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LOW-COST FABRICATION OF ABLATIVE HEAT SHIELDS

By A. M. Cecka and W. C. Schofield

June, 1972

Prepared under Contract No. NAS 1-11004 by
FANSTEEL INC.-REFLECTIVE LAMINATES DIVISION
Newbury Park, California

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

A material and process study was performed using subscale panels in an attempt to reduce the cost of fabricating ablative heat shield panels. Although no improvements were made in the material formulation, a significant improvement was obtained in the processing methods compared to those employed in the previous work under Contract NAS 1-9947. The principal feature of the new method is the press filling and curing of the ablation material in a single step with the bonding and curing of the face sheet. This method was chosen to replace the hand troweling and autoclave curing procedure used previously.

Honeycomb cores of glass-phenolic, Kraft paper and Nomex were investigated. The glass-phenolic material was superior in the thermal performance tests. The 1.27 centimeter (1/2 inch) cell honeycomb was easier to fill but performed less effectively as a char layer reinforcement in the arc-jet tests than the .95 centimeter (3/8 inch) cell size core.

Two other resins, Dow Corning's Sylgard 184 and General Electric's RTV-615, were nearly as effective as the Sylgard 182 material used previously. However, the latter was selected for the full scale panels because it gave better results in arc-jet specimen tests.

Ten full-size 61 x 122 x 5.08 centimeter (24 x 48 x 2 inch) flat, low-density elastomeric panels were fabricated to establish a better baseline for estimating production costs. Actual cost data generally verified previous estimates although small quantity cost estimates were higher and large quantity cost estimates were lower. These changes reflect higher material and labor costs, a more realistic allowance for scrap and loss factors, and the use of new fabrication methods.

Double-curvature panels of the same size as the flat panels were fabricated to investigate fabrication problems. It was determined that the same materials and processes used for flat panels can be used to produce the curved panels. A design with severe curvatures consisting of radii of 61 x 122 centimeters (24 x 48 inches) was employed for evaluation. Ten low-density and ten high-density panels were fabricated. With the exception of difficulties related to short run non-optimum tooling, excellent panel filling and density uniformity were obtained.

INTRODUCTION

The feasibility of producing low-cost ablative heat shields for space shuttles has been demonstrated under a previous program (Contract NAS 1-9947, Report NASA CR-111814, Low-Cost Ablative Heat Shields for Space Shuttles). Materials, tooling and methods were developed for ease of fabrication and the least number of operations. Full size panels were fabricated to provide a basis for realistic cost estimates of heat shield production.

During this earlier work several processing difficulties were encountered. To solve these problems, recommendations were made to modify some of the materials and processes. These improvements also presented an opportunity for further fabrication cost reductions.

The work reported here was performed under a follow-on program. The effort consisted of a study to explore procedures for further reducing ablative panel costs while improving the fabrication processes and suitability to in-process inspection, to establish a better baseline for estimating panel production costs, and to investigate the fabrication of large double-curvature ablative panels. Only the elastomeric ablation materials were considered for this investigation.

The program was divided into two tasks:

A. Subscale panels were fabricated to investigate different resins systems, honeycomb materials, honeycomb cell sizes, honeycomb filling techniques, face sheet bonding methods, panel trimming and panel warpage. This task was directed towards simplification of the processes, cost reduction, resolving the problem of the honeycomb filling with the ablation compounds, improving the panel edge density control and durability, and providing a means of inspecting the honeycomb fill. Arc-jet specimens were fabricated from the best subscale panels for thermal performance testing by National Aeronautics and Space Administration, Langley Research Center.

B. Using materials and processes selected from the first task results, full size panels were fabricated to provide a better baseline for panel cost estimates. Ten flat, low-density, elastomeric panels were manufactured. A double-curvature panel of the same size was produced to investigate fabrication problems. Twenty double-curvature panels, ten low-density and ten high-density elastomeric material, were fabricated. The panels were delivered to the National Aeronautics and Space Administration, Langley Research Center. Fabrication costs were itemized and flight vehicle quantity production estimates were prepared.

The results of the program demonstrated that flat panels can be manufactured with confidence. The development of improved processes and a press filling method produced additional cost reductions and increased the adaptability of the fabrication processes to quality control procedures. Double-curvature panels can be produced by the same manufacturing processes and methods as the flat panels. Refinements of the tooling are recommended to obtain the required panel uniformity and quality.

Measurement values are expressed in the International System of Units and the customary units. The principal measurements and calculations were made in customary units and converted to the International System.

I. SUBSCALE PANEL INVESTIGATIONS

Elastomeric ablation materials were used for all panel fabrication. The constituents were phenolic Microballoons and silicone resins. The percentages of each constituent, the honeycomb materials and cell sizes, the face sheet materials and bonding methods, and the panel filling methods were investigated for ease of fabrication while meeting the desired densities of approximately 240 and 448 kg/m^3 (15 and 28 lb/ft^3) for the low and high density panel respectively. Table 1 lists the materials used for this study.

Arc-jet specimens for thermal performance testing were prepared from each promising material and fabrication process. Structural test specimens were prepared to evaluate face sheet to honeycomb bond strength. Table 2 presents a list of the panels fabricated, the purpose of the evaluation, and the results obtained.

A. Press Filling of Honeycomb Panels

The press molding method of filling honeycomb panels with elastomeric ablation materials was evaluated as a replacement for the hand troweling method employed on the previous program (NAS 1-9947). This method consists of precompacting the ablation material in a mold and pressing the honeycomb into the compound in a hydraulic press.

Preliminary investigations were conducted on 15.2 x 15.2 centimeter (6 x 6 inch) panels. The low-density ablation material was selected for the experimental work since it has been previously found to be more difficult to fill than the high-density formulation. Six panels of HRP 3/8-GF 12-3.2 glass-phenolic honeycomb without face sheets or primer coat were filled with a mixture of 20% Sylgard 182 resin and 80% phenolic Microballoons. A pre-weighed charge calculated to produce the desired finished panel density was loaded into the mold. The mixture was compacted to varying densities for the different panels to evaluate the effects on panel filling and density uniformity. The honeycomb was pressed into the precompacted ablation material, the panels were cured and plugs of the filler were extruded from the honeycomb for evaluation. The quality of the ablation materials was examined by sectioning and handling. Panel densities were calculated.

It was determined from this study that an even distribution of the ablation material in the mold and application of 68.9 kN/m^2 (10 psi) pressure produced a uniform density. This pressure yields approximately the same compacted thickness as the honeycomb panel thickness. As a result, the same press stops can be used for the ablation material precompaction and honeycomb filling operations. A slow application of 206.8 to 275.8 kN/m^2 (30 to 40 psi) pressure forced the honeycomb panel into the compacted material providing a margin of safety for the crushing strength of the different honeycomb materials evaluated.

TABLE 1.

MATERIALS INVESTIGATED

Materials	Description	Manufacturer
Resins	Sylgard 182 Silicone	Dow Corning
	Sylgard 184 Silicone	Dow Corning
	RTV 615 Silicone	General Electric Co.
Microballoons	BJO-0930 Phenolic	Union Carbide Co.
	BJO-0931 Phenolic	Union Carbide Co.
Honeycomb Core	Glass-Phenolic	
	HRP 3/8-GF 12-3.2	Hexcel Corp.
	HTP 1/2-3.0/4.0	Honeycomb Products Co.
	Nomex	
	HRH 10-3/8-2.0	Hexcel Corp.
	HMX 1/2-3.5	Honeycomb Products Co.
	Kraft Paper	
	KP 3/8-3.0/4.0	Honeycomb Products Co.
	KP 1/2-3.0/4.0	Honeycomb Products Co.
Core Primer	SC 1008 Phenolic Resin	Monsanto
Face Sheet	SP 5102/1581 Epoxy/Glass Cloth Prepreg	DuPont Co.
Face Sheet Adhesive	RTV 1200 Primer	Dow Corning

TABLE 2.

SUBSCALE PANEL EVALUATION OF MATERIALS AND PROCESSES

NO.	PURPOSE [a]	CORE	ABLATION MATERIAL COMPOSITION	ABLATION MATERIAL % WT.	FABRICATION METHOD	SIZE [b] CENTIMETERS	SIZE [b] (INCHES)	AVERAGE DENSITY [e] ARC-JET SPECIMEN KG/M^3	AVERAGE DENSITY [e] ARC-JET SPECIMEN (LB/FT^3)	PANEL WARPAGE MM	PANEL WARPAGE (INCHES)
1	4/5 Control	HRP 3/8-GF 12-3.2 Glass/Phenolic	Sylgard 182 Microballoons	27 73	Press	60.96 x 121.92	(24 x 48)	229.57	(14.33)	2.74	(.108)
1A[c,d]	4	" " "	Sylgard 182 Microballoons	27 73	Press	60.96 x 121.92	(24 x 48)	220.43	(13.76)		
1B[c,d]	4	" " "	Sylgard 182 Microballoons	27 73	Press	60.96 x 121.92	(24 x 48)	239.82	(14.97)		
2	4 Control	" " "	Sylgard 182 Microballoons	67 33	Press	30.48 x 60.96	(12 x 24)	447.76	(27.95)		
3[c]	1/5	" " "	Sylgard 184 Microballoons	27 73	Press	30.48 x 60.96	(12 x 24)	226.68	(14.15)	1.22	(.048)
4	1	" " "	Sylgard 184 Microballoons	67 33	Press	30.48 x 60.96	(12 x 24)	450.96	(28.15)		
5	1/5	" " "	GE RTV-615 Microballoons	27 73	Press	30.48 x 60.96	(12 x 24)	231.49	(14.45)	.38	(.015)
6	1	" " "	GE RTV-615 Microballoons	67 33	Press	30.48 x 60.96	(12 x 24)	440.23	(27.48)		
7	2/4	HTP 1/2-3.0/4.0 Glass/Phenolic	Sylgard 182 Microballoons	27 73	Press	30.48 x 60.96	(12 x 24)	239.66	(14.96)		
8	2/4	" " "	Sylgard 182 Microballoons	27 73	Hand/ Autoclave	30.48 x 60.96	(12 x 24)	216.11	(13.49)		
9	2/4	" " "	Sylgard 182 Microballoons	67 33	Press	30.48 x 30.48	(12 x 12)	471.31	(29.42)		
9A[d]	2/4	" " "	Sylgard 182 Microballoons	67 33	Press	30.48 x 30.48	(12 x 12)	441.03	(27.53)		
10	2/4	" " "	Sylgard 182 Microballoons	67 33	Hand/ Autoclave	30.48 x 60.96	(12 x 24)	440.39	(27.49)		
11	3	HRH 10-3/8-2.0 Nomex	Sylgard 182 Microballoons	34 66	Press	30.48 x 30.48	(12 x 12)	214.51	(13.39)		
12	3/5	HMX 1/2-3.5 Nomex	Sylgard 182 Microballoons	27 73	Press	30.48 x 60.96	(12 x 24)	223.64	(13.96)	1.78	(.070)
13	3/5	KP 3/8-3.0/4.0 Kraft Paper	Sylgard 182 Microballoons	27 73	Press	30.48 x 60.96	(12 x 24)	227.80	(14.22)	1.35	(.053)
14	3/5	KP 1/2-3.0/4.0 Kraft Paper	Sylgard 182 Microballoons	27 73	Press	30.48 x 60.96	(12 x 24)	221.72	(13.84)	.762	(.030)
15	2/3/4	HRH 10-3/8-2.0 Nomex	Sylgard 182 Microballoons	30 70	Hand/ Autoclave	30.48 x 30.48	(12 x 12)	219.15	(13.68)		
16	2/3/4	HMX 1/2-3.5 Nomex	Sylgard 182 Microballoons	30 70	Hand/ Autoclave	30.48 x 30.48	(12 x 12)	217.71	(13.59)		
17	2/3/4	KP 3/8-3.0/4.0 Kraft Paper	Sylgard 182 Microballoons	30 70	Hand/ Autoclave	30.48 x 30.48	(12 x 12)	212.75	(13.28)		
18	2/3/4	KP 1/2-3.0/4.0	Sylgard 182	30	Hand/ Autoclave	30.48 x 30.48	(12 x 12)	210.18	(13.12)		

a Purpose of Evaluation

1. Resin
2. Honeycomb size
3. Honeycomb material
4. Panel filling method
5. Panel warpage

b All panels were 5.08 cm. (2 inches) thick

c Cured without face sheets. All others fabricated with primary bonded one ply 181 glass cloth prepreg.

d Core not resin primer. All others coated with SC 1008 resin.

e Excluding face sheet

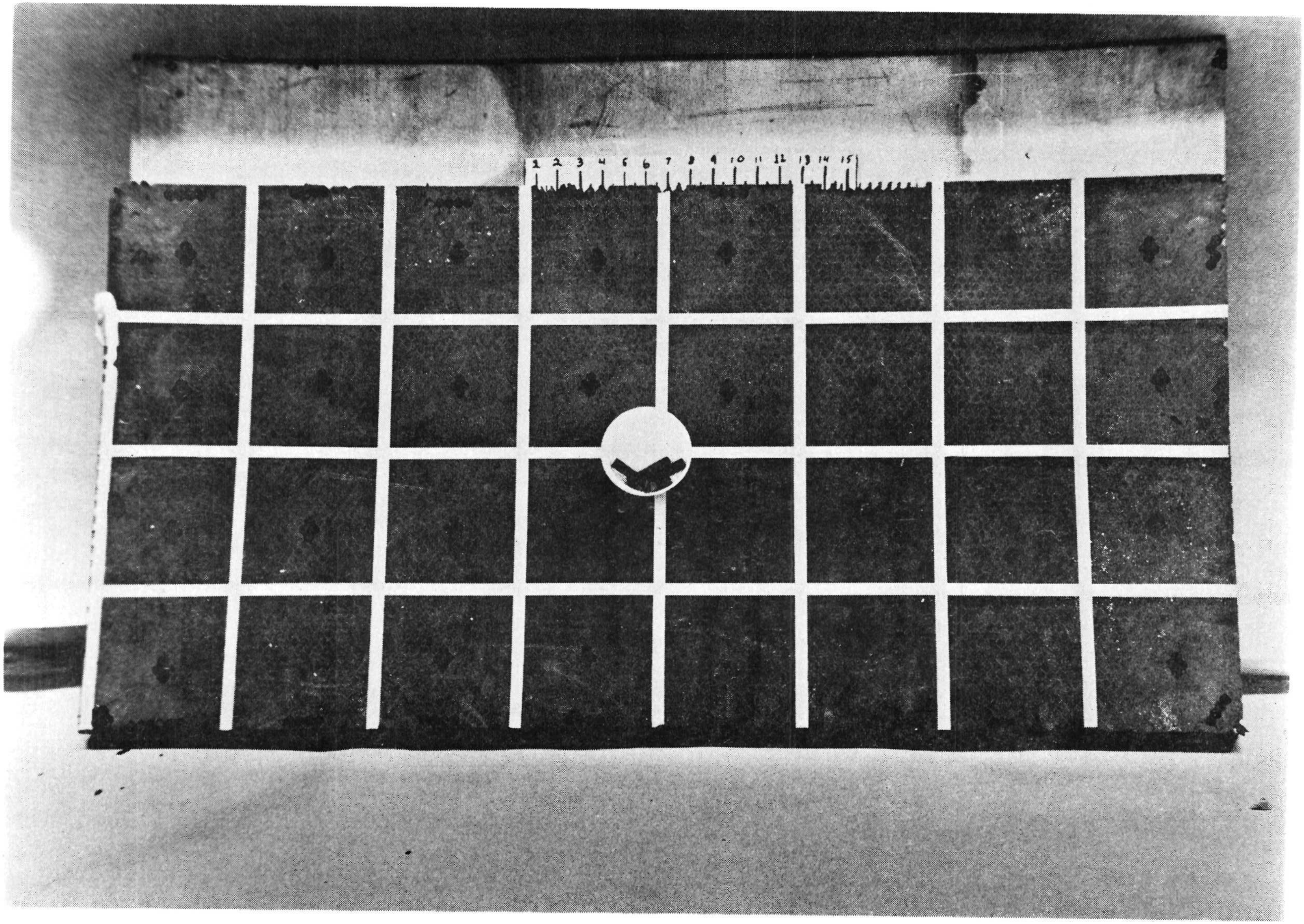


Figure 1. Density Evaluation of Press Filled Panel

After insertion of the panel, a pressure of 689.5 to 861.9 kN/m^2 (100 to 125 psi) was applied for 5 minutes to minimize ablation material springback when the mold was opened to apply the face shield prepreg material.

An evaluation of this procedure was made on a full size 60.9 x 121.9 centimeter (24 x 48 inch) panel fabricated without a face sheet or honeycomb primer. As shown in Figure 1, four plugs were removed from each location and weighed. The measured densities are listed in Table 3.

Further evaluation of the press fill method was performed on the high density ablation material and 1.27 centimer (1/2 inch) cell honeycomb during the fabrication of the subscale panels and arc-jet test specimens. Kraft paper and Nomex honeycomb materials were also investigated. The resulting densities were comparable to those of the experimental specimens. Both the press filled subscale panels and experimental test specimens had very uniform densities.

B. Resins

Three resins including Sylgard 182, which was used in the previous program, Sylgard 184 and RTV-615 were selected for evaluation. The objectives were lower curing temperature (preferably room temperature), better honeycomb filling characteristics, improved durability of the cured heat shield panels, and an alternate material supplier.

Sylgard 184 was chosen for its room temperature curing properties. The panel filling qualities were the same as for Sylgard 182. However, the manufacturer's recommended cure of 24 hours at room temperature failed to provide sufficient handling strength with the Microballoon filled compound. An elevated temperature cure produced properties similar to those of Sylgard 182 although the latter displayed slightly better durability and handling strength as determined by the sharpness of cut edges. Panel surface abrasion resistance was the same for both. However, the pot life of Sylgard 184 is shorter making it less suitable for large volume production.

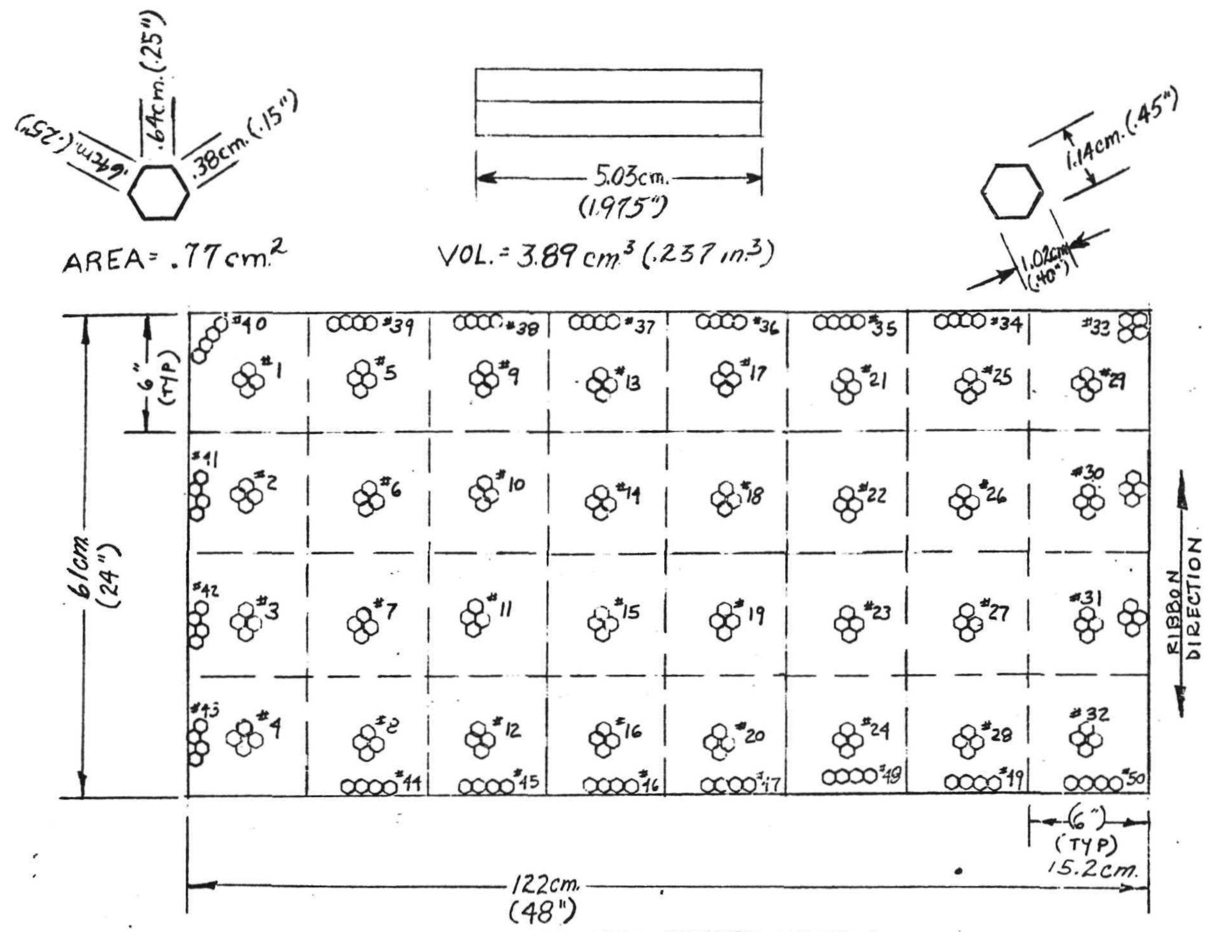
RTV-615 displayed generally the same characteristics as Sylgard 182 from the standpoint of processability. The quality of the cured ablation material was also comparable. This material can be considered as an acceptable alternate for future programs thereby providing a second source for the elastomeric resin.

All three resins were used for fabrication of subscale panels and arc-jet test specimens. Comparable densities were obtained when the same processes were used.

C. Honeycomb Core

Three different honeycomb materials of two different cell sizes were investigated. The 3/8-3.2 phenolic/glass core which was evaluated on the previous contract was used as a control. In addition, panels were fabricated from Kraft paper and Nomex honeycombs. Each material was evaluated in .95 and 1.27 centimeter (3/8 and 1/2 inch) cell sizes.

TABLE 3. ABLATION MATERIAL DENSITY EVALUATION



Spec No.	Wt.(Gr's)	Density kg/m^3	Density lb/ft^3
1	3.4590	222.7	13.903
2	3.3672	216.3	13.534
3	3.2051	206.7	12.882
4	3.2955	211.4	13.245
5	3.0725	198.5	12.349
6	3.1220	201.8	12.548
7	3.1353	203.4	12.602
8	3.1557	204.6	12.684
9	3.2627	209.8	13.114
10	3.4328	221.1	13.797
11	3.2535	209.2	13.077
12	3.4301	221.1	13.797
13	3.4600	222.7	13.907
14	3.3668	216.3	13.532
15	3.2128	207.2	12.913
16	3.4618	222.7	13.914
17	3.5660	229.6	14.333
18	3.3215	213.0	13.350
19	3.2635	209.8	13.117
20	3.3923	217.9	13.634
21	3.3095	212.4	13.302
22	3.5077	226.0	14.098
23			
24	3.3550	215.5	13.485
25	3.2850	210.8	13.203
26	3.4725	223.3	13.957
27	3.4814	224.3	13.993
28	3.4995	225.6	14.065
29	3.4944	225.6	14.045
30	3.3735	216.6	13.559
31	3.3848	217.4	13.604
32	3.3414	214.7	13.430
33	3.4315	221.1	13.792
34	3.5193	226.8	14.145
35			
36	3.5930	231.4	14.441
37	3.5930	231.4	14.441
38	3.5520	228.6	14.276
39	3.1870	205.5	12.809
40	3.2630	209.8	13.115
41	3.3825	217.2	13.595
42	3.3995	218.4	13.663
43	3.5140	226.5	14.124
44	3.3450	214.9	13.444
45	3.5335	225.8	14.202
46	3.6135	232.6	14.523
47	3.2615	209.6	13.109
48	3.4165	221.0	13.732
49	3.5980	231.6	14.461
50	3.4720	223.3	13.955

The use of the lower cost Kraft paper honeycomb was considered as a means of further reducing heat shield cost. Both sizes were filled without difficulty or damage to the cells by either the press molding or hand fill/autoclave cure methods. The press fill method produced high densities. Incomplete filling was observed in some of the panels adjacent to the cell walls indicating the effects of honeycomb surface roughness.

Nomex honeycomb was evaluated because of its smooth foil surfaces and lower weight. The foil smoothness presents less frictional resistance to filler compaction. However, foil wrinkling and cell distortion have apparently affected the density distribution of the press filled 3/8-2.0 Nomex core. The hand-filled panel was more uniform. The heavier 1/2-3.5 core was filled without difficulty by either method. In this case press filling produced higher densities. All panels were processed without any evidence of crushing the honeycomb.

Flatwise tensile specimens were fabricated and tested to evaluate the honeycomb/face sheet bond strength. The specimens were prepared from 5.08 centimeter (2 inch) thick panels with face sheets bonded to both surfaces. One face sheet was applied by the modified primary bond method described in the following section. The second face sheet was adhered by a heavy, high strength adhesive secondary bond. Each specimen was 4.95 x 4.95 centimeters (1.95 x 1.95) inch) in cross section and bonded to aluminum test blocks (See Figure 2). The tests were performed at room temperature using test procedure MIL-A-25463, Paragraph 4.6.1. The results are shown in Table 4.

TABLE 4

FACE SHEET TO HONEYCOMB
FLATWISE BOND STRENGTH

Specimen No.	Honeycomb Core	Average Strength kN/m^2	(psi)	Mode of Failure
1-1, 1-2	HRP 3/8-GF 12-3.2 Phenolic-Glass	660.05	(95.8)	Prepreg Bond
12-1, 12-2	HMX 1/2-3.5 Nomex	605.4	(87.8)	Core and Prepreg Bond
13-1, 13-2	KP 3/8-3.0/4.0 Kraft Paper	1023.9	(148.5)	Core
14-2	KP 1/2-3.0/4.0 Kraft Paper	954.9	(138.3)	Prepreg Bond

D. Face Sheet

A single ply of 181 style glass cloth impregnated with epoxy resin was substituted for the 3-ply isotropic layup of 120 style glass cloth prepreg used in the previous program. This resulted in fabrication labor savings without any apparent loss of panel strength, rigidity or face sheet-to-honeycomb bond strength.

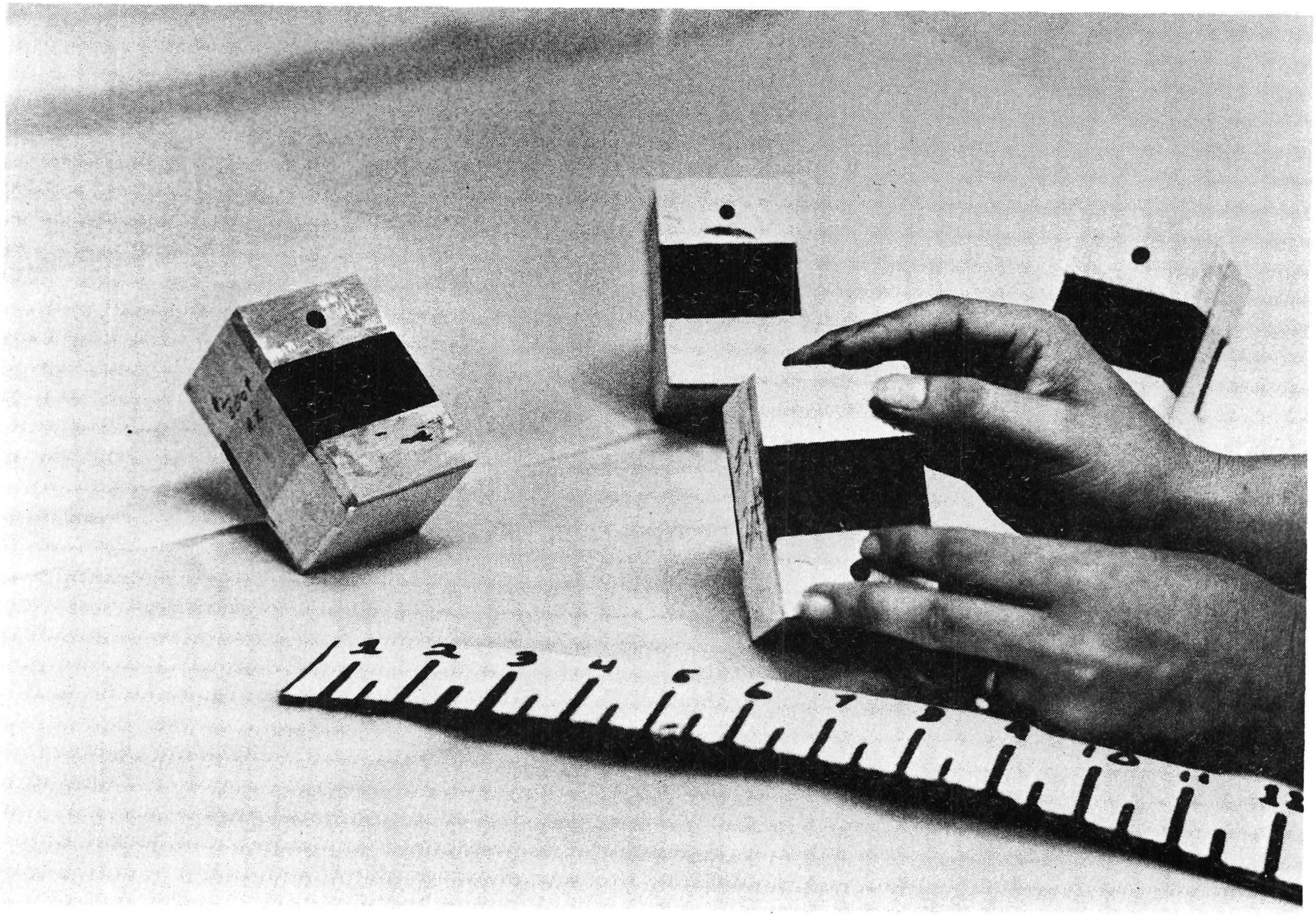


Figure 2. Flatwise Tensile Test Specimens

A study was made of different methods of bonding the face sheet to the honeycomb core. The objectives of this effort were the reduction of fabrication time, improvement of the panel filling process, provision for in-process inspection of the core filler and elimination of the face sheet influence on panel warpage.

Two methods were considered to offer the best potential for realizing these objectives: Secondary bonding and a modified primary bond of the face sheet to the panel.

An evaluation was made of the secondary bonding method. Two small panels of HRP 3/8-GF 12-3.2 honeycomb were filled with the high density formulation of ablation compound and cured in a press. Both surfaces of each panel were scuff sanded and a coating of RTV 1200 primer was applied to one panel. A single ply glass cloth/epoxy prepreg was applied to each face of the panels and cured in an autoclave at a pressure of 413.7 kN/m^2 (60 psi) and a temperature of 433°K (325°F). The flatwise tensile test results are shown in Table 5.

TABLE 5

FLATWISE TENSILE STRENGTH OF SECONDARY BONDED FACE SHEET

Specimen No.	Adhesive Primer	Test Temperature °K	(°F)	Bond Strength kN/m^2	(psi)
1	RTV 1200	294	(70)	689.5	(100)
2	None	294	(70)	599.9	(87)
3	RTV 1200	422	(300)	344.7	(50)
4	None	422	(300)	344.7	(50)

The modified primary bond method consists of filling the honeycomb with precompacted ablation material, brushing the honeycomb bonding surface free of filler material, applying the face sheet prepreg and then curing the complete panel in a single operation. A preliminary evaluation of this method showed that it produced excellent bonds. This method was selected for fabrication of all subscale panels for the material and process evaluation. The results of flatwise tensile bond tests of face sheets applied by the primary bond method are shown in Table 4.

As a result of this process modification, one curing step was eliminated, ease of honeycomb core filling with ablation materials was enhanced and a means was provided for inspecting the core filling prior to bonding the face sheet.

E. Composition of Ablation Material

Three low density compositions were evaluated in the subscale fabrication tasks. The formulations contained 20, 27 and 34% resin and the balance Microballoons.

The panels fabricated from the 20% resin compsosition were the most fragile from the standpoint of edge weakness and surface abrasion resistance. Although only one panel was made from the 34% resin formulation to investigate the filling of 3/8-2.0 Nomex honeycomb, it demonstrated substantially greater toughness and strength than the other materials while being the easiest to mix and compact into the panel. A compromise between these two materials was obtained with the 27% resin formulation which was easier to process and provided greater durability than the 20% resin material used for panel fabrication in the previous contract.

A change was made from the earlier program in the selection of Microballoons. During preliminary evaluation BJO-0931 Microballoons were found easier to mix, contained less moisture and formed a stronger bond with the elastomer than the previously used BJO-0930 grade. As a result all further fabrication work utilized the new material.

F. Panel Curing

An abbreviated cure cycle was selected for the press filling and curing method to conserve press time. After efforts to develop room temperature curing formulations failed, fast curing materials were investigated. However, these have displayed short pot life making them unsuitable for large production quantities.

Therefore, a higher curing temperature and a shorter cure cycle were incorporated into the fabrication process. Two variations were evaluated. Initially a slow rate of heating was used to bring the temperature to 450°K (350°F) in four hours and then the press was cooled to 322°K (120°F). The panels were cured in the press mold which was closed to stops set at the honeycomb core thickness. The initial pressure on the ablation material at this setting was approximately 862 kN/m^2 (125 psi). The panels were postcured at 450°K (350°F) in an oven for one hour. This procedure was later modified by the addition of a two hour dwell time at 378°K (220°F) and a four hour hold at 450°K (350°F). Also the postcure step was eliminated.

The effects of the cure temperature on panel warpage have been minimized by the one step curing method. This is partly due to reduced shrinkage differentials between the face sheet and ablation material. Also the application of a higher molding pressure precompresses the Microballoons, which offsets their larger coefficient of thermal expansion and reduces the thermal contraction differentials of the panel constituents upon cooling.

Six subscale panels were measured for warpage. The 61 x 122 centimeter (24 x 48 inch) control panel was bowed 2.74 millimeters (.108 inch). The maximum bow of the 30 x 61 centimeter (12 x 24 inch) panels was 1.78 millimeters (.070 inch).

G. Panel Trimming

An evaluation was made of the methods of finishing the panel edges. It was concluded that making the panels approximately 1.25 centimeters (1/2 inch) oversize on all edges and then trimming the excess is more cost effective than attempting to fill the panel to the final dimensions. This procedure also eliminates the major source of panel density deficiencies which occur along the edges, apparently caused by corner restriction to material compaction and molding pressure distribution. Further evaluation of panel trimming was made in the fabrication of the full size panels under the second task of this contract.

H. Arc-jet Test Specimens

Three blunt body specimens, 6.35 centimeter (2 1/2 inch) diameter x 1.27 centimeter (1/2 inch) thick (shown in Figure 3) and three flat specimens, 12.70 x 12.70 x 3.81 centimeter (5 x 5 x 1 1/2 inch)(shown in Figure 4) were machined from each subscale panel listed in Table 2. Two specimens of each design from each panel, except Panel No. 1B, were shipped to NASA, Langley Research Center for arc-jet testing to determine the thermal performance of different materials and fabrication processes. A total of forty (40) specimens of each type was shipped.

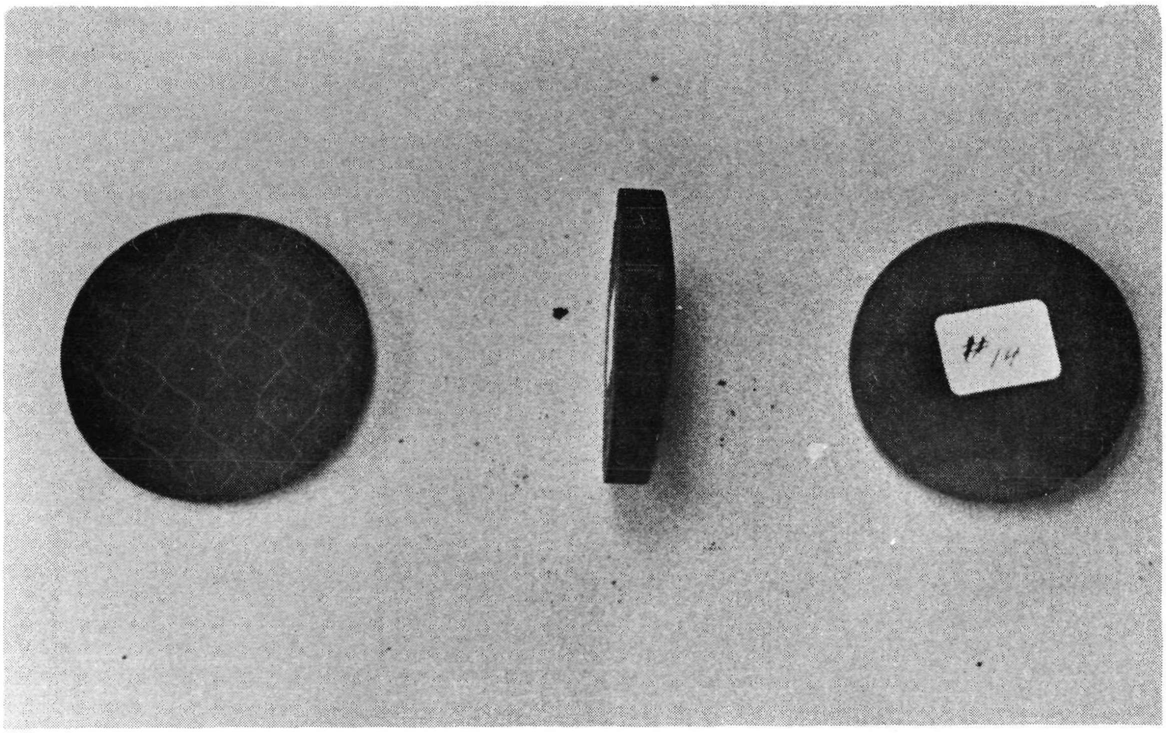


Figure 3. Blunt Body Arc-jet Test Specimen

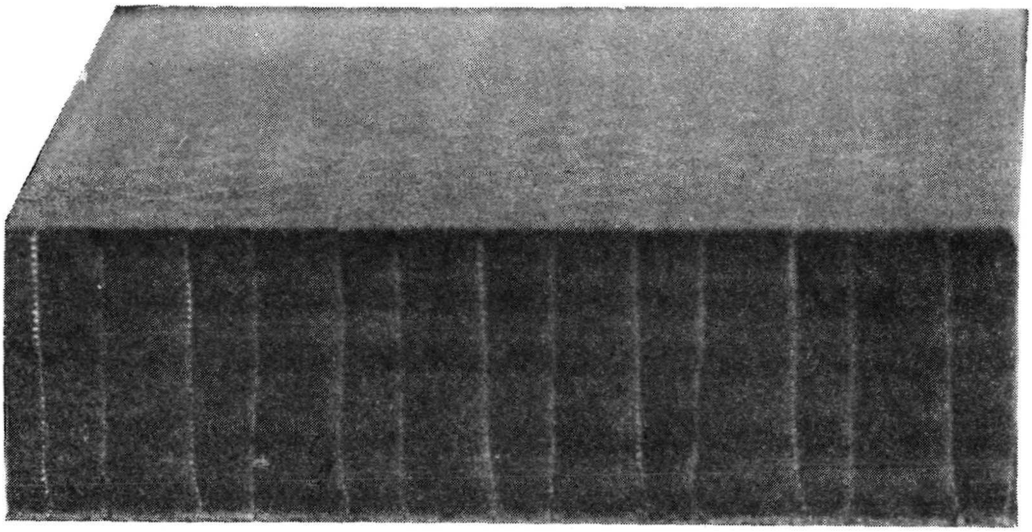


Figure 4. Flat Arc-jet Test Specimen

II. FULL-SIZE PANEL FABRICATION

The purpose of this task was to fabricate full-size 61 x 122 x 5.08 centimeter (24 x 48 x 2 inch) panels to provide data for better cost estimates and to investigate double-curvature panel fabrication problems. The optimum ablation material compositions, processes and panel components determined from the first task were used in the fabrication. The design of the double-curvature panel shown in Figure 5 was submitted and approved by the National Aeronautics and Space Administration technical representative. Fabrication of tooling and the panels was then initiated.

The following heat shield panels were fabricated:

Ten (10) flat, low-density, elastomeric panels
Ten (10) double-curvature, low-density, elastomeric panels
Ten (10) double-curvature, high-density, elastomeric panels

With the approval of the NASA technical representative the panels were fabricated without the holes for panel attachments.

A. Materials

The materials selection was based on the ease of fabrication, quality control, density, mechanical properties and thermal performance of the sub-scale panels. The results of the material and process investigation and the arc-jet tests were reviewed with the NASA technical representative. It was agreed to fabricate the full-size panels using the materials listed in Table 6.

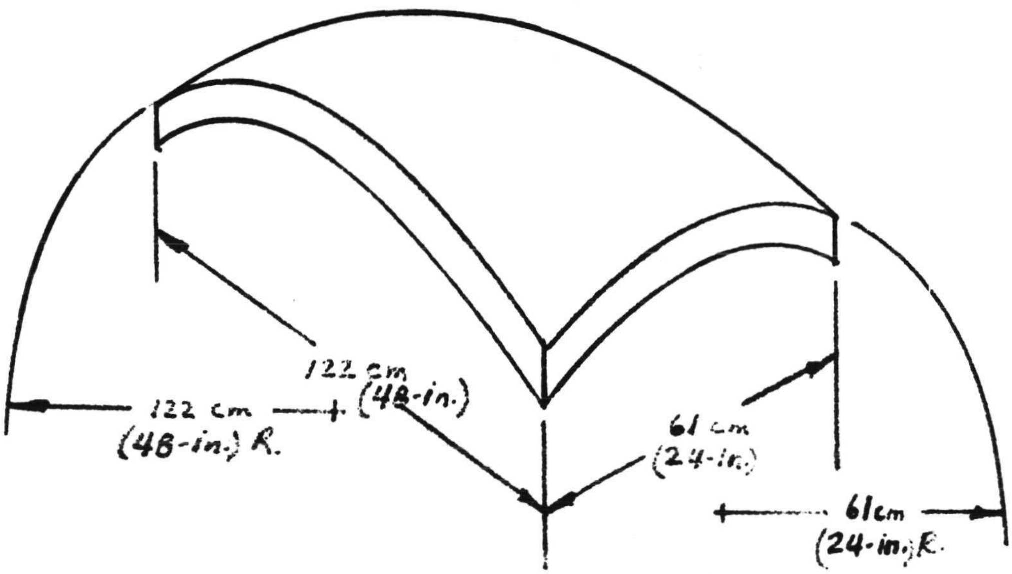


Figure 5. Double-Curvature Ablative Heat Shield Design

TABLE 6

MATERIALS FOR FULL-SIZE PANELS

Material	Designation	Ablation Material Composition		
		Low Density, %		High Density, %
		Flat	Curved	
Honeycomb Core	HRP 3/8-GF 12-3.2 Glass-Phenolic			
Core Primer	SC 1008 Phenolic Resin			
Resin Binder	Sylgard 182 Elastomer	27	25	67
Microballoons	BJO-0931 Phenolic	73	75	33
Face Sheet	SP 5101/1581 Epoxy/ Glass Prepreg			
Core Splicing Adhesive	3M 1357			

Glass-phenolic honeycomb in .95 centimeter (3/8 inch) cell size was chosen because of its superior performance in the arc-jet tests. The Kraft paper and Nomex honeycombs became degraded and tended to shrink excessively which weakened the char layer of the ablation material. The test specimens produced from 1.27 centimeter (1/2 inch) cell size honeycomb also showed evidence of char layer weakening apparently due to the larger unreinforced area of ablative filler. From the standpoint of panel fabrication the selected honeycomb produced panel densities comparable to those of the other materials and cell sizes with equivalent ease of fabrication.

The Sylgard 182 elastomer was selected because of its slightly better fabrication characteristics and long pot life. This elastomer also produced a smoother char surface than the RTV 615 material although there was no discernable difference in thermal performance.

The selection of the type of Microballoons and face sheet material was based on fabrication considerations and mechanical properties evaluated under the first task of this program. The core primer and honeycomb splicing adhesive were of the same type of materials that were used with satisfactory results in the previous contract.

B. Processes

The same fabrication processes were employed for both the flat and curved panels. The selections were based on the results of the subscale panel evaluation.

1. Honeycomb preparation

The honeycomb panel was trimmed with a band saw to the required size and cleaned free of dust and surface contamination by spray rinsing with isoprophyl alcohol. After air drying the honeycomb cells were sprayed with a uniform coating of SC 1008 resin diluted with an equal volume of isoprophyl alcohol.

The panel coating was oven dried at 355°K (180°F) for 60 minutes. This process staged the resin by removing all volatiles and leaving a "tack free" uncured resinous surface.

Where honeycomb splicing was required the splice technique consisted of an interlock nesting of the cell walls which were bonded with 3M 1357 contact adhesive. This technique was developed and evaluated in the previous contract.

2. Mixing ablative materials

Using the technique developed in the previous contract, the ablative materials were mixed in a Hobart Model No. M-802 mixer employing a multifluted mixer blade (see Figure 6). This is a planetary type of mixing machine and operates with a ratio of 2 1/4 revolutions of the mixing blade to one revolution of the planetary spindle. The compounds were mixed at a rate of 25 revolutions per minute of the planetary spindle.

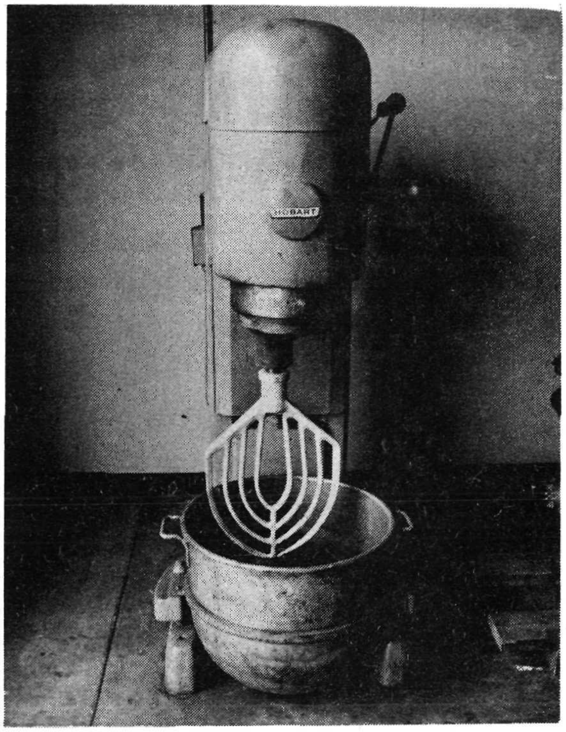


Figure 6. Hobart Planetary Mixer

The resin and hardener were premixed in a paint and resin blender and a measured quantity was poured into the Hobart mixing container. The Microballoons were gradually added while continuously blending the mixture. After the Microballoons were added thorough blending of the materials was performed by mixing for 20 minutes.

3. Panel filling, facing and curing

The press molding method of filling and curing the ablative panels was used. The face sheet was applied and cured by the primary bond method. Both of these methods were evaluated in the subscale panel fabrication task and described in a preceding section of this report.

4. Panel trimming and finishing

The cured panels were trimmed to final size using a band saw. The sawed edges of the ablative panels were hand-sanded smooth.

5. Mold preparation

The mold surfaces were solvent cleaned free of adhered resin and other contaminates. A coat of high temperature mold release was sprayed on all surfaces. A thin sheet of teflon coated fiberglass fabric was placed on the bottom surface of the mold and over the top of the ablative heat shield panel before placing the top plate in position.

C. Tooling

1. Flat panel mold

The flat panel filling and curing mold used in the previous contract was modified by the addition of structural members to the base. A 1/2 inch thick aluminum pressure plate was used for filler compaction and a sheet aluminum cawl plate was used as the top plate during the curing operation (see Figure 7).

2. Curved panel mold

A cast aluminum mold base with a matching top plate was fabricated. Both halves of the mold were heated by thermostatically controlled electric strap heaters. Figure 8 shows the mold installed in a press.

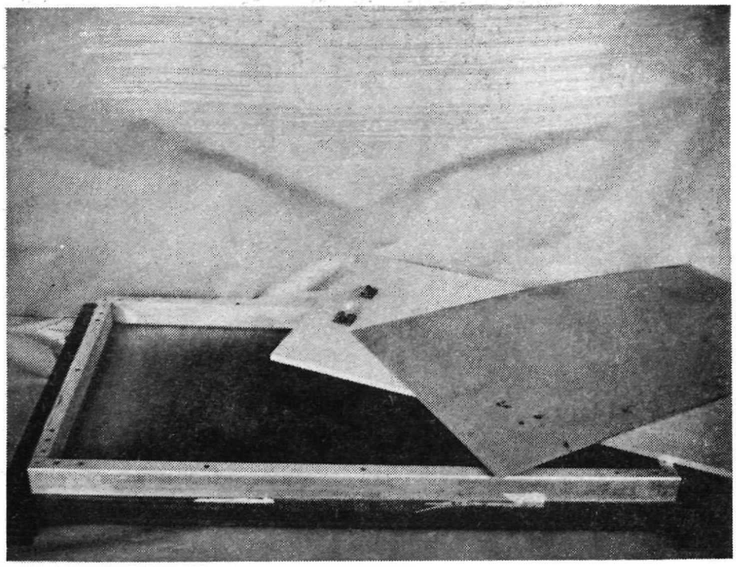


Figure 7. Mold for Flat Panels

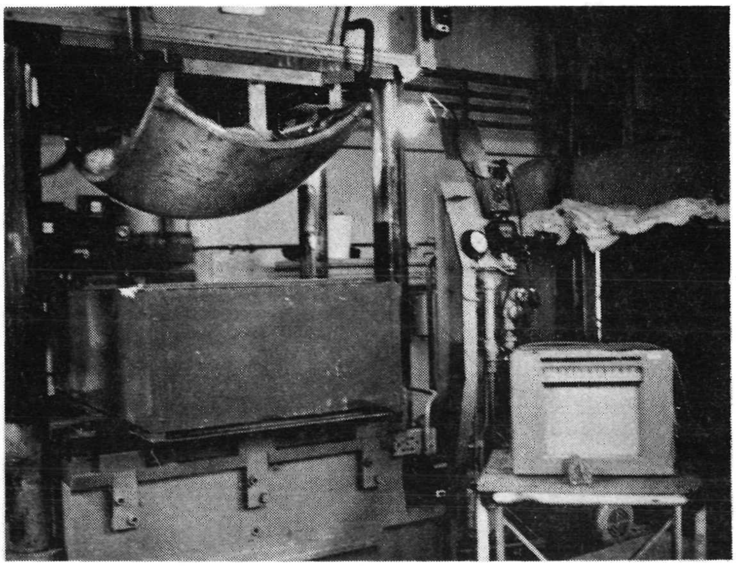


Figure 8. Mold for Double-Curvature Panels

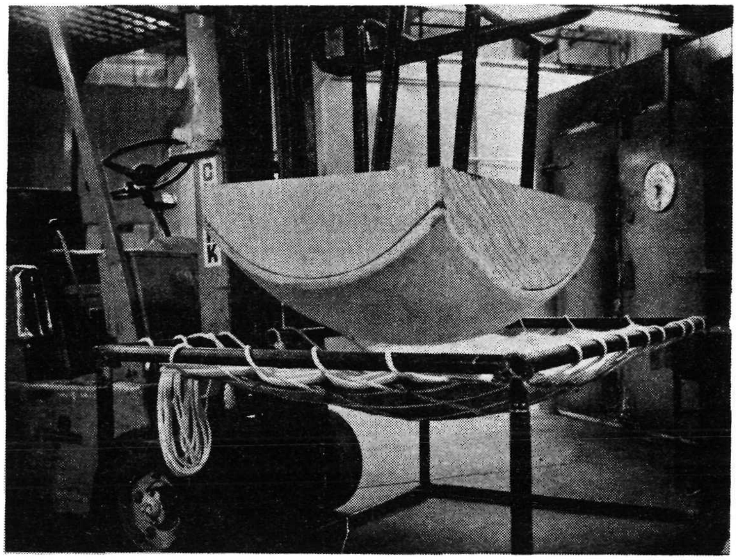


Figure 9. Fixture for Forming Double-Curvature Honeycomb

3. Curved honeycomb forming fixture

The fixture for heat forming the double-curvature honeycomb panel consisted of a steel-frame supported, stretchable canvas base and a weighted plaster punch. The fixture is shown in Figure 9.

4. Curved panel trim fixture

A wood frame fixture consisting of support points for locating the double-curvature panel and a guide for trimming the panel was fabricated for use in the bandsaw trimming operation.

D. Panel Production

The ablative heat shield panels were fabricated according to the operational and sequential outline of the production planning documents included as Appendix A. A cost accounting system was established to record labor and material expenditures itemized by the principal fabrication stops.

1. Flat panel fabrication

Ten panels were fabricated using identical material compositions, processes and components. All panels exhibited uniformly dense ablation material fill (see Figure 10). The face sheets were smooth and completely bonded (see Figure 11).

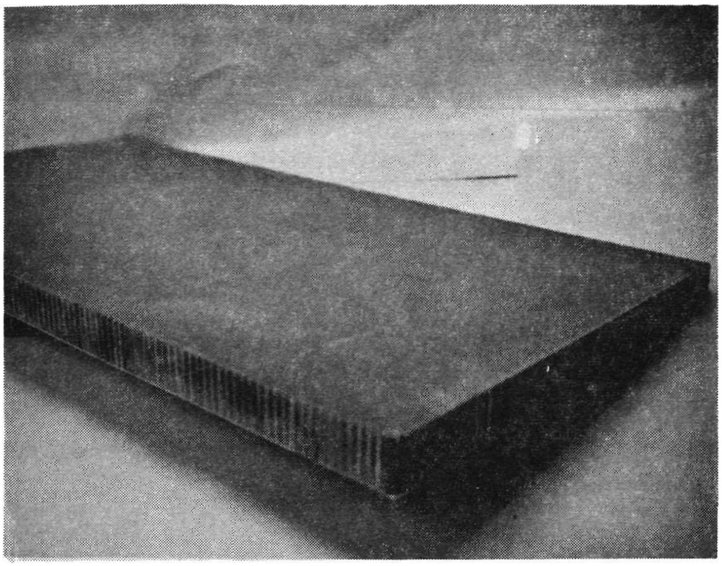


Figure 10. Flat Heat Shield-Ablative Surface

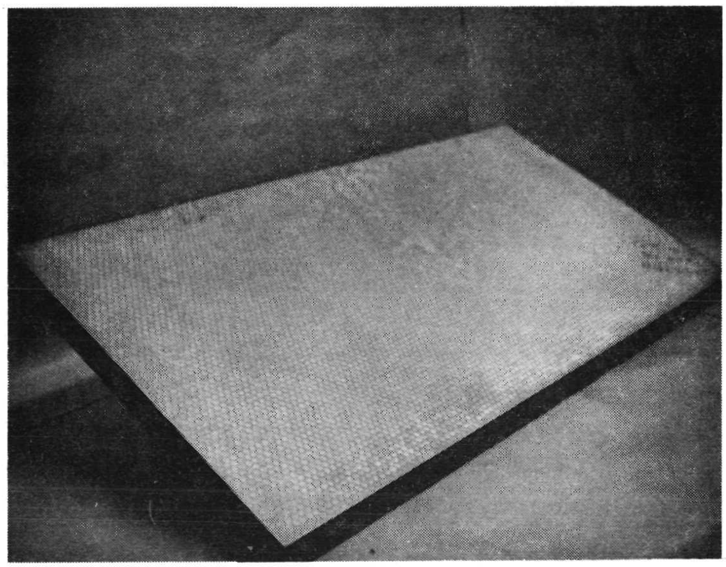


Figure 11. Flat Heat Shield-Face Sheet Surface

Two of these panels were molded to final edge dimensions to further evaluate this technique. With the exception of a few instances where the ablation material adhered to the mold sides and became dislodged from the panel, apparently due to inadequacy of the mold release, the "as molded" edges were uniform in appearance.

The trimmed panels also had uniform edges with the exception of some instances of ablation material loss from partial cells. This was attributed to the bandsawing operation and the associated stresses generated by the sawing action. The face sheet was also considered excessively abrated by the sawing. Future fabrication should use a thin blade, fine tooth, rotary saw to minimize these effects.

All panels were slightly warped. The warpage consisted of simple bowing. The maximum bow was 4.32 millimeter (.170 inch) and the average bow was 2.60 millimeter (.102 inch).

The panels were weighed and dimensionally inspected. The average calculated density was 235 kg/m^3 (14.67 lb/ft^3).

2. Double-curvature panel fabrication

Ten low-density and ten high-density panels were fabricated, each type using identical material compositions, processes and components. This fabrication effort demonstrated that the methods used for the fabrication of flat panels are completely applicable to double-curvature panels. Uniform filling and densities of the ablation material were observed when the proper processing conditions prevailed. Smooth face sheets with strong bonds to the honeycomb core were obtained under proper molding conditions.

However, three areas of tooling related difficulties were encountered. The most serious of these was associated with forming of the honeycomb core to the required curvature. The other problems were caused by a slight mismatch of the mold surfaces and failure of conventional mold releases to effect separation of the molded panels.

The decision was made to form the honeycomb in Fansteel's own facilities due to the long lead time and tooling expense required for vendor supplied curved panels. Figure 12 illustrates the method by which the panels were formed with a high degree of success in the later stages of fabrication. Prior to the introduction of the canvas-base forming tool a rigid plaster mold was used which resulted in extensive honeycomb node separation and panel creasing. These defects were repaired by bonding and splicing techniques. The repaired core, however, was uneven in thickness and the honeycomb cells were excessively distorted. Consequently, filling of the core with ablation material was restricted and the required molding pressure could not be applied to the thinned-out areas. As a result, incompletely filled areas and poor face sheet bonds were obtained in affected panels. Implementing the use of the flexible, canvas-base fixture has virtually eliminated damaged cores.

Figure 12. Double-Curvature Honeycomb Panel Forming

The mold contour mismatch is attributed to the use of the cavity and punch in the "as cast" condition. Although a good quality pattern was used, local imperfections and lack of fidelity of the casting mold caused the surface mismatch. As a result uneven molding pressure was applied to the panels and areas of poor face sheet bonds were produced. This condition was partially corrected by hand grinding the mold contour irregularities.

The use of a conventional spray-on type of mold release did not form a sufficient barrier to adhesion of the ablation material and face sheet to the surfaces of the mold. To eliminate this problem teflon coated glass cloth was incorporated into the process. However, this caused occasional wrinkling of the face sheet.

These problems can be readily eliminated by the use of better tooling for honeycomb forming, similar to that employed by experienced honeycomb manufacturers. Machined molds would provide the necessary accuracy to match the panel buildup and effect uniform molding pressure. The use of a bonded film mold release would preclude the need for loose release materials.

The low density ablation compound consisting of 25% resin and 75% Microballoons differed from that of the flat panels. This formulation was chosen because more difficult conditions were sought for evaluation of the curved panel filling and molding than those which were experienced with the 27% resin/73% Microballoons used for processing the flat panels.

The cured panels were trimmed to size and dressed to remove the ablative surface irregularities. The dressing was accomplished by shaving off high areas with a sharp tool and then finishing to the cell surface by sanding with a medium grit paper. Figures 13 and 14 show the ablative and face sheet sides of a completed panel.

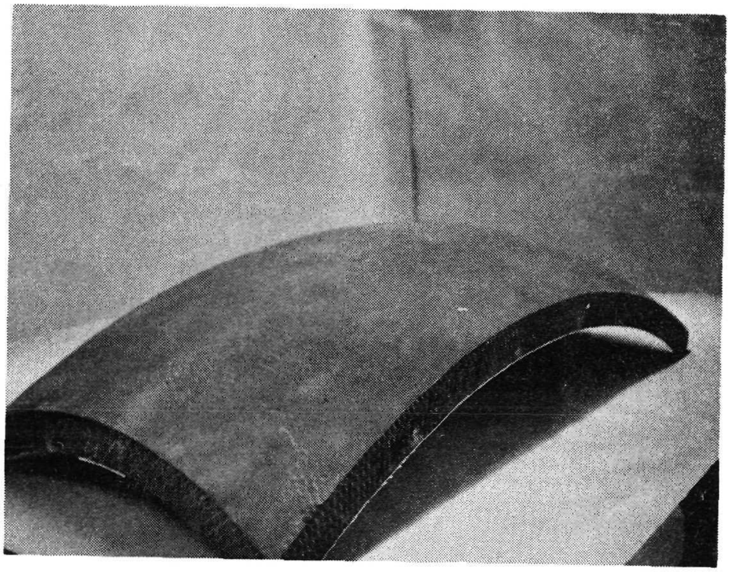


Figure 13. Double-Curvature Heat Shield-
Ablative Surface

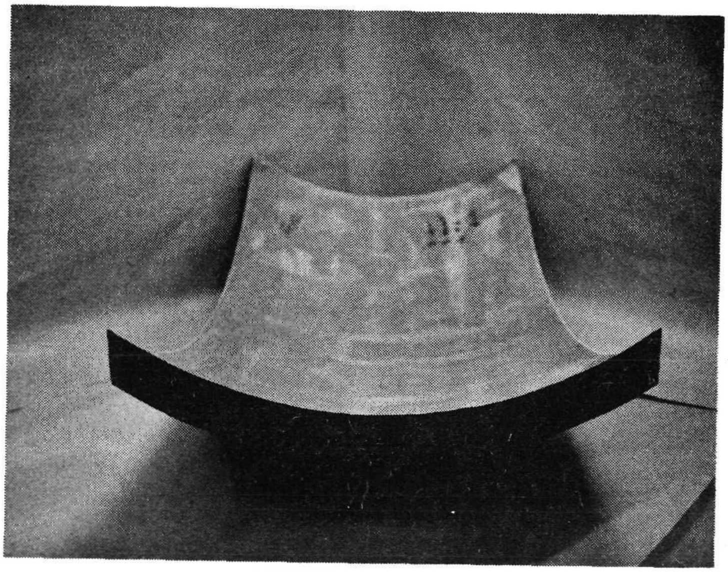


Figure 14. Double-Curvature Heat Shield-
Face Sheet Surface

The panels were weighed and the densities calculated. The average densities were 242 kg/m^3 (15.05 lb/ft^3) for the low-density panels and 478 kg/m^3 (29.80 lb/ft^3) for the high-density configuration.

III. COST ANALYSIS AND ESTIMATES

A. Tooling

The major tools used in the manufacture of the heat shield panels were produced as subcontracted items. A cost breakdown of the tooling is as follows:

Tool	Cost: Flat	Cost: Curved
Double Curvature Mold		$5,971.88
Flat Mold, Original Cost	$ 670.00	
Flat Mold Modifications	560.00	
Honeycomb Forming Fixture		950.00
Curved Panel Trim Fixture		26.00
Total Tooling Cost	$1,230.00	$6,947.88

B. Cost Analysis of Fabricated Heat Shields

Tables 7 and 8 present a detailed breakdown of material and labor costs of the heat shield panels fabricated under this contract.

The costs reflect only the deliverable panels and do not include materials and labor expended for process development, engineering assistance in manufacturing or scrapped panels. The panel costs include the material waste resulting from trimming the prepreg and honeycomb, and from the preparation of the ablation compound and panel primer.

C. Cost Estimates - Heat Shield Panels

The estimated unit costs (excluding profit or fee) for producing various sizes and quantities of heat shield panels and tooling are shown in Tables 9 through 12.

1. Tooling configuration

The estimated tooling costs are based on the same concept as that which was used in the fabrication of the panels on this contract. The tooling also includes template or dies for cutting the face sheet material, fixtures and patterns for cutting the honeycomb panels, and drill jigs for producing the panel attachment hole patterns.

TABLE 7.

COST ANALYSIS - LOW-DENSITY ELASTOMERIC HEAT SHIELD

Material	Quantity	Unit Cost	Cost/Panel Flat	Cost/Panel Curved
SP 5102 15/81 Prepreg	2.58 m. (2.83 yd.)	\$4.70/m. (4.29/yd.)	\$12.12	\$12.12
HRP 3/8-3.2 Honeycomb	.93 m^2 (10.00 $ft.^2$)	96.80/m^2 (9.00/$ft.^2$)	90.00	90.00
Sylgard 182 Silicone Resin with hardener	1.81/2.44 kg. (4.00/5.38 lb.)	12.90/kg. (5.90/lb.)	23.60	31.74
BJO-0931 Microballoons	5.38/8.11 kg. (11.86/17.87 lb)	2.17/kg. (.98/lb.)	11.62	17.51
SC-1008 Phenolic resin	.80 kg. (1.76 lb.)	1.34/kg. (.61/lb.)	1.07	1.07
Shop Aids			1.50	1.50
Total Material Cost			\$139.91	\$153.94

Manufacturing Operation	Labor Hours/Panel Flat	Labor Hours/Panel Curved
Cut honeycomb core	1.25	1.25
Form honeycomb core		1.50
Spray honeycomb core	1.75	.50
Dry honeycomb core	2.00	2.00
Prep. mold	4.25	5.25
Mix filler	2.25	2.50
Apply filler to honeycomb core	2.25	3.25
Cut and lay up prepreg	1.00	1.50
Install thermocouple and close mold	2.00	1.25
Remove from mold	1.50	2.00
Trim and finish	1.25	2.25
Total Labor Hours	19.50	23.25

TABLE 8.

COST ANALYSIS - HIGH-DENSITY ELASTOMERIC HEAT SHIELD DOUBLE-CURVATURE

Material	Quantity	Unit Cost	Cost/Panel Curved
SP 5102 15/81 Prepreg	2.58 m.(2.83 yd.)	\$4.70/m.(4.29/yd.)	\$ 12.12
HRP 3/8-3.2 Honeycomb	.93 m^2(10.00 ft^2)	96.80/m^2(9.00/ft^2)	90.00
Sylgard 182 Silicone resin with hardener	13.30 kg. (29.20 lb.)	12.90/kg. (5.90/lb.)	172.00
BJO-0930 Microballoons	7.22 kg(16.00 lb.)	2.17/kg(.98/lb.)	15.68
SC-1008 Phenolic resin	.80 kg(1.76 lb)	1.34/kg(.61/lb.)	1.07
Shop aids			2.00
Total Material Cost			\$297.87

Manufacturing Operation	Labor Hours/Panel
Cut honeycomb core	1.25
Form honeycomb core	1.50
Spray honeycomb core	.50
Dry honeycomb core	2.00
Prep mold	5.25
Mix filler	3.00
Apply filler to honeycomb core	4.25
Cut and lay up prepreg	1.50
Install thermocouple and close mold	1.25
Remove from mold	2.00
Trim and finish	2.25
Total Labor Hours	24.75

2. Manufacturing approach

The panel fabrication estimates are based on the same manufacturing approach as that which was described for the fabrication of the panels on this contract. The honeycomb panels for the curved panels would be formed by the supplier.

All panels would be manufactured with 1.27 centimeter (1/2 inch) overstock on all edges and trimmed to net dimensions after filling and curing the ablative compound.

The panel thickness for all heat shields is 5.08 centimeter (2 inch).

Estimated material costs are based on current supplier prices. The labor costs are based on experience obtained through manufacture of the full size panels.

Due to the minimum order purchase of some materials and the varying material waste factor depending on the heat shield quantity and size, all of the following estimated costs cannot be accurately related to a standard learning curve. Included in the "Other Costs" is a loss and scrap factor of 15% for quantities of 1 and 10, and 10% for the quantity of 100 panels.

The costs shown for any quantity, heat shield type and configuration are estimated on a stand-alone basis. There is no combining of quantities or heat shield types for purposes of pricing individual items.

D. Cost Estimates - Space Shuttle Flights

The estimated costs (excluding profit or fee) of heat shields for the space shuttle vehicle are presented in Table 12. Each flight is considered to require approximately 740 square meters (8,000 square feet) of ablative heat shield and a total weight of approximately 11,350 kilograms (25,000 pounds) of ablation material. The estimates are based on low density elastomer panels.

Two categories of cost estimates are listed. The first consists of all flat panels, 40% of which are 12.2 x 18.3 meters (4 x 6 feet), 40% are 9.2 x 15.3 meter (3 x 5 feet), and 20% are 6.1 x 12.2 meter (2 x 4 feet). The second category consists of a mix of flat and curved panels of which 50% are flat or nearly flat and 50% are curved including 20% double curvature panels of varying configurations. A loss and scrap factor of 5% was used in the preparation of the estimates.

TABLE 9.

COST ESTIMATE - 6.1 X 12.2 METER (2 X 4 FOOT)
LOW-DENSITY ELASTOMER HEAT SHIELD

	Flat Panel		Double-Curvature Panel	
	Quantity		Quantity	
	10	100	10	100
Material	$ 140.00	$ 115.00	$ 154.00	$ 126.00
Manufacturing Labor	195.00	94.00	232.50	112.00
Other Costs	107.80	55.40	124.60	63.20
Sub-total	$ 442.80	$ 264.40	$ 511.10	$ 301.20
Tooling	125.00	17.50	577.50	87.75
Total Cost Per Panel*	$ 567.80	$ 281.90	$1088.60	$ 388.95

TABLE 10.

COST ESTIMATE - 9.2 X 15.3 METER (3 X 5 FOOT)
LOW-DENSITY ELASTOMERIC HEAT SHIELD

	Flat Panel		
	1	10	100
Material	$ 980.00	$ 247.00	$ 203.00
Manufacturing Labor	520.00	250.00	120.00
Other Costs	483.00	160.00	85.70
Sub-total	$1983.00	$ 657.00	$ 508.70
Tooling	1875.00	187.50	26.25
Total Cost Per Panel*	$3858.00	$ 844.50	$ 434.95

* Excluding profit or fee

TABLE 11.

COST ESTIMATE - 12.2 X 18.3 METER (4 X 6 FOOT)
LOW-DENSITY ELASTOMERIC HEAT SHIELD

	Flat Panel		
	1	10	100
Material	$1000.00	$ 379.00	$ 312.00
Manufacturing Labor	630.00	300.00	146.00
Other Costs	526.00	219.00	121.50
Sub-total	$2156.00	$ 898.00	$ 579.50
Tooling	2500.00	250.00	35.00
Total Cost Per Panel*	$4656.00	$1148.00	$ 614.50

* Excluding profit or fee

TABLE 12.

COST SUMMARY - LOW-DENSITY ELASTOMERIC HEAT SHIELD PANELS

Panel Configuration- 5.08 m (2 in.) thick	Quantity	Unit Cost* Excluding Tooling $\$/m^2$	($\$/ft^2$)	Including Tooling $\$/m^2$	($\$/ft^2$)
6.1 x 12.2m(2 x 4 ft.) Flat	1	$1473.00	($ 136.87)	$3153.00	($ 293.12)
	10	596.00	(55.35)	764.00	(70.97)
	100	356.00	(33.05)	378.50	(35.28)
9.2 x 15.3m(3 x 5 ft.) Flat	1	$1425.00	($ 132.20)	$2765.00	($ 257.20)
	10	471.50	(43.80)	606.00	(56.30)
	100	293.20	(27.25	312.00	(29.00)
12.2 x 18.3m (4 x 6ft.) Flat	1	$ 967.00	($ 89.83)	$2080.00	($ 194.00)
	10	402.00	(37.42)	514.00	(47.83)
	100	259.70	(24.14)	274.50	(25.58)
6.1 x 12.2m (2 x 4 ft.) Double-curvature	1	$1685.00	($ 156.60)	$9410.00	($ 876.00)
	10	688.00	(64.00)	1461.00	(136.08)
	100	404.50	(37.60)	522.80	(48.67)
Flight Vehicle-740m^2 (8,000 ft.^{2}) - All Flat Panels	1	$ 263.80	($ 24.52)	$ 277.80	($ 25.82)
	10	179.50	(16.68)	186.50	(17.33)
	100	139.20	(12.94)	142.68	(13.26)
Flight Vehicle-740m^2 (8,000 ft.^{2}) - Flat and Curved Panels	1	$ 278.10	($ 25.85)	$2185.00	($ 203.70)
	10	187.20	(17.40)	373.60	(35.19)
	100	143.97	(13.38)	163.12	(15.16)

* Excluding profit or fee

IV. CONCLUSIONS AND RECOMMENDATIONS

Two additional elastomeric resins, Sylgard 184 and RTV 615, were evaluated and determined to be nearly as effective as Sylgard 182 which was evaluated in the previous contract. However, the latter still had the best all around fabrication and thermal performance characteristics.

The 1.27 centimeter (1/2 inch) cell size honeycomb was easier to fill and compact with ablation materials but did not perform as well in the arc-jet tests as the .97 centimeter (3/8 inch) cell size core.

Kraft paper and Nomex honeycomb produced strong face sheet bonds but were weak char layer reinforcements in comparison to the glass-phenolic core.

The press molding method for filling and curing the heat shield panels is far superior to the previously used hand troweling and autoclave curing method. The advantage is enhanced by the bonding and curing of the face sheet with the ablation material in a single step procedure. The face sheet to honeycomb bond strength produced by this method is just as effective as other bonding methods. Warpage occurred in all panels but the extent of warp, which consisted of simple bowing, was small and was not affected by the higher cure temperature used in the press molding method.

Fabrication of oversize panels and trimming to final size appeared to be more effective than molding to net dimensions. However, the benefits are small and possibly with high quality tooling the net molding method may be more desirable. Future trimming should be performed with a fine tooth rotary saw instead of the bandsawing method used on this program.

Double-curvature panels can be fabricated by the same methods and with the same materials as the flat panels. The elastomeric material was compacted and the honeycomb was filled without noticeable differences. However, accurately fabricated tooling is required to produce good quality panels and face sheet bonds.

The actual fabrications costs and production cost estimates were revised from the previous study (Contract NAS 1-9947). Small quantity costs are higher while large quantity costs are lower. This is partly due to higher material and labor costs and to the application of more realistic material loss and scrap factors which tend to increase the costs of all quantities. Offsetting these increases is the advantage of the new and more efficient fabrication methods and processes which provide the cost reductions for the large quantities of heat shields.

The large production quantities would create a great demand for press equipment and facilities. To alleviate this condition is is recommended that further attempts be made to reduce the ablation material cure cycle or to incorporate a two-step cure into the manufacturing process, the first consisting of a short press cure and the second consisting of an oven postcure.

APPENDIX

PRODUCTION PLANNING

FANSTEEL/REFLECTIVE LAMINATES

CUSTOMER NASA-Langley

PART NO. -1015

PART NAME Ablative Panel

RELEASE DATE 3/24/72

REVISION DATE

DEPT.	OPERATION	EFF
0	OUTSIDE PROCESSING	
1	HT METAL CUTTING	
2	HT METAL FORMING	
3	HT WELDING	
4	HT PRESS	
5	HT SEWING	
6	HT INSULATION	
7	HT ASSEMBLY	
8	KIT CUTTING	
9	GRIT BLASTING	
10	CLEANING	
11	PRESS	X
12	TAPE WRAPPING	
13	FILAMENT WINDING	
14	PREPREG LAYUP	X
15	WET LAYUP	
16	OVEN	
17	AUTOCLAVE	
18	MACHINE	
19	TRIM	X
20	ASSEMBLY	
21	PAINT	
22	INSPECTION	X
23	Q.C. LAB	
24	Q.C. X-RAY	
25	STORES	
26	SHIPPING	X
27	IDENTIFICATION	
28		
29		
30		

PREPARED BY K L Dixon

ENGRG APPVL Greg Bock

Q.C. APPL L Slatter 3-24-72

PRODUCTION PLANNING

Part Number -1015	Part Name Ablative Panel	Rel. Date 3/24/72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
		MATERIAL AND TOOL LIST			
		H/C Core---HRP 3/8-GF 12-3.2 Glass/phenolic 2.0" thick			Record material RR and lot number
					on the M. O./traveler
		Prepreg---SP5102/1581 epoxy/glass			
		Filler---BJO-0931 phenolic microballoons			
		Filler Resin---Silgard 182 silicone resin			
		Coating Resin---SC-1008 phenolic resin			
		Thinner---RC-2650 isoprophyl alcohol			
		TOOLING			
		T-20639---Layup plate			

PRODUCTION PLANNING

Part Number -1015	Part Name Ablative Panel	Rel. Date 3/24/72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
14	10	The H/C core shall be cut to size and primed in accordance with the following procedure:			
		Sequence #1 Cut the HRP 3/8-GF12-3.2 H/C core into a panel 24" x 48"			
		Sequence #2 Mix the SC-1008 phenolic resin with the RC-2650 isoprophyl alcohol to the following formula:	*		Verify mix
		SC-1008 100 parts by volume			
		RC-2650 100 parts by volume			
		Sequence #3 Clean the H/C core by spray rinsing with RC-2650 isoprophyl alcohol			
		Sequence #4 Spray coat the cells of the H/C core completely with a uniform film of the SC-1008/RC-2650 resin mix			
		Sequence #5 Oven cure the H/C core panel for 60 ± 10 minutes at 180 F + 10	*		Verify coating and curing of the H/C core as specified.
		Sequence #6 Protective wrap the panel until ready for further processing			

PRODUCTION PLANNING

Part Number -1015	Part Name Ablative Panel	Rel. Date 3/24/72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
11	20	The filler material shall be prepared and the panel molded as follows:			
		Sequence #1 Mix the Sylgard 182 silicone resin to the following formula:	*		Verify mix
		Resin 1820 gr's			
		Hardener 182 gr's			
		Sequence #2 Mix the Sylgard 182 resin mix with the BJO-0931 microballoons as follows:	*		Verify mix
		Sylgard 182 2002 gr's			
		BJO-0931 5440 gr's			
		Sequence #3 Clean and apply release agent to the mold overlay with a ply of Armalon release cloth			
		Sequence #4 Install the T-20639 mold in the press			
		Sequence #5 Spread approximately one half of the filler compound uniformly in the mold			
		Sequence #6 Place the top plate on the mold and close press to compact the compound			

PRODUCTION PLANNING

Part Number	Part Name	Rel. Date	Rev. Date
-1015	Ablative Panel	3/24/72	

Dept	Opr		Mfg	Ins	Inspection
11	20	Sequence #7 Spread and compact the remaining filler mix in the mold.			
		Sequence #8 Place the H/C core panel on the filler and close mold until H/C core is pressed completely into the filler			
		Sequence #9 Handfill any unfilled or low density areas and remove excess filler material			
		Sequence #10 Overlay with one ply of SP5102/1581 epoxy prepreg			
		Sequence #11 Overlay the prepreg with a ply of Armalon release cloth and install top plate of mold			
		Sequence #12 Attach a thermocouple to the top and bottom surface of the panel. The cure cycle shall be monitored and controlled by the thermocouples. Identify the core chart with the part number, serial number, S/O number, date and press number.			

PRODUCTION PLANNING

Part Number -1015	Part Name Ablative Panel	Rel. Date 3/24/72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
11	20	Sequence #13 Close the press and heat panel to 220F± 10 and hold at temperature for 2 hours			
		Sequence #14 Raise panel temperature and cure for a minimum of 4 hours at 350 F ± 10	*		Verify cure
		Sequence #15 Allow panel to cure below 125 F prior to release of pressure			
		Sequence #16 Remove panel from mold and clean up. Weigh panel and record weight on the M.O./traveler	*		Verify weighing and recording of weight
19	30	The panel shall be trimmed and finished as follows:			
		Sequence #1 Trim approximately 1/8" to 3/16" from all four edges of the panel	*		Verify trim
				*	Verify recording of material on M.O./traveler
		Sequence #2 Identify part with part number and serial number		*	Perform dimensional inspection and check the flatness of the panel
26	40	Package and ship			

PRODUCTION PLANNING

FANSTEEL/REFLECTIVE LAMINATES

CUSTOMER NASA-LANGLEY

PART NO. -2015

PART NAME DOUBLE CURVATURE-LOW DENSITY ABLATIVE PANEL

RELEASE DATE 4-18-72

REVISION DATE

DEPT.	OPERATION	EFE
0	OUTSIDE PROCESSING	
1	HT METAL CUTTING	
2	HT METAL FORMING	
3	HT WELDING	
4	HT PRESS	
5	HT SEWING	
6	HT INSULATION	
7	HT ASSEMBLY	
8	KIT CUTTING	
9	GRIT BLASTING	
10	CLEANING	
11	PRESS	*
12	TAPE WRAPPING	
13	FILAMENT WINDING	
14	PREPREG LAYUP	
15	WET LAYUP	
16	OVEN	*
17	AUTOCLAVE	
18	MACHINE	
19	TRIM	*
20	ASSEMBLY	
21	PAINT	*
22	INSPECTION	*
23	Q.C. LAB	
24	Q.C. X-RAY	
25	STORES	
26	SHIPPING	*
27	IDENTIFICATION	
28		
29		
30		

PREPARED BY [signature]

ENGRG APPVL Sieg Bong

Q.C. APPL [signature]

PRODUCTION PLANNING

Part Number -2015	Part Name ABLATIVE PANEL			Rel. Date 4-18-72	Rev. Date

Dep't	Opr		Mfg	Ins	Inspection
		MATERIAL AND TOOL LIST			
		H/C CORE - HRP 3/8-GF12-3.2 GLASS/PHENOLIC 2.0" THICK	*		RECORD MATERIAL RECEIVING AND LOT NUMBERS
		PREPREG - SP5102/1581 EPOXY/GLASS			ON M.O./TRAVELER
		FILLER - BJO-0931 PHENOLIC MICROBALLOONS			
		FILLER RESIN - SYLGARD 182 SILICONE RESIN			
		COATING RESIN - SC-1008 PHENOLIC RESIN			
		THINNER - RC 2650 ISOPROPHYL ALCOHOL			
		TOOLING			
		T-20767 - DOUBLE CURVATURE LAYUP MOLD			
		T-20840 - TRIM FIXTURE			
16	10	THE H/C CORE PANEL SHALL BE FORMED IN ACCORDANCE WITH THE FOLLOWING			
		PROCEDURE.			
		SEQ. #1. CUT THE HRP 3/8-GF 12-3.2 H/C CORE INTO A 30" x 54"			
		PANEL.			
		SEQ. #2. PLACE THE PANEL IN A PREHEATED OVEN AT A TEMPERATURE			
		OF 600°F TO 800°F FOR 30 TO 60 SECONDS AS REQUIRED.			
		SEQ. #3. REMOVE FROM THE OVEN AND IMMEDIATELY PLACE IN FORMING TOOL			
		AND FORM TO THE REQUIRED CONFIGURATION.			

PRODUCTION PLANNING

Part Number -2015	Part Name ABLATIVE PANEL	Rel. Date 4-18-72	Rev. Date

Dep't	Opr		Mfg	Ins	Inspection
16	10	SEQ. #4. AFTER COOLING, INSPECT FOR NODE SEPARATION. REPAIR	*		VERIFY FORMING OF H/C CORE AND REPAIRING
		ANY SEPARATED NODES BY BONDING WITH 3M 1357 OR STABOND			OF SEPARATED NODES AS SPECIFIED
		T-190 POLYCHLOROPRENE ADHESIVE.			
21	20	THE FORMED H/C CORE PANEL SHALL BE PRIMED AS FOLLOWS:			
		SEQ. #1. MIX THE SC-1008 PHENOLIC RESIN WITH RC-2650 ISOPROPHYL	*		VERIFY MIX
		ALCOHOL TO THE FOLLOWING FORMULA:			
		SC-1008 - 100 PARTS BY VOLUME			
		RC-2650 - 100 PARTS BY VOLUME			
		SEQ. #2. CLEAN THE H/C CORE PANEL BY SPRAY RINSING WITH RC-2650			
		ISOPHROPHYL ALCOHOL.			
		SEQ. #3. SPRAYCOAT THE CELLS OF THE CORE COMPLETELY WITH A UNIFORM			
		FILM OF THE SC-1008/RC-2650 RESIN MIX.			
		SEQ. #4. OVEN CURE THE H/C CORE PANEL FOR 60 ± 10 MINUTES AT	*		VERIFY COATING AND CURING OF THE H/C
		180°F ± 10°.			CORE AS SPECIFIED.
		SEQ. #5. PROTECTIVE WRAP THE PANEL UNTIL READY FOR FURTHER			
		PROCESSING.			
11	30	THE FILLER MATERIAL SHALL BE PREPARED AND THE PANEL MOLDED AS			
		FOLLOWS:			

PRODUCTION PLANNING

Part Number -2015	Part Name ABLATIVE PANEL	Rel. Date 4-18-72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
11	30	SEQ. #1. MIX THE SYLGARD 182 SILICONE RESIN TO THE FOLLOWING	*		VERIFY MIX
		FORMULA.			
		RESIN - 2450 GRAMS			
		HARDNER - 245 GRAMS			
		SEQ. #2. MIX THE SYLGARD 182 RESIN MIX WITH THE BJO-0931 MICRO-	*		VERIFY MIX
		BALLOONS AS FOLLOWS:			
		SYLGARD 182 - 2695 GRAMS			
		BJO-0931 - 8130 GRAMS			
		SEQ. #3. CLEAN AND APPLY RELEASE AGENT TO THE MOLD. OVERLAY WITH			
		A PLY BIAS CUT ARMALON RELEASE CLOTH.			
		SEQ. #4. INSTALL THE T-20767 MOLD IN THE PRESS.			
		SEQ. #5. SPREAD APPROX. ONE HALF OF THE FILLER COMPOUND UNIFORMLY			
		IN THE MOLD.			
		SEQ. #6. PLACE THE TOP PLATE ON THE MOLD & CLOSE PRESS TO COMPACT			
		THE COMPOUND.			
		SEQ. #7. SPREAD AND COMPACT THE REMAINING FILLER MIX IN THE MOLD.			
		SEQ. #8. PLACE THE H/C CORE PANEL ON THE FILLER AND CLOSE MOLD			
		UNTIL H/C CORE IS PRESSED COMPLETELY INTO THE FILLER.			

PRODUCTION PLANNING

Part Number -2015	Part Name ABLATIVE PANEL	Rel. Date 4-18-72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
11	30	SEQ. #9. HANDFILL ANY UNFILLED OR LOW-DENSITY AREAS AND REMOVE EXCESS FILLER MATERIAL.			
		SEQ.#10. REPAIR ANY NODE SEPARATIONS IN H/C CORE BY OVERLAP APPROX. 1/2" ON EACH SIDE OF THE SEPARATION WITH A PIECE OF 2" THICK HRP 3/8-GF 12-3.2 H/C CORE. THE SPLICE CORE SHALL BE PRECOATED WITH SC 1008/RC 2650 RESIN MIX.			
		SEQ.#11. OVERLAY WITH ONE PLY OF BIAS CUT SP5102/1581 EPOXY PREPREG.			
		SEQ.#12. OVERLAY THE PREPREG WITH A PLY OF BIAS CUT ARMALON RE-LEASE CLOTH AND INSTALL TOP PLATE OF MOLD.			
		SEQ.#13. ATTACH A THERMOCOUPLE TO THE TOP AND BOTTOM SURFACE OF THE PANEL. THE CURE CYCLE SHALL BE MONITORED AND CONTROLLED BY THE THERMOCOUPLES. IDENTIFY THE CURE CHART WITH THE PART NO., SERIAL NO., S/O NO., DATE AND PRESS NO.			
		SEQ.#14. CLOSE THE PRESS AND HEAT PANEL TO 220°F ± 10°.			
		SEQ.#15. CURE FOR A MINIMUM OF (2) HOURS AT 220°F ± 10°.			
		SEQ.#16. RAISE THE PART TEMPERATURE AND CURE FOR A MINIMUM OF OF (4) HOURS AT 350°F ± 10°.	*		VERIFY CURE

PRODUCTION PLANNING

Part Number -2015	Part Name ABLATIVE PANEL	Rel. Date 4-18-72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
11	30	SEQ. #17. ALLOW PANEL TO COOL BELOW 125°F PRIOR TO RELEASE OF			
		PRESSURE.			
		SEQ. #18. REMOVE PANEL FROM MOLD & CLEAN UP. WEIGH PANEL AND	*		VERIFY WEIGHING AND RECORDING OF WEIGHT
		RECORD WEIGHT ON THE M.O./TRAVELER.			
19	40	THE PANEL SHALL BE TRIMMED AS FOLLOWS:			
		SEQ. #1. USING THE T-20840 TRIM FIXTURE, TRIM THE PANEL TO A	*		VERIFY TRIM
		24" x 48" SIZE. SUBMIT 2"x 2"x 2" DENSITY SPEC'S TO Q.C.		*	VERIFY RECORDING OF MATERIAL ON M.O./
					TRAVELER
		SEQ. #2. IDENTIFY PART WITH PART NO. AND SERIAL NO.		*	PERFORM DIMENSIONAL INSPECTION AND CHECK
					THE CONTOUR OF THE PANEL.
				*	PERFORM (3) DENSITY TESTS PER
26	50	PACKAGE AND SHIP			FTMS 406, METHOD 5011
					VERIFY IDENTIFICATION OF CURE CHART

PRODUCTION PLANNING

FANSTEEL/REFLECTIVE LAMINATES

CUSTOMER NASA - LANGLEY

PART NO. -2028

PART NAME DOUBLE CURVATURE-HIGH DENSITY ABLATIVE PANEL

RELEASE DATE 4-20-72

REVISION DATE

DEPT.	OPERATION	EFF
0	OUTSIDE PROCESSING	
1	HT METAL CUTTING	
2	HT METAL FORMING	
3	HT WELDING	
4	HT PRESS	
5	HT SEWING	
6	HT INSULATION	
7	HT ASSEMBLY	
8	KIT CUTTING	
9	GRIT BLASTING	
10	CLEANING	
11	PRESS	*
12	TAPE WRAPPING	
13	FILAMENT WINDING	
14	PREPREG LAYUP	
15	WET LAYUP	
16	OVEN	*
17	AUTOCLAVE	
18	MACHINE	
19	TRIM	*
20	ASSEMBLY	
21	PAINT	*
22	INSPECTION	*
23	Q.C. LAB	
24	Q.C. X-RAY	
25	STORES	
26	SHIPPING	*
27	IDENTIFICATION	
28		
29		
30		

PREPARED BY [illegible]

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PRODUCTION PLANNING

Part Number -2028	Part Name ABLATIVE PANEL	Rel. Date 4-26-72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
		MATERIAL AND TOOL LIST			
		H/C CORE - HRP 3/8-GF12-3.2 GALSS/PHENOLIC 2.0" THICK	*		RECORD MATERIAL RECEIVING AND LOT NUMBERS
		PREPREG - SP5102/1581 EPOXY/GLASS			ON M.O./TRAVELER
		FILLER - BJO-0931 PHENOLIC MICROBALLOONS			
		FILLER RESIN - SYLGARD 182 SILICONE RESIN			
		COATING RESIN - SC-1008 PHENOLIC RESIN			
		THINNER - RC 2650 ISOPROPHYL ALCOHOL			
		TOOLING			
		T-20767 - DOUBLE CURVATURE LAYUP MOLD			
		T-20840 - TRIM FIXTURE			
16	10	THE H/C CORE PANEL SHALL BE FORMED IN ACCORDANCE WITH THE FOLLOWING			
		PROCEDURE.			
		SEQ. #1. CUT THE HRP 3/8-GF 12-3.2 H/C CORE INTO A 30" x 54"			
		PANEL.			
		SEQ. #2. PLACE THE PANEL IN A PREHEATED OVEN AT A TEMPERATURE			
		OF 600°F TO 800°F FOR 30 TO 60 SECONDS/AS REQUIRED.			
		SEQ. #3. REMOVE FROM THE OVEN AND IMMEDIATELY PLACE IN FORMING TOOL	*		VERIFY FORMING OF H/C CORE
		AND FORM TO THE REQUIRED CONFIGURATION.			
21	20	THE FORMED H/C CORE PANEL SHALL BE PRIMED AS FOLLOWS:			

PRODUCTION PLANNING

Part Number -2028	Part Name ABLATIVE PANEL	Rel. Date 4-26-72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
21	20	SEQ. #1. MIX THE SC-1008 PHENOLIC RESIN WITH RC-2650 ISOPROPHYL	*		VERIFY MIX
		ALCOHOL TO THE FOLLOWING FORMULA:			
		SC-1008 - 100 PARTS BY VOLUME			
		RC-2650 - 100 PARTS BY VOLUME			
		SEQ. #2. CLEAN THE H/C CORE PANEL BY SPRAY RINSING WITH RC-2650			
		ISOPROPHYL ALCOHOL.			
		SEQ. #3. SPRAYCOAT THE CELLS OF THE CORE COMPLETELY WITH A UNI-			
		FORM FILM OF THE SC-1008/RC-2650 RESIN MIX.			
		SEQ. #4. OVEN CURE THE H/C CORE PANEL FOR 60 $\pm$ 10 MINUTES AT	*		VERIFY COATING AND CURING OF THE H/C
		$180^\circ F \pm 10^\circ$.			CORE AS SPECIFIED.
		SEQ. #5. PROTECTIVE WRAP THE PANEL UNTIL READY FOR FURTHER			
		PROCESSING.			
11	30	THE FILLER MATERIAL SHALL BE PREPARED AND THE PANEL MOLDED AS			
		FOLLOWS:			
		SEQ. #1. MIX THE SYLGARD 182 SILICONE RESIN TO THE FOLLOWING	*		VERIFY MIX
		FORMULA.			
		RESIN - 13930 GRAMS			
		HARDENER - 1393 GRAMS			

PRODUCTION PLANNING

Part Number	Part Name	Rel. Date	Rev. Date
-2028	ABLATIVE PANEL	4-26-72	

Dept	Opr		Mfg	Ins	Inspection
11	30	SEQ. #2. MIX THE SYLGARD 182 RESIN MIX WITH THE BJO-0931 MICRO-	*		VERIFY MIX
		BALLOONS AS FOLLOWS:			
		SYLGARD 182- 15323 GRAMS			
		BJO-0931 - 7550 GRAMS			
		SEQ. #3. CLEAN AND APPLY RELEASE AGENT TO THE MOLD. OVERLAY WITH			
		A PLY OF BIAS CUT ARMALON RELEASE CLOTH.			
		SEQ. #4. INSTALL THE T-20767 MOLD IN THE PRESS.			
		SEQ. #5. SPREAD APPROX. ONE HALF OF THE FILLER COMPOUND UNIFORMLY			
		IN THE MOLD.			
		SEQ. #6. PLACE THE TOP PLATE ON THE MOLD AND CLOSE PRESS TO COM-			
		PACT THE COMPOUND.			
		SEQ. #7. SPREAD AND COMPACT THE REMAINING FILLER MIX IN THE MOLD.			
		SEQ. #8. PLACE THE H/C CORE PANEL ON THE FILLER AND CLOSE MOLD			
		UNTIL H/C CORE IS PRESSED COMPLETELY INTO THE FILLER.			
		SEQ. #9. HANDFILL ANY UNFILLED OR LOW-DENSITY AREAS AND REMOVE			
		EXCESS FILLER MATERIAL.			
		SEQ. #10. REPAIR ANY NOD SEPARATIONS IN H/C CORE BY OVERLAP SPLICING			
		APPROX. 1/2" ON EACH SIDE OF THE SEPARATION WITH A PIECE			
		OF @" THICK HRP 3/8-GF 12-3.2 H/C CORE. THE SPLICE CORE			

PRODUCTION PLANNING

Part Number -2028	Part Name ABLATIVE PANEL			Rel. Date 4=26-72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
11	30	SHALL BE PRECOATED WITH SC 1008/RC 2650 RESIN MIX.			
		SEQ. #11. OVERLAY WITH ONE PLY OF BIAS CUT SP5102/1581 EPOXY			
		PREPREG.			
		SEQ. #12. OVERLAY THE PREPREG WITH A PLY OF BIAS CUT ARMALON RE-			
		LEASE CLOTH AND INSTALL TOP PLATE OF MOLD.			
		SEQ. #13. ATTACH A THERMOCOUPLE TO THE TOP SURFACE AND IN THE			
		CENTER OF THE PANEL. THE CURE CYCLE SHALL BE MONITORED			
		AND CONTROLLED BY THE THERMOCOUPLES. IDENTIFY THE CURE			
		CHART WITH THE PART NO., SERIAL NO., S/O NO., DATE			
		AND PRESS NO.			
		SEQ. #14. CLOSE THE PRESS AND HEAT PANEL TO 220°F ± 10°.			
		SEQ. #15. CURE FOR A MINIMUM OF (2) HOURS AT 220°F ± 10°.			
		SEQ. #16. RAISE THE PART TEMPERATURE AND CURE FOR A MINIMUM OF	*		VERIFY CURE
		(4) HOURS AT 350°F ± 10°.			
		SEQ. #17. ALLOW PANEL TO COOL BELOW 125°F PRIOR TO RELEASE OF			
		PRESSURE.			
		SEQ. #18. REMOVE PANEL FROM MOLD & CLEAN UP. WEIGH PANEL AND	*		VERIFY WEIGHING AND RECORDING OF WEIGHT
		RECORD WEIGHT ON THE M.O./TRAVELER.			

PRODUCTION PLANNING

Part Number -2028	Part Name ABLATIVE PANEL	Rel. Date 4-26-72	Rev. Date

Dept	Opr		Mfg	Ins	Inspection
19	40	THE PANEL SHALL BE TRIMMED AS FOLLOWS:			
		SEQ. #1. USING THE T-20840 TRIM FIXTURE, TRIM THE PANEL TO A	*		VERIFY TRIM
		24" x 48" SIZE. SUBMIT 2" x 2" x 2" DENSITY SPEC'S TO			VERIFY RECORDING OF MATERIAL ON M.O./
		TO Q.C.			TRAVELER
		SEQ. #2. IDENTIFY PART WITH PART NO. AND SERIAL NO.		*	PERFORM DIMENSIONAL INSPECTION AND CHECK
					THE CONTOUR OF THE PANEL
				*	PERFORM (3) DENSITY TESTS PER FTMS 406,
					METHOD 5011
				*	VERIFY IDENTIFICATION OF PANEL AND
					CURE CHART
26	50	PACKAGE AND SHIP			