (in.)	Grams of Phenolic	Grams of Nylon	Grams of Microballoons	Thickness Obtained (in.)	Density Obtained	Mixing Equip
1	15% Phenolic 15% Nylon 70 Micro	300°F for 16 hr	1 atmos	17 lb/ft^3	2.250	42.994	42.994	198.171	3.025	11.23 lb/ft^3	Patterson Kelly Twin Shell
2*	15% Phenolic 15% Nylon 70% Micro	300°F for 16 hr	1 atmos	17 lb/ft^3	2.250	41.314	41.314	192.768	2.960	11.9 lb/ft^3	Patterson Kelly Twin Shell
3**	15% Phenolic 15% Nylon 70% Micro	300°F for 16 hr	40 psi Press.	17 lb/ft^3	2	36.502	36.502	170.25	2.108	13.717 lb/ft^3	Patterson Kelly Twin Shell
4***	15% Phenolic 15% Nylon 70% Micro	300°F for 16 hr	42 psi (pos) 15 psi (vac)								Patterson Kelly Twin Shell

*Material pressed into core in three stages
**See figure 10.
***Part cured in autoclave; thermocouple reading at the center of mix reached 750°F at the 15th hour (overnight cure). When removed from the autoclave, the mix material and core were on fire. Exotherm heating caused specimen to burn.

TABLE 4. - HIGH-DENSITY NYLON-PHENOLIC SPECIMENS

Formulation	Core Cycle	Pressure and Type	Density Goal	Thickness Goal (in.)	Grams of Phenolic	Grams of Nylon	Thickness Obtained (in.)	Density Obtained	Mixing Equipment
50% Phenolic 50% Nylon	300°F for 16 hr	1 atmos	30 lb/ft^3	2.250	267.747	267.747	2.623	24.184 lb/ft^3	Patterson Kelly Twin Shell

TABLE 5. CORE-FACE FLATWISE TENSION TESTS

Prepreg Type and Manufacturer	Strength (psi)		Prepreg Weight/Sq Ft	Remarks
	Room Temp	300° F		
R1714 (Reliabond Corp.)	36.6	29.6	18.2 grams	Facing selected for panels.
Trevarno F268-18 (Coast Mfg. & Supply Co.)	17.5	19.9*	42.8 grams	Two specimens failed in handling*
R1714-1331 (Reliabond Corp)	13.8	---	55.0 grams	Not tested at 300° F

NOTES:

1. All specimens were cured at 300° F for 1 1/2 hours with 14.7 psi (approx) vacuum pressure. Bond area was approximately four square inches.
2. Room temperature values were on one specimen only.
3. 300° F specimen results are an average of 3 specimens except as noted. *
4. R1714-1331 was eliminated from further evaluation after room-temperature testing.

4.	Dow Corning	92-019	Silicone
5.	Dow Corning	Sylgard	Silicone
6.	Monsanto Resinox	1008	Phenolic varnish

Honeycomb samples were primed with the various primers (face sheets were added before priming); then ablative material formulations were added and cured. By general observation and hand peeling, it was determined that the Dow Corning 1203 would be used for the elastomeric filled panels and the Monsanto 1008 for the phenolic and nylon-filled panels. Priming of the core was performed by hand-dipping the core and face sheet subassembly into the priming pan, face sheet up, and priming within one eighth of an inch of the face sheet.

By observation and testing, it was decided to bond one face sheet to the core prior to fill, then fill the core with the ablative formula, and, before curing, add the second face sheet. The main reason for this procedure was to take advantage of the increased permeability of one face ply over two to alleviate the problem of trapping air in the core cells.

Another method considered was to slit the core before bonding to the face sheet; however, the former method was the most expedient and economical and did alleviate the trapping of air.

Core filling procedures. - Filling procedures were evaluated, some at the same time the test specimens were made. Methods were tried with such variations as:

1. Filling a cavity tool and compressing the core into the fill

2. Positioning the core in a cavity tool and filling the core

3. Same as 1, except that the material was compressed to a predetermined height before compressing the core into the fill

4. Same as 2, except that the material filler was pressed in stages

5. Filling and tamping the filler material into a vertical mold (figure 5) and then compressing the core into the compressed material

6. Dispersing the material through screens and flour sifters for even dispersion and to break up the globules

7. Injecting the filler material into the core by air pressure

The methods were tried with different degrees and types of pressure such as vacuum, autoclave, press, and combinations. The final methods used were filling the mold cavity and pressing the core in for the elastomer fills, and the reverse procedure for the phenolic nylon and microballoon, i.e., inserting the core and face sheet subassembly in a mold cavity and then filling the core with ablation material.

No problem was anticipated in mixing the phenolic and nylon and the phenolic-nylon and microballoons, which proved to be the case. A Patterson-Kelly Twin Shell Blender was available and was used for these compounds.

Cure cycles were, in general, satisfactory. However, it was found that after curing the first high-density elastomer 2-ft by 4-ft flat panel, excessive bowing resulted. Upon investigation it was found that the cause was the differential contraction of the dissimilar materials during cool-down. The Dow Corning Co. was consulted and stated that Sylgard 182 could be cured at a minimum temperature of 150°F. Therefore, a 10-inch test panel was fabricated and cured at 170°F for 27 hours. Results indicated complete curing and the panel had a 1/32-inch bow in one direction only. A request was then made to NASA-LRC for a cure cycle change, which was granted. (Appendix A).

The original concept of filling a curved panel in the flat, then clamping and vacuum-bagging the filled assembly to the contoured tool and curing proved to be practical. After a few trial runs with specimen size blocks, this procedure was tried with a full-scale (26-inch by 50-inch oversize) panel. This procedure was used thereafter for all the full-scale panels.

Hole and plug procedures. The methods for making holes in the finished panels were tested on various scrap material generated from the previous tests. Drilling with standard drills, punching with cookie cutters by hand and by press, and drilling with hole saws were the methods tested. The cookie cutter in a press was used to cut out the holes in the elastomer formula panels. The standard drill was used on the 50-percent phenolic-50-percent nylon. The hole saw was used on the 15-percent phenolic 15-percent nylon and 70-percent microballoon panels.

The method of using a Teflon plug installed in the core prior to the fill was tried. This method could be used. However, punching or drilling out the holes after curing was faster and less expensive.

Fabrication of the plugs was tested at the same time as test drilling of the holes. The theory was that the plug produced when cookie cutting the hole could be used. However, it became too difficult to remove the plug intact from the cutter, so a separate cookie cutter was made with a bevel ground on the outer diameter. This was used to press out the plugs for all formulas except the 50-percent phenolic and 50-percent nylon plugs. These had to be ground to the required diameter.

700-86-988N

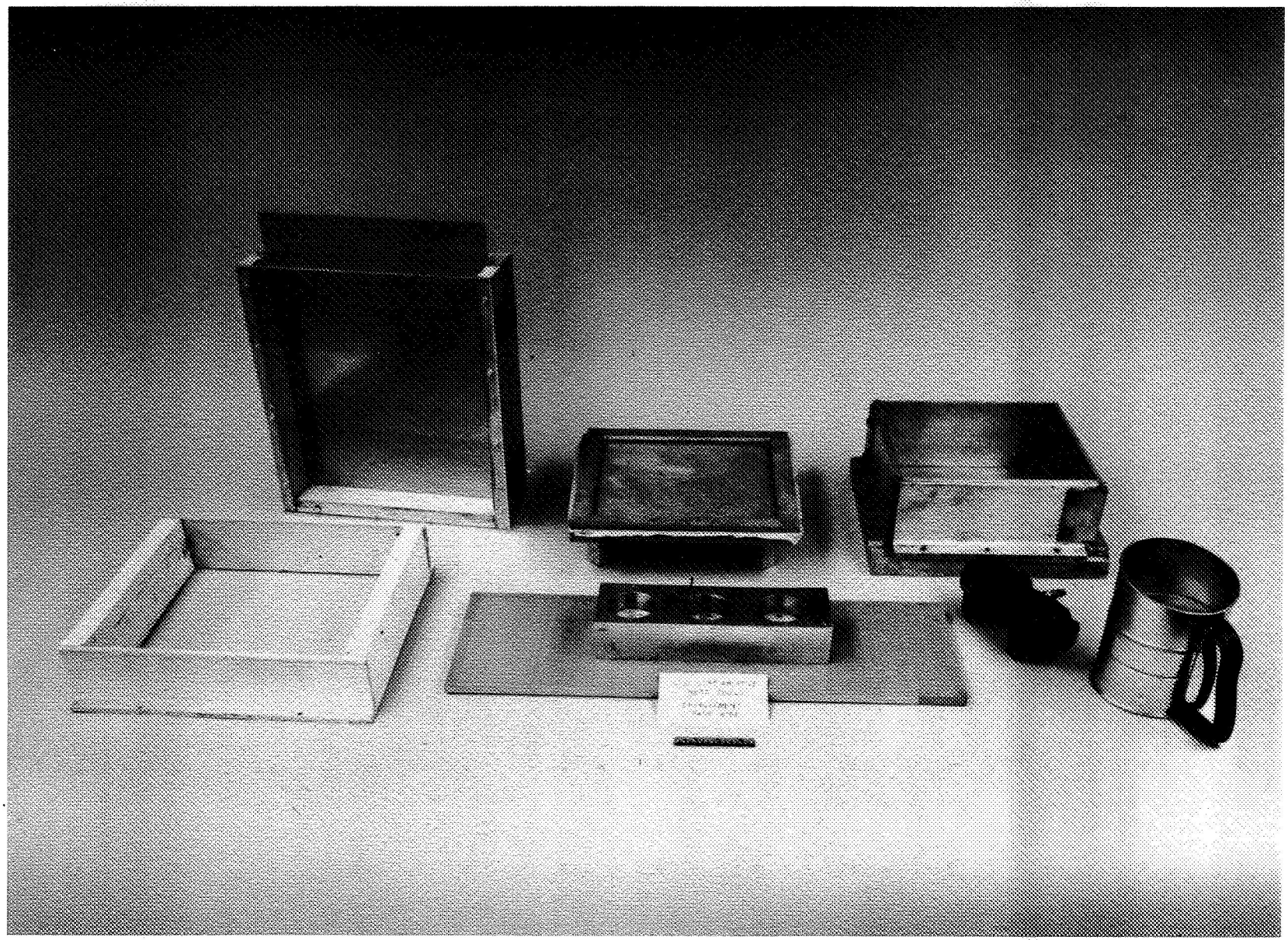


Figure 5. - Shop Aids

700-86-954

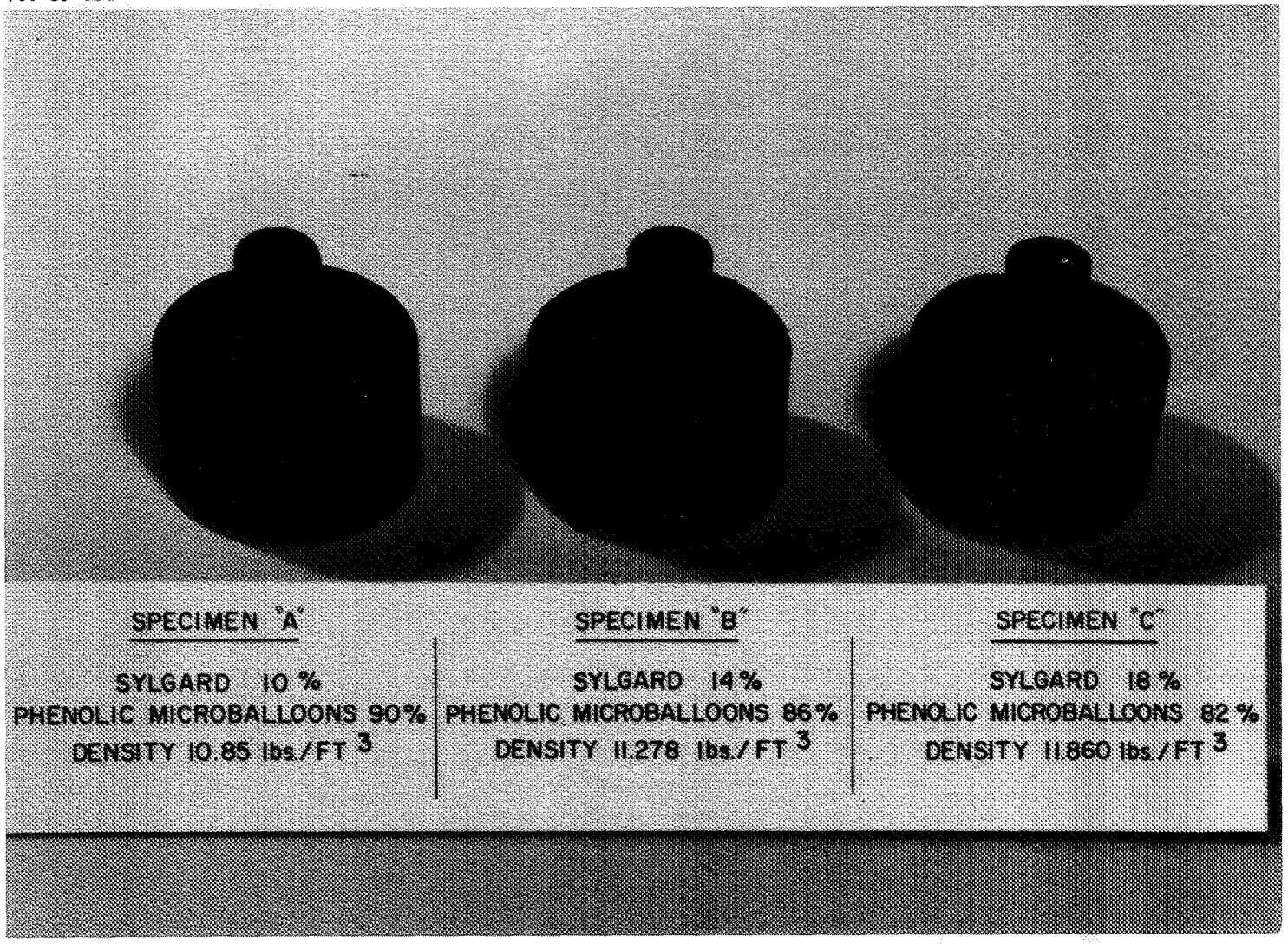


Figure 6. - Densities of Low-Density Elastomeric Compounds

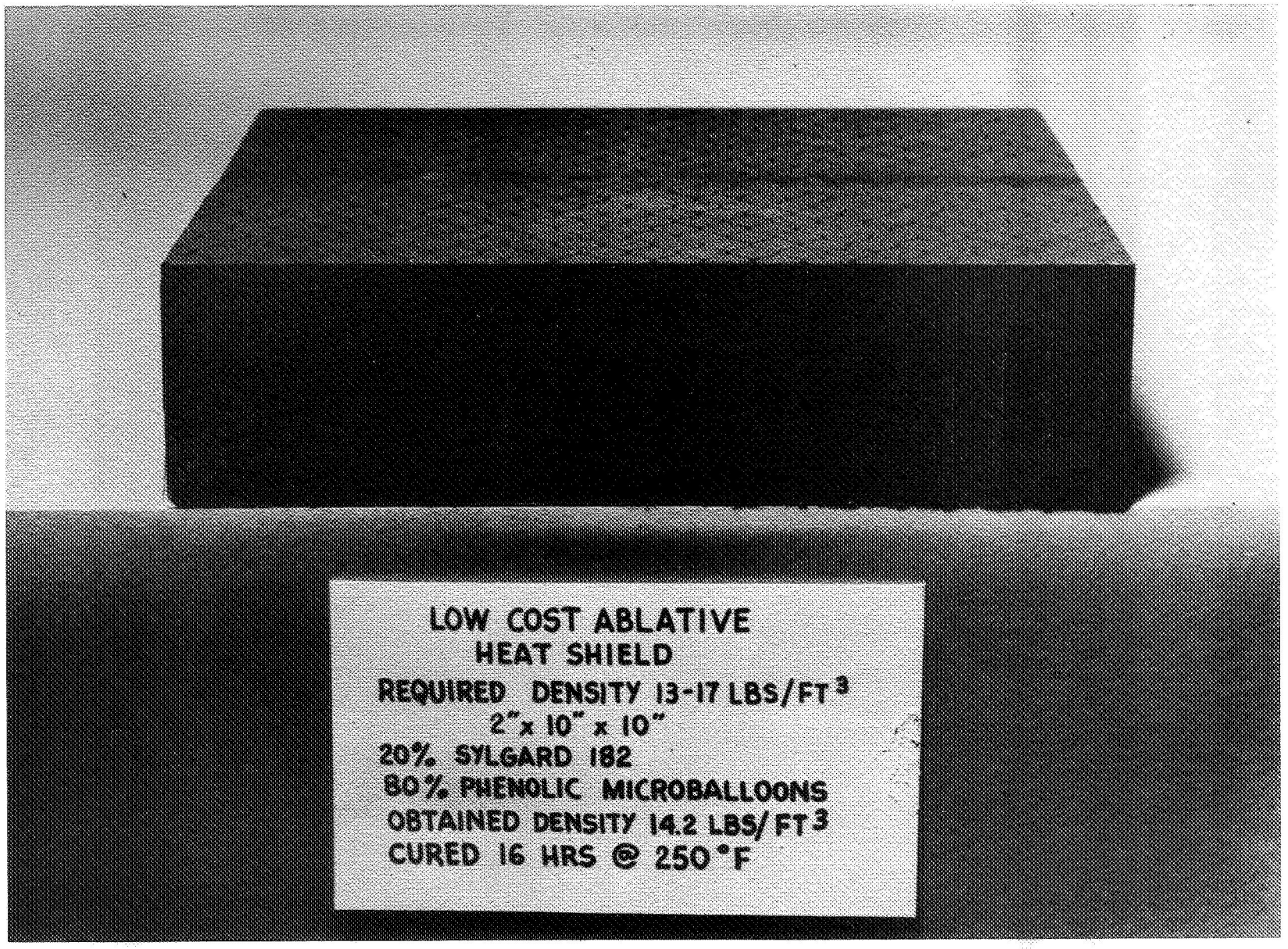


Figure 7. - Low-Density Elastomeric Specimen

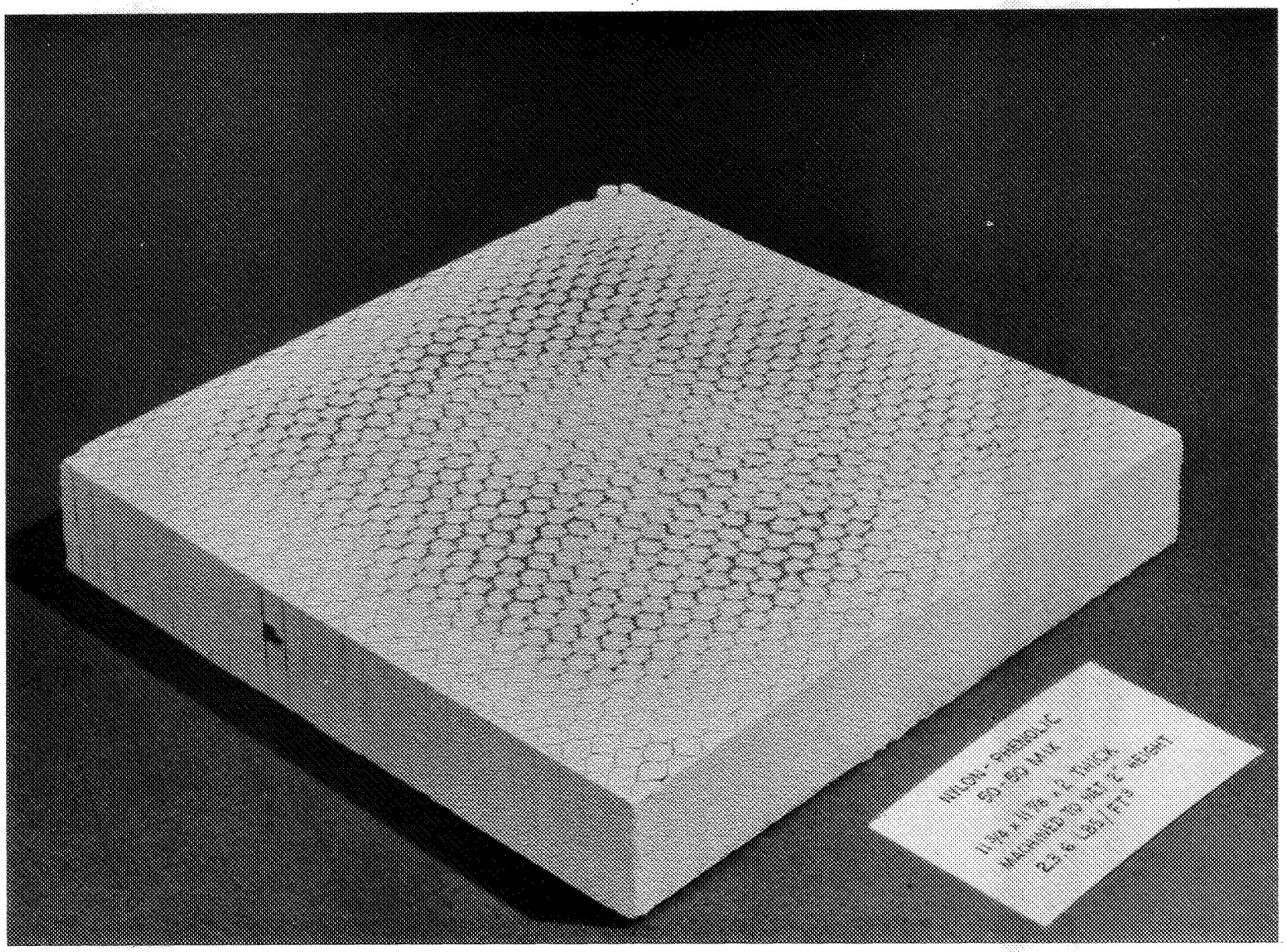


Figure 8. - High-Density Nylon-Phenolic Specimen



Figure 9. - High-Density Elastomeric Specimen

700-81-1384

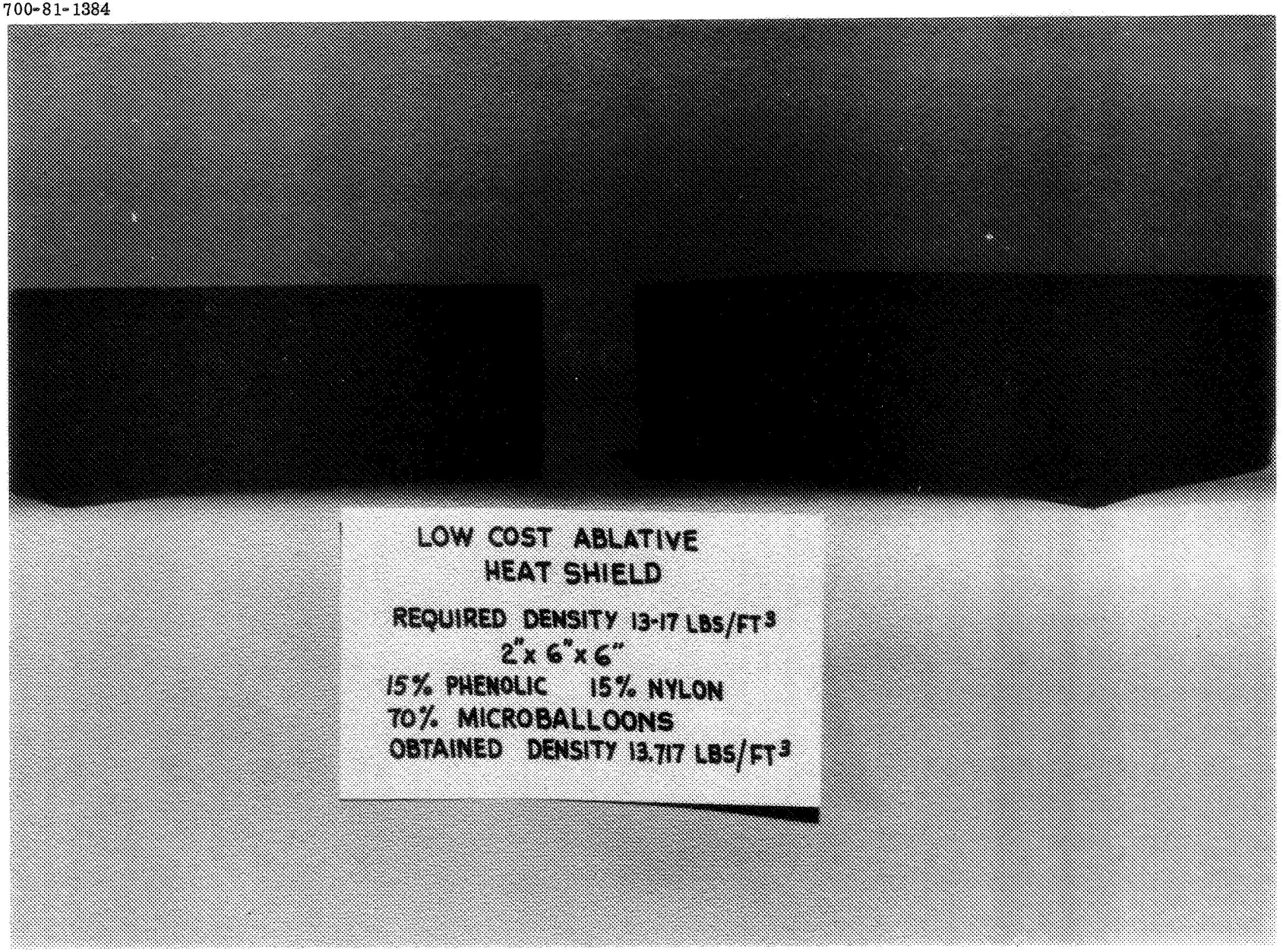


Figure 10. - Low-Density Nylon-Phenolic Specimen

DELIVERABLE PANEL FABRICATION

The major objectives of this part of the program were (1) to fabricate and deliver four flat and four curved panels made of the four material compositions, and (2) to provide qualified cost-estimating data for manufacture of various quantities, shapes, and sizes of panels as requested by the NASA/LRC RFP. This section is the culmination of the development and test operations described in the preceding section. Figure 11 shows the dimensions and configurations of a typical flat panel. A typical curved panel is shown in figure 12. In figure 13 are the details for the two types of plugs.

To fabricate the deliverable panels, additional baselines were necessary because of the large panel size. The honeycomb panel size was 26 by 50 inches in order to allow a one-inch trim on all four edges after each panel had been filled and heat cured. The six plugs required for each panel were fabricated from the material trimmed from the edges. The trimmed panel edges were fairly good indicators of how well the total panel had been filled and compacted.

The scheduled sequence of panel fabrication suffered a few setbacks which were primarily caused by scale-up from test specimen size to large panels. However, through logical evaluation of the "cause-and-effect", plus redirection in the method of approach, the panels were remade to an acceptable status. The major detrimental aspects were panel warping after cutting, core crushing during filling and compaction, and incomplete filling of the core cells.

On the other hand, several unique fabrication devices were realized as a result of the program. One innovation was a low-cost drying system developed to dehumidify or demoisturize ablative materials before mixing (see fig. 14 and 15). Another was the use of a "tackyless" nitrite uncured rubber (fig. 16) mounted on an Ensolite blanket, to compact each of the two phenolic-nylon powder mixtures into the honeycomb. A third was the concept of using silicone rubber end rails that were satisfactory for panel bagging in the flat and transferring to a curved curing tool. The panel densities and general remarks are shown in table 6.

TABLE 6.- PANEL DENSITIES

Composition	Type of Panel	Required Density (lb/ft^3)	Actual Density (lb/ft^3)	Remarks
Elastomeric 20-80	Flat	13-17	14.5	Excellent quality. Best dimensional stability.
	Curved	13-17	14.6	Best dimensional stability - made on springback compensated tool (18-1/2 inch radius) surface sanded.
Elastomeric 67-33	Flat	25-30	27.3	Rejected due to underfilling and distortion
	Flat	25-30	29.35	Bowed 9/16 inch in 4-foot length
	Curved	25-30	28.5	Rejected due to underfilling and distortion
	Curved	25-30	28.97	Made on spring-back compensated tool. Has some cells slightly underfilled.
Nylon-phenolic 15-15-70	Flat	13-17	14.5	Very fragile - required resurfacing; slight convex bow
	Curved	13-17	14.4	Excellent quality even though fragile - no resurfacing used.
Nylon-phenolic 50-50	Flat	25-30	28.9	Rejected due to core crushing 1-7/8 inch thick (fig. 17)
	Flat	25-30	26.1	Very good quality; slight concave bow
	Curved	25-30	25.2	Core splitting caused surface defects which were repaired (fig. 18)

Tooling

Where possible, aluminum was used for tooling. Whereas most of the test specimens were fabricated with expendable shop-aid type of tooling, the 2 by 4 foot panel fabrication necessitated more rigid tooling to meet the size, handling, compacting, and curing requirements. The designs of all tools fabricated for the program are included in this report.

The mechanical portion of the system developed to dehumidify ablative materials is detailed in figure 19. By using a vacuum and heat principle, measurable quantities of moisture were removed from the microballoon and powder materials.

The pan shown in figure 20 and detailed in figure 21, was used for both the silicone room-curing and the phenolic heat-curing primers. The pan was filled to a specific depth; the honeycomb was placed in the pan; and then all excess liquid was drained and saved for the next priming operation.

Two honeycomb-fill fixtures were required - one for the flat panels (3/8-inch hexagonal cells) and one for the curved panels (3/8-inch over-expanded cells). The fixture shown in figures 16 and 22 was used for the fill operation and for the final cure of the flat panels. The fill fixture for the curved panels (filled in the flat mode) is shown in figures 23 and 24.

The fixture shown in figures 25 and 26 was used in the core-to-skin bonding operations for both panel configurations.

Final cure of a curved panel, after it had been filled and compacted in the flat condition, was performed on the tool shown in figures 27 and 28.

The tooling philosophy specified for this program was low cost, ease in setup, reusability, low weight, and adaptability. During the program, evaluation of the tools proved the soundness of this philosophy.

Materials and Mixing

Honeycomb core. - Two basic types of honeycomb configuration were used in the panel fabrication: (1) 3/8-inch hexagonal and (2) 3/8-inch over-expanded (OX). All cores supplied by Hexcel Products were of inferior quality. Because of schedule commitments, it was decided to rework the cores or to purchase on-the-shelf materials with slight deviations to the original purchase requirement.

The detailed descriptions for the two types of purchased cores are as follows:

1. HRP-3/8 - GF11-2.2 Density, 2 inch thick
2. HRP-OX - GF11-2.7 Density, 2 inch thick

The ribbon direction (26 inches for projected 2 inch trim-off) was spliced with a phenolic resin to meet the 26 inch requirement. In the case of the OX core, two splice joints were performed by Hexcel. The phenolic splices were foamy and extended into the adjacent cells. These poor quality joints were removed and re-spliced with either Bloomingdale HT-424, an epoxy-phenolic core splice material, or Shell Epon 954, a room-temperature curing modified epoxy for high-temperature application. The re-splicing operation was conducted on the OX cores only (for curved panels), whereas the hexagonal core was butt jointed (without use of a secondary adhesive) with the original joint removed.

This operation resulted in a loss of two hexagonal core-to-face sub-assembly panels. Consequently, the on-the-shelf buy was started requiring a deviation. The plus factor for the new core was that it was free of splice joints (one piece). This core was identified as HRP-3/8-GF12-3.2, which was one pound per cubic foot heavier than the original. The one-piece 3.2-pound cores were subsequently used for both flat panels of the low-density formulations.

Face sheets. - Three candidate epoxy types of prepreg materials were evaluated for flatwise tensile strength at 300 F after 10-minute exposure. The selected prepreg material, Reliabond R1714, was most consistent in terms of strength reproducibility. The weight of the cured single-ply laminate was 0.05 pound per square foot; and even with a 3-ply laminate, it was determined that the maximum weight requirement of 0.18 pound per square foot posed no difficulty.

The R1714 material is a nitrile epoxy system impregnated on a 3-ounce open-weave boat-cloth type of fabric. Typical adhesive additives, such as thioarsenate aluminum powder, titanium dioxide, and the like, were purposely eliminated to reduce opacity and to obtain translucency to visually inspect the honeycomb-to-face bond. The open-weave 3-ounce boat cloth was used to enhance porosity in order to prevent air entrapment during the ablative fill operation.

Other attributes of the selected R1714 prepreg system are as follows:

1. Has good drapability and sufficient tack for laminating into compound contours.

2. Can be stored under ambient conditions for over two weeks without apparent loss in tack, drape, and mechanical properties.

3. Demonstrated toughness and high peel to resist delamination or disbond from the core, especially on sharp corners.

4. Uncured prepreg can be compositely cured with the uncured phenolic resin system without any inhibition of both polymer systems, eliminating multiple-stage bonding on future ablative programs.

5. Coupled with the excellent shelflife condition of prepreg, the material will cure at temperatures as low as 170 F for 12 hours and up to 350 F for 1/2-hour exposures.

Elastomeric compound (high density). - The 67/33 formulation consisted of 67 parts by weight (pbw) of Dow Corning Sylgard 182 (including 10-percent curing agent) and 33 parts by weight of phenolic BJO-0930 microballoons (see fig. 29). A homogeneous mixture was obtained by using the vertical helicone mixer. The mixing procedure was as follows:

1. The Sylgard 182 resin was first hand mixed for 10 minutes with the catalyst in the following quantities: 819 grams of resin and 81 grams of catalyst.

2. The premixed material (900 grams) was then hand mixed with 450 grams of predried phenolic microballoons (BJO-0930) for 5 minutes.

3. The 1350-gram total (2.97 pounds, capacity of the mixer) was then mixed in an Atlantic Research mixer, Model 8CV (fig. 10) for 24 minutes, alternating the forward and reverse motion of the blades every 6 minutes.

4. The procedure was repeated 14 times to arrive at the required amount of at least 40 pounds mixture.

5. Each batch as mixed was stored in a double polythylene container marked with the batch number, weight, and date of mixture, and stored in the freezer at 0 F until ready for use.

The volume displacement of the honeycomb skin to the final density obtained in the actual panel was ignored on all ablative systems. The calculated value of the NR-selected honeycomb/skin ranged in percent volume displacement from 2.8 to 3.5, which was equal to the percent weight loss

found after cure of the various ablative materials. The calculated weight loss of the ablative materials after cure ranged from 210 to 540 grams. In the most severe condition, these figures represent an unpredictable anomaly of the final density of 0.2 pound per cubic foot. Therefore, the target density was based on the total weight of honeycomb/skin plus the weight of the actual ablative material.

The 67/33 material can exceed the maximum density requirement because the bulk density of the compound itself was determined to be 26.5 pounds per cubic foot. A 1000 ml container was used to determine the bulk density. The material was lightly hand-packed into the container to ensure that no gross voids were present. The calculation used was as follows:

$$\frac{\text{Gram weight of hand-packed material}}{1000\ \text{ML}} = \frac{x\ (\text{measured bulk density})}{62.4\ (\text{cubic foot of } H_2O)}$$

Because a variation of 0.2 pound per cubic foot due to displacement and weight loss was possible, the target density selected for the flat panel was 29.8 pounds per cubic foot. The lightest weight honeycomb/skin weight (2.8 pounds per cubic foot) was selected for use, which should result in a compaction change from bulk density to final density of only 0.5 pound per cubic foot. Fortunately the final density result was 29.4 pounds per cubic foot before trim and 29.1 after trim. See figures 30, 31, and 32.

The honeycomb/skins for the curved panels were in the range of 3.5 pounds per cubic foot, which could result in a final density of 30.3 pounds per cubic foot, providing that compaction could be controlled once again to 0.5 pound per cubic foot. The final density attained was 30.1 pounds per cubic foot with incomplete fill. See figure 33.

The cure temperature was changed from the specified 250 F on both (67/33 and 80/20) elastomer systems after approval was received from cognizant NASA personnel. Consultation was first initiated with Dow Corning in regards to lowering the cure temperature to the range of 180 F since the published brochure claimed that full cure may be started as low as 150 F.

The problem encountered at the higher temperature was the result of warpage in the flat panel. Since it was understood that the elastomer material had a minimum shrinkage and was characterized by a higher coefficient of thermal expansion than that of the honeycomb and face sheet, it was obvious that the problem was that of expansion and contraction. For this reason, a higher temperature cure will tend to further augment the degree of distortion. By reducing the cure temperature, the warpage was reduced from a 1 3/4-inch midspan (fig. 34 and 35) offset (in a 4-foot length) to 9/16 inch (fig. 36).

Elastomeric compound (low density). - Mixing of the 90 pbw microballoons-to-10 pbw Sylgard 182 formulation specified in the contract resulted in a non-homogeneous, flaky mixture. In addition, the minimum panel density of 13 pounds per cubic foot was not obtained after repeated tries with the hexagonal core of 2.2 pounds per cubic foot.

After a contract change from 90/10 to 80/20 mixture was requested, acceptable subscale panels were fabricated. The actual bulk density for the 80/20 mixture was 12 pounds per cubic foot in comparison to 10 pounds per cubic foot for the 90/10 formulation. Therefore, with the 2.8 pounds per cubic foot honeycomb/skin combination and the 80/20 mixture, the minimum density of 13 pounds per cubic foot was attainable. The final density obtained on the flat panel was 14.5 pounds per cubic foot (see fig. 37 and 38) and 14.6 pounds per cubic foot on the curved panel (see fig. 39 and 40).

The mixing procedure was the same as that used with the high-density elastomeric compound except for the formulation weight changes and batch size. The batch size per mixer load was 1.5 pounds and approximately 12 batches, or 18 pounds, were required per panel.

Nylon/phenolic compound (high density). - This formulation consisted of 50 pbw Polymer Corporation Polypenco 66D (nylon) and 50 pbw Union Carbide BRP 5549 (phenolic powder). The measured bulk density to obtain 27 pounds per cubic foot was approximately 18 pounds per cubic foot. However, this material when fabricated under a zero-void condition can obtain a density of 70 pounds per cubic foot. Under the one atmosphere molding condition (without honeycomb core), a density of 32 pounds per cubic foot was obtained.

It was apparent that the difficulties encountered earlier in the program at NR in not meeting the minimum density were due to inadequate compaction caused by the restriction of the honeycomb sidewall. Consequently, by using the pre-compaction putty assist method, the density range of the contract requirement was soon achieved.

The intermittent voids caused by agglomerates of the phenolic powder can be attributed to improper mixing of the compound. The subscale panels appeared to be uniform and free of voids, and only the full-scale panels exhibited this sporadic pitted condition. The only noted difference between the two mixes was that of quantities mixed in the one-cubic-foot twin shell blender. Mixing of the subscale panel occupied less than one-third of the container, whereas the full scale panel mixes occupied about half of the container. Once again, due to schedule commitments, optimum parameters were not initiated.

Each batch consisted of 1500 grams of phenolic resin (BRP-5549) and 1500 grams of nylon (Polypenco 66D) mixed in a Patterson Kelly Twin Shell Blender (see fig. 11) for 42 minutes at 25 rpm. The procedure was repeated

six times to arrive at the required amount of at least 40 pounds of mixture. Each batch as mixed was stored in a double polyethylene container marked with the batch number, weight and date of mixture and stored at room temperature until ready for use. Final density obtained was 26.1 pounds per cubic foot (see fig. 42 flat panel) and 25.2 pounds per cubic foot on the curved panel (see fig. 43).

Nylon/phenolic compound (low density). - The low-density nylon phenolic formulation required 15 pbw of nylon, 15 pbw of phenolic, and 70 pbw of phenolic microballoons. Since this was the last of the compounds to be investigated, extensive knowledge and experience had been acquired while working with the preceding formulations, the problems encountered were relatively minor.

Because of the high concentration of the microballoons the mixture was very loose; and, although attempted, pre-compaction resulted in spring-back. Care must be taken to obtain uniform fill by vibration to obtain a maximum fill condition. Even under the one atmosphere pressure, the material will compact to a higher degree than the 50/50 formulation. In order to obtain the proper density, the bagging technique is highly important in preventing binding and/or bridging of the bleeder and bag material for free movement during the cure operation.

The mixing procedure consisted of mixing 225 grams of phenolic with 225 grams of nylon and 1050 grams of phenolic microballons in a Patterson Kelly Twin Shell blender for 42 minutes at 25 rpm. The procedure was repeated six times to arrive at the required amount of at least 18 pounds of mixture. Each batch as mixed was stored in a double polyethylene container marked with the batch number, weight, and date of mix and stored at room temperature until ready for use. The final density obtained on the flat panel was 14.5 pounds per cubic foot (see fig. 44) and 14.4 pounds per cubic foot on the curved panel (see fig. 45).

Edge sealing compounds. - During the final trim operation of the first flat 80/20 elastomer, the ablative material exhibited relatively poor cohesive and adhesive properties. For this reason, a request was submitted to the NASA/LRC program office for permission to incorporate a protective coating around the edges of all panels. Permission was granted. The compound selected to protect the elastomer ablative material was Dow Corning Silastic 184, a room-temperature-curing silicone rubber similar in chemical properties to the Silastic 182.

A room-temperature curing epoxy/polyamide (nylon) system was used to coat the nylon/phenolic ablative panels. The material consisted of 40 pbw of Epon 812 (Shell Chemical epoxy resin) and 60 pbw of Versamid 125 (General Mills polyamide resin). The higher ratio of the polyamide resulted in a flexible cured polymer.

Fabrication

The operations for all panels (curved and flat) were relatively similar up to the point of filling with the ablative materials. The four elastomer honeycomb panels were bonded with one ply of the epoxy prepreg, and the four nylon/phenolic (NP) panels were bonded with two to three plies of the prepreg material. Correspondingly, the elastomer panels were primed with Dow Corning DC 1203, a silicone primer, while the NP panels were primed with dilute Monsanto SC-1008 phenolic resin.

Tooling application. - A simple 3/4-inch-thick aluminum base plate with 2-inch aluminum angle frames (to prevent core crushing) bolted to the base plate was used to bond all facing sheets to the core. This tool is illustrated in figure 25.

Since the fill tool was planned for usage during cure and handling up to the point of final machining, it was decided that two tools would be required to meet the delivery schedule. In order to reduce cost, the flat panel tool was less complicated than the tool for the curved panel. See figures 22 and 23. Four-inch angle frame with localized welded gussets was used for the flat panel tool, while the curve tool employed two sets of 2 by 2-inch aluminum bar stock with 2- by 2-inch cast RTV on the bottom edge members (width) for curving purposes. Except for bolt holes in the 3/4-inch thick base plate for mounting the edge members, all other members were interchangeable. These included the perforated 3/4-inch cover plate with handles and the remaining shim stocks. An additional 3/4-inch-thick top platen plate was fabricated to compensate for the variations in flatness condition of the production press platen.

Two forming tools (curve tool) illustrated in figure 27 were fabricated to perform the forming and curing operations for the curved panels. I-bolts were equally spaced on each side of the tool for the "avi-strap" lagging operation. The edge member with the RTV rubber ends from the flat fill tool made the final constituent of this tool. The two tools differed only in curvature: 18.5-inch radius (undersize) and 22-inch radius (net). The choice of a 18.5-inch radius tool was made through analysis of a subscale elastomer panel.

Flat panel fabrication - elastomer. - The process for the 80/20 and 67/30 elastomeric formulations in relation to filling, pressing, and curing were identical.

The fill operation was initiated in the single-edge fill tool less the core-to-face sheet assembly. A predetermined amount of material was added

after a pelletizing (1/4-inch metal mesh screen) operation to assure uniformity. Leveling was assured by using a graduated adjustable doctor blade with stops resting on the top surface of the tool as the guideline.

The tool with the ablative material was then transferred to the platen press (see fig. 46 and 47) and compressed to within 0.100 to 0.125 inch of the measured honeycomb/face sheet thickness (2.000 to 2.035 inches). This was accomplished with the 3/4-inch perforated cover plate (with handles) with teflon lining and pre-calculated shims pressing to stops. In all cases, no more than 10-psi pressure was required for compaction.

The plate and shims were then removed and inspected for fold-overs and wrinkles. The low spots were then filled with excess material by using a spatula. The 80/20 formulation did not require filling, whereas the 67/83 mixture required as much as 300 grams of secondary fill material.

The one-ply bonded honeycomb assembly was then placed over the elastomeric material with the honeycomb side down for the "cookie" cutting operation. One ply of tailored 3-mil porous Teflon fabric and one ply of 8-mil Dacron fabric were superimposed over the facing sheet for venting during the "cookie" cut operation.

The cover plate was placed over the Dacron fabric, and re-calculated shims were added for compression to within 0.030 to 0.050 inch of the final desired thickness. This "cookie" cutting operation employed the multiple ramming technique (bumping of the press platens for assuring bleed-out of trapped air) and from 40 to 80 psi before closing to stops at the predetermined thickness.

Before opening the press, the pressure was increased to 100 to 125 psi on the stops and held from two to five minutes to prevent spring-back and to obtain the proper nesting.

Immediately after removal from the press, the tool with the cover plate in place was transported to the oven area for bagging. The cover was removed, and the necessary deflashing, cleanup, and visual inspection operations were performed. The second ply of the uncured epoxy prepreg was laid up over the cured facing by aid of a heat gun and Teflon squeegee paddle.

Bleeder/release fabric or fabrics were laid over the epoxy prepreg along with a thin metal caul sheet, and the assembly was bagged and cured with the facing side up.

After removal from the tool, the panel was trimmed, trepanned, and edge sealed according to standard shop practices.

The warped condition of the 67/33 panel can be further improved by reversing the node or ribbon direction. On a typical hexagonal core, the ribbon direction is much stiffer than the opposite direction. The honeycomb delivered from Hexcel exhibited ribbon direction parallel to the width; consequently, the length was much more prone to bending.

Curved panel fabrication - elastomer. - The two-piece edge-member tool was used on the curved panels. A thin aluminum sheet (0.020 inch) was placed between the edge member and the 3/4-inch base plate. The aluminum sheet (bottom caul) was approximately 2 inches longer and 4 inches wider than the projected panel. Holes were stamped on the caul sheet to match the bolt holes of the edge members. Between the bottom caul and base plate an Armalon (Teflon-coated fiberglass) sheet was sandwiched for gliding purposes.

All operations for the curved panels were identical to those of the flat panels (including the "cookie" cutting) until the second-ply laminating operations.

After removal from the press, the cover plate was removed and a full sheet of 5-mil polyvinyl chloride (PVC) was placed on top of the uncured epoxy prepreg. The PVC extended the full width of the base plate, folding completely over the side members. The cover plate was installed over the PVC and C-clamped to the base plate. This operation was necessary; otherwise the panel would lift or edge curl from the tool upon removal of the top section of edge members.

The top edge members were carefully removed, and the PVC was putty sealed to the 20-mil bottom caul. The attachment holes on the caul sheet were sealed with a metal masking tape by sliding the sheet with the panel in place, releasing the C-clamp pressure, and gliding away from the base plate with assistance from the Armalon fabric.

Since the face sheet was still face upward, a "flip-flop" operation had to be performed so that the face sheet would be in the bottom position on the curve tool. The panel was stabilized for "flip-flopping" after the PVC bag was sealed to the bottom caul sheets, which completely enveloped the edge members and the panel.

The entire envelope became relatively stiff after evacuation, and the C-clamp and cover plate were removed. The envelope was then "flip-flopped" (the PVC on the tool surface with the metal caul plate facing up) onto the curve tool and positioned to center lines. The vacuum was released slowly at which time the panel became flexible and seated to within 1/2-inch on both sides.

The PVC/sealant putty was released from the metal caul plate and the plate was removed, exposing the ablative material. The PVC was trimmed around the periphery of the edge members. The remaining PVC between the facing sheet and the curved tool surface later served as the release film after curing of the ablative material.

Three equal sections of 20-mil Teflon-lined caul sheets, sized to seat 1/8-inch inside the curved edge members were substituted for the removed caul plate. Avistraps were harnessed to the eye bolts, alternating tensions from strap to strap and back; operations were repeated until complete contact of the panel to the tool was assured. See figures 48 and 49 for arrangements of caul sections and straps.

Starting from one end, the straps of the section were removed along with the caul sheet. Once again a section of the elastomer was exposed. The elastomer was inspected for separation from the cell walls, and additional elastomeric material was roller coated. However, in most cases small amounts of the elastomer, from one area or section, were replaced in the areas requiring additional filling. This operation was repeated on the other two sections while strap tension was maintained on the remaining two sections at all times. The 80/20 panel was free of separation or low spots and did not require re-shuffling of the elastomer.

After all of the sections were reworked and the strap operation repeated, standard bleeder fabrics were installed and the assembly was bagged and cured. The bag was removed after cure, and the parts were trimmed, trepanned, and sealed for final inspection.

As stated in the tooling discussion, the elastomer curved panels were formed and cured on the lower dimensioned (18.5-inch radius) tool. No apparent spring-back was noted on the 80/20 panel. However, the 67/33 panel moved to within 1/4-inch of final dimension.

Flat panel fabrication - nylon/phenolic (NP). - The processes for filling, pressing, and curing operations of the 15/15/70 and the 50/50 nylon-phenolic (NP) compounds were identical.

The honeycomb to face sheet assembly was completely masked with a pressure-sensitive tape on the face sheet surface with additional double-faced pressure-sensitive tape continuously on all four peripheral surfaces.

The masked assembly was hand-pressed into the single edge fill tool, honeycomb side up, making the double-faced pressure-sensitive surface contact the base plate.

The tool with the unfilled panel was placed on a vibrator platform (fig. 50), and approximately 80 percent of the dry powder was poured in the honeycomb cells under vibration. This procedure resulted in about an 1/8 to 1/4-inch overfill, which was troweled to uniform thickness with the adjustable doctor blade. The double-faced pressure-sensitive tape in intimate contact with the base plate prevented the NP material from sifting under the face sheet during the vibration operation.

A 1/2-inch-thick rectangular Ensolite blanket (polyurethane flexible foam) sized to the cover plate and laminated with 1/4 to 3/8 inch thick uncured, uncatalyzed putty was placed in the tool; the putty face was in contact with the NP material.

The cover plate and required shims were added, and the assembly was mounted in a press. Because of the unpredictable thickness of the Ensolite/ putty layer, the press operation was conducted under a positive (no stops) condition. The positive pressure for compaction ranged from 50 to 80 psi.

The shims and pressure plate were removed along with the Ensolite/ putty layer and one-half of the remaining 20 percent NP material was added. The tool was reassembled and the pressure was applied. The process was repeated until the NP material was expanded. The compaction operation was repeated only once on the 15/15/70 NP formulation since it was found that the material remained loose and resisted compaction.

After the final compaction operation, and removal of the plate, shims, and Ensolite/putty, a porous Teflon fabric was placed over the exposed NP material. The perforated cover plate was reinstalled over the Teflon fabric, and suitable bleeder fabrics were placed in various areas of the tool before bagging. It should be noted that, because of the condensation reaction of the phenolic during cure and the necessity to prevent binding or bridging of the bleeder fabric with the vacuum bag, placement of the bleeder cloth and the bagging procedure are highly critical in order to obtain the target density.

The final trim, trepan, and edge seal operation of the 15/15/70 were the most difficult to complete successfully. Consequently, several changes were incorporated in the curved panel and are discussed in the next section.

Curve panels - nylon/phenolic (NP). - The NP curved panels were processed the same as the NP flat panels, up to the press compaction operation, utilizing the double edge tool. As stated in the previous section, the 15/15/70 did not require the press compaction operation.

The double-edge tool was prepared in a way similar to the elastomer curved panel method with the bottom caul sheet and the Armalon glide sheet. After adequate compaction was confirmed (press method for the 50/50 and vibration only for the 15/15/70), the upper half of the edge members were removed. This operation was not preceded with the C-clamp hold-down method (used for the elastomer curve panels), since the facing sheet was on the bottom of the tool and secured by the double-faced pressure-sensitive tape to the bottom caul sheet.

A one-piece, Teflon-lined, perforated caul sheet (0.02-inch aluminum) was laid over the NP material. The caul sheet was tailored oversize on the width dimension to accommodate the dimension change due to "fanning" of the curved surface. The luxury of inspection after curving with the three-piece caul sheet, as performed on the elastomer panel, was not possible due to the loose and powdery condition of the NP material.

A PVC bag was installed over the top caul sheet and sealed with putty to the bottom caul sheet. The envelope was glided from the base plate with assistance from the Armalon and centered to the curve (22.0-inch radius) tool.

The envelope was strapped into shape in a way similar to the elastomer curved panel. When complete seating was assured, the PVC film was removed while the bottom caul sheet remained with the assembly.

Bleeder fabrics were installed over the top perforated caul sheets and around the edge members. The initial assembly was bagged and cured.

After removal from the tool the 15/15/70 panel was seal-coated on all edges and the trim areas of the top surface. Both panels were trimmed to final dimension, trepanned, and sealed. The preliminary seal coat operation prevented debonding and flaking of the material during trim.

In the following pages, step-by-step manufacturing fabrication procedures are listed for the four flat and four curved panels. The numbered operations correspond to the numbers shown in the sequence of operations illustrated in figures 51 and 52.

Problems and Solutions

Since most of the developmental problems and their solutions have been previously discussed, a condensed recapitulation of the problems and their solutions is presented in table 7.

TABLE 7. - RECAPITULATION OF PROBLEMS AND SOLUTIONS

Area	Problem	Solution
Materials and compounds	Mixing of 10-percent elastomer/90-percent microballoons.	Vertical helicone or ribbon blade mixer was used.
	Density of 10/90 composition too low.	Composition was modified to 20-percent elastomer/80-percent microballoons and precompacted.
	Density of 67/33 composition marginally high.	Elastomer content should be reduced in future.
	Density of 15/15/70 composition too low.	Powder was precompacted into core using vibration and/or pressed sealant technique.
	Density of 50/50 composition too low.	Powder was precompacted into core using vibration and pressed sealant technique.
	Core splices too wide and foamy.	All core splices were removed. Hexagonal core was nested without splicing. OX core was respliced and cured.
	OX core low in density with cell size distortion and variation; core crushed readily.	Additional prime coat was added. Improved core source should be investigated.

TABLE 7. - RECAPITULATION OF PROBLEMS AND SOLUTIONS - Continued

Area	Problem	Solution
	Hexagonal core (2.2 lb/ft^3) crushed during powder compaction.	Replaced with higher density core. Used reduced compaction pressure.
Panel fabrication	Underfilling with 67/33 elastomeric compound.	Increased filler content up to maximum density allowed.
	Excessive warpage when filled with 67/33 compound. Caused crack on curved panel.	Reduced cure temperature from 250 to 180 F. Elastomer content should be reduced. Undersize curved tool used to offset springback.
	Curved elastomeric panels are undersize in radius.	See above comments regarding 67/33 warpage. Both panels made on undersize tool. Springback occurred on 67/33 but not on 20/80 panel.
	Panel edges easily damaged after trimming.	All edges coated with flexible resin systems.
	Flat 50/50 panel, 1/8-inch too thin due to crushed core.	Replaced, using higher density core and less compaction pressure.
	Surface of 15/15/70 flat panel damaged.	Surface was sanded.
	Surface defects in curved 50/50 panel.	Surface defects removed by cleaning out, filling, recuring and filing smooth.
Cost accumulation	Extensiveness of panel development effort made accurate cost data accumulation very difficult.	Full-time industrial engineer assigned to take work measurements.

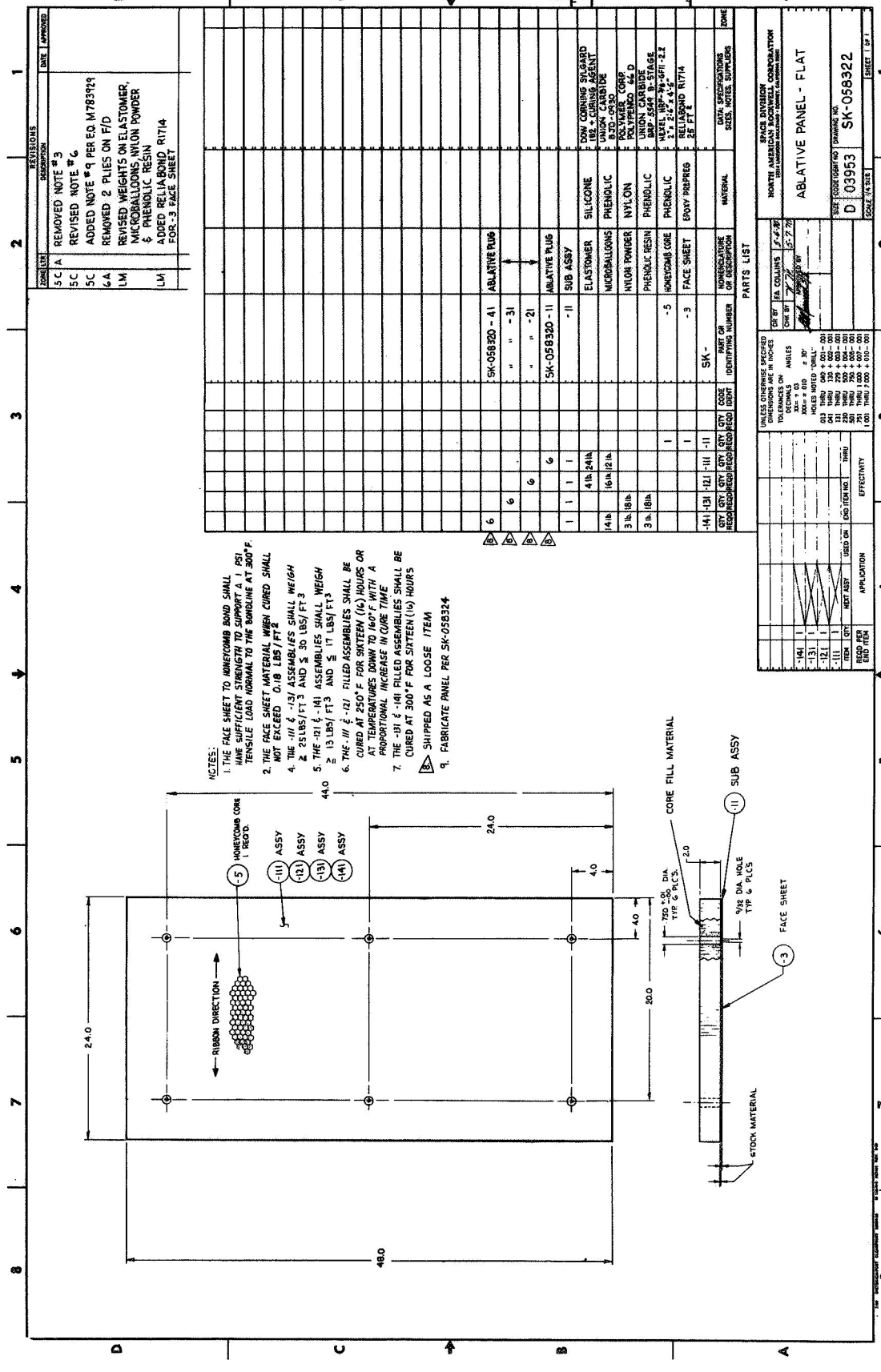


Figure 11. - Typical Flat Panel

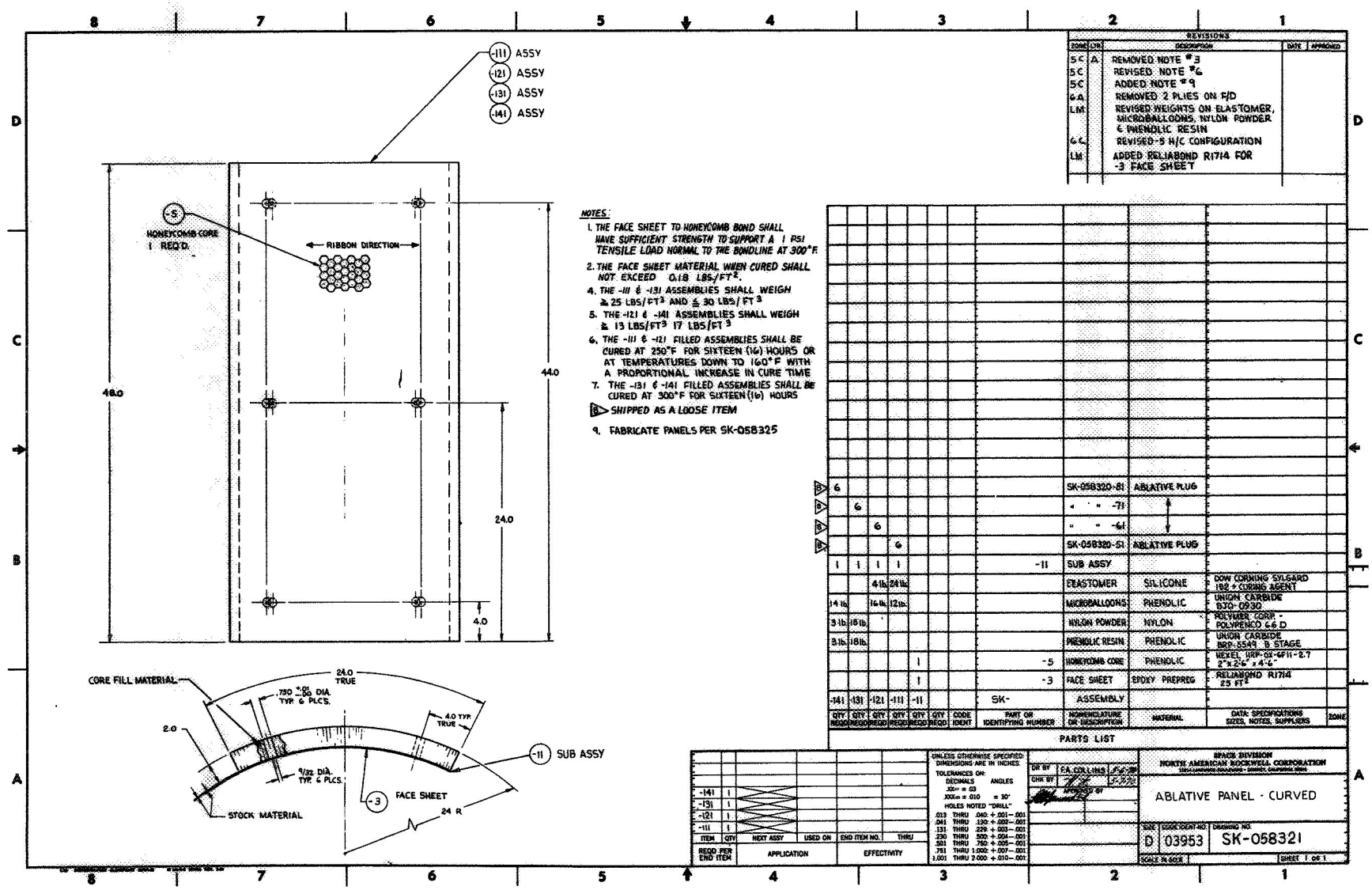


Figure 12. - Typical Curved Panel

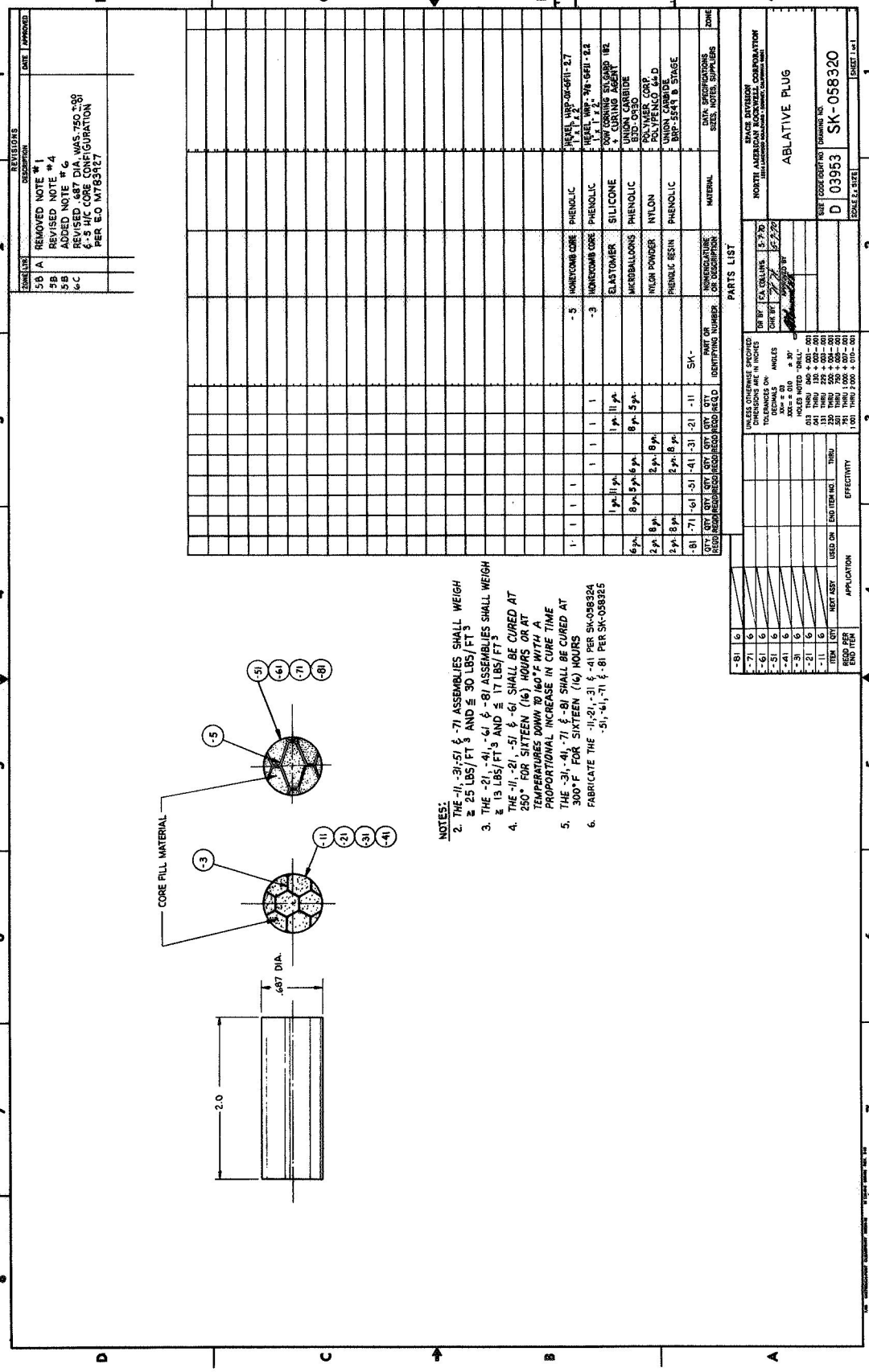


Figure 13. - Two Types of Ablative Plugs

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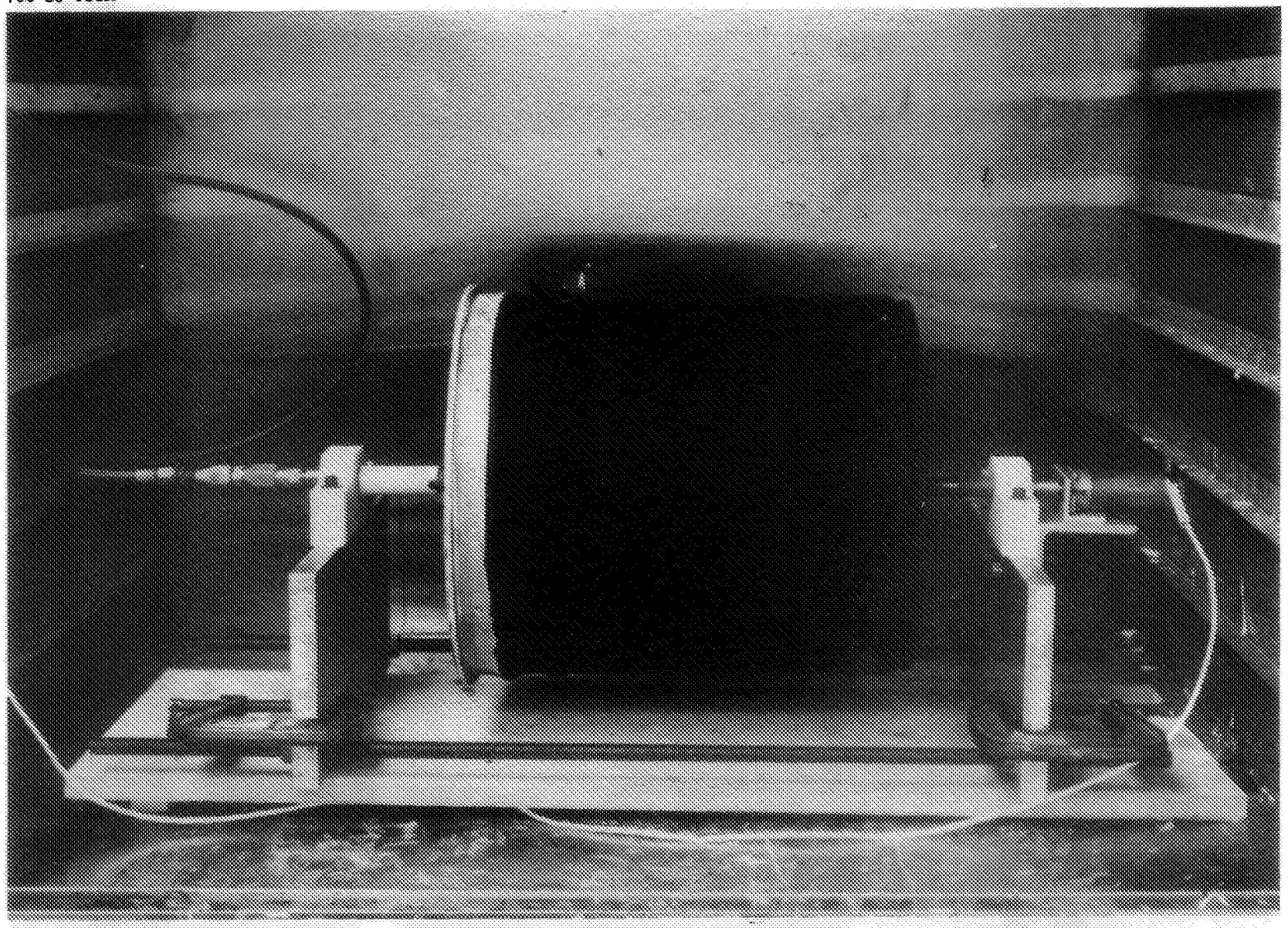


Figure 14. - Low-Cost Dehumidifier

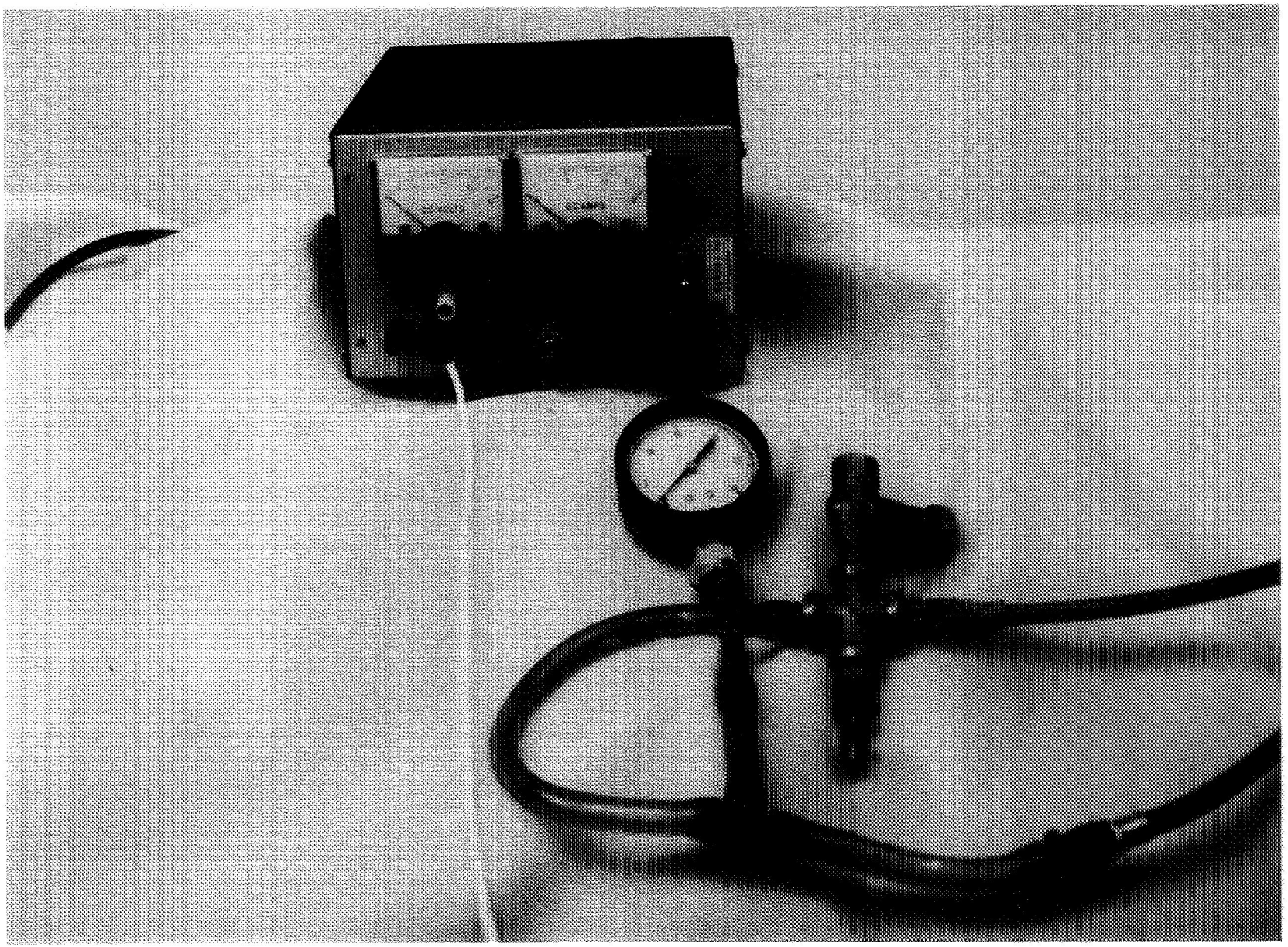


Figure 15. - Dehumidifier Apparatus

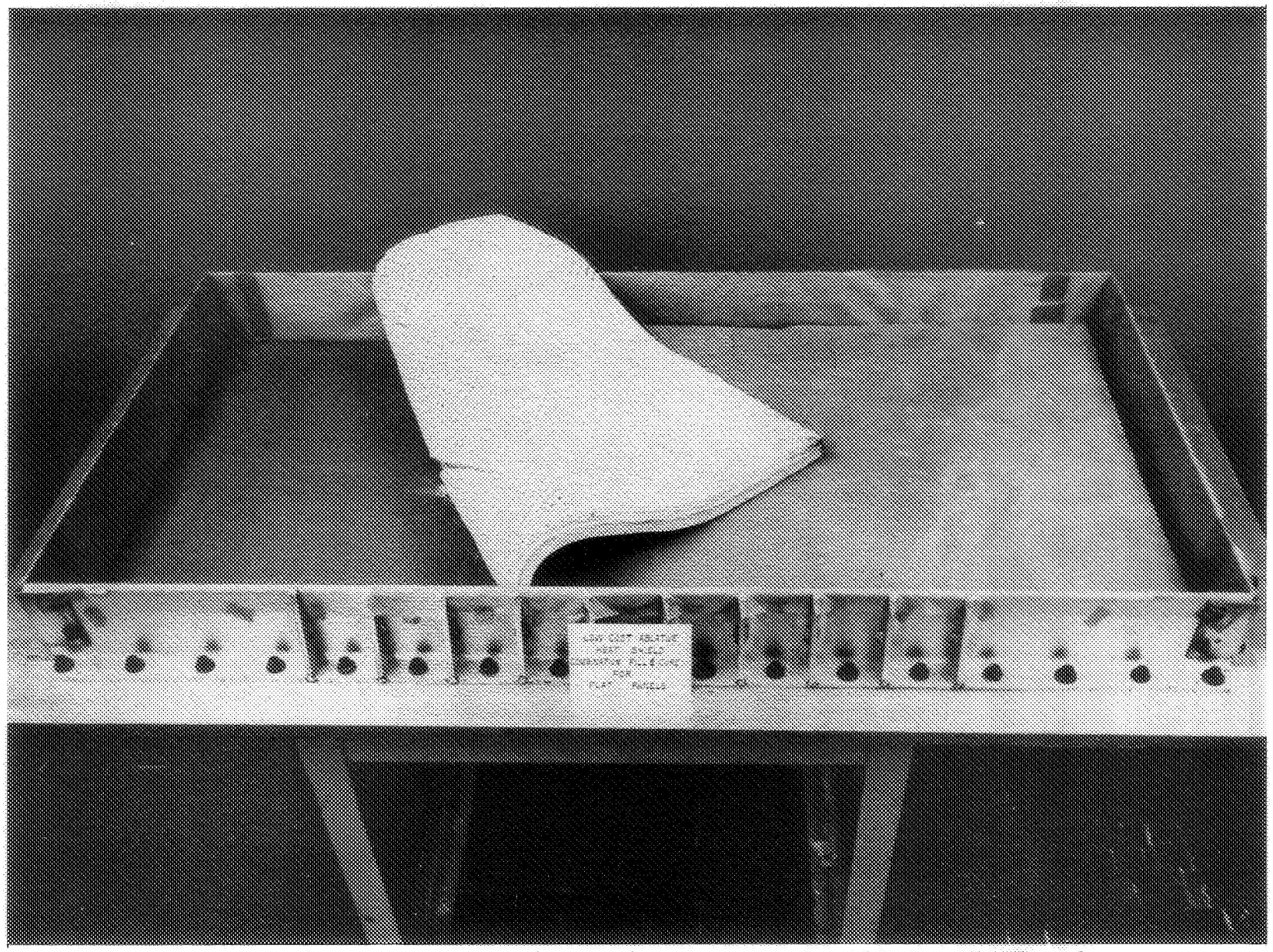


Figure 16. - Combination Fill and Cure Fixture for Ablative Flat Panel
(Compaction Blanket Shown)

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Figure 17. - Magnified Section of Crushed Core (Filled)

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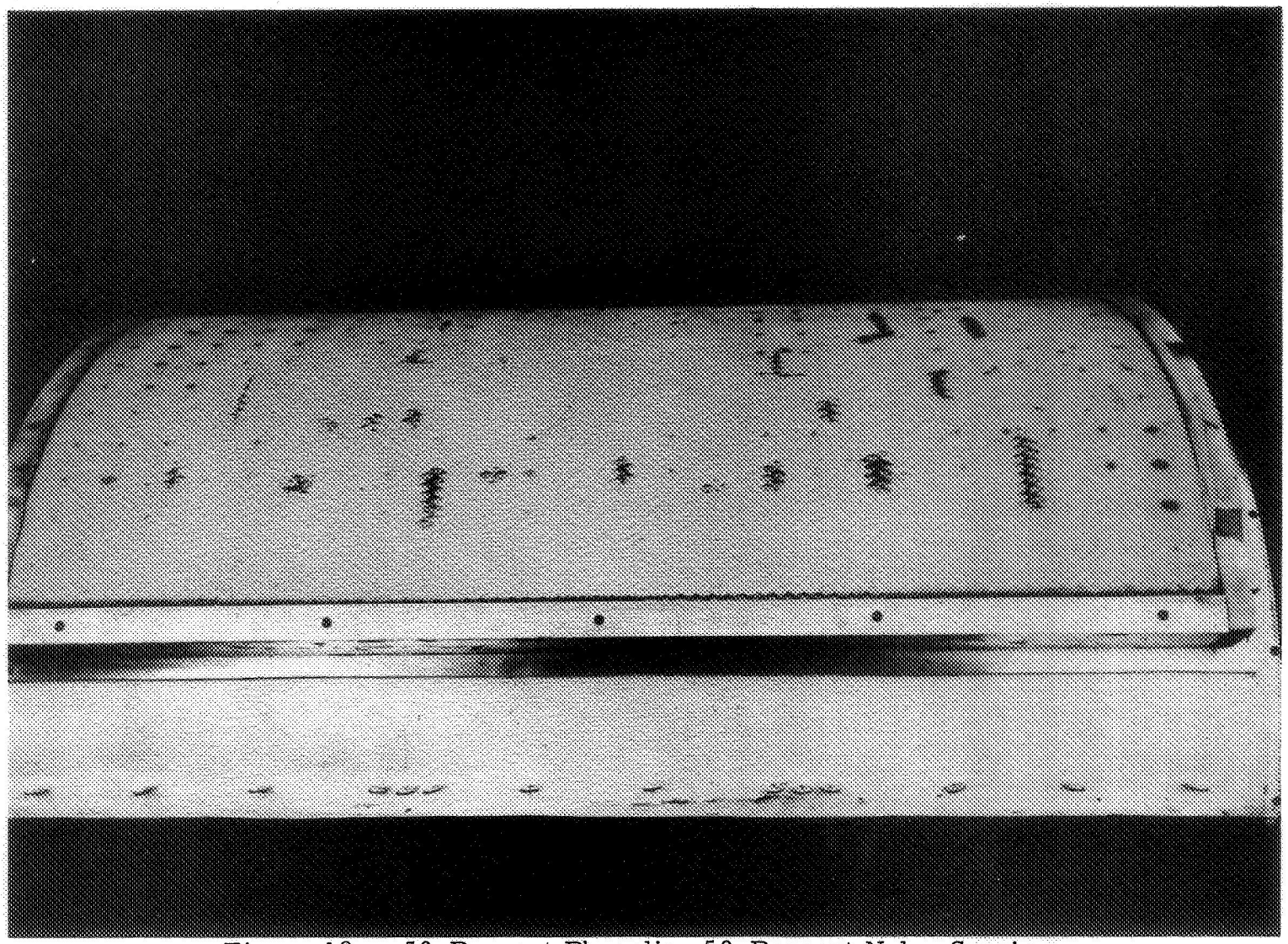


Figure 18. - 50-Percent Phenolic, 50-Percent Nylon Specimen (Shown After Cure While Still on Tool With Vacuum Bag and Straps Removed and With Silicone Edge Members and Side Rails Still in Place)

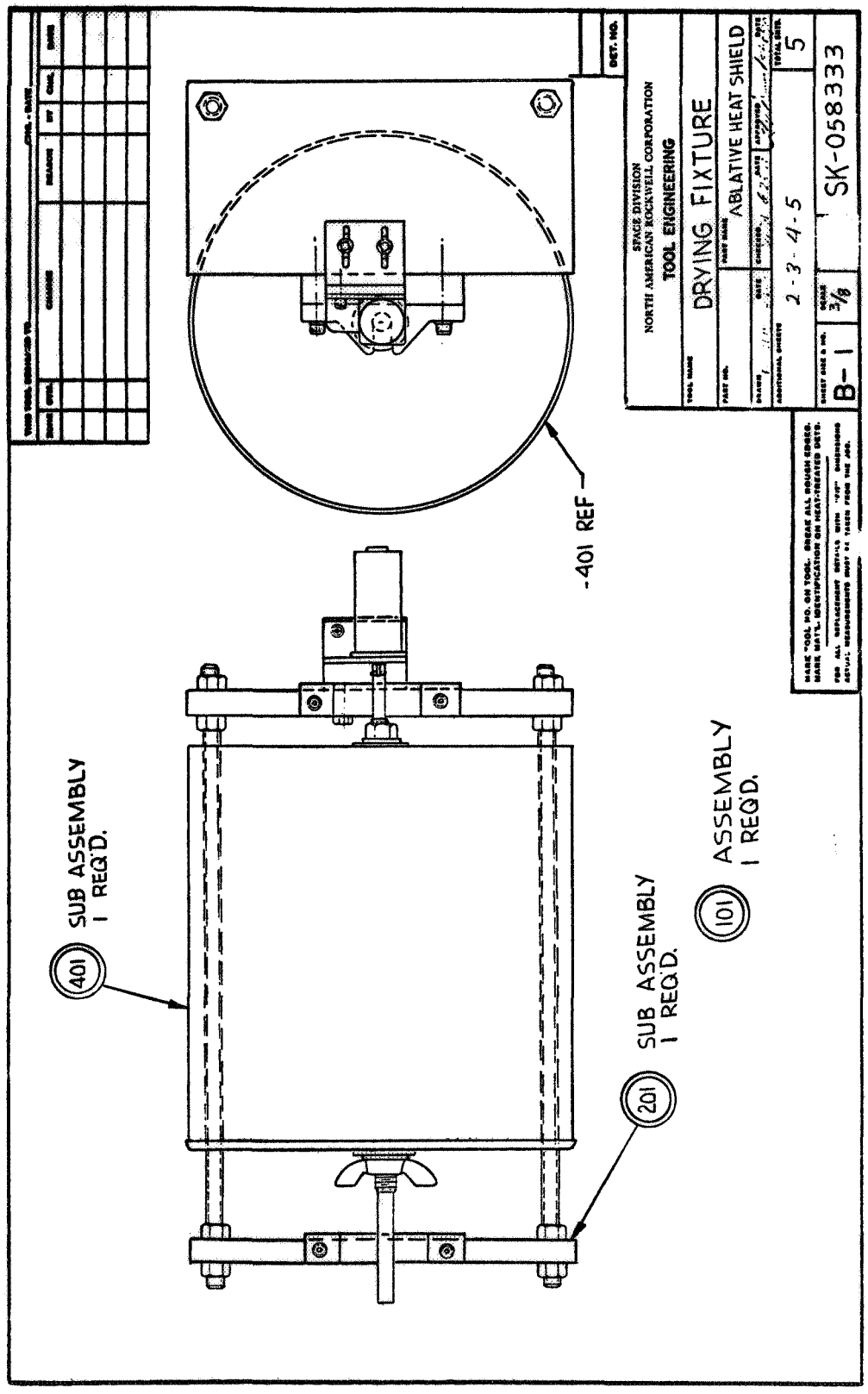


Figure 19. - Drying Fixture

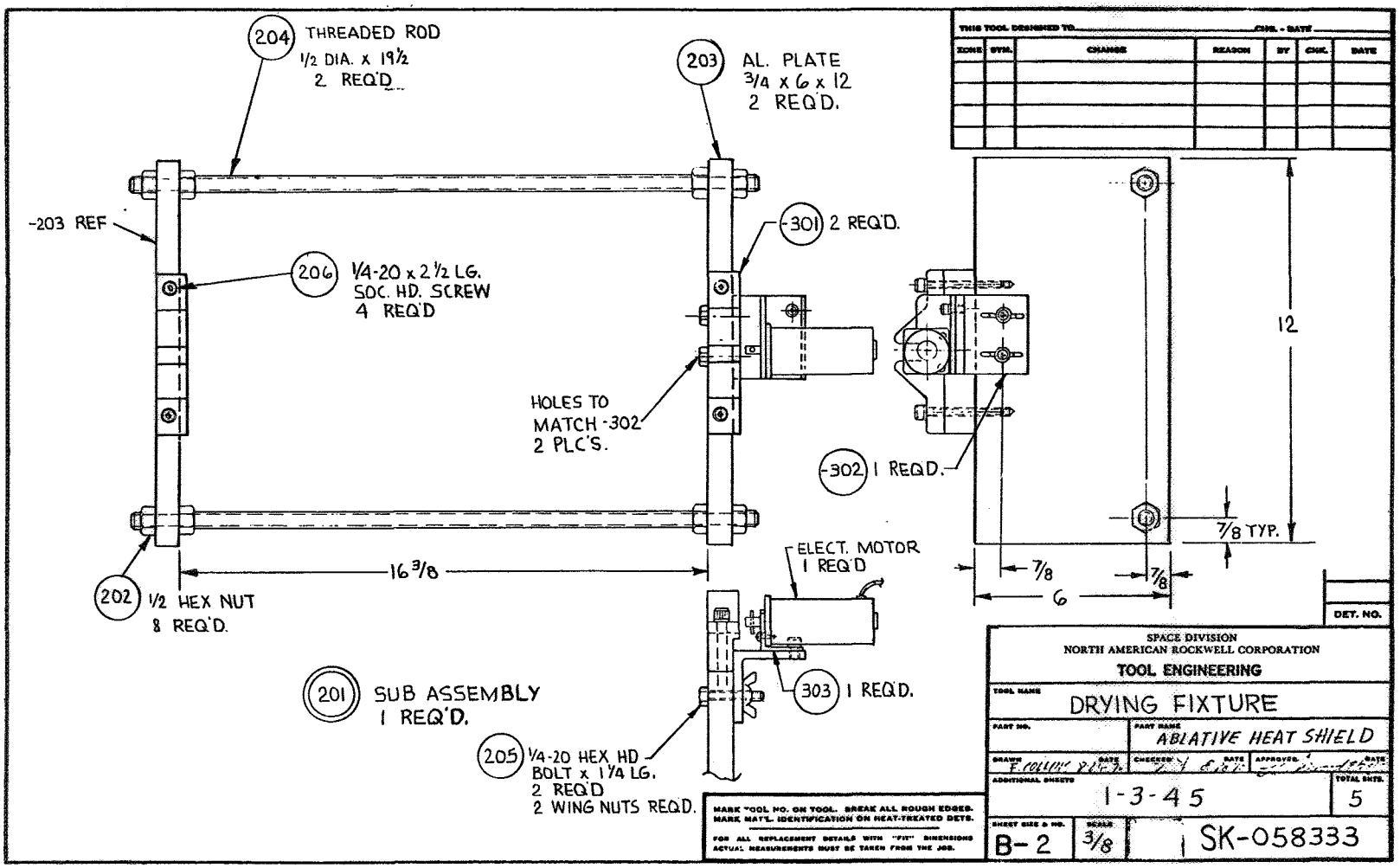


Figure 19. - Continued

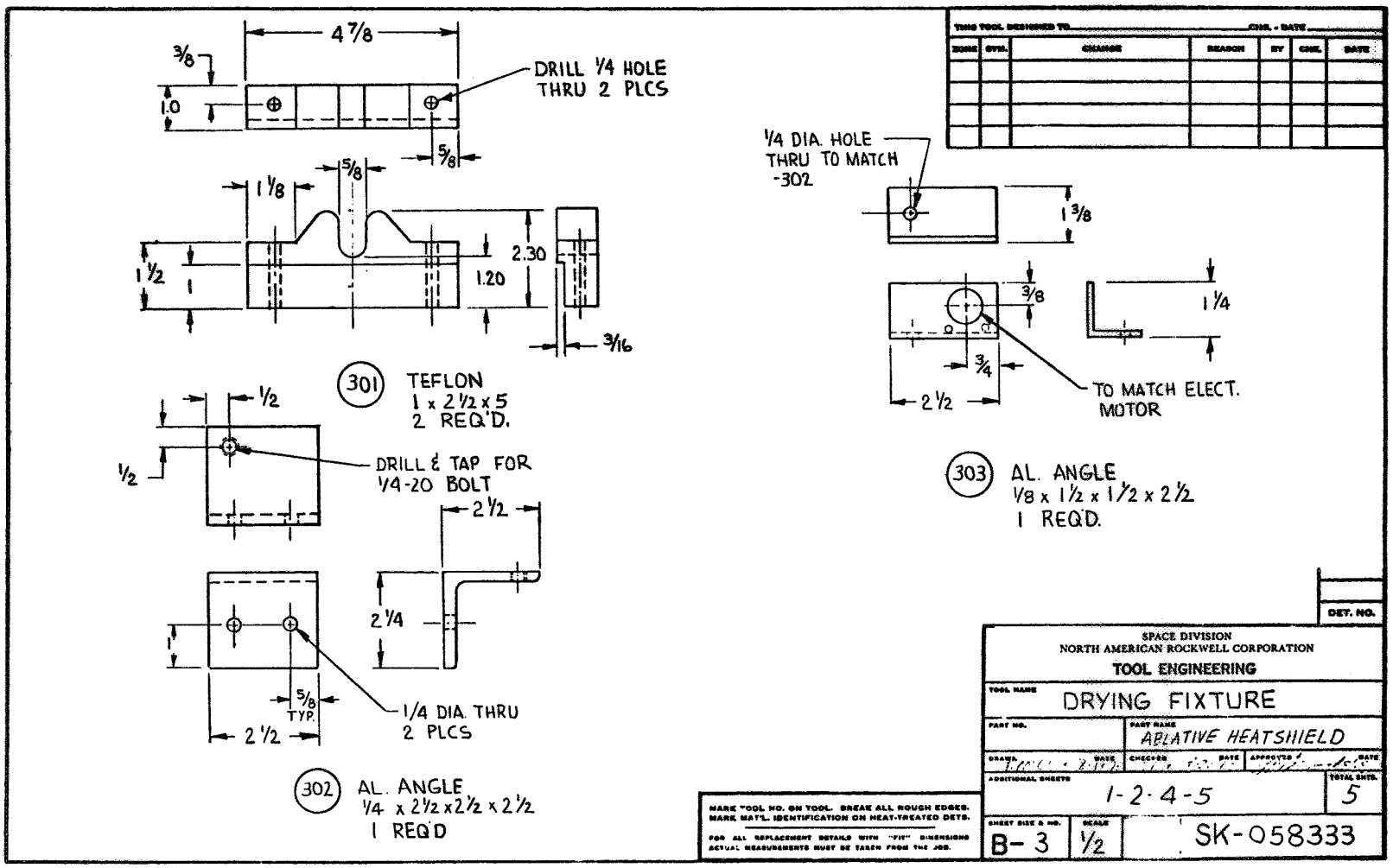


Figure 19. - Continued

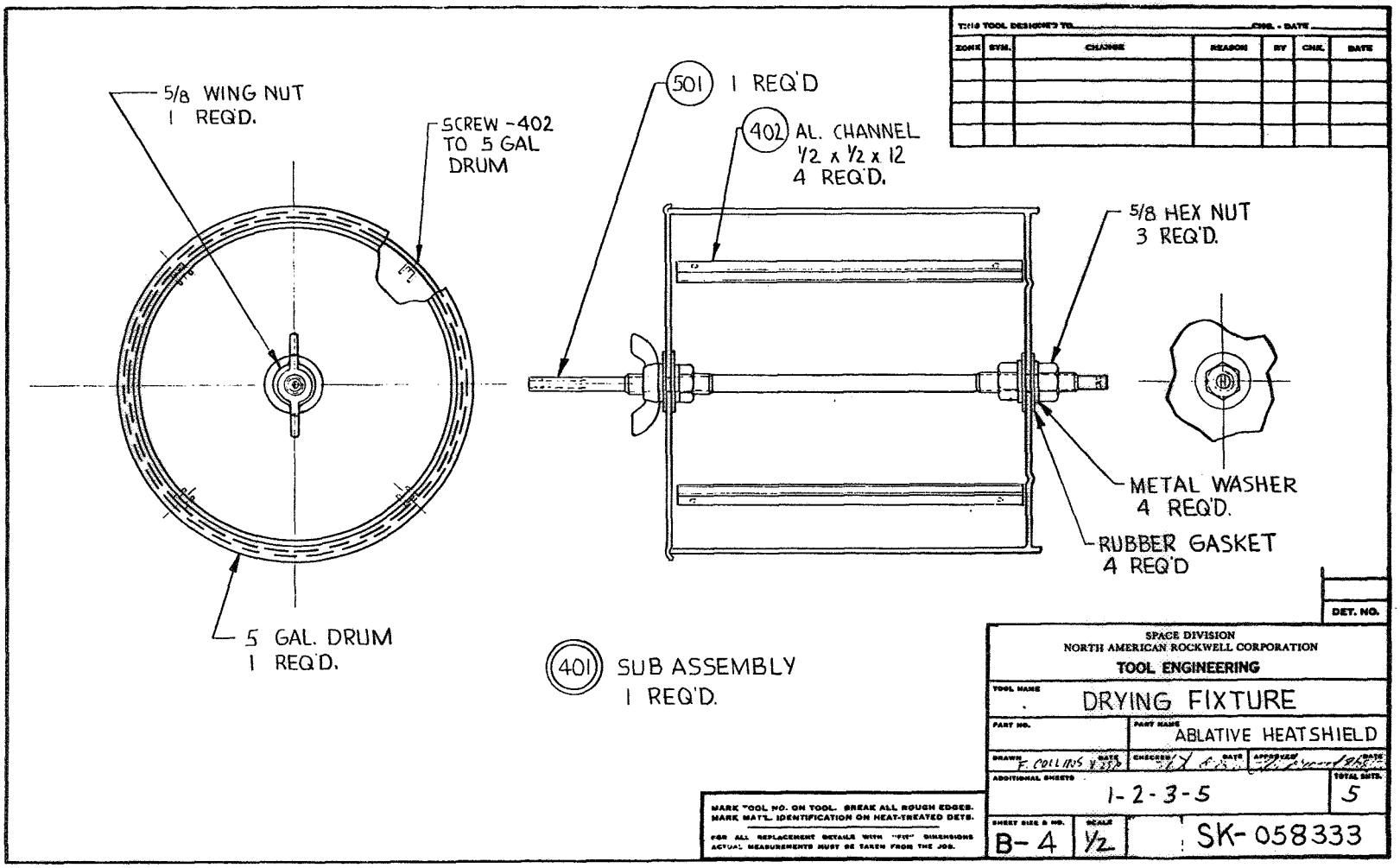


Figure 19. - Continued

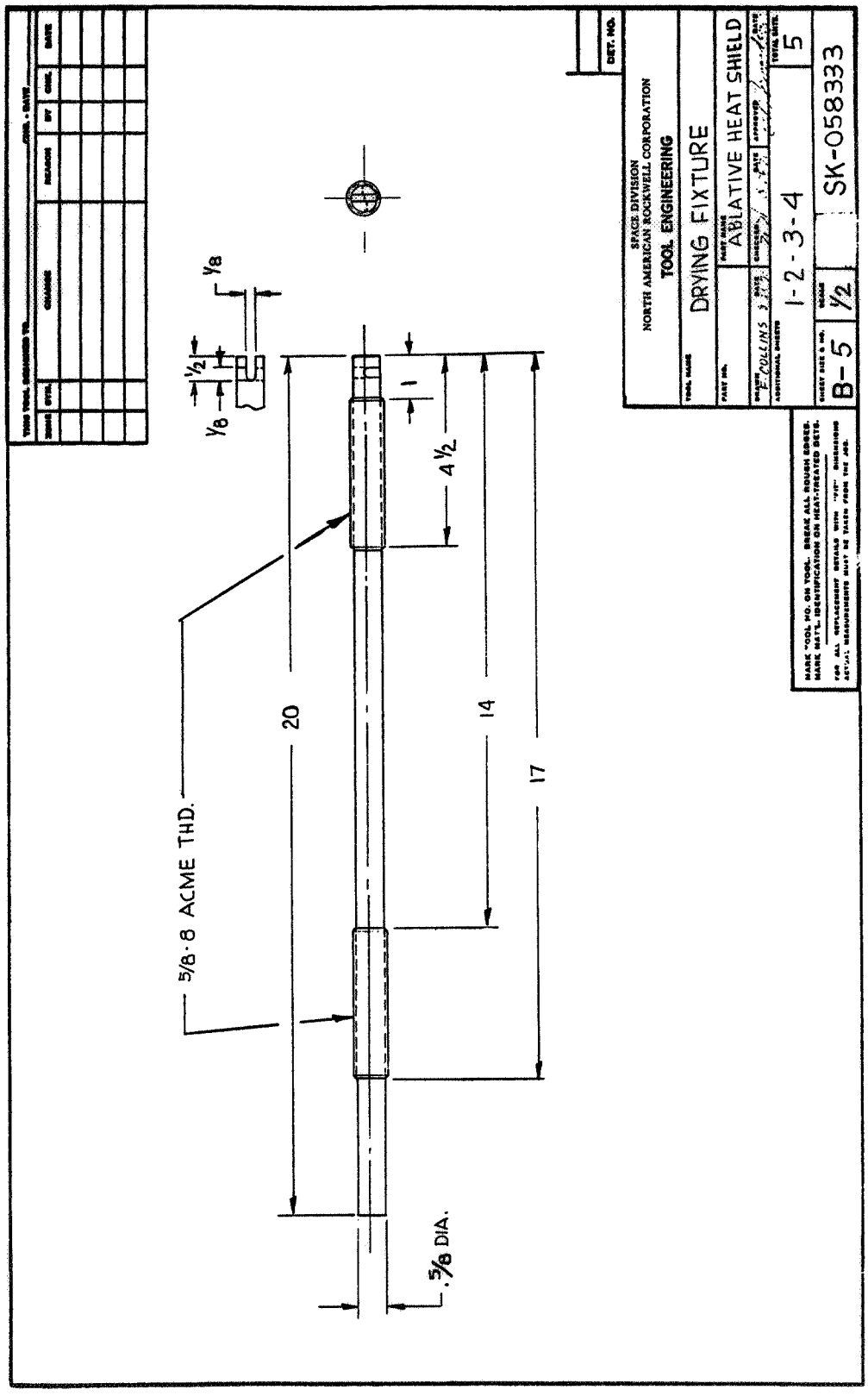


Figure 19. - Concluded

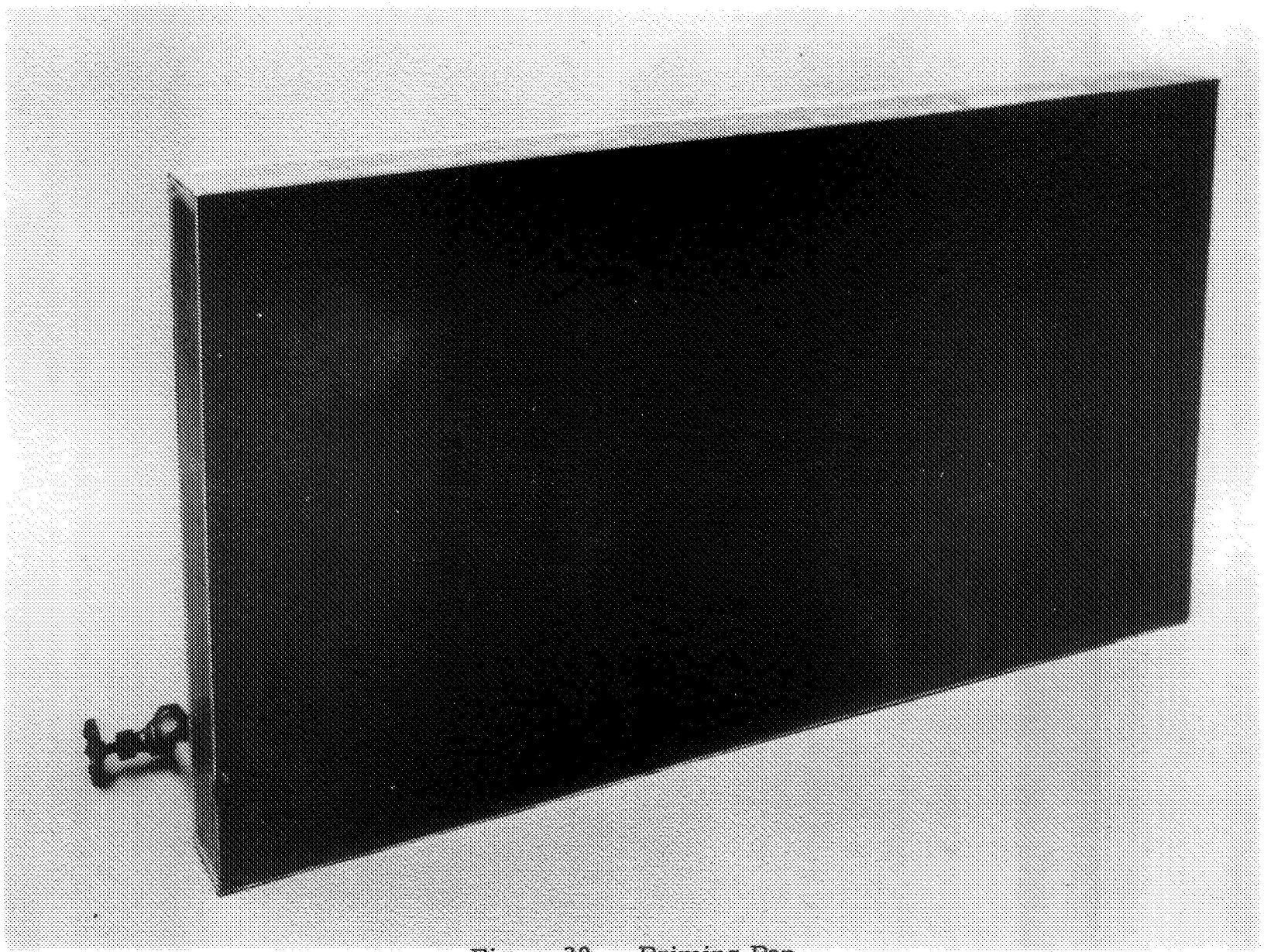


Figure 20. - Priming Pan

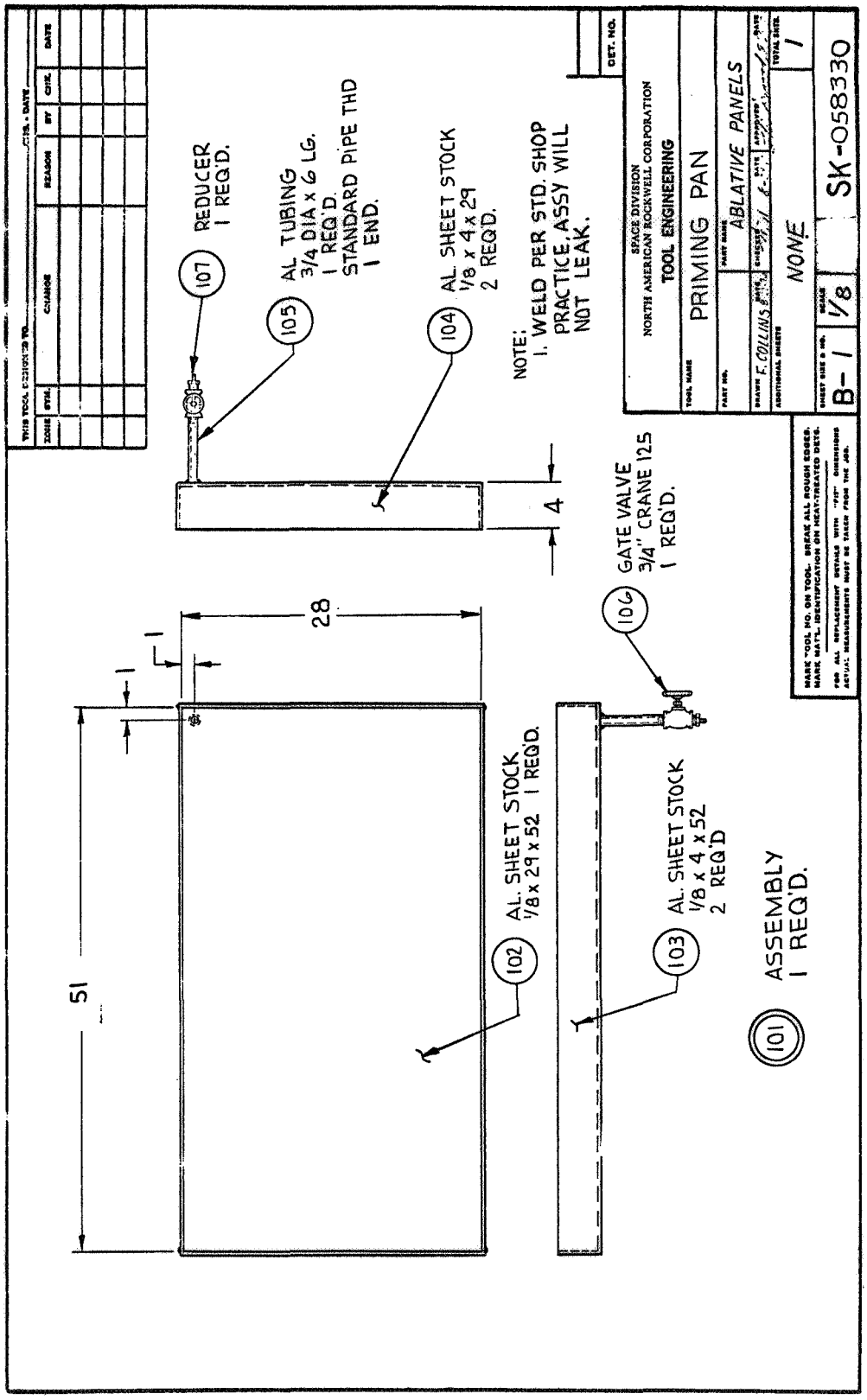


Figure 21. - Priming Pan Detailed Design

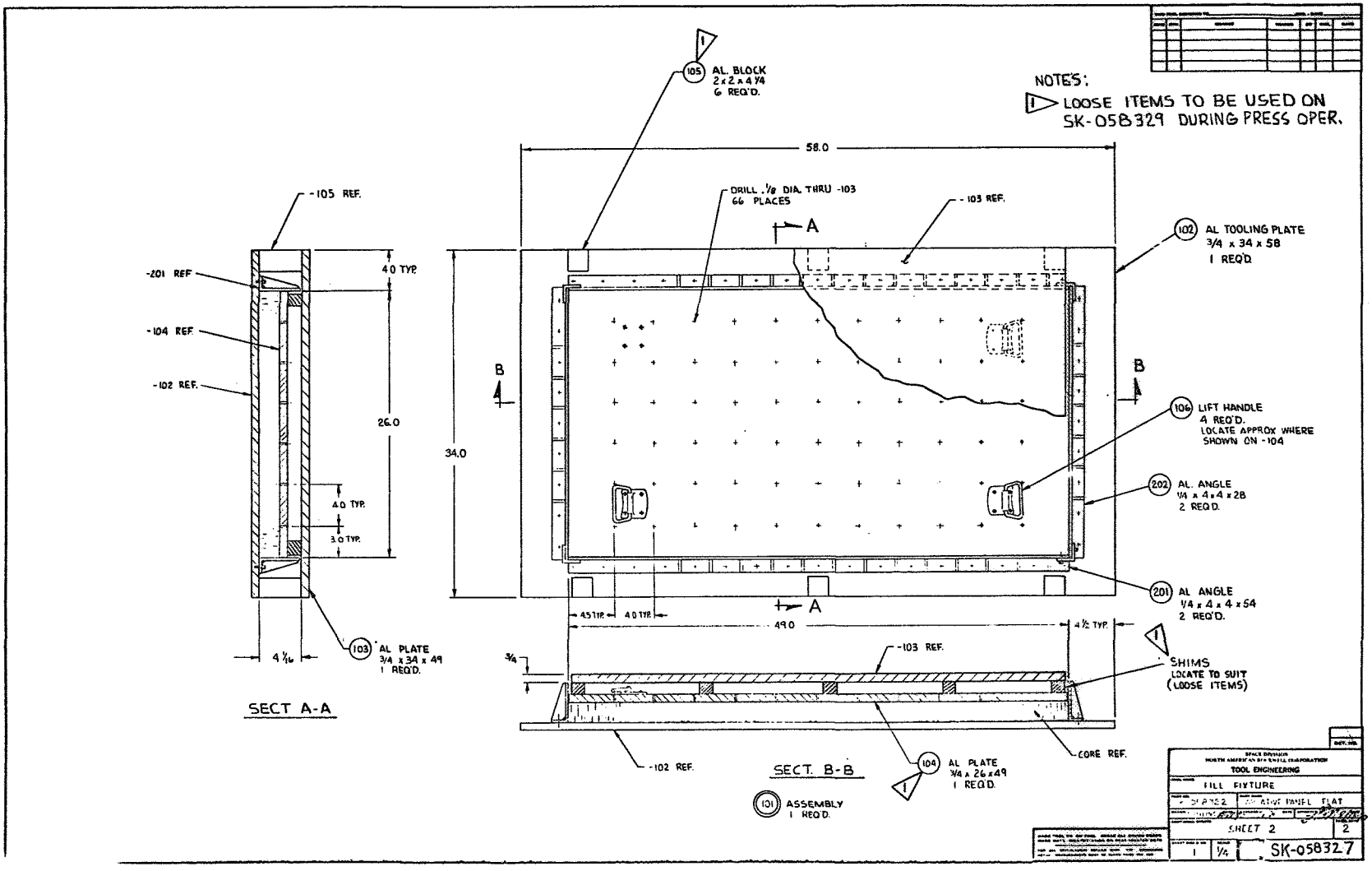


Figure 22. - Combination Fill and Cure Fixture Detail Design, Ablative Flat Panel

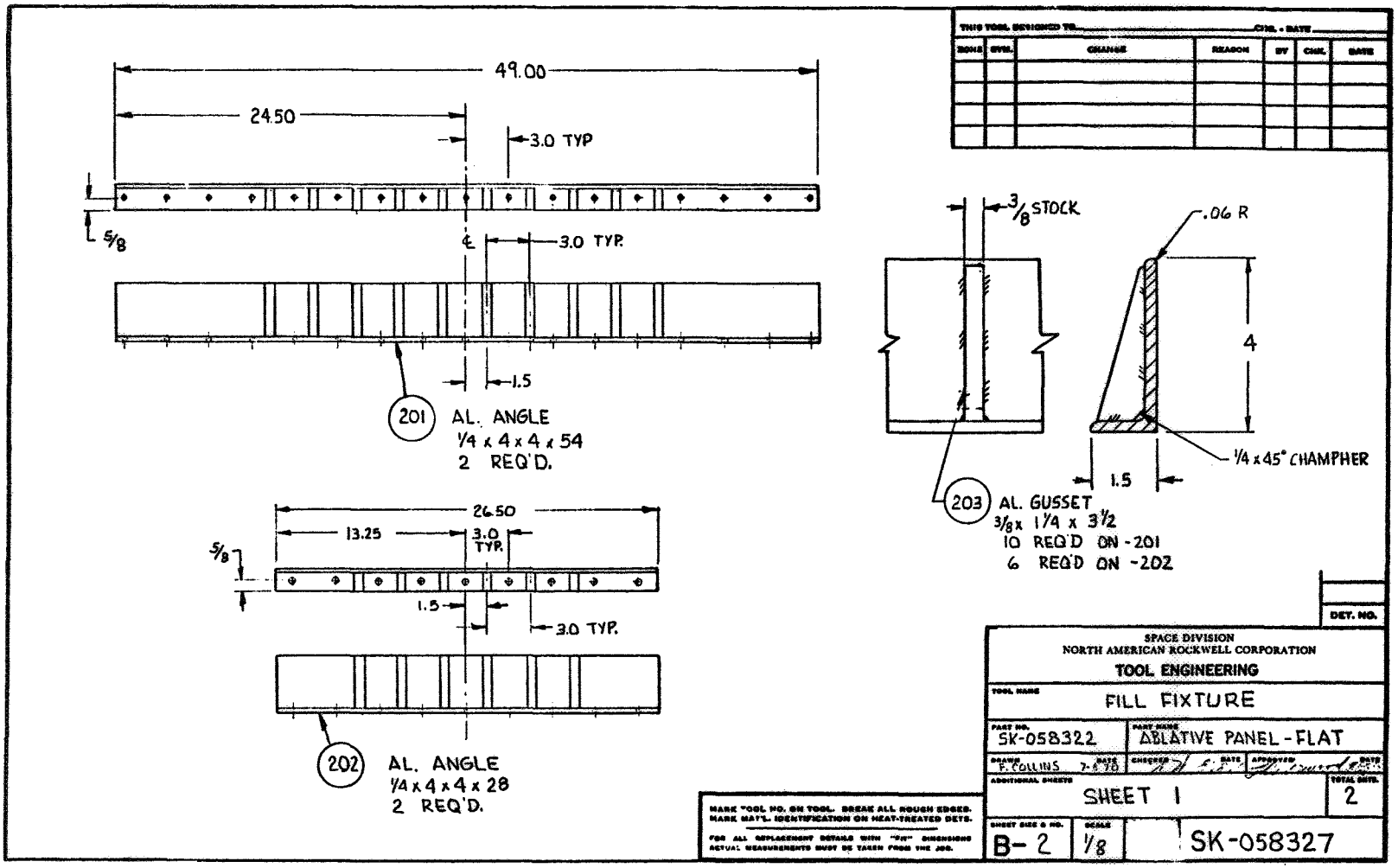


Figure 22. - Concluded

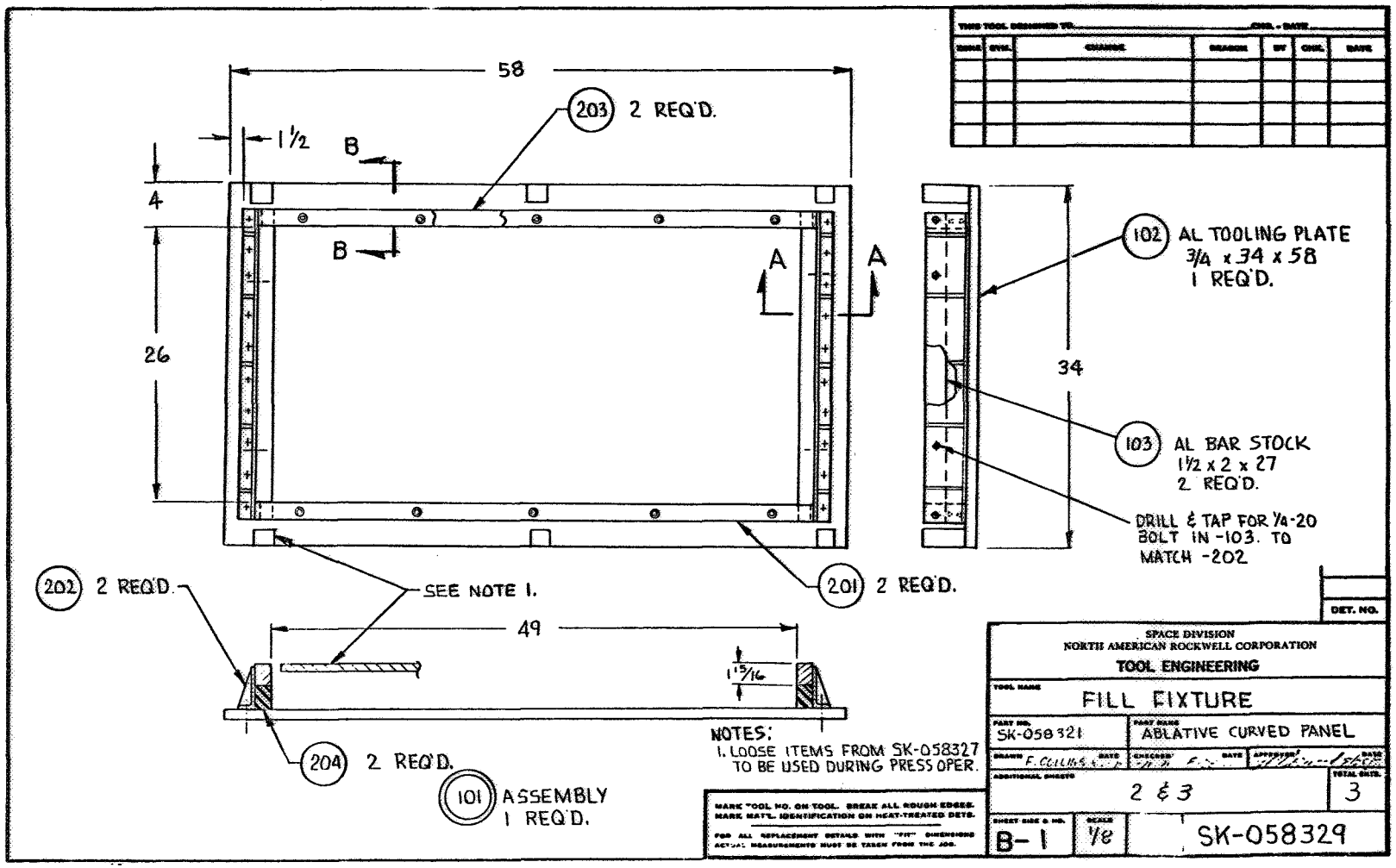


Figure 23. - Fill Fixture Detailed Design, Ablative Curved Panels

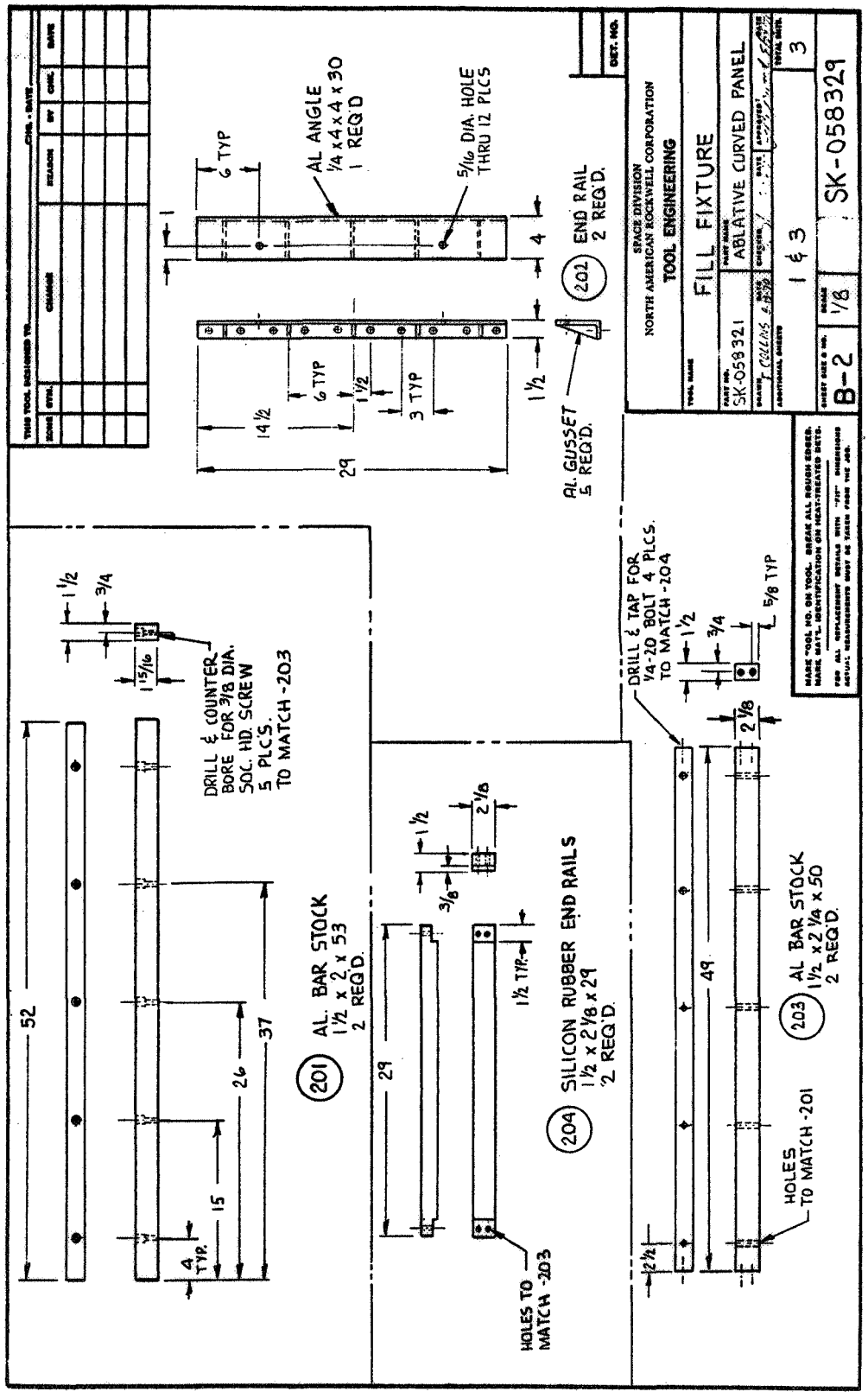


Figure 23. - Continued

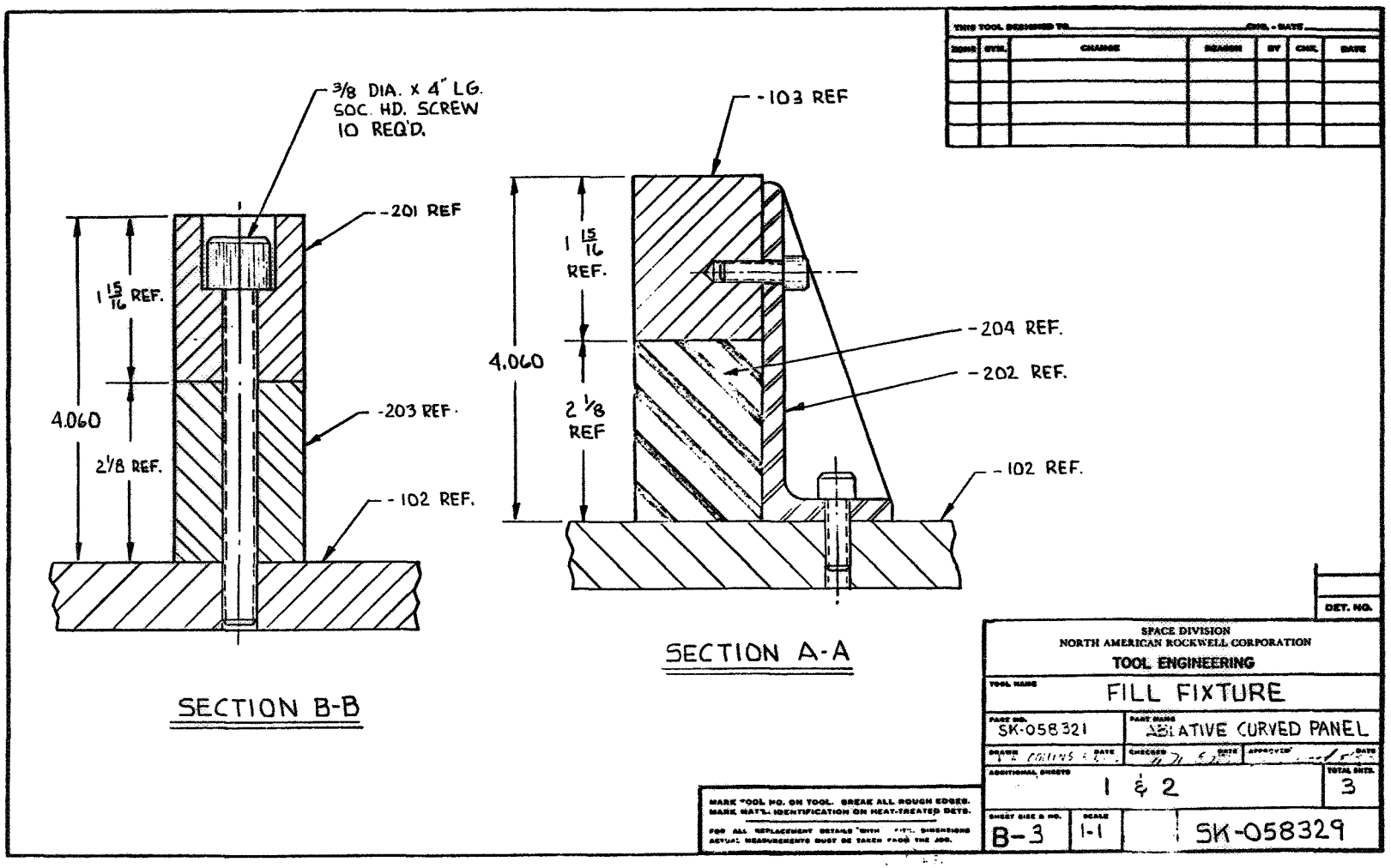


Figure 23. - Concluded

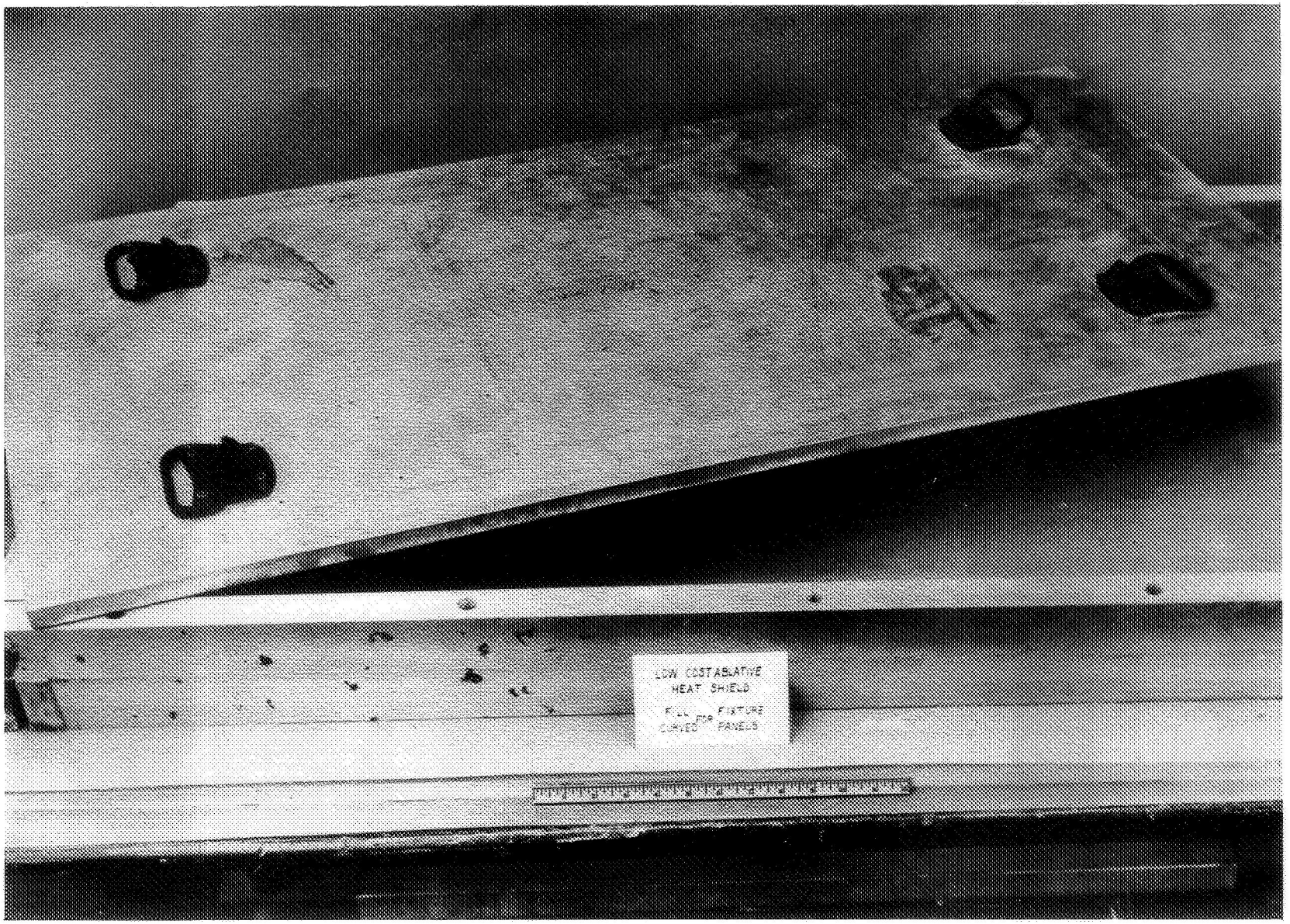


Figure 24. - Fill Fixture for Curved Panels

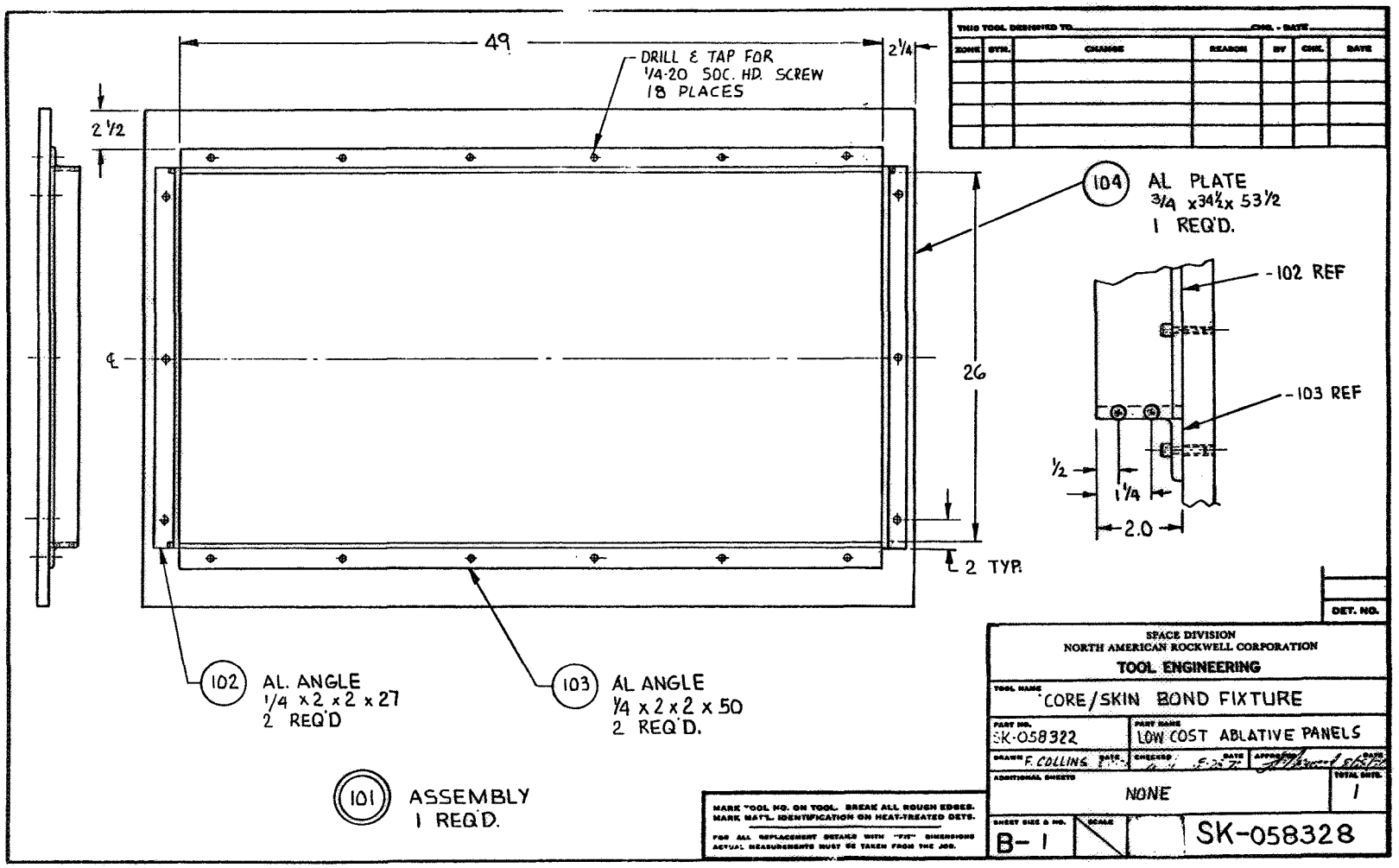


Figure 25. - Core-to-Skin Bond Fixture Detailed Design

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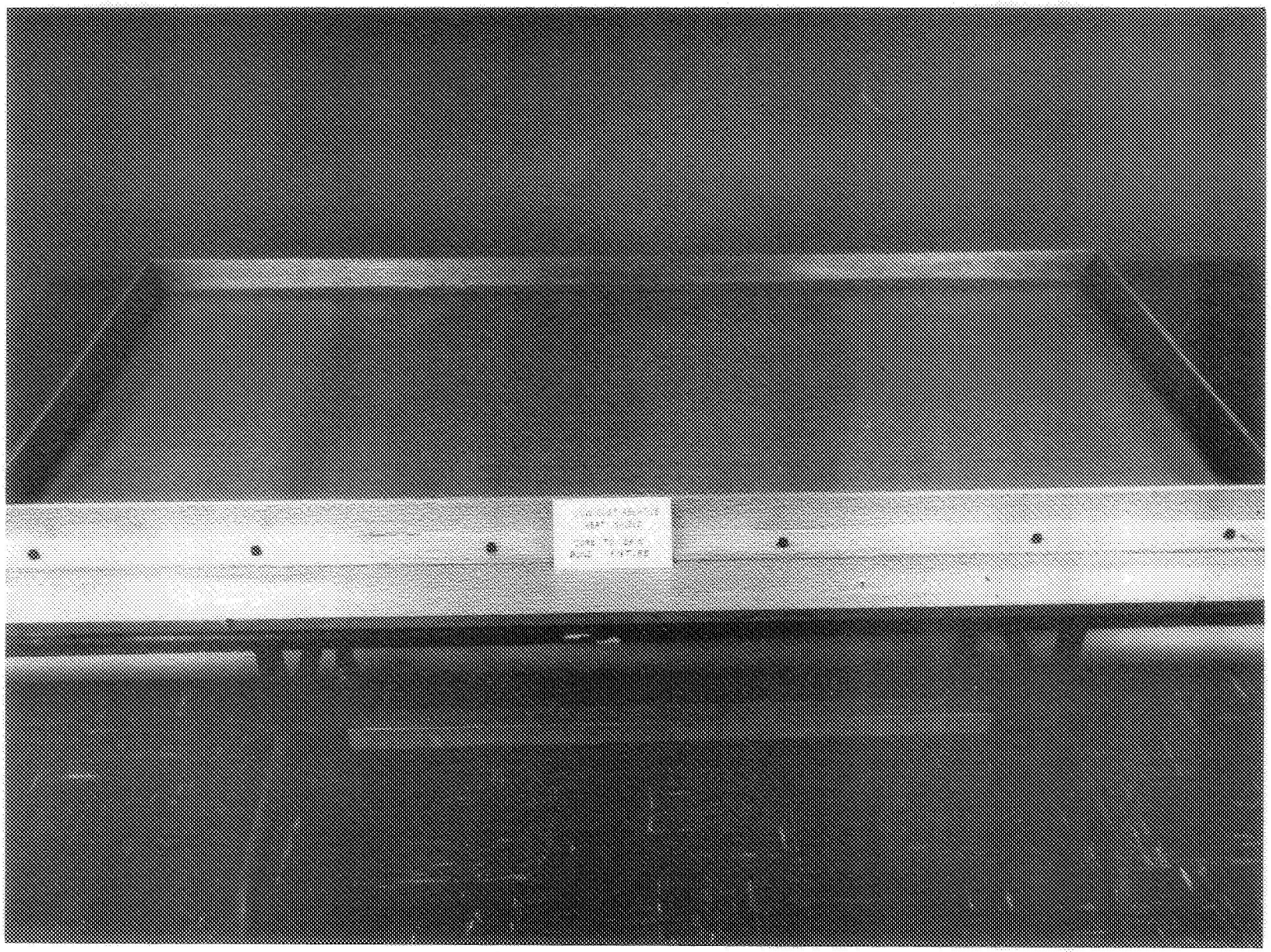


Figure 26. - Core-to-Skin Bond Fixture

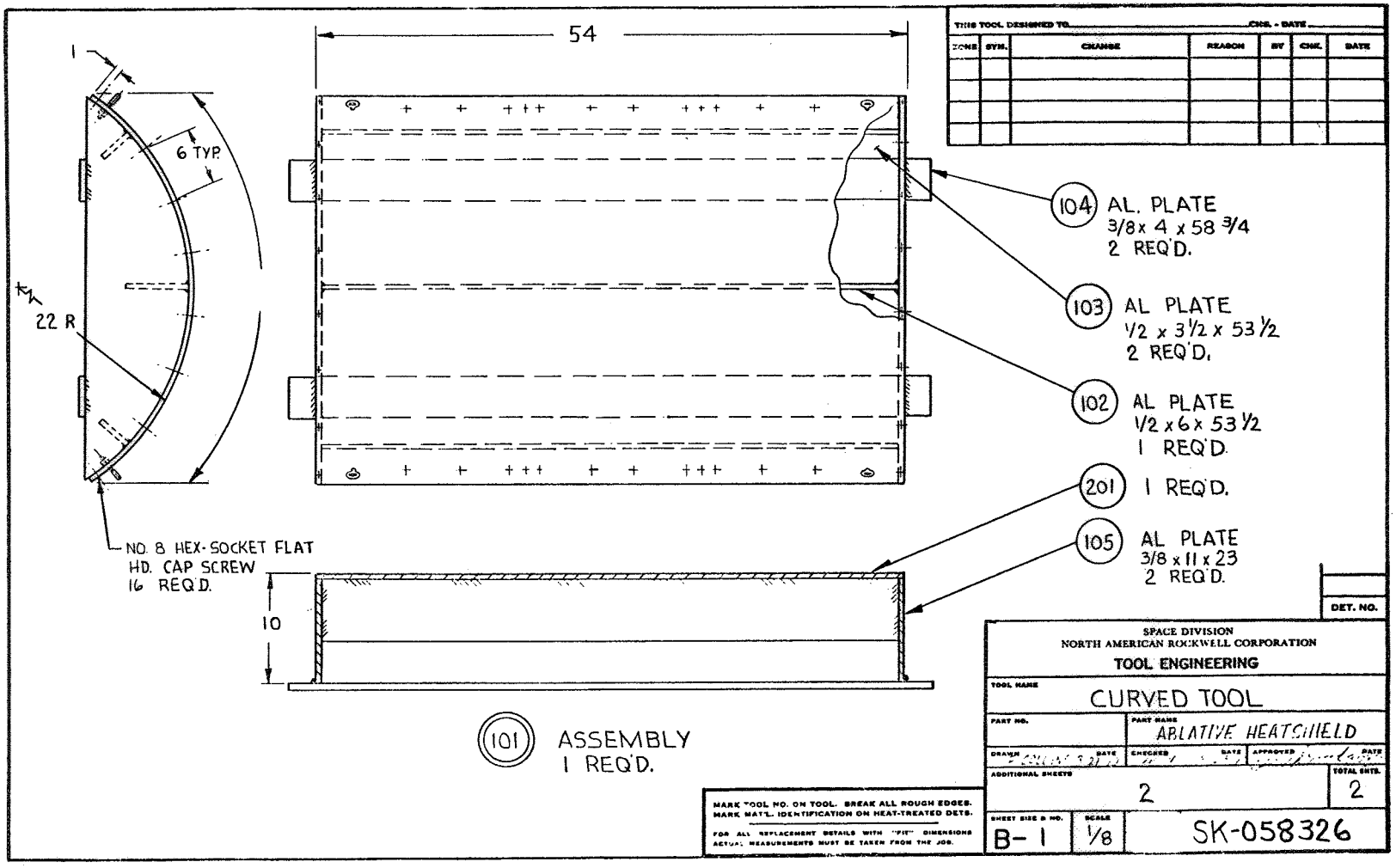


Figure 27. - Cure Fixture Detailed Design, Ablative Curved Panels

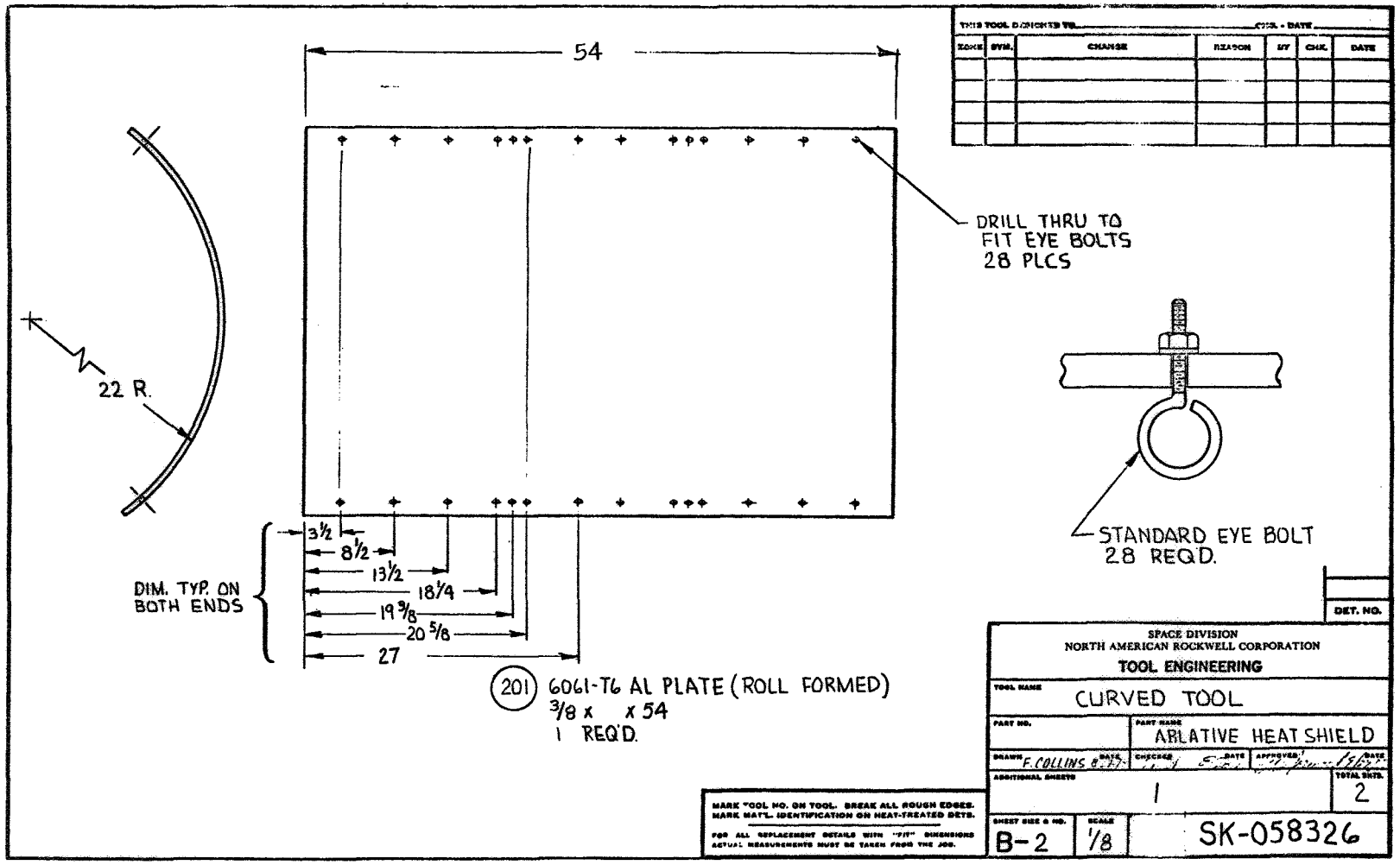
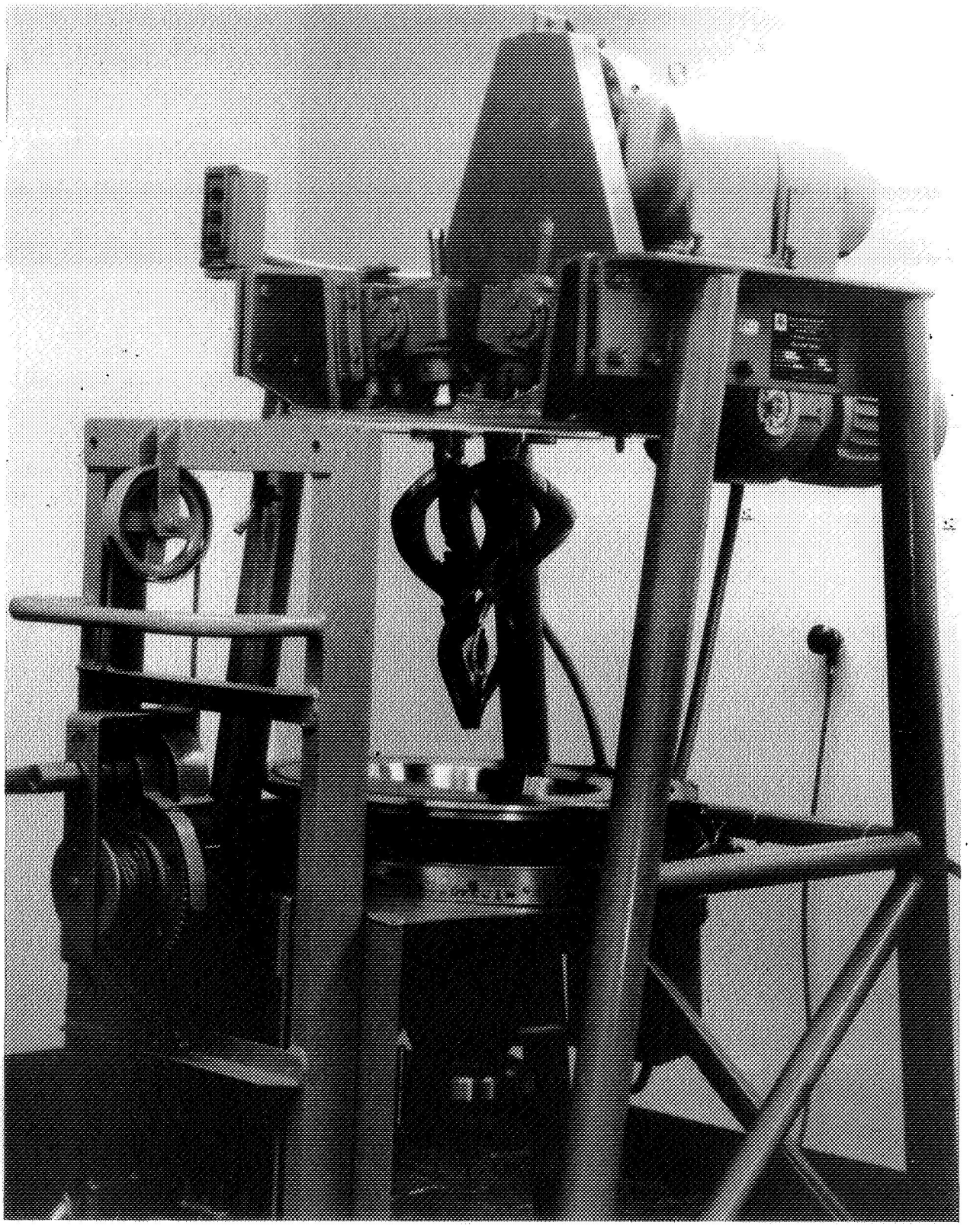


Figure 27. - Concluded



Figure 28. - Cure Fixture for Ablative Curved Panels (Flexible End Members Shown)



700-86-9598

Figure 29. - Vertical Helicone Mixer,
Atlantic Research Co., Model 8CV

700-86-974C

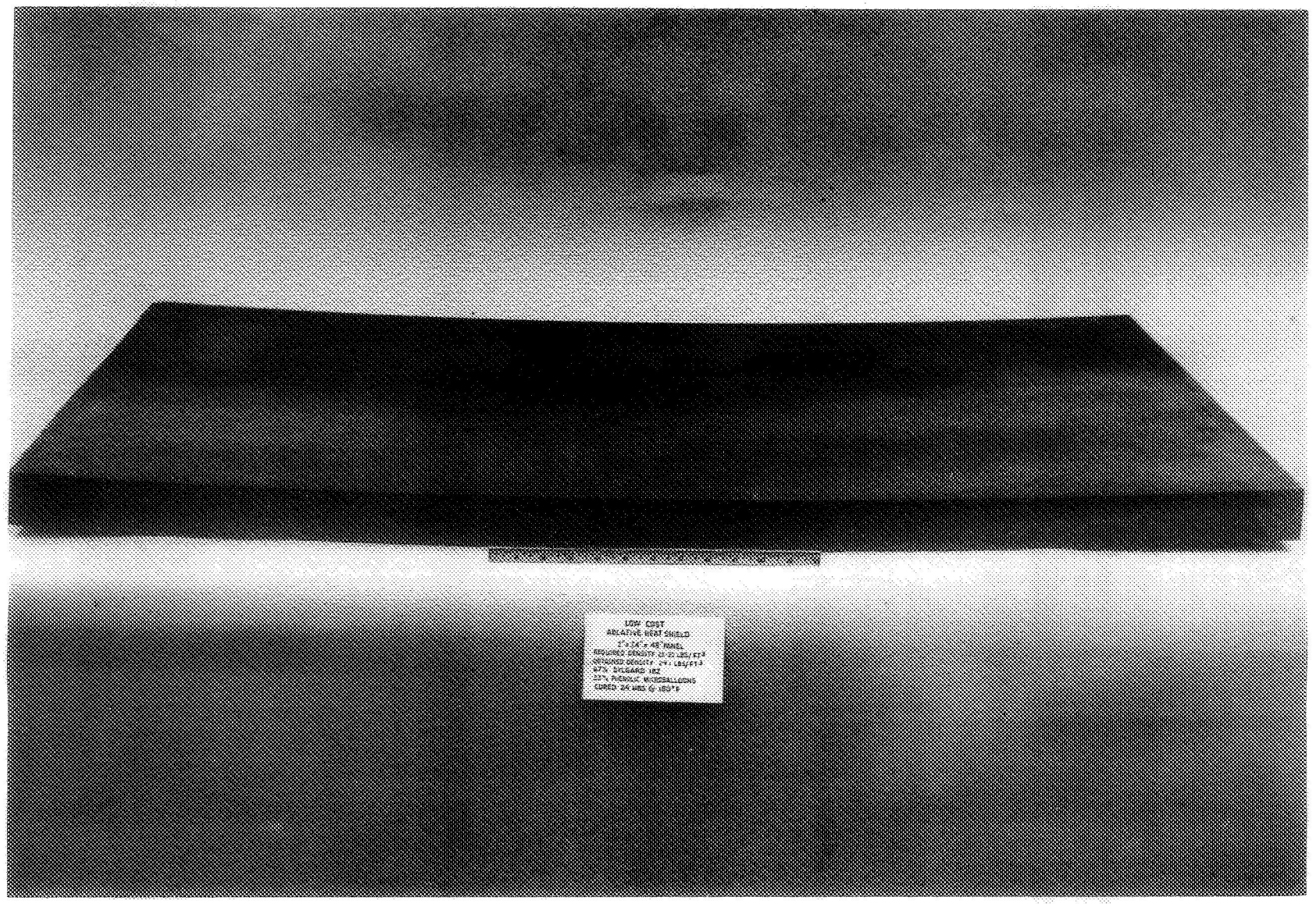


Figure 30. - Elastomeric Flat Panel With Slight Curve (Face Sheet Down)



Figure 31. - Elastomeric Flat Panel After Curing (Face Sheet Up)

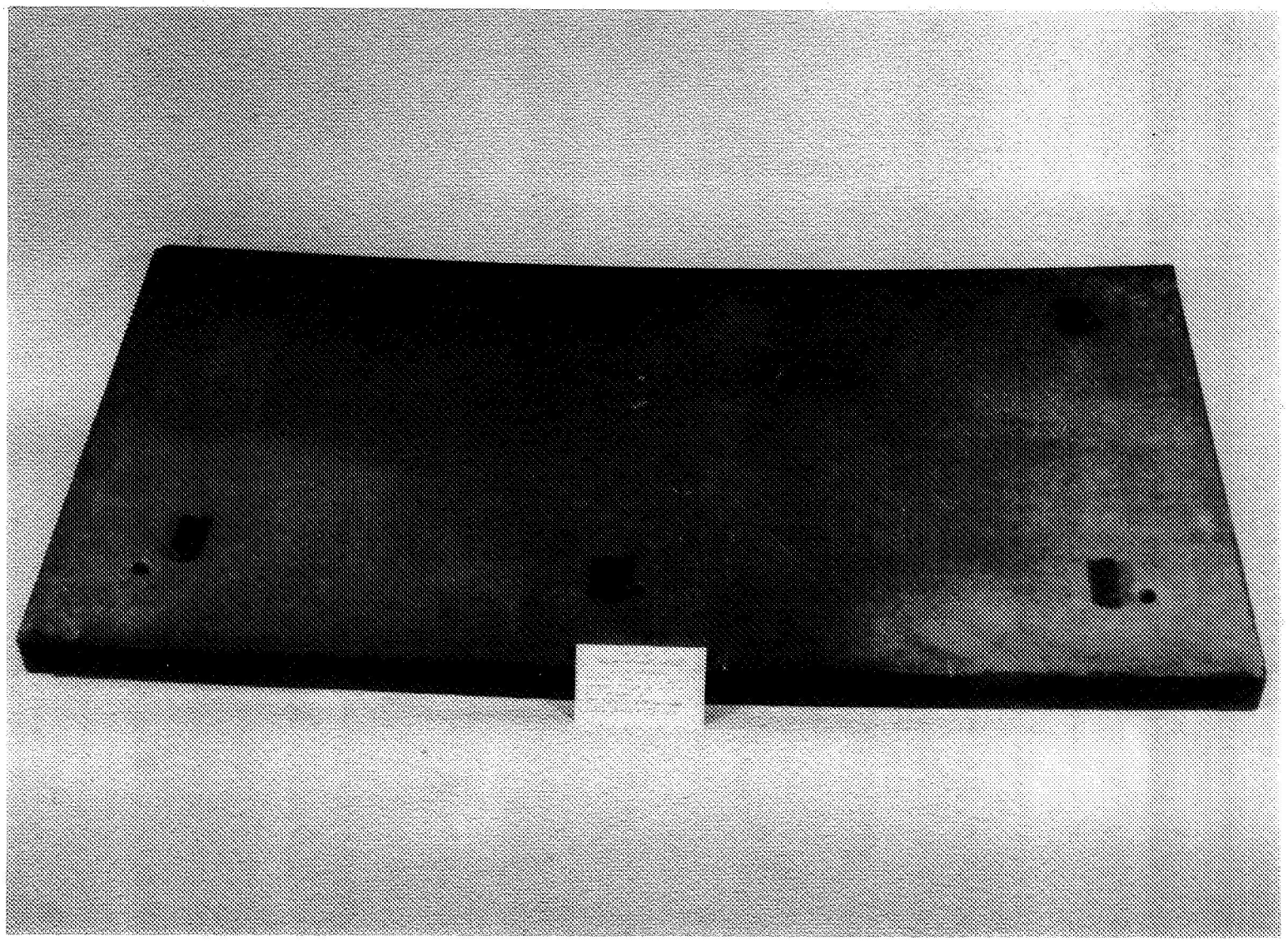


Figure 32. - Finished Elastomeric Flat Panel and Plugs

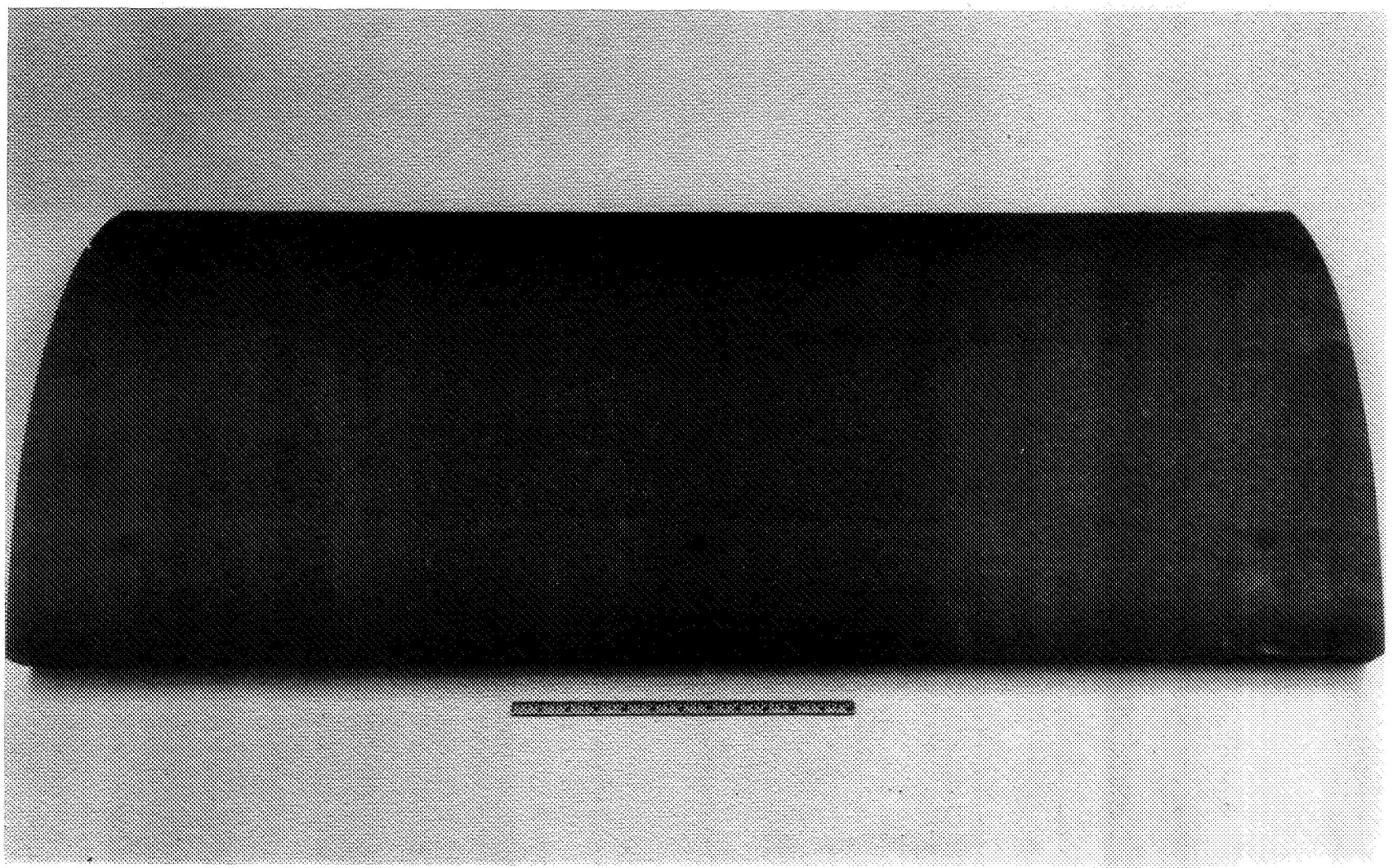


Figure 33. - Elastomeric Curved Panel (67-Percent Elastomer, 33-Percent Microballoons)

700-86-966B

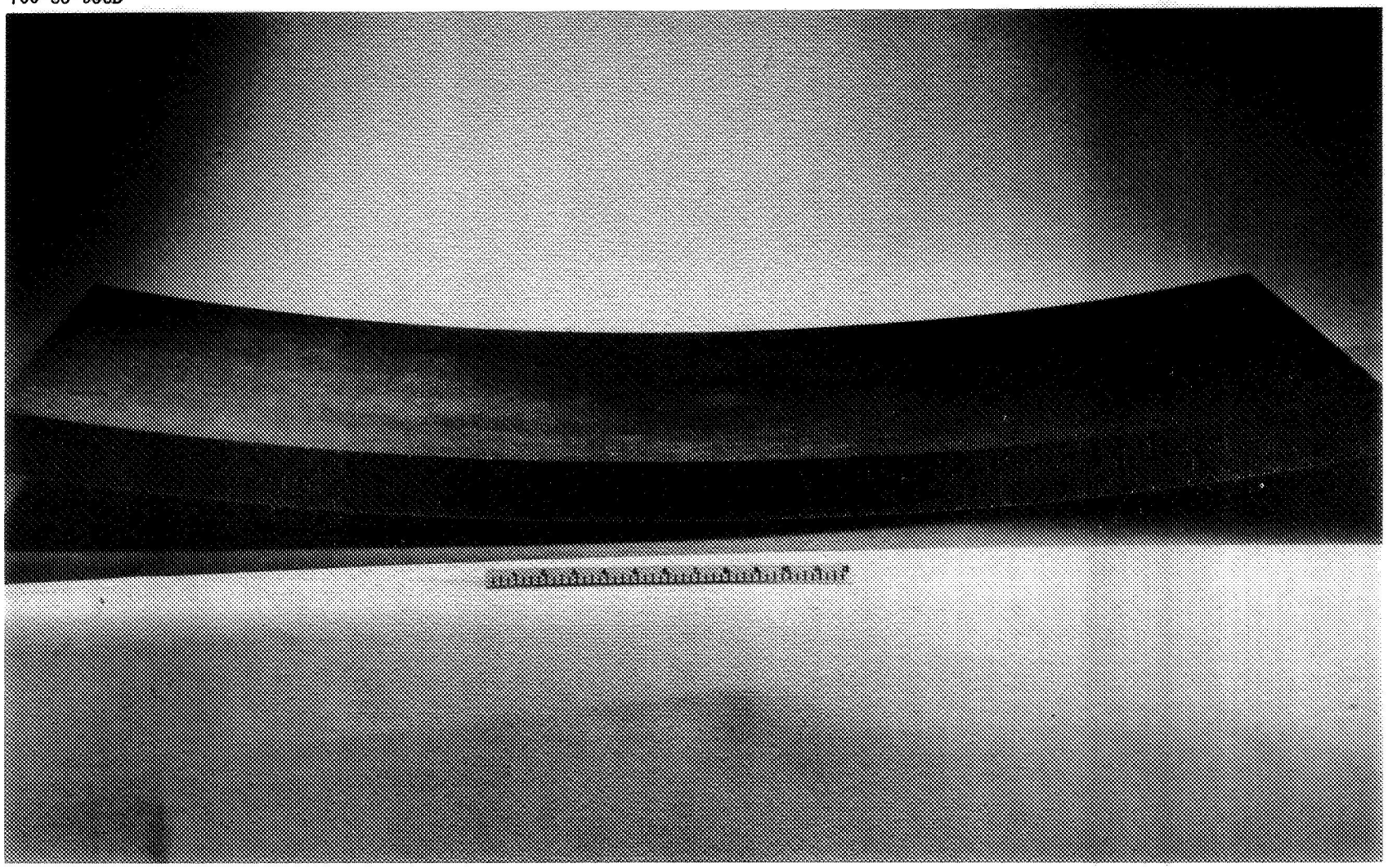


Figure 34. - First 67-33 Panel Cured at 250 F for 16 Hours (Reject), 1-3/4-Inch Warp

700-86-966C

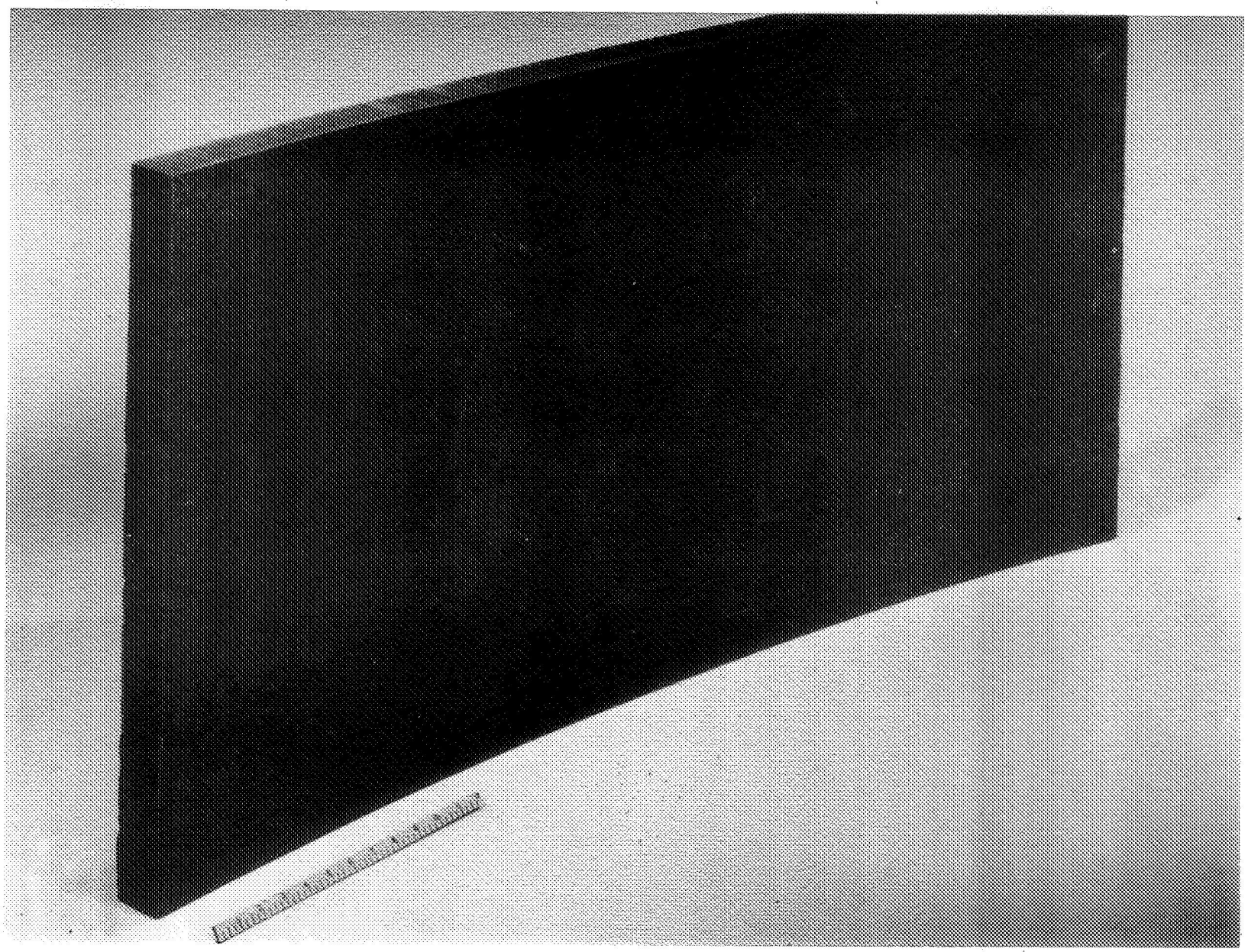


Figure 35. - Elastomeric Flat Panel (Reject), 1-3/4-Inch Warp

700-86-974B

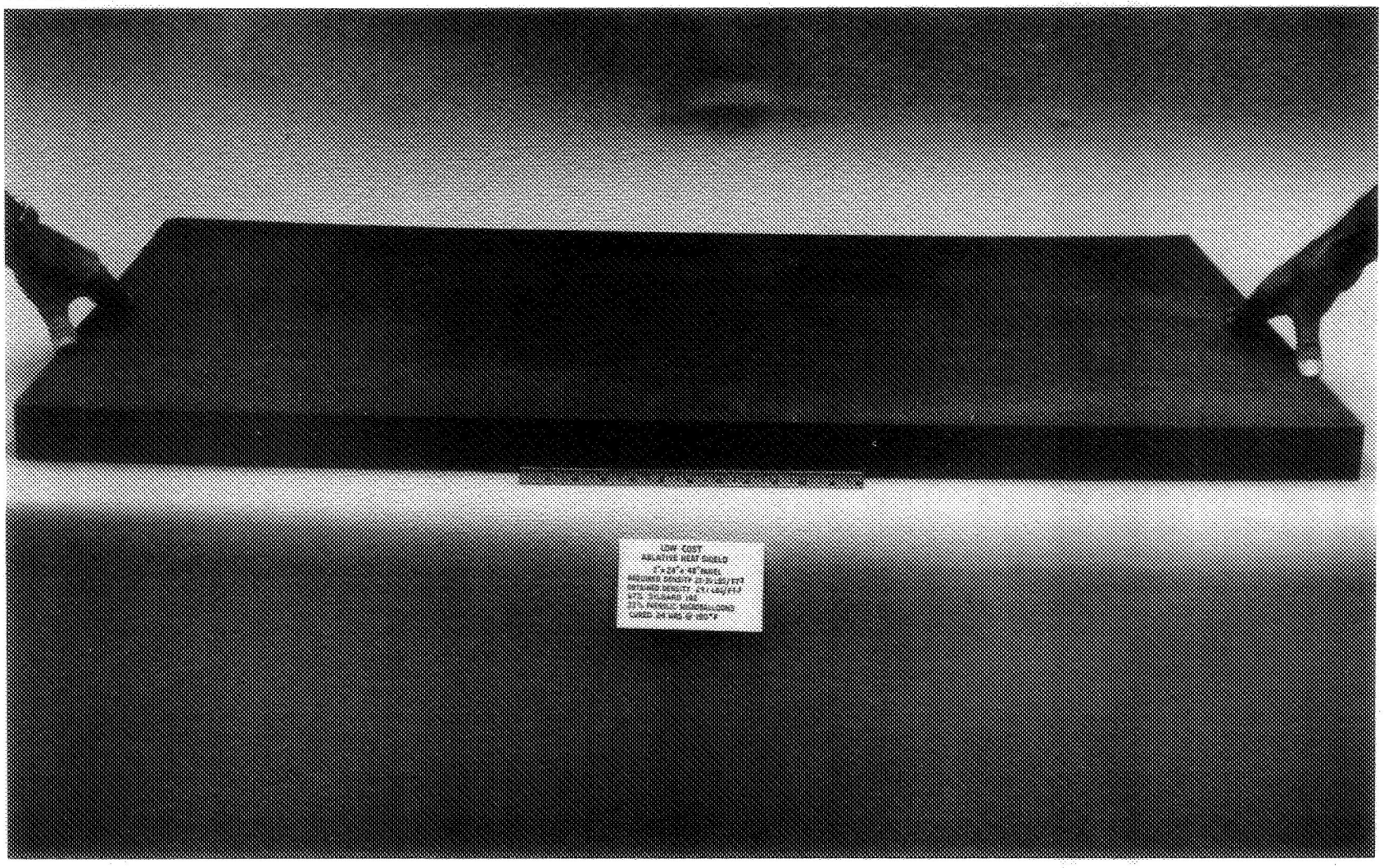


Figure 36. - Hand-Pressed Elastomeric Flat Panel, 9/16-Inch Warp

700-86-981B

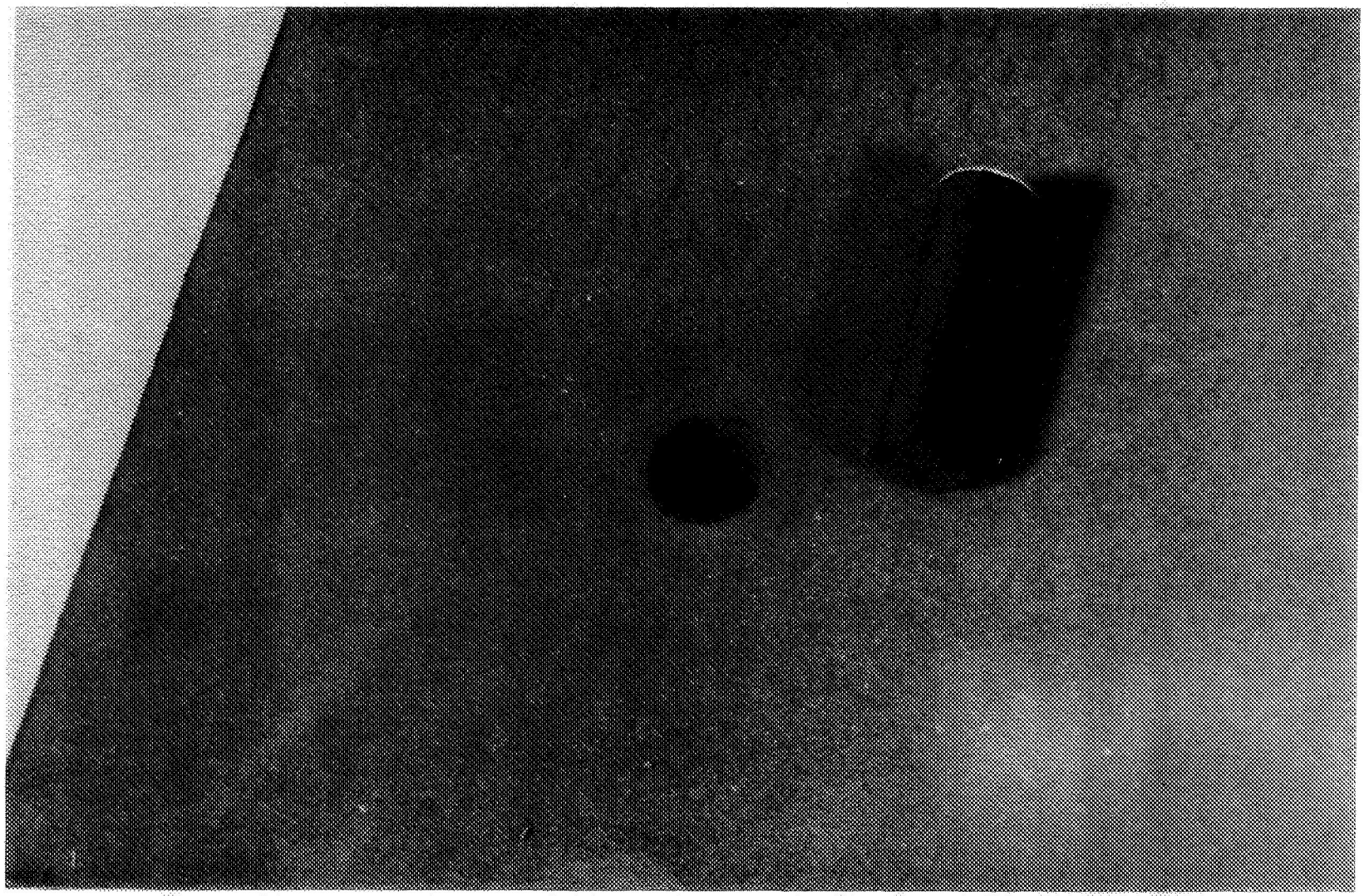


Figure 37. - Typical Hole and Plug, Elastomeric Flat Panel (20-Percent Sylgard, 80-Percent Phenolic Microballoons)

700-86-981A

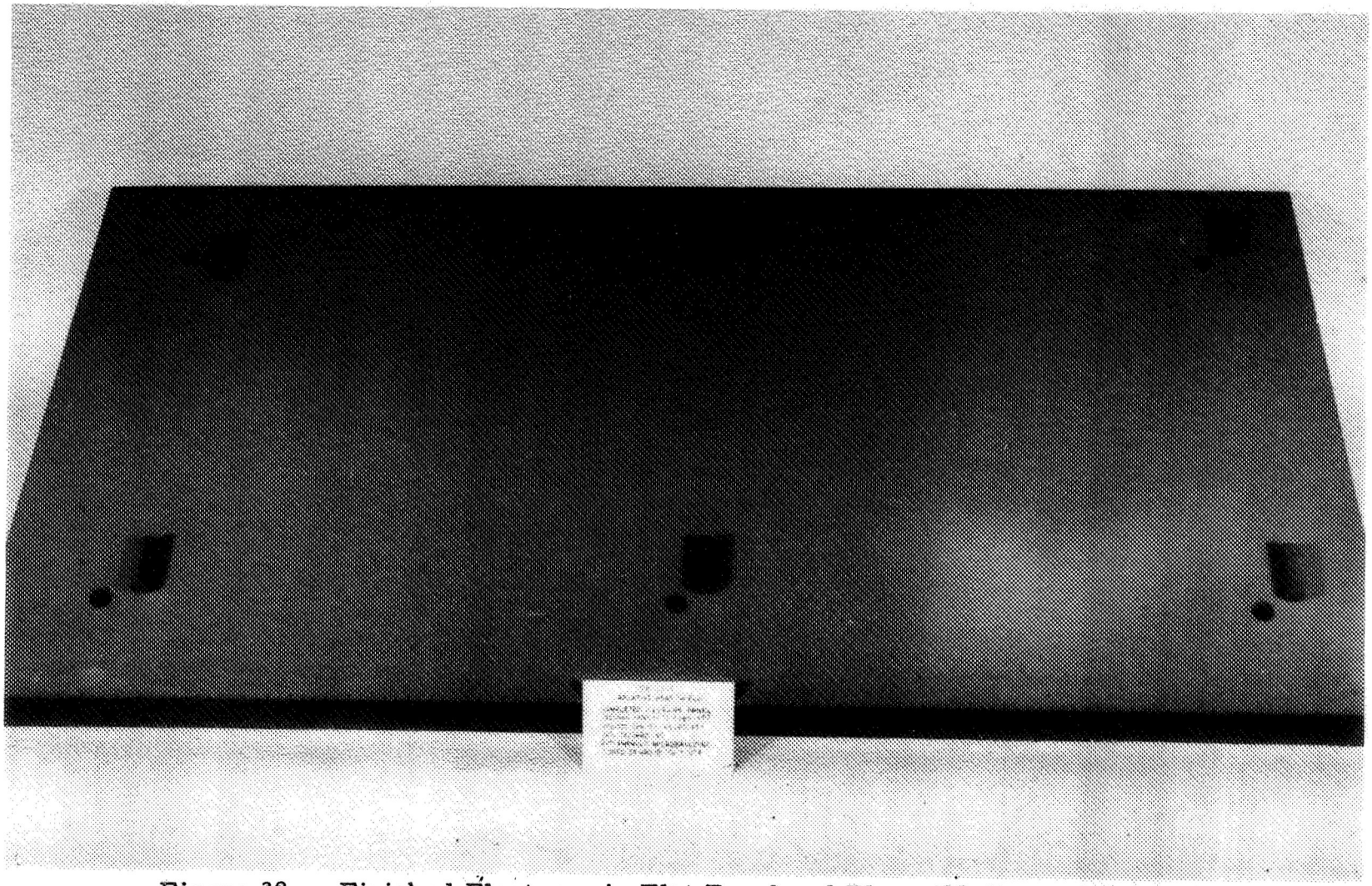


Figure 38. - Finished Elastomeric Flat Panel and Plugs (20-Percent Sylgard, 80-Percent Microballoons)

700-86-985A

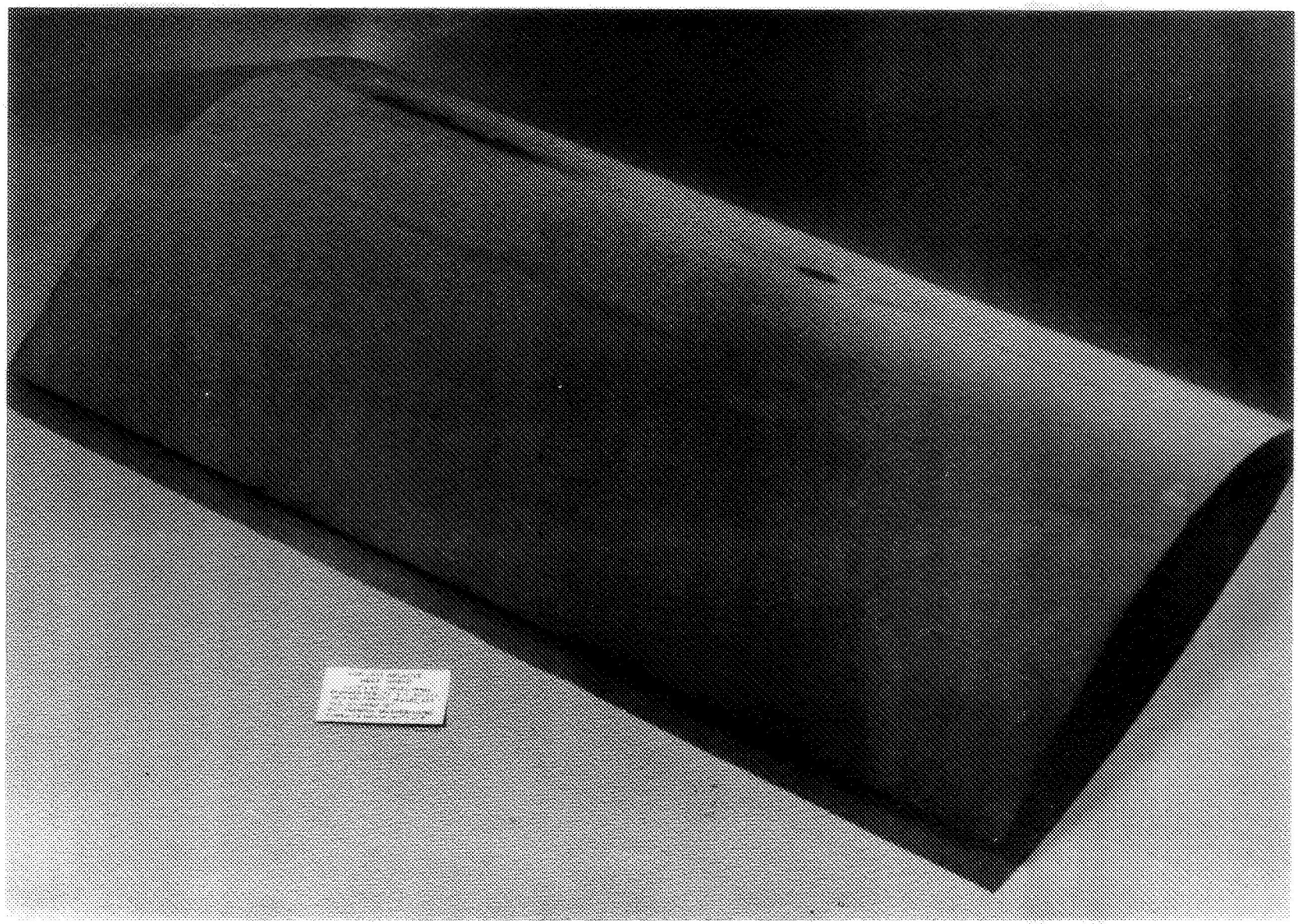


Figure 39. - Elastomeric Curved Panel Without Holes (20-Percent Sylgard, 80-Percent Microballoons)

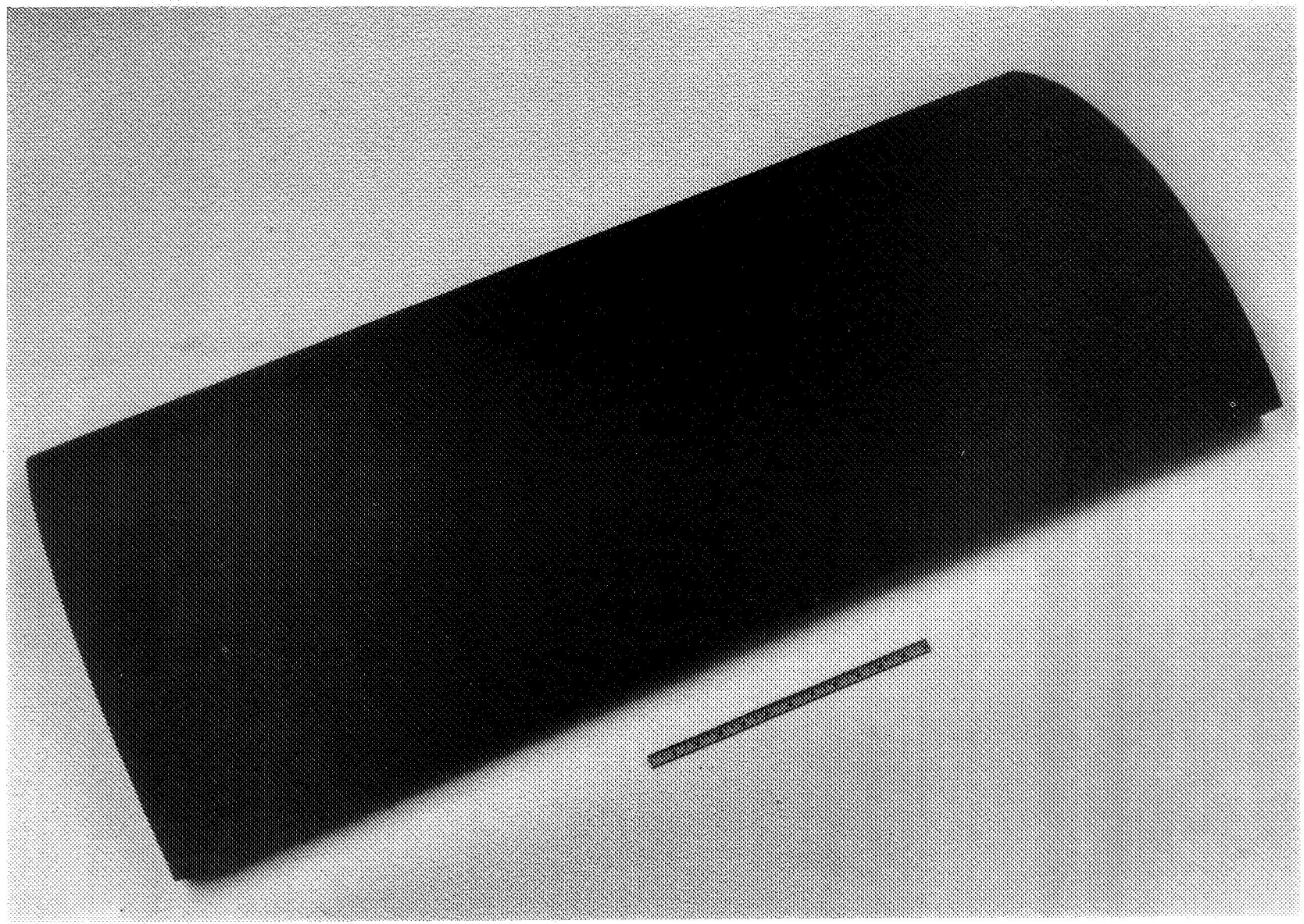
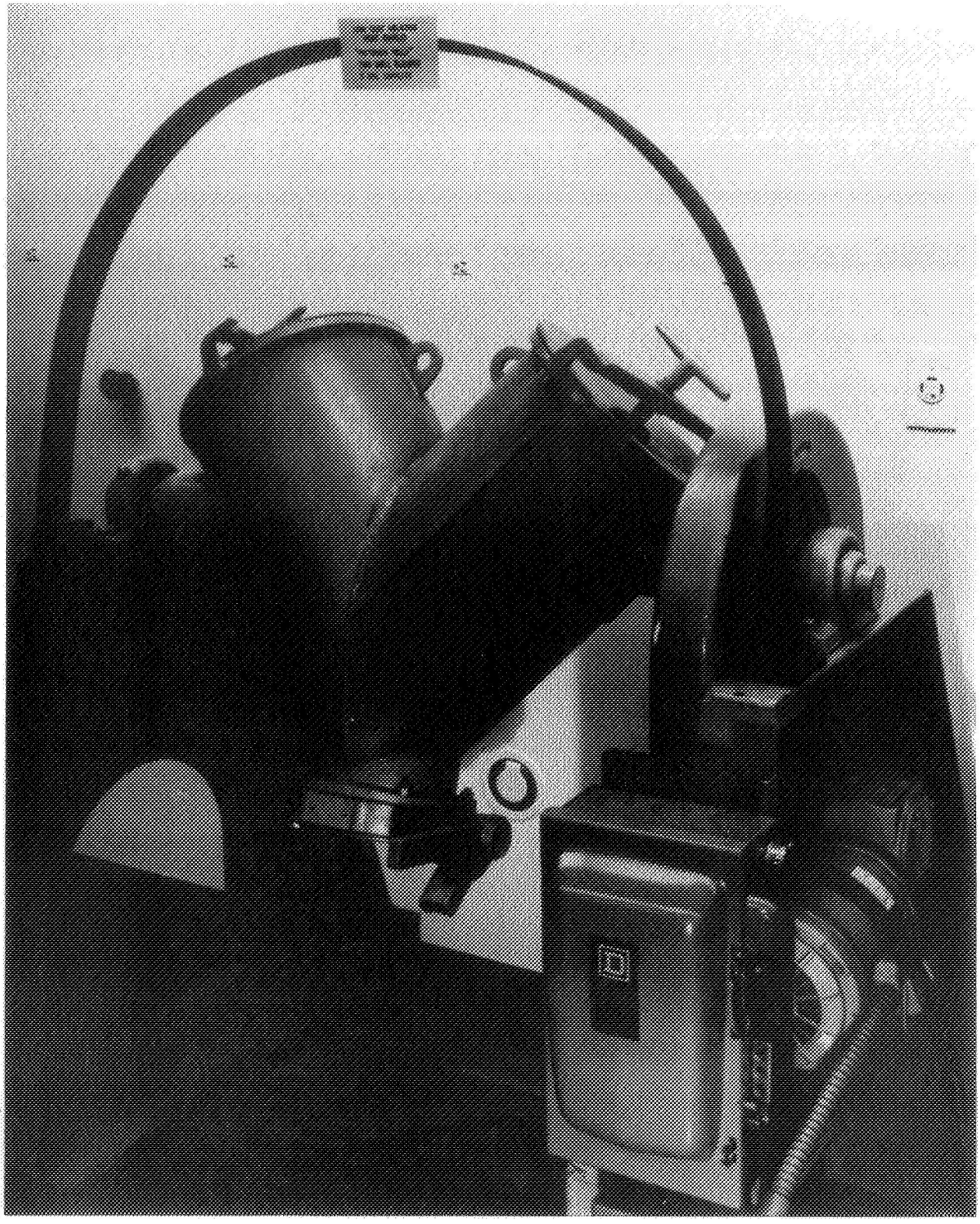


Figure 40. - Elastomeric Curved Panel With Holes (20-Percent Sylgard, 80-Percent Microballoons)



700-81-1331

Figure 41. - Twin Shell Blender, Patterson Kelly

700-86-985C

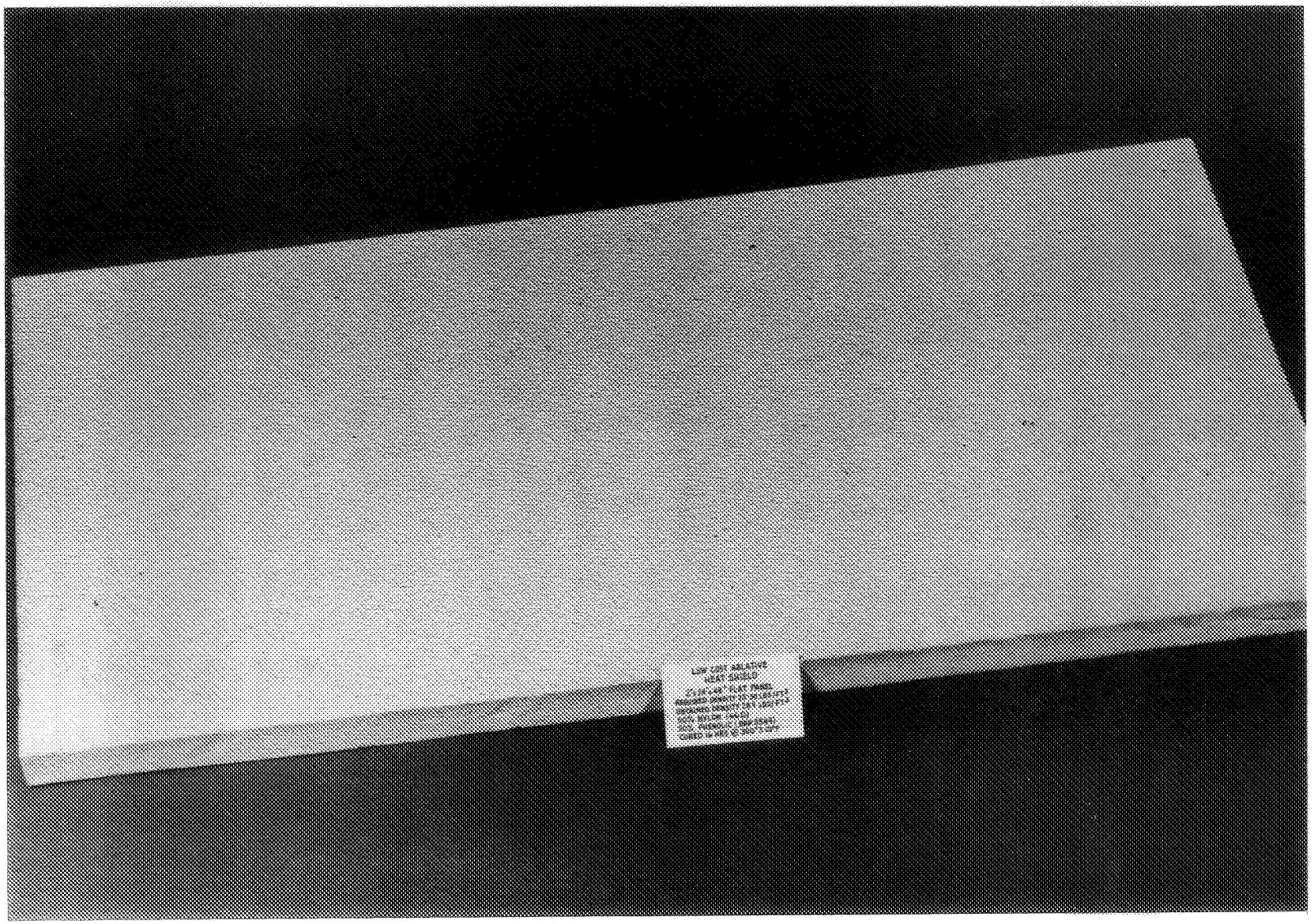


Figure 42. - Nylon-Phenolic Flat Panel

700-86-988G

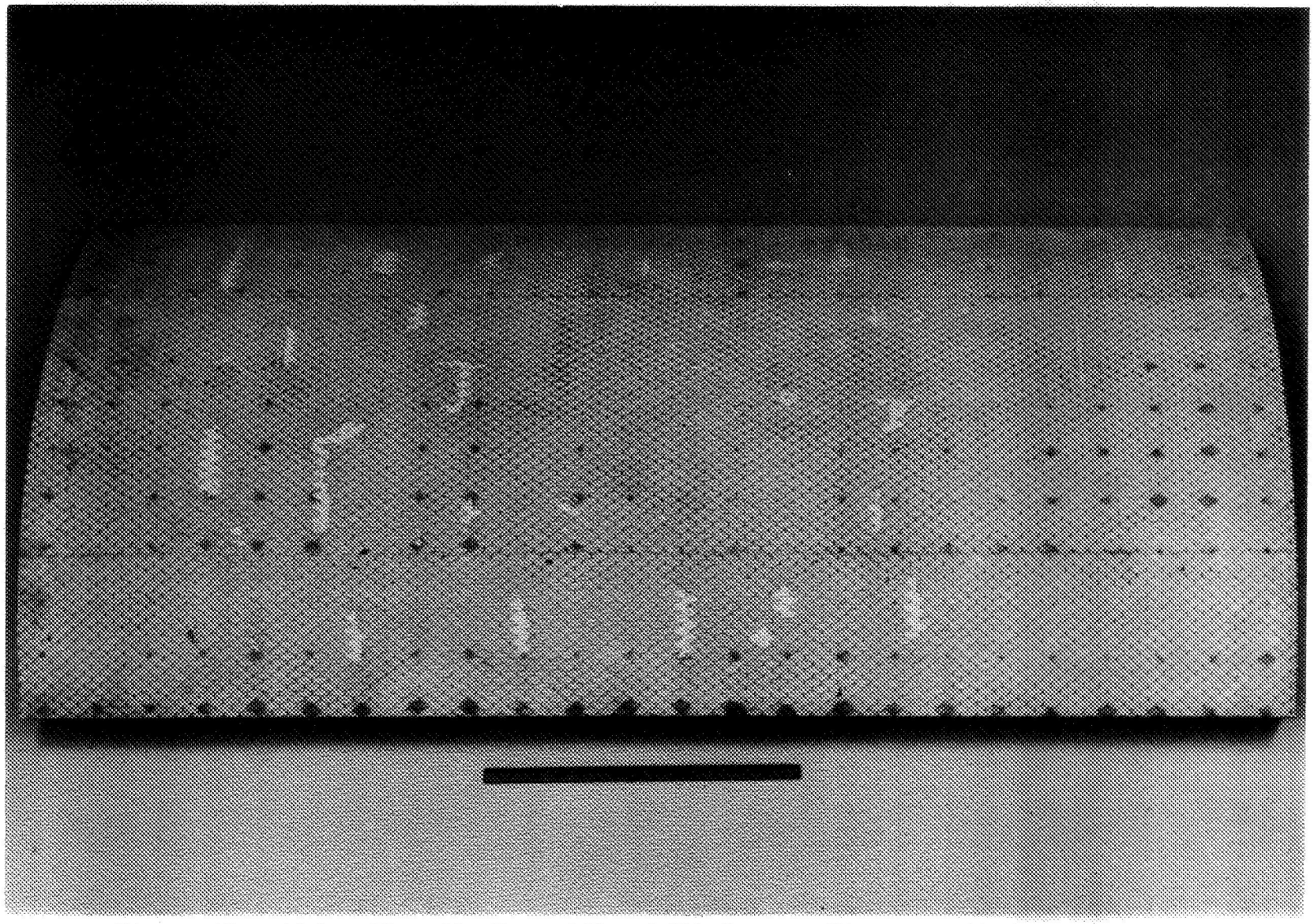


Figure 43. - Nylon-Phenolic Curved Panel (50-Percent Phenolic, 50-Percent Nylon)

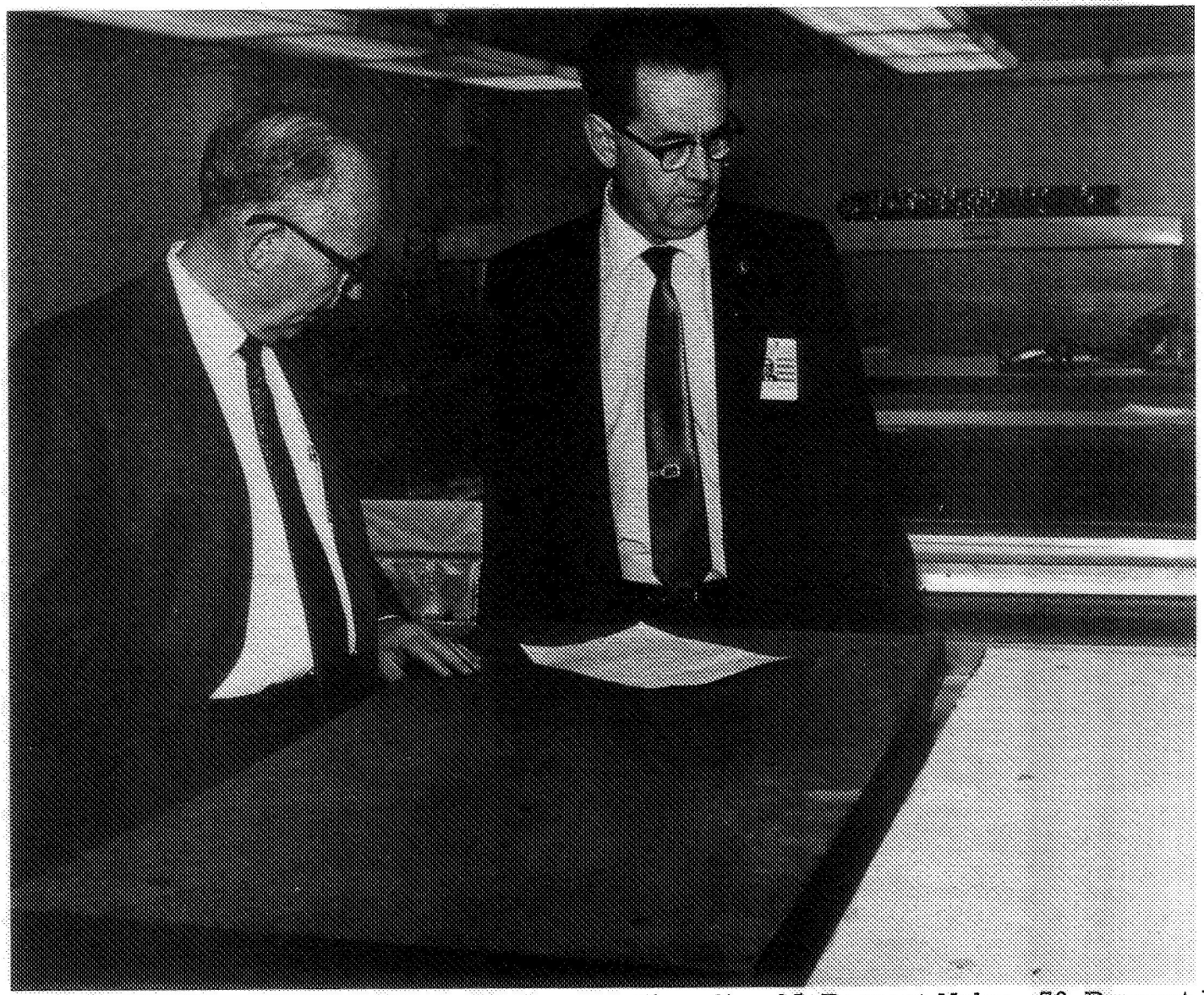


Figure 44. - Nylon-Phenolic Flat Panel (15-Percent Phenolic, 15-Percent Nylon, 70-Percent Phenolic Microballoons) Being Inspected by C. H. Feltz, Space Shuttle-Orbiter Program Vice President, and L. B. Norwood, Low-Cost Ablative Heat Shield Program Manager

700-86-988Q

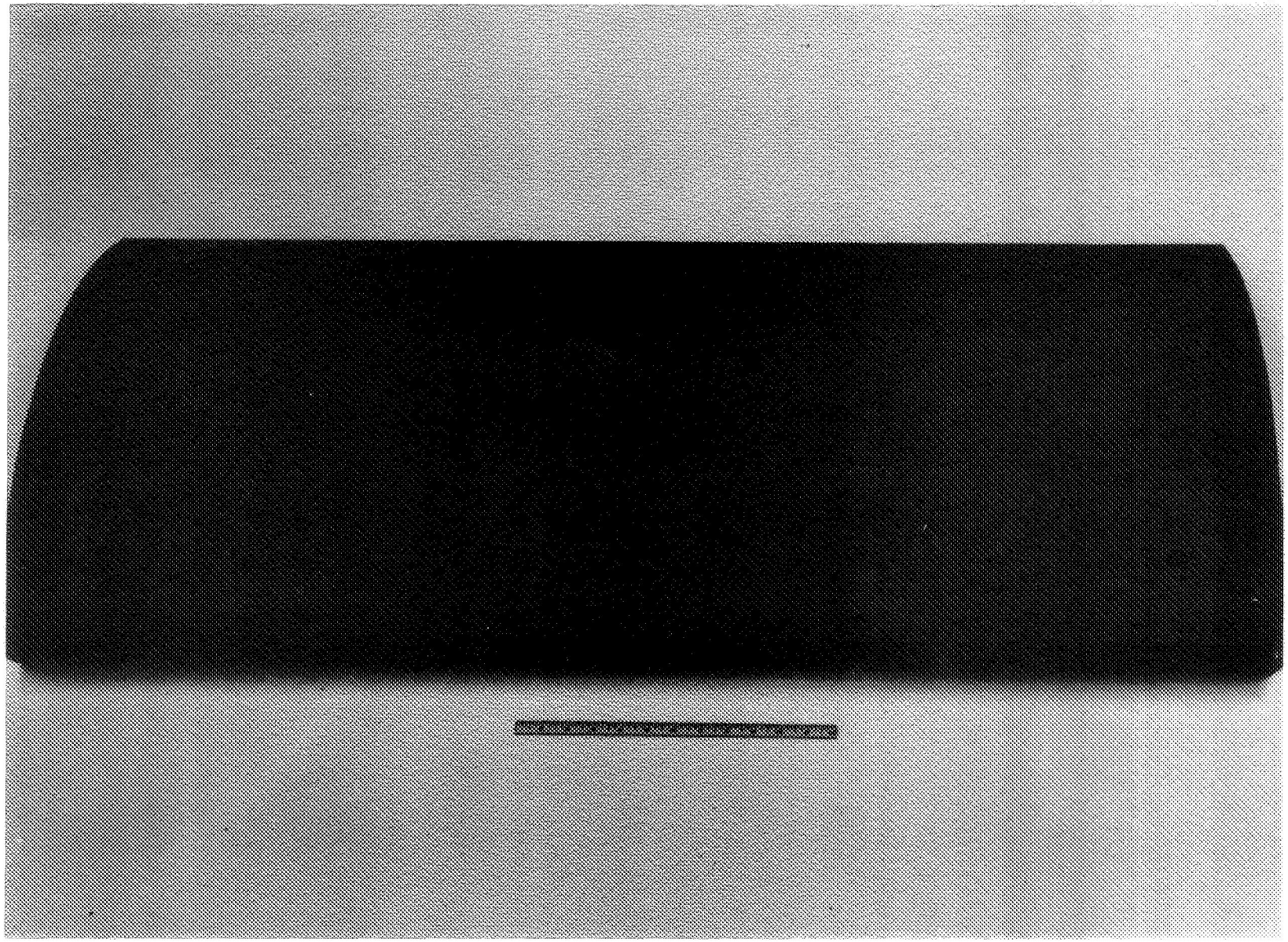
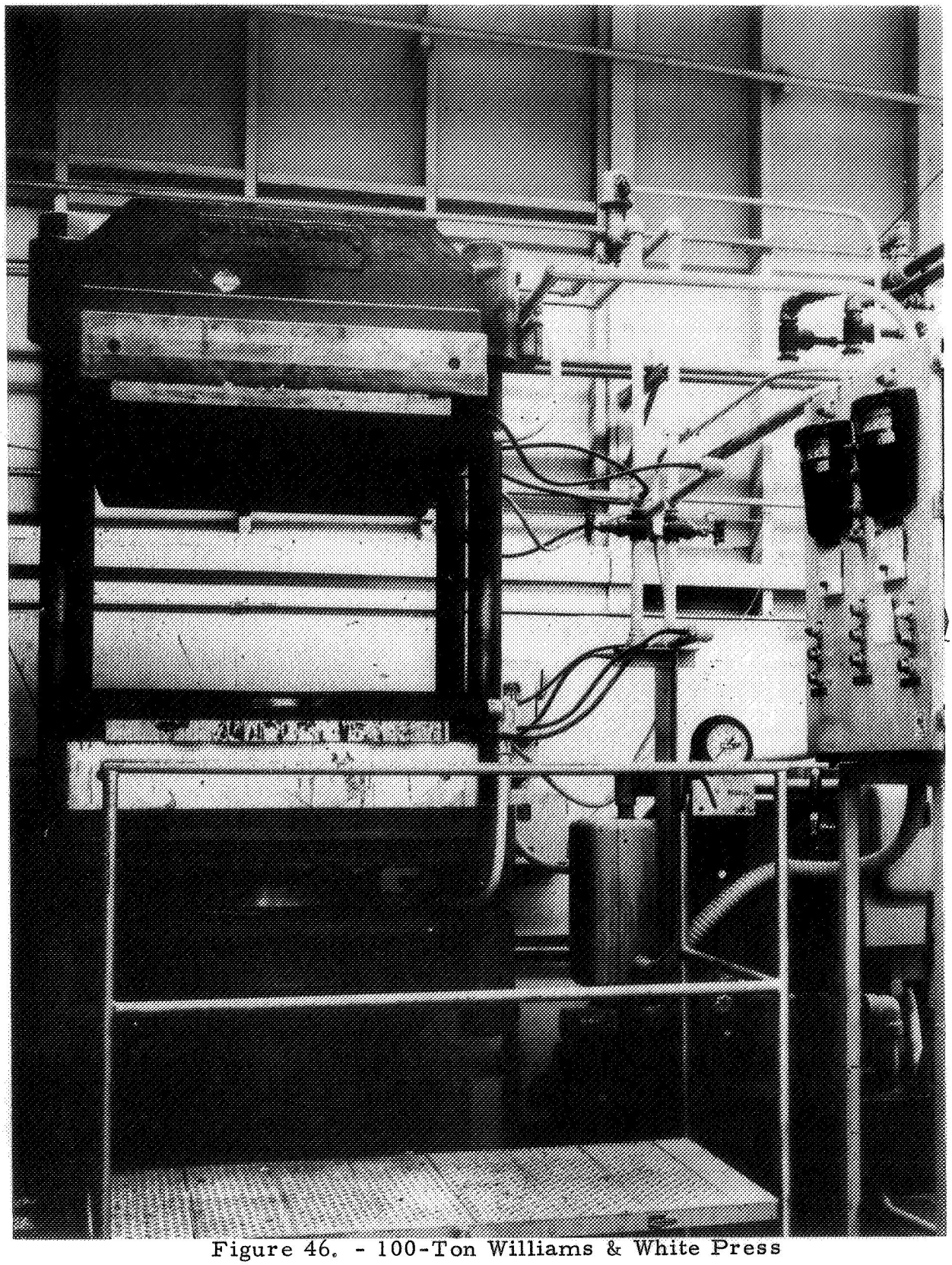


Figure 45. - Nylon-Phenolic Curved Panel (15-Percent Phenolic, 15-Percent Nylon, 70-Percent Microballoons)



700-86-988D

Figure 46. - 100-Ton Williams & White Press
Used for Compressing Ablative Fill

700-86-988C

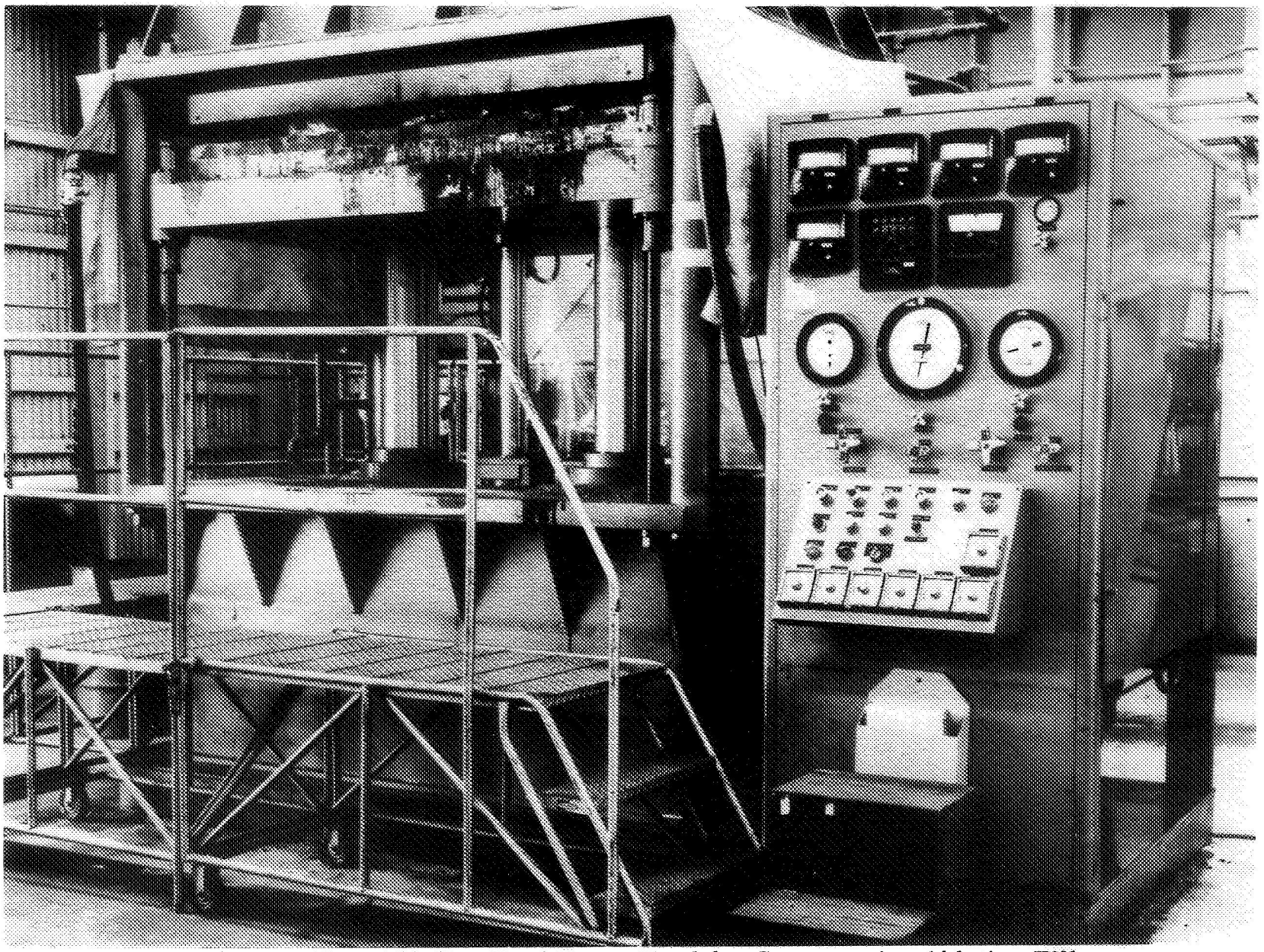


Figure 47. - 150-Ton Kard Press Used for Compressing Ablative Fill

700-86-988P

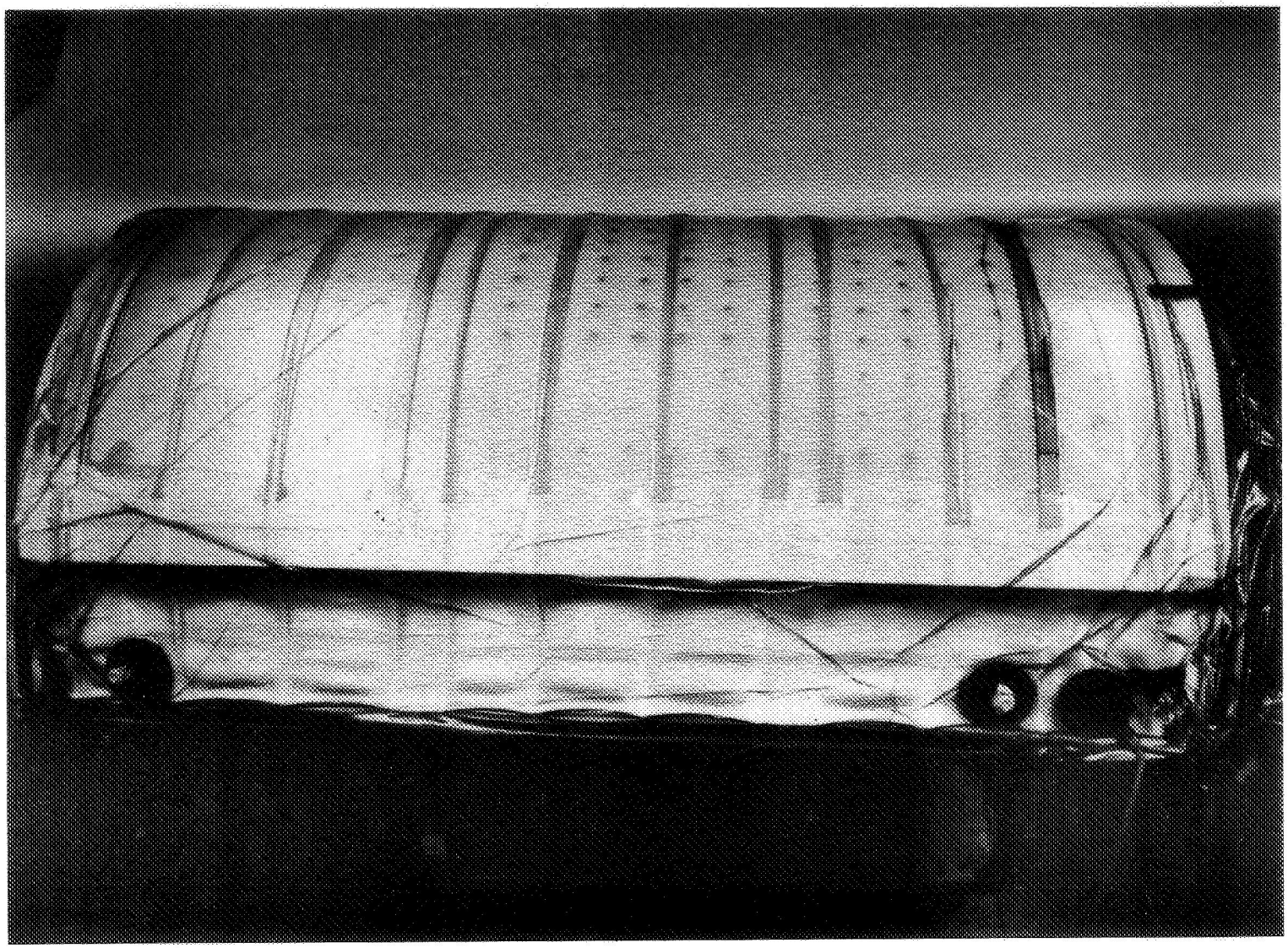


Figure 48. - Curved Panel Just After Cure With Vacuum Bag Still in Place
(Three Caul Sections Can Be Seen)

700-86-988K

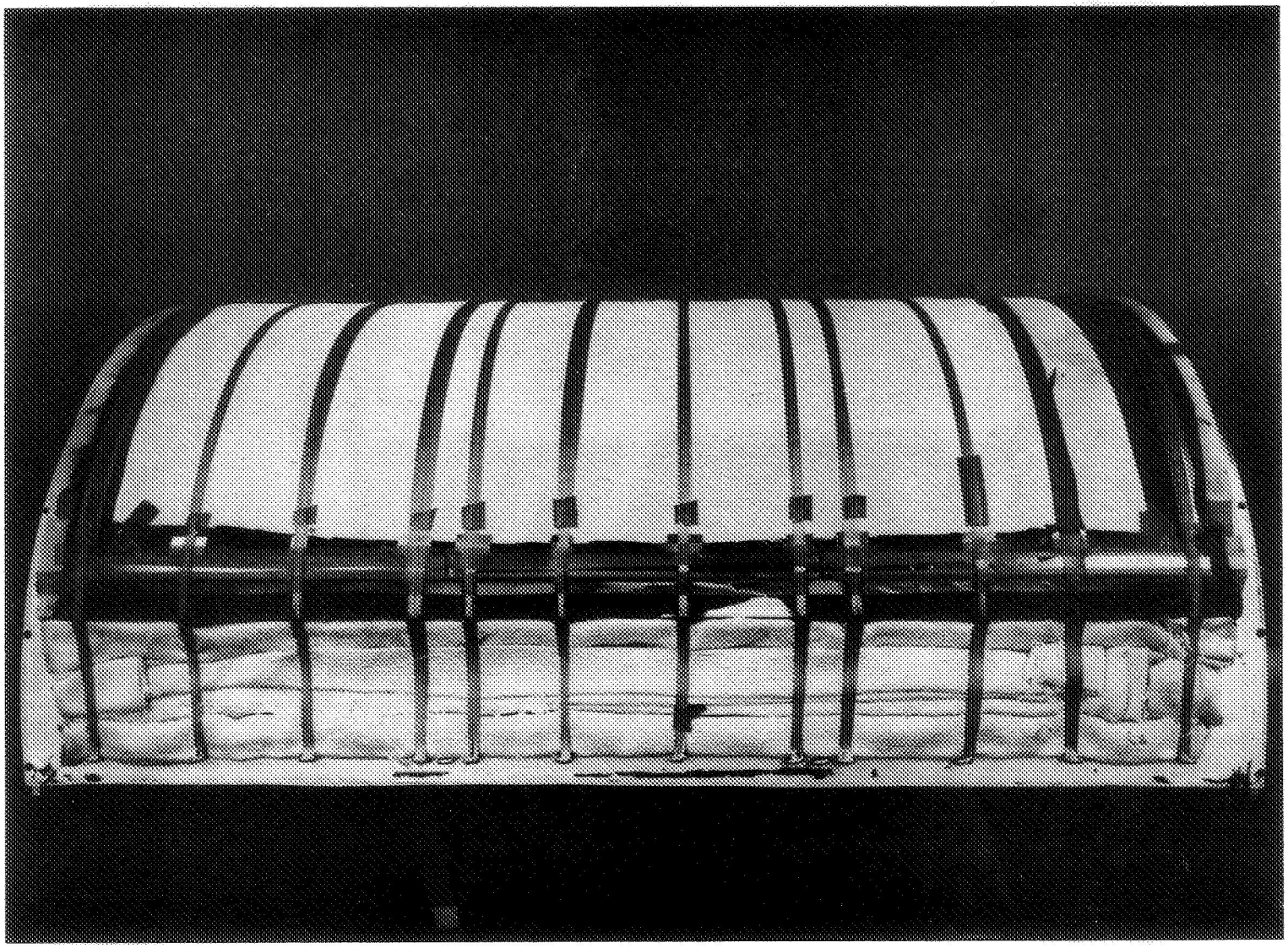


Figure 49. - Curved Panel Just After Cure
(Strap Arrangements Shown)

700-86-988F

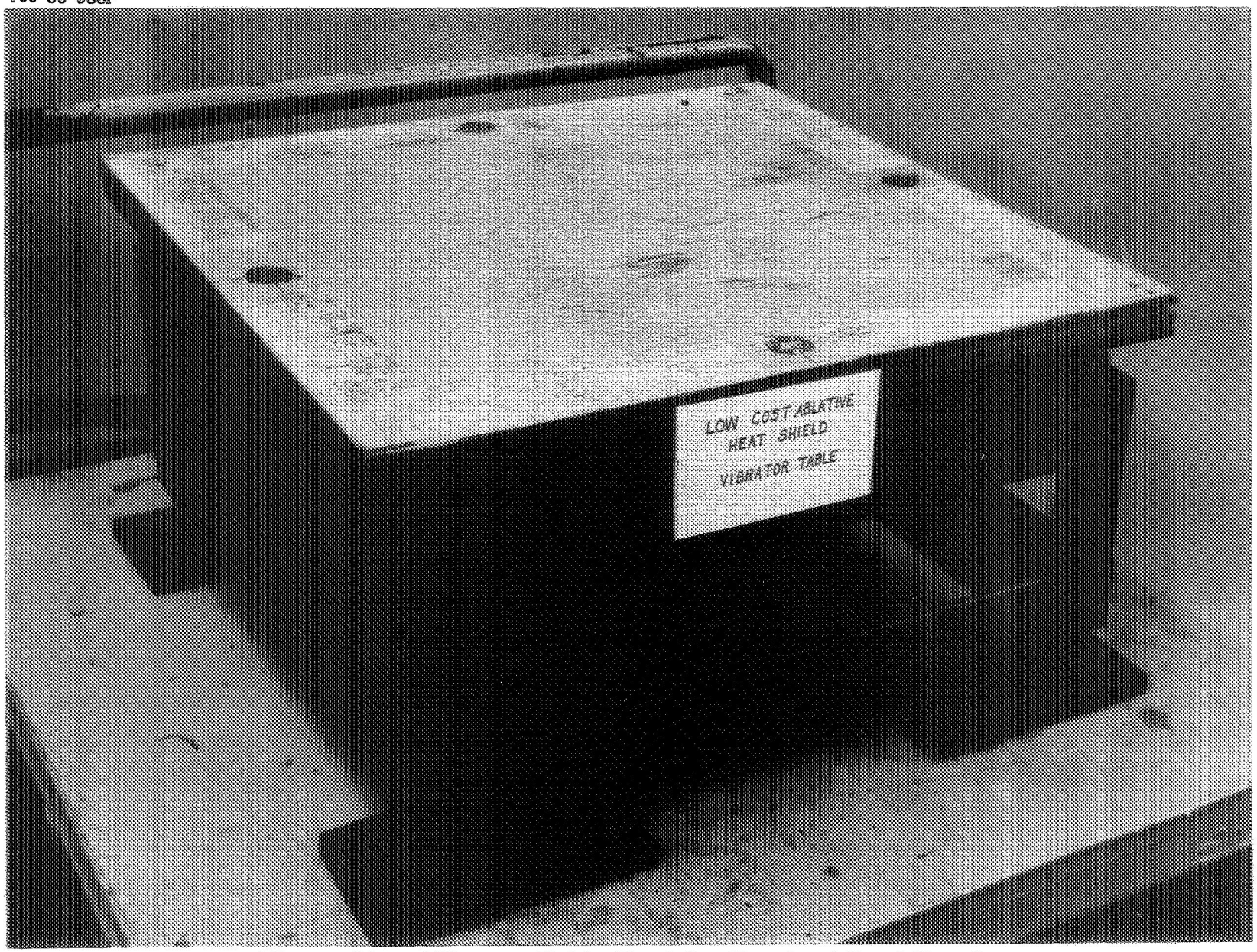


Figure 50. - Vibrator Table Used for Powder Mixed Panels

SK-058321-111 (67-Percent Sylgard, 33-Percent Microballons)

Operation	Details
	SHEET A
	-3 Face Sheet
1	1. Remove prepregnated material (Reliabond R1714) from the freezer.
1	2. Cut two pieces to 26 by 50 inches with scissors.
	-5 Honeycomb
1	1. Cut HRP-3/8-GF11-2.2 or 3/8-GF12-3.2 (honeycomb core) to size, 2 by 26 by 50 inches. Note: 2-inch dimension as received from the supplier. Ribbon direction across the 26-inch dimension.
2	2. Clean core per MA0110-024, Table XIV, protective wrap.
	-11 Subassembly
3	1. Clean shop aid with MEK.
3	2. Apply RAM 225 release agent or equivalent to shop aid and allow to cure at room temperature for a minimum of 1 hour.
4	3. Prefit core to fit shop aid.
4	4. Add core material for flatwise specimens (first item only).
4	5. Apply one ply of Reliabond R1714 (epoxy prepregnated) to core and add one thermocouple wire.
4	6. Apply one layer of TX1040 (separator cloth) to the face of prepregnated and 1 layer of dacron.
4	7. Apply one layer of dacron to the TX1040.
4	8. Add 1/8-inch aluminum plate.
5	9. Add vacuum bag (standard technique) and seal with zinc chromate.
5	10. Test vacuum bag for leaks.
6	11. Position the assembly in the oven and raise the oven temperature to 300 F; pull full vacuum on the assembly; when thermocouple readings reach 300 F, hold for 90 minutes.
7	12. Lower temperature to at least 125 F, release vacuum pressure, open oven, and remove the assembly.
7	13. Remove vacuum bag and remove the assembly; visual check for defects. Test specimens for compliance with the 1-psi tensile load requirement (protective wrap, first item only).
	SHEET B
	-111 Assembly
8	1. Position the -11 subassembly (face sheet up) into the shop aid (pan) filled with DC1203, and dip the core into the primer to within 1/8 inch of the face sheet.
8	2. Raise -11 subassembly from the primer (bath) and allow to drip dry for a minimum of 10 minutes, then place on absorbent paper toweling. 3. Allow the primer to air dry at room temperature for a minimum of 1 hour.

Figure 51. - Manufacturing Fabrication Procedure for Ablative Flat Panel

Operation	Details
9	4. Load the shop aid (drying unit) with phenolic microballoons (BJO-0930) and place in oven. Rotate the drum at 8 rpm; pull partial vacuum 0.5 inches of mercury and raise the oven temperature to 200 F and hold for 3 hours minimum.
10	5. Remove the phenolic microballoons from the drying unit and store in a freon-cleaned polyethylene sealed container.
11	6. Premix Sylgard 182 with catalyst per manufacturer's recommendations (10 parts by weight of resin to one part by weight of catalyst) in a 5-gallon container, mix by hand for 10 minutes.
12	7. Add required quantity of predried microballoons (Operation 9) to the precatalyzed Sylgard 182 (Operation 11) in the 5-gallon container to formulate a mix of 67 percent by weight of Sylgard to 33 percent by weight of phenolic microballoons and premix by hand. After premixing, transfer the mixed material into an Atlantic Research Corp., Model 8CV mixer and mix for 30 to 36 minutes alternating reverse and forward motion every 6 to 8 minutes (approximately 3 pounds per batch mixed).
13	8. Remove the mixed material (Operation 12) and apply mixed material into a double polyethylene container and seal. 9. Weigh the sealed bagged material and record weight, date, and mix and store in freezer at 0 F (not to exceed 3 weeks).
	SHEET C
14	10. Apply RAM 225 release agent or equivalent to shop aid (fill fixture) and allow to cure at room temperature for a minimum of 1 hour.
15	11. Remove sufficient quantity of stored mixed material from the freezer and reweigh for checking purposes.
16	12. Apply a precalculated amount of mixed material (Operation 12) through a screen sieve (expanded metal lathe 1/4 by 3/8 inch) into a polyethylene container. Transfer this material to the fill fixture and disperse evenly over the entire area of the tool.
17	13. Add one layer of TX1040 and 3/4-inch caul plate and required shims and transfer to press.
17	14. Position the filled shop aid in the press (Kard Inc., 150 Ton, 4- by 7-foot bed).
17	15. Close press and compress filled material to the stops on the shop aid.
17	16. Open press and remove the shims and 3/4-inch caul plate and TX-1040.
18	17. Position -11 subassembly (1 face ply, bonded to core) face sheet up on top of compressed material.
18	18. Add one layer of TX1040 to the top of face ply, then add one layer of dacron and thin aluminum caul plate and add the required shims.
18	19. Close press and press the core into the compressed material to the stops on the shop aid (maximum pressure 100 psi—gradual increase in pressure).
	SHEET D
19	20. Open press and remove the shop aid and assembly. Remove shop aid shims, caul plate, TX1040, and dacron.
20	21. Add one ply of Reliabond 1714 (epoxy prepregnated) to the existing one ply and add one thermocouple wire to the bond line.
20	22. Add one layer of TX1040 (separator cloth), and one 0.020-inch caul plate.

Figure 51. - Continued

Operation	Details
20	23. Add vacuum bag and seal with zinc chromate.
20	24. Test vacuum bag for leaks.
21	25. Position the shop aid and assembly in the oven and raise the temperature to 180 ± 10 F. Pull vacuum on the assembly (minimum of 22 inches of mercury). When the thermocouple reading reaches 180 ± 10 F, hold for 24 hours.
21	26. Lower the temperature to at least 100 F, release vacuum pressure, open oven, and remove the assembly.
22	27. Remove filled assembly from the shop aid.
22	28. Visually check cured assembly.
23	29. Cut off excess material around the periphery to 2- by 4-foot finished dimensions.
24	30. Using shop aid tool and a 0.750-inch diameter cookie cutter, cut out six 0.750-inch diameter holes. With a 9/32-inch diameter punch, punch out the six 9/32-inch diameter holes through face sheet. Edge seal with Sylgard 184 (room temperature cure 24 hours).
25	31. Weigh completed panel and record.
25	32. Final inspection.

SK-058322-121 (20-Percent Sylgard, 80-Percent Microballoons)

Operation	Details
	1. Same as SK-058322-111 -11 Subassembly 1. Same as SK-058322-111 -121 Final Assembly 1. Same as SK-058322-111 except as listed below: a. Paragraph 7, Operation 12 Add required quantity of predried microballoons (Operation 9) to the precatalyzed Sylgard 182 (Operation 11) in the 5-gallon container to formulate a mix of 20-percent Sylgard and 80-percent phenolic microballoons and hand mix. After hand mixing, transfer the mixed material into an Atlantic Research Corp., Model 8CV mixer and mix for 30 to 36 minutes alternating reverse and forward motion every 6 to 8 minutes.

SK-0583221-131 (50-Percent Phenolic, 50-Percent Nylon)

Operation	Details
	1. Same as SK-058322-111 -11 Subassembly 1. Same as SK-058322-111

Figure 51. - Continued

Operation	Details
	SHEET B
	-131 Final Assembly
8	1. Position the -11 subassembly (face sheet up) into the shop aid (pan) filled with Monsanto SC1008, and dip the core into the primer to within 1/8 inch of the face sheet. SC1008 cut 50 percent with Butyl-Isopropoalcohol.
8	2. Raise -11 subassembly from the shop aid (pan) and allow to drip dry for a minimum of 10 minutes, then place on absorbent paper toweling.
8A	3. Cure the SC1008 at 280 F for 1 hour in an air-circulating oven.
9	4. Load the shop aid (drying unit) with nylon powder (Polypenco 66D) and place in oven. Rotate the drum at 10 to 15 rpm. Pull partial vacuum (0.5 inches of mercury) and raise the oven temperature to 200 F and hold until there is no visual moisture being drawn off.
10	5. Remove the nylon powder from the drying unit and store in a freon-clean polyethylene container.
12A	6. Mix 50-percent by weight of phenolic resin (BRP-5549 with 50 percent by weight of nylon powder 66D in a Patterson Kelly twin shell blender (one ft^3 capacity) at approximately 25 rpm for 42 minutes. Due to capacity of blender, store in polyethylene container until the required amount is mixed.
14	7. Apply RAM 225 release agent or equivalent to shop aid (fill fixture) and allow to cure at room temperature for a minimum of 1 hour.
16A	8. Prefit -11 subassembly to the shop aid (fill fixture), remove and add one layer of armalon, one layer of TX1040, then add the -11 subassembly (face sheet down) into the shop aid. Note: To prevent adherence of excess fill curing on face (mask back side with aluminum tape).
16A	9. Apply a precalculated amount of mixed material (Operation 12A) to the top of honeycomb cells. Disperse the mixed material over the entire area of core. Position the filled shop aid on a syntron packer model VP554 and vibrate the assembly. Continue to add precalculated amounts of material and vibrate the assembly until all cells are filled. Then, add a precalculated amount again to the top of honeycomb cells. Add a combination 1/2-inch zinc chromate and 1/2-inch ensolite blanket (zinc chromate down) to the face of filled material. Add 3/4-inch caul plate, shims, top plate, and stops.
18A	10. Position the filled shop aid in the press (Kard Inc., 150-ton, 4- by 7-foot bed).
18A	11. Close press and compress the filled material into the core. Repeat operation 3 times. Maximum 100-psi pressure used. Release the pressure and remove top plate, shims, 3/4-inch caul plate, and zinc chromate, and ensolite blanket. Replace 3/4-inch caul plate and shims and close press until the press hits the stops on the shop aid.
	SHEET D
19	12. Open press and remove shop aid and assembly.
19	13. Remove top plate and shop aid shims and TX 1040.
20	14. Add one layer of TX1040 and one layer of armalon and one 0.020-inch perforated caul plate to the face of the assembly and additional bleeder fabric.
20	15. Add vacuum bag and seal with zinc chromate.

Figure 51. - Continued

Operation	Details
20	16. Test vacuum bag for leaks.
21	17. Position the shop aid and assembly in the oven and raise the temperature to 300 F. Pull full vacuum 22 inches of mercury on the assembly, when the thermocouple reading reaches 300 F, hold for 16 hours.
21	18. Lower the temperature to at least 125 F. Release vacuum pressure, open oven, and remove the assembly.
22	19. Remove filled assembly from the shop aid.
22	20. Visually check cured assembly.
23	21. Cut off excess material around the periphery to 2- by 4-foot finished dimensions.
24A	22. Using a shop aid drill tool with a 5/8-inch sleeve, hand drill six 5/8-inch holes with a flat bottom drill to prevent damage to face sheet. Remove the 5/8-inch sleeve from the shop aid tool and with a 0.750-inch cookie cutter, clean out holes to 0.750-inch diameter. Punch the 9/32-inch diameter holes through face sheet with a 9/32-inch cookie cutter.
25	23. Plugs are rough cut on a band saw from excess material and double-back taped to shop aid mandrell then hand ground on a belt sander using a #240 grit. Edge seal 60 to 40 versimide 115 and Epon 812. Cure at room temperature for 24 hours.
26	24. Weigh completed panel and record.
26	25. Final inspection.

SK-058322-141 (15-Percent Phenolic, 15-Percent Nylon, 10-Percent Microballoons)

Operation	Details
	1. Same as SK-058322-111 -11 Subassembly 1. Same as SK-058322-111 -141 Final Assembly 1. Same as SK-058322-131 except as listed below: a. Add phenolic microballoon operations (Paragraph 4, Operation 9 and Paragraph 5, Operation 10 from SK-058322-111). b. Paragraph 6, Operation 12A Mix 15 percent by weight of phenolic powder (BRP-5549 "B" Stage) with 15 percent by weight of nylon powder (Polypenco 66D) and 70 percent by weight of the predried phenolic microballoons (BJO-0930) in a Patterson-Kelly twin shell blender (one ft^3 capacity) at approximately 25 rpm for 42 minutes. c. Paragraph 30, Operation 24 Using shop aid tool and a 0.750-inch diameter cookie cutter, cut out six 0.75-inch diameter holes. With a 9/32-inch diameter punch, punch out the six 9/32-inch diameter holes through the face sheet. Edge seal with Sylgard 184 (room temperature cure 24 hours).

Figure 51. - Continued

A

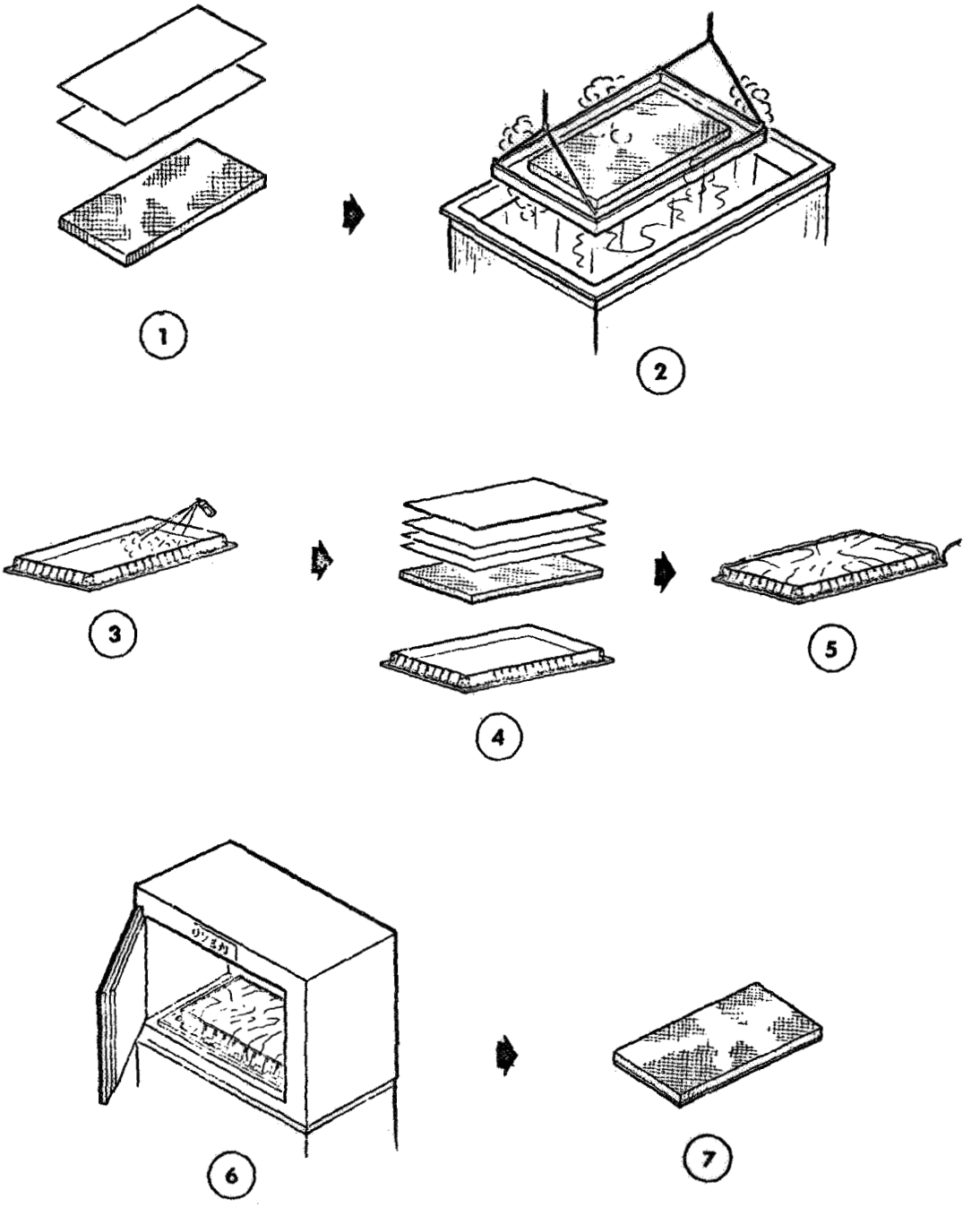


Figure 51. - Continued

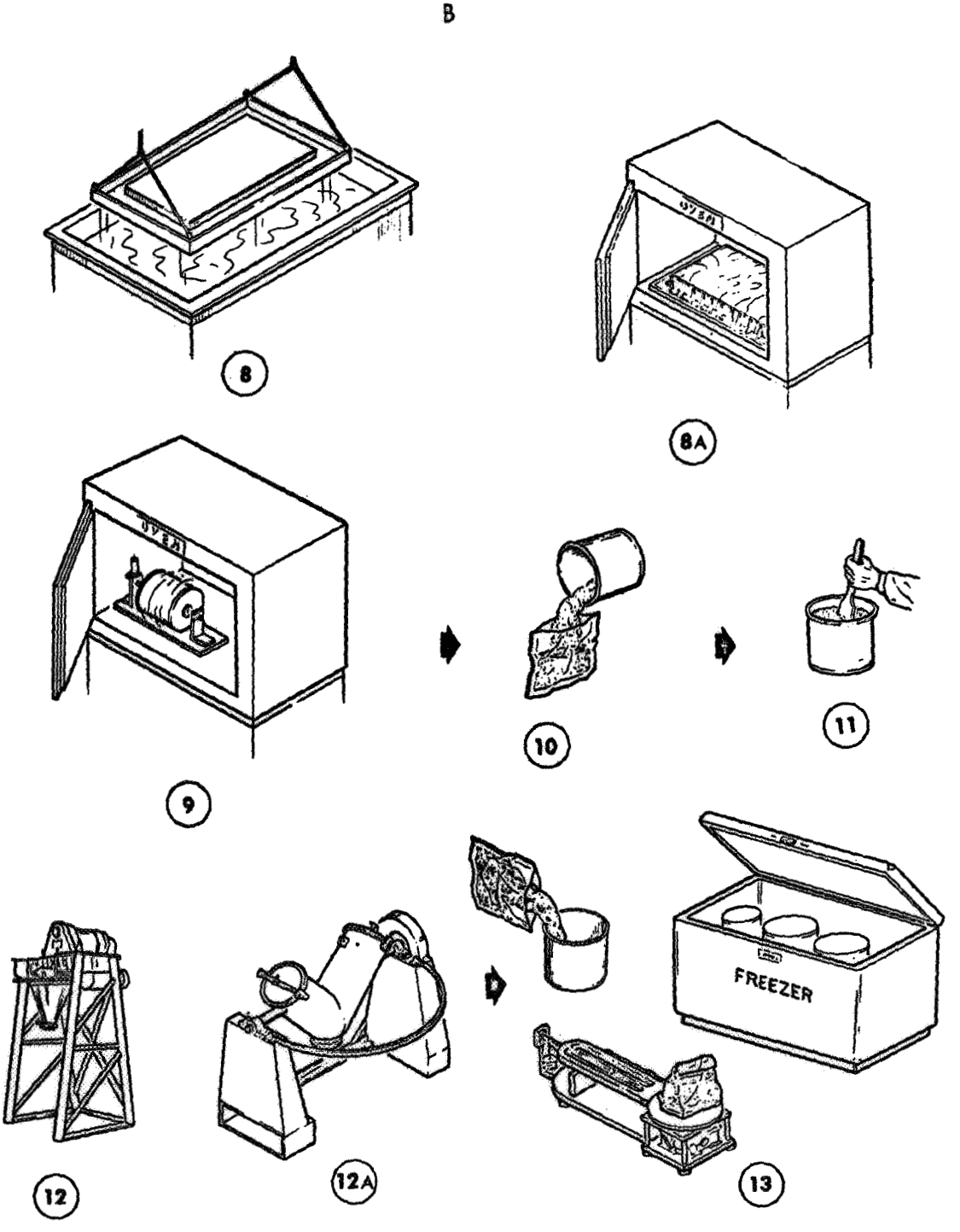


Figure 51. - Continued

C

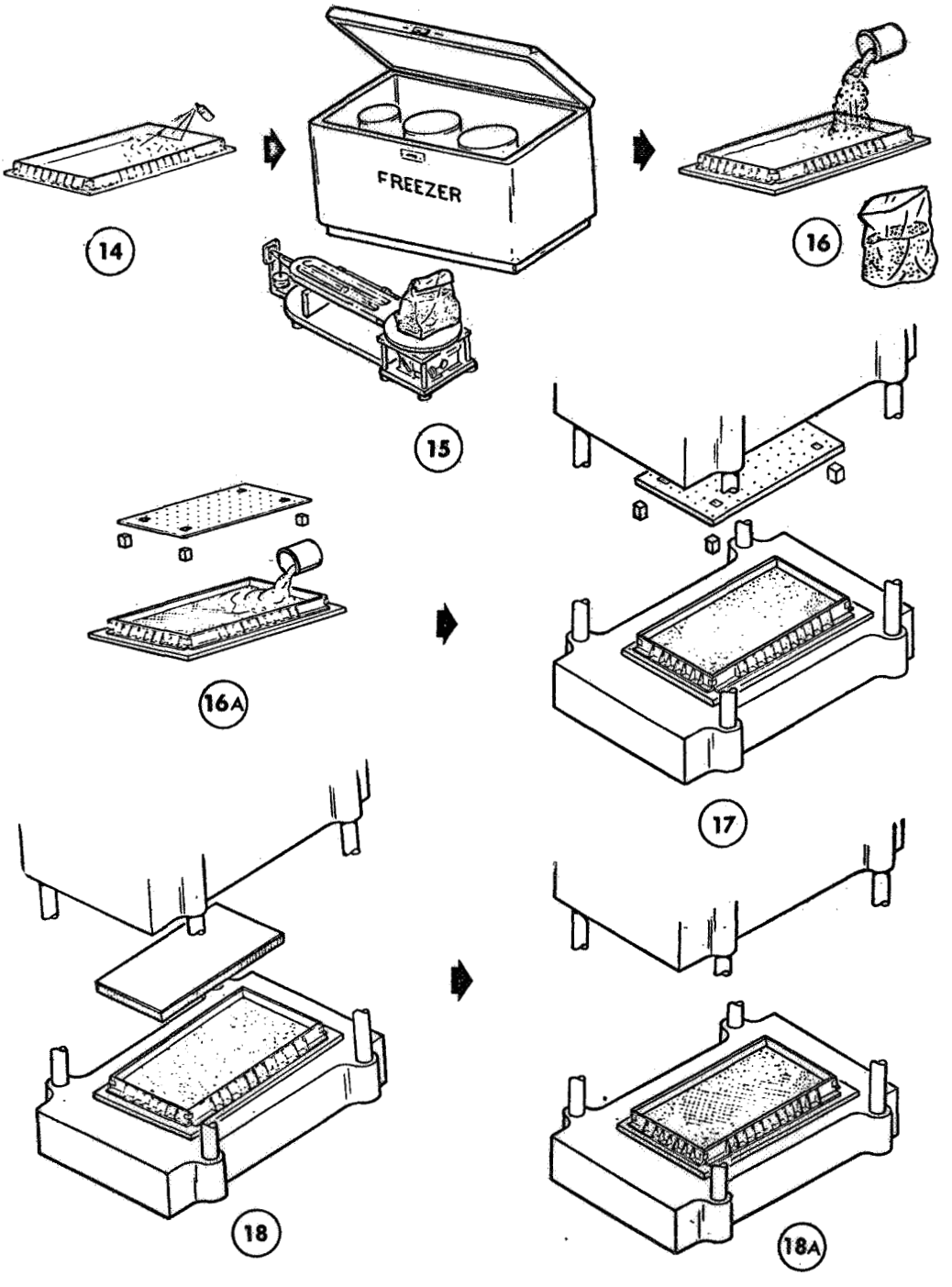


Figure 51. - Continued

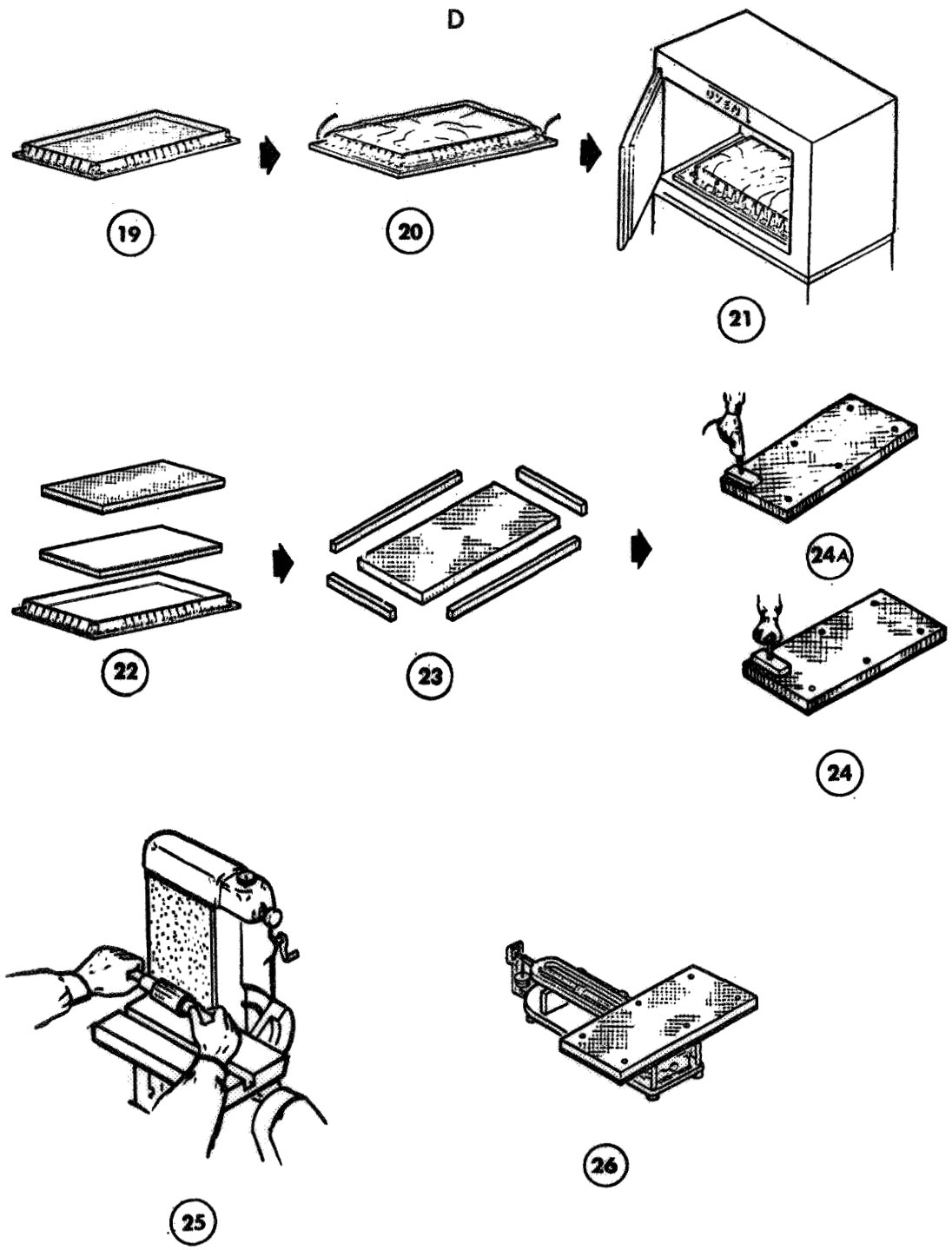


Figure 51. - Concluded

SK-058321-111 (67-Percent Sylgard, 33-Percent Microballoons)

Operation	Details
	SHEET A
	-3 Face Sheet
1	1. Remove prepregnated material (Reliabond R1714) from the freezer.
1	2. Cut two pieces to 26 by 50 inches with scissors.
	-5 Honeycomb
1	1. Cut HRP-OX-GF11-2.7 (honeycomb core) to size, 2 by 26 by 50 inches. Note: 2-inch dimension as received from the supplier. Ribbon direction across to 26-inch dimension.
2	2. Clean core per MA0110-024, Table XIV, protective wrap.
	-11 Subassembly
3	1. Clean shop aid with MEK.
3	2. Apply RAM 225 release agent or equivalent to shop aid and allow to cure at room temperature for a minimum of 1 hour.
4	3. Prefit core to fit shop aid.
4	4. Add core material for flatwise specimens (first item only).
4	5. Apply one ply of Reliabond R1714 (epoxy prepregnated) to the core in which the Sylgard system is being used and two plies of Reliabond R1714 (epoxy prepregnated) in the dry powdered system. Add one thermocouple wire.
4	6. Apply one layer of TX1040 (separator cloth) to the face of prepregnated and one layer of dacron.
4	7. Apply one layer of dacron to the TX1040.
4	8. Add 1/8-inch aluminum plate.
5	9. Add vacuum bag (standard technique) and seal with zinc chromate.
5	10. Test vacuum bag for leaks.
6	11. Position the assembly in the oven and raise the oven temperature to 300 F; pull full vacuum on the assembly; when thermocouple readings reach 300 F, hold for 90 minutes.
7	12. Lower temperature to at least 125 F, release vacuum pressure, open oven, and remove the assembly.
7	13. Remove vacuum bag from the assembly; visual check for defects. Test specimens for compliance with the 1-psi tensile load requirement (first item only). Protective wrap.
	SHEET B
	-111 Final Assembly
8	1. Position the -11 subassembly (face sheet up) into the shop aid (pan) filled with DC1203, and dip the core into the primer to within 1/8 inch of the face sheet.

Figure 52. - Manufacturing Fabrication Procedure for Ablative Curved Panel

Operation	Details
8	2. Raise -11 subassembly from the primer (bath) and allow to drip dry for a minimum of 10 minutes, then place on absorbent paper toweling.
8	3. Allow the primer to air dry at room temperature for a minimum of 1 hour.
9	4. Load the shop aid (drying unit) with phenolic microballoons (BJO-0930) and place in an oven. Rotate the drum at 8 rpm, pull partial vacuum 0.5 inches of mercury and raise the oven temperature to 200 F and hold for 3 hours minimum.
10	5. Remove the phenolic microballoons from the drying unit and store in a freon-clean polyethylene sealed container.
11	6. Premix Sylgard 182 with catalyst per manufacturer's recommendations (10 parts by weight of resin to one part by weight of catalyst) in a 5-gallon container, mix by hand for 10 minutes.
12	7. Add required quantity of predried microballoons (Operation 10) to the precatalyzed Sylgard 182 (Operation 11), in the 5-gallon container to formulate a mix of 67 percent by weight of Sylgard and 33 percent by weight of phenolic microballoons and hand mix. After hand mixing, transfer the mixed material into an Atlantic Research Corp., Model 8CV mixer and mix for 30 to 36 minutes alternating reverse and forward motion every 6 to 8 minutes (approximately 3 pounds per batch mixed).
13	8. Remove the mixed material (Operation 12) and apply mixed material into a double polyethylene container and seal.
13	9. Weigh the sealed bagged material and record weight, date, and mix and store in freezer at 0 F.
14	10. Apply RAM 225 release agent or equivalent to shop aid (fill fixture) and allow to cure at room temperature for a minimum of 1 hour.
15	11. Remove sufficient quantity of stored mixed material from the freezer and reweigh for checking purposes.
	SHEET C
16	12. Apply a precalculated amount of mixed material (Operation 12) through screen sieve into the shop aid and disperse evenly over the entire area of tool.
17	13. Add one layer of TX1040 and 3/4-inch caul plate of shop aid and required shims.
17	14. Position the filled shop aid in the press (Kard Inc., 150-ton, 4- by 7-foot bed).
17	15. Close press and compress filled material to the stops on the shop aid.
17	16. Open press and remove the shims and 3/4-inch caul plate of shop aid and TX1040.
18	17. Position -11 subassembly (1 face ply, bonded to core) face sheet up on top of compressed material.
18	18. Add one layer of TX1040 to the top of face ply, then add one layer of dacron thin sheet caul plate and add the required shims.
18	19. Close press and press the core into the compressed material to the stops on the shop aid. Maximum pressure, 100-psi; gradual increase in pressure.

Figure 52. - Continued

Operation	Details
19	20. Open press and remove the shims and top plate of the shop aid. Remove the assembly from the shop aid with lower side rails in place and invert assembly.
20	21. Apply RAM 225 release agent to shop aid (curved fixture) and allow to air dry at room temperature for a minimum of 1 hour.
21	22. Position one ply of Reliabond 1714 to the shop aid. Position filled assembly on top of the one ply of Reliabond 1714 and press filled assembly to the contoured face of shop aid. Clamp in position and add one thermocouple wire to the corner of filled assembly. Add one layer of TX1040 and one layer of armalon. Add vacuum bag, pull full vacuum, and check for leaks.
	SHEET D
22	23. Position the assembly in the oven and raise the oven temperature to 180 ± 10 F, pull full vacuum. When the thermocouple reading reaches 180 ± 10 F, hold for 24 hours at this temperature and pressure.
23	24. Remove shop aid and cured filled assembly from the oven. Remove filled assembly from the shop aid.
23	25. Visually check cured assembly.
24	26. Cut off excess material around periphery to 2- by 4-foot finished dimensions. Edge seal with Sylgard 184 (room temperature cure 24 hours).
25	27. Using shop aid tool and a 0.750-inch diameter cookie cutter, cut out six 0.750-inch diameter holes. With a 9/32-inch diameter punch, punch out the six 9/32-inch diameter holes through face sheet. Edge seal with Sylgard 184 (room temperature cure 24 hours):
26	28. Weigh completed panel and record.
26	29. Final inspection.

SD-058321-121 (20-Percent Sylgard 80-Percent Microballoons)

Operation	Details
	1. Same as SK-058321-111 -11 Subassembly 1. Same as SK-058321-111 -121 Final Assembly 1. Same as SK-058321-111 except as listed below: a. Add required quantity of predried microballoons (Operation 9) to the precatalyzed Sylgard 182 (Operation 11) in the 5-gallon container to formulate a mix of 20 percent by weight of Sylgard and 80 percent by weight of phenolic microballoons and hand mix. After hand mixing, transfer the mixed material into an Atlantic Research Corp., Model 8CV mixer and mix for 30 to 36 minutes alternating reverse and forward motions every 6 to 8 minutes.

Figure 52. - Continued

SK-058321-131 (50-Percent Phenolic 50-Percent Nylon)

Operation	Details
	1. Same as SK-058321-111
	SHEET A
	-131 Final Assembly
8	1. Position the -11 subassembly (face sheet up) into the shop aid (pan) filled with Monsanto SC1008, and dip the core into the primer to within 1/8 inch of the face sheet.
8	2. Raise -11 subassembly from the shop aid (pan) and allow to drip dry for a minimum of 10 minutes, then place on absorbent paper toweling.
8A	3. Cure the SC1008 at 280 F for 1.0 hours in an air-circulating oven.
	SHEET B
9	4. Load the shop aid (drying unit) with nylon powder (polypenco 66D) and place in oven. Rotate the drum at 10 to 15 rpm. Pull partial vacuum 0.5 inches of mercury and raise the oven temperature to 200 F and hold for a minimum of 3 hours.
10	5. Remove the nylon powder from the drying unit and store in a freon-clean polyethylene container.
12A	6. Mix 50 percent by weight of phenolic resin (BRP-5549 "B" Stage) with 50 percent by weight of the predried nylon powder in a Patterson-Kelly twin shell blender (one ft^3 capacity) at approximately 25 rpm for 40 minutes (approximately 3 pounds per batch mixed).
14	7. Apply RAM 225 release agent or equivalent to shop aid (fill fixture) and allow to cure at room temperature for a minimum of 1 hour.
	SHEET C
16A	8. Position -11 subassembly (face sheet down) into the shop aid (fill fixture).
16A	9. Apply a precalculated amount of mixed material (Operation 12A) to the top of honeycomb cells. Disperse the mixed material evenly over the entire area of core. Add top plate of shop aid and required shims.
18	10. Position the filled shop aid in the press (Kard Inc., 150-ton, 4- by 7-foot bed).
18	11. Close press and compress filled material to the stops on the shop aid.
19	12. Open press and remove the shims and top plate of the shop aid. Remove assembly from the shop aid with lower side rails in place.
20	13. Apply RAM 225 release agent or equivalent to shop aid (curved fixture) and allow to cure at room temperature for a minimum of 1 hour.
21	14. Position filled assembly and press filled assembly to the contoured face of the shop aid and clamp in position. Add one thermocouple wire to the corner of filled assembly. Add one layer of TX1040 and one layer of armalon, add vacuum bag, pull full vacuum, and check for leaks.

Figure 52. - Continued

Operation	Details
	SHEET D
22	15. Position the assembly in the oven and raise the oven temperature to 300 F, pull full vacuum. When the thermocouple reading reaches 300 F, hold for 16 hours at this temperature and pressure.
23	16. Remove shop aid and cured filled assembly from the oven and remove filled assembly from the shop aid.
23	17. Visually check cured assembly.
24	18. Cut off excess material around the periphery to 2- by 4-foot finished dimensions.
25A	19. Using a shop aid drill tool with a 5/8-inch sleeve, hand drill 5/8-inch holes with a flat bottom drill to prevent damage to the face sheet. Remove the 5/8-inch sleeve from the shop aid drill tool and with a 0.750-inch cookie cutter, clean out holes to 0.750-inch diameter. Punch the 9/32-inch diameter holes through face sheet with a 9/32-inch cookie cutter.
26	20. Plugs are rough-cut on band saw from excess material and double-back taped to shop aid mandrell, and hand ground on a belt sander using #240 grit.
27	21. Weigh completed panel and record.
27	22. Final inspection.

SK-058321-141 (15-Percent Phenolic, 15-Percent Nylon, 70-Percent Microballoons)

Operation	Details
	1. Same as SK-058321-111 -11 Subassembly 1. Same as SK-058321-111 -141 Final Assembly 1. Same as SK-058321-131 except as listed below: a. Add phenolic microballoon drying operations (Paragraph 4, Operation 9; and Paragraph 5, Operation 10; from SK-058321-111). b. Paragraph 6, Operation 12A Mix 15 percent by weight of phenolic powder (BRP-5549 "B" Stage) with 15 percent by weight of nylon powder (Polypenco 66D) and 70 percent by weight of the predried phenolic microballoons (BJO-093) in a Patterson-Kelly twin shell blender (one ft^3 capacity) at 25 rpm for 40 minutes. c. Paragraph 26, Operation 25 Using shop aid tool and a 0.750-inch diameter cookie cutter cut out six 0.750-inch diameter holes. With a 9/32-inch diameter punch, punch out the six 9/32-inch diameter holes through face sheet. Edge seal with Sylgard 184 (room temperature cure 24 hours).

Figure 52. - Continued

A

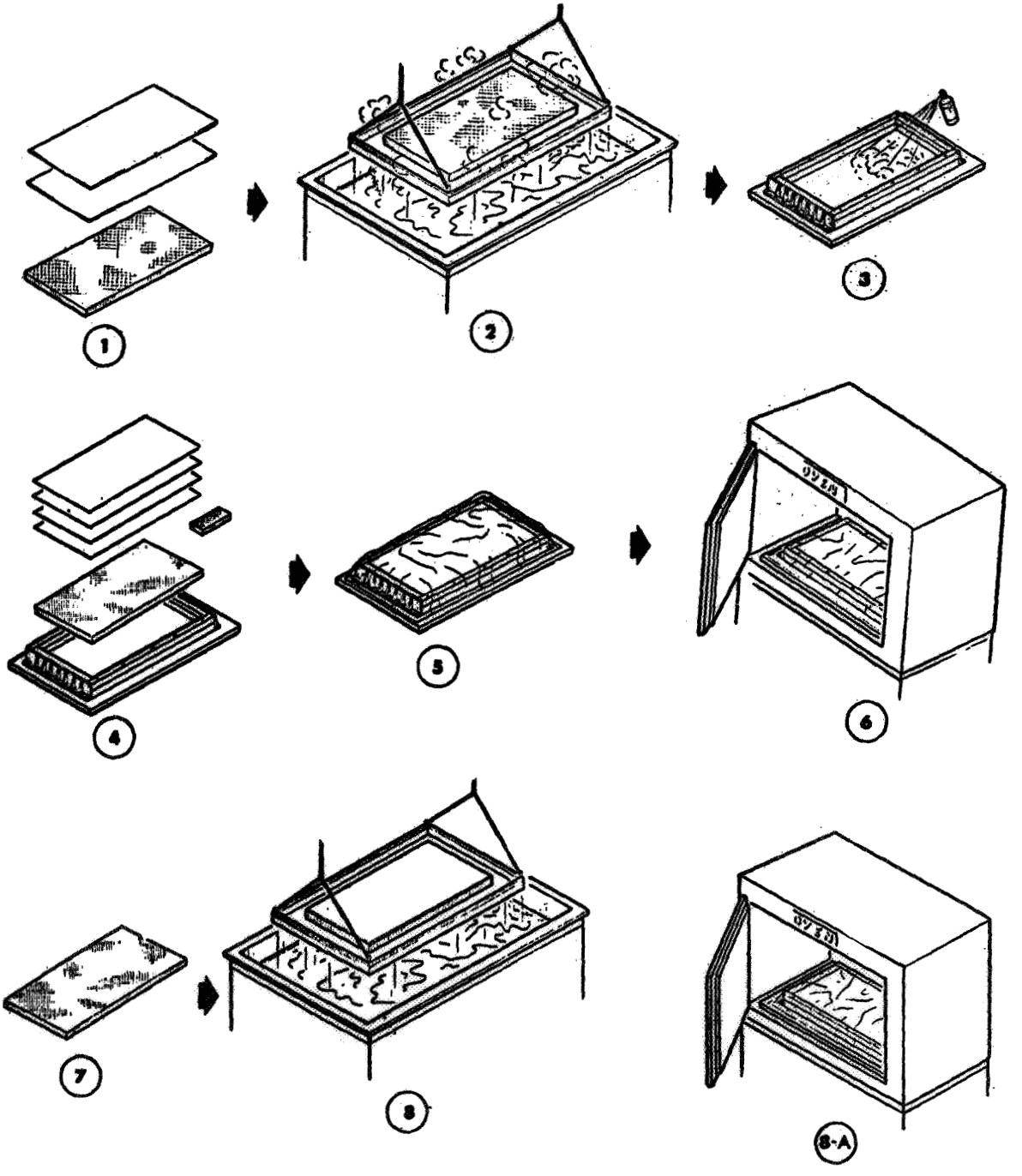


Figure 52. - Continued

B

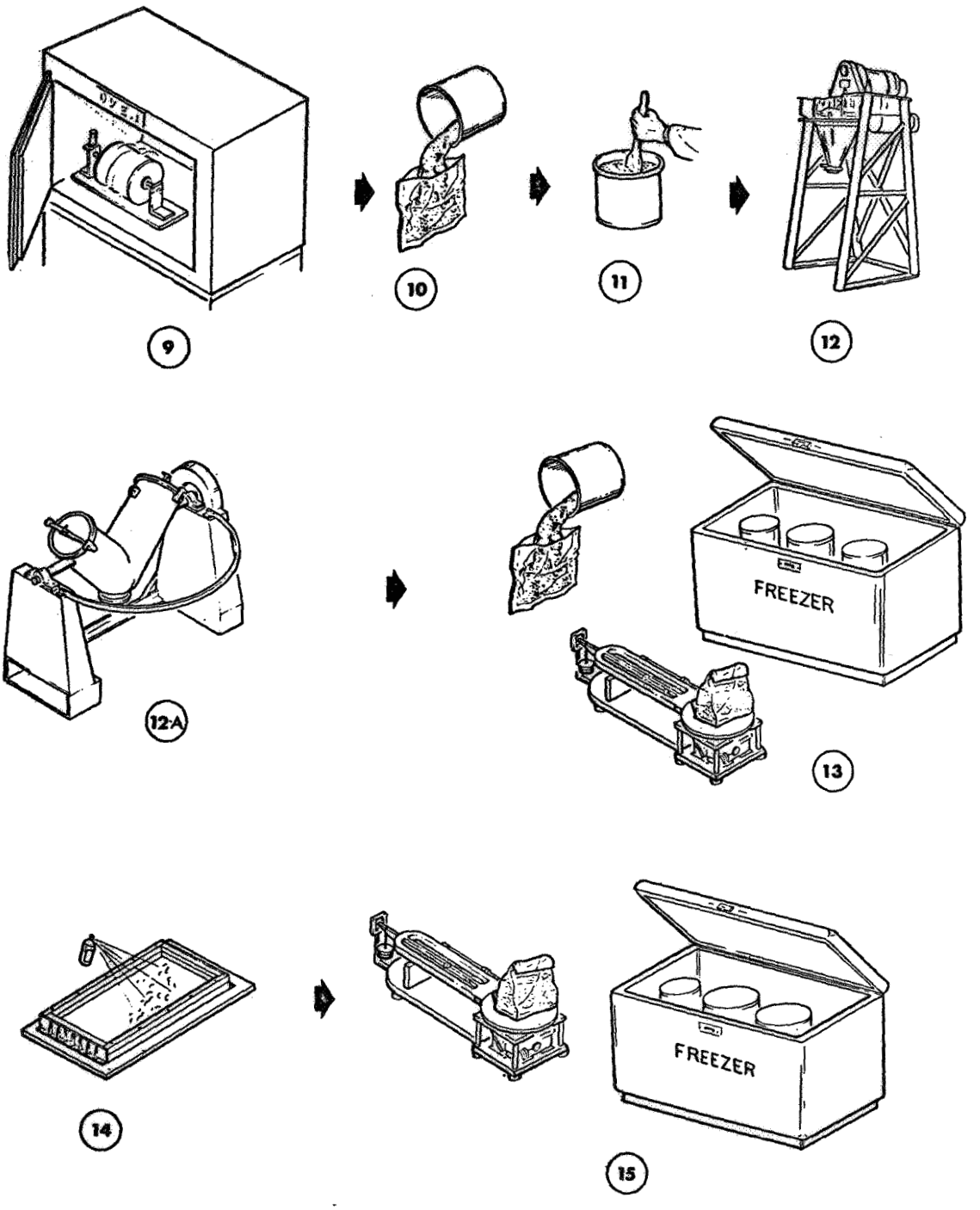


Figure 52. - Continued

C

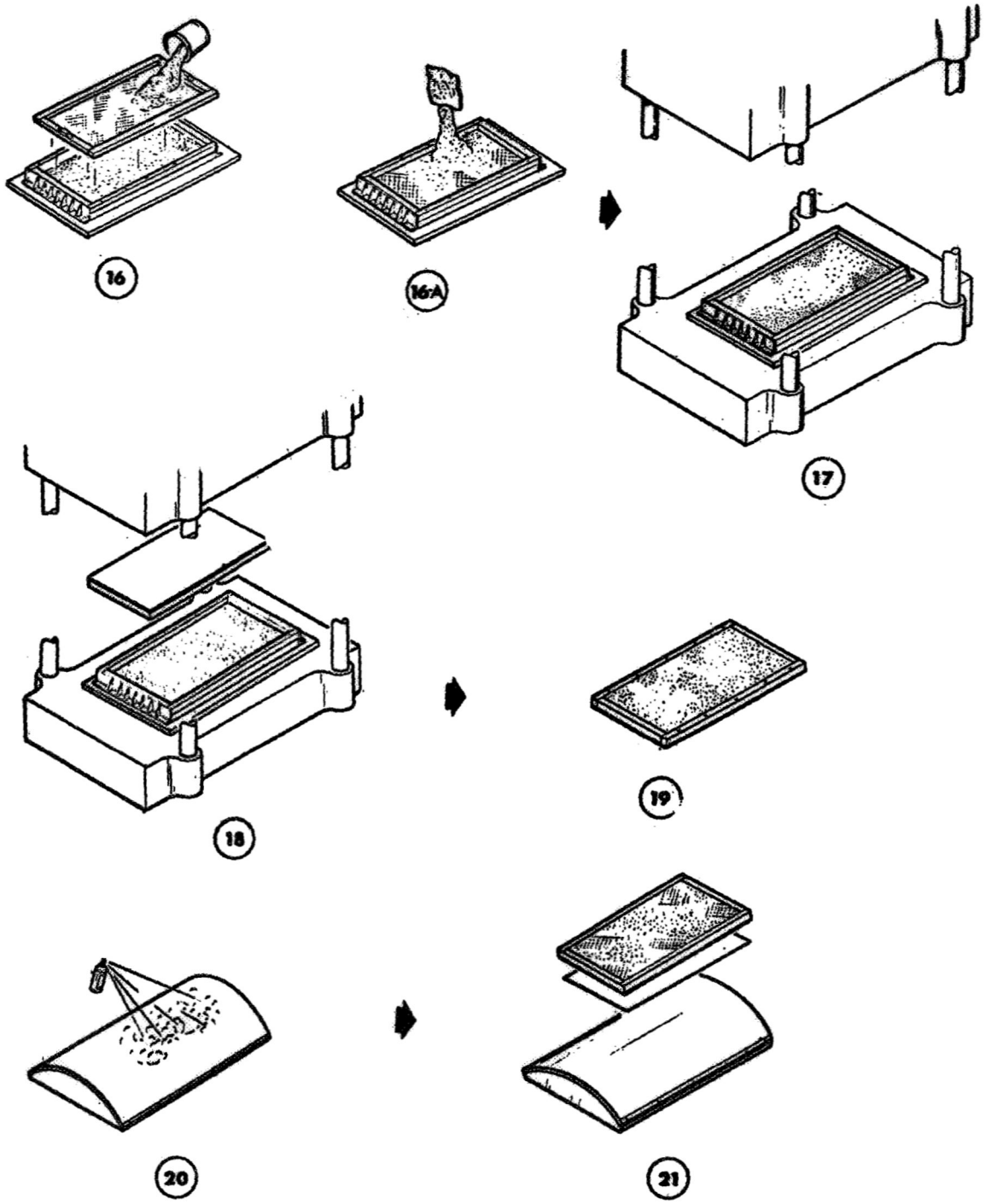


Figure 52. - Continued

D

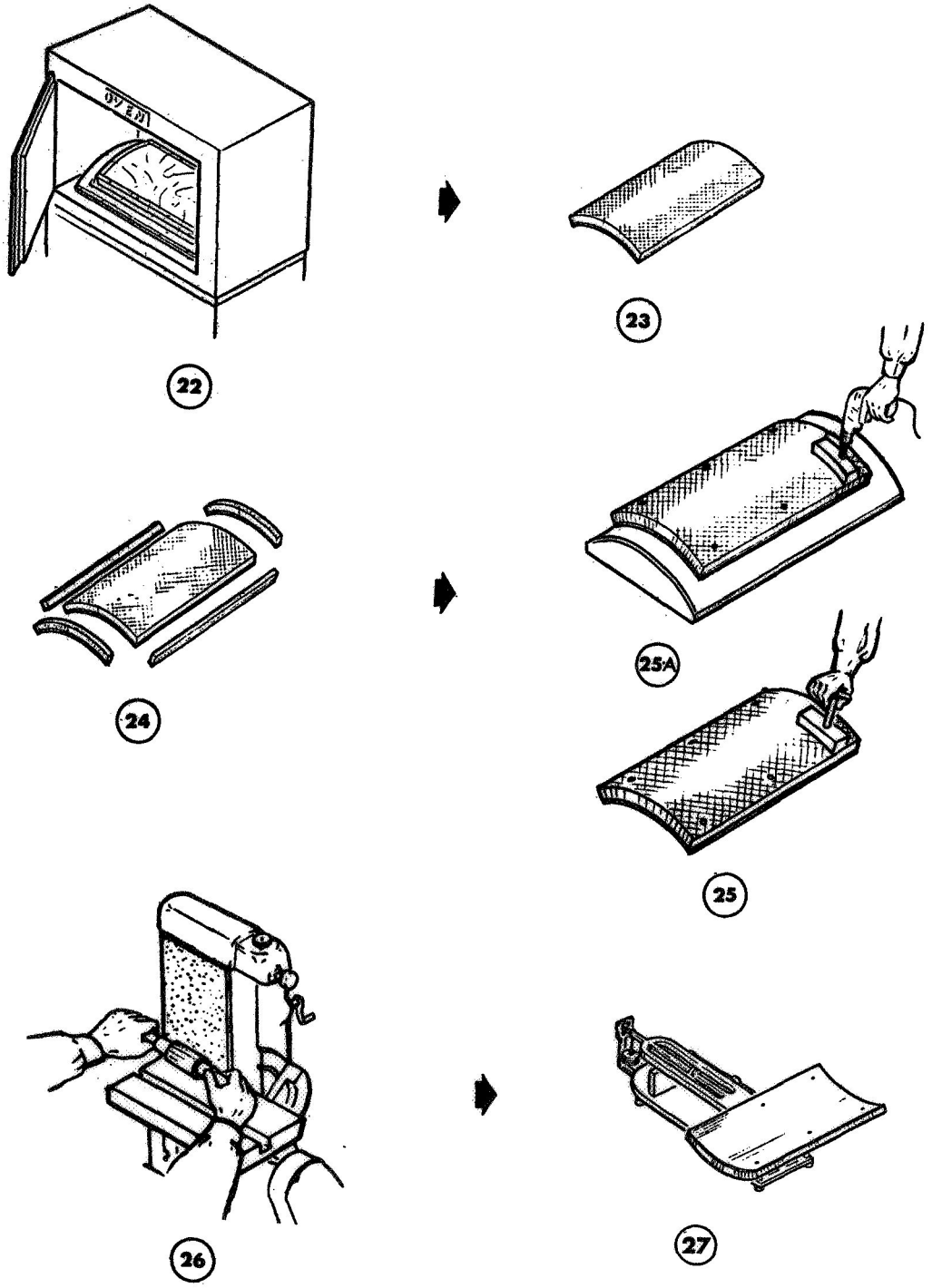


Figure 52. - Concluded

QUALITY CONTROL

Quality Control Procedures

The primary effort of Quality Control for the development stages of this contract was to establish control and verification of the fabrication sequences encountered for each ablative system. This effort was generally the same for each flat and curved panel fabricated as detailed:

1. Verify materials for bonding the core-to-face sheet.
2. Inspect the layup and cure of the core-to-face sheet.
3. Inspect the core-to-face sheet assembly for visual defects.
4. Verify materials for filling and fabricating the panels.
5. Inspect the application and cure of the honeycomb core primer.
6. Inspect the tool preparation and core filler material mixing.
7. Inspect the fill, layup, cure and trim of the panel.
8. Inspect the hole cutout, all dimensions, weight, identification, and verify the core-to-face sheet bond.
9. Inspect panel protective packaging.
10. Inspect the identification, dimensions, and packaging of the ablative plugs made from panel excess material.

In addition to the process inspection, the panels were packaged and accumulated for shipping in one container for flat panels and one container for curved panels. This operation received the normal shipping inspection for parts, packaging, and paperwork.

The main problem encountered in the inspection was the numerous process changes encountered to develop acceptable panels. This problem required changing from detailed planning tickets to laboratory notebook records. The inspector observed laboratory notebook records and used a generalized fabrication planning ticket for acceptance. The core-to-face sheet bond was initially qualified, and test coupons were not required for each

of the eight delivered panels. However, evidence of core-to-face sheet bond was visually inspected at the detail and final assembly stages. It is recommended that test coupons be required for lot control for future production contracts.

In order to establish criteria for future contracts and to develop a confidence level of core fill and detection of internal voids, nondestructive testing (NDT) techniques were studied on a limited basis. Liquid crystal thermography was employed to detect voids on the face sheet side of the panel. Also, test samples were radiographed to establish void detection limits. Both techniques were successful in detecting voids.

The liquid crystal thermography technique showed good results in detecting voids next to the face sheet due to lack of core fill, which was one of the more difficult fabrication problems and required several process changes to resolve. Radiographic techniques showed void detection to 1/8 inch and measurable to 1/4 inch in diameter. Neither of these techniques was used as inspection rejection criteria since internal voids were not specifically excluded as quality requirements. The liquid crystal inspection was performed on all delivered flat panels.

It is recommended that NDT techniques, such as liquid crystal, radiography, neutron radiography, and the like, be studied in detail and inspection acceptance criteria include the results of these studies for future production contracts.

Liquid Crystal Thermography

Thermographic techniques of various types are being used as a means of detecting defects in various materials and structures. One of the most recent of these techniques involves the use of liquid crystals as a detection medium.

Liquid crystals are a crystalline organic substance which, over clearly defined temperature ranges, appears to possess the flow characteristics of a liquid while retaining much of the molecular order of the crystalline solid. Liquid crystals are said to be in either the smectic, nematic, or cholesteric configuration. It is the crystals of the cholesteric configuration that show the unique optical properties applicable to the nondestructive testing field.

Since cholesteric liquid crystals reflect colors dependent upon the temperature of their environment, they may be used to show a visual color picture of the transient temperature anomalies, or minute thermal gradients associated with material discontinuities. These discontinuities may sufficiently impede the flow of heat to disturb the normal temperature patterns of a material being inspected. The defects, because of their impaired thermal transmission characteristics, will then show up as distinct color patterns.

Based on this theory of thermal transmission characteristics of a material, liquid crystal thermography appeared as a prime method of locating unfilled cells in the low-cost ablative heat shield panels.

Initial tests were conducted on a section, measuring approximately 16 by 24 inches, removed from a 67-33 mixture production panel which was known to contain the unfilled cell condition. Thermographic inspection was performed on this panel with encapsulated liquid crystals with a 35 to 36 C color transformation range which were held in intimate contact with the panel surface by a vacuum bagging technique. Two 1000-watt photographic floodlights, which were used as the heat sources, were positioned at various distances from the panel's top surface to vary the rate of thermal input and were oriented to provide even heat distribution across the panel. Excellent determinations of both filled and unfilled cells could be achieved by using either of two heating techniques:

1. Observation of the color change during a slow thermal input.

2. A rapid heat input and the observation of the color change during cooldown.

Figure 53 graphically illustrates the overall condition of the panel with respect to cell fill. Figure 54 illustrates the degree of cell fill as seen with the face sheet removed. Correlation of the thermographic results with the destructive examination of the panel revealed that the specific cells which exhibited a slower color change corresponded to the filled cells in the panel. The filled cells as seen in figure 54 can also be seen as the darker colored cells (black, red, and green) as exhibited by the liquid crystals in figure 53.

Upon completion of the larger panel section, three small 10 by 10-inch density check panels of the 67-33 and 50-50 mixture ratios were evaluated with liquid crystal thermography. These three specimens were of known good quality, and each exhibited a slow, even color transformation across the panel. Figure 55 is an example of the results obtained during the evaluation of these three panels. The photograph of the 50-50 mix panel illustrates the even color change shown on a sample which has complete cell fill. The liquid crystal response which can be expected on both a good panel and one which contains unfilled cells can be seen by the comparison of figures 53 and 55.

Upon completion of the initial trial tests of the four small panels, four flat production panels, measuring 2' by 4' by 2", were inspected by using the liquid crystal thermographic technique. Two of the panels checked were of the 67-33 mixture, and the remaining two were of the 50-50 mixture ratio. No thermographic inspection was made of the 15-15-70 mixture panel due to the inherent fragility of the panel.

The procedure used on the four production flat panels was identical to that used on the initial trial tests. Any suspect areas located during the process were marked on the nylon vacuum bag, and overlays were made on tracing paper as a means of documentation.

The thermographic technique utilized on the flat panels was tried on the curved panels; however, unsatisfactory results were obtained. The concave curve of these panels resulted in the flood lamp yielding hot spots on the outer edges and a cooler area in the center. Different heating systems are presently being evaluated for use on these curved panels. A printed circuit heat composed of nichrome wire embedded in silicon rubber appears to be a possible heat source when used with an aluminum sheet between the heater and the panel to evenly distribute the heat input. At the present time, no tests have been performed on the curved panels with the new heater arrangement due to the lack of availability of the panels.

The use of liquid crystal thermography appears to be a feasible means for the inspection of these low-cost ablative heat shield panels for the determination of unfilled cells. The technique offers the advantages of low cost, rapid inspection turnaround, ease of interpretation, and results in a vivid display with respect to the cell fill condition of the article being checked.

In order to refine the thermographic technique to a completely reliable and usable system, the following areas require further development:

1. Fabrication of specific vacuum tooling to shorten the inspection time.

2. Evaluation of heating systems resulting in the fabrication of a specific heating fixture so that the entire panel can be inspected at one time.

3. Definition of precise technique parameters in order to eliminate any process variables.

4. Fabrication of test standards to assure process sensitivity and obtain information regarding the color change time interval in relation to the degree of cell fill.

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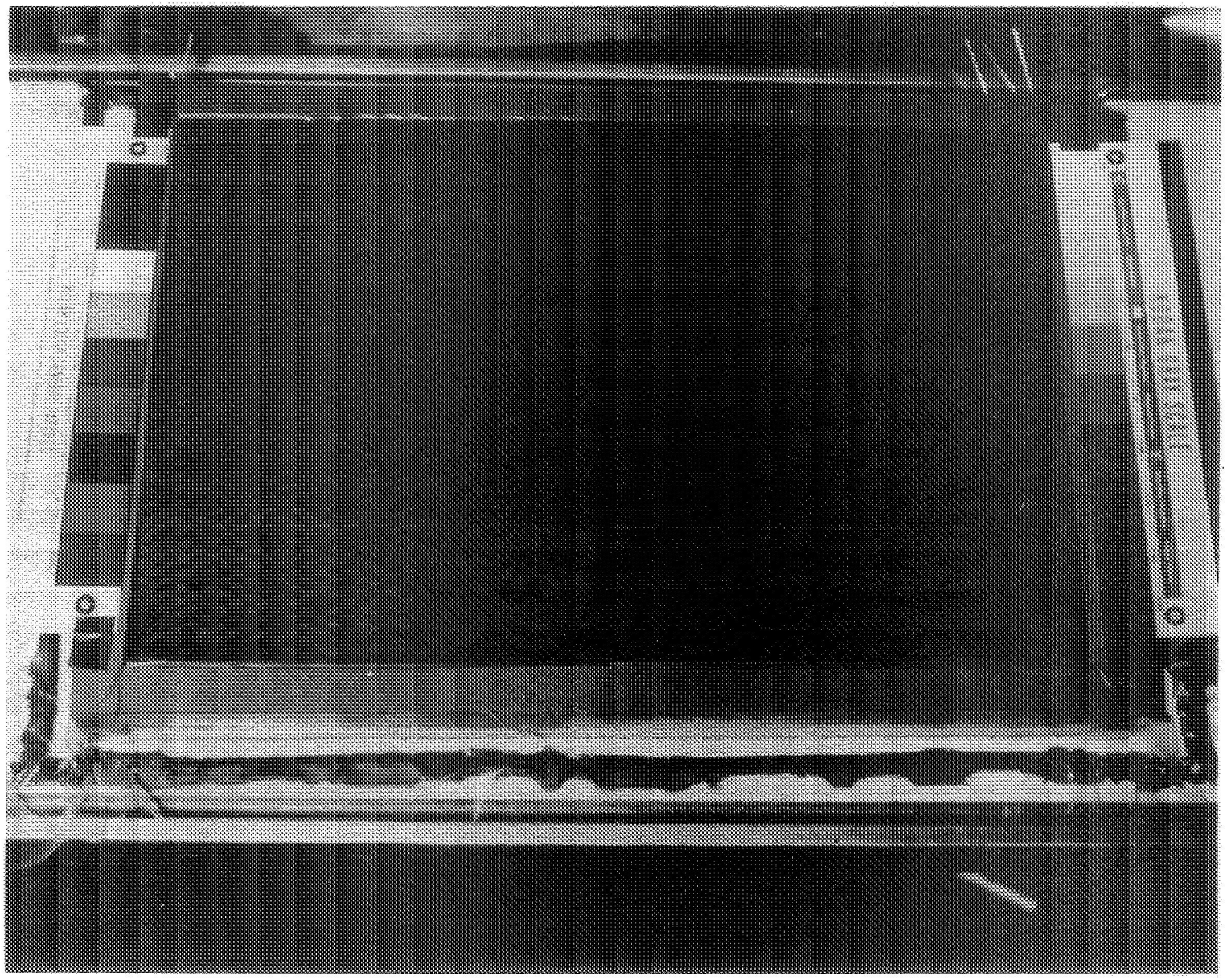


Figure 53. - Overall Condition of Panel

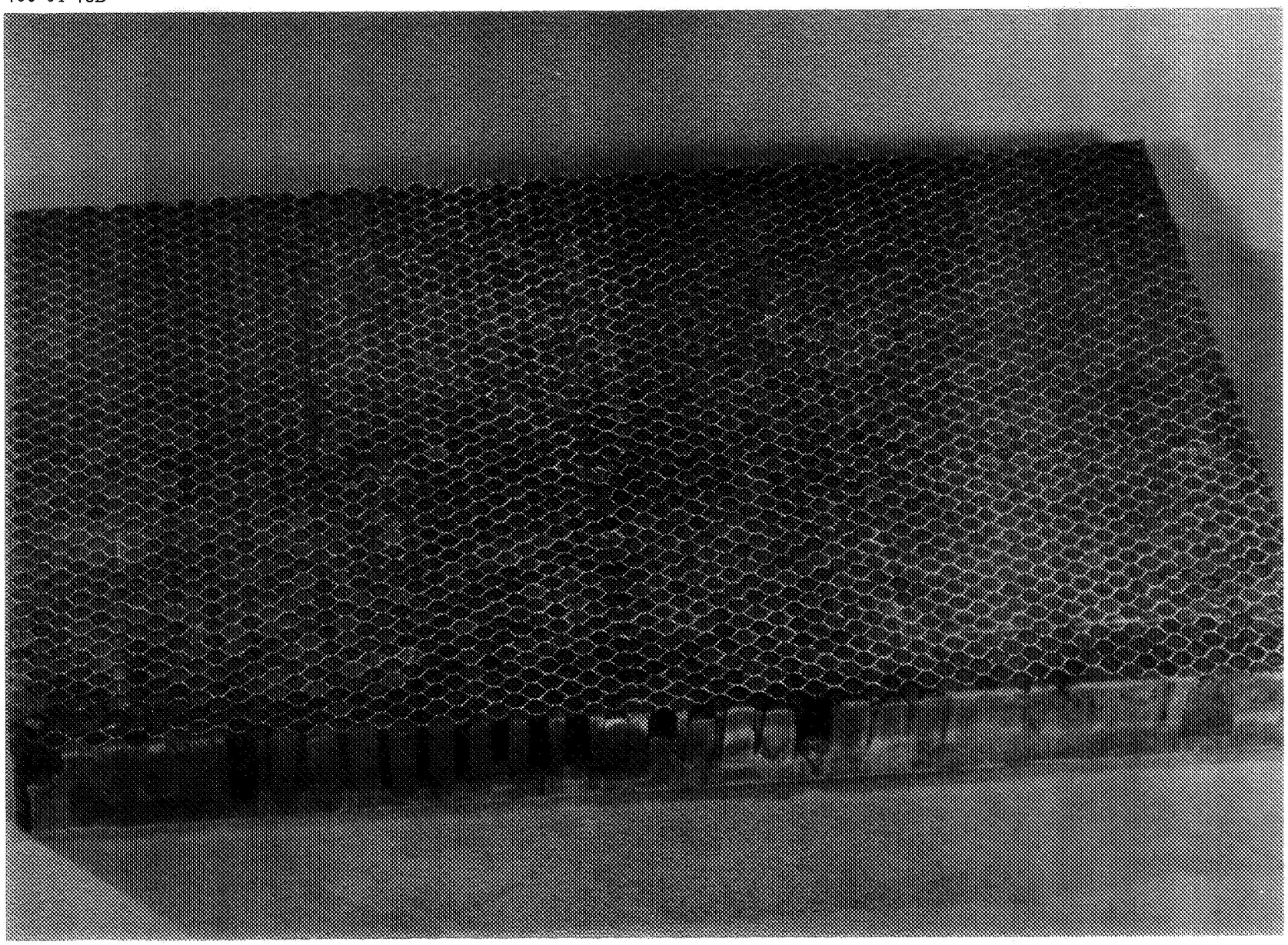


Figure 54. - Degree of Cell Fill

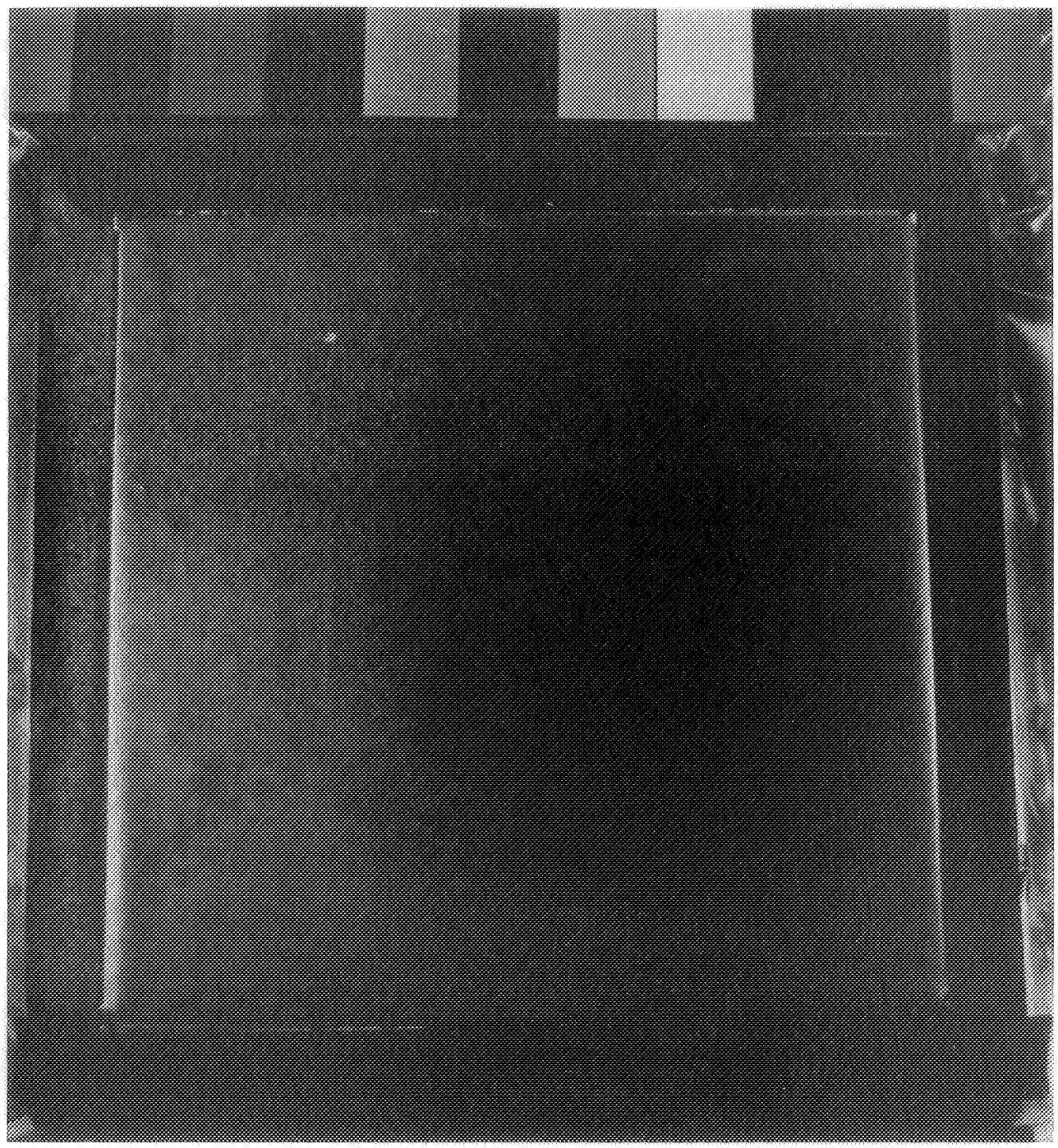


Figure 55. - Results of Evaluation of Three Panels

FABRICATION COSTS AND ESTIMATING PROCEDURES

In order to establish a basis for the required projections of fabrication costs for various quantities and configurations of ablative panels, the actual fabrication processes were observed and analyzed by qualified industrial engineers. These observations led to the development of standards for each step and process in the fabrication cycle. The standards were developed by using acceptable work measurement techniques such as measurement time methods (MTM), time study, standard data, and the like. These derived time standards were utilized to develop first unit costs for the noted fabrication processes, assuming anticipated methods improvements due to transition from the observed development program and its associated problems to a true production operation.

The cost projections were developed by industrial engineers using accepted industrial engineering work measurement techniques.

Table 8 summarizes the labor hours required for each fabrication operation on the completed panels. These hours were compiled from weekly reports made by each operator, time study observations, and work sampling techniques.

Dimensional tooling for completed panels are as follows:

Item	Time (hr)
SK-058326, Curved Cure Fixture	48
SK-058327, Flat Fill and Cure Fixture	60
SK-058328, Core to Skin Bond Fixture	30
SK-058329, Curved Fill Fixture	60
SK-058330, Priming Pan	24
SK-058333, Drying Fixture	68
Total Hours	290

TABLE 8. - FABRICATION HOURS PER COMPLETED PANELS

Operations (See Figure 28)	Flat				Operations (See Figure 28)	Curved			
	SK 058322					SK 058321			
	-111*	-121*	-131*	-141*		-111*	-121*	-131*	-141*
1	3	3	3	3	1	4	3	3	3
2	1	1	1	1	2	1	1	1	1
3	3	3	5	4	3	2	3	3	4
4 and 5	5	8	5	7	4 and 5	8	8	7	7
6	1	1	1	2	6	1	1	1	1
7	4	2	5	1	7	2	1	1	1
Subtotal	16	18	20	18	Subtotal	18	17	16	17
8	5	4	1	9	8	4	4	6	7
9 and 10	40	-	12	3	9 and 10	-	-	3	-
11 and 13	50	34	-	-	11 and 13	34	34	-	-
12A	-	-	30	18	12A	-	-	16	19
14	4	5	5	4	14	5	3	4	5
15 and 16	9	10	-	-	15 and 16	8	6	-	-
16A	-	-	8	10	16A	-	-	12	16
17 and 19	14	12	-	-	17 and 18	11	13	-	-
18A	-	-	12	14	18A	-	-	6	-
19	-	-	2	3	19	4	5	6	-
20	8	6	5	7	20	1	1	1	2
21	5	6	4	3	21	6	7	10	14

TABLE 8. - FABRICATION HOURS PER COMPLETED PANELS - Concluded

Operations	Flat SK 058322 -111*	-121*	-131*	-141*	Operations	Curved SK 058321 -111*	-121*	-131*	-141*
22	2	1	2	2	22	6	2	4	4
23	2	1	2	2	23	3	4	4	3
24	1	1	3	2	24	3	3	2	2
25	2	1	1	1	25	2	2	-	-
Subtotal	142	81	87	78	25A			3	2
Plugs	2	4	4	2	26	1	1	1	1
Ship	3	3	3	3	Subtotal	87	85	78	75
Total	163	104	114	101	Plugs	1	1	3	2
					Ship	2	2	2	2
					Total	108	105	99	96

*Panel identification
-111 High-density elastomer
-121 Low-density elastomer
-131 High-density NP
-141 Low-density NP

The following summary represents the labor hour projections of panel fabrication, dimensional tooling, and production planning costs for various quantities and configurations of ablative panels.

The fabrication estimates for the 2- by 4-foot flat and curved panels, 3- by 5-foot flat, and 4- by 6-foot flat panels are based on actual processes observed, and from these observations, the development of first unit costs were made. The 2- by 4-foot double curvature panels estimate is based upon the judgement of Space Division Manufacturing Engineering. This evaluation projects fabrication costs of the double curvature panels to be 2:1 in complexity to the 2- by 4-foot curved panels.

Production Planning and Production Control operations are based upon the historical experience of North American Rockwell with previous programs. Projections are forecast as 12 percent of fabrication and 6 percent of dimensional tooling.

Dimensional tooling estimates are based upon tooling experience on the development program and analyzed to production contract requirements. The sustaining calculations for 10 units and 100 units are based on current experience with a 120 percent sustaining slope. Table 9 shows the estimated hours cost of specific production units as required by the Contract Statement of Work. Table 10 shows the material costs for the fabricated panels. Table 11 shows the estimated material costs for production lots.

Table 12 gives the estimated prices per square foot for flat panels 2 by 4 feet, 3 by 5 feet, and 4 by 6 feet and for single and complex curved panels 2 by 4 feet in lots of 1, 10, and 100. Estimated fabrication times were derived from time studies of the four flat panels 2 by 4 feet and the four curved panels 2 by 4 feet during actual fabrication and from evaluation of the improvements that could be made with increased production. All costing elements—i. e., materials, direct and indirect labor, and G&A—have been included in the established cost estimates except the fee, which was omitted.

The following method improvements were included in the direct labor hour yield costs:

1. Use of templates for cutting, layout, etc.
2. Use of forklift to load fixture or shop aid loaded with mixed materials into the press for compression (requires less manpower).
3. Curing of more than one unit in the oven at one time.
4. Use of rolling work tables to move assemblies between stations.
5. Storage of tools, supplies, and materials close to work stations.
6. Use of a larger mixer to mix ablative materials (mixer used in the R&D program required the use of the mixer 12 times to mix materials for one unit.)
7. A good layout for operations to be performed in sequence and minimum distance between stations.
8. Use of a one-piece heavier honeycomb core to prevent rework and replacement costs.
9. Use of a better vibrator when mixed materials are placed in the honeycomb core in fixture for units -131 and -141 flat and curved panels.

TABLE 9. - LOW-COST ABLATIVE PANELS, HOURS SUMMARY

Area	1 Unit	10 Units	100 Units
FLAT PANELS 2 BY 4 FEET			
Fabrication			
-111	102	553	3647
-121	98	508	3477
-131	109	587	3925
-141	104	546	3739
Production Planning			
-111	12	20	60
-121	12	20	60
-131	12	20	60
-141	12	20	60
Tool Planning	10	10	20
Dimensional Tooling	62	62	92
Inspection	12.5	68	466
CURVED PANELS 2 BY 4 FEET			
Fabrication			
-111	115	638	4369
-121	115	614	4159
-131	121	668	4581
-141	117	649	4451
Production Planning			
-111	14	23	68
-121	14	23	68
-131	14	23	68
-141	14	23	68
Tool Planning	20	20	40
Dimensional Tooling	110	110	144
Inspection	14.5	80	548

TABLE 9. - LOW-COST ABLATIVE PANELS,
HOURS SUMMARY - Continued

Area	1 Unit	10 Units	100 Units
FLAT PANELS 3 BY 5 FEET			
Fabrication			
-111	126.0	658	4505
-121	120.0	627	4290
-131	140.0	732	5006
-141	131.0	685	4684
Production Planning			
-111	12	20	60
-121	12	20	60
-131	12	20	60
-141	12	20	60
Tool Planning	15	15	25
Dimensional Tooling	100	100	137
Inspection	16	84	578
FLAT PANELS 4 BY 6 FEET			
Fabrication			
-111	151.0	789	5399
-121	142.0	742	5077
-131	163.0	852	5828
-141	152.0	794	5435
Production Planning			
-111	12	20	60
-121	12	20	60
-131	12	20	60
-141	12	20	60
Tool Planning	20	20	30
Dimensional Tooling	152	152	213
Inspection	19	100	679

TABLE 9. - LOW-COST ABLATIVE PANELS,
HOURS SUMMARY - Concluded

Area	1 Unit	10 Units	100 Units
COMPOUND CURVED PANELS 2 BY 4 FEET*			
Fabrication			
-111	251.0	1316	9010
-131	280.0	1464	10012
Production Planning			
-111	24	40	120
-131	24	40	120
Tool Planning	35	35	45
Dimensional Tooling	252	232	360
Inspection	34	174	1189

*Panel identification
-111 High-density elastomer
-121 Low-density elastomer
-131 High-density NP
-141 Low-density NP

TABLE 10. - FABRICATED PANELS, MATERIAL COSTS

Item	Costs
1. Material Cost For Items Fabricated (flat)	
a. Phenolic 15 percent, nylon 15 percent, microballoons 70 percent	
1. HRP - 3/8 - GF11 - 2.2 (core)	$ 84.00
2. Reliabond R1714 prepreg	12.00
3. Phenolic	1.00
4. Nylon	13.00
5. Microballoons	18.00
6. Misc	15.00
	$143.00 + 20%
	28.00
	$171.00
b. Phenolic 50 percent, nylon 50 percent (flat)	
1. HRP - 3/8 - GF11 - 2.2 (core)	$ 84.00
2. Reliabond R1714 prepreg	12.00
3. Phenolic	6.00
4. Nylon	90.00
5. Misc	15.00
	$207.00 + 20%
	40.00
	$247.00
c. Elastomer 20 percent, microballoons 80 percent (flat)	
1. HRP - 3/8 - GF11 - 2.2 (core)	$ 84.00
2. Reliabond R1714 prepreg	12.00
3. Elastomer	22.00
4. Microballoons	32.00
5. Misc	15.00
	$165.00 + 20%
	32.00
	$197.00

TABLE 10. - FABRICATED PANELS, MATERIAL COSTS - Concluded

Item	Costs
d. Elastomer 67 percent, microballoons 33 percent (flat)	
1. HRP - 3/8 - GF11 - 2.2 (core)	$ 84.00
2. Reliabond R1714 prepreg	12.00
3. Elastomer	144.00
4. Microballoons	24.00
5. Misc	15.00
	$279.00 + 20%
	56.00
	$335.00
2. Material cost for items fabricated (curved)	
Note: Add $36.00 to all the flat figures to take into consideration the OX core.	

TABLE 11. - PRODUCTION UNITS, MATERIAL COSTS

Item		Costs		
		1 Flight	10 Flights	100 Flights
1. Material costs in lots of 1, 10, and 100				
a. Phenolic 15 percent, nylon 15 percent, microballons 70 percent				
1. HRP - 3/8 - GF11 - 2.2 (core)	8000 ft^2 at 5.00/ft^2	$ 40,000.00	$ 360,000.00	$3,200,000.00
2. Reliabond R1714 prepreg	1800 y^2 at 3.00/y^2	5,400.00	48,600.00	432,000.00
3. Phenolic	3750 lbs at 0.20/lb	750.00	6,750.00	60,000.00
4. Nylon	3750 lbs at 3.50/lb	13,125.00	118,130.00	1,050,000.00
5. Microballoons	17500 lbs at 1.30/lb	22,750.00	204,750.00	1,820,000.00
6. Misc	800 panels at 15.00/panel	12,000.00	108,000.00	960,000.00
	Total	$ 94,025.00	$ 846,230.00	$7,522,000.00
	+ 20 percent	18,805.00	169,246.00	1,504,000.00
		$112,830.00	$1,015,476.00	$9,026,400.00
b. Phenolic 50 percent, nylon 50 percent				
1. HRP - 3/8 - GF11 - 2.2 (core)		$ 40,000.00	$ 360,000.00	$3,200,000.00
2. Reliabond R1714 prepreg		5,400.00	48,600.00	432,000.00
3. Phenolic	12,500 lb at 0.20/lb	2,500.00	22,500.00	200,000.00
4. Nylon	12,500 lb at 3.50/lb	43,750.00	393,750.00	3,500,000.00
5. Misc		12,000.00	108,000.00	960,000.00
	Total	$103,650.00	$ 932,850.00	$8,292,000.00
	+ 20 percent	20,730.00	186,570.00	1,658,400.00
		$124,380.00	$1,119,420.00	$9,950,400.00
c. Elastomer 20 percent, microballoons 80 percent				
1. HRP 3/8 GF11 - 2.2 (core)		$ 40,000.00	$ 360,000.00	$3,200,000.00
2. Reliabond R1714 prepreg		5,400.00	48,600.00	432,000.00
3. Elastomer	5000 lb at 4.00/lb	20,000.00	180,000.00	1,600,000.00
4. Microballoons	20,000 lb at 1.30/lb	26,000.00	234,000.00	2,080,000.00
5. Misc		12,000.00	108,000.00	960,000.00
	Total	$103,400.00	$ 930,600.00	$8,272,000.00
	+ 20 percent	20,680.00	186,120.00	1,654,400.00
		$124,080.00	$1,116,720.00	$9,926,400.00
d. Elastomer 67 percent, microballoons 33 percent				
1. HRP 3/8 GF11 - 2.2 (core)		$ 40,000.00	$ 360,000.00	$ 3,200,000.00
2. Reliabond R1714 prepreg		5,400.00	48,600.00	432,000.00
3. Elastomer	16,750 lb at 4.00/lb	67,000.00	603,000.00	5,360,000.00
4. Microballoons	8,250 lb at 1.30/lb	10,725.00	96,520.00	858,000.00
5. Misc		12,000.00	108,000.00	960,000.00
	Total	$135,125.00	$1,216,120.00	$10,810,000.00
	+ 20 percent	27,025.00	243,224.00	2,162,000.00
		$162,150.00	$1,459,344.00	$12,972,000.00

Notes:

1. Original prices of materials were cut by 25 to 30 percent to establish price for lots of 1 8000 ft^2.
2. For lots of 10, the price of the material used for lots of 1 was cut by 10 percent.
3. For lots of 100, the price of the material used for lots of 1 was cut by 20 percent.
4. Miscellaneous includes prime, bleeder cloth, vac pack, etc.
5. To the sum Total; a 20 percent scrap factor was added.

TABLE 12. - LOW-COST ABLATIVE PANELS, COST SUMMARY

Panel Size and Identification Number*	Cost (dollars per square foot)		
	1 Unit	10 Units	100 Units
FLAT PANELS			
2 by 4 feet - 111	$430.00	$183.00	$133.00
- 121	399.00	155.00	107.00
- 131	430.00	178.00	124.00
- 141	406.00	157.00	107.00
3 by 5 feet - 111	328.00	141.00	107.00
- 121	299.00	116.00	82.00
- 131	329.00	135.00	98.00
- 141	306.00	118.00	82.00
4 by 6 feet - 111	282.00	122.00	94.00
- 121	254.00	97.00	70.00
- 131	275.00	113.00	84.00
- 141	256.00	96.00	68.00
CURVED PANELS			
2 by 4 feet - 111	$587.00	$223.00	$150.00
- 121	563.00	195.00	129.00
- 131	584.00	215.00	146.00
- 141	564.00	198.00	131.00
COMPOUND CURVED PANELS			
2 by 4 feet - 111	$1277.00	$466.00	$328.00
- 131	1320.00	481.00	333.00

*Panel Identification
-111 High-density elastomer
-121 Low-density elastomer
-131 High-density NP
-141 Low-density NP

CONCLUSIONS

Much was learned during the course of the program in developing low-cost methods for ablative heat shields; however, it is known that several potential advancements should be investigated toward achieving additional cost reduction measures. Because of cost and time limitations the program was restricted to completion of the contractual Statement of Work.

1. It was proven that development efforts are essential to successful completion of advanced hardware programs.

2. The program determined that large honeycomb panels can be filled and compacted with ablative materials in a reasonably quick and effective manner by using tooling and techniques developed during the program.

3. Curved panels can be filled and compacted in a flat position and then placed on a contoured tool to be vacuum bagged and heat-cured.

4. The phenolic-nylon powder mixtures require comparatively slow heating and good vacuum bagging; otherwise an exothermic reaction results and the panel is destroyed.

5. The originally specified 10-percent elastomer, 90-percent micor-balloon mixture would not meet the required density values. Accordingly, NASA approved a mixture change to 20-percent elastomer, 80-percent microballoons, which proved satisfactory.

6. Over-expanded (OX) honeycomb was not available in full-size panels without splice joints, which proved detrimental to the fill and compaction procedures.

7. Nondestructive testing of ablative heat shields by using the liquid crystal concept can detect face sheet-filler voids in a finished panel.

8. Future planning and scheduling operations will be more definitive as a result of the knowledge gained from the program.

9. Future ablative programs can now be performed with lower labor grade personnel.

10. Ablative heat shield capability has now been established to support Space Shuttle technology.

11. Estimated prices per square foot are based on the eight panels fabricated. With respect to the compound curved panels, the estimating was based on an assumed configuration and complexity factors. In lots of 100 units, the costs for flat and single curvature panels are considered attractive since estimates show the costs to be under $150 per square foot.

RECOMMENDATIONS

During the program, it was recognized that ultimate definition of ablative heat shield producibility and costing factors could not be realized with this program. It is therefore recommended that a program be initiated that would encompass the following pursuits:

1. Investigate improved low-cost manufacturing techniques to include the following:

   a. Lower cost mixing methods for ablative compounds.

   b. Eliminate drying of microballoons and nylon powder by obtaining predried.

   c. Use splice-free, flexible, low-cost core, e.g., Nomax.

   d. Reduce cure cycles and temperatures.

   e. Study methods to reduce or eliminate warpage.

   f. Develop reliable low-cost pre-compaction core fill methods or devise means to eliminate pre-compaction.

   g. Increase resin content (binder) of low-density filler compounds to reduce handling problem.

   h. Evaluate primers to improve bond strength between core and filler.

   i. Establish multiple core-face bonding feasibility.

2. Conduct fabrication study for compound curved panels, such as wing and stabilizer leading edges.

3. Study panel attachment and quick replacement methods.

4. Establish repair techniques.

5. Evaluate protective seal coatings to minimize handling problems and to weatherproof the panels.

6. Evaluate low-cost NDT inspection methods, such as liquid crystal thermography.

North American Rockwell Corporation
Downey, California, September 21, 1970

APPENDIX A
AMENDMENTS

KDA:bbw

CONTRACTOR'S COPY

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

PAGE 1 OF 2

1. AMENDMENT/MODIFICATION NO. 2
2. EFFECTIVE DATE AUG 4 1970
3. REQUISITION/PURCHASE REQUEST NO. Not Applicable
4. PROJECT NO. (If applicable)

5. ISSUED BY CODE
National Aeronautics and Space
Administration
Langley Research Center
Hampton, Virginia 23365

6. ADMINISTERED BY (If other than block 5) CODE

7. CONTRACTOR NAME AND ADDRESS (Street, city, county, state, and ZIP Code) CODE FACILITY CODE

North American Rockwell Corporation
Space Division
12214 Lakewood Boulevard
Downey, California 90241

8. ☐ AMENDMENT OF SOLICITATION NO. _____
DATED _____ (See block 9)
☒ MODIFICATION OF CONTRACT/ORDER NO. NAS1-9943
DATED 4/28/70 (See block 11)

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS

☐ The above numbered solicitation is amended as set forth in block 12. The hour and date specified for receipt of Offers ☐ is extended, ☐ is not extended.

Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods: (a) By signing and returning _____ copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKOWLEDGMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA (If required)

Not Applicable

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS

(a) ☐ This Change Order is issued pursuant to _____
The Changes set forth in block 12 are made to the above numbered contract/order

(b) ☐ The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12.

(c) ☒ This Supplemental Agreement is entered into pursuant to authority of Clause 12, Excusable Delays, Section A of Basic Agreement NAS7-448.
It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

JUL 21 1970

I. Part III, Period and Place of Performance, paragraph A, is changed to read as follows:

"A. The period of performance shall be seven (7) months from the date of this contract inclusive of submission of the final report."

II. Part IV, Reports, subparagraph C.8, the last sentence is changed to read:

"The Contractor shall submit the required approval copies of the final report five (5) months from the date of the contract."

Except as provided herein, all terms and conditions of the document referenced in block 8, as heretofore changed, remain unchanged and in full force and effect.

13. ☐ CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT ☒ CONTRACTOR/OFFEROR IS REQUIRED TO SIGN THIS DOCUMENT AND RETURN 3 COPIES TO ISSUING OFFICE

14. NAME OF CONTRACTOR/OFFEROR
/s/ [illegible]
(Signature of person authorized to sign)

15. UNITED STATES OF AMERICA
BY [signature]
(Signature of Contracting Officer)

15A. NAME AND TITLE OF SIGNER (Type or print)
R. Silver, Director, Program Adm.
Adv. Programs, Space Division

16. DATE SIGNED
7-29-70

17. NAME OF CONTRACTING OFFICER (Type or print)
LEON W. FITCHETT

18. DATE SIGNED
AUG 4 1970

30-101-f-p

III. Part VI, Delivery, Inspection, and Acceptance, subparagraph A, item 1, is changed to read under "From Date of Contract," to "$5\frac{1}{2}$ months" in lieu of "$4\frac{1}{2}$ months."

IV. There shall be no change in the estimated cost or fixed fee as a result of this modification.

KDA:bbw

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

PAGE 1 OF 1

1. AMENDMENT/MODIFICATION NO.	2. EFFECTIVE DATE	3. REQUISITION/PURCHASE REQUEST NO.	4. PROJECT NO. (If applicable)
1	7/2/70	Not Applicable	

5. ISSUED BY CODE

National Aeronautics and Space
Administration
Langley Research Center
Hampton, Virginia 23365

6. ADMINISTERED BY (If other than block 5) CODE

7. CONTRACTOR NAME AND ADDRESS (Street, city, county, state, and ZIP Code) CODE FACILITY CODE

North American Rockwell Corporation
Space Division
12214 Lakewood Boulevard
Downey, California 90241

8.
☐ AMENDMENT OF SOLICITATION NO. _____
DATED _____ (See block 9)
☒ MODIFICATION OF CONTRACT/ORDER NO. NAS1-9943
DATED 4/28/70 (See block 11)

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS

☐ The above numbered solicitation is amended as set forth in block 12. The hour and date specified for receipt of Offers ☐ is extended, ☐ is not extended.

Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods:

(a) By signing and returning _____ copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKOWLEDGMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA (If required)

Not Applicable

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS

(a) ☒ This Change Order is issued pursuant to Clause 2, Changes, of Section A, Basic Agreement NAS7-448
The Changes set forth in block 12 are made to the above numbered contract/order.

(b) ☐ The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12.

(c) ☐ This Supplemental Agreement is entered into pursuant to authority of _____
It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

I. Part II, Statement of Work, paragraph 4.c. of the Contract Schedule, is hereby changed to read:

"c. Elastomer - 10%, Microballoons - 90% or Elastomer - 20%, Microballoons - 80%, 13 lb/ft^3 ≤ Density ≤ 17 lb/ft^3."

II. There shall be no change in cost, fee or period of performance as a result of this change.

Received 18 Aug 1970

Except as provided herein, all terms and conditions of the document referenced in block 9, as heretofore changed, remain unchanged and in full force and effect.

13. ☐ CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT ☒ CONTRACTOR/OFFEROR IS ~~REQUIRED~~ requested TO SIGN THIS DOCUMENT AND RETURN 1 COPIES TO ISSUING OFFICE acknowledging receipt thereof

14. NAME OF CONTRACTOR/OFFEROR	17. UNITED STATES OF AMERICA
BY _____ (Signature of person authorized to sign)	BY _____ (Signature of Contracting Officer)
15. NAME AND TITLE OF SIGNER (Type or print) / 16. DATE SIGNED	18. NAME OF CONTRACTING OFFICER (Type or print): LEON W. FITCHETT / 19. DATE SIGNED: 7/2/70

30-101-f-p

* U.S. GOVERNMENT PRINTING OFFICE : 1966 O—SJR-645

KDA:bbw

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

PAGE 1 OF 1

1. AMENDMENT/MODIFICATION NO.	2. EFFECTIVE DATE	3. REQUISITION/PURCHASE REQUEST NO.	4. PROJECT NO. (If applicable)
3	8/13/70	Not Applicable	

5. ISSUED BY CODE

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23365

6. ADMINISTERED BY (If other than block 5) CODE

7. CONTRACTOR NAME AND ADDRESS (Street, city, county, state, and ZIP Code) CODE FACILITY CODE

North American Rockwell Corporation
Space Division
12214 Lakewood Boulevard
Downey, California 90241

8.
☐ AMENDMENT OF SOLICITATION NO. _____
DATED _____ (See block 9)
☒ MODIFICATION OF CONTRACT/ORDER NO. NAS1-9943
DATED 4/28/70 (See block 11)

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS

☐ The above numbered solicitation is amended as set forth in block 12. The hour and date specified for receipt of Offers ☐ is extended, ☐ is not extended.

Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods:

(a) By signing and returning _____ copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKOWLEDGMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA (If required)

Not Applicable

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS

(a) ☒ This Change Order is issued pursuant to Clause 2, Changes, of Basic Agreement NAS7-448

The Changes set forth in block 12 are made to the above numbered contract/order.

(b) ☐ The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12

(c) ☐ This Supplemental Agreement is entered into pursuant to authority of _____

It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

AUG 17 1970

I. Part II, Statement of Work, is changed as follows:

Under B. Configuration and Materials, item 5, sentence two, change from "The elastomeric panels shall be cured at 250°F for sixteen (16) hours" to "The elastomeric panels shall be cured at 250°F for sixteen (16) hours or at temperatures down to 160°F with a proportional increase in cure time."

II. There will be no change in cost, fixed fee, or period of performance as a result of this change.

Except as provided herein, all terms and conditions of the document referenced in block 8, as heretofore changed, remain unchanged and in full force and effect

13. ☐ CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT ☒ CONTRACTOR/OFFEROR IS REQUIRED TO SIGN THIS DOCUMENT AND RETURN 1 copy requested COPIES TO ISSUING OFFICE acknowledging receipt thereof.

14. NAME OF CONTRACTOR/OFFEROR

BY _____ (Signature of person authorized to sign)

15. NAME AND TITLE OF SIGNER (Type or print)

16. DATE SIGNED

17. UNITED STATES OF AMERICA

BY _____ (Signature of Contracting Officer)

18. NAME OF CONTRACTING OFFICER (Type or print)

LEON W. FITCHETT

19. DATE SIGNED

8/13/70

30-105-6 f-p

U S GOVERNMENT PRINTING OFFICE 1966 O 250-848

APPENDIX B
TECHNICAL LETTER PROGRESS REPORT

Technical Letter Progress Report on

LOW-COST ABLATIVE HEAT SHIELDS

for

SPACE SHUTTLES

FROM: Space Division - North American Rockwell
12214 Lakewood Boulevard
Downey, California 90241

TO: National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23365
Contract No. NAS 1-9943
Attention: Mr. Kenneth D. Albert
Mail Stop 126

FOREWORD

In submitting this Technical Letter Progress Report, the North American Rockwell Space Division conforms with the requirements expressed in the Statement of Work contained in the NASA/Langley Research Center Contract No. NAS 1-9943. The activities covered in this report took place during the first two months of the Contract, April 28 to June 28, 1970.

INTRODUCTION

The information contained in this report was extracted from the Laboratory Notebook issued to the Program Manager at the start of the Low-Cost Ablative Heat Shields for Space Shuttles Contract. In the notebook, daily activities were logged so that comprehensive data would be available for historical and reporting purposes.

A detailed schedule of program milestones and events was prepared, a copy of which, reflecting the program status, is included in this report. The text of the report narrates the first two months' proceedings, the problems encountered and action taken to resolve them, and the intended approach to be taken during the balance of the program.

For information purposes, the pictorial aspects of the program, such as tooling, the assembly sequence drawing, the equipment used, the panel designs, test specimens, etc., are presented. These will also be included in the Final Report.

Any questions concerning the contents of this report should be directed to L. B. Norwood, Program Manager, Area Code 213, 922-1919.

SEQUENCE OF EVENTS

The sequence of events in the first two months of the program, in general, followed the events listed in the Schedule. (See FIGURE 1.) Before Contract go-ahead small specimens were prepared to determine preliminary baselines and requirements. This effort was accomplished with material already on hand, some of it being samples, the rest stock items used in plastics development operations.

With the notice of Contract award various materials were ordered and received for the test specimens. This included the required miscellaneous items, such as the 20-40 mesh screen and the rubber sheeting. At the same time, drawings were made for the flat and curved deliverable panels, and of the manufacturing sequence to be followed in their fabrication. (See FIGURES 2 through 5 .)

In the course of preparing the test specimens several activities essential to subsequent operations were pursued, which included:

- Face sheet permeability selection
- Honeycomb core slotting methods (if required)
- Optimal core priming procedures and primer selection
- Oven-vacuum drying of powders and microballoons
- Vacuum bagging procedures
- Mixing and curing cycles
- Assembly contouring (springback)
- Hole machining
- Trim and check procedures
- Plug turning
- Preparing holes for fill
- Testing release agent for tools

With the drawings for the preliminary shop aids completed, and the caul plate material on hand, the next efforts to be progressively defined involved the following activities:

- Making teflon plugs
- Cutting rubber sheeting
- Fabricating fill fixture with edge members
- Making locating template for holes
- Shaping silicone edge members for mold
- Fabricating the male contour fixture

Prior to completion of the preceding activities and with the material requirements established, purchase orders were initiated, and all materials have been received for the production panels. This completed the sequence of events to the June 28, 1970 reporting date. Next, a discussion is presented on the

LOW COST ABLATIVE HEATSHIELD FOR SPACE SHUTTLE

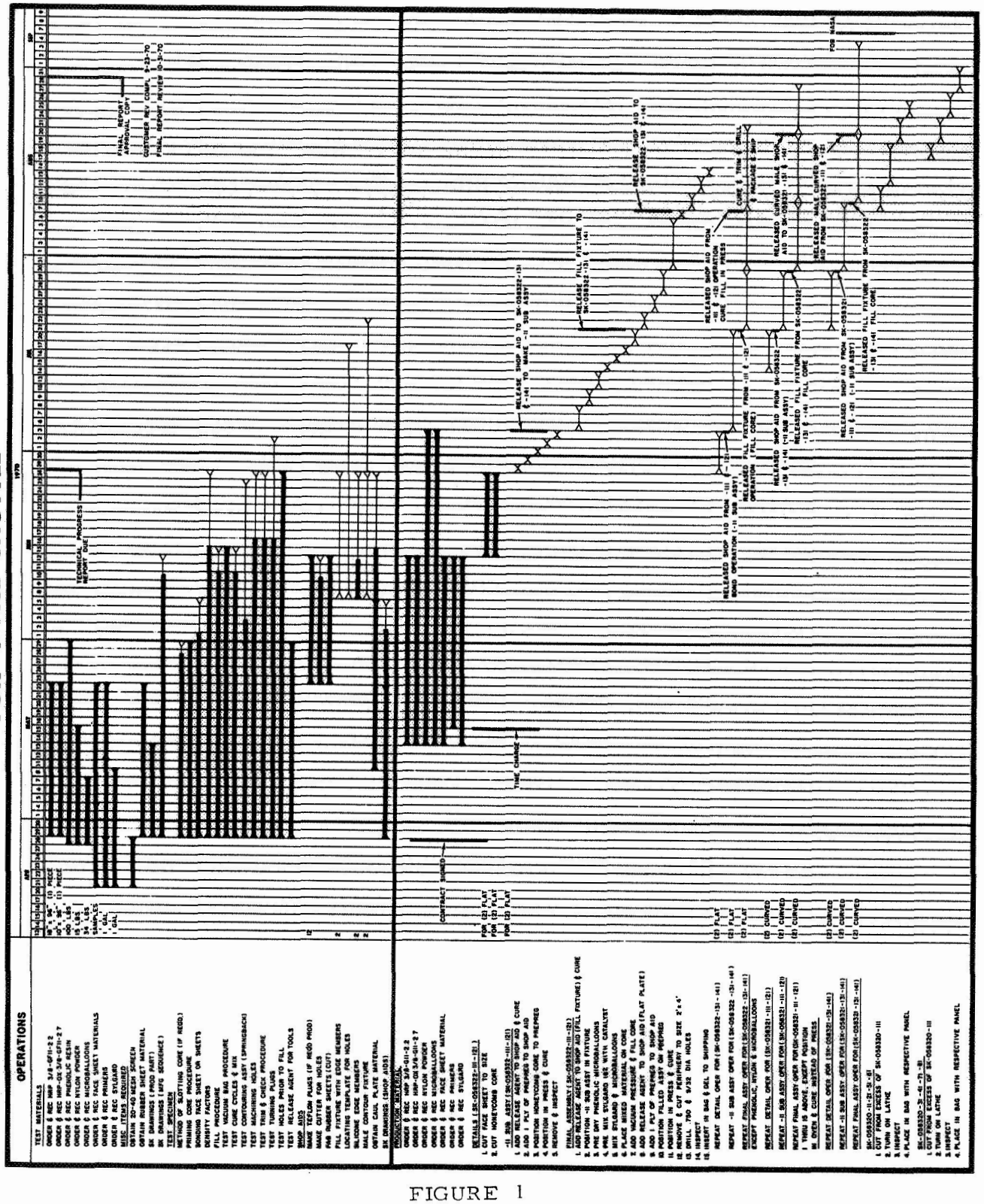


FIGURE 1

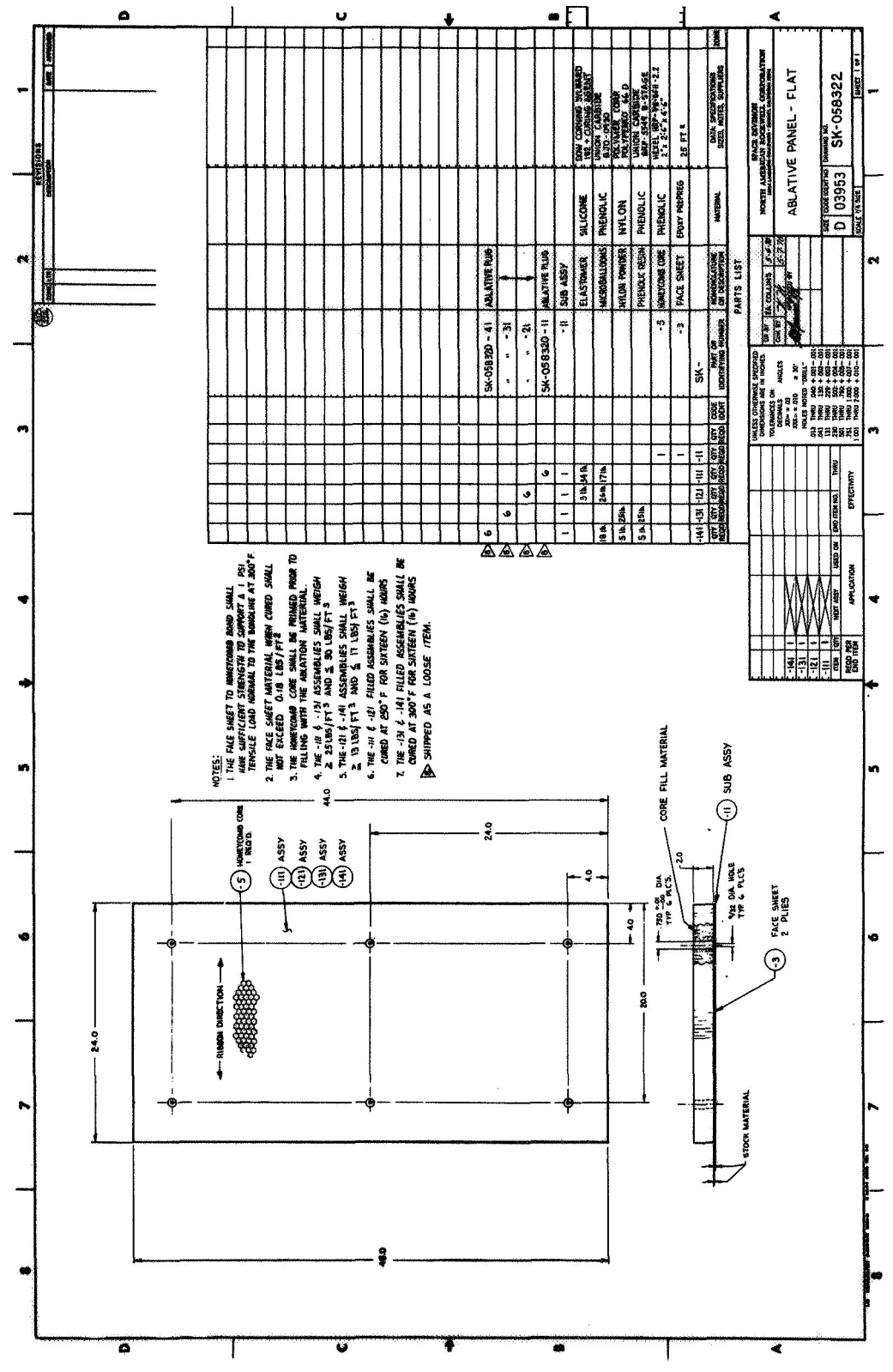

ABLATIVE PANEL - FLAT
SK-058322
D 03953
PARTS LIST
NOTES:
1. THE FACE SHEET TO HONEYCOMB BOND SHALL HAVE SUFFICIENT STRENGTH TO SUPPORT A 1 PSI TENSILE LOAD NORMAL TO THE BONDLINE AT 300°F.
2. THE FACE SHEET MATERIAL WHEN CURED SHALL NOT EXCEED 0.18 LBS/FT²
3. THE HONEYCOMB CORE SHALL BE PRIMED PRIOR TO FILLING WITH THE ABLATION MATERIAL.
4. THE -111 & -131 ASSEMBLIES SHALL WEIGH ≥ 25 LBS/FT³ AND ≤ 30 LBS/FT³
5. THE -121 & -141 ASSEMBLIES SHALL WEIGH ≥ 13 LBS/FT³ AND ≤ 17 LBS/FT³
6. THE -111 & -121 FILLED ASSEMBLIES SHALL BE CURED AT 250°F FOR SIXTEEN (16) HOURS
7. THE -131 & -141 FILLED ASSEMBLIES SHALL BE CURED AT 300°F FOR SIXTEEN (16) HOURS
▲ SHIPPED AS A LOOSE ITEM.
RUBBER DIRECTION
HONEYCOMB CORE 1 REQ'D.
-111 ASSY
-121 ASSY
-131 ASSY
-141 ASSY
CORE FILL MATERIAL
SUB ASSY
FACE SHEET 2 PLIES
STOCK MATERIAL

FIGURE 2

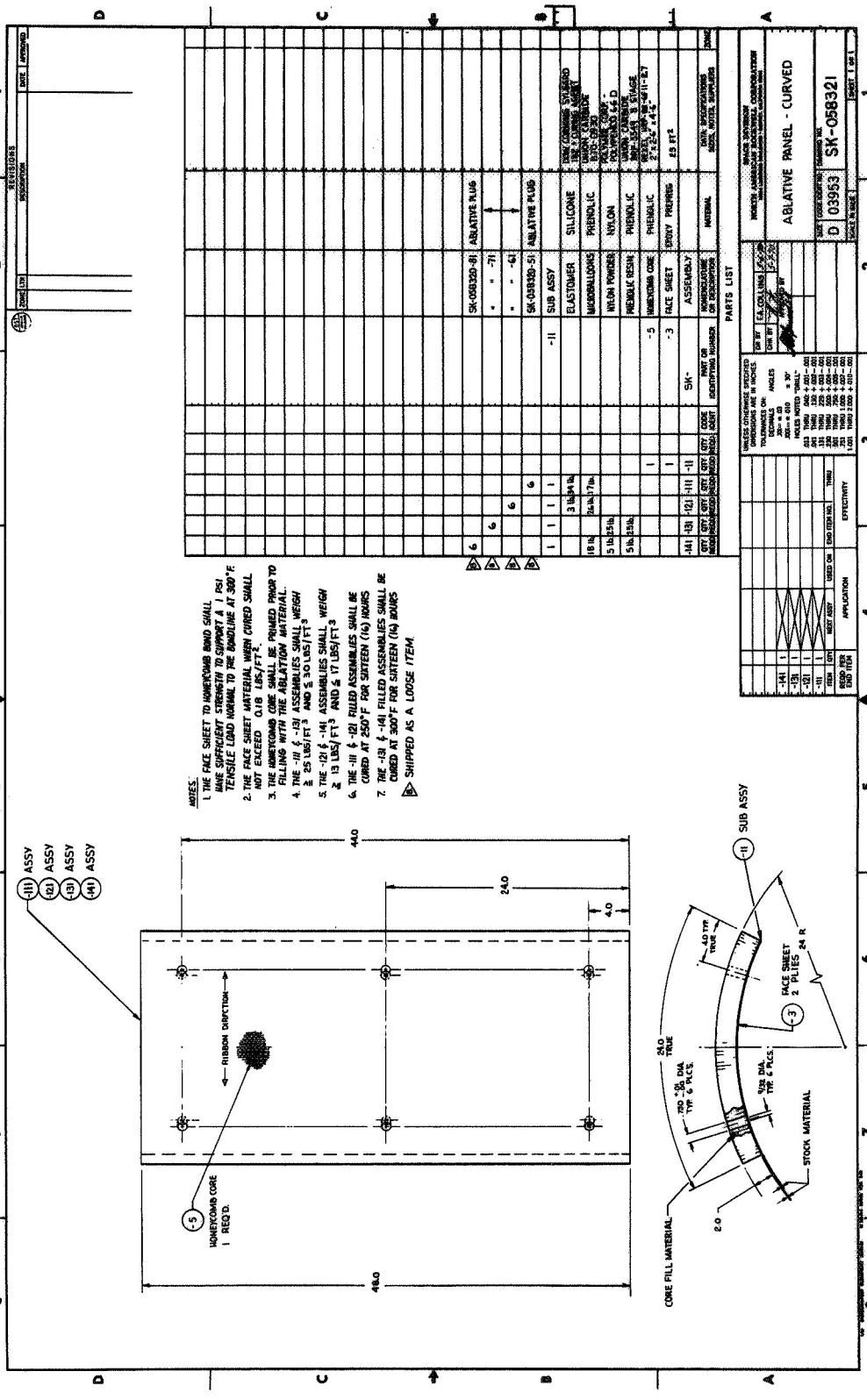

ABLATIVE PANEL - CURVED
SK-058321
D 03953
PARTS LIST
NOTES:
1. THE FACE SHEET TO HONEYCOMB BOND SHALL HAVE SUFFICIENT STRENGTH TO SUPPORT A 1 PSI TENSILE LOAD NORMAL TO THE BONDLINE AT 300°F.
2. THE FACE SHEET MATERIAL WHEN CURED SHALL NOT EXCEED 0.18 LBS/FT².
3. THE HONEYCOMB CORE SHALL BE PRIMED PRIOR TO FILLING WITH THE ABLATION MATERIAL.
4. THE -111 & -131 ASSEMBLIES SHALL WEIGH ≥ 25 LBS/FT³ AND ≤ 30 LBS/FT³
5. THE -121 & -141 ASSEMBLIES SHALL WEIGH ≥ 13 LBS/FT³ AND ≤ 17 LBS/FT³
6. THE -111 & -121 FILLED ASSEMBLIES SHALL BE CURED AT 250°F FOR SIXTEEN (16) HOURS
7. THE -131 & -141 FILLED ASSEMBLIES SHALL BE CURED AT 300°F FOR SIXTEEN (16) HOURS
SHIPPED AS A LOOSE ITEM
-111 ASSY
-121 ASSY
-131 ASSY
-141 ASSY
44.0
24.0
40.0
4.0
RIBBON DIRECTION
-5 HONEYCOMB CORE 1 REQ'D.
-11 SUB ASSY
24.0 TRUE
.190 -.86 DIA. TYP - 6 PLCS.
4.0 TYP
RAD
24 R
-3 FACE SHEET 2 PLIES
1/32 DIA. TYP 6 PLCS.
STOCK MATERIAL
CORE FILL MATERIAL
2.0

FIGURE 3

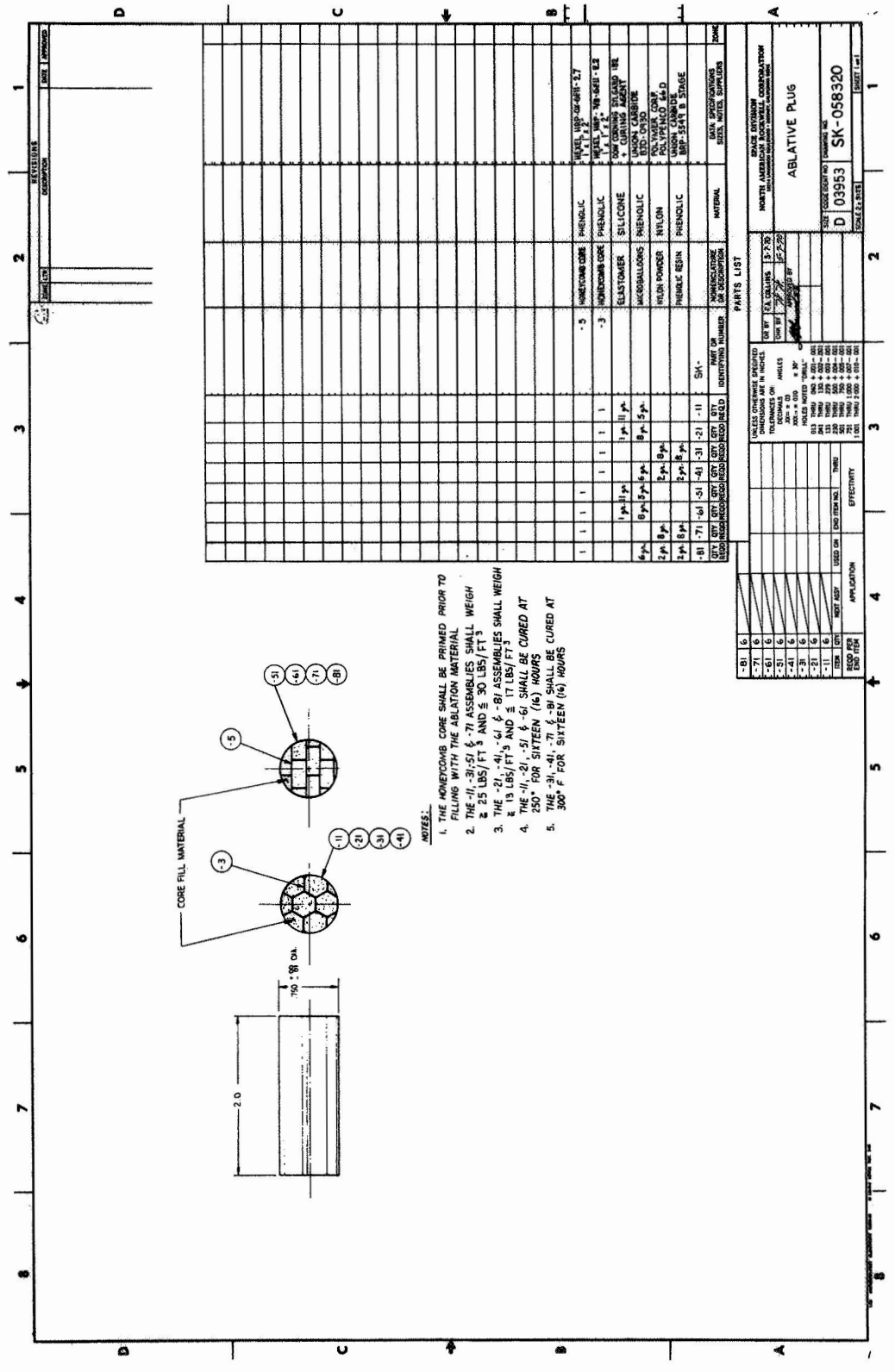

CORE FILL MATERIAL
2.0
.750 ± .98 DIA.
NOTES:
1. THE HONEYCOMB CORE SHALL BE PRIMED PRIOR TO FILLING WITH THE ABLATION MATERIAL
2. THE -11, -31, -51 & -71 ASSEMBLIES SHALL WEIGH ≥ 25 LBS/FT³ AND ≤ 30 LBS/FT³
3. THE -21, -41, -61 & -81 ASSEMBLIES SHALL WEIGH ≥ 13 LBS/FT³ AND ≤ 17 LBS/FT³
4. THE -11, -21, -51 & -61 SHALL BE CURED AT 250° F FOR SIXTEEN (16) HOURS
5. THE -31, -41, -71 & -81 SHALL BE CURED AT 300° F FOR SIXTEEN (16) HOURS
PARTS LIST
ABLATIVE PLUG
SK-058320
D 03953

FIGURE 4

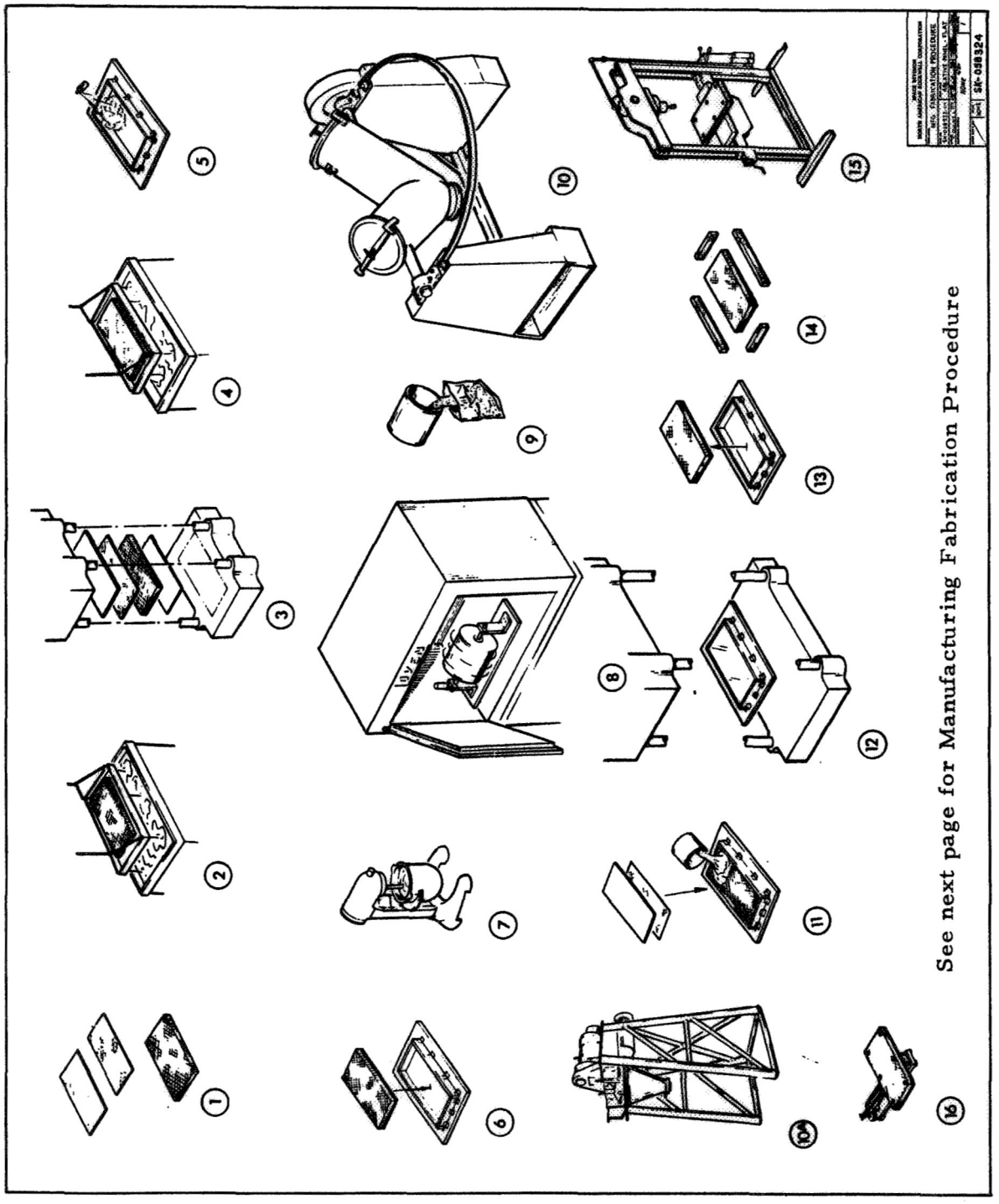


FIGURE 5

MANUFACTURING FABRICATION PROCEDURE
SK-058322-111 Ablative Panel-Flat

DETAILS:

-3 Face Sheet

OPERATION #1
1. Remove prepreg material (Reliabond R1714) from the freezer.
2. Cut two pieces to 26" X 50" with scissors.

-5 Honeycomb

OPERATION #1
1. Cut HRP-3/8-FG11-2.2 (honeycomb core) to size, 2" X 26" X 50".
NOTE: 2" dimension as received from supplier.

OPERATION #2
2. Clean core by inserting core in MEK solvent bath.

OPERATION #2
3. Remove and allow to dry at room temperature for a minimum of one hour.

-11 Sub Assembly

OPERATION #3
1. Apply RAM 225 release agent to both shop aids (flat plates) and cure at room temperature for a minimum of one hour.

OPERATION #3
2. Apply 1 sheet of TI 1040 (separator cloth) to shop aid (flat plate).

OPERATION #3
3. Apply 2 plies of Reliabond 1714 (epoxy prepreg) to the dry cloth, stretch taut and tape in position.

OPERATION #3
4. Apply the honeycomb core (HRP-3/8-GF11-2.2) to the prepreg and tape in place.

OPERATION #3
5. Add the second shop aid to the face of core.

OPERATION #3
6. Invert the overall assembly and position in the press (Ward Inc. 150 Ton 4' X 7' bed).

OPERATION #3
7. Close press and set pressure gage to 13-15 PSI, raise temperature to 300° F and hold for 1½ hours.

OPERATION #3
8. Open press and remove -11 sub assembly.

-111 Final Assembly

OPERATION #4
1. Position the -11 sub assembly (face sheet up) into the shop aid (pan) filled with DC 1203 and dip the core into the primer to within 1/8" of the face sheet.

OPERATION #4
2. Raise -11 sub assembly from the primer (bath) and allow to drip dry for a minimum of 10 minutes (place on absorbant paper toweling).

OPERATION #4
3. Allow the primer to cure at room temperature for a minimum of one hour.

OPERATION #5
4. Add RAM 225 release agent to shop aid (fill fixture) and allow to cure at room temperature for a minimum of one hour.

OPERATION #6
5. Position -11 sub assembly (face sheet down) into the shop aid (fill fixture).

OPERATION #7
6. Pre-mix Sylgard 182 with catalyst per manufacturer's recommendations (10 parts by weight of resin, to one part by weight of catalyst) in Hobart 5 gallon capacity mixer.

OPERATION #8
7. Load the shop aid (drying unit) with phenolic microballoons and place in an oven, rotate the drum at 8 RPM, pull partial vacuum .5 inches of mercury and raise the oven temperature to 200° F and hold for 3 hours minimum.

OPERATION #9
8. Remove the phenolic microballoons from the drying unit and store in a clean polyethylene container.

OPERATION #10
9. Mix 67% precatalized Sylgard resin (reference #7) and 33% of predried microballoons (reference #9) in an Atlantic Research Corp, Model 8CV Mixer, at approximately 15 RPM for one hour.

OPERATION #11
10. Apply mixed material (reference 10 to the top of honeycomb cells, disperse, the mix evenly over entire honeycomb core.

OPERATION #11
11. Add separator cloth, required tooling plate or plates, bleeder cloth and thermocouples.

OPERATION #12
12. Position shop aid (fill fixture) and filled assembly in the press (Ward Inc. 150 Ton, 4' X 7' bed).

OPERATION #12
13. Close the press and set the pressure to 15 psi and the temperature to 250° F.

OPERATION #12
14. Observe the overall height and thermocouple readings, when the overall height of the assembly reaches the predetermined limit and the thermocouple readings reach 250° F, hold pressure and temperature for 16 hours.

OPERATION #13
15. Remove shop aid (fill fixture) and cured filled assembly from the press, and remove filled assembly from the shop aid.

OPERATION #14
16. Visually check cured assembly.

OPERATION #14
17. Cut off excess material around the periphery to 2' X 4' finished dimensions.

OPERATION #15
18. Using shop aid (locating template) and cookie cutters in arbor press, add the six .750" diameter holes and the six 9/32" diameter holes.

OPERATION #16
19. Weigh completed panel and record.

OPERATION #16
20. Final inspection.

SK-058322-121

DETAILS:
1. Same as SK-058322-111
-11 Sub Assembly
1. Same as SK-058322-111
121 Final Assembly
1. Same as SK-058322-111 except as listed below.
(Paragraph 9, Operation #10) Mix 10% precatalyzed Sylgard resin (reference #7 with 90% of predried microballoons (reference #9) in an Atlantic Research Corp, Model 8CV mixer, at approximately 15 RPM for one hour.

SK-058322-131

DETAILS:
1. Same as SK-058322-111
-11 Sub Assembly
1. Same as SK-058322-111
121 Final Assembly
1. Same as SK-058322-111 except as listed below.
   a. Paragraph 1, Operation #4
   (Position -11 sub assembly, face sheet up) into the shop aid (pan) filled with Monsanto SC1008 and dip the core into the primer to within 1/8" of face sheet).
   *b. Paragraph 3, Operation #4
   (Cure the SC1008 primer at 140°F for 1.5 hours in an air circulating oven)
   c. Paragraph 6, Operation #7
   (Not required)
   d. Paragraph 7, Operation #8
   (Load the shop aid, drying unit, with nylon powder (Polypenco 660) and place in an oven. Rotate the drum at 10 to 15 RPM. Pull partial vacuum .5 inches of mercury and raise the oven temperature to 200° F and hold for 3 hours minimum.
   e. Paragraph 8, Operation #9
   Remove the nylon powders from the drying unit and store in a clean polyethylene container.
   f. Paragraph 9, Operation #10 (Operation 10A)
   (Mix 50% of phenolic powder (BJO-0930) with the 50% of the predried nylon powders, reference #9, in a Patterson Kelly twin shell day blender. (One 11 ft³ cap) at at 25 RPM for 40 minutes.
   g. Paragraph 13, Operation #12
   (Close the press and set the pressure to 15 psi and the temperature to 300°F.
   h. Paragraph 14, Operation #12
   Observe the overall height and thermocouple readings, when the overall height reaches the predetermined limit and the thermocouple readings reach 300° F, hold pressure and temperature for 16 hours.
   i. Paragraph 18, Operation #15
   Using the shop aid (locating template) drill the six .750" diameter holes, using a 3/4" standard, 3/4" diameter drill, speed 100 RPM feed 5/8" per minute, for clean up. Use a flat bottom drill to prevent damage to the face sheet, punch the 9/32" diameter hole through the face sheet with a cookie cutter.

SK-058322-141

DETAILS:
1. Same as SK-058322-131
-11 Sub Assembly
1. Same as SK-058322-131
-111 Final Assembly
1. Same as SK-058322-131 except as listed below.
   a. Paragraph c (Paragraph 6, Operation #7 is required)
   b. Paragraph f
   (Mix 15% of phenolic powder (BJO-0930) with 15% nylon powder (Polypenco 66D) and 70% of the predried phenolic microballoons in a Patterson Keyy, Twin Sheel Blender one ft³ capacity at 25 PRM for 40 minutes.

   c. Paragraph i, Operation #15
   (Using the shop aid (locating template) first precut with a 3/4" diameter hole saw, finish cut the remaining material out with a flat bottom drill. Punch the 9/32 diameter hole through the face sheet with a cookie cutter.

problems encountered and the actions taken to resolve them.

PROBLEMS AND CORRECTIVE ACTIONS

As with all programs of a developmental nature, problems were encountered during the early phases of test specimen fabrication. Although termed as problems, they were only limiting factors in achieving parametric definition of the optimal approach.

Face Sheet Prepreg Evaluation

The supplier of the face sheet prepreg material (R1714) was asked to increase the resin content as early tests proved the material to be too dry for reliable core-to-face bond strength. Since the material was only one-half of the allowable weight, increasing the resin content slightly was a plausible recourse.

Core Priming Procedure

A problem arose in dipping the core (bonded to a single face sheet) into the Dow Corning 1203 primer. Even though the primer depth was 1/8-inch less than core thickness, the core's capillary attraction wet the face sheet. This created a problem in bonding the second face sheet, which can be resolved in a number of ways. Efforts to determine the optimal priming method are continuing.

Bulk Density Factors and Compound Mixing

During the preparation of materials for the test specimens difficulty was experienced in obtaining a thorough mix of the low-density elastomeric compound (10% Elastomer/90% Microballoons). Several quantities of the ingredients were carefully weighed and mixed in three different ways; (1) manually kneaded in a sealed plastic bag, (2) mechanically mixed in a Hobart mixer, and (3) mechanically mixed in a Hobart mixer with a modified wiper blade. The first two were unsatisfactory, but the third method showed considerable improvement. The cured specimens, however, were still fragile from a handling and hole cutting standpoint.

An alternate compound ratio of 82% microballons/18% Sylgard 182 was requested to improve mixing uniformity, reduce mixing time, reduce handling damage, improve machinability, and which would satisfy the specified density of 13- to 17-lbs./cu. ft.

Through information furnished by Messrs. C. Pittman, Technical Representative, and W. Haraway of the NASA/LRC, it was learned that an Atlantic Research Corporation (ARC) Model 8CV Helicone Mixer was suitable for nearly-dry mixing, and a mixing procedure was provided. The unit rents for $500 a month, or sells for $9,800. Arrangements were completed to rent the ARC Model 8CV which has now been placed into use to confirm mixing parameters for the elastomeric compounds.

While waiting for the Helicone Mixer, Mr. C. Pittman notified Mr. L. Norwood, NR program manager, that we try adding an equal weight of Heptane solvent to the Sylgard 182 elastomer to help the dispersion process with the microballoons. Then, after thorough mixing (in modified Hobart Mixer) vaporize off the solvent. This was done which produced a uniform mixture and showed an added surface improvement over prior specimens. No increase in desirable density was noted.

The Space Division received mixing support from NR Rocketdyne, McGregor, Texas where low-density material samples were sent to be mixed by equipment located there. Satisfactory results were reported, and the mixed material was returned to the Space Division for further processing. The results after curing showed the 10% elastomer/90% microballoon mix to be no better than the results attained by the Space Division with in-house mixed material of the same composition.

The low-density problems were discussed with Mr. Claude M. Pittman of the NASA/LRC during his visit to the Space Division on June 16, 1970. (See TABLE 1 .) At that time he examined the low-density test specimens which had caused mixing and debulking problems, and which were below the required minimum density. Mr. Pittman suggested the possibility of developing mixing percentages that would be in a narrower density range rather than the 13- to 17-lb./cu. ft. range. Although he expressed concern over the low densities obtained, he indicated approval of the program progress as of the June 16 date.

The ARC Helicone Mixer was put into operation on June 23, and the first 90%/10% mixture was made which produced no better results than previously found. On June 24 Mr. Pittman telephoned Mr. Norwood that a request for a contract change had been submitted to their Contracting Officer to approve 20% elastomer/ 80% microballoon composition, and to provide for an optional 30-day time extension. Fabrication of specimens using this new composition are currently underway to verify density.

Core Fill Procedure

The low-density compositions created some problems in incomplete core filling and compacting to the required two-inch depth. Various top-fill methods have been tried in addition to an inverted pressing of the core into the mix. The reverse displacement method looks the best for the elastomeric system. Development continues toward achieving the most cost-effective method commensurate with the required quality.

Contour Assemblies

A problem to be resolved is the springback tendency and warpage of contoured test specimens. After being cured on a contoured tool, the radial extremities do not make contact with the tool's surface. This may be due to contraction of the ablative compound, incomplete cell filling, tool deflection,

DENSITY VERIFICATION TESTS

(Panel Size: 2" x 6" x 6")

	COMPOSITION	REQUIRED DENSITY	ACTUAL DENSITY	REMARKS
1.	14% Elastomer - 86% Microballoons	13-17 lbs/ft^3	12.32 lbs/ft^3	Vacuum bag cured at 258 F for 16 hours
2.	20% Elastomer - 80% Microballoons	13-17 lbs/ft^3	13.154 lbs/ft^3	20% Hestane used. After filling was vacuum outgassed approximately 48 hours. Then vacuum bag cured at 250 F for 16 hours. Some weight loss found after outgassing
3.	67% Elastomer - 33% Microballoons	25-30 lbs/ft^3	29.42 lbs/ft^3	Vacuum bag cured at 250 F for 16 hours
4.	15% Nylon - 15% Phenolic - 70% Microballoons	13-17 lbs/ft^3 13-17 lbs/ft^3	11.23 lbs/ft^3 13.717 lbs/ft^3	Vacuum bag cured at 300 F for 16 hours 40 psi used in press, cured at 300 F for 16 hours. Part incompletely cured around periphery.
5.	50% Phenolic - 50% Nylon	25-30 lbs/ft^3	24.18 lbs/ft^3	Vacuum bag cured at 300 F for 16 hours

TABLE 1. - DENSITY VERIFICATION TESTS

or a combination. Investigation continues towards determining the cause and how to correct it. One approach is to use a reduced radius which can be pre-calculated for the tool if measurement of the springback on several specimens shows conformance to a set pattern.

Hole and Plug Procedures

Four procedures were initially tried in producing the required holes; (1) using a tubular gasket-type cutter on the unfilled core, then inserting a teflon plug prior to the fill and cure operation, (2) drilling the hole in the filled and cured specimen, (3) using the gasket cutter pressed into the filled and cured specimen, and (4) hole sawing into the filled and cured specimen. The results are shown in TABLE 2.

Two procedures have been used in making the plugs; (1) turning the plugs on a lathe, and (2) using the gasket cutter in the same manner as making holes in the filled and cured specimens. Although both methods have merit, the pressed-in gasket cutter method is more expedient, hence less costly.

HOLE CUTTING DATA

(Partial Results Only)

COMPOSITION TYPE	HOLE CUTTING METHODS TRIED	RESULTS
10% Elastomer - 90% Microballoons	1. Molding to teflon plug insert	Satisfactory hole, preindexing of holes more expensive
	2. Pressed-in gasket cutter	Satisfactory hole, but has risk of cutting into fabric skin
67% Elastomer - 33% Microballons	1. Pressed-in gasket cutter	Satisfactory hole
15% Nylon - 15% Phenolic - 70% Microballoons	1. Hole sawing (speed 5/8"/min. speed 100 rpm) and flat bottom drill clean up	Satisfactory hole
50% Phenolic - 50% Nylon	1. Hole sawing (same as above)	Fair quality, some burn tendency
	2. Drilling	Satisfactory hole
	3. Pressed-in gasket cutter	Unsatisfactory, ablative fractured

TABLE 2. - HOLE CUTTING DATA

CORE-TO-FACE FLATWISE TENSION TESTS

To determine the highest core-to-face sheet tensile values of the candidate prepreg materials, two-inch square flatwise tensile test specimens were prepared and tested by Space Division's Laboratories and Test department. Tests were conducted at room temperature, and at 300 F. Of the three prepreg materials listed in TABLE 3, the Reliabond Corporation's R1714 material produced the highest strengths. This material will be used for the face sheets on the deliverable panels.

MISCELLANEOUS ACTIVITIES

One of the objectives during the development activity was to establish a core-to-face sheet bonding process that would permit visual examination of bond-line integrity. In other words, the face sheet (one-ply) should be transparent to the extent that the image of the attached core, if completely bonded, would be of the same intensity over the total face sheet area. This was accomplished without any difficulty by using state-of-the-art techniques.

Another objective was to produce a permeable condition in the laminated two-ply face sheet so there would not be air entrapment during the core-fill procedure. In this manner, slotting the honeycomb core could be eliminated, and a stronger bond line could be achieved. The objective was accomplished by controlling the resin content between the two face sheets using open-weave fabric and placing the face sheet over the top surface of the core during the initial bonding operation. Gravity flow thus improved filleting to the core and maximized porosity in the facing.

Trimming the edges of the production panels will be accomplished with a diamond-toothed circular saw blade. A test specimen (15% phenolic, 15% nylon, and 70% microballoons) was used to test the saw, which produced a much smoother cut than could be obtained with a band saw. The panels will be built oversize but only to the extent required for clean-up trimming and to obtain like material for plug cutting.

The shop aids (tooling) for the program are minimal in extent but adequate for their intended function. From the Space Division's diversified experience with other plastics programs, fabrication of the shop aids is a simple matter and will be completed in a cost-effective manner. Basically, the same type of low-cost tooling would be used for high-production quantities of ablative heat shields for the Shuttle.

Before each lay-up of the test specimens, the contacting surfaces of the shop aids were coated with the release agent RAM-225. This will also be used on the shop aids for the deliverable panels as no difficulty is experienced in removing the parts after curing when this material is used.

CORE-FACE FLATWISE TENSION TESTS

PREPREG TYPE AND MANUFACTURER	STRENGTH, PSI ROOM TEMP	300 F	PREPREG WEIGHT/SQ FT	REMARKS
R1714 (Reliabond Corp.)	36.6	29.6	18.2 Grams	Facing selected for panels
Trevarno F268-18 (Coast Manufacturing & Supply Co.)	17.5	19.9*	42.8 Grams	2 Spec. failed in handling*
R1714-1331 (Reliabond Corp.)	13.8	---	55.0 Grams	Not tested at 300 F

Notes: 1. All specimens were cured at 300 F for 1-1/2 hours with 14.7 psi (approximately) vacuum pressure. Bond area was approximately 4 sq. in.

2. Room temperature values were on one specimen only.

*3. 300 F specimen results are an average of 3 specimens except as noted.

4. R1714-1331 was eliminated from further evaluation after R. T. testing.

TABLE 3. - CORE-FACE FLATWISE TENSION TESTS

CONCLUSIONS AND RECOMMENDATIONS

In appraising the progress made during the last two months the Space Division is reasonably certain the problematical areas have been narrowed to the extent that fabrication of the eight panels can be accomplished to the satisfaction of the NASA/LRC. The only remaining gray areas are; (1) establishing the volumetric requirements per panel size for core fill and compaction (the low-density compositions) to eliminate excess material removal after curing, and (2) defining the optimal percentage values of the low-density materials to achieve the required lbs./cu. ft. density. Efforts will continue in these pursuits.

In view of the Contract requirement to establish effective estimating parameters for Shuttle quantities of ablative heat shields, it is believed the current program is not sufficiently "in-depth" to thoroughly optimize the preceding gray areas. Although considerable progress has been made in these areas, the Space Division is certain that more definitive data can be realized if additional effort is put forth in these pursuits.

Therefore, it is recommended that a program be initiated to accomplish the following objectives.

1. Determine the most cost-effective method of core fill and compaction for production quantities of compound and aerodynamic configured panels made with low-density materials.

2. Define the requirements for greater than one atmosphere pressure to accomplish the optimal surface uniformity without machining or sanding, and to achieve a consistent controllable density within narrower weight limits.

3. Develop a method to quickly determine the interstitial space existing in a measure and volume of microballoons. (Photomicrographs, 150X, of microballon samples showed as many as six different sizes of microballoons, which it is believed has caused variations in density values.)

Much more development effort has been necessary than was anticipated at the start of the program. This might be traced to inconsistency in the specified materials between those used at Langley and at the Space Division, or to the scale-up in test specimen size and material quantity. For this reason it is desirable that development be conducted on a broader scale to more accurately qualify the estimating procedures for 3- by 6-foot and 4- by 8-foot panels.

FUTURE ACTIVITIES

Having reached the June 28 two-month reporting date, the program is ready to proceed with the initial fabrication of the deliverable flat panels. Based upon the parameters established during the development phase, each assembly procedure will be carefully time-checked and evaluated to provide definitive data for estimating panel job lots per Shuttle flight, as specified in the Contract.

The operations involved in fabricating the panels are sequentially illustrated and specifically defined in the Manufacturing Fabrication Procedures, FIGURES 2 through 5. These are the controlling documents to be used by Planning, the Plastics Shop, and Time Study personnel. Any deviation in the execution of the procedures can only be effected by issuance of an authorized Engineering Order (EO), which then becomes part of the controlling document.

During the fabrication of the panels, data will be accumulated for preparation of the Final Report. This report will include a summary and delineation of the developmental activities contained in this Technical Letter Progress Report, together with the documentation and photographic coverage of the actual fabrication of the panels. The approval copy of the Final Report will be submitted four months from date of contract award.