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Final Report

LOW-COST ABLATIVE HEAT SHIELDS FOR SPACE SHUTTLES

By Huel H. Chandler

FOR U.S. GOVERNMENT AGENCIES AND THEIR CONTRACTORS ONLY

Prepared under Contract No. NAS1-9946 by
MARTIN MARIETTA CORPORATION
Denver, Colorado 80201

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

This report is submitted in accordance with Part IV-C-8 of the statement of work for Contract NAS1-9946.

The report is the result of a team effort in close cooperation with the NASA Technical Monitor, Mr. Claud Pittman. The Martin Marietta Corporation effort was managed by Mr. Daniel V. Sallis and directed by Mr. Huel H. Chandler.

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Final Report

LOW-COST ABLATIVE HEAT SHIELDS FOR SPACE SHUTTLES

By Huel H. Chandler
Martin Marietta Corporation

SUMMARY

This report presents the results of a study performed under Contract NAS1-9946 to determine the cost of fabricating replaceable ablative heat shield panels. Curved and flat, 2x4-ft panels were fabricated from four ablative compositions using processes developed under this study. Time studies were conducted to estimate the cost of fabricating panels of various configurations and lot sizes, based on one, 10, and 100 flights. Panel costs varied from a high of $296.66 per square foot for a double-contoured, 2x4-ft panel made of 67% silicone resin and 33% phenolic Microballoons to a low of $48.96 per square foot for 4x6-ft panels composed of 90% Microballoons and 10% silicone resin. Table 1 list the cumulative average cost for a space shuttle vehicle using all nylon-phenolic or all elastomeric ablative panels. Figure 1 depicts the cost breakdown determined in this study.

TABLE 1

AVERAGE VEHICLE COST PER SQUARE FOOT FOR ABLATIVE PANELS

No. of flights	Nylon-phenolic	Elastomeric
1	$125.86	$147.07
10	$ 78.26	$ 90.13
100	$ 58.85	70.50

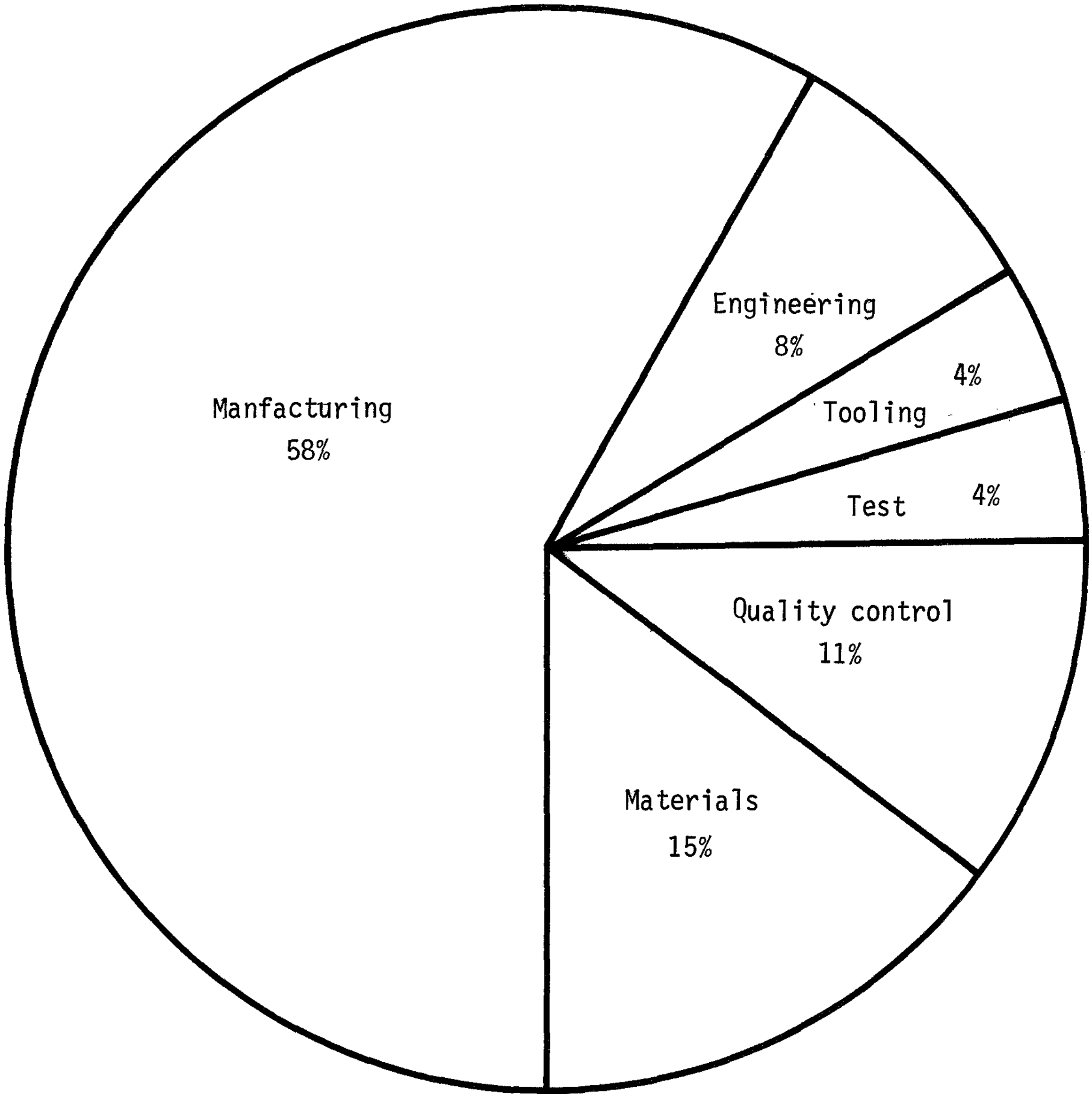

Figure 1.- Cost Breakdown for Low-Density, 2x4-ft, Flat, Elastomeric Ablative Panel

INTRODUCTION

Ablative heat shields provide the most reliable thermal protection system for entry vehicles. Experience has shown that flight safety can be best achieved by using ablative panels, rather than coated refractory-metal TPS panels. Thus, ablative materials will play an important role in the thermal protection system for the Space Shuttle. Present estimates are that they could be used over 10 to 20% of the surface of the orbiter (figs. 2 and 3). But to be economically feasible, the high cost of ablative heat shields must be reduced significantly.

The study described in this report was conducted to establish a relistic cost estimate of ablative panels based on actual fabrication times of typical panels. From these, times and material usage cost estimates were made using normal estimating procedures so that the results would respresent a valid production cost, and in effect, an actual quote. The following ground rules were used to establish the cost estimates.

1. The ablative panel design has already been fixed in a previous development phase, and the same process procedures used to fabricate the test panels will be used for the production panels.
2. Manufacturing processes will be improved during the production run, but no automation will be included.
3. All costs are based on August 1970 labor rates for forward pricing. No economic adjustments are added to reflect future costs.
4. Panel costs are exclusive of travel, computer, overtime, and any contract data requirements.
5. All costs are exclusive of any fee or profit.
6. Only all nylon-phenolic or all elastomeric ablative panels will be used on the vehicle.
7. The production rate used to establish tooling and shipping costs is one vehicle per month.
8. The panel distribution assumed for a typical vehicle is listed in Table 2.

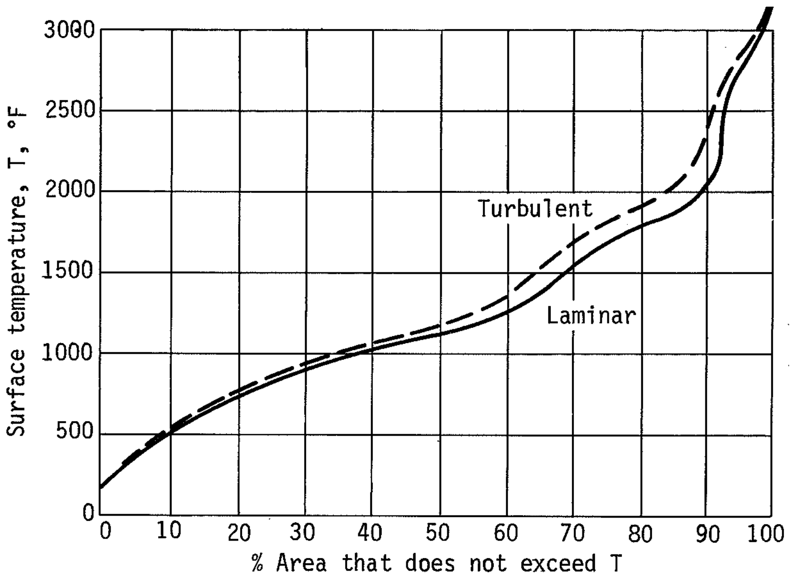

Figure 2.- Maximum Temperature vs Percent Surface Area for Space Shuttle Orbiter

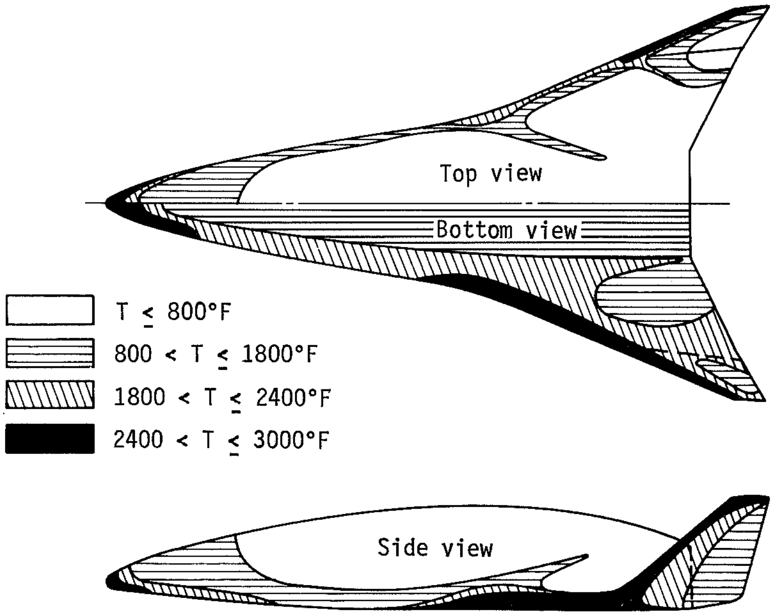

Figure 3.- Isotherm Profiles for Space Shuttle Orbiter

TABLE 2

PANEL DISTRIBUTION IN SQUARE FEET PER VEHICLE

Panel configuration	High-density ablator	Low-density ablator
2x4-ft flat	800	800
3x5-ft flat	600	600
4x6-ft flat	600	600
2x4-ft single-curved	1000	1000
2x4-ft double-curved*	2000	-

*Requires over-expanded honeycomb core.

The author wishes to acknowledge the assistance of Mr. Claud Pittman of NASA-Langley, who served as Technical Monitor for this study effort.

PROCESS STUDIES

Given the four ablative compositions, it was necessary to develop a process for each in order to fabricate the large 2x4-ft panels. Each composition had a different bulk density and packing ability, as well as unique mixing requirements. Because only limited experience with processing the particular compositions existed when the contract was awarded, a series of process investigations was conducted before fabricating the panels to assure that:

1) The densities of the fabricated panels would fall within specified ranges;
2) The panels would be free of major defects;
3) The panels would be structurally sound.

In addition, we wanted the fabrication technique to be as simple as possible and require minimum tooling, yet not affect the quality of the final panels. Ease of fabrication denotes operations with the following characteristics:

1) Not requiring high skill levels;
2) Not requiring time-consuming steps;
3) Suitable for volume production;
4) Readily controllable;
5) Lending themselves to automation.

Face Sheet-to-Core Bonding

The bond strength between the face sheet and the core was required to be 1 psi or greater at 300°F. Primary bonding of the face sheet to the core was thought to be the most desirable method because the face sheets could be cured while being bonded. This would save the time required to bond the face sheets and eliminate the cost of expensive adhesive films. The face sheet selected was two plies of 181 glass cloth impregnated with Hexcel F-161 high-temperature epoxy resin. The procedure for bonding and curing the face sheets to the core is detailed in Appendix A and summarized below:

1) Blow core clean with clean dry nitrogen;
2) Vapor-degrease core;
3) Place face sheet prepreg on tooling;
4) Place core over prepreg;
5) Vacuum-bag assembly (see fig. 4);
6) Cure for 1 hr at 325°F under full vacuum pressure;
7) Allow panel to cool to 150°F or less before removing vacuum pressure.

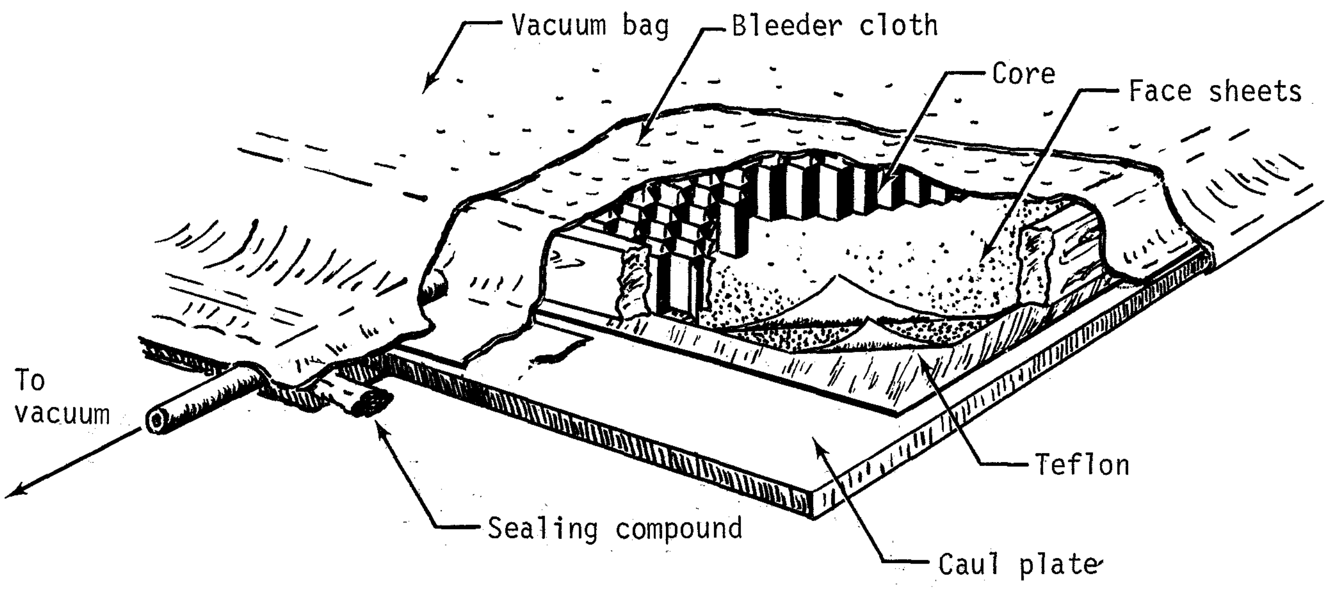

Figure 4.- Core Bonding Setup

The core selected for the panels was Hexcel's 3/8-in. hexagonal glass phenolic honeycomb (HRP 3/8-FG11), weighing 2.2 lb/ft^3. The core, as made, has a maximum width of 18 in. and had to be spliced to achieve the 24 in. required.* Preformed core (24-in. radius) was used for the curved panels because it is less expensive than the overexpanded core or flex-core that could have been used.

Bond strength.- Five tensile test specimens were prepared to verify the strength requirement. The core with face sheets was bonded to 1.85-in.-square aluminum blocks with Epon 934 adhesive. The specimens were soaked for 1 hr at 300°F and pulled at 300°F with a hand scale. None of the specimens failed at a tensile strength lower than 6.2 psi, the limit of the test equipment. Figure 5 depicts a test specimen.

Face-sheet cell venting.- It was necessary to drill a hole through the face sheet opening at each core cell to allow air to be vented when the ablator was packed into the cells. Because the face sheets were translucent it was easy to locate the center of each cell through the face sheet. We chose carbide drills instead of hardened steel drills to save time in sharpening and replacing the drills and to minimize delamination at the periphery of the hole. The drilling was done quickest by using a hand-held small Dumore grinder (fig. 6), rather than a drill press or conventional hand-held drill motor. The hole diameter was selected to be 0.0625 in. Drill breakage was experienced, accompanied by an enlarged and frayed hole. An analysis revealed that the drill was catching on the fiberglass and screwing through the face sheet rather than cutting cleanly through it. A relief groove was machined into the drill to correct the problem, but the groove weakened the drill and resulted in breakage. This was solved by shortening the drill to only a one-fourth twist length, which prevented the sudden pulling down of the drill. Figure 7 depicts the drill that was used.

Open-weave face sheet.- The porous face sheet that was investigated (fig. 8) consisted of two plies of an open-weave (17 mesh) fiberglass cloth. These plies were impregnated with phenolic varnish and primary-bonded to the core. The open weave eliminated the need for drilling holes through the face sheet. The even distribution of these numerous small holes over the cell should lower the possibility of entrapping air next to the face sheet when filling the ablator. If face sheet porosity is undesirable, the openings can be sealed off with a spray coating after curing the panels. Although the open-weave face sheet has distinct advantages over the standard glass fabric laminate, it was not incorporated into large panel fabrication because the development occurred too late in the program to procure the necessary materials.

An analysis of the time study conducted for 2x4-ft elastomeric panels resulted in cell venting representing 34% of the panel subassembly labor times, and 12% of the total direct manufacturing labor. Since 58% of the total cost of this panel is manufacturing cost (fig. 1), the impact would be approximately 7% of the total cost. Applying this factor to the production cost of

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*In actual flight panels, this splice would have to be eliminated.

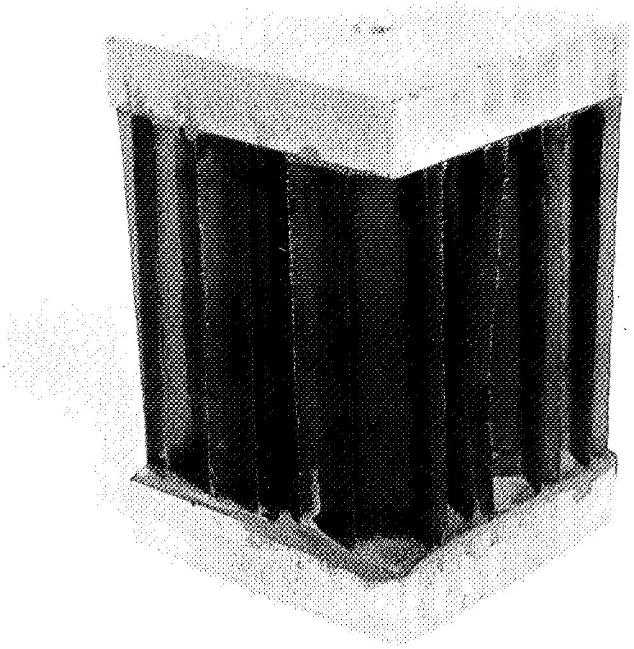


Figure 5.- Tensile Test Specimen

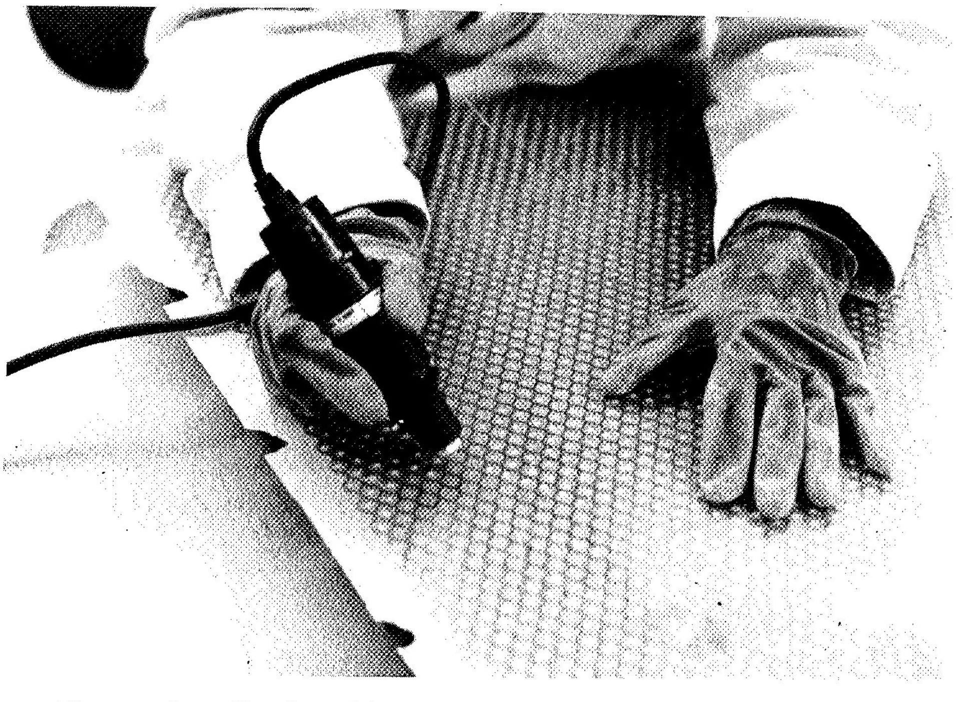


Figure 6.- Hand-Held Grinder Used for Cell Venting

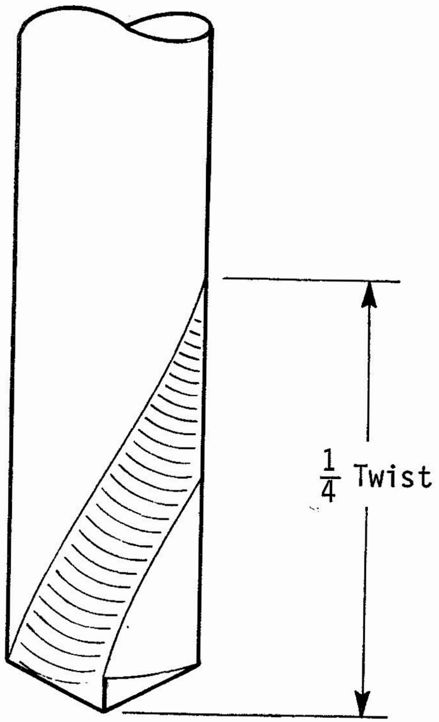


Figure 7.- Modified $\frac{1}{16}$-in. Carbide Drill

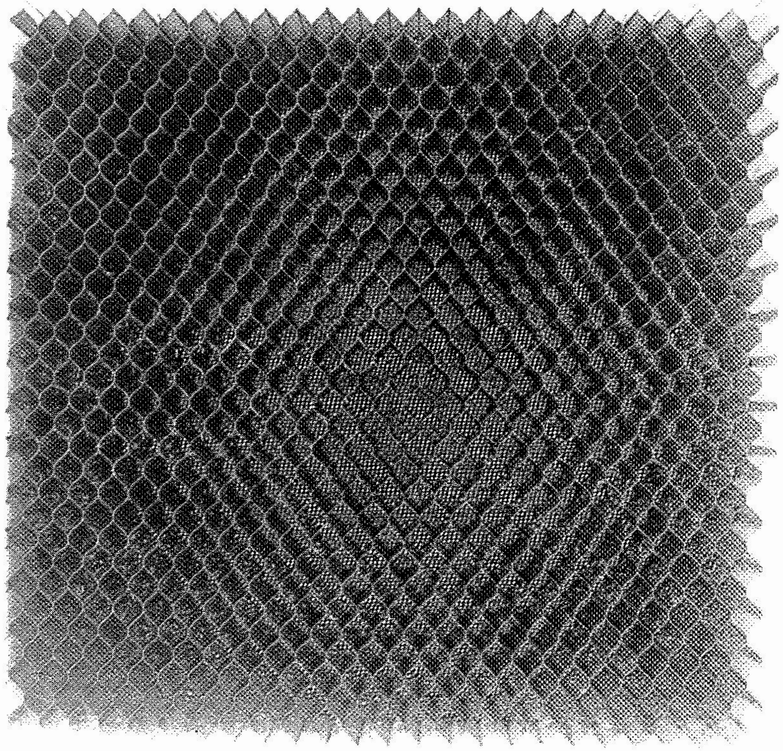


Figure 8.- Porous Face Sheet

100 flights, the average cost per square foot of a 4x6-ft panel would appear to be reduced from $48.96 to $45.53. However, this is not necessarily true because learning curves used for 100 flights assume charges such as these for cost reduction.

Filler Pretreatment

Three of the ablator compositions contain phenolic Microballoons. Microballoon drying will be discussed in this general section, rather than for each specific composition. Phenolic Microballoons contain moisture that should be removed before coating with the matrix resins. Because the Microballoons will oxidize if heated in air at a relatively low temperature, they should be dried under a vacuum to quicken the drying time and prevent combustion. The drying was accomplished by heating the material in a Patterson Kelly twin-shell solids processor (fig. 9) for 2 hr at 180°F under full vacuum while rotating the processor. The vacuum in the processor also allowed the Microballoons to fall freely and broke up any conglomerates that were present. Thus, Microballoon screening is not necessary. In order to prevent Microballoon breakage the intensifier bar was not used during the drying operation.

Core Filling

Filling the core with ablative materials is the most time-consuming operation and the one most likely to cause defects in the ablator. The filling method selected must assure a uniform density over the entire panel. It must be economical and be least subject to operator errors. The conventional cell filling method is to gun each cell individually. However, this method was not investigated because it is considered too time-consuming for high production. Instead, the final method selected for all but the high-density elastomeric composition was to pneumatically tamp and vibrate the ablative materials into the core under vacuum. The high-density elastomeric mix, which has good flow characteristics, was squeegeed into the cells under vacuum plus a light pneumatic tamp, and vibrated to ensure uniform density.

The introduction of the ablative material into the core depends on the viscosity of the material and/or the coefficient of friction between the ablator and the cell walls. If the material does not flow readily, then the force applied to the ablator transfers to the cell walls rather than forcing the ablator material down into the core (see fig. 10). As the height of the core increases and the cell size decreases, the problem of core filling increases. The difficulty manifests itself in the form of voids near the face sheet and/or a density variation from the front to the back of the panel. Perhaps the most economical method is to lay the ablative material in a tray and press the core into the mixture; this was the first method studied. The two low-density mixtures were used for the experiment because they were expected to be the most difficult to load. Four different pressure-application methods were tried. The results were as follows:

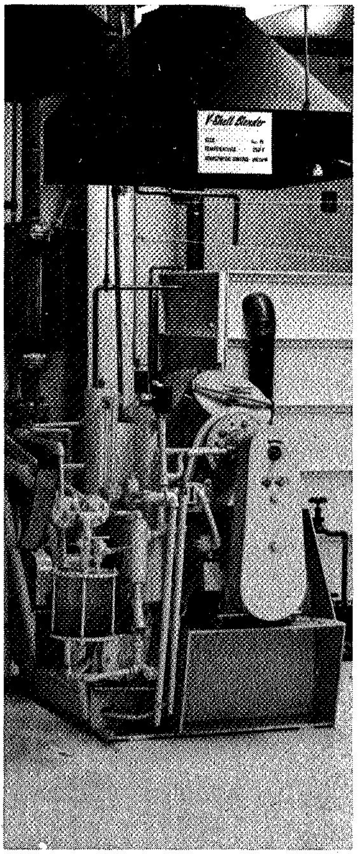


Figure 9.- Patterson Kelly Twin-Shell Blender

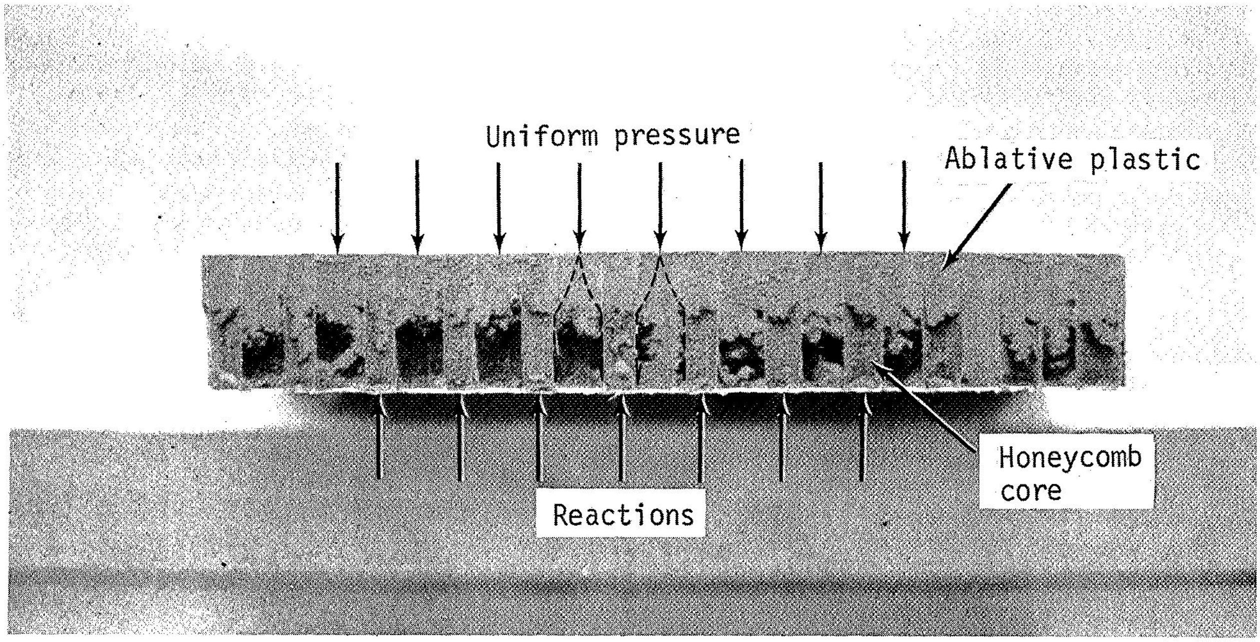


Figure 10.- Force Transfer along Cell Walls

Method	Remarks
Hand pressure	The core moved unevenly into the ablator.
Vacuum bag	The core did not move down far enough. The vacuum bag pressed against the exposed core and wedged between the core and around the edges of the tray. The bag had to be rearranged after the panel had travelled only a short distance into the material.
Autoclave	After applying the vacuum bag, the panel was placed in an autoclave and the pressure was increased in increments of 1 atmosphere up to 5 atmospheres. The panel was inspected after each pressure increase. At 5 atmospheres, the panels bottomed out at the required depth, but when cured, the density varied from the front face to the back face.
Hydraulic press	Pressing the panel into the ablative mixture required pressures in excess of 100 psi to bottom out. This method would only be satisfactory for flat panels.

The vacuum bag and autoclave methods were repeated with the core cell walls wet-coated. A silicone resin was used for the elastomeric ablators and phenolic varnish was used for the nylon-phenolic composition. It was thought that the wet coat would tend to lubricate the cell walls; however, no noticeable difference was noted between a wet coated and dry core.

The next loading procedure attempted, pressing the ablator into the core, was more or less the reverse of the above methods. A picture frame holder was placed over the core; a sliding trap door was placed next to the core. Ablative material was evenly distributed in the container over the core. Then the trap door was removed and the material was hand-pressed into the core. Next, the panel was vacuum-bagged and the pressure in the autoclave was raised to 5 atmospheres.

Loading by this method was generally satisfactory for the low-density elastomeric system; however, the nylon-phenolic system had a spring-back and the loading method produced density variations and voids. The autoclave pressurization or isostatic loading appeared to be too sensitive to unknown variables to guarantee a sound panel.

While the material was being pressed into the core, it appeared that it had to be vibrated to overcome the tendency of the material to "hangup" on the cell walls, so a pneumatic vibrator tool was tried (see fig. 11). The panels were loosely filled with ablative material, and ½ in. of excess material was loaded on top. Then the vacuum was applied and the material was tamped into the cells. Additional material was added and tamped until full packing was achieved. The density of the cured panels was within the required range and did not vary from front to back.

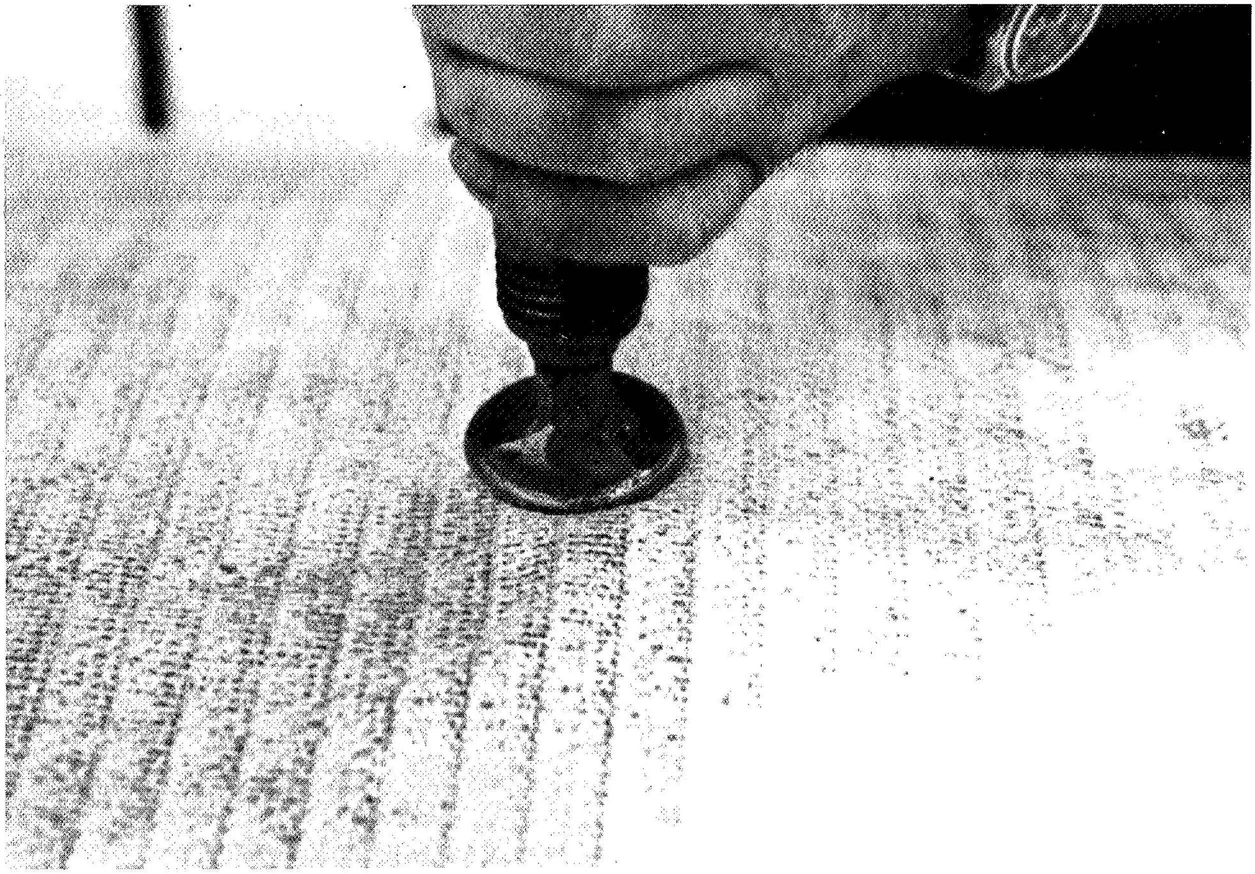


Figure 11.- Pneumatic Vibrator Used to Pack Ablative Material

Panels were also made from the two high-density compositions. The elastomeric material had sufficient flow and could be squeegeed into the cells. However, vibration tamping was incorporated to ensure uniform density through the panel. The nylon-phenolic mixture, loaded using vibration packing, was cured to the desired density, and there was no apparent soft material near the face sheet. Vibration packing was selected as the method for the large panels. The next step would have been to use vibration while pressure was applied isostaticly in the autoclave. However, high tooling costs prevented the investigation of this method at this time.

Tooling

The desired tooling concept was one that was simple, yet produced the desired quality of product. Simple aluminum caul sheets were designed with a wooden picture frame edge member to prevent the core from being distorted by side pressures during the vacuum-bagging. The inside dimensions of the frame during the face sheet bonding were set at 24x48 in. After all the face sheets were bonded, the frame was opened 1 in. to allow for an excess of 0.5 in. of ablator material around the periphery. The excess material, which was later trimmed, gave a better edge to the panels. Teflon film was used on all contact surfaces to prevent the panels from adhering to the tooling. The vacuum bag was made from nylon film and sealed with vacuum tape. Coarse fiberglass tooling cloth was used as the bleeder cloth. To prevent deflection of the frame under pressure, the frame was pinned to the aluminum caul sheets. The six required attachment holes were precut into the core and plugged with 0.75-in.-diameter Teflon rods that were tapped for a No. 6 machine screw. Pilot holes were drilled through the face sheet at the six attachment hole locations. These pilot holes, which were later enlarged to specified drawing dimensions, were also used to locate the edge of the panel. The caul sheet was spot-faced to accept the screw heads. Figure 12 depicts the tooling that was used.

Panel Machining

While the panels were curing, it was necessary to have an excess of ablative material over the core to accommodate shrinkage. The excess was later machined off to the core level or panel thickness. Experience has shown that the material can most easily be removed by cutting rather than grinding. Planing the excessive material was demonstrated to be satisfactory. Final finishing of the panel was done by hand sanding. All edges were cut with a carbide-tipped band saw. Because the attachment holes were premolded into the panels, no hole machining was required. The plugs were rough cut from small 6x6-in. cured panels and ground to dimensions in a lathe with a tool post grinder. Turning was not used since a standard lathe cutting tool tends to tear the core and break the bond between the core and the ablator.

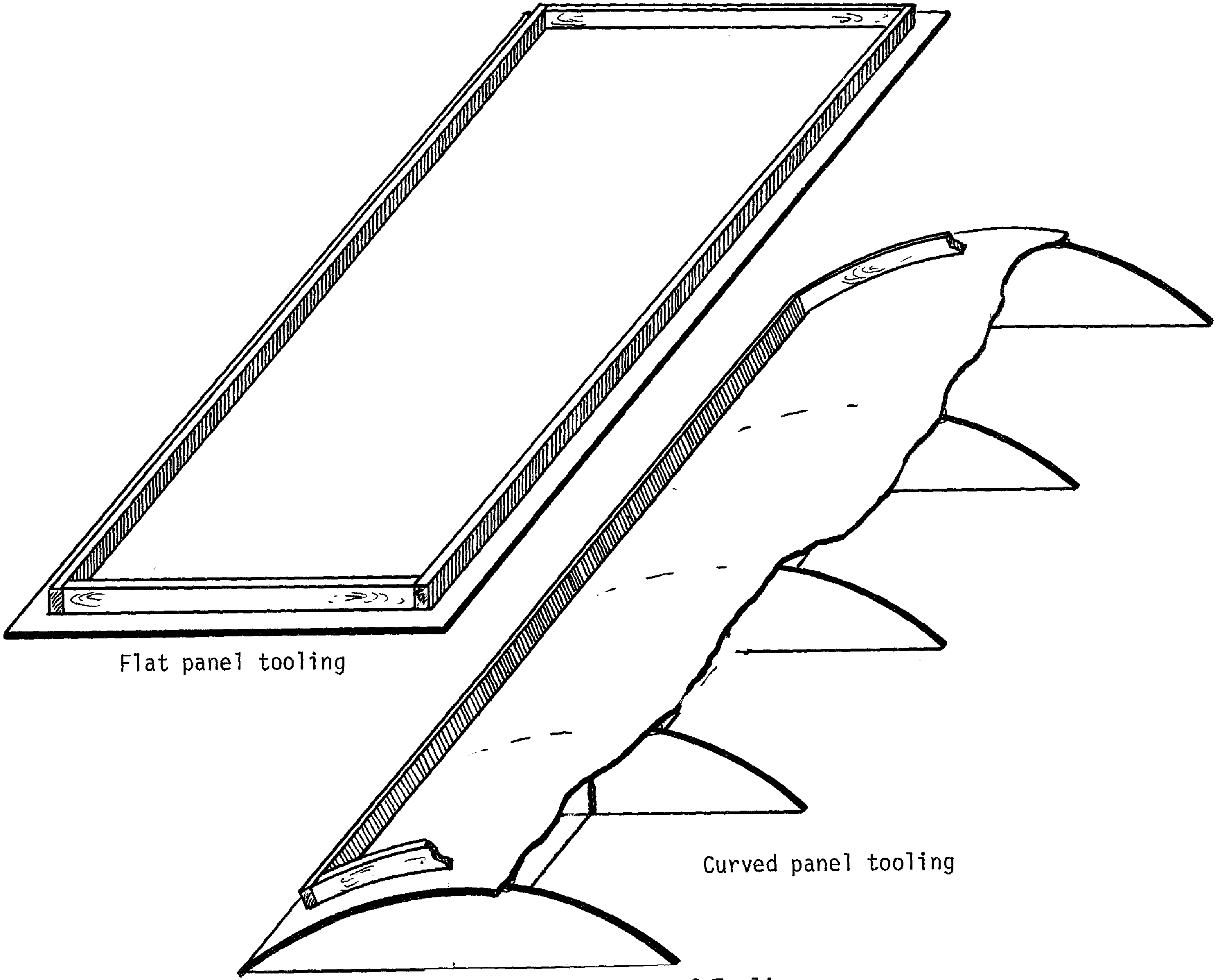


Figure 12.- Types of Tooling

Mixing Development

Each of the four compositions required a different mixing procedure to produce a compactable mixture. Each composition is discussed below.

<u>90% phenolic Microballoons, 10% elastomeric resin</u>.- This composition was investigated first since it was expected to give the most difficulty in evenly distributing the resin as a coating over the Microballoons. The first mixing procedure that was tried was to mix the resin and catalyst in a Hobart 2-quart planetary mixer and then slowly add the catalyzed resin to the Microballoons, which were in the mixer. An examination revealed that the resin was not evenly dispersed after 30 minutes of mixing. Next, a series of mixtures was prepared with heptane-thinned resin. (We worked with pure "paint grade" heptane because impure heptane retards the curing of silicone resins.) The heptane-to-resin ratios were 1 to 1, 2 to 1, and 3 to 1, by weight. After mixing, the material was spread out on trays and dried under vacuum to flash off the heptane. The resin in all mixtures appeared to be well dispersed.

When making large batches of the ablative material, a 1:1 heptane-to-resin ratio was used to reduce the mixing time and aid the dispersion of the resin. The ablator was mixed in the Ross planetary mixer (fig. 13), which has the capability of mixing under a vacuum. The mixing procedure was as follows. The resin, catalyst, and heptane were first blended in a Hobart mixer. Then half of this blended material was added to the dried Microballoons, and these ingredients were mixed for 5 minutes in the Ross mixer. Then the rest of the resin was added and mixed for an additional 25 minutes. Next, the mixing chamber was evacuated to full vacuum, and the mixing was continued for 1 hr to flash off the heptane. (If the chamber is heated, this flashoff time can be reduced.) This mixture was used to make 12x12x2-in. verification panels.

Prior to filling, the core was spray coated with DC-1200 primer. After curing the primer for 2 hr at room temperature, catalyzed Sylgard 181 resin thinned with 15% heptane was sprayed into the core using a pressurized spray gun. The pot pressure and atomizing pressure were 20 psi and 40 psi, respectively. An excess wet coat was applied. The coating was allowed to drain down into the core for 30 minutes, and then the panel was inverted and the excess resin was allowed to drain off for 2 hr. After the panel was filled, cured, and machined to size, the density measured 13.9 lb/ft^3, close to that of the first experimental panels.

<u>15% nylon powder, 15% phenolic powder, 70% phenolic Microballoons</u>.- This mixture was the most difficult to prepare and produced the most fragile composition. The material, as mixed dry, has a bulk density of about 7 lb/ft^3 and must be compressed to about twice this value in the core. When pressure is released after compression, the material springs back because there is no inherent tack to hold it together. In addition, the repose angle is shallow, which makes it difficult to keep the material near the edges in place during the loading operation. However, the most serious drawback is that, under vacuum bag pressure, the material becomes a hard, low-density substance with no discernable flowability. This makes it difficult to compact the material into the cells. In addition, the material shrinks away from the cell walls while curing.

Figure 13.- Ross Planetary Mixer

To overcome as many of these difficulties as possible, flowability and tack had to be incorporated. The loading mixture was blended under vacuum in the twin-shell blender for 30 minutes to eliminate the segregation caused by density differences between the Microballoons and the phenolic and nylon resins. The dry mix was transferred to a planetary mixer, where methyl alcohol was added. It was necessary to retain the alcohol in the mixture during loading and flash it off under vacuum while the panels were being cured. Mixtures using methyl alcohol in amounts by weight of 5% to 100% of the weight of Microballoons were prepared to establish the required amount of alcohol. Thirty percent was the minimum amount of alcohol that would yield a mixture of the desired flowability and tack.

Before the alcohol addition procedure, various attempts were made to solvate the phenolic resin and add it in a liquid state to give additional tack to the mix. However, the dry phenolic powder specified was in the "B" stage and could not be completely dissolved. The resultant ablator was not uniform; however, cured samples exhibited superior strength over the other "dry" mixes. The phenolic resin that dissolved in alcohol was decanted off and used in a test panel. The mixing, packing, and appearance of this panel was superior to that of previous panels.

In another procedure, phenolic varnish (SC-1008), diluted with 50% methyl alcohol, was used in place of the dry phenolic resin in the system. Again, a stronger and more uniform panel could be made. However, replacing the phenolic powder with a phenolic varnish was considered to be a deviation from the specified materials, and this procedure was not pursued further.

SC-1008 phenolic varnish sprayed into the core was used for the wet coat for all panels.

50% nylon, 50% phenolic.- The powder packed well in the dry state and no solvent was required. The only problem encountered with this material was that both the phenolic and nylon powders contained conglomerates that manifested themselves in the cured ablator as large, dark phenolic blotches and white blotches of nylon. Running the intensifier bar in the twin-shell blender while mixing the powders reduced the number and size of the conglomerates, but was insufficient to produce a homogeneous mixture. As a result, the materials were screened through a 40-mesh sieve before being mixed in the twin-shell blender. The core was then wet-coated in the same manner as the 15% nylon, 15% phenolic, 70% Microballoon composition.

67% elastomeric resin, 33% phenolic Microballoons.- This mixture exhibited good flow and had enough resin to be mixed directly. The resin and catalyst were first mixed in a Hobart planetary mixer; then the phenolic Microballoons were slowly added. The mixture heated up rapidly during mixing due to its high viscosity; however, reducing the mix time still gave a homogeneous mixture. This material could easily be squeegeed and vibrated into the cells under vacuum and could be compacted in one bagging operation. The composition showed a tendency to be up to 3 lb/ft^3 over the required density. However, when care was taken to apply minimum local down-pressure during the squeegee and vibration operation, and when a bleeder cloth was used to absorb the excess resin that was expelled from the panel during curing, the density of the panels was kept within the required range. Bleeder cloths are necessary to distribute the vacuum over the large panels and also to vent the air from the cells through the face sheet. The final composition of the panel is estimated to contain between 60 and 65% resin after cure. With the high resin content of the mixture, a wet coating of the core was not considered necessary, and only DC-1200 primer was applied to promote bonding. Warpage was noted in the experimental panel.

Because of the warpage, a test was made to determine if the resin could be cured and set at a lower temperature than the specified 250°F. The preliminary curing temperature was set at 175°F, which is about the lowest temperature that will polymerize the resin. Because phenolic Microballoons tend to inhibit the cure of the Sylgard resin, the curing temperature must be higher than that for the resin without a filler. The panel was cured at 175°F for 24 hr and then held at 250°F for the required 16 hr. Panel warpage was reduced. This cure cycle was then established for the full-scale panels, and fabrication was begun.

A warpage of 1.5 in. due to residual strains occurred in the long direction of the flat panels, but the curved panel did not exhibit this severe warpage. In order to establish whether the problem was due to differential thermal expansion or shrinkage during the curing process, the panel was reheated to 250°F. It regained its shape, which indicated the problem was due to differential thermal expansion. The ablator was set at the elevated temperature. On cooling, it contracted more than the face sheet, resulting in a concave warpage. Because the core ribbon direction was across the panel, the core was stiffer in this direction and deflection was restricted. The warpage of the curved panel, which was fabricated first, was low because the panel's moment of inertia was much greater than that of the flat panel due to the effective thickness increase resulting from curvature.

An attempt was made to determine if the warped panel could be straightened. The panel was heated to 250°F and loaded so that a reverse 0.5-in. bow would be introduced into the panel during cooldown. After about 5 minutes the panel failed at the midpoint.

In order to produce a flat panel, three approaches were analyzed. The first was to mold the panel on curved tooling so that on cooling down the panel would be in a relatively flat state. However, the locked-in residual strains would still be present. The second approach was to continue the lower 175°F cure for a much longer time and not incorporate the 250°F cure. However, some warpage would probably be present. The third approach, and the one used for the flat panel, was to fill the core with ablative material without using a face sheet, cure and machine the panel to the required thickness, and bond a cured face sheet to it. This procedure produced a flat, strain-free panel.

Bonding the face sheet to the filled cure was accomplished with A-4000 silicone contact adhesive. To assure even bonding pressure, the bond was allowed to set with the panel vacuum-bagged. The bond strength was found to be greater than 1 psi at 300°F. Visual inspection of the face sheet bond is ruled out by this technique: it will be necessary to rely on ultrasonic inspection on production panels.

Figures 14 through 18 are flow diagrams of the processes developed to fabricate the ablative panels.

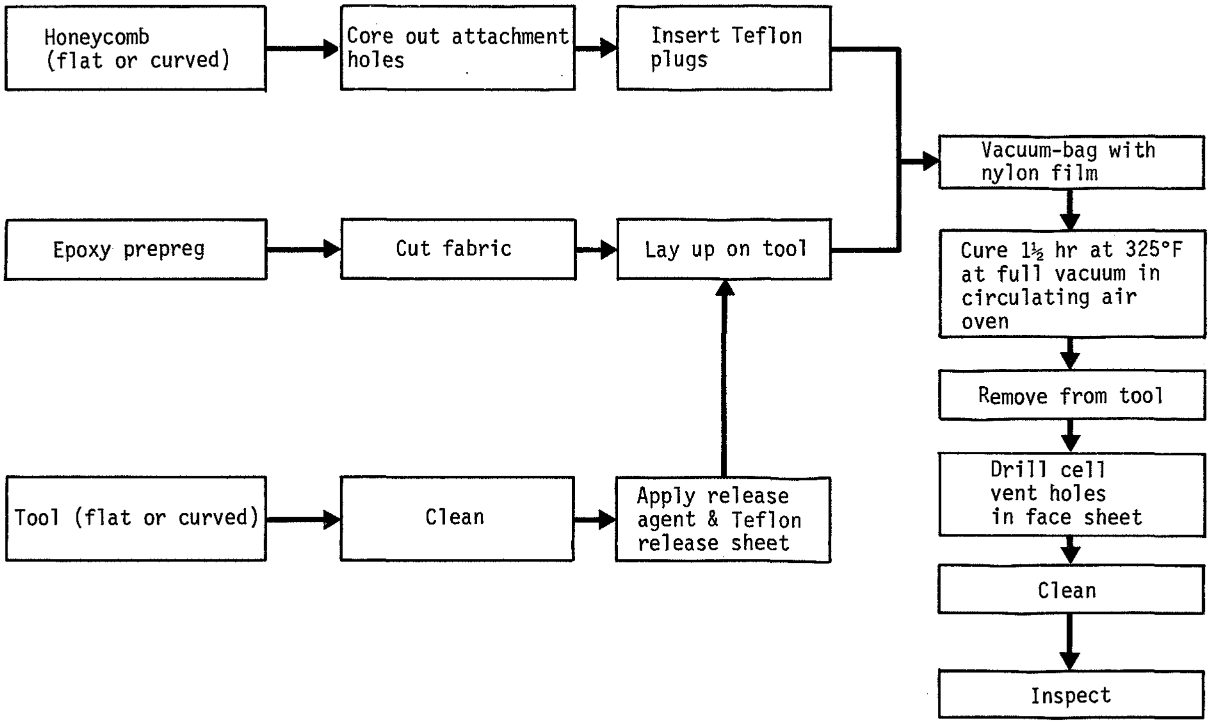


Figure 14.- Core/Face Sheet Assembly

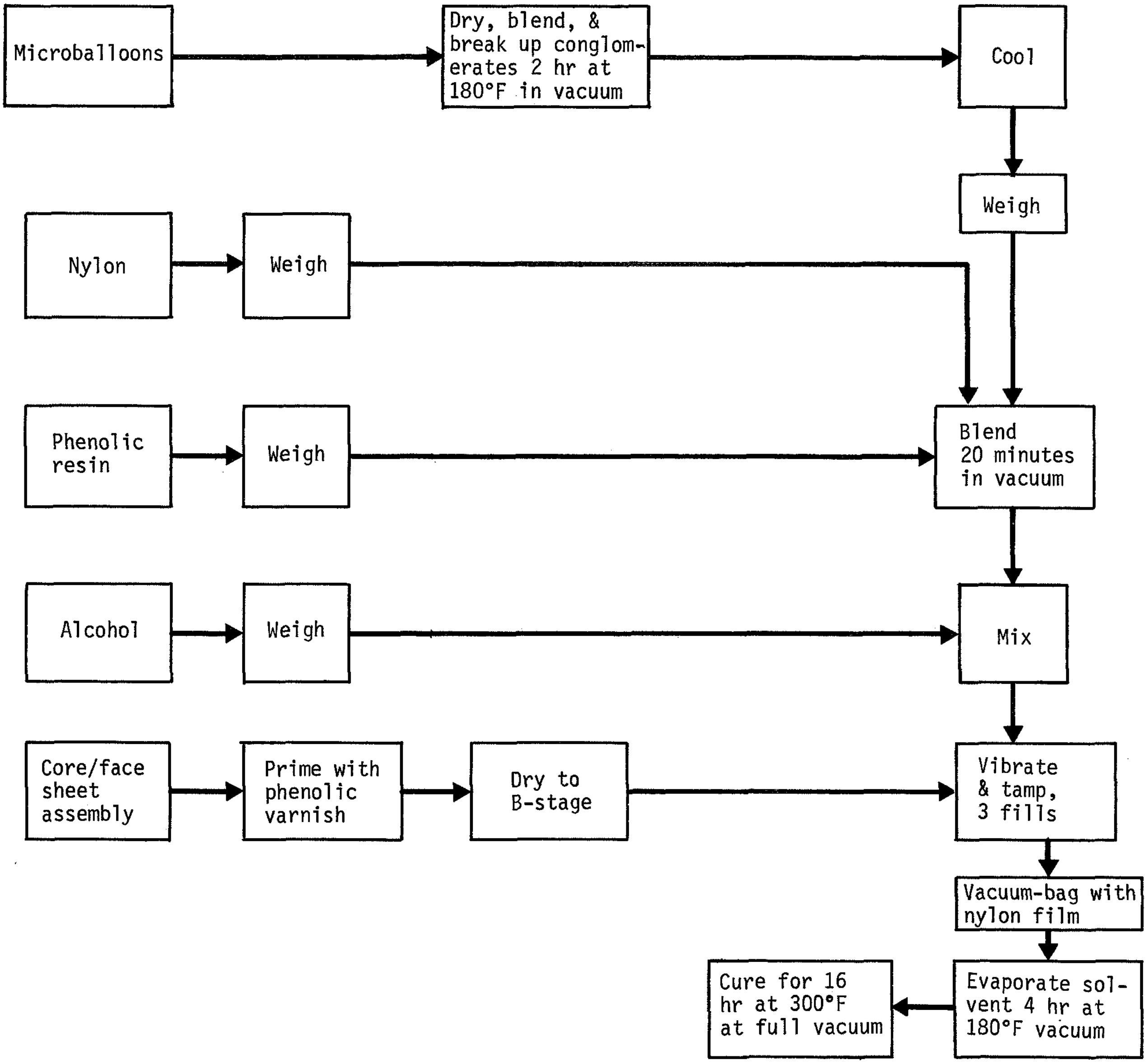


Figure 15.- Process Flow Diagram - 15% Nylon/15% Phenolic Resin/70% Microballoons (13 to 17 lb/ft^3)

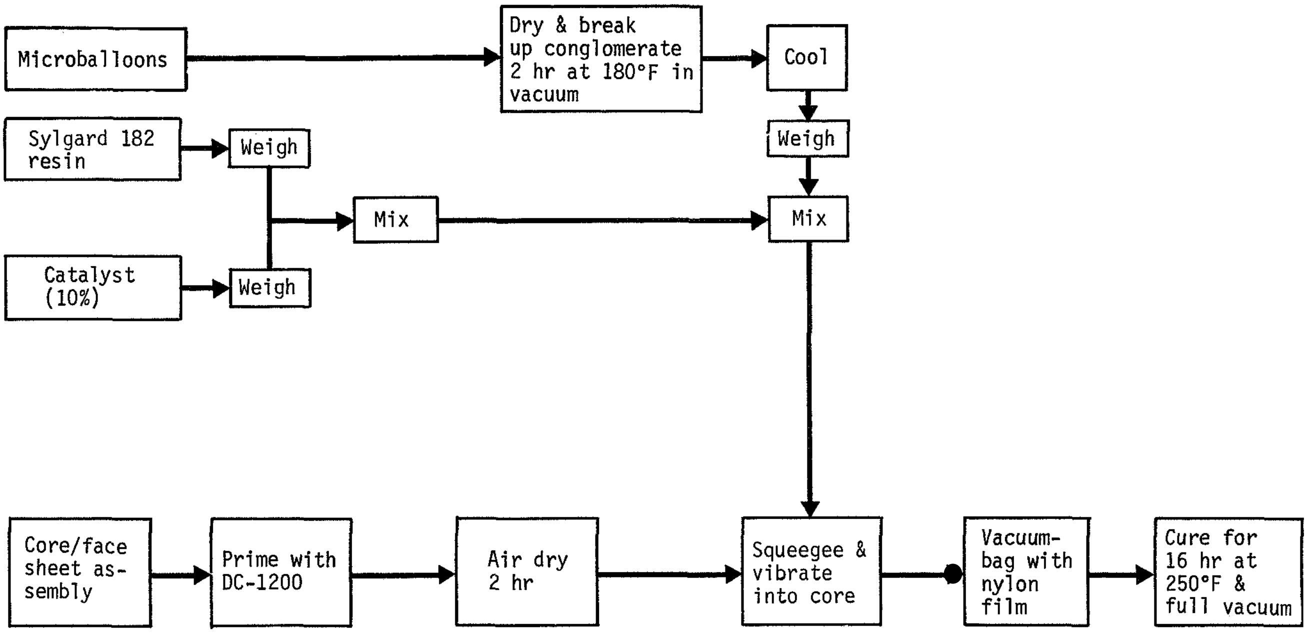


Figure 16.- Process Flow Diagram - 67% Sylgard 182/33% Microballoons (25 to 30 lb/ft^3)

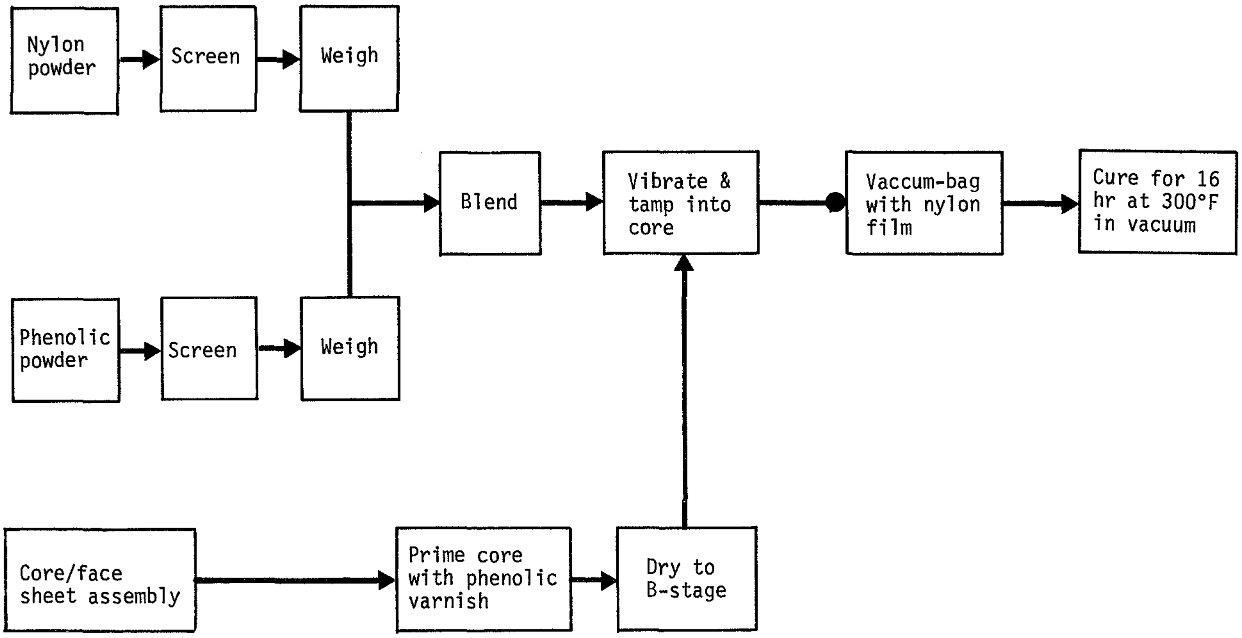


Figure 17.- Process Flow Diagram - 50% Nylon/50% Phenolic (25 to 30 lb/ft^3)

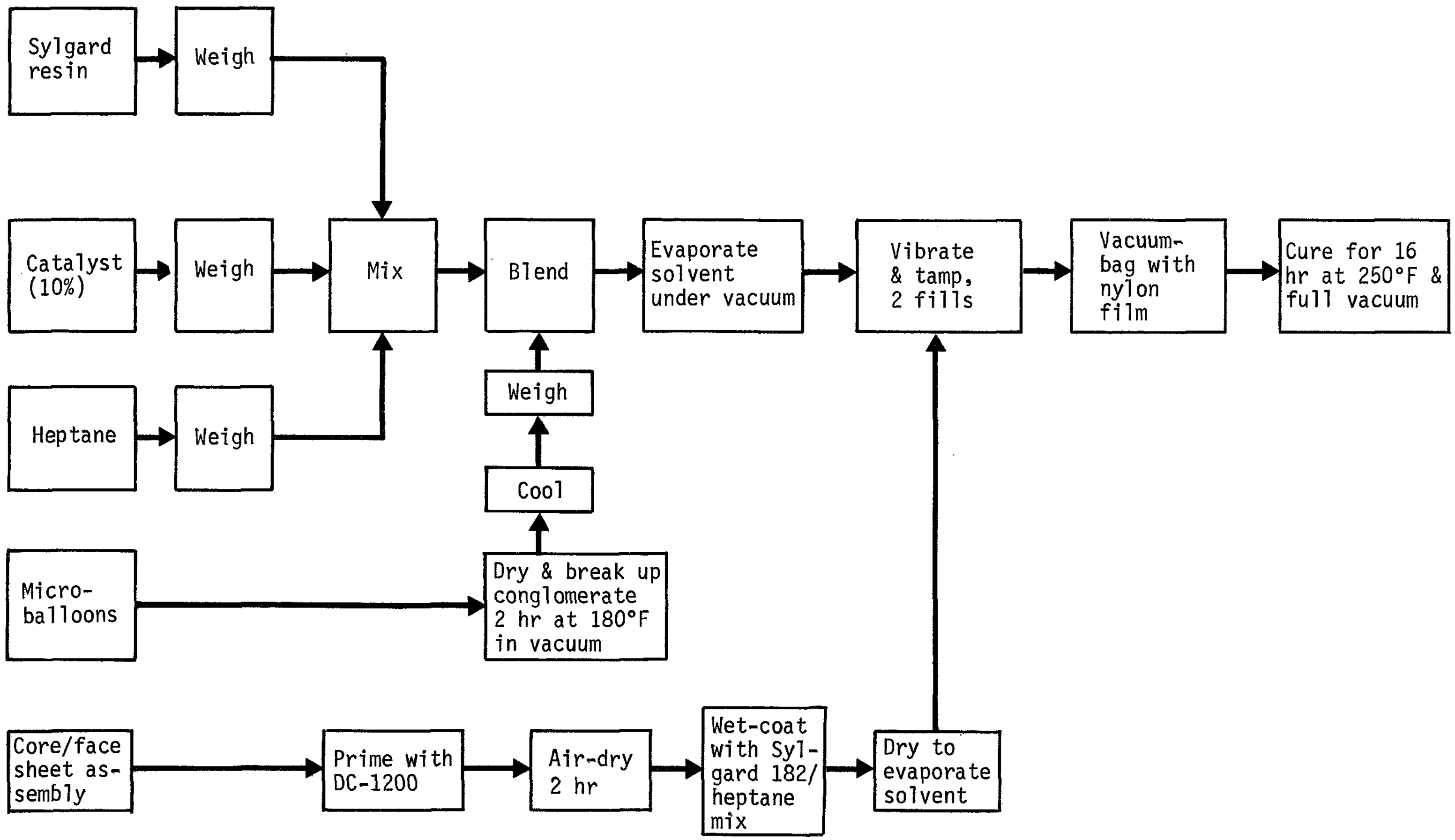


Figure 18.- Process Flow Diagram - 10% Sylgard 182/90% Microballoons (13 to 17 lb/ft^3)

LARGE PANEL FABRICATION

Eight 24x48x2-in. ablative panels and six attachment hole plugs for each panel were fabricated. The panels were manufactured according to processes developed during the development phase. Figures 19 and 20 depict the panels.

A curved panel and a flat panel were made from each of the four ablative compositions. During their fabrication, the actual times of each step in the operation were recorded. These times form the basis on which the production costs given later in this report are projected. The recorded times are itemized in Appendix A. The four ablative compositions, densities, and curing conditions are summarized below.

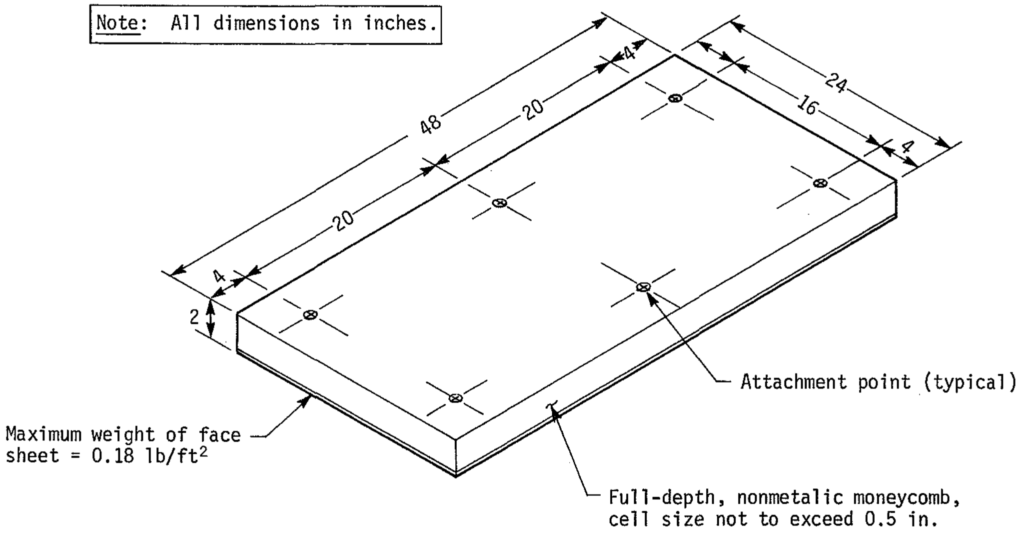
Formulation	Density range	Cure
15% phenolic resin powder 15% nylon powder 70% Microballoons	13 to 17 lb/ft^3	300°F for 16 hr
50% phenolic resin powder 50% nylon powder	25 to 30 lb/ft^3	300°F for 16 hr
10% silicone resin 90% Microballoons	13 to 17 lb/ft^3	250°F for 16 hr
67% silicone resin 33% Microballoons	25 to 30 lb/ft^3	250°F for 16 hr

Each panel was reinforced with 3/8-in.-cell, 2.2-lb/ft^3 phenolic glass honeycomb. A face sheet consisting of two plies of 181 fiberglass cloth impregnated with a high-temperature epoxy resin was bonded to the core. Listed below are the panel densities for each of the eight panels. These densities were determined after final machining.

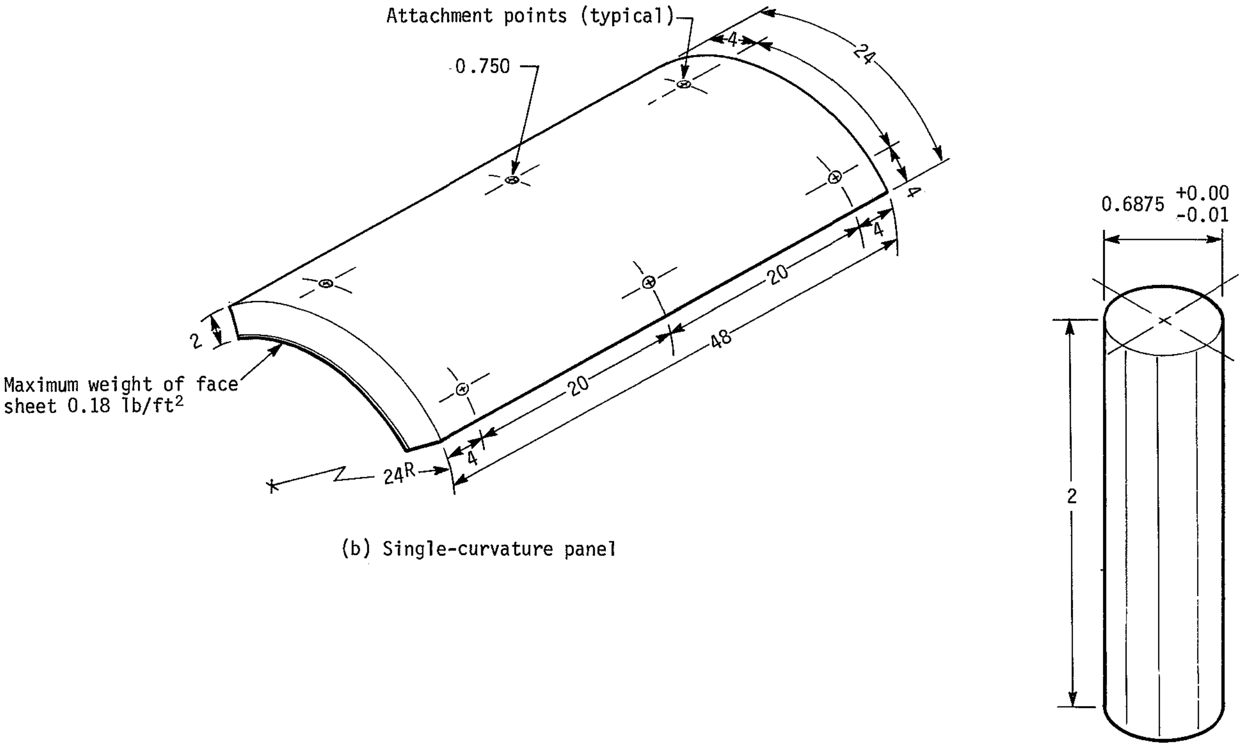
	Density, lb/ft^3	
Ablator	Flat panel	Curved panel
Low-density silicone	13.9	13.6
High-density silicone	29.9	28.6
Low-density nylon-phenolic	13.2	13.8
High-density nylon-phenolic	26.5	27.6

Core Subassembly

Five flat panels and five curved panels were prepared. The honeycomb was received to the correct thickness, but was too long and too wide. The core was placed on the bonding tool and the edges were cut to size using a dough knife cutter. The cut core was then replaced in the bonding tool for a dimensional check. Next, the attachment holes were located and cut at the six locations using a 1-in.-diameter punch-type rubber cutter. The core was blown



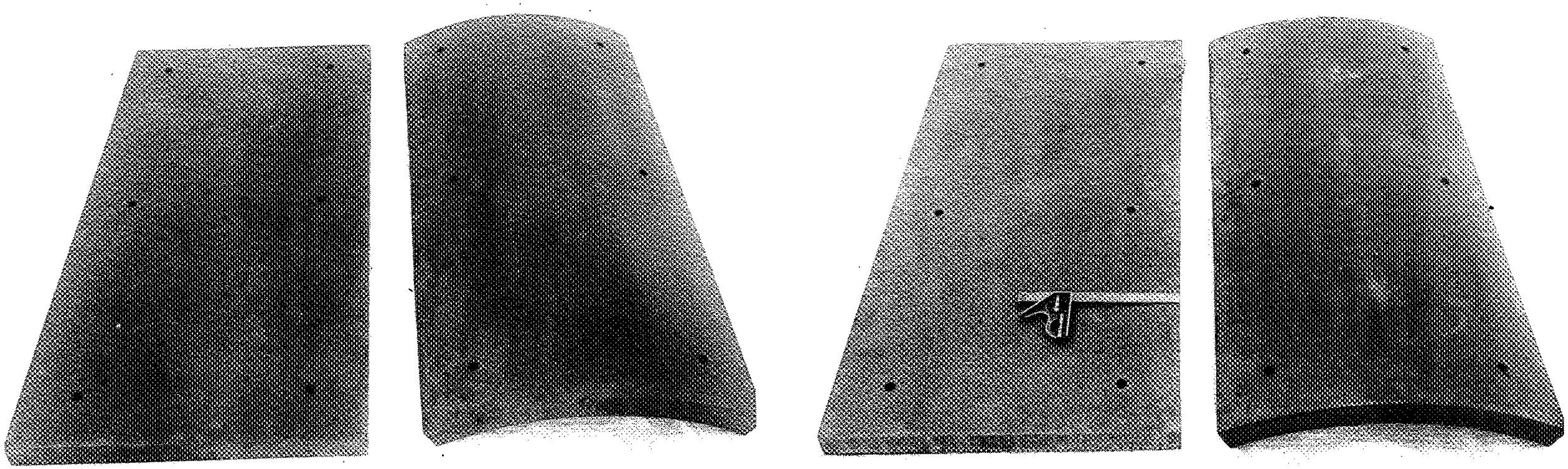
(a) Flat panel



(b) Single-curvature panel

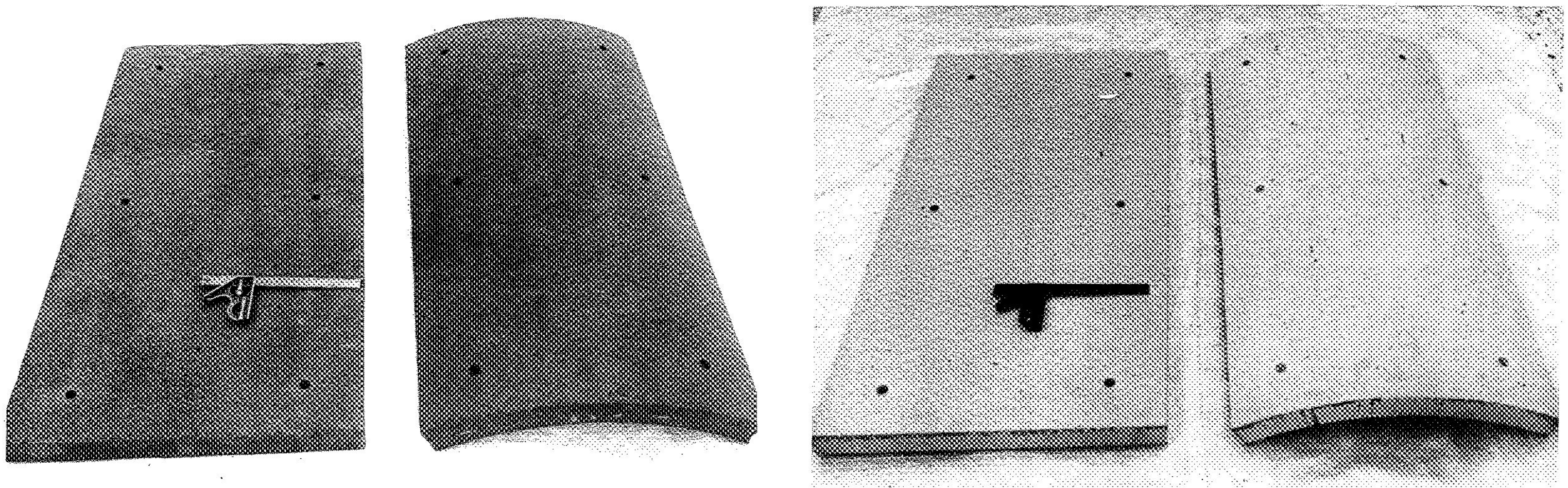
(c) Cylindical plug

Figure 19.- Panel Details



(a) 90% Microballoons, 10% silicone resin

(b) 33% Microballoons, 67% silicone resin



(c) 15% Nylon, 15% phenolic, 70% Microballoons

(d) 50% Nylon, 50% phenolic

Figure 20.- Types of Panels Fabricated

clean with dry nitrogen and vapor-degreased with trichlorethylene. To protect the core from contamination until use, it was wrapped in kraft paper.

The bonding fixture was cleaned with solvent and 1-mil Teflon film was placed against the caul sheet. Teflon tape was applied to the wooden side frames of the tool. After the face sheet prepreg was removed from cold storage (40°F) and allowed to warm to room temperature, two 25x49-in. sheets were cut for each panel. This allowed for an overhang of 0.5 in. on each side of the panel, which provided support for the edges of the panels. The unprotected faces of the prepregs were placed together and rolled smooth. Then the protective film was stripped from one side of the sheets and the two sheets were placed against the Teflon release material. Next, the sheets were rolled smooth against the tool and the protective film was stripped from the other side. The side frame of the tool was then positioned over the edges of the face sheet. After the protective paper was removed from the core, the core was positioned on top of the face sheets and the assembly was vacuum-bagged. A bleeder cloth was placed over the tool to prevent the bag from being torn and to distribute the vacuum pressure evenly. The material was then cured at 325°F for 1.5 hr. Afterward, the assembly was allowed to cool to 150°F before removing the vacuum and the core from the tool. The bonded assembly is shown in figure 21.

The finished subassemblies were inspected and wrapped in kraft paper for storage.

Cell venting was done with a hand-held 1/16-in.-diameter modified drill (fig. 6). After drilling, the panels were blown clean with filtered air and rewrapped in paper.

All times reported for the subassembly operations are the average times for all the panels.

Tool Modification

After all face sheets were bonded, the side frames of the tools were opened from inside dimensions of 24x48 in. to 25 by 49 in. so the edges of the panels could be packed better. Partial cells next to the side frames were very difficult to fill. The faces of the caul sheets were spot-faced 1/2 in. diameter by 1/8 in. deep to accommodate the screw heads that held the Teflon attachment hole plugs in place on the subassembly (fig. 22). For all panels, a layer of coarse tooling fiberglass cloth was placed against the caul sheet and passed under the side frames to provide a venting passage as the cells were filled. During the panel packing, only a transparent vacuum bag film was used on top of the panels. However, on the last packing cycle, and during the curing cycle, a layer of fiberglass tooling cloth was placed between the film and the panel to distribute the vacuum and serve as a bleeder cloth.

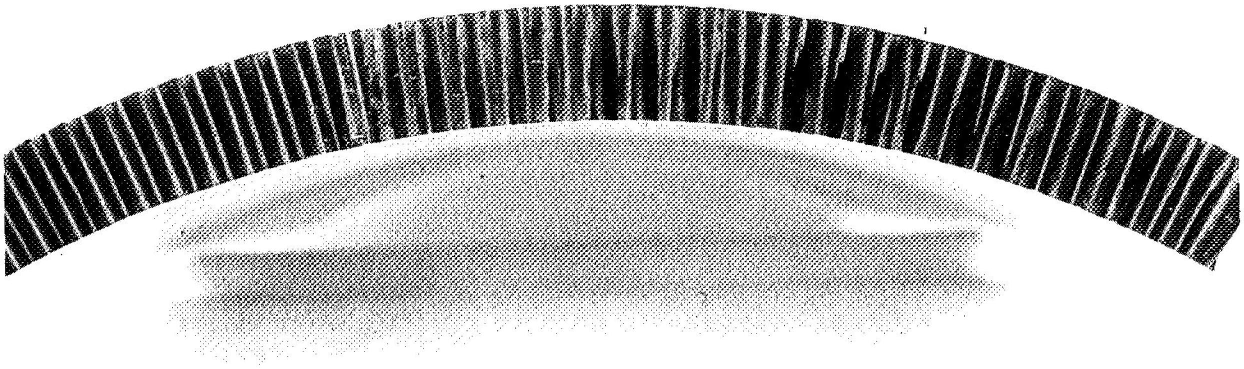


Figure 21.- Core with Face Sheet

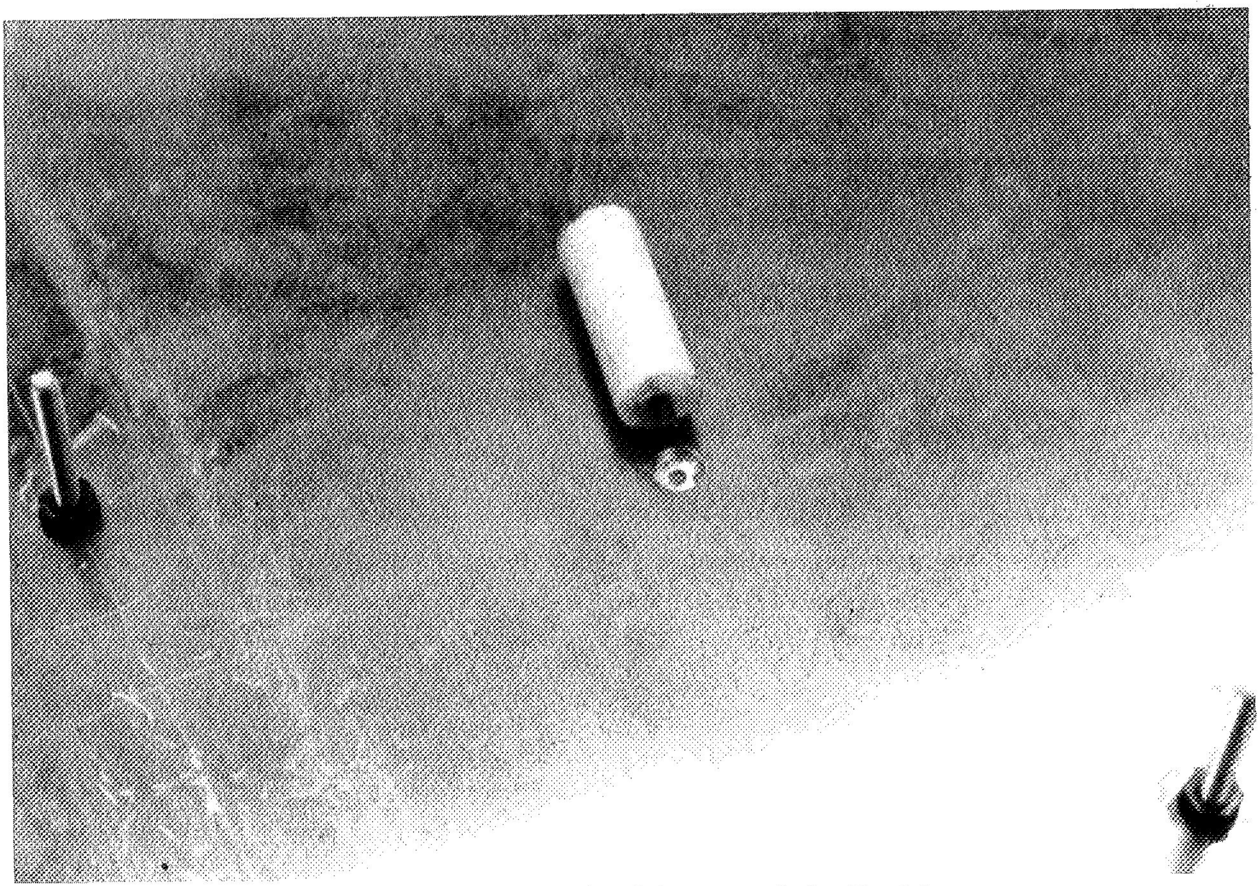


Figure 22.- Screw Head Recessed in Tooling

Panel Fabrication

All panels except the high-density silicone ablator panels were fabricated by the processes developed. The processes worked as expected. As previously described, the flat high-density silicone ablator panel warped. The process times given for this panel are those for the warped panel. We found that it took just as long to make the panel with the secondary-bonded face sheet as it did to make the primary-bonded panel: the bonding operation took as long as the vent-hole drilling operation.

Panel Filling

Preliminary filling of all panels was done in the same way. First, the edges next to the side frame and around the Teflon inserts were hand-filled and packed with ablative material to assure that the hard-to-fill zones received sufficient material (see fig. 23). Next, the loading frame was placed over the core and filled level with ablative material (fig. 24). The trap door on the frame was then removed and the ablative material was pressed into the core. Finally, the panel was bagged and the material was vibrated into the cells. When the high-density silicone panels were made, both vibration and squeegeeing were used to load the material (see fig. 25).

The bulk density and packing characteristics of the four materials varied considerably and required that the filling operation be repeated in some cases. The list below shows the number of filling operations required for each composition.

Composition	No. of filling operations
Low-density silicone	2
High-density silicone	1
Low-density nylon-phenolic	3
High-density nylon-phenolic	2

When filling the curved high-density silicone panel, we noticed that the material did not pack as expected. An analysis showed that the bottom bleeder cloth was being sealed off by the tool side frame. This prevented the entrapped air in the cells from being released. The bleeder cloth was changed from 181 to 482 fiberglass cloth. The bottom bleeder cloth was extended under the side frame of the tool, so that it would connect to the top bleeder cloth completely around the periphery of the frame.

The processing time recorded for this panel reflect this problem. Even though these times may not be typical of this composition, they indicate the delay that can be expected to occur when manufacturing ablative materials, and were purposely left in the cost analysis.

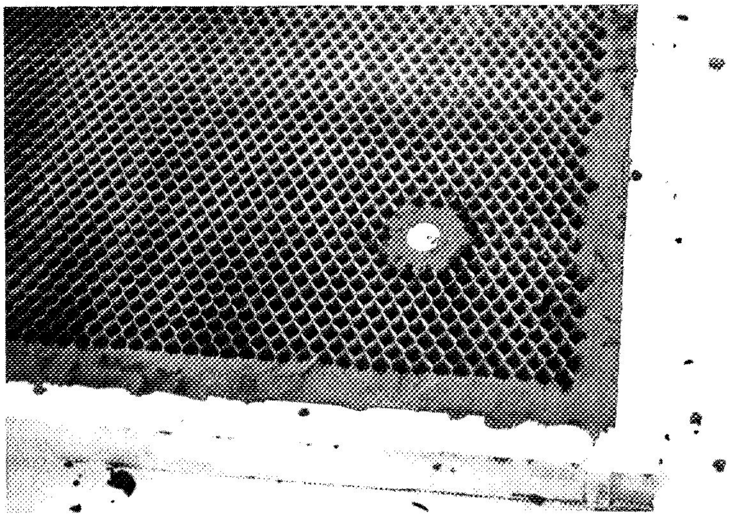


Figure 23.- Preliminary Packing of Ablative Material

Figure 24.- Ablative Material Being Put in Loading Frame

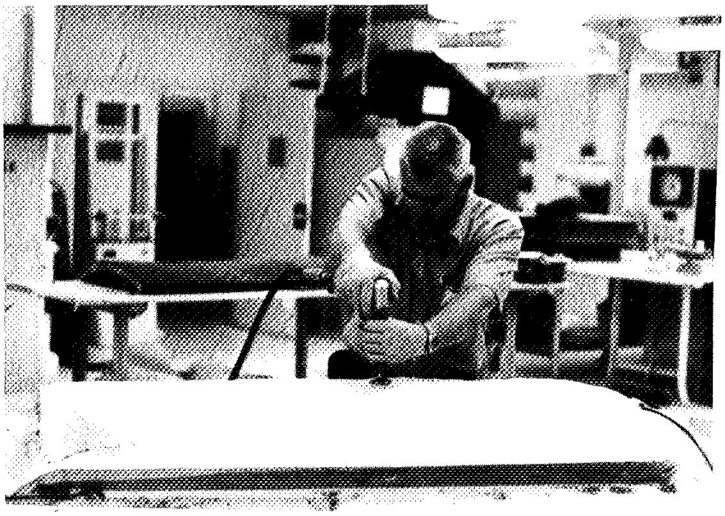


Figure 25.- Ablative Material Being Vibrated into Core

The low-density nylon-phenolic panel was as difficult to fabricate as expected. The time difference encountered in filling the curved panel (818 minutes, vs 742 minutes for filling the flat panel) was a result of the material falling off the edges when the loading frame was removed (see Appendix A).

Panel Curing

Three of the four compositions were held at a temperature lower than the final cure temperature to reduce panel warpage and to reduce the tendency of the panel to cure on the outer surfaces before the center starts curing. The fourth composition, that of the low density elastomeric formulation, was not held at a lower temperature as the Microballoons were expected to retard polymerization sufficiently long so that the entire thickness of the panel would be uniformly heated prior to cure. Both the low and high density nylon phenolic composition were held at 180°F to obtain flow and wetting out of the phenolic resin. The low density composition was held at 180°F for 3 hr prior to the 16 hr cure at 300°F. The high density nylon phenolic composition was held for 16 hr at 180°F in order to prevent panel warpage. Final cure was 16 hr at 300°F. The high density elastomeric panels were held at 175°F for 24 hr to reduce panel warpage before being raised to 250°F for 16 hr, the final cure.

Panel Machining

All panels were machined in the same way -- planed and then finish sanded. There was no apparent trouble with any of the compositions. As would be expected, the curved panels required more machining time than the flat panels.

Panel Finishing

After being machined, the panels should be coated with a protective material to prevent contamination. A spray-coating operation was incorporated into the time study. The low-density nylon-phenolic composition that had been found to be relatively weak was given a phenolic coating to improve its handling quality. This coating required a cure cycle. All other panels were priced with a room temperature-type coating. The elastomeric panels were spray coated with DC 92-009 dispersion. The high density nylon phenolic panels were priced using a urethane varnish even though the actual panels were not coated during this contract. Times were derived from the elastomeric spray operation.

Equipment Usage

Table 3 gives the usage time for all large equipment used to fabricate and finish each of the types of panels. This table reflects a single batch for each composition. The relative size of the equipment has not been included because it depends on the rate and lot size.

TABLE 3

EQUIPMENT USAGE TIMES*

Equipment	Composition			
	Low-density silicone	High-density silicone	Low-density nylon-phenolic	High-density nylon-phenolic
Oven face-sheet bonding	240	240	240	240
Solid processor	210	210	255	45
Screening	---	---	126	113
Planetary mixer	20	30	---	---
Vacuum mixer	95	---	30	---
Small wet-coat mixer	20	---	---	---
Spray booth	70	35	35	35
Oven	1440	2880	1440	2880
Protective spray-coat booth	30	30	30	30
Oven coating cure	---	---	300	---

*Times are in minutes and are complete turn-around times.

Repair Procedures

It was necessary to repair the panel edges that had been damaged during machining and subsequent handling. The damaged areas were wet coated with the respective catalyzed resins before the panels were patched. The elastomeric panels were patched with GE 652 silicone resin and phenolic Microballoons. The nylon-phenolic panels were patched with Epox 828/DTA; ground up ablative material was used as the filler. This filler was obtained from the excess ablative material that had been machined from the tops of the panels.

PRODUCTION COST ESTIMATES

Existing Martin Marietta cost-estimating procedures were used with the labor studies shown in Appendix B to compute the costs of the various ablative panels. Material costs were quoted by vendors on the basis of the total lot size for each material. Standard industrially accepted factors were applied to the time studies to convert them into production run costs. All necessary supporting activities were also included.

The labor times shown in Appendix A formed the basis for the cost estimates. The eight large ablative panels were fabricated by engineers and Plastics Laboratory technicians who were experienced in this work. To correlate their actual times into those expected from production labor, a 25% increase was applied for motivation and skill levels. The times shown on the MPPs reflect this increase.

The direct manufacturing, labor, tooling, and shipping charges shown in Appendix B were computed as follows:

1) Production runs of one lot were based on a 95% cumulative average learning curve. Lots of 10 and 100 were given 92% and 90% learning curves, respectively;
2) Based on previous experience and that gained in this study program, a 25% increase in manufacturing labor was added to account for scrap and rework;
3) Tooling costs were established from the lot size and assumed flight rate of one per month;
4) Laboratory personnel were assumed to have the same experience as factory labor in fabricating the tenth panel;
5) Shipping estimates were based on using one nonreturnable container for each 25 panels.

Quality charges were based on charges experienced for similar products and were modified to reflect specific materials and processes. The Quality Test costs provide for 100% radiographic inspection of the production panels.

Engineering charges include estimated costs for drafting, specification maintenance, and process liaison. We assumed that development was completed and that Class 1 drawings were available.

Manufacturing support operations, such as supervision, in-scope design changes, production control, and industrial engineering, were also included in the estimate.

Labor and overhead charges were applied using the Division's September 1970 rates for each department involved. G&A rates were applied to the above charges and direct material costs. Equipment amortization is included in the overhead charges. Note that the total charges given in tables 4 through 11 do not include overtime, travel, computer time, contract data requirements, and fee or profit. Lots are the total number of panels released at a time to the manufacturing shop.

TABLE 4
TOTAL COST PER SQUARE FOOT - ONE FLIGHT

Type of panel	Mat'l*	Qty.	Square feet	Lots of one	Lots of 10	Lots of 100
2x4-ft flat panel						
	A	100	800	$162.62	$138.55	$132.16
	B	100	800	151.58	128.57	121.14
	C	100	800	190.21	158.66	148.52
	D	100	800	158.42	130.61	124.24
3x5-ft flat panel						
	A	40	600	128.25	115.41	112.00
	B	40	600	115.39	102.53	99.14
	C	40	600	143.01	126.17	120.79
	D	40	600	118.96	104.08	101.29
4x6-ft flat panel						
	A	25	600	124.04	117.26	115.18
	B	25	600	111.67	103.68	101.55
	C	25	600	138.95	128.52	125.21
	D	25	600	114.76	105.47	103.37
2x4-ft double curvature						
	A	250	2000	296.66	225.27	198.10
	B	250	2000	162.97	131.32	124.90

*A = 67% silicone and 33% Microballoons;

B = 50% phenolic and 50% nylon;

C = 70% Microballoons, 15% nylon, and 15% phenolic;

D = 90% Microballoons and 10% silicone.

TABLE 5
TOTAL COST PER PANEL - ONE FLIGHT

Type of panel	Mat'l*	Qty.	Square feet	Lots of one	Lots of 10	Lots of 100
2x4-ft flat panel						
	A	100	800	$1301	$1108	$1057
	B	100	800	1213	1029	969
	C	100	800	1522	1269	1188
	D	100	800	1267	1045	994
3x5-ft flat panel						
	A	40	600	1923	1731	1680
	B	40	600	1731	1538	1487
	C	40	600	2145	1893	1812
	D	40	600	1784	1561	1519
4x6-ft flat panel						
	A	25	600	2976	2814	2764
	B	25	600	2680	2488	2437
	C	25	600	3334	3084	3004
	D	25	600	2754	2531	2480
2x4-ft double curvature						
	A	250	2000	2373	1802	1585
	B	250	2000	1304	1051	999

*A = 67% silicone and 33% Microballoons;

B = 50% phenolic and 50% nylon;

C = 70% Microballoons, 15% nylon, and 15% phenolic;

D = 90% Microballoons and 10% silicone.

TABLE 6
TOTAL COST FOR ONE FLIGHT USING ELASTOMERIC PANELS

Type of panel	Mat'l*	Qty.	Square feet	Lots of one	Lots of 10	Lots of 100
2x4-ft flat panel						
	A	100	800	$130 094	$110 838	$105 724
	D	100	800	126 733	104 488	99 391
3x5-ft flat panel						
	A	40	600	76 932	69 233	67 189
	D	40	600	71 363	62 437	60 760
4x6-ft flat panel						
	A	25	600	74 411	70 343	69 097
	D	25	600	68 844	63 268	62 008
2x4-ft single curvature						
	A	125	1000	285 333	205 923	195 731
	D	125	1000	158 399	135 909	124 452
2x4-ft double curvature						
	A	250	2000	593 326	450 536	396 200
Total		830	8000	$1 585 435	$1 272 975	$1 180 552
Cost per square foot				$198.18	$159.12	$147.57

*A = 67% silicone and 33% Microballoons;

D = 90% Microballoons and 10% silicone.

TABLE 7
TOTAL COST FOR 10 FLIGHTS USING ELASTOMERIC PANELS

Type of panel	Mat'l*	Qty.	Square feet	Lots of 100
2x4-ft flat panel				
	A	1000	8 000	$692 744
	D	1000	8 000	572 843
3x5-ft flat panel				
	A	400	6 000	532 729
	D	400	6 000	443 640
4x6-ft flat panel				
	A	250	6 000	539 204
	D	250	6 000	456 104
2x4-ft single curvature				
	A	1250	10 000	970 261
	D	1250	10 000	678 229
2x4-ft double curvature				
	A	2500	20 000	2 324 659
Total		8300	80 000	$7 210 413
Cost per square foot				$90.13

*A = 67% silicone and 33% Microballoons;

D = 90% Microballoons and 10% silicone.

TABLE 8
TOTAL COST FOR 100 FLIGHTS USING ELASTOMERIC PANELS

Type of panel	Mat'l[*]	Qty.	Square feet	Lots of 100
2x4-ft flat panel				
	A	10 000	80 000	$5 560 569
	D	10 000	80 000	4 380 505
3x5-ft flat panel				
	A	4 000	60 000	3 798 961
	D	4 000	60 000	2 927 870
4x6-ft flat panel				
	A	2 500	60 000	3 822 797
	D	2 500	60 000	2 937 452
2x4-ft single curvature				
	A	12 500	100 000	9 794 956
	D	12 500	100 000	5 550 615
2x4-ft double curvature				
	A	25 000	200 000	18 821 327
Total		83 000	800 000	$57 595 052
Cost per square foot				$71.99

[*] A = 67% silicone and 33% Microballoons;

D = 90% Microballoons and 10% silicone.

TABLE 9
TOTAL COST FOR ONE FLIGHT USING NYLON-PHENOLIC PANELS

Types of panel	Mat'l*	Qty.	Square feet	Lots of one	Lots of 10	Lots of 100
2x4-ft flat panel						
	B	100	800	$121 264	$102 853	$96 909
	C	100	800	152 165	126 929	118 814
3x5-ft flat panel						
	B	40	600	69 234	61 516	59 484
	C	40	600	85 806	75 703	72 473
4x6-ft flat panel						
	B	25	600	66 989	62 194	60 918
	C	25	600	83 355	77 099	75 108
2x4-ft single curvature						
	B	125	1000	151 575	127 538	121 144
	C	125	1000	197 670	157 318	152 235
2x4-ft double curvature	B	250	2000	325 932	262 640	249 808
Total		830	8000	$1 253 990	$1 053 790	$1 006 893
Cost per square foot				$156.75	$131.72	$125.86

*B = 50% phenolic and 50% nylon;

C = 70% Microballoons, 15% nylon, and 15% phenolic.

TABLE 10
TOTAL COST FOR 10 FLIGHTS USING NYLON-PHENOLIC PANELS

Type of panel	Mat'l*	Qty.	Square feet	Lots of 100
2x4-ft flat panel				
	B	1000	8 000	$574 970
	C	1000	8 000	677 403
3x5-ft flat panel				
	B	400	6 000	443 942
	C	400	6 000	527 929
4x6-ft flat panel				
	B	250	6 000	459 898
	C	250	6 000	549 682
2x4-ft single curvature				
	B	1250	10 000	718 537
	C	1250	10 000	846 519
2x4-ft double curvature				
	B	2500	20 000	1 508 120
Total		8300	80 000	$6 307 000
Cost per square foot				$78.84

*B = 50% phenolic and 50% nylon;

C = 70% Microballoons, 15% nylon, and 15% phenolic.

TABLE 11
TOTAL COST FOR 100 FLIGHTS USING NYLON-PHENOLIC PANELS

Type of panel	Mat'l*	Qty.	Square feet	Lots of 100
2x4-ft flat panel				
	B	10 000	80 000	$4 700 462
	C	10 000	80 000	5 132 872
3x5-ft flat panel				
	B	4 000	60 000	3 049 860
	C	4 000	60 000	3 178 458
4x6-ft flat panel				
	B	2 500	60 000	3 028 642
	C	2 500	60 000	3 441 331
2x4-ft single curvature				
	B	12 500	100 000	5 950 932
	C	12 500	100 000	6 415 470
2x4-ft double curvature				
	B	25 000	200 000	12 179 178
Total		83 000	800 000	$47 077 205
Cost per square foot				$58.85

*B = 50% phenolic and 50% nylon;

C = 70% Microballoons, 15% nylon, and 15% phenolic.

TABLE 13 COST OF ONE PANEL AND 10 PANELS

	Material	One Panel	10 Panels
2x4-ft Flat panel	A	$ 5 920	$ 22 940
	B	5 590	21 380
	C	5 850	22 760
	D	5 660	21 890
4x6-ft Flat panel	A	8 970	38 520
	B	7 920	33 730
	C	8 830	37 300
	D	8 010	34 460
3x5-ft Flat panel	A	6 770	25 270
	B	6 120	23 010
	C	6 680	24 130
	D	6 290	23 560
2x4-ft Single curvature	A	10 740	33 460
	B	9 280	23 360
	C	10 290	28 910
	D	8 390	22 620
2x4-ft Double curvature	A	18 100	40 950
	B	15 590	30 840

TABLE 12 TOOLING COST (any material)

	One Panel	10 Panels
2x4-ft Flat panel	$ 960	$ 1 330
3x5-ft Flat panel	1 510	2 110
4x6-ft Flat panel	3 760	5 280
2x4-ft Single curvature	4 720	6 600
2x4-ft Double curvature	9 210	12 880

Table 14 lists the material costs for one, 10, and 100 flights, respectively. These costs include scrap, overage, and out-of-shelf-life factors.

TABLE 14
MATERIAL COSTS FOR VARIOUS NUMBERS OF FLIGHTS

Flight composition	One flight	10 flights	100 flights
Elastomeric	$216 511	$2 006 473	$19 374 624
Nylon phenolic	145 360	1 299 979	12 200 442

Table 15 summarizes the cost breakdown for a 2x4-ft, low-density, elastomeric Space Shuttle panel.

TABLE 15
COST BREAKDOWN FOR A TYPICAL
2x4-FT FLAT PANEL

Material	15%
Engineering	8%
Tooling	4%
Manufacturing	58%
Quality Control	11%
Test	4%

QUALITY ASSURANCE

This plan defines the quality assurance program and outlines the detailed controls that would be applied during procurement, fabrication, testing, and delivery of hardware.

Organization

A Quality Control representative, responsible to Martin Marietta's quality director will be assigned to the program and will report to the Program Manager. He would direct all Quality activities defined herein, and will be responsible for assuring that all deliverable articles meet contractual and engineering requirements.

Inspection Requirements

Control of procured materials.- The Quality Control representative will review purchase requisitions before their release to ensure that the supplier is an approved source and that quality standards and technical requirements are documented in the contract with the supplier. He will inspect all incoming materials for damage, proper documentation, and compliance with purchase order requirements. Materials that have been inspected and identified as to inspection status, part number, lot or batch number, and shelf life requirements will be placed in storage until required for issue. Special environmental requirements, such as temperature and humidity control, will be strictly enforced.

Chemical analyses and physical tests, when required to determine conformance to specifications, will be conducted in the Quality Laboratory.

Fabrication Inspection

Quality will review the manufacturing process plan and specify the in-process inspection requirements to be met when applying the ablative materials. Quality will provide in-line inspection of preparation, layup, cure, and dimensional checks. The results of these in-line inspections will be documented.

Nondestructive Testing

The Quality Laboratory will perform 100% X-ray inspection to detect any voids present in the ablative material. Acceptance criteria will be established for final acceptance of the deliverable panels. Destructive testing, as required, will be done concurrently with hardware fabrication. The results of these tests will be documented.

Batch Control

Materials and compounds with limited storage lifes will be strictly controlled to ensure that the prescribed batches are properly mixed. Batch samples will be identified and submitted for laboratory evaluation. Any compounds whose shelf life has expired will be rejected.

Material Review

All nonconforming material will be positively identified and segregated to ensure that all deliverable hardware meets engineering and contractual requirements. The Quality Control representative will review each instance of nonconformance and prescribe one of the following dispositions:

1) Rework - Incomplete items will be corrected in accordance with drawing requirements;
2) Scrap - Items that are not reworkable or are uneconomical to repair will be recommended for scrap.

Inspection, Testing, and Measuring Equipment

All inspection gages and measuring and test equipment necessary to determine conformance with specifications, drawings, and contract requirements will be properly selected, evaluated, maintained, and controlled. All equipment will be calibrated using standards traceable to the National Bureau of Standards.

Government-Furnished Property

Materials furnished by the Government will be inspected for transit damage, inventoried for identification, and verified for configuration status and quantity.

Quality Documentation

Quality will maintain records of all inspections, tests, and nonconformance data accumulated during the period of performance. Records will be made available to designated NASA representatives for review.

Shipping Inspection

Before being shipped, each article will be inspected for condition, configuration, and proper packaging to ensure completeness of hardware and to prevent degradation of the quality of the article.

CONCLUSIONS

1. The low-density elastomeric panels were the least expensive for 100 flights.

2. The low-density nylon-phenolic composition had the highest manufacturing cost, mainly because of the difficulty in packing the material into the honeycomb matrix.

3. The cost of ablative heat shield panels can be significantly reduced by the time the Space Shuttle is fabricated. The large volume of a single configuration is effective in reducing cost due to-appropriate learning.

4. Large lot sizes will have an additional effect of reducing panel cost.

5. The most expensive panel was the high-density elastomeric composition in the 2x4-ft double curvature. The average cost for one flight was $296.66 per square foot. However, this cost reflects tooling problems in fabricating the single curvature 2x4-ft panel.

6. The least expensive panel was the 4x6-ft, 90% Microballoon - 10% silicone resin panel in lots of 100 for 100 flights. The cumulative average cost of these panels was $48.96 per square foot.

7. Panel edges were susceptible to chipping and had to be repaired.

RECOMMENDATIONS

The following recommendations are based on the experience gained in the performance of this contract:

1. After being machined, the large panels were difficult to handle. To prevent damaging an edge, the final panel design should include an edge member.

2. An investigation should be conducted to determine if a liquid phenolic resin could be substituted for the dry resin in the low-density nylon-phenolic system without affecting ablation performance. The mechanical strength and ease of packing are increased by this substitution.

3. An ablation test in which partial oxygen pressure and ablator temperature are simulated for a typical flight should be made on the two low-density systems. Because phenolic Microballoons can burn at a very low temperature, this will show whether burning would continue after a vehicle has reentered the atmosphere.

4. Because of the high thermal expansion of the high-density elastomeric system, the panels will experience high thermal strains. A rigorous thermal strain analysis of the panel should be made. Particular attention should be given to the attachment points.

5. The highest cost and most manufacturing difficulty are associated with loading the core. A study should be made to either eliminate the core or increase its cell size.

6. A core splice was necessary to make a 24-in. wide panel. This splice can not be permitted on flight panels because it inhibits filling the core and because the ablation rate of the adhesive is higher than that of the rest of the panel. Special tooling should be set up to manufacture the core to the required width.

Martin Marietta Corporation
Denver, Colorado, October 2, 1970

TABLE 16
MANUFACTURING PROCESS PLAN
70% MICROBALLOONS, 15% NYLON RESIN, 15% PHENOLIC RESIN

PART NAME LOW COST ABLATIVE SHIELD	SHEET 1 OF 8	PROJECT	DRAW FROM	ROUTE TO	PART NUMBER	MFG. SUF.	D A

MATERIAL/NOTES
70% MICROBALLOONS, 15% NYLON & 15% PHENOLIC

GRID/FIND NO. ☐ LOG ☐ NONLOG
ISSUE WITH
TOOLING PHILOSOPHY
☐ PRODUCTION
☐ SPARES ☐ OTHER

EFFECTIVE DATE OF PLAN	CHANGE AUTHORITY/P.T.	DCN	SHT.	NEXT ASSEMBLY	UNIT EFFECTIVITY	CONTROL POINT	P/A	P/M	PLANNER	CHECKER/QUAL.

ENG. CHG. AUTH. CHG. SHT.
PLAN'G. CHG. MAT'L. CHG

	REV	DEPT.	STEP	OPERATION CODE AREA	TYPE	DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	RUN	TOTAL
1																	
2										FABRICATION METHOD FOR ABLATIVE HEAT SHIELD							
3																	
4										FACE SHEET BONDING TO PHENOLIC GLASS (HONEYCOMB)							
5										CORE -FLAT OR CONTOURED PANELS - CORE MAT'L.							
6										PURCHASED WITH FORMED RADIUS OR FLAT AS REQUIRED.							
7																	
8										Layout O/S profile of core material and holes					6.00	13.00	
9										per drawing.							
10																	
11										Hand cut core to layout using dough cutter and					6.00	13.00	
12										punch holes using (rubber type) hand punch.							
13																	
14										Clean core material by blowing with nitrogen or					3.00	6.00	
15										filtered air.							
16																	
17										Vapor degrease core mat'l. - Submerge in vapors						19.00	
18										only. -							
19																	
20										Wrap core material in kraft paper until use.					4.00	6.00	
21																	
22										Wipe tools with safety solvent to clean and prepare						113.00	
23										for bond. - Apply release agent to tool - Mold							
24										tools required -							
25																	
26																	

TABLE 16.- Continued
MANUFACTURING PROCESS PLAN
70% MICROBALLOONS, 15% NYLON RESIN, 15% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 2 OF 8	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										Remove pre-preg from refrigerator - let warm to						6.00	
3										room temperature - hand cut (2) pieces of pre-					6.00	38.00	
4										preg to suit mold tool (2 thicknesses required)							
5																	
6										Start Panel Layup -					13.00	19.00	
7										Lay pre-preg on tool, roll out wrinkles, strip							
8										protective film from pre-preg, and apply second							
9										layer same as first.							
10																	
11										Install clean honeycomb core material on pre-						6.00	
12										preg layup on tool.							
13																	
14										Place bleeder cloth (Fiberglass Cloth) over						6.00	
15										core material.							
16																	
17										Apply vacuum bag over assembly, seal with tape					6.00	38.00	
18										and pull full vacuum (23+ inch mercury).							
19																	
20										Place vacuum sealed assembly into oven.						6.00	
21																	
22										Cure at 325°F for (2) hours at temp.							
23																	
24										Remove assembly from oven and let cool under							
25										vacuum to 150°F min. before removing assembly						13.00	
26										from tool.							
27																	
28										Hand drill 1/8 dia. holes thru face sheet at					6.00	145.00	
29										(approx.) center of each honeycomb cell.				(1/16 Holes @ 60/min)			
30										Approx. 7000 holes in panel, require special							
31										carbide drills. Plus (6) attachment holes.							
32																	
33										Wrap subassembly in kraft paper until used.					4.00	6.00	
34																	
35																	
36																	
37																	
38																	
39																	

FORM MM-71A (2-67)

TABLE 16.- Continued
MANUFACTURING PROCESS PLAN
70% MICROBALLOONS, 15% NYLON RESIN, 15% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 3 OF 8	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	TYPE	DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	RUN	TOTAL
1																	
2										70% MICROBALLOONS, 15% NYLON, 15% PHENOLIC							
3																	
4										~~Dry~~ Microballoons mat'l. (2) hours at 180°F under					6.00	13.00	
5										~~vacuum in a solids processor.~~							
6																	
7										Allow material to cool to 140°F under vacuum						13.00	
8										before removing from processor.							
9																	
10										Store Microballoons mat'l. in a desiccated sealed					6.00	25.00	
11										container.							
12																	
13										Screen nylon powder thru a 40 mesh sieve.					19.00	50.00	
14																(1000G)	
15																	
16										Screen phenolic powder thru a 40 mesh sieve.					19.00	38.00	
17																(1200G)	
18																	
19										Weigh correct formulation, 70% Microballoons,					13.00	31.00	
20										15% nylon and 15% phenolic and place into a							
21										blender.							
22																	
23										Blend for 30 minutes.						38.00	
24																	
25										Remove from blender, place weighed amount into							
26										planetary mixer, add 20% of blend by weight of					13.00	56.00	
27										methol alcohol and blend 20 minutes in							
28										planetary mixer.							
29																	
30										Blow panel subassembly clean with nitrogen or					3.00	6.00	
31										filtered air.							
32																	
33										Spray core mat'l. with phenolic varnish (SC1008							
34										Monsanto) into core cells making 4 passes or coats					13.00	25.00	
35										by criss cross (2) coats each direction.							
36																	
37																	
38																	
39																	

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TABLE 16.- Continued
MANUFACTURING PROCESS PLAN
70% MICROBALLOONS, 15% NYLON RESIN, 15% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 4 OF 8	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	OPERATION CODE TYPE	OPERATION CODE DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	TIME STANDARD RUN	TIME STANDARD TOTAL
1																	
2										Place panel on draw pan for excess varnish to							
3										drip thru 1/16 dia. holes.							
4																	
5										Let panel dry for 24 hours minimum.							
6																	
7										Install nylon plug to face sheet using screw to					3.00	13.00	
8										attach plug.							
9																	
10										Apply (Fiberglass Cloth) bleeder cloth on tool.					3.00	6.00	
11																	
12										Spray bleeder cloth with teflon release agent.					3.00	13.00	
13																	
14										Position core panel with face sheet to bleeder							
15										cloth on tool							
16																	
17										Install picture frame part of tool around core					3.00	6.00	
18										panel and locate to base tool.							
19																	
20										Place ablative material between side frame of tool							
21										and panel edge; pack ablative material around							
22										attachment holes.					9.00	25.00	
23																	
24										Weigh of 70% Microballoons, 15% Nylon,							
25										and 15% phenolic mixture out and place amount					13.00	302.00	FLAT
26										of mix on assembly to fill core and extend above						378.00	CURVED
27										core approx. 1/2" after spreading evenly inside							
28										picture frame part of tool.							
29																	
30										Remove picture frame part of tool and cover mix-					13.00	44.00	
31										ture with bleeder cloth, cloth to extend over							
32										edges of mixture and assembly down to and mate							
33										with bottom bleeder cloth.							
34																	
35										Place vacuum bag over assembly, seal and pull					6.00	38.00	
36										full vacuum.							
37																	
38																	
39																	

FORM MM-71A (2-67)

TABLE 16.- Continued
MANUFACTURING PROCESS PLAN
70% MICROBALLOONS, 15% NYLON RESIN, 15% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 5 OF 8	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										Vibrate assembly to settle mixture into core					3.00	38.00	
3										material using rivet bucking air tool with							
4										large head.							
5																	
6										NOTE: CAUTION - DO NOT CRUSH CORE.							
7																	
8										Remove vacuum bag and top bleeder cloth.						4.00	
9																	
10										Replace top picture frame of tool and add approx.							
11										1/2" deep mixture of 70% Microballoons, 15% nylon,					3.00	13.00	
12										and 15% phenolic over area of assembly.							
13																	
14										Remove top picture frame part of tool and cover							
15		(TEFLON BLEEDER CLOTH IS								mixture with teflon coated bleeder cloth, cloth					13.00		
16		BUY ITEM).								to extend over edges of mixture and assembly							
17										down to and mate with bottom bleeder cloth.							
18																	
19										Place vacuum bag over assembly, seal and pull							
20										full vacuum.					6.00	38.00	
21																	
22										Vibrate assembly to settle mixture into core					3.00	38.00	
23										material using rivet bucking air tool with							
24										large head.							
25																	
26										NOTE: CAUTION - DO NOT CRUSH CORE							
27																	
28										Remove vacuum bag and top bleeder cloth.						6.00	
29																	
30										Place top picture frame of tool over assembly							
31										and add balance of weighed mixture on assembly.					6.00	63.00	
32										Spread evenly over assembly.							
33																	
34										Remove top picture frame part of tool and cover							
35										mixture with teflon coated bleeder cloth, cloth					13.00	44.00	
36										to extend over edges of material and assembly							
37										down to and mate with bottom bleeder cloth.							
38																	
39																	

FORM MM-71A (2-67)

TABLE 16.- Continued
MANUFACTURING PROCESS PLAN
70% MICROBALLOONS, 15% NYLON RESIN, 15% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 6 OF 8	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	OPERATION CODE TYPE	OPERATION CODE DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	TIME STANDARD RUN	TIME STANDARD TOTAL
1																	
2										Place vacuum bag over assembly. Seal and pull					6.00	38.00	
3										full vacuum.							
4																	
5										Vibrate assembly to settle mixture into or 1/16"					3.00	38.00	
6										above core material using rivet bucking air tool							
7										with large head.							
8																	
9										NOTE: CAUTION - DO NOT CRUSH CORE							
10																	
11										Place assembly into oven at 300°F for 16 hours						13.00	
12										under full vacuum.							
13																	
14										Remove assembly from oven and cool under vacuum						13.00	
15										to 150°F min. before removing assembly from tool.							
16																	
17										Use wood hand plane and remove excess material					4.00	63.00	FLAT
18										down to core. Finish by sanding with 80 grit						75.00	CURVED
19										emery cloth.							
20																	
21										Layout periphery of part for final, trim in					6.00	13.00	
22										relation to nylon plugs.							
23																	
24										Saw periphery of assembly per layout on band						75.00	FLAT
25										saw.						113.00	CURVED
26																	
27										NOTE: Carbide tipped saw blades required and							
28										dust collector equipped saw.							
29																	
30										Spray complete assembly with (1) coat of phenolic					3.00	25.00	
31										varnish.							
32																	
33										Place assembly back on mold tool. Place vacuum					6.00	38.00	
34										bag over assembly and pull a full vacuum.							
35																	
36										Place assembly in oven and cure at 325°F for (2)						13.00	
37										hours at temp.							
38																	
39																	

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TABLE 16.- Continued
MANUFACTURING PROCESS PLAN
70% MICROBALLOONS, 15% NYLON RESIN, 15% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 7 OF 8	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										Remove assembly from oven and cool to 140°F (min)						13.00	
3										under vacuum.							
4																	
5										Remove vacuum bag and assembly from tool.						13.00	
6																	
7										Remove teflon tooling plugs and screws from						13.00	
8										assembly.							
9																	
10										Open P/Holes to print dims. in face sheet.						6.00	
11																	
12										Seal assembly in plastic bag and identify.					6.00	19.00	
13																	
14																	
15																	
16																	
17																	
18																	
19																	
20																	
21																	
22																	
23																	
24																	
25																	
26																	
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	
36																	
37																	
38																	
39																	

FORM MM-71A (2-67)

TABLE 16.- Concluded
MANUFACTURING PROCESS PLAN
70% MICROBALLOONS, 15% NYLON RESIN, 15% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 8 OF 8	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										FABRICATION OF PLUGS FOR FILLING HOLES IN CORE							
3										ASSEMBLY.							
4																	
5										Fabricate a small section of material along with					13.00	40.00	
6										flat panel for making plug fillers for shipping							
7										with assemblies to fill tooling plug holes on							
8										installation.							
9																	
10										Grind or plane to core material thickness.					4.00	50.00	
11																	
12										Saw O/S .75 dia. X core thickness for turning						20.00	
13										to size on lathe.							
14																	
15										Make setup on lathe to grind outside diameter					34.00	146.00	
16										to drawing dims. or fit of panel holes.							
17										(Use live center (1) end and sand paper opposite							
18										end to hold in lathe).							
19																	
20										(1) Plug required for each hole on panel.							
21																	
22										Spray sealer on plugs same as panel assembly.					3.00	19.00	
23																	
24										Place plugs into plastic bag, seal and identify					6.00	19.00	
25										with type of plug material or type assembly.							
26																	
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	
36																	
37																	
38																	
39																	

FORM MM-71A (2-67)

TABLE 17
MANUFACTURING PROCESS PLAN
50% NYLON RESIN, 50% PHENOLIC RESIN

PART NAME	SHEET 1 OF 7	PROJECT	DRAW FROM	ROUTE TO	PART NUMBER		MFG. SUF.	D A
MATERIAL/NOTES 50% NYLON 50% PHENOLIC				GRID/FIND NO.	☐ LOG ☐ NONLOG	ISSUE WITH		
				TOOLING PHILOSOPHY		☐ PRODUCTION ☐ SPARES ☐ OTHER		

EFFECTIVE DATE OF PLAN	CHANGE AUTHORITY/P.T.	DCN	SHT.	NEXT ASSEMBLY	UNIT EFFECTIVITY	CONTROL POINT	P/A	P/M	PLANNER	CHECKER/QUAL.

ENG. CHG. AUTH.	CHG.		PLAN'G. CHG.
	SHT.		MAT'L. CHG.

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1										FABRICATION METHOD FOR ABLATIVE HEAT SHIELD							
2																	
3										FACE SHEET BONDING TO PHENOLIC GLASS (HONEYCOMB)							
4										CORE.-FLAT OR CONTOURED PANELS - CORE MAT'L.							
5										PURCHASED WITH FORMED RADIUS OR FLAT AS REQUIRED.							
6																	
7																	
8										Layout O/S profile of core material and holes					6.00	13.00	
9										per drawing.							
10																	
11										Hand cut core to layout using dough cutter and					6.00	13.00	
12										punch holes using (rubber type) hand punch.							
13																	
14										Clean core material by blowing with nitrogen or					3.00	6.00	
15										filtered air.							
16																	
17										Vapor degrease core material - Submerge in						19.00	
18										vapors only - .							
19																	
20										Wrap core material in kraft paper until use.					4.00	6.00	
21																	
22										Wipe tools with safety solvent to clean and pre-						113.00	
23										pare for bond. - Apply release agent to tool -							
24										-Mold tools required.-							
25																	
26																	

TABLE 17.- Continued
MANUFACTURING PROCESS PLAN
50% NYLON RESIN, 50% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 2 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	OPERATION CODE TYPE	OPERATION CODE DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	TIME STANDARD RUN	TIME STANDARD TOTAL
1										Remove Pre-Preg from refrigerator. - Let warm						6.00	
2										to room temperature - Hand cut (2) pieces of Pre-					6.00	38.00	
3										Preg to suit mold tool (2 thicknesses required)							
4																	
5										Start Panel Layup.							
6																	
7										Lay Pre-Preg on tool, roll out wrinkles, strip					13.00	19.00	
8										protective film from Pre-Preg and apply second							
9										layer same as first.							
10																	
11										Install clean honeycomb core material on Pre-Preg						6.00	
12										layup on tool.							
13																	
14										Place bleeder cloth (Fiberglass cloth) over core						6.00	
15										material.							
16																	
17										Apply vacuum bag over assembly, seal with tape					6.00	38.00	
18										and pull full vacuum (23+ inch Mercury).							
19																	
20										Place vacuum sealed assembly into oven.						6.00	
21																	
22										Cure at 325°F for (2) hours at temp.							
23																	
24										Remove assembly from oven and let cool under						13.00	
25										vacuum to 150°F min. before removing assembly							
26										from tool.							
27																	
28										Hand drill 1/8 dia. holes thru face sheet at					6.00	145.00	
29										(approx.) center of each honeycomb cell.							
30																	
31										Approx. 7000 holes in panel, require special					(1/16	holes at 60/Min)	
32										carbide drills. Plus (6) attachment holes.							
33																	
34										Wrap subassembly in kraft paper until used.					4.00	6.00	
35																	
36																	
37																	
38																	
39																	

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TABLE 17.- Continued
MANUFACTURING PROCESS PLAN
50% NYLON RESIN, 50% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 3 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										50 - 50 NYLON+PHENOLIC							
3																	
4																	
5										Screen nylon powder thru a 40 mesh sieve.					19.00	44.00	
6															(1000G)		
7																	
8										Screen Phenolic powder thru a 40 mesh sieve.					19.00	31.00	
9															(1700G)		
10																	
11										Measure equal amounts of each material into a					13.00	25.00	
12										twin shell blender.							
13																	
14										Close blender pull full vacuum and blend for					13.00	38.00	
15										30 minutes.							
16																	
17										Remove material from blender and place into a					6.00	13.00	
18										plastic sealed container until ready for use.							
19																	
20																	
21																	
22																	
23																	
24																	
25																	
26																	
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	
36																	
37																	
38																	
39																	

FORM MM-71A (2-67)

TABLE 17.- Continued
MANUFACTURING PROCESS PLAN
50% NYLON RESIN, 50% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 4 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	OPERATION CODE TYPE	OPERATION CODE DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	TIME STANDARD RUN	TIME STANDARD TOTAL
1																	
2										Blow panel subassembly clean with nitrogen or					3.00	6.00	
3										filtered air.							
4																	
5										Spray core material with phenolic varnish					13.00	25.00	
6										(SC1008 Monsanto) into core cells making 4 passes							
7										or coats by criscross (2) coats each direction.							
8																	
9										Place panel on drain pan for excess varnish to						6.00	
10										drip thru 1/16 dia. holes.							
11																	
12										Let panel dry for 24 hours minimum.							
13																	
14										Install nylon plug to face sheet using screw to					3.00	13.00	
15										attach plug.							
16																	
17										Apply (Fiberglass Cloth) bleeder cloth on tool.					3.00	6.00	
18																	
19										Spray Bleeder Cloth with Teflon Release Agent.					3.00	13.00	
20																	
21																	
22										Position core panel with face sheet to bleeder						6.00	
23										cloth on tool.							
24																	
25										Install picture frame part of tool around core					3.00	6.00	
26										panel and locate to base tool.							
27																	
28										Place ablative material between side frame of					9.00	25.00	
29										tool and panel edge; pack ablative material							
30										around attachment holes.							
31																	
32										Weigh ______ of 50-50 nylon phenolic mix-					(16,00G)		
33										ture out and place amount of mix on assembly							
34										to fill core and extend above core approx. 1/2"							
35										after spreading evenly inside picture frame part					13.00	125.00	
36										of tool.							
37																	
38																	
39																	

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TABLE 17.- Continued
MANUFACTURING PROCESS PLAN
50% NYLON RESIN, 50% PHENOLIC RESIN

	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 5 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER				MFG. SUF.	D A		
	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1										Remove picture frame part of tool and cover mixture							
2										with bleeder cloth, cloth to extend over edges					13.00	25.00	
3										of mixture and assembly down to and mate with							
4										bottom bleeder cloth.							
5																	
6										Place vacuum bag over assembly, seal and pull full					6.00	38.00	
7										vacuum.							
8																	
9										Vibrate assembly to settle mixture into core							
10										material using rivet bucking air tool with large							
11										head.							
12																	
13										CAUTION NOTE: DO NOT CRUSH CORE							
14																	
15										Remove vacuum bag and top bleeder cloth.						4.00	
16																	
17										Replace top picture frame of tool and add approx.					3.00	19.00	
18										1/2" deep mixture of 50-50 nylon - phenolic over							
19										area of assembly.							
20																	
21										Remove top picture frame part of tool and cover							
22		(TEFLON BLEEDER CLOTH IS								mixture with teflon coated bleeder cloth. Cloth					13.00	31.00	
23		BUY ITEM.)								to extend over edges of mixture and assembly							
24										down to and mate with bottom bleeder cloth.							
25																	
26										Place vacuum bag over assembly, seal and pull					6.00	38.00	
27										full vacuum.							
28																	
29										Vibrate assembly to settle mixture into or 1/16							
30										to 1/4 above core material using rivet bucking					3.00	38.00	
31										air tool with large head.							
32																	
33										NOTE: CAUTION - DO NOT CRUSH CORE							
34																	
35										Place assembly into oven at 300°F for 16 hours						13.00	
36										under full vacuum.							
37																	
38																	
39																	

FORM MM-71A (2-67)

TABLE 17.- Continued
MANUFACTURING PROCESS PLAN
50% NYLON RESIN, 50% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 6 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										Remove assembly from oven and cool under vacuum to						13.00	
3										150°F min. before removing assembly from tool.							
4																	
5										Hand grind or hand plane to remove excess mat'l.					4.00	113.00	(CURVED)
6										flush to honeycomb core mat'l.						60.00	(FLAT)
7																	
8										NOTE: SPECIAL TOOLING REQUIRED TO MACHINE							
9										EXCESS MATERIAL ON PRODUCTION RUN.							
10																	
11										Layout periphery of part for final trim in					6.00	13.00	
12										relation to nylon plugs.							
13																	
14										Saw periphery of assembly per layout on band saw.						63.00	
15																	
16										NOTE: CARBIDE TIPPED SAW BLADES REQUIRED AND							
17										DUST COLLECTOR EQUIPPED SAW.							
18																	
19										Remove teflon tooling plugs and screws.						13.00	
20																	
21										Open P/Holes in face sheet to blue/print dim.					4.00	6.00	
22																	
23										Spray entire assembly with (1) coat urethane					4.00	25.00	
24										varnish.							
25																	
26										- Allow varnish to dry -							
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	
36																	
37																	
38																	
39																	

FORM MM-71A (2-67)

TABLE 17.- Concluded
MANUFACTURING PROCESS PLAN
50% NYLON RESIN, 50% PHENOLIC RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 7 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	OPERATION CODE TYPE	OPERATION CODE DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	TIME STANDARD RUN	TIME STANDARD TOTAL
1																	
2										FABRICATION OF PLUGS FOR FILLING HOLES IN CORE							
3										ASSEMBLY							
4																	
5																	
6										Fabricate a small section of material along with					10.00	38.00	
7										flat panel for making plug fillers for shipping							
8										with assemblies to fill tooling plug holes							
9										on installation.							
10																	
11										Grind or plane to core material thickness.					4.00	49.00	
12																	
13										Saw O/S .75 Dia. x core thickness for turning							
14										to size on lathe.						13.00	
15																	
16										Make setup on lathe to grind outside diameter							
17										to drawing dims. or fit of panel holes. (Use					33.00	109.00	
18										live center (1) end and sand paper opposite end							
19										to hold in lathe.)							
20																	
21										(1) Plug required for each hole on panel.							
22																	
23										Spray sealer on plugs same as panel assembly.]					3.00	19.00	
24																	
25										Place plugs into plastic bag, seal and identify					4.00	19.00	
26										with type of plug material or type assembly.							
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	
36																	
37																	
38																	
39																	

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TABLE 18
MANUFACTURING PROCESS PLAN
67% SILICONE RESIN, 33% MICROBALLOONS

PART NAME	SHEET 1 OF 6	PROJECT	DRAW FROM	ROUTE TO	PART NUMBER		MFG. SUF.	D
								A

MATERIAL/NOTES
67% SILICONE 33% MICROBALLOONS

GRID/FIND NO. ☐ LOG ☐ NONLOG
ISSUE WITH
TOOLING PHILOSOPHY
☐ PRODUCTION
☐ SPARES ☐ OTHER

EFFECTIVE DATE OF PLAN	CHANGE AUTHORITY/P.T.	DCN	SHT.	NEXT ASSEMBLY	UNIT EFFECTIVITY	CONTROL POINT	P/A	P/M	PLANNER	CHECKER/QUAL.

ENG. CHG. AUTH.	CHG.		PLAN'G. CHG.	MAT'L. CHG.
	SHT.			

	R E V	DEPT.	STEP	OPERATION CODE AREA	OPERATION CODE TYPE	OPERATION CODE DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	TIME STANDARD RUN	TIME STANDARD TOTAL
1																	
2										FABRICATION METHOD FOR ABLATIVE HEAT SHIELD							
3																	
4										FACE SHEET BONDING TO PHENOLIC GLASS (HONEYCOMB)							
5										CORE - FLAT OR CONTOURED PANELS -							
6										CORE MAT'L. PURCHASED WITH FORMED RADIUS OR							
7										FLAT - AS REQUIRED.							
8																	
9										Layout O/S profile of core mat'l. and							
10										holes per drawing.					6.00	13.00	
11																	
12										Hand cut core to layout using dough cutter							
13										and punch holes using (rubber type) hand							
14										punch.					6.00	13.00	
15																	
16										Clean core mat'l. by blowing with nitrogen							
17										or filtered air.					3.00	6.00	
18																	
19										Vapor degrease core. Material submerge in							
20										vapors only.						19.00	
21																	
22										Wrap core material in kraft paper until use.					4.00	6.00	
23																	
24										Wipe tools with safety solvent to clean and							
25										prepare for bond. Apply release agent to							
26										tool - Mold tools required.						113.00	

TABLE 18.- Continued
MANUFACTURING PROCESS PLAN
67% SILICONE RESIN, 33% MICROBALLOONS

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 2 OF 6	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	R E V	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										Remove Pre-Preg from refrigerator						6.00	
3																	
4										- Let warm to room temperature -							
5																	
6										Hand cut (2) pieces of Pre-Preg to suit mold Tool					6.00	38.00	
7										(2 thicknesses required)							
8																	
9										Start Panel Layup					13.00	19.00	
10										Lay pre-preg on tool, rollout wrinkles, strip							
11										protective film from pre-preg and apply second							
12										layer same as first.							
13																	
14										Install clean honeycomb core material on pre-preg						6.00	
15										layup on tool.							
16																	
17										Place bleeder cloth (Fiberglass Cloth) over					6.00	6.00	
18										core material.							
19																	
20										Apply vacuum bag over assy., seal with tape and						38.00	
21										pull full vacuum (23+ inch Mercury).							
22																	
23										Place vacuum settled assembly into oven						6.00	
24																	
25										Cure at 325°F for (2) hours at Temp.							
26																	
27										Remove assembly from oven and let cool under						13.00	
28										vacuum to 150°F min. before removing assembly							
29										from tool.							
30																	
31										Hand Drill 1/8 dia. holes through face sheet at					6.00	145.00	
32										(approx.) center of each honeycomb cell.							
33										Approx. 7000 holes in panel, require special						(1/16"	holes
34										carbide drills. Plus (6) attach holes.						at 60/m	in.)
35																	
36										Wrap subassembly in kraft paper until used.					4.00	6.00	
37																	
38										SEE NEXT SHEET FOR MIXING OF MATERIAL.							
39																	

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TABLE 18.- Continued
MANUFACTURING PROCESS PLAN
67% SILICONE RESIN, 33% MICROBALLOONS

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 3 OF 6	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	OPERATION CODE TYPE	OPERATION CODE DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	TIME STANDARD RUN	TIME STANDARD TOTAL
1										67% SILICONE	33% MICROBALLOONS						
2																	
3										Dry Microballoons material(2) hours at 180°F under					6.00	13.00	
4			POT LIFE OF MIXTURE							vacuum in a solids processor.							
5			IS (8) HOURS.														
6										Allow material to cool to 140°F under vacuum							
7										before removing from processor.						13.00	
8																	
9										Store Microballoons mat'l. in a desiccated sealed							
10										container when not used immediately.					6.00	25.00	
11																	
12										Weigh ________ proper amount of silicone resin							
13										& catalyst into a planetary mixer.					13.00	125.00	
14															(25 Min/Batch		
15															4 Batches		
16															2769G Res.		
17															277G Cat)		
18																	
19										Add required weight ________ of dry Microballoons							
20										to planetary mixer and mix (20) minutes					6.00	50.00	
21																	
22										NOTE: Mixture Pot Life is (8) hours.							
23																	
24										Blow panel subassembly clean with nitrogen or					3.00	6.00	
25										filtered air.							
26																	
27										Spray prime panel & core with -DC1200 Silicone					13.00	25.00	
28										primer.							
29																	
30										Allow primer to dry (2) hours minimum to (12)							
31										maximum.							
32																	
33										Record Date & Time ________ panel primed					3.00	13.00	
34																	
35										Install nylon plug to face sheet using screws					3.00	13.00	
36										to attach plug.							
37																	
38										Apply (Fiberglass Cloth) bleeder cloth on tool.					3.00	6.00	
39																	

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TABLE 18.- Continued
MANUFACTURING PROCESS PLAN
67% SILICONE RESIN, 33% MICROBALLOONS

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 4 OF 6	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										Spray bleeder cloth with teflon release agent.					3.00	13.00	
3																	
4										Position core panel with face sheet on bleeder						6.00	
5										cloth on tool.							
6																	
7										Install picture frame part of tool around core					3.00	6.00	
8										panel and locate to base tool.							
9																	
10										Place ablative material between side frame of					9.00	25.00	
11										tool and panel edge; pack ablative material							
12										around attachment holes.							
13																	
14										Place ______ weighed material into picture					13.00	124.00	FLAT
15										frame of tool on core and hand press mixture						1324.00	CURVED
16										into core of honeycomb.							
17																	
18										Vibrate					3.00	19.00	
19																	
20										Remove picture frame part of tool and install					13.00	44.00	
21										teflon coated bleeder cloth over mat'l. and core							
22										assembly. Bleeder cloth to extend over edges of							
23										assembly down to and mate with bottom bleeder							
24										cloth.							
25																	
26										Place vacuum bag over assembly, seal & pull					6.00	38.00	
27										full vacuum.							
28										Vibrate.					3.00	19.00	
29																	
30										Squeeze ablative material into core while under					3.00	19.00	
31										vacuum.							
32																	
33										Place assembly on tool into oven and cure (16)							
34										hours at 250°F under full vacuum.						13.00	
35																	
36										Remove assembly from oven and cool under vacuum						13.00	
37										to 150°F min. before removing assembly from tool.							
38																	
39																	

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TABLE 18.- Continued
MANUFACTURING PROCESS PLAN
67% SILICONE RESIN, 33% MICROBALLOONS

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 5 OF 6	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1										Use wood hand plane and remove excess mat'l. down					4.00	94.00	
2										to core. Finish by sanding with 80 grit emery							
3										cloth.							
4																	
5										Layout periphery of part fix final trim in					6.00	13.00	
6										relation to nylon plugs.							
7																	
8										Saw periphery of assembly per layout on band saw.						38.00	(FLAT
9																50.00	CURVED
10																	
11										NOTE: CARBIDE TIPPED SAW BLADES REQUIRED AND							
12										DUST COLLECTOR EQUIPPED SAW)							
13																	
14										Remove teflon tooling plugs from assembly.						13.00	
15																	
16										Open P/Holes at plug locations to drawing dims.					3.00	6.00	
17										in face sheet.							
18																	
19										Spray (1) coat of silicone dispersion (DC92007)					3.00	25.00	
20										on complete assembly.							
21																	
22										Allow assembly to air dry at room temp. for (24)							
23										hours.							
24																	
25										Place assembly in plastic bag and identify.					6.00	19.00	
26																	
27										FABRICATION OF PLUGS FOR FILLING HOLES IN CORE							
28										ASSEMBLY.							
29																	
30										Fabricate a small section of material along with					13.00	38.00	
31										flat panel for making plug fillers for shipping							
32										with assemblies to fill tooling plug holes on							
33										installation.							
34																	
35										Grind or plane to core material thickness.					4.00	13.00	
36																	
37										Saw O/S .75 Dia. X core thickness for turning						13.00	
38										to size on lathe.							
39																	

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TABLE 18.- Concluded
MANUFACTURING PROCESS PLAN
67% SILICONE RESIN, 33% MICROBALLOONS

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 6 OF 6	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	OPERATION CODE TYPE	OPERATION CODE DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	TIME STANDARD RUN	TIME STANDARD TOTAL
1										Make setup on lathe to grind outside diameter to					38.00	75.00	
2										drawing dims. or fit of panel holes. (Use live							
3										center (1) end and sand paper opposite end to						(6 PLUGS)	
4										hold in lathe).							
5																	
6										(1) plug required for each hole on panel.							
7																	
8										Spray sealer on plugs same as panel assembly.					3.00	19.00	(6 PLUGS)
9																	
10										Place plugs into plastic bag, seal and identify					6.00	19.00	
11										with type of plug material or type assembly.							
12																	
13																	
14																	
15																	
16																	
17																	
18																	
19																	
20																	
21																	
22																	
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TABLE 19
MANUFACTURING PROCESS PLAN
90% MICROBALLOONS, 10% SILICONE RESIN

PART NAME	SHEET 1 OF 7	PROJECT	DRAW FROM	ROUTE TO	PART NUMBER	MFG. SUF.	D A
MATERIAL/NOTES 90% MICROBALLOONS 10% SILICONE RESIN				GRID/FIND NO.	☐ LOG ☐ NONLOG	ISSUE WITH	
				TOOLING PHILOSOPHY		☐ PRODUCTION ☐ SPARES ☐ OTHER	

EFFECTIVE DATE OF PLAN	CHANGE AUTHORITY/P.T.	DCN	SHT.	NEXT ASSEMBLY	UNIT EFFECTIVITY	CONTROL POINT	P/A	P/M	PLANNER	CHECKER/QUAL.

ENG. CHG. AUTH.	CHG.	PLAN'G. CHG.	MAT'L. CHG.
	SHT.		

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										FABRICATION METHOD FOR ABLATIVE HEAT SHIELD							
3																	
4										Face Sheet Bonding to Phenolic Glass (Honeycomb)							
5										Core. - Flat or Contoured Panels - Core mat'l.							
6										purchased with formed radius or flat as required.							
7																	
8										Layout O/S profile of core mat'l. and holes per					6.00	13.00	
9										drawing.							
10																	
11										Hand cut core to layout using dough cutter and					6.00	13.00	
12										punch holes using (rubber type) hand punch.							
13																	
14										Clean core mat'l. by blowing with nitrogen or					3.00	6.00	
15										filtered air.							
16																	
17										Vapor Degrease core mat'l. - Submerge in vapors						19.00	
18										only -							
19																	
20										Wrap core mat'l. in kraft paper until use.					4.00	6.00	
21																	
22										Wipe tools with safety solvent to clean and pre-							
23										pare for bond. - Apply release agent to tool. -						113.00	
24										- Mold Tools Required. -							
25																	
26																	

TABLE 19.- Continued
MANUFACTURING PROCESS PLAN
90% MICROBALLOONS, 10% SILICONE RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 2 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	OPERATION CODE TYPE	OPERATION CODE DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	TIME STANDARD RUN	TIME STANDARD TOTAL
1																	
2										Remove pre-preg from refrigerator.						6.00	
3										- Let warm to room temperature -							
4										Hand cut (2) pieces of pre-preg to suit mold					6.00	38.00	
5										tool (2 thicknesses required)							
6																	
7										- Start Panel Layup -							
8										Lay pre-preg on tool, roll out wrinkles, strip					13.00	19.00	
9										protective film from pre-preg and apply second							
10										layer same as first.							
11																	
12										Install clean honeycomb core mat'l. on pre-preg						6.00	
13										layup on tool.							
14																	
15										Place bleeder cloth (Fiberglass cloth) over						6.00	
16										core mat'l.							
17																	
18										Apply vacuum bag over assembly, seal with tape					6.00	38.00	
19										and pull full vacuum (23+ inch mercury)							
20																	
21										Place vacuum sealed assembly into oven.							
22																	
23										Cure at 325°F for (2) hours at temp.							
24																	
25										Remove assembly from oven and let cool under						13.00	
26										vacuum to 150°F min. before removing assembly							
27										from tool.							
28																	
29										Hand drill 1/8 dia. holes thru face sheet at					6.00	145.00	
30										(approx.) center of each honeycomb cell.							
31										Approx. 7000 holes in panel, require special				(1/16" holes @ 60/min)			
32										carbide drills. Plus (6) attachment holes.							
33																	
34										Wrap subassembly in kraft paper until used.					4.00	6.00	
35																	
36																	
37																	
38																	
39																	

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TABLE 19.- Continued
MANUFACTURING PROCESS PLAN
90% MICROBALLOONS, 10% SILICONE RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 3 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	TYPE	DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	RUN	TOTAL
1																	
2																	
3										Dry Microballoons material (2) hours at 180°F					6.00	13.00	
4										under vacuum in a solids processor.							
5																	
6										Allow material to cool to 140°F under vacuum						13.00	
7										before removing from processor.							
8																	
9										Store Microballoons mat'l. in a desiccated sealed					6.00	25.00	
10										container when not used immediately.							
11																	
12										Weigh ________ of silicone resin and catalyst					13.00	19.00	
13										into a small planetary mixer.							
14																	
15										Add equal amount of heptane to mixer as silicone					13.00	13.00	
16										resin and catalyst.							
17																	
18										Mix for 10 minutes						13.00	
19																	
20										Place weighed amount ________ of dry Micro-					6.00	38.00	
21										balloons into large planetary vacuum mixer. Add							
22										1/2 of mixed resin and catalyst mixture to							
23										Microballoons and mix (2) minutes.							
24																	
25										Add remainder of resin and catalyst mix to Micro-					6.00	13.00	
26										balloons mixture and mix for 25 to 28 minutes.					MIX	38.00	
27																	
28										Apply full vacuum to mixer and mix for additional							
29										45 minutes.					13.00	63.00	
30																	
31										NOTE: This Operation flashes off solvent.							
32																	
33										Blow panel subassembly clean with nitrogen or					3.00	6.00	
34										filtered air.							
35																	
36										Spray Prime Panel and Core with DC1200 Silicone					13.00	25.00	
37										Primer.							
38																	
39																	

FORM MM-71A (2-67)

TABLE 19.- Continued
MANUFACTURING PROCESS PLAN
90% MICROBALLOONS, 10% SILICONE RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 4 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1										Allow primer to dry (2) hours minimum to (12)							
2										hours maximum.							
3																	
4										Record date and time ______________					3.00	13.00	
5										panel primed.							
6																	
7																	
8										- Mix Wet Coat -							
9										Mix 90% silicone resin, 10% catalyst and heptane					13.00	25.00	
10										equal to 10% of resin and catalyst in a small							
11										planetary mixer for (10) minutes.							
12																	
13										Spray wet coat mixture on inside of honeycomb					6.00	38.00	
14										core.							
15										- (4) coats required -							
16										(2) Two Cross Coats each direction.							
17																	
18										Allow assembly to drain (1) hour.					6.00		
19																	
20																	
21										Apply (Fiberglass Cloth) bleeder cloth on tool.					3.00	6.00	
22																	
23										Spray bleeder cloth with teflon release agent.					3.00	13.00	
24																	
25										Position core panel with face sheet on bleeder						6.00	
26										cloth on tool.							
27																	
28										Install picture frame part of tool around core					3.00	6.00	
29										panel and locate to base tool.							
30																	
31										Place ablative material between side frame of					9.00	25.00	
32										tool and panel edge; Pack ablative material							
33										around attachment holes.							
34																	
35										Weigh ______________ of mixture out and place					13.00	38.00	
36										amount of mix on ass'y. to fill core and extend							
37										above core approx. 1/2" after spreading evenly							
38										inside picture frame part of tool.							
39																	

FORM MM-71A (2-67)

TABLE 19.- Continued
MANUFACTURING PROCESS PLAN
90% MICROBALLOONS, 10% SILICONE RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 5 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE AREA	OPERATION CODE TYPE	OPERATION CODE DET.	U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD SET-UP	TIME STANDARD RUN	TIME STANDARD TOTAL
1																	
2										Remove picture frame part of tool and cover					13.00	31.00	
3										mixture with bleeder cloth, cloth to extend							
4										over edges of mixture and assembly down to and							
5										mate with bottom bleeder cloth.							
6																	
7										Place vacuum bag over assembly, seal and pull					6.00	38.00	
8										full vacuum.							
9																	
10										Vibrate assembly to settle mixture into core					3.00	19.00	
11										material using rivet bucking air tool with large							
12										head.							
13																	
14										NOTE: CAUTION - DO NOT CRUSH CORE.							
15																	
16										Remove vacuum bag and top bleeder cloth.						4.00	
17																	
18										Replace top picture frame of tool and add balance					3.00	13.00	
19										of mixture and spread evenly over area of ass'y.							
20																	
21										Remove top picture frame part of tool and cover							
22		(TEFLON BLEEDER CLOTH IS								mixture with teflon coated bleeder cloth, cloth					13.00	31.00	
23		BUY ITEM.)								to extend over edges of mixture and assembly							
24										down to and mate with bottom bleeder cloth.							
25																	
26										Place vacuum bag over assembly, seal and pull					6.00	38.00	
27										full vacuum.							
28																	
29										Vibrate assembly to settle mixture into or 1/16"							
30										above core material using rivet bucking air tool					3.00	19.00	
31										with a large head.							
32																	
33										NOTE: CAUTION - DO NOT CRUSH CORE							
34																	
35										Place assembly and tool into oven and cure (16)						13.00	
36										hours at 250°F under full vacuum.							
37																	
38																	
39																	

FORM MM-71A (2-67)

TABLE 19.- Continued
MANUFACTURING PROCESS PLAN
90% MICROBALLOONS, 10% SILICONE RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 6 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF. D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										Remove assembly from oven and cool under vacuum						13.00	
3										to 150°F min. before removing assembly from tool.							
4																	
5										Use wood hand plane and remove excess material					4.00	81.00	(CURVED)
6										down to core. Finish by sanding with 80 grit						75.00	(FLAT)
7										emery cloth.							
8																	
9										Layout periphery of part for final trim in					6.00	10.00	
10										relation to nylon tooling plugs.							
11																	
12										Saw periphery of assembly per layout on Band Saw.						38.00	(FLAT)
13																50.00	(CURVED)
14										NOTE: CARBIDE TIPPED SAW BLADES REQUIRED AND							
15										DUST COLLECTOR EQUIPPED SAW.							
16																	
17										Remove teflon tooling plugs from assembly.						13.00	
18																	
19										Open pilot holes at plug locations to drawing					3.00	6.00	
20										dims. thru face sheet.							
21																	
22										Spray (1) coat of silicone dispersion (DC92007)					3.00	25.00	
23										on complete assembly.							
24																	
25										Allow assembly to air dry at room temp. for (24)							
26										hours.							
27																	
28										Place assembly in plastic bag and identify.					6.00	19.00	
29																	
30																	
31																	
32																	
33																	
34																	
35																	
36																	
37																	
38																	
39																	

FORM MM-71A (2-67)

TABLE 19.- Concluded
MANUFACTURING PROCESS PLAN
90% MICROBALLOONS, 10% SILICONE RESIN

PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	PLAN DATE	SHEET 7 OF 7	GRID/FIND NO.	PLANNER	CHECKER/QUAL.	PART NUMBER	MFG. SUF.	D A

	REV	DEPT.	STEP	OPERATION CODE			U OR D	QTY. REQ. PER ASSY.	MAT'L. HAND'G.	TOOL NO. OR PART NO.	FIND	REMOVE FROM/ADDED TO	SPEED	FEED	TIME STANDARD		
				AREA	TYPE	DET.									SET-UP	RUN	TOTAL
1																	
2										FABRICATION OF PLUGS FOR FILLING HOLES IN CORE							
3										ASSEMBLY.							
4																	
5										Fabricate a small section of material along with					13.00	38.00	
6										flat panel for making plug fillers for shipping							
7										with assemblies to fill tooling plug holes on							
8										installation.							
9																	
10										Grind or plane to core material thickness.					4.00	50.00	
11																	
12										Saw O/S .75 Dia. X core thickness for turning to						13.00	
13										size on lathe.							
14																	
15										Make setup on lathe to grind outside diameter							
16										to drawing diameters or fit of panel holes.					38.00	175.00	
17										(Use live center (1) end and sand paper opposite							
18										end to hold in lathe).							
19																	
20										(1) plug required for each hole on panel.							
21																	
22										Spray sealer on plugs same as panel assembly.					3.00	19.00	
23															(6 PLUGS)		
24																	
25										Place plugs into plastic bag, seal and identify							
26										with type of plug material or type assembly.					6.00	19.00	
27																	
28																	
29																	
30																	
31																	
32																	
33																	
34																	
35																	
36																	
37																	
38																	
39																	

FORM MM-71A (2-67)

TABLE 20

MANUFACTURING AND TOOLING DIRECT COST[*] - ONE FLIGHT

Description[†]	Mat'l[‡]	No. of panels	Lots of 1					Lots of 10					Lots of 100 or total lot				
			Tooling labor, hr	Tooling mat'l, $	Fabrication labor, hr	Pack, & ship labor, hr	Pack, & ship mat'l, $	Tooling labor, hr	Tooling mat'l, $	Fabrication labor, hr	Pack, & ship labor, hr	Pack, & ship mat'l, $	Tooling labor, hr	Tooling mat'l, $	Fabrication labor, hr	Pack, & ship labor, hr	Pack, & ship mat'l, $
2x4-ft flat panel	A	100	170	510	3 000	72	648	238	714	2 300	72	648	272	816	2100	72	648
	B	100	170	510	3 100	72	648	238	714	2 400	72	648	272	816	2200	72	648
	C	100	170	510	4 300	72	648	238	714	3 400	72	648	272	816	3100	72	648
	D	100	170	510	3 400	72	648	238	714	2 600	72	648	272	816	2400	72	648
3x5-ft flat panel	A	40	68	204	1 640	36	324	95	285	1 360	36	324	109	327	1280	36	324
	B	40	68	204	1 680	36	324	95	285	1 400	36	324	109	327	1320	36	324
	C	40	68	204	2 360	36	324	95	285	2 000	36	324	109	327	1880	36	324
	D	40	68	204	1 840	36	324	95	285	1 520	36	324	109	327	1440	36	324
4x6-ft flat panel	A	25	43	129	1 600	18	162	60	180	1 450	18	162	69	207	1400	18	162
	B	25	43	129	1 650	18	162	60	180	1 475	18	162	69	207	1425	18	162
	C	25	43	129	2 325	18	162	60	180	2 100	18	162	69	207	2025	18	162
	D	25	43	129	1 800	18	162	60	180	1 600	18	162	69	207	1550	18	162
2x4-ft single-curved panel	A	125	213	639	6 250	90	810	298	894	5 125	90	810	341	1023	4750	90	810
	B	125	213	639	3 875	90	810	298	894	3 000	90	810	341	1023	2750	90	810
	C	125	213	639	5 625	90	810	298	894	4 375	90	810	341	1023	4000	90	810
	D	125	213	639	4 250	90	810	298	894	3 125	90	810	341	1023	2875	90	810
2x4-ft double-curved panel	A	250	416	1248	13 000	180	1620	582	1746	10 500	180	1620	666	1998	9250	180	1620
	B	250	416	1248	8 250	180	1620	582	1746	6 000	180	1620	666	1998	5500	180	1620

[*] Hours based on using: 95% curve for lots of one;
92% curve for lots of ten;
90% curve for lots of one hundred.

[†] Fabrication labor includes 25% allowance for rejection and rework.
Select one high-density panel and one low-density panel for each configuration.

[‡] A = 67% silicone, 33% Microballoons;
B = 50% phenolic, 50% nylon;
C = 70% Microballoons, 15% nylon, 15% phenolic;
D = 90% Microballoons, 10% silicone.

TABLE 21

MANUFACTURING AND TOOLING DIRECT COST* - 10 FLIGHTS

				Lots of 1				Lots of 10					Lots of 100 or total lot				
Description†	Mat'l‡	No. of panels	Tooling labor, hr	Tooling mat'l, $	Fabrication labor, hr	Pack, & ship labor, hr	Pack, & ship mat'l, $	Tooling labor, hr	Tooling mat'l, $	Fabrication labor, hr	Pack, & ship labor, hr	Pack, & ship mat'l, $	Tooling labor, hr	Tooling mat'l, $	Fabrication labor, hr	Pack, & ship labor, hr	Pack, & ship mat'l, $
2x4-ft flat panel	A	1000	500	1500	25 000	720	6 480	700	2100	18 000	720	6 480	800	2400	11 000	720	6 480
	B	1000	500	1500	26 000	720	6 480	700	2100	19 000	720	6 480	800	2400	11 000	720	6 480
	C	1000	500	1500	36 000	720	6 480	700	2100	27 000	720	6 480	800	2400	16 000	720	6 480
	D	1000	500	1500	29 000	720	6 480	700	2100	20 000	720	6 480	800	2400	12 000	720	6 480
3x5-ft flat panel	A	400	200	600	13 600	360	3 240	280	840	10 400	360	3 240	320	960	9 200	360	3 240
	B	400	200	600	14 000	360	3 240	280	840	10 400	360	3 240	320	960	9 200	360	3 240
	C	400	200	600	19 600	360	3 240	280	840	15 200	360	3 240	320	960	13 200	360	3 240
	D	400	200	600	15 600	360	3 240	280	840	11 600	360	3 240	320	960	10 000	360	3 240
4x6-ft flat panel	A	250	125	375	13 500	180	1 620	175	525	11 000	180	1 620	200	600	9 750	180	1 620
	B	250	125	375	14 000	180	1 620	175	525	11 250	180	1 620	200	600	10 000	180	1 620
	C	250	125	375	19 750	180	1 620	175	525	16 000	180	1 620	200	600	14 250	180	1 620
	D	250	125	375	15 250	180	1 620	175	525	12 000	180	1 620	200	600	10 750	180	1 620
2x4-ft single-curved panel	A	1250	625	1875	45 000	900	8 100	875	2625	32 500	900	8 100	1000	3000	23 750	900	8 100
	B	1250	625	1875	27 500	900	8 100	875	2625	18 750	900	8 100	1000	3000	13 750	900	8 100
	C	1250	625	1875	40 000	900	8 100	875	2625	27 500	900	8 100	1000	3000	20 000	900	8 100
	D	1250	625	1875	30 000	900	8 100	875	2625	20 000	900	8 100	1000	3000	13 750	900	8 100
2x4-ft double-curved panel	A	2500	1250	3750	92 500	1800	16 200	1750	5250	65 000	1800	16 200	2000	6000	45 000	1800	16 200
	B	2500	1250	3750	57 500	1800	16 200	1750	5250	37 500	1800	16 200	2000	6000	27 500	1800	16 200

*Hours based on using: 95% curve for lots of one;
92% curve for lots of ten;
90% curve for lots of one hundred.

†Fabrication labor includes 25% allowance for rejection and rework.
Select one high-density panel and one low-density panel for each configuration.

‡A = 67% silicone, 33% Microballoons;
B = 50% phenolic, 50% nylon;
C = 70% Microballoons, 15% nylon, 15% phenolic;
D = 90% Microballoons, 10% silicone.

TABLE 22

MANUFACTURING AND TOOLING DIRECT COST* - 100 FLIGHTS

			Lots of 1					Lots of 10					Lots of 100 or total lot				
Description†	Mat'l‡	No. of panels	Tooling labor, hr	Tooling mat'l, $	Fabri- cation labor, hr	Pack, & ship labor, hr	Pack, & ship mat'l, $	Tooling labor, hr	Tooling mat'l, $	Fabri- cation labor, hr	Pack, & ship labor, hr	Pack, & ship mat'l, $	Tooling labor, hr	Tooling mat'l, $	Fabri- cation labor, hr	Pack, & ship labor, hr	Pack, & ship mat'l, $
2x4-ft flat panel	A	10 000	2000	6 000	180 000	7 200	64 800	2800	8 400	110 000	7 200	64 800	3200	9 600	70 000	7 200	64 800
	B	10 000	2000	6 000	190 000	7 200	64 800	2800	8 400	110 000	7 200	64 800	3200	9 600	80 000	7 200	64 800
	C	10 000	2000	6 000	260 000	7 200	64 800	2800	8 400	160 000	7 200	64 800	3200	9 600	110 000	7 200	64 800
	D	10 000	2000	6 000	200 000	7 200	64 800	2800	8 400	120 000	7 200	64 800	3200	9 600	80 000	7 200	64 800
3x5-ft flat panel	A	4 000	800	2 400	116 000	3 600	32 400	1120	3 360	80 000	3 600	32 400	1280	3 840	44 000	3 600	32 400
	B	4 000	800	2 400	120 000	3 600	32 400	1120	3 360	84 000	3 600	32 400	1280	3 840	48 000	3 600	32 400
	C	4 000	800	2 400	168 000	3 600	32 400	1120	3 360	120 000	3 600	32 400	1280	3 840	64 000	3 600	32 400
	D	4 000	800	2 400	128 000	3 600	32 400	1120	3 360	88 000	3 600	32 400	1280	3 840	12 000	3 600	32 400
4x6-ft flat panel	A	2 500	500	1 500	97 500	1 800	16 200	700	2 100	67 500	1 800	16 200	800	2 400	47 500	1 800	16 200
	B	2 500	500	1 500	100 000	1 800	16 200	700	2 100	70 000	1 800	16 200	800	2 400	50 000	1 800	16 200
	C	2 500	500	1 500	141 000	1 800	16 200	700	2 100	97 500	1 800	16 200	800	2 400	70 000	1 800	16 200
	D	2 500	500	1 500	107 500	1 800	16 200	700	2 100	75 000	1 800	16 200	800	2 400	55 000	1 800	16 200
2x4-ft single-curved panel	A	12 500	2500	7 500	375 000	9 000	81 000	3500	10 500	225 000	9 000	81 000	4000	12 000	182 500	9 000	81 000
	B	12 500	2500	7 500	247 500	9 000	81 000	3500	10 500	125 000	9 000	81 000	4000	12 000	100 000	9 000	81 000
	C	12 500	2500	7 500	337 500	9 000	81 000	3500	10 500	187 500	9 000	81 000	4000	12 000	137 500	9 000	81 000
	D	12 500	2500	7 500	250 000	9 000	81 000	3500	10 500	137 500	9 000	81 000	4000	12 000	100 000	9 000	81 000
2x4-ft double-curved panel	A	25 000	5000	15 000	775 000	18 000	162 000	7000	21 000	450 000	18 000	162 000	8000	24 000	325 000	18 000	162 000
	B	25 000	5000	15 000	500 000	18 000	162 000	7000	21 000	275 000	18 000	162 000	8000	24 000	200 000	18 000	162 000

*Hours based on using: 95% curve for lots of one;
92% curve for lots of ten;
90% curve for lots of one hundred.

†Fabrication labor includes 25% allowance for rejection and rework.
Select one high-density panel and one low-density panel for each configuration.

‡A = 67% silicone, 33% Microballoons;
B = 50% phenolic, 50% nylon;
C = 70% Microballoons, 15% nylon, 15% phenolic;
D = 90% Microballoons, 10% silicone.

NASA CR-111800

National Aeronautics and Space Administration
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Huel H. Chandler. October 1970.

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This report presents the results of a study to determine the cost of fabricating replaceable ablative heat shield panels for Space Shuttles. Curved and flat 2x4-ft panels were fabricated from four ablative compositions using processes developed under this study. Time studies were conducted to estimate the cost of fabricating panels of various configurations and lot sizes, based on one, 10, and 100 flights. Panel costs varied from a high of $296.66 per square foot for a double-contoured, 2x4-ft panel made of 67% silicone resin and 33% phenolic microballoons to a low of $48.96 per square foot for a 4x6-ft panel composed of 90% microballoons and 10% silicone resin.

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