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# REFURBISHMENT COST STUDY OF THE THERMAL PROTECTION SYSTEM OF A SPACE SHUTTLE VEHICLE

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NASA CR-112034-1

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## FINAL REPORT - PHASE II SUPPLEMENT

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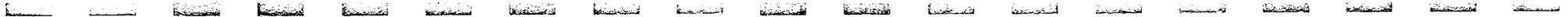


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## FINAL REPORT - PHASE II SUPPLEMENT

### Refurbishment Cost Study of the Thermal Protection System of a Space Shuttle Vehicle

By D. W. Haas & V. M. Gerler - McDonnell Douglas Astronautics Company - East

#### SUMMARY

This report contains the results of Task II of the subject study which was an extension of the Task I, Phase II, effort documented in NASA CR-112034, dated 1 April 1972. The purpose of the Task II effort was to identify the labor costs and techniques associated with the maintenance of a bonded-on ablator thermal protection system (TPS) concept, suitable for Space Shuttle application, in a manner similar to that done for TPS concepts tested during Task I. The objectives and scope of the extension work were identical with that performed previously, except as noted herein. For purposes of brevity, many of the detailed aspects of the overall test program are not repeated in this document; the reader is therefore, referred to the basic report for more complete information. Only those aspects of the Task I effort which are needed to substantiate the Task II effort have been repeated.

The baseline approach to TPS attachment proposed by MDAC for the Space Shuttle Orbiter involves bonding reusable surface insulation (RSI) and/or ablators to the structural skin of the vehicle. The RSI and/or ablators in the form of either flat or contoured panels can be bonded to the skin of the primary structure directly or by way of an intermediate silicone foam rubber pad. The use of foam rubber pads permits the use of buckling skins and protruding head rivets on the primary structure, minimizing structural weight and fabrication costs. In the case of the RSI, the foam rubber pad serves as a required strain isolator. For purposes of comparison, test data were obtained for an installation with and without the use of a strain isolator. During Task I, the refurbishment aspects of a bonded-on RSI concept (without a strain isolator) were examined experimentally along with several externally removable panel concepts employing both ablator and RSI TPS. The various concepts are compared in this report.

The two most important aspects of the Task II effort were to:

- (1) determine the scheduled and unscheduled maintenance costs and techniques of the bonded-on ablator TPS concept and
- (2) establish an inspection and certification plan to verify ablator panel-to-substructure bond integrity.

Scheduled maintenance, as defined here, would involve 100 percent removal and replacement of TPS panels associated with vehicle maintainability after the vehicle has experienced its normal flight environment. Unscheduled maintenance,

on the other hand, involves partial removal and replacement of the TPS panels prior to flight-environment exposure. Those activities, which would affect unscheduled maintenance include, but are not necessarily limited to, handling, transportation, prelaunch operations, and aborts. It was not the intention of this study to cite or analyze all the possibilities which might occur in the maintenance of a vehicle's TPS, but rather to give enough basic information concerning refurbishment so that the reader can understand his own particular situations and formulate estimates of similar or related systems.

In verifying bond integrity, consideration was given to state-of-the-art nondestructive evaluation (NDE) methods assuming:

- (1) that access to the unprotected side of the vehicle structure could be achieved and
- (2) that access to the unprotected side of the vehicle structure could not be achieved.

Static bonding tests were conducted to determine task duration and productive times involved in verifying bond integrity as one approach to NDE inspection.

Scheduled removal and replacement task duration time and manpower requirements of the bonded-on ablator TPS concept in comparison with the TPS concepts investigated during Task I are provided in table 1.

**TABLE 1**  
**SCHEDULED REMOVAL AND REPLACEMENT COMPARISON**

TPS ATTACH CONCEPT	TASK DURATION TIME HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTIVE PRODUCTIVE TIME MHR/M <sup>2</sup> (MHR/FT <sup>2</sup> )
ABLATOR KEY/KEYWAY	0.492(0.046)	0.753(0.070)
ABLATOR PI-STRAP	0.516(0.048)	1.001(0.093)
ABLATOR MULTIPLE FASTENER	0.527(0.049)	1.173(0.109)
HCF KEY/KEYWAY	0.764(0.071)	1.248(0.116)
ABLATOR BOND-ON (WITHOUT STRAIN ISOLATOR)	(1) 2.063(0.191) (2) 2.894(0.346)	4.406(0.409) 6.043(0.561)
ABLATOR BOND-ON (WITH STRAIN ISOLATOR)	(1) 2.911(0.270) (2) 4.200(0.390)	6.032(0.561) 8.576(0.797)
HCF BOND-ON (WITHOUT STRAIN ISOLATOR)	(1) 6.370 (0.592)	10.954(1.018)

- (1) DENOTES "NON-WATER-BREAK" FREE SURFACE
- (2) DENOTES "WATER-BREAK" FREE SURFACE

These data represent a situation based on the assumption that the TPS has gone through an entry environment which has rendered the heat shield assembly not reusable, necessitating 100 percent replacement. In each concept noted, the data are representative of the largest size panel tested. The term "water-break" and "nonwater-break" free surface refers to the degree of cleanliness of

the skin of the primary structure prior to bonding on the heat shield material. Detail aspects of the subject are contained in the main text. In the case of the ablator multiple fastener attach concept, the support panel, under scheduled maintenance conditions, would remain on the vehicle. Access to internal equipment in this instance would not be possible unless the support panel was removed. In both the ablator pi-strap (so named for its  $\pi$  shape) and ablator and HCF key/keyway attach concepts, both the heat shield and the support panel would come off the vehicle at the same time. The time required to remove the heat shield from the support panel in these latter concepts is not included, since this function would probably take place at a later time and possibly at a different location. Either new or reconditioned TPS components would be used for replacement in all cases. It should be noted that the ablator key/keyway attach concept values are based on extrapolation of test data, since this configuration was not tested in Task I of the program. Also, values shown for the HCF direct bond approach were taken to be equal to one-third of those shown for the unscheduled HCF direct bond approach.

Unscheduled removal and replacement task duration and manpower requirements of the bonded-on ablator TPS concept in comparison with the other TPS concepts investigated during Task I are provided in table 2.

**TABLE 2  
UNSCHEDULED REMOVAL AND REPLACEMENT COMPARISON**

TPS ATTACH CONCEPT	TASK DURATION TIME HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTIVE PRODUCTIVE TIME MHR/M <sup>2</sup> (MHR/FT <sup>2</sup> )
ABLATOR MULTIPLE FASTENER	0.549(0.051)	1.237(0.115)
ABLATOR PI-STRAP	0.667(0.062)	1.410(0.131)
ABLATOR KEY/KEYWAY	1.474(0.137)	2.152(0.200)
HCF KEY/KEYWAY	3.411(0.317)	5.800(0.539)
ABLATOR BOND-ON (WITHOUT STRAIN ISOLATOR)	(1) 2.594(0.241) (2) 3.583(0.333)	5.662(0.526) 7.616(0.708)
ABLATOR BOND-ON (WITH STRAIN ISOLATOR)	(1) 3.556(0.331) (2) 5.092(0.474)	7.499(0.697) 10.536(0.979)
HCF DIRECT BOND	(1) 19.110(1.776)	32.861(3.054)

(1) DENOTES "NON-WATER-BREAK" FREE SURFACE

(2) DENOTES "WATER-BREAK" FREE SURFACE

These data represent situations in which a random TPS panel would be removed and replaced prior to flight for one, or a combination, of the following reasons:

damage has occurred to the basic heat shield and/or support panel

access to internal insulation or equipment is required

damage has occurred to TPS support structure.

The data cited above give the requirements for removing and replacing a selected heat shield assembly surrounded by similar components of the same design. The primary difference between the scheduled and unscheduled situations lies in the boundary conditions between panels at the time of removal and/or replacement. In the case of the scheduled removal and replacement exercise, successive removal of the panels is made easier by the elimination of one or more edge constraints of the previously removed panel. On the other hand, during the unscheduled maintenance situation, panels must be removed or fitted in place between adjacent panels (with all four edges of the panel coming into play). Values shown for the unscheduled ablator direct bond approach are approximately 25 percent higher than those shown for the scheduled ablator direct bond approach.

As in the case of the TPS concepts investigated during Task I, the bonded-on ablator concept was analyzed for a representative Space Shuttle configuration. This analysis was parametric in nature and was based on the use life of a single vehicle having a 100-flight life. That is, various use-life estimates of the heat shield material and percentages of the vehicle TPS area refurbished during scheduled and unscheduled maintenance were assumed.

The results of the analysis show that average \$/flight to refurbish a vehicle employing a bonded-on ablator TPS can range anywhere from approximately \$88,600 to \$127,800. Correspondingly, results of the Task I effort show that the bonded-on RSI TPS concept can range anywhere from approximately \$14,800 to \$50,000 per flight. From the analysis it is evident that of the variables considered, heat shield material use-life is by far the most significant. Current state-of-the-art ablators have, for the most part, a use-life of one flight. However, if the ablator material does not experience temperatures above 672°K (750°F) it is assumed that its use-life could be extended to 100 flights. The current goal in the development of RSI is to have a use-life of at least 100 flights.

Comparison of the bonded-on TPS concepts with the externally removable panel concepts, investigated in Task I, shows a marked distinction. Analysis of these latter TPS concepts, for the same vehicle configuration, shows the maintenance labor costs to vary from \$3,000 to \$17,000 per flight. Thus, it is clear from a maintenance labor point of view that the externally removable TPS concept is more cost effective than the bonded-on TPS approach.

During the course of the Task II effort, various types of nondestructive evaluation (NDE) techniques for establishing bond integrity were assessed, including X-ray, acoustics, microwave, ultrasonics, acoustic emission, holography, and proof loading. With the exception of X-ray, all other techniques provide some promise of establishing bond integrity. However, none of these methods has been developed to the extent that it provides an absolutely positive NDE approach. The most reliable method to date involves proof or static testing.

Since even this approach has some significant limitations, bond integrity verification currently represents a major NDE problem for the Space Shuttle TPS. Therefore, much more extensive work must be done in this area on the part of industry and the government to come up with a totally reliable technique(s) for bond inspection.

Because of the above limitations, the quality assurance plan included in this report is limited to external access bond verification by tensile testing of process control coupons fabricated in parallel with the bonded-on ablator panels. This, coupled with carefully executed and fully documented material and process control, is considered to be the only available bond quality assurance approach at this time. The in-process control method of bond certification implements traceability and qualification of raw materials, proven state-of-the-art fabrication, and bonding techniques.

## INTRODUCTION

This document presents the results of Task II of NASA Contract NAS 1-10990 (Phase II) of the "Refurbishment Cost Study of the Thermal Protection System of a Space Shuttle Vehicle" performed for the National Aeronautics and Space Administration - Langley Research Center (NASA-LRC) by the McDonnell Douglas Astronautics Company - East (MDAC-E), St. Louis, Missouri. The results of Task I are reported in NASA CR-112034, dated 1 April 1972.

The proposed baseline TPS for the NASA Space Shuttle Orbiter consists of a reusable surface insulation (RSI) and/or ablator material bonded directly to the skin of the primary structure. During Task I the refurbishment aspects of a bonded-on RSI concept were examined experimentally on a full-scale mockup, along with several externally removable panel concepts employing both ablator and RSI TPS. To complete the data base, the contract was extended to determine the operational costs and problems associated with the maintenance of a bonded-on ablator concept. This document presents the results of that investigation and compares them with the results obtained in Task I.

The test program conducted in Task II was similar to that performed in Task I. Specifically Task II consisted of designing an aluminum sheet-stringer structure to which various size ablator panels are bonded with a silicone adhesive, fabricating required components for use on a full scale mockup, monitoring specific maintenance task functions simulating operational procedures, and evaluating these maintenance functions from both cost and technique standpoints.

A critical parameter with the bonded-on ablator concept is verification of bond integrity. Thus, a plan was generated for inspection and certification of the ablative TPS after bonding to insure acceptable bond integrity. Consideration was given to state-of-the-art nondestructive evaluation (NDE) methods assuming

- (1) access to the unprotective side of the aluminum structure could be achieved and
- (2) that access to the unprotected side of the aluminum structure could not be achieved.

In addition static bonding tests were conducted to verify bond integrity and estimates made as to the number and cost of such tests for an actual Space Shuttle TPS.

Mr. D. W. Haas, Study Manager, was responsible for overall technical direction of the study. In support of the study manager, other members of the McDonnell Douglas engineering staff included V. M. Gerler (Deputy Study Manager), F. R. LeTrello, M. J. Snyder, W. Bennett, R. Fleck, W. E. Wehrend, and J. R. Cadieux.

Mr. G. C. Olsen, of the Materials Division, Langley Research Center, Hampton, Virginia, was the NASA Technical Monitor for the study.

The units used for the physical quantities defined in this report are given in both the International System of Units (SI) and U. S. customary units. Factors relating the units of these systems are given in reference 33.

#### OBJECTIVES AND SCOPE

The individual objectives of Task II were to:

design an aluminum sheet-stringer structure to which ablator panels are bonded

design ablator panels using the same materials and ablator composition used in Task I

select a material for adhesively bonding the ablator panels to the aluminum structure

manufacture the aluminum structure and ablator panels

develop a "Maintenance Task Schedule" in the same manner as those prepared in Phase I (NAS 1-10093)

develop a Test Plan including:

a plan for adhesively bonding the ablator panels to the aluminum substructure

a plan for filling the joints between edges of adjacent panels after bonding

a plan for inspection and certification of the ablative TPS after bonding to insure acceptable bond integrity

a plan for removing the ablator panels from the aluminum structure, including cleaning the aluminum

implement the Test Plan on the NASA-LRC mockup, using the same documentation procedures employed in Task I

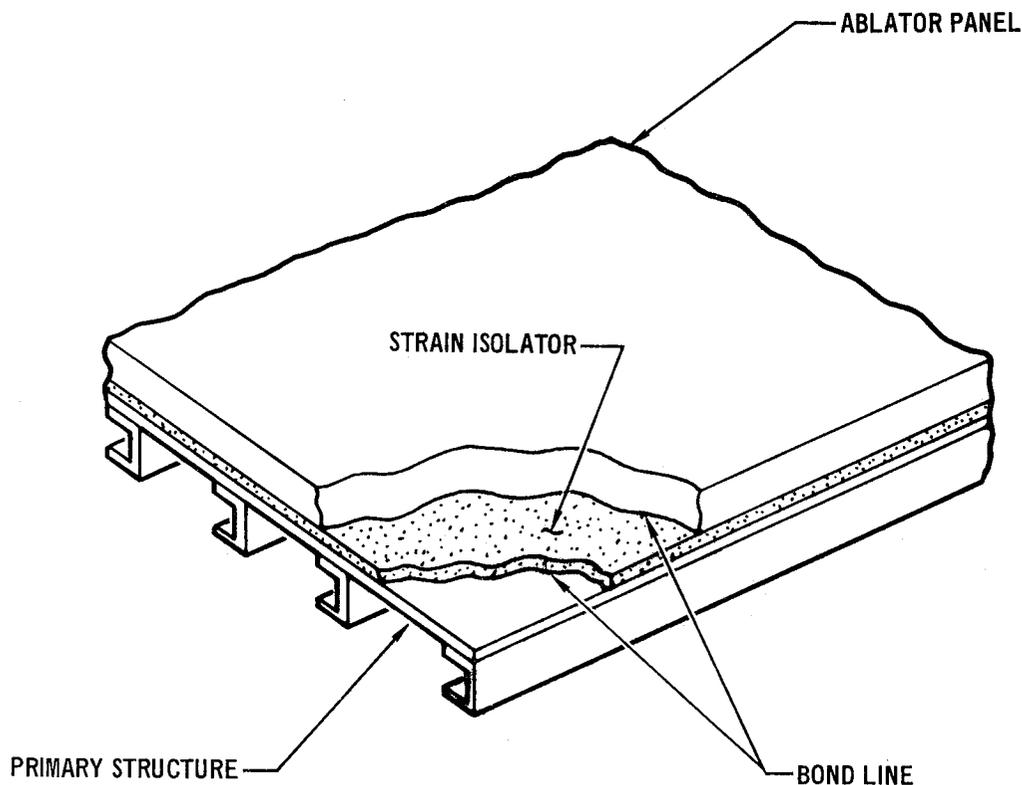
The experimental test program reported in Task I, Phase II, of NASA CR-112034 served as the baseline approach for the work performed during Task II. The test program was limited to the investigation of bonded-on ablator panels. The term ablator panel as applied herein refers to the combination of an elastomeric material in a phenolic glass honeycomb core. Ablator panel sizes were limited to approximately 56 by 142 centimeters (22 by 56 inches), and 56 by 71 centimeters (22 by 28 inches). The aluminum substructure was flat and measured approximately 152 by 178 centimeters (60 by 70 inches). Skin gauges and stiffener spacing were consistent with those proposed by MDAC for the Space Shuttle Orbiter Vehicle.

In general, the test program consisted of investigating various refurbishment activities, concluded by a final layup of the test panels on the mockup for display purposes. Individual tests covered initial installation of the ablator panels on the aluminum substructure, performance of static tests to verify bond integrity, removal of the ablator panels after charring under a simulated thermal environment, cleaning and reconditioning the skin of the substructure, and reapplication of new ablator panels to the substructure. The ultimate objective of each test was to assess the individual maintenance task functions in terms of number of manhours, elapsed time, equipment, and techniques required to perform a specific refurbishment activity.

#### TPS ATTACH CONCEPT

The baseline approach to TPS attachment proposed by MDAC for the Space Shuttle Orbiter involves bonding RSI and/or ablators to the structural skin of the vehicle, as shown in figure 1. The RSI and/or ablators in the form of flat or contoured panels are bonded to the skin of the primary structure, either directly or by way of an intermediate silicone sponge pad. The use of the silicone sponge permits the use of buckling skins and protruding head rivets on the primary structure, minimizing structural weight and fabrication costs. In the case of RSI, the silicone sponge serves as a required strain isolator. Both the direct bond and intermediate silicone sponge approach were investigated in this study. The use of the silicone sponge is currently considered as Shuttle baseline TPS by MDAC and is described in detail in subsequent text.

Prior to bonding, vehicle skins are thoroughly cleaned to provide a "water-break" free surface which cannot be allowed to oxidize between final cleaning and the first bonding operation. The term "water-break" free surface implies a true wetting of the surface in which the water forms a film on the surface without any breaks in the film or formation of beads. After the vehicle surface is



**FIGURE 1 DIRECT BOND-ON ATTACH CONCEPT**

cleaned, a thin coating of silicone primer is brushed or spray applied to the structural skin. The primer is allowed to hydrolyze for a period of time (time depending on the relative humidity and temperature in the application area). For the adhesive bond to be reliably effected, acceptable humidity and temperature conditions must be maintained to assure proper prime hydrolysis.

After acceptable cure, a thin layer of silicone adhesive is applied to the primed surface with an automatic mixer/application head, which proportions and (air-free) mixes the two components of the adhesive immediately prior to application. Once the adhesive is applied to a given work area, the silicone sponge is installed and held in position under a uniform pressure for a minimum of 24 hours to allow the adhesive to cure. The load can be applied mechanically or by using differential atmospheric pressure.

Once the silicone sponge is securely bonded to the skin of the vehicle, the same process of adhesive application is repeated to the outer moldline of the silicone sponge for subsequent application of the ablator panels. After ablator panel installation, a uniform pressure is then reapplied and held for the same period of time as in the case of the silicone sponge installation. A vehicle as large as the Space Shuttle Orbiter presents obvious manufacturing problems, in that TPS installation will require extensive multilevel work stands. These must enable placement of panels, as well as application of contact pressure during adhesive cure.

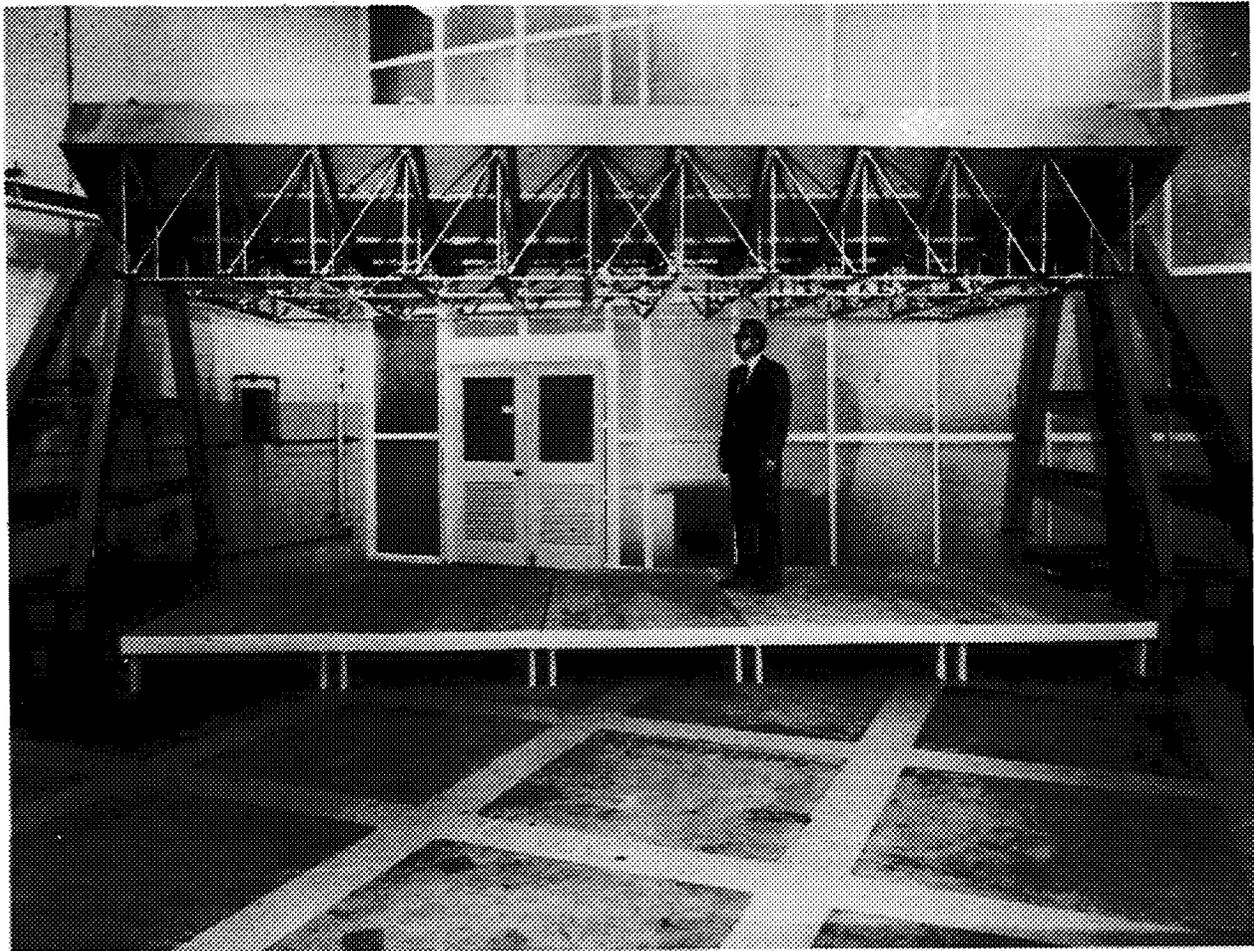
Other operational adhesive bonding systems which could affect installation and replacement times are described below. It should be noted, however, that such bonding systems are not commercially available at this time. Further development of such systems would have to be accomplished before they become applicable for Space Shuttle use. One option considers a calendered adhesive that would be bought in film form, cut to shape, applied, and cured. Such a film silicone material must be capable of storage for extended periods, must not cure or set up in storage, and must cure at room-temperature. This probably means that the material has a limited shelf-life and a requirement for storage at temperatures below 25°K (0°F). Benefits of such a system would be ease of adhesive application, better control of adhesive thickness (with resulting lower weight), and increased confidence in meeting TPS target weight. Another bonding option would be a composite adhesive/silicone sponge system. In this concept, the silicone sponge would be procured with the required adhesive already applied to one or both surfaces of the material. The adhesive/sponge system combination would use either a pressure-sensitive adhesive or an adhesive that can be stored for periods of time without curing. Benefits of this concept are that the two bonds (structure-to-sponge and sponge-to-ablator panel) can be effected at one time, adhesive thickness and weight can be accurately controlled, and fewer operations to affect final bond are required.

One of the most critical problems surrounding TPS design and related maintenance concerns joints and seals between adjacent panels. In this area, incompatibilities exist. On the one hand, gaps between panels must be provided to allow for normal panel expansion and contraction under environmental extremes. Yet these same gaps have to be minimized, if not eliminated, to prevent the inflow of hot boundary layer gases and water. In the case of ablative TPS, the problem is approached either by installing preformed elastomeric gaskets between panel edges or by caulking the gap with a silicone elastomeric-type material.

#### MOCKUP CONFIGURATION

The full-scale mockup, shown in figure 2, used during Task I was also used in Task II for attaching the panel support assembly (described in the next section) while testing the direct bond-on ablator TPS concept. The direct bond-on ablator panel support assembly was bolted to the transverse hat section panel support beams of the mockup. As shown in the figure, tubular links, in a post arrangement, support these beams and position the TPS panels at the mold-line some distance from the basic mockup structure.

All test data, recorded in Appendix A, obtained during the program were taken with the mockup positioned to simulate the bottom surface of a Space Shuttle vehicle. Thus, all maintenance tasks were performed in an overhead position. It was assumed that working in an overhead position would be more



**FIGURE 2 MOCKUP CONFIGURATION**

working on either the sides or top surface of the vehicle. Test results, therefore would be representative of the worst working conditions. However, if personnel are not allowed to walk on vehicle surfaces (i.e., top surface of wings) but forced to work in a prone position from platforms extending across the surface, the test data obtained may be somewhat optimistic. No manipulation of the test data was made to account for this set of possible circumstances.

#### TPS DESIGN

The design effort associated with the direct bonded-on ablator TPS concept consisted of preparing drawings defining all of the specific components to be manufactured, and methods of attaching the assemblies to the mockup configuration. The specific drawings generated include:

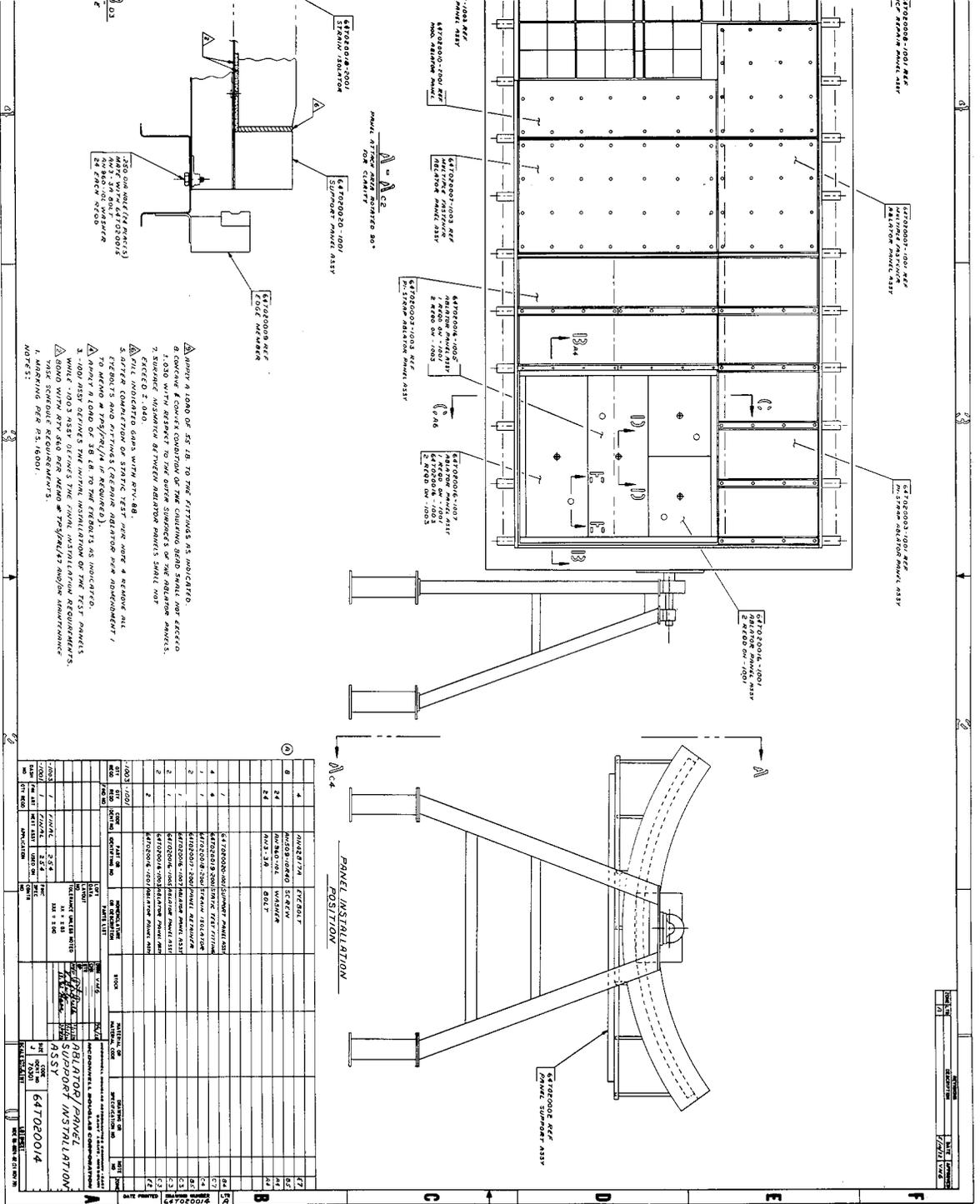
<u>TITLE</u>	<u>FIGURE NO.</u>
Ablator/Panel Support Installation Assembly (64T020014)	3
Ablator Panel Support Assembly (64T020015)	4
Ablator Panel Assembly (64T020016)	5
Pi-Strap Ablator Panel Retainer (64T020017)	6
Strain Isolator (64T020018)	7
Static Test Fitting (64T020019)	8
Metallic/Ablator Panel Support Assembly (64T020020)	9

Ablator/Panel Support Installation Assembly (64T020014)

The general arrangement selected, as well as the specific instructions for attaching the ablator panel assemblies and the panel support assembly to the mockup configuration, are defined in figure 3. As illustrated, the two different size ablator panels, and the panel support assembly, were located on one end (right side) of the mockup. Four of the large pi-strap attach ablator panel assemblies installed in Task I were removed from this area and replaced with the panel support assembly (64T020014), to which the direct bond-on ablator panels were installed. After completion of the various maintenance tasks associated with the refurbishment tests, one of the pi-strap attach panels was reinstalled adjacent to the panel support assembly. Two wood moldings (figure 6) were attached for supporting the panel along the edge adjacent to the panel support assembly.

The panel support assembly (figure 4) was attached to the mockup by bolting it to hat section beams, with twenty-four AN3-3A bolts. The ablator panel assemblies were then bonded to the panel support assembly with RTV 560 adhesive. As shown in figure 3, two large and two small ablator panels were initially bonded to the panel support assembly. Section B-B shows that one of the large panels was bonded to a silicone sponge strain isolator, which had been previously bonded to the panel support assembly. The second set of ablator panels were bonded on (after the first set had been charred and removed) by interchanging the large panel (that was bonded to the strain isolator) with two small panels.

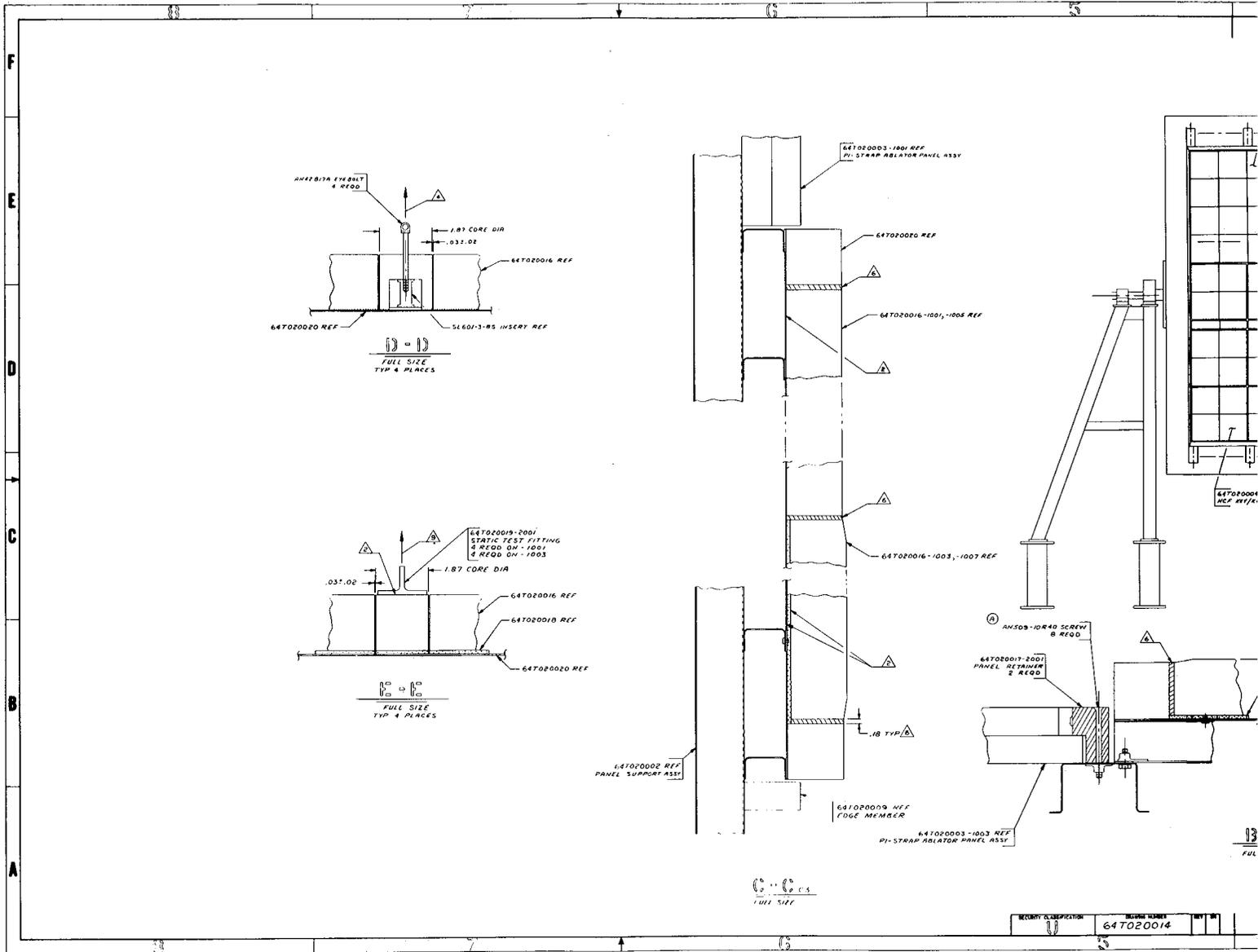
The 0.46-centimeter (0.18-inch) wide gaps between the ablator panels were filled with RTV-88 (General Electric) silicone compound. RTV-88, defined in more detail in the "Ablator Panel Fabrication" section, is a two-part, room-temperature-curing, dimethyl silicone compound.



- 1. SHOW A LOAD OF 55 LB TO THE FITTINGS AS INDICATED.
- 2. COVERING & COMPLETE CONDITION OF THE CHAINING BAND SHALL NOT EXCEED 1.000 IN. TO THE DIMENSIONS INDICATED ON THE DRAWING.
- 3. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 4. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 5. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 6. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 7. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 8. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 9. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 10. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
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- 13. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
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- 16. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 17. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 18. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 19. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).
- 20. AFTER COMPLETION OF STATIC TEST THE WIRE & REMOVE ALL FITTINGS AND FITTINGS (REPAIR DEFECTIVE PARTS AND REPAIRS).

NO.	QTY	DESCRIPTION	UNIT	REVISION	DATE	BY	CHKD	APP'D	REVISION	DATE	BY	CHKD	APP'D
1	1	MANUFACTURE	PIECE										
2	2	MANUFACTURE	PIECE										
3	2	MANUFACTURE	PIECE										
4	1	MANUFACTURE	PIECE										
5	1	MANUFACTURE	PIECE										
6	1	MANUFACTURE	PIECE										
7	1	MANUFACTURE	PIECE										
8	1	MANUFACTURE	PIECE										
9	1	MANUFACTURE	PIECE										
10	1	MANUFACTURE	PIECE										
11	1	MANUFACTURE	PIECE										
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16	1	MANUFACTURE	PIECE										
17	1	MANUFACTURE	PIECE										
18	1	MANUFACTURE	PIECE										
19	1	MANUFACTURE	PIECE										
20	1	MANUFACTURE	PIECE										

64705003-1001 PNL ASSY  
 64705003-1002 PNL ASSY  
 64705003-1003 PNL ASSY  
 64705003-1004 PNL ASSY  
 64705003-1005 PNL ASSY  
 64705003-1006 PNL ASSY  
 64705003-1007 PNL ASSY  
 64705003-1008 PNL ASSY  
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 64705003-1013 PNL ASSY  
 64705003-1014 PNL ASSY  
 64705003-1015 PNL ASSY  
 64705003-1016 PNL ASSY  
 64705003-1017 PNL ASSY  
 64705003-1018 PNL ASSY  
 64705003-1019 PNL ASSY  
 64705003-1020 PNL ASSY



**FIGURE 3 ABLATOR/PANEL SUPPORT INSTALLATION ASSEMBLY**  
 (All Dimensions in Inches)









In addition, this drawing also specifies the requirements for static testing the ablator panels to the panel support assembly bond. As illustrated in sections D-D and E-E, two different techniques were employed for applying a pre-determined load to the bonded areas. In one case, fittings (randomly located) were bonded to the external surface of the ablator panel, while for the other, eyebolts were threaded into inserts which were imbedded in the ablator panels. For each technique, 4.75-centimeter (1.87-inch) diameter plugs were machined in the ablator material, concentric with the fittings and the inserts. The depth of these machined cuts were controlled to prevent damaging the sheet metal structure.

#### Ablator Panel Support Assembly (64T020015)

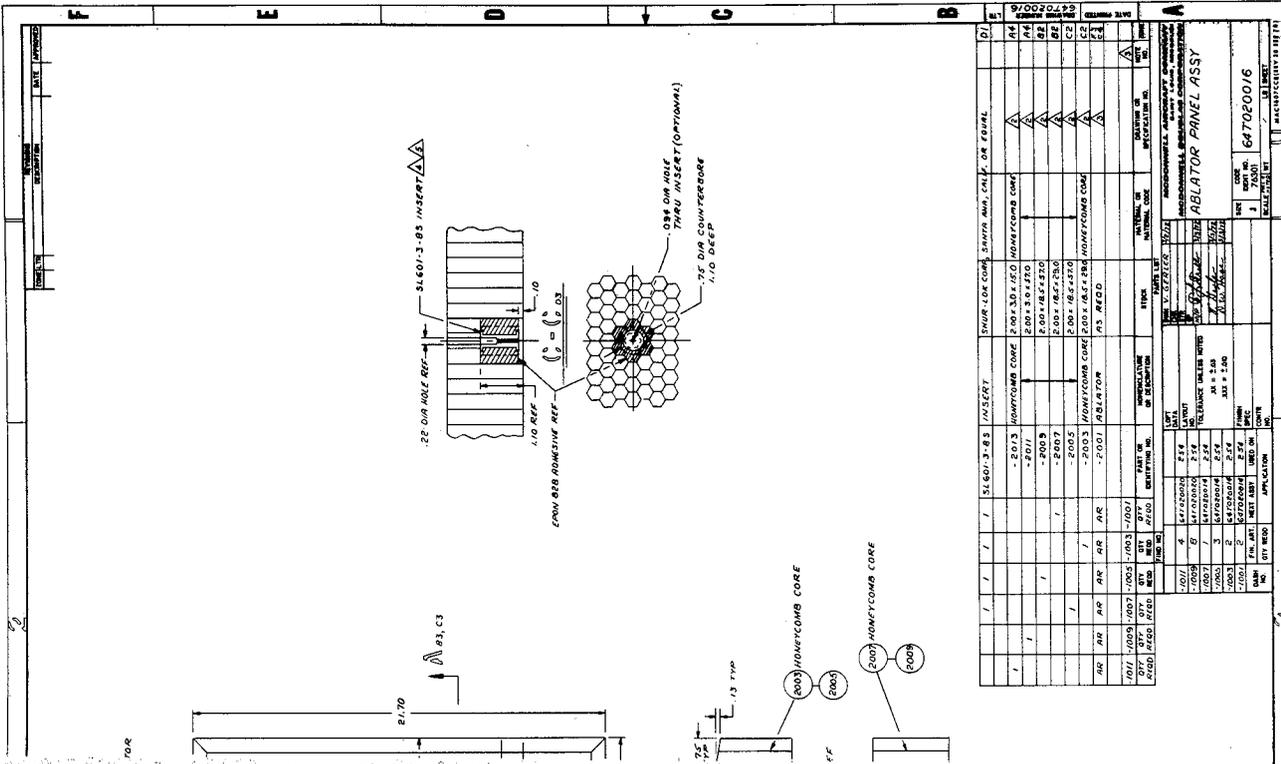
The panel support assembly selected for simulating a portion of the Space Shuttle's primary structure consisted of a thin skinned, stiffened aluminum structure, shown in figure 4. The overall size of this assembly was 152.40 by 177.29 centimeters (60.00 by 69.80 inches). The 0.127-centimeter (0.050-inch) thick aluminum skin was manufactured in two sections and spliced together using a butt joint, as illustrated in section A-A. The skin was chem-milled to a thickness of 0.056 centimeters (0.022 inches) between the stiffener attach areas. The 0.102-centimeter (0.040-inch) thick aluminum channels were riveted to the skins and spaced 11.20 centimeters (4.60 inches) apart. Both flush head and universal head rivets were used to attach the 16 channels to the skin. It should be noted that the universal head rivets were used in the area where a silicone sponge strain isolator was positioned between the panel support assembly and the ablator panels.

Four 0.318 by 5.59 by 177.29-centimeter (0.125 by 2.20 by 69.80-inch) plates were riveted across the channels, opposite the skins, to stiffen the assembly, allowing normal handling techniques to be employed and preventing excessive deflections.

#### Ablator Panel Assembly (64T020016)

The ablator panel assemblies, defined in figure 5, consists of a 5.1-centimeter (2.0-inch) thick elastomeric-resin-filled honeycomb core assembly. The honeycomb core is composed of 0.953-centimeter (0.375-inch) hexagon-shaped cells, having a density of 35.24 kilograms per cubic meter (2.2 pounds per cubic foot). The ablator material contains a mixture of phenolic microballoons and silicone elastomeric resin, and is designated as NASA's 80/20 blend (i.e., 80 parts by weight of phenolic microballoons to 20 parts by weight of elastomeric resin).

A total of eight panels were manufactured, four measuring 5.1 by 55.1 by 70.5 centimeters (2.0 by 21.70 by 27.74 inches) and four measuring 5.1 by 55.1 by



QTY	DESCRIPTION	UNIT	DATE
1	ABLATOR PANEL ASSY	PC	6470200/6
1	2.2 DIA HOLE REF	REF	
1	1/10 DIA HOLE REF	REF	
1	1/10 DIA COUNTERBORE	REF	
1	0.38 DIA HOLE TYPE 'A' INSERT (OPTIONAL)	REF	
1	.75 DIA COUNTERBORE	REF	
1	200 HONEYCOMB CORE	REF	
1	600 HONEYCOMB CORE	REF	
1	1.3 TYP	REF	

QTY	DESCRIPTION	UNIT	DATE
1	2.2 DIA HOLE REF	REF	
1	1/10 DIA HOLE REF	REF	
1	1/10 DIA COUNTERBORE	REF	
1	0.38 DIA HOLE TYPE 'A' INSERT (OPTIONAL)	REF	
1	.75 DIA COUNTERBORE	REF	
1	200 HONEYCOMB CORE	REF	
1	600 HONEYCOMB CORE	REF	
1	1.3 TYP	REF	

6470200/6





141.4 centimeters (2.0 by 21.70 by 55.66 inches). Two of the small panels and one large panel had the edges bevelled on one side. This was done to fair the outer surfaces with adjacent panels that were installed without the strain isolator.

In addition to the above panels, 12 narrow ablator panels 5.05 centimeters (1.99 inches) wide were manufactured and subsequently bonded to the panel support assembly to simulate adjacent panels. Eight of these panels were 142.29 centimeters (56.02 inches) long, while the remaining four measured 35.00 centimeters (13.78 inches) in length .

#### Pi-Strap Ablator Panel Retainer (64T020017)

In order to retain the large pi-strap attach ablator panel adjacent to the direct bond-on ablator panel support assembly redesigned panel retainers were required. The two wooden panel retainers manufactured, which replaced the ablator pi-strap assemblies along one edge of the panel, are shown in figure 6.

#### Strain Isolator (64T020018)

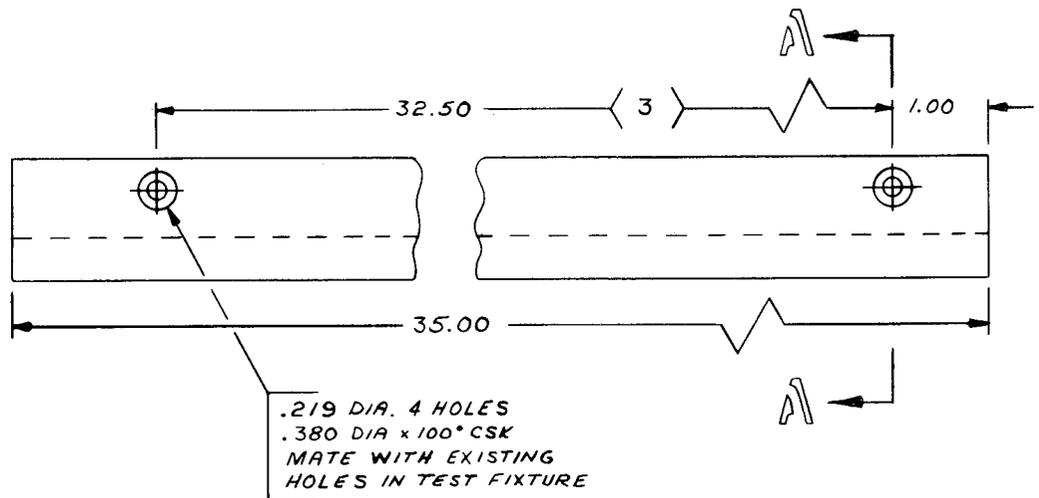
As stated previously, a strain isolator was positioned between the panel support assembly and the ablator panels over approximately one-third of the area. This 0.318-centimeter (0.125-inch) thick pad (figure 7) consisted of a closed cell silicone sponge, designated as S-105, manufactured by Raybestos Manhattan. This material had a density of approximately 560 kilograms per cubic meter (35 pounds per cubic foot). RTV 560 adhesive was used to bond the strain isolator to the primed surface of the panel support assembly.

#### Static Test Fitting (64T020019)

During the bond integrity evaluation phase of the test program, tensile loads were applied to machined plugs in both the bonded-on ablator panels and process control coupons (fabricated in-parallel with the bonded-on ablator panels). Loads were applied to the machined plugs by means of aluminum fittings, bonded to the exposed surfaces. The fittings are described in figure 8..

#### Metallic/Ablator Panel Support Assembly (64T020020)

Prior to attaching the panel support assembly to the mockup, the narrow ablator panels, shown in figure 5, were bonded around the periphery of the



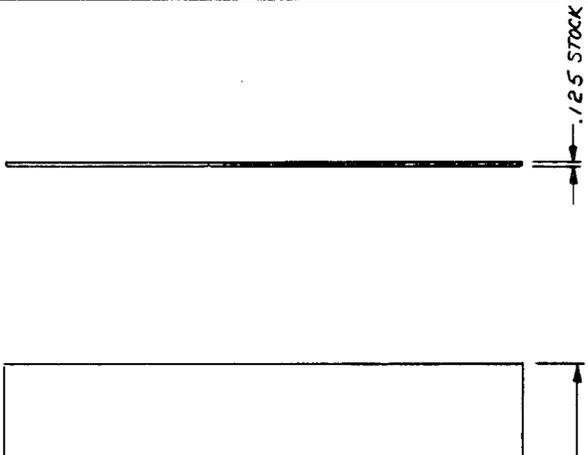
4. ALL SURFACES ARE TO BE SANDED SMOOTH, SEALED AND VARNISHED.
3.  $\triangle$  DENOTES NUMBER OF EQUAL SPACES.
2. BREAK ALL SHARP EDGES.
1. MARKING PER P.S. 16001.
- NOTES:

QTY REQD	QTY REQD	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	STOCK
			- 2001	PANEL RETAINER	1.4 x 2.2 x
	FIND NO.				PA
				LOFT DATA	DWN V. G
				LAYOUT NO.	CHK
				TOLERANCE UNLESS NOTED	STR
				.XX = ± .03	GP
				.XXX = ± .010	m/p R. J.
-2001	2	64702001A	254	FINISH SPEC	T. B.
DASH NO.	FIN. ART.	NEXT ASSY	USED ON	CONTR NO.	D. W.
	QTY REQD	APPLICATION			

MAC 1198C (Rev 30 Sep 70)

FIGURE 6 PI-STRAP ABLATOR PANEL RETAINER<sup>†</sup>  
(All Dimensions in Inches)

REVISIONS	DESCRIPTION	DATE	APPROVED



DATE PRINTED  
DRAWING NUMBER 647020018 LTR

FORM	S-105	2	NOTE NO.	ZONE

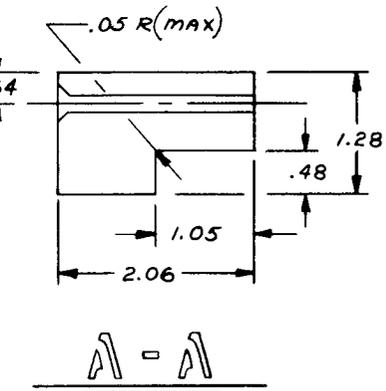
**MCDONNELL AIRCRAFT COMPANY**  
SAINT LOUIS, MISSOURI  
**MCDONNELL DOUGLAS CORPORATION**

*TRAIN ISOLATOR*

CODE IDENT NO. <b>76301</b>	<b>647020018</b>
E. 1/4 WT	LB SHEET

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REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



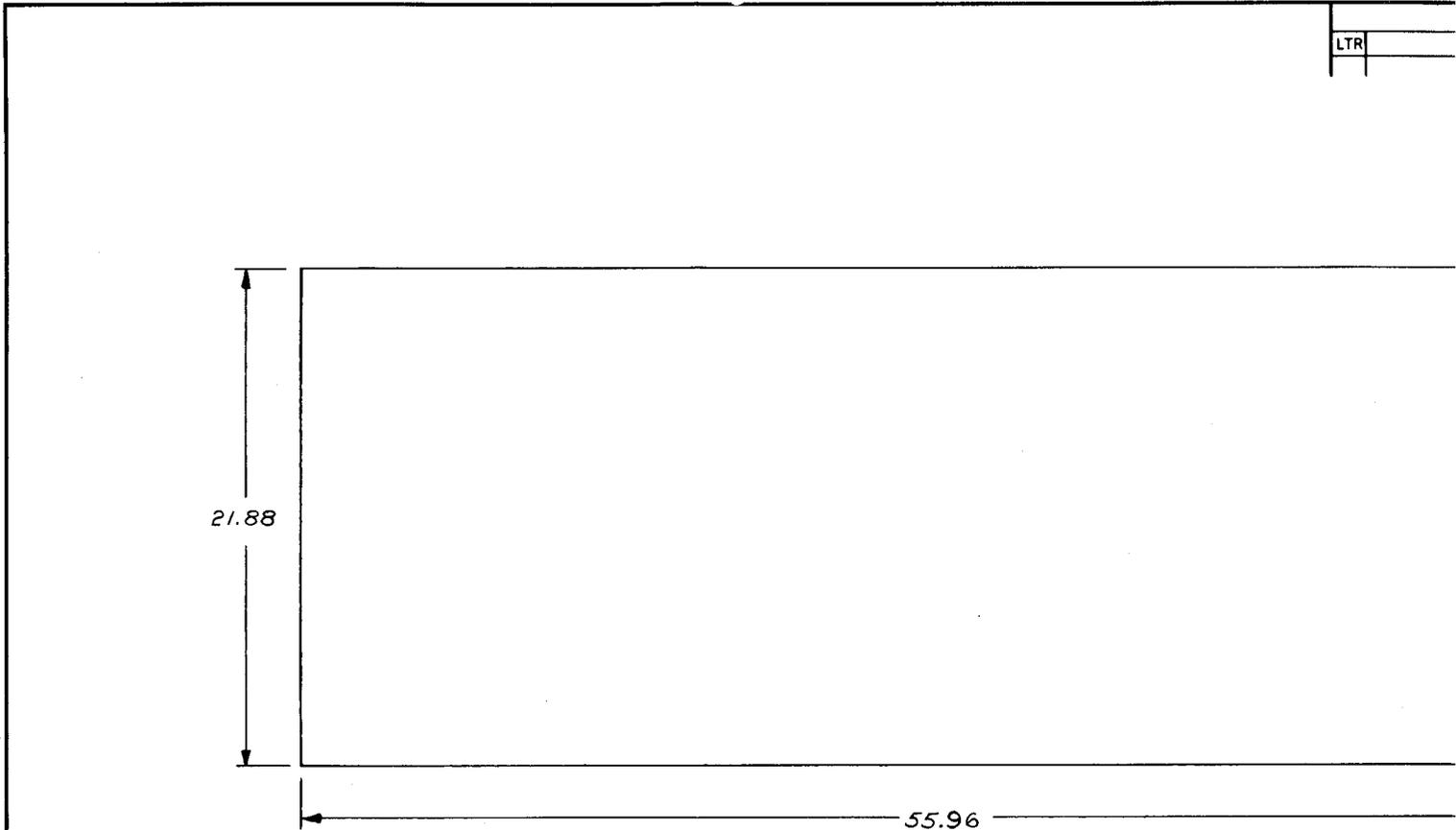
DRAWING NUMBER  
64T020017

DATE PRINTED

0	WOOD	HARD MAPLE		
	MATERIAL OR MATERIAL CODE	DRAWING OR SPECIFICATION NO.	NOTE NO.	ZONE

LIST			
LER	3/2/72	<b>MCDONNELL AIRCRAFT COMPANY</b> SAINT LOUIS, MISSOURI <b>MCDONNELL DOUGLAS CORPORATION</b>	
		PANEL RETAINER - PI-STRAP ABLATOR	
	3/3/72		
	3/5/72		
	3/9/72		
SIZE	CODE		
C	IDENT NO.	64T020017	
SCALE FULL WT		LB SHEET	

U

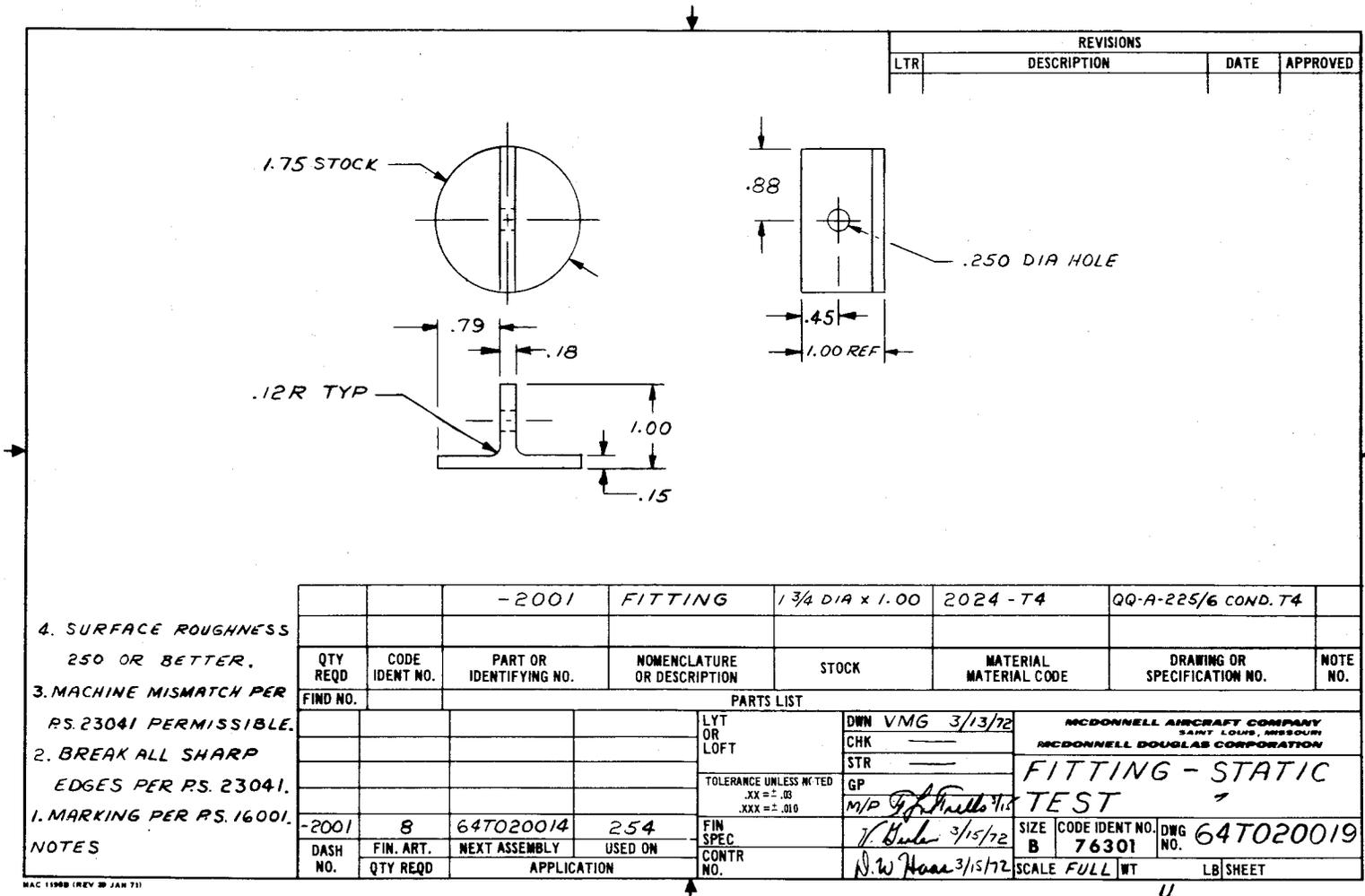


2. RAY-BESTOS MANHATTAN,  
 CHARLESTON, S. C.  
 1. MARKING PER P.S. 16001.  
 NOTES:

				-2001	STRAIN ISOLATOR	.125 x 24.0 x 58.0	SILICONE
QTY REQD	QTY REQD	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION		STOCK	MATER MATERI
	FIND NO.	PARTS LIST					
				LOFT DATA		DWN V. GERLER	9/2/72
				LAYOUT NO.		CHK STR	
				TOLERANCE UNLESS NOTED		GP	
				.XX = ±.03		M/P <i>[Signature]</i>	5/6/72
				.XXX = ±.010		<i>[Signature]</i>	9/6/72
						<i>[Signature]</i>	3/6/72
-2001	3	647020014	254	FINISH SPEC			
DASH NO.	FIN. ART.	NEXT ASSY	USED ON	CONTR NO.			
	QTY REQD	APPLICATION					

FIGURE 7 STRAIN ISOLATOR  
 (All Dimensions in Inches)

FIGURE 8 STATIC TEST FITTING  
(All Dimensions in Inches)



REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

4. SURFACE ROUGHNESS 250 OR BETTER.		-2001		FITTING	1 3/4 DIA x 1.00	2024 - T4	QQ-A-225/6 COND. T4	
3. MACHINE MISMATCH PER RS. 23041 PERMISSIBLE.		QTY REQD	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	STOCK	MATERIAL MATERIAL CODE	DRAWING OR SPECIFICATION NO.
2. BREAK ALL SHARP EDGES PER RS. 23041.		FIND NO.	PARTS LIST					
1. MARKING PER RS. 16001.								
NOTES								
					LYT OR LOFT	DWN VMG 3/13/72	MCDONNELL AIRCRAFT COMPANY SAINT LOUIS, MISSOURI MCDONNELL DOUGLAS CORPORATION	
					TOLERANCE UNLESS NOTED .XX ± .03 .XXX ± .010	CHK STR	FITTING - STATIC TEST	
		-2001	8	64T020014	254	GP M/P <i>J. P. ...</i>	SIZE B	CODE IDENT NO. 76301
		DASH NO.	FIN. ART.	NEXT ASSEMBLY	USED ON	FIN SPEC CONTR NO.	DWG NO.	64T020019
			QTY REQD	APPLICATION			SCALE FULL	WT LB SHEET

MAC 1199B (REV 20 JAN 71)

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panel support assembly, as shown in figure 9. As in Task I, these edge members were used to simulate adjacent panels. The edge members were positioned so that the distance between opposite edges allowed 0.46-centimeters (0.18-inch) wide gaps between adjacent ablator panels and between the edge members and their adjacent ablator panels. RTV 560 was used to bond the edge members to the primed surface of the panel support assembly.

#### ABLATOR PANEL FABRICATION

The ablator panel assemblies fabricated were basically similar to hardware panels fabricated in Task I, with the following exceptions:

assemblies were 5.1 centimeters (2.0 inches) thick instead of 2.54 centimeters (1.0 inch) thick;

assemblies did not have a face sheet;

the honeycomb core was primed with a phenolic instead of a silicone primer;

each panel was fabricated with an insert (static test plug) for later NDE evaluation of bond integrity;

material evaluations were conducted to select adhesive and caulking compounds;

no attach provisions were incorporated, since the panels were bonded to the substructure.

#### Material Evaluations

Materials for adhesive priming, adhesive bonding, and caulking, intended for use while installing the ablator panels on the mockup, were selected from current state-of-the-art materials used in similar or related applications.

Adhesive.- The adhesives selected for evaluation (for subsequent bonding operations) were room-temperature-curing silicone elastomers. These adhesives have the most desirable handling, ease of cure, mechanical properties, and high temperature capability characteristics. Adhesive selection was based on parallel work being conducted on other related NASA programs, both at MDAC-E and at other aerospace companies.

After a literature search, two adhesives were selected from a number of candidates for further detailed investigation. These were Dow Corning's DC 93-046 and General Electric's RTV 560. Both adhesives are two-part, room-temperature-curing compounds. The DC 93-046, formulated from a dimethyl silicone polymer, possesses excellent strength and elongation with a low-temperature capability of approximately 219°K (-65°F). The DC 93-046 adhesive, freshly catalyzed, is a tough, paste-like material which is difficult to mix





or apply by hand. The paste-like consistency of the material requires troweling, and its application time is considerably slower than that of the RTV 560. The RTV 560 is formulated from a methyl-phenyl base silicone polymer containing iron oxide. The viscosity of this adhesive is considerably lower than that of DC 93-046 and may best be described as being pourable and easily mixed by hand. The methyl-phenyl polymer permits use temperatures down to 158°K (-175°F), a desirable feature for Shuttle application because of the long cold soak environments expected. The RTV 560 appears to be the current choice of several contractors in the evaluation of adhesives for bonding reusable surface insulation (RSI).

Primer.- Three primers were evaluated for conditioning the metallic surface prior to bonding the ablators and strain isolators to the substructure. Two were General Electric's SS 4004 and SS 4155, and the third Dow Corning's DC 1200 primer. All three are current state-of-the-art silicone adhesive primers. To effect an adequate bond to metal surfaces, all are dependent on control of humidity at temperature for proper hydrolyzation. Most priming operations were conducted at temperatures of 297  $\pm$  3°K (75  $\pm$  5°F) with relative humidities of 40 to 60 percent. In all cases the primer cure followed the temperature/relative humidity requirements specified by the manufacturer.

Initial bonding evaluations were conducted using DC 93-046 and RTV 560 in conjunction with the DC 1200 primer. Small 15.2 by 15.2 by 5.1-centimeter (6.0 by 6.0 by 2.0-inch) ablator panels, containing NASA's 80/20 ablator mix in 0.953-centimeter (0.375-inch) hexagonal honeycomb, were bonded to aluminum sheets. Prior to application of adhesive, the aluminum sheet was wiped clean with methyl-ethyl-ketone (MEK) and primed with .0013 to .0025 centimeters (.0005 to .001 inches) of primer. The primer was cured to the manufacturer's primer cure schedule. Adhesive was applied both to the ablator and to the primed aluminum sheets. The DC 93-046 adhesive took considerable time to apply and, therefore, required thinning with 30-percent toluene in order to provide a smooth coverage (brush applied) on the ablator panel. On the other hand, the DC 93-046 was applied without thinner to the aluminum sheets using a trowel. Approximately .038 to .051 centimeters (.015 to .020 inches) was applied to each surface.

The RTV 560, being of considerably lower viscosity, was easily applied to the ablator and aluminum sheet with brush application techniques. Approximately .025 to .038 centimeters (.010 to .015 inches) was applied to each surface. Both ablator test panels (i.e., with DC 93-046 and RTV 560) were cured for 24 hours at room temperature under deadweight pressure (shot bags) of approximately 4530 grams (10 pounds). After curing, both panels demonstrated that the ablator could not be separated from the aluminum sheet under substantial hand pull and twist pressure.

The ease of mixing, fast application time, low-temperature capability, and acceptable cure characteristics are decided advantages of the RTV 560. Thus, it was decided that RTV 560 would be the adhesive used for all bonding operations on the mockup.

Essentially, the same evaluations were conducted in bonding the silicone sponge pad (strain isolator) to the aluminum. The silicone sponge (closed cell foam) manufactured by Raybestos-Manhattan is identified as S-105 and has a density of approximately 560 kilograms per cubic meter (35 pounds per cubic foot). The S-105 foam is formulated from a methyl-phenyl silicone resin, and is the current MDAC choice for RSI strain isolation (in conjunction with RTV



560 adhesive). Attempts to bond the strain isolator to the aluminum sheets with DC 1200 primer and RTV 560 proved unsatisfactory. The bond was noted to be inconsistently cured, exhibiting areas of tackiness and lack of adhesion. It was felt that the primer may not have been adequate to effect the proper bond. Also, the use of one manufacturer's primer with another manufacturer's adhesive was not desirable, although direct bonding the ablator to the aluminum presented no problems.

Two additional primers were then evaluated, including General Electric's SS 4004 and SS 4155. The SS 4004 primer (pink in color) relies on color hue to determine proper film coverage. The SS 4155 (light blue in color) demonstrates a whitish film after hydrolyzing and provides a more positive indication of cure. The SS 4004 requires very close visual observation to determine cure and proper film coverage. Several test coupons of strain isolator and ablator panels were evaluated using the SS 4004 and SS 4155 primers. A "water-break" free surface was obtained on the aluminum sheet prior to priming. This was done by scrubbing the aluminum sheet with nylon/silicon carbide abrasive cloths (Bear-tex) and rinsing with deionized water. After wiping dry with clean cheesecloth, the sheet was primed. In most cases the SS 4004 primer was unpredictable. This was later attributed to a 'bad' lot of primer, as noted by the supplier. The SS 4155 primer was recommended by General Electric, because it provided a more consistent cure and a better method of visual coverage (hydrolyzation) than the SS 4004. Several test coupons of strain isolator were bonded with the RTV 560 using the SS 4155 primer. Results were generally good, although one coupon did demonstrate poor adhesion. The SS 4155 primer was selected for subsequent bonding operations.

Bonding of the strain isolator material (S-105 silicone sponge) has been inconsistent, even in applications with RSI. While all of the contributing factors have not been identified, it is suspected that curing agent, foaming agent residuals, silanols, and release agents within the foam are inhibiting the bond cure. This material is being intensively evaluated by MDAC-E and the manufacturer in an effort to identify all of the contributing factors and to rectify them.

Caulking Compound.- Two compounds were evaluated for caulking gaps between ablator panels, Dow Corning's 90-006 and General Electric's RTV 88. The compounds were selected initially on the basis of available literature and upon recommendation of the manufacturer for the intended application. Both are two-part, room-temperature-curing, dimethyl silicone compounds formulated with iron oxide for high temperature use (up to 589°K (600°F)). Density of both materials (cured) is 1480 kilograms per cubic meter (92.5 pound per cubic feet). The manufacturer(s) recommended these materials primarily for their handling characteristics (i.e., both compounds provide good extrusion and nonsag caulking characteristics), particularly for overhead caulking operations. Another desirable characteristic is that these compounds can be packaged in small 227-gram (8-ounce) cartridges for rapid mixing at the operations site without the need of cumbersome and time consuming mixing and cartridge filling equipment. Each cartridge contains a measured quantity of resin and catalyst (curing agent), proportioned to allow approximately 2 hours working time. A simple stroking procedure is used for mixing the two-part materials within the cartridge. The cartridge is then installed in a pneumatic operated

(plunger-type) gun with the plunger being trigger-actuated to extrude the material. Several nozzles were evaluated in the course of the caulking operations.

Two sets of ablator test panels (approximately 15.2 by 15.2 by 5.1 centimeters (6.0 by 6.0 by 2.0 inches) were clamped to aluminum sheets with a 0.477-centimeter (0.180-inch) gap between ablator panels. Cartridges filled with DC 90-006 and RTV 88 were used to caulk the gaps between these ablator panels. Approximately 217 to 276 kilonewtons per square meter (30 to 40 pounds per square inch) of air pressure were used to extrude the silicone compound into the gaps. Both materials flowed well into the gaps, with the RTV 88 displaying slightly better flow and fill characteristics. The freshly caulked panels were then inverted (caulking face down) and allowed to cure overnight at room temperature. The RTV 88 displayed a more thorough cure (no soft spots) after 24 hours. Several soft spots were detected in the DC-006; however, these spots cured after an additional 6 to 8 hours curing time. The DC 90-006 provided an extremely tough cured product, more so than the RTV 88. However, the RTV 88 was selected as the caulking compound, primarily because of the relative ease of extrusion and fill characteristics. The low-temperature capability of both candidate caulking compounds is approximately 214 to 208°K (-75 to -85°F), based upon manufacturer's data. This would indicate a dimethyl silicone base compound. In actual Shuttle use, a caulking compound with a lower temperature capability (down to at least 150°K (-175°F)) would be desirable. Since methyl-phenyl silicone caulking compounds are not available as off-the-shelf compounds, only the dimethyl silicone compounds could be evaluated within the time/cost constraints of the program.

#### Preliminary Ablator Panel Fabrication Evaluation

Prior to fabrication of full-scale ablator panels, several processing parameters required evaluation. These included:

primer processing - a phenolic primer was used instead of a silicone primer for priming honeycomb

honeycomb filling characteristics of a 5.1-centimeter (2.0-inch) thick panel when filling with the NASA 80/20 ablator mix

cure characteristics of the 5.1-centimeter (2.0-inch) thick ablator panels

core splicing of the honeycomb

Previous work conducted with the NASA 80/20 ablator mix in the Task I effort did not present any problems in mixing and blending; therefore, it was assumed that the same processing conditions could apply equally well for manufacturing the Task II ablator panels. Small test panels approximately 22.8 by 22.8 by 5.1 centimeters (9.0 by 9.0 by 2.0 inches) thick were processed using a 0.953-centimeter (0.375-inch) hexagonal cell glass/phenolic honeycomb, primed with a 'B' stage phenolic resin, filled with the NASA 80/20 ablator mix, and cured under vacuum bag at 394 to 400°K (250 to 260°F) for 8 hours. ('B' staging

is an intermediate stage in the curing of a thermosetting resin. It occurs while the resin is still soft or tacky.)

Four panels were made, with and without core splices. A two-side filling technique was used to fill the honeycomb cells with the freshly catalyzed NASA 80/20 ablator material. The core splice was a double cell crush splice, with the splice length perpendicular to the ribbon direction. The phenolic resin used to prime the honeycomb on two of the panels was cured ('B' stage) at 355 to 361°K (180 to 190°F) for 2 hours. The phenolic primer (i.e., Resinox SC-1008) contains approximately 40 percent by weight of isopropyl alcohol. The other two panels were primed with Sylgard 182 (wet coated) prior to filling with the NASA 80/20 mixture.

All panels cured satisfactorily at 394 to 400°K (250 to 260°F) under vacuum bag for 8 hours. Panels primed with SC 1008 were lower in density ( $\approx$  222 kilograms per cubic meter) ( $\approx$  13.9 pounds per cubic foot) than the panels primed with the silicone wet coat ( $\approx$  253 kilograms per cubic meter) ( $\approx$  15.8 pounds per cubic foot)). No voids were detected by x-ray. After trimming, the panels were bonded to a primed aluminum sheet ( $\approx$  15 centimeters (0.06 inches) thick) with RTV 560 and cured at room temperature under a dead weight (shot bags) of approximately 4530 grams (10 pounds). Bond integrity was excellent, with a cured bond thickness of approximately 0.051 to 0.060 centimeters (0.020 to 0.025 inches).

The cure of a large panel 61.2 by 152.4 by 5.1 centimeters (24 by 60 by 2.0 inches) was attempted, using the process parameters established for the small panels. The SC 1008 primer was selected because it was a simpler method and produced the lowest density composite. This large panel did not cure. A subsequent small panel using the same lot of silicone resin and phenolic microballoons cured with no difficulty at 394 to 400°K (250 to 260°F). It was judged that the mass of ablator material was the cause of the large panel's failure to cure. A 61.2 by 61.2 by 5.1 centimeters (24.0 by 24.0 by 2.0 inches) thick panel was fabricated and cured between 422 and 428°K (300 and 310°F) at an arbitrary time of 4 hours. The panel cured approximately half way, top of panel to midpoint, with the bottom half uncured. A post cure of 4 hours at 422 to 428°K (300 to 310°F) (without vacuum bag), with the panel 'soft' (semicured) side up, cured the remaining part of the panel. Therefore, the remainder of the large production panels (61.2 by 152.4 by 5.1 centimeters) (24 by 60 by 2.0 inches) were processed in the same manner as the small test panels, except that the cure temperature was set at 422  $\pm$ 6°K (300  $\pm$ 10°F) for 8 hours.

#### Fabrication of Ablator Nondestructive Evaluation (NDE) Test Panels

Additional test panels were fabricated to evaluate bond integrity by NDE techniques. Three small test panels, 22.8 by 22.8 by 5.1 centimeters (9.0 by

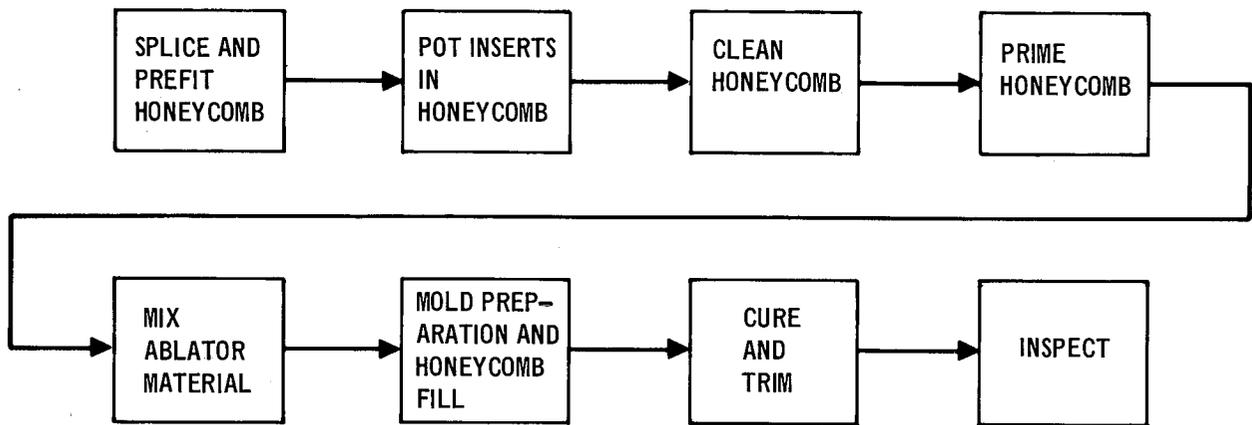
9.0 by 2.0 inch) thick, were made employing the NASA 80/20 ablator in glass/phenolic honeycomb using the baseline process conditions selected from the preliminary work. The ablator panels were bonded, with RTV 560, to aluminum sheets which were previously cleaned with MEK and primed with Dow Corning DC 1200. Bonded panels were cured for 24 hours at room temperature under a deadweight (shot bags) of approximately 4350 grams (10 pounds). Bond thickness did not exceed 0.05 centimeters (0.020 inches). These panels were static tested as subsequently described in the Static Test Section. A larger test panel, consisting of two ablator panels, 5.1 by 38.1 by 50.8 centimeters (2.0 by 15.0 by 20.0 inches), bonded to a single aluminum sheet, 0.081 centimeters (0.032 inch) thick was also fabricated as described above. The bonding operations consisted of the conventional cleaning, priming, and adhesive application as for the static test panels with the following exceptions, (1) controlled defects (unbonds) were introduced into the bondline, and (2) a strain isolator was included in the bond layout. One ablator panel was bonded directly to the aluminum sheet with controlled defects in the bondline. The defects (unbonds) were introduced at discrete areas by placing 0.013 centimeter (0.005 inch) thick Mylar film discs, up to 10.2 centimeters (4 inches) in diameter on the surface to be bonded. The other ablator panel was bonded to a 0.318-centimeter (.125-inch) thick strain isolator which had been previously bonded with RTV 560 to the aluminum sheet. Controlled defects were likewise introduced into the strain isolator during bonding operations. After a 24-hour cure at room temperature, the ablator panel was bonded to the strain isolator pad with RTV 560, with controlled defects introduced again by Mylar film discs. The ablator/strain isolator bond was cured under deadweight (shot bags) pressure. The controlled defects panel was then submitted for NDE using selected methods detailed in the section "Nondestructive Evaluations."

#### Fabrication of Ablator Panel Assembly

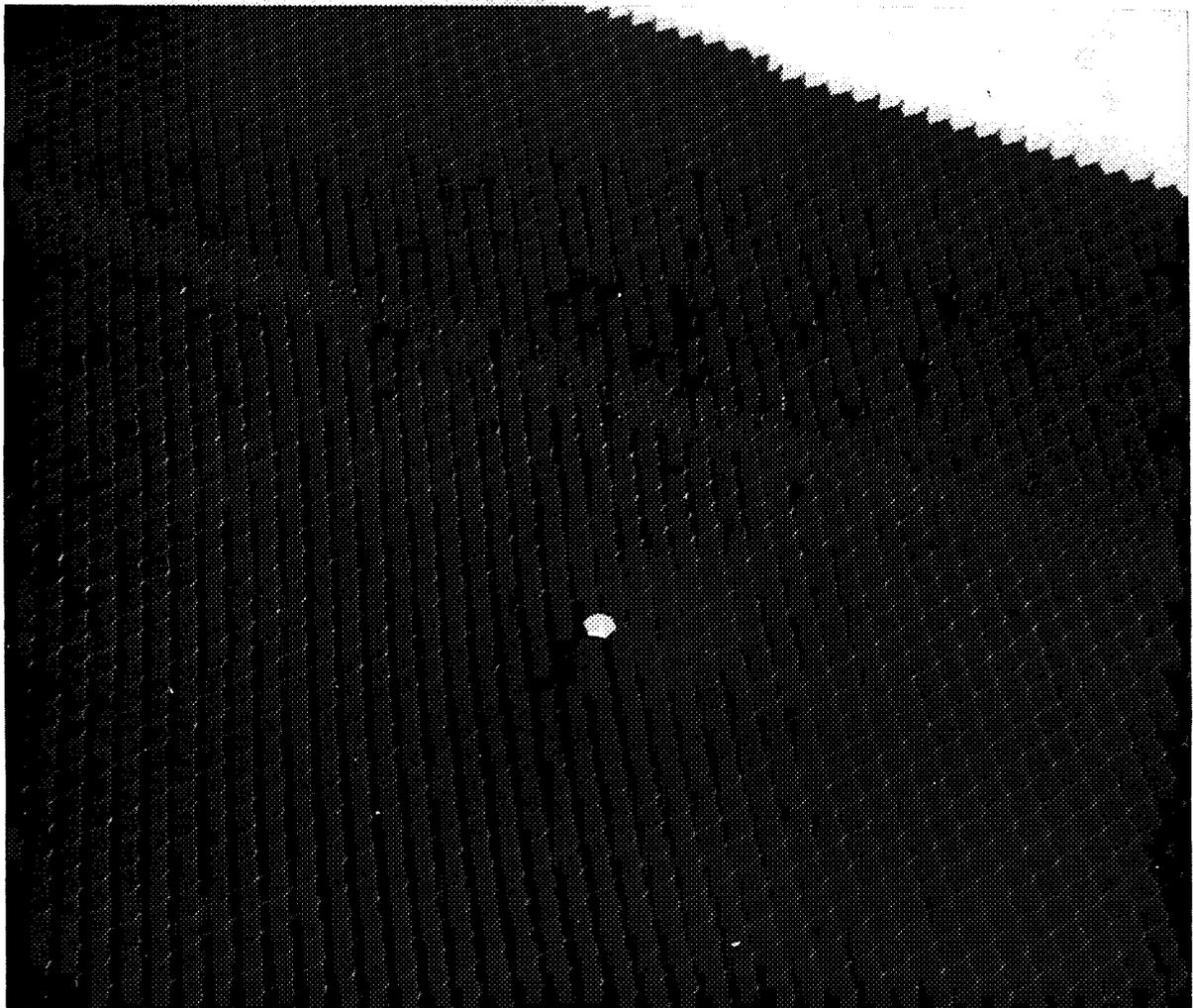
The ablator panel consisted of NASA 80/20 ablator material processed into a glass/phenolic honeycomb. The honeycomb was 5.1 centimeters (2.0 inches) thick and consisted of 0.953-centimeter (0.375-inch) hexagonal cells. Prior to filling the honeycomb matrix, the honeycomb was spliced using a crush splice technique, inserts were potted in place, and the cells primed with a phenolic resin primer. The basic fabrication cycle for the ablator panels is depicted in the processing flow diagram shown in figure 10. The tools, equipment, and materials used in the fabrication of the ablator panels are listed in appendix B.

Honeycomb Core Preparation.- The honeycomb was cut and double lap crush spliced as shown in figure 11. After splicing, the core was cut, allowing an additional inch in the width and length dimensions over the drawing requirements. Following cure, this excess material was trimmed off.

Inserts (for NDE testing) were potted into the honeycomb using an epoxy potting compound in accordance with MDAC Specification 14022 after counter-boring and trimming the honeycomb. The potted inserts were cured either for



**FIGURE 10 ABLATOR PANEL PROCESSING FLOW DIAGRAM**



**FIGURE 11 HONEYCOMB SPLICE AND POTTED INSERT RETAINER**

1 hour at 366 to 369°K (200 to 250°F) or at room temperature for 24 hours. If room temperature curing was used, a post cure under heat lamps was conducted for 2 hours at 339°K (150°F) (surface temperature), provided that there was evidence of "softness" in the potting compound.

The honeycomb was racked and cleaned with TURCO wash per MDAC Specification 11321. The TURCO wash is a steam cleaning (spray) operation in which a commercial alkaline cleaner (in water solution) is mixed with steam. The core was thoroughly rinsed in demineralized water and dried in an air-circulating oven for 2 to 2.5 hours at 339 to 350°K (150 to 170°F). After cleaning, the dried core was wrapped in clean Kraft paper until ready for priming.

The cleaned honeycomb was immersed in a bath of phenolic resin primer (i.e., Resinox SC 1008) and the honeycomb cells flushed with the primer. The honeycomb was allowed to drain for 5 minutes over the primer pan and then placed on dry, clean absorbent paper towels for an additional 5 minutes to remove excess primer. The primed honeycomb was then suspended in an air circulating oven and cured ('B' stage) at 355 to 361°K (180 to 190°F) for 2 hours. After priming, the honeycomb was covered with clean Kraft paper until ready for ablator filling operations.

Mixing the Ablator Material.- The ablator material (NASA 80/20 blend) used in fabricating the ablator panels was identical to that used in Task I ablator heatshield processing. It consisted of:

80 parts by weight - Union Carbide BJO-0930 phenolic microballoons

20 parts by weight - Sylgard 182 resin (includes catalyst)

Dried phenolic microballoons (2 hours at  $369 \pm 6^\circ\text{K}$  ( $205 \pm 10^\circ\text{F}$ )) were added slowly and in small quantities to a Hobart mixer bowl which contained the prescribed amount of catalyzed Sylgard 182 resin. Mixing in the Hobart was accomplished at slow speed ( $\approx 45$  to 50 rpm). After addition of all microballoons, mixing was continued for an additional 20 minutes. During the mixing, the temperature of the ablator material was checked periodically. If the temperature increased above 300°K (80°F), mixing was stopped and the ablator material allowed to cool below 300°K (80°F) before continuing the mixing operation.

Mold Preparation & Honeycomb Core Fill Procedure.- The mold fixture used for honeycomb fill and curing operations was basically identical to the molds used in the Task I fabrication, except that the mold edge members, fabricated from 2024-T3 aluminum, were of a height sufficient to accommodate the 5.1-centimeter (2.0-inch) thick ablator. The L-shaped edge members were attached to the base plate by means of high-temperature aluminized tape (figure 12). The tape provided easy disassembly of the mold edge members during the two-sided honeycomb fill operation. The outer sides of the edge members were taped together with high-temperature glass/silicone tape. The assembled mold was cleaned with MEK, wiped dry with clean cheesecloth, and treated with a mold release agent (fluorocarbon dispersion). An aluminum caul plate,  $\approx 0.15$  centimeter (0.06) thick, cleaned and treated with mold release agent was

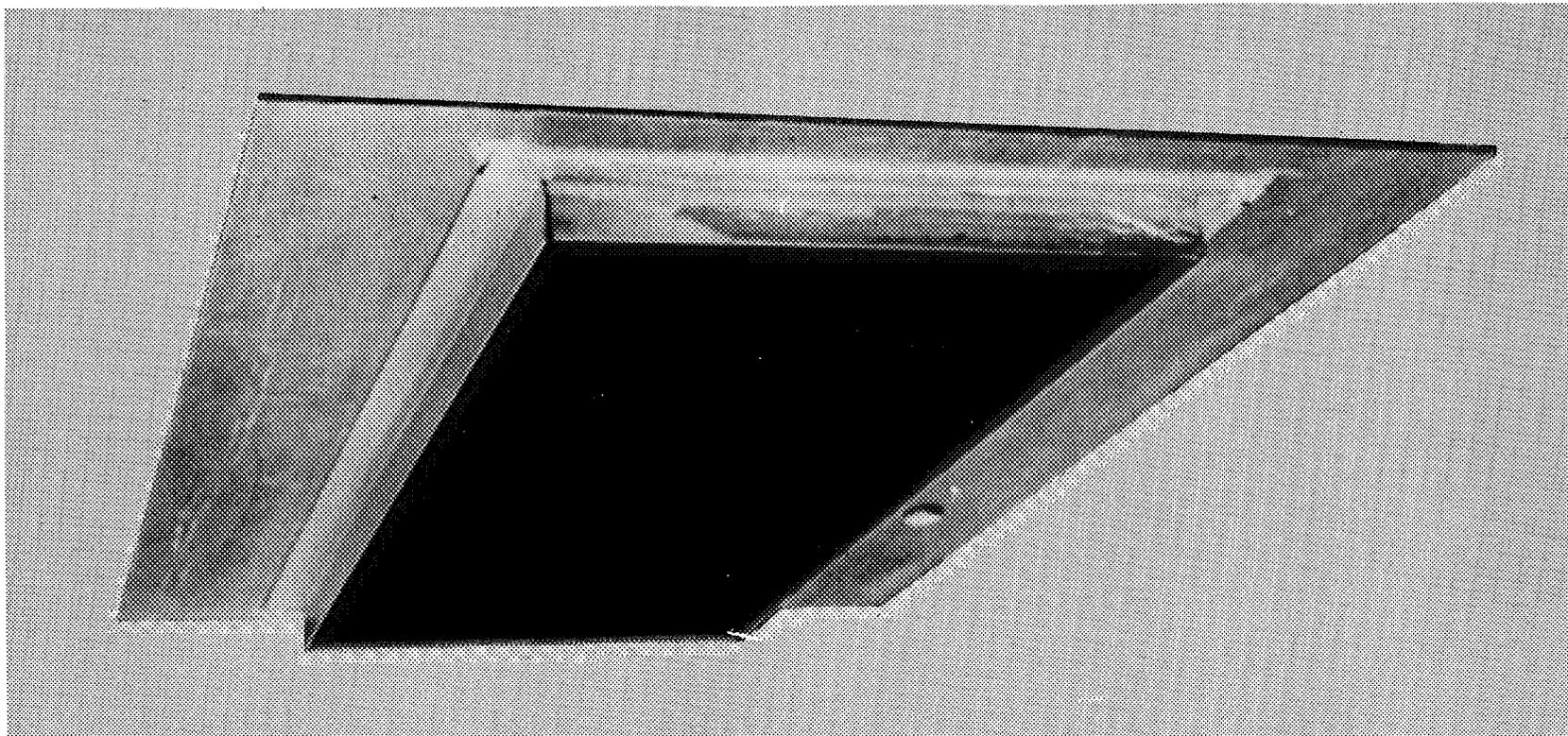
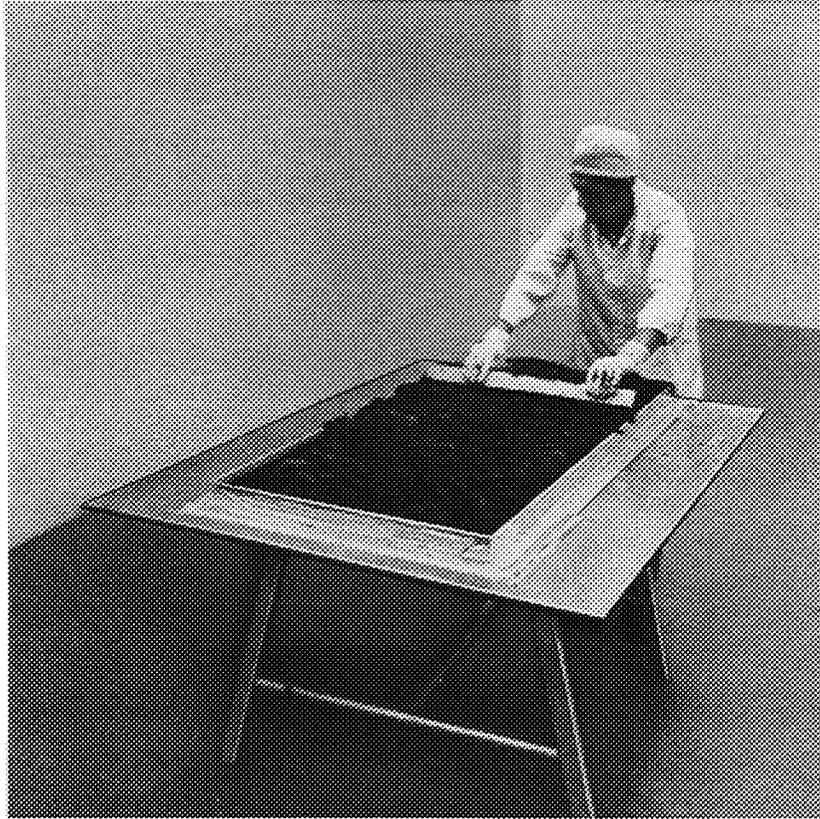


FIGURE 12 HONEYCOMB INSTALLED IN MOLD FIXTURE

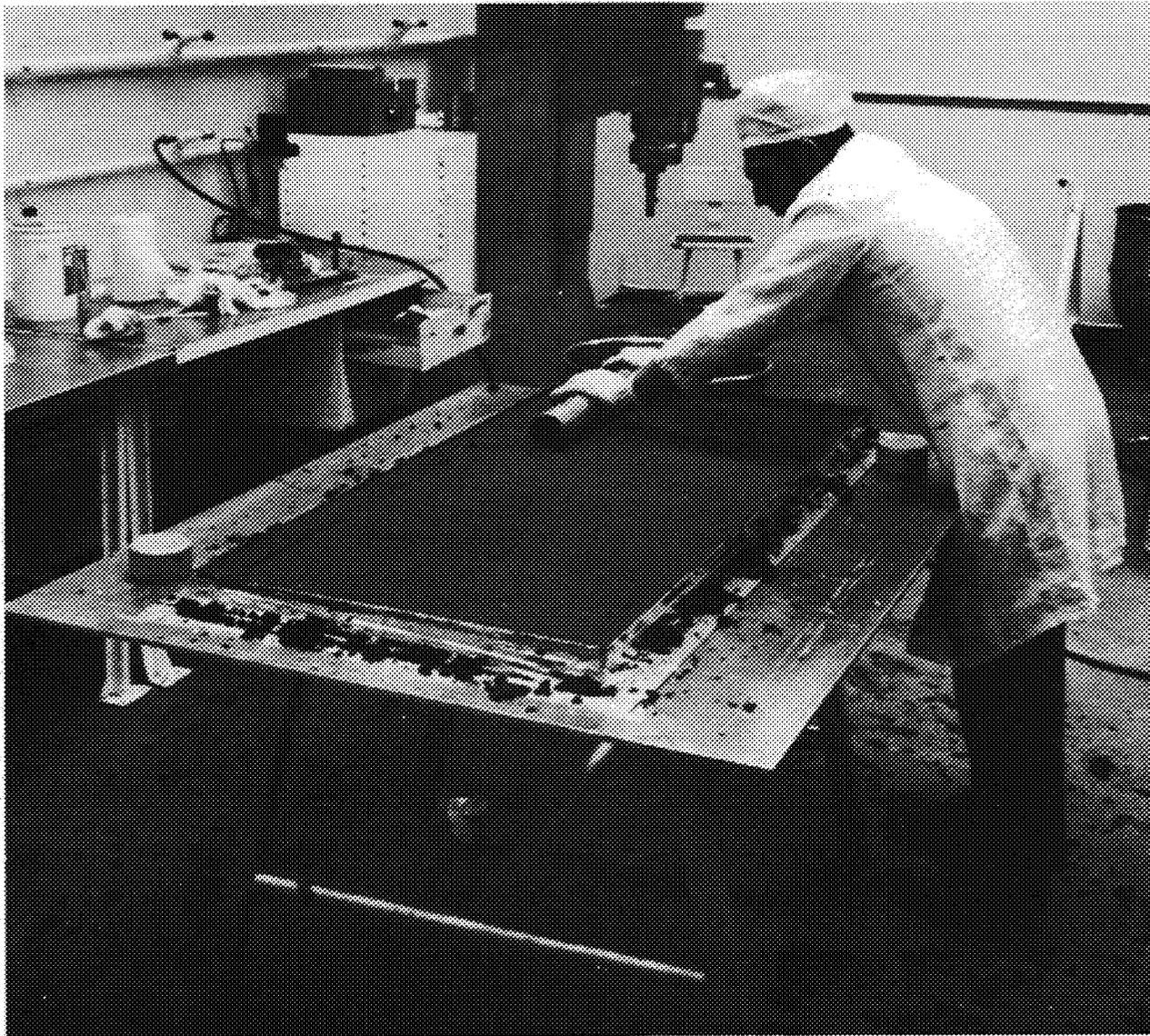


**FIGURE 13 TROWELING OF ABLATOR MATERIAL OVER HONEYCOMB**

installed in the bottom of the mold within the L-shaped edge members. The primed honeycomb was then installed in the mold (over the caul plate).

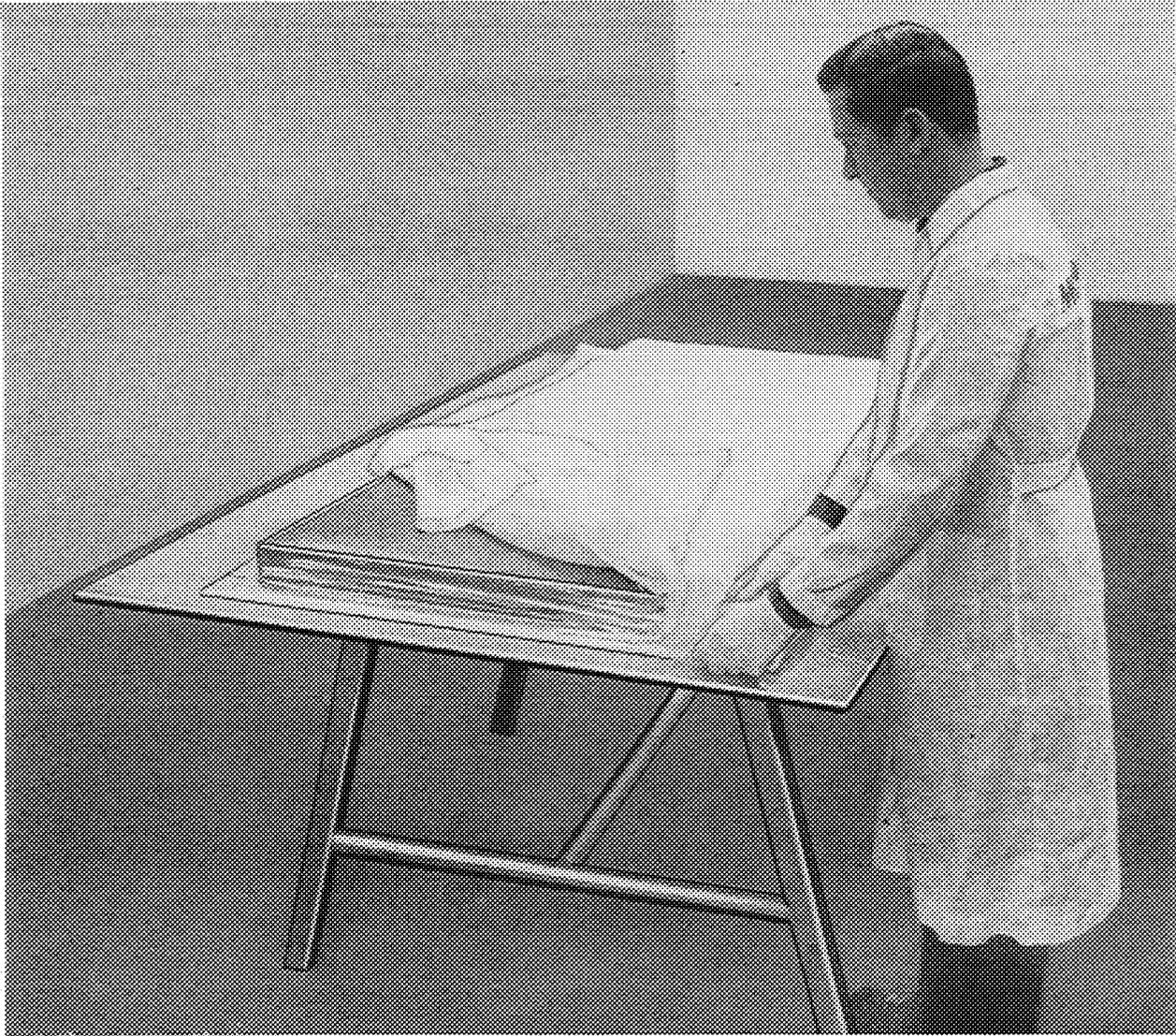
Freshly mixed ablator material was troweled and screeded to a height of 6.4 to 7.6 centimeters (2.5 to 3 inches) over the top surface of the honeycomb, as shown in figure 13. This material was then tamped into the honeycomb cells with particular attention given to the areas of the honeycomb splice and the edges of the mold. Additional material was troweled, screeded, and tamped into the cells until firmly compacted. A burden of ablator material (approximately 0.25 to 0.38 centimeter) (0.10 to 0.15 inch) was rolled smooth over the top of the honeycomb cells using a metal tubular roller. Another clean, mold-release-treated caul plate was placed over the top of the filled ablator panel.

After filling one side of the panel, two adjacent taped edge members were removed from the mold. The ablator panel, sandwiched between two caul plates, was removed from the baseplates. All loose ablator material was cleaned from inside the mold. The ablator panel/caul plate sandwich was then rotated (bottom side up) and repositioned in the mold. The bottom caul plate was gently pulled out from under the ablator panel. The two edge members were then remounted. The fill operation on the opposite side of the ablator panel was identical to that for the first side. Troweling, screeding, tamping, and rolling were continued until the ablator material was firmly compacted into the honeycomb cells, as shown in figure 14. A burden of approximately 0.51 to 0.64 centimeter (0.20 to 0.25 inch) was rolled smooth over the top of the honeycomb cells.



**FIGURE 14 ROLLING OF ABLATOR MATERIAL**

Curing Operation.- After the honeycomb was filled, three thermocouples were installed in the ablator material. The ablator material was then covered with a layer of glass release cloth, followed by a layer of glass breather cloth. A 1.52-centimeter (0.60-inch) aluminum caul plate was then installed over the glass release and breather cloth. The mold was then covered with a layer of glass breather cloth, as shown in figure 15. Additional glass cloth was layered around the side of the mold for improved evacuation of the mold. A conventional Mylar film vacuum bag was installed over the entire assembly, sealed, and vacuum leak-checked.



**FIGURE 15 APPLYING VACUUM BAG**

Ablator panels were cured for 8 hours at  $422 \pm 6^\circ\text{K}$  ( $300 \pm 10^\circ\text{F}$ ) under a vacuum bag pressure of 88.05 kilonewtons per square meter (26 inches of mercury) (minimum) in an air-circulating oven. The panels were allowed to cool to below  $322^\circ\text{K}$  ( $120^\circ\text{F}$ ) before removal from the oven.

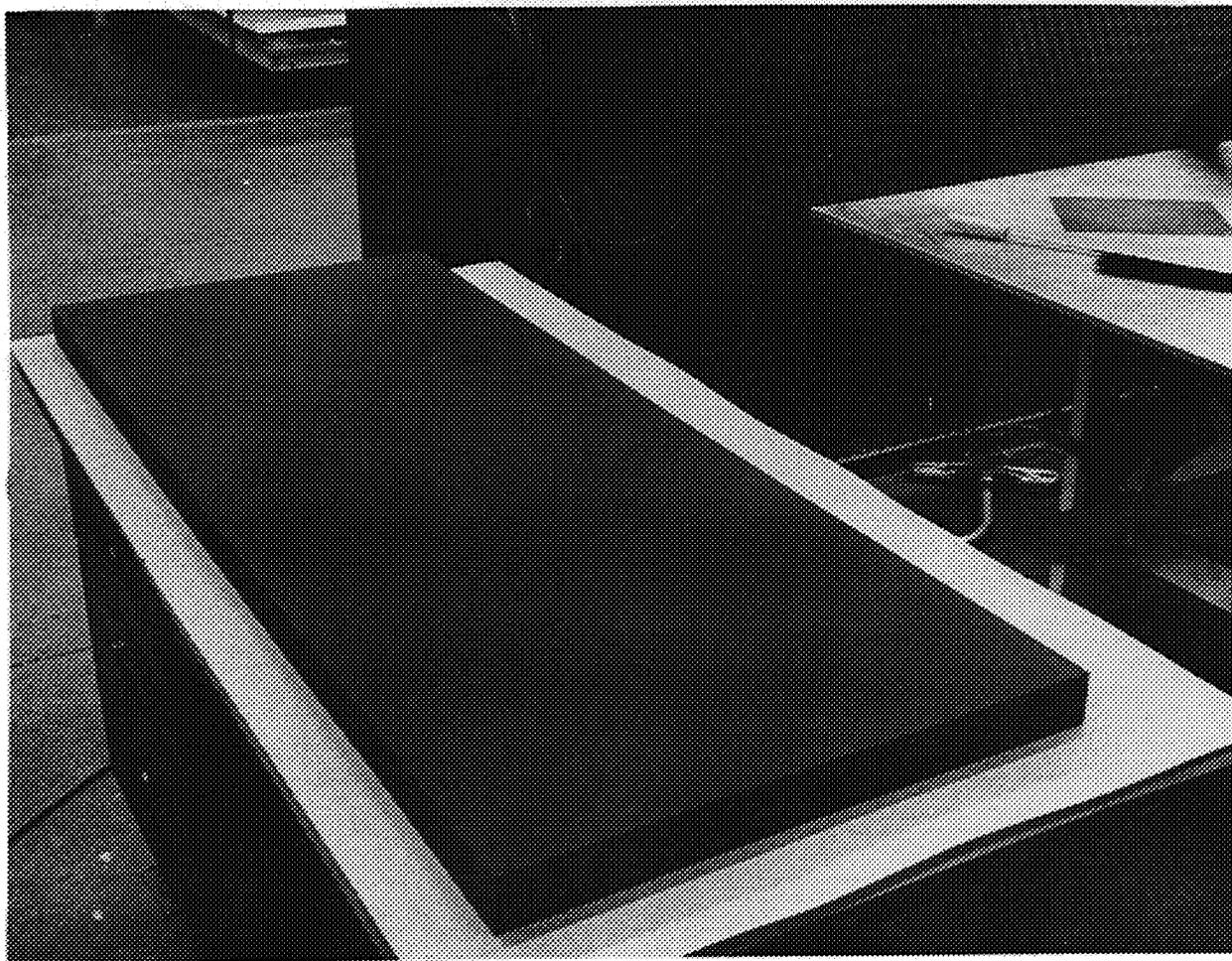
Trimming.- The panels were hand trimmed of burden (top and bottom) with sharpened putty knives. Panels were then cut to the required surface dimensions with a band saw following a template. The surface of the ablator panel was smoothed down with abrasive cloth until the ablator material was flush with the honeycomb core. Panels requiring an edge chamfer were ground and smoothed to drawing requirements using abrasive cloth following a template.

Repairs.- Where ablator panel surface and edge damage was incurred, repairs were accomplished in accordance with the repair procedure defined in NASA CR 112034.

Inspection.- Upon completion of processing, each panel was subjected to inspection in accordance with the requirements of the engineering drawing. A photograph of a completed 5.1 by 55.1 by 141.4-centimeter (2.0 by 21.70 by 56.66-inch) panel is shown in figure 16.

#### BOND INSPECTION AND CERTIFICATION

One of the objectives in Task II was to develop a plan for inspecting and certifying the ablative TPS after bonding to insure acceptable bond integrity. Consideration was to be given to state-of-the-art NDE methods assuming



**FIGURE 16 ABLATOR PANEL**  
5.1 x 55.1 x 141.4 CM (2.0 x 21.70 x 56.66 IN.)

(1) access to the unprotected side of the aluminum structure could be achieved and (2) that access to the unprotected side of the aluminum structure could not be achieved. A test plan for inspection and certification of the ablator panels after bonding to insure acceptable bond integrity was developed. In addition, static tests were to be proposed and employed to verify bond integrity. This section of the report, therefore, gives the results of this investigation.

### Nondestructive Evaluation (NDE)

Our NDE investigation started with a literature survey (see references and bibliography) to discern the various methods available for verifying bond integrity. Secondly, these methods were compared and evaluated. Within the time and cost constraints of the program, several of the methods were laboratory tested on subscale panels. Finally, conclusions and recommendations were generated concerning the subject matter.

NDE Method Survey.- The various candidate NDE methods presently available to detect voids, cracks, delaminations, moisture, unbonds, etc are given in table 3. With the exception of the x-ray and microwave methods, all others provide some promise of establishing bond integrity. Each of the methods listed will require refinement for use in both in-process control and in refurbishment evaluation. The status of each method for the determination of bond integrity is discussed in the following paragraphs.

Radiography.- Radiography employs radio frequency energy in a wavelength band which is orders of magnitude shorter than microwave. Since the wavelengths involved are generally much shorter than the nuclei which comprise the materials interrogated, we can not observe reflective phenomena. Absorption and scattering are observed which are dependent upon the energy level (wavelength) of the radiation used. The amount of energy transmitted through the sample may be measured either with film or other types of sensors, such as scintillation counters or x-ray sensitive vidicon tubes.

**TABLE 3 CANDIDATE NDE METHODS**

INSPECTION METHOD	TYPE OF DEFECTS DETECTED					TWO-SIDE ACCESS REQUIRED
	VOIDS	CRACKS	DELAMINATIONS	MOISTURE	UNBONDS	
X-RAY	X	X				X
ACOUSTIC	X		X		X	
MICROWAVE	X	X	X	X		
ULTRASONIC					X	X
ACOUSTIC EMISSION					X	X
HOLOGRAPHIC	X	X	X		X	X
PROOF LOADING			X		X	
VISUAL		X			X	

The method allows us to measure such anomalies as adhesive voids or variations in the density of the sample caused by voids or foreign inclusions. In order to detect an unbonded condition, the energy must be transmitted tangent to the bond line. Thus, radiography is ruled out for most applications to unbonds in direct-bonded ablators. Geometry may allow tangential exposures in some areas of the Shuttle structure, but film placement will, in most cases, be geometry-limited to less than satisfactory locations.

Lopilato (1) and Oaks (2) report that the effort documented in reference (3) was abandoned in favor of film radiography with image enhancement to provide the required sensitivity. The enhancement technique used was to produce a contact positive print on Kodabromide E-5, semimatte paper. It increased sensitivity by a factor of two, which proved sufficient to detect rejectable voids.

Acoustic Methods.- Acoustic methods involve the illumination of the test sample with acoustic energy in the audio range (i.e., 30-10000 Hz). There are three basic methods of observing the interaction of this energy with the sample. They are:

- (1) Acoustic Reflection.- In the reflection method (sometimes referred to as the pulse-echo method), we measure the amplitude of energy returned from anomalies in the sample. Differences in acoustic impedance at an interface (i.e., the product of material density and acoustic velocity) affect the degree to which acoustic energy is reflected. Voids, such as an unbond, will cause more energy to be reflected. This effect can be used to detect unbonds which are of the same (or larger) order of magnitude as the wave length of the impinging energy.
- (2) Acoustic Through-Transmission.- The through-transmission method can be likened to a "shadow-graph" method. The acoustic energy is introduced at one face of the sample, while the intensity of the energy transmitted through the sample is measured at the opposite face. Due to the fact that a portion of the energy is reflected at interfaces between substances of differing acoustic impedance, the intensity of the energy arriving at the exit face is a function of the anomalies existing within the sample. While this method measures the same sort of anomalies as the reflection method, there is less attenuation of energy within the sample, since the total path length within the sample is less. The method is useful in detecting density variations, voids, foreign inclusions, and unbonds.
- (3) Acoustic Resonance.- The resonance method relies on the measurement of the response of a test article to the impingement of acoustic energy at various frequencies. Resonant frequencies will vary with changes in article geometry, density, and homogeneity. By careful control of those variables not of interest, we may relate resonant responses to such anomalies as unbonds, voids, foreign inclusions, thickness, or density variations.

Acoustic techniques have been applied to low density materials in thick ( 5-centimeter (2-inch)) sections, bonded to metallic substrates, to detect

unbonds, voids, and delaminations. This work, which has been successful to limited degrees, is reported in the references cited. The requirement for a foam coupler reported by Clotfelter (4,5) has been investigated by Tiede (6) and shown to be unnecessary for use on low-density materials such as the NASA 80/20 ablator. This is attributed to a reduced degree of mismatch in acoustic impedance between these materials and air.

These methods show promise for one and two sided detection of voids, delaminations, and unbonds of TPS materials. A development effort is required, however, to advance the method from the laboratory to practical use in both production and in-service inspection applications. Equipment must be designed and prototyped which will introduce the acoustic energy and measure its modification by the test article. These modifications must then be correlated with natural or artificial defects by means of carefully constructed calibration standards, an effort which will be of significant magnitude.

Microwave Methods.- Microwaves (radio frequency energy in the gigahertz ( $10^9$  Hz) range) can be used to interrogate dielectric materials. The interaction of this energy with materials is closely analogous to that of mechanical (acoustic) waves. Here, however, the key to the detection of anomalies is not the difference in acoustic or mechanical impedance but in differences in the dielectric constants (i.e., the refractive indices, the electrical conductivities, and the scattering constants or loss tangents) involved. As in the case of the acoustic method, we may measure the amplitude of reflected energy or, where no electrically conducting (nondielectric) layers are interposed, we may measure the amplitude of the signal transmitted through the sample. Additionally, phase shifts in the returned signals contain useful information about the characteristics of the materials being interrogated.

Microwave reflectometry (3,6-11) shows great promise for the detection of voids, cracks, delaminations, and moisture content. The presence of a totally reflecting, conductive substrate permits the application from the external surface only. By selecting the appropriate mode (i.e., continuous wave, time domain, or frequency domain), assessment of ablator anomalies is possible.

Rockowitz, et al, (3) report the detection of voids as small as 0.318 by 0.635 centimeters (0.125 by 0.250 inch) and density variations as little as  $\pm 5$  percent using a frequency of 69 GHz. Lucian, et al, (7) recommend the use of  $K_a$  band, 25 to 40 GHz, but give no data in support of the recommendation. Since defects must be greater in size than  $1/2$  wavelength to afford scattering of the microwave energy, the minimum detectable defect diameter,  $d$ , must be

$$d = \frac{\lambda}{\pi}$$

where  $\lambda$  = wavelength of the medium

Thus, for a minimum detectable spherical defect of 0.1-centimeter (0.039 inch) diameter, the required wavelength is 0.314 centimeter (0.124 inch), or a frequency of about 100 GHz.

Microwave methods have been applied to the detection of voids, density variations, cracks, moisture content, and unbonds in low density, dielectric materials similar to the filled, phenolic honeycomb ablator panels. The unbond

application, however, did not progress beyond the laboratory stage and would require much further development. In view of the problems referred to in references (1) and (12), further development does not appear warranted for this application. Additional work does seem appropriate to develop methods for measuring the other anomalies mentioned above.

Ultrasonics.- The ultrasonic method of NDE is similar to the acoustic method discussed previously, the difference being the frequency or wavelength involved. As discussed previously, the response of a material to mechanical energy is dependent upon the relationship of the wavelength of the energy to the size of the anomalies to be detected. Ultrasound (0.1 to 40 MHz) is used in the resonance, pulse-echo (or reflection), and through-transmission modes to detect many types of material variations.

Considerable work has been done on bond examination using ultrasonic resonance methods. Clemens, et al, (12, 13) report on the use of the Fokker Bond Tester. Their work correlated cohesive bond strength for FM-47 adhesive, as measured by instrument indications, with the results of destructive tests. After extensive and careful correlation, they were able to predict cohesive strengths with a satisfactory degree of accuracy. They make no claim, however, of being able to measure adhesive bond strength, and point out that, in the absence of any known method of adhesive bond NDE, strict process control and proof testing must be relied upon. Extensions of this work with the Fokker instrument (14-16) have confirmed earlier findings and have developed data for other adhesives, (e.g., vinyl nitrile epoxy phenolic, FM 1000, Redux 775, Metlband 4021 and HT-424).

Lockyer (17) and others have reported results of ultrasonic velocity and attenuation measurements and their relationship to bulk density, ultimate tensile strength, and modulus of elasticity of thermal protective composites. While these data have been taken on heat shield materials of a higher density than the NASA 80/20 ablator, similar investigations using lower frequencies (20 to 40 kHz) to accommodate the higher attenuation should produce data of a similar nature.

A phase analysis approach to unbond detection is reported by Lopilato, et al. (18) The same method has been investigated and used by General Dynamics/ Fort Worth (19) and others with considerable success in appropriate applications. The theory is well covered by Wood. (20) This approach requires that the acoustic impedance ratios ( $Z_2/Z_1$ ) at the various interfaces be less than 1.0 to produce the necessary phase shifts for significant results. Since the acoustic impedance of air is less than that of the ablator panels and less than the adhesive used, an unbond condition will cause a phase reversal of an ultrasonic wave reflected from the air in the unbond back into the ablator. Currently available instrumentation is theoretically capable of detecting this phase reversal, but additional development is required to overcome the extremely high ultrasonic energy absorption of the ablator material.

Preliminary MDAC-E investigations have confirmed the applicability of the Fokker instrument to the detection of unbonds when applied from the internal surface of the panels. Additionally, the Sondicator, utilizing dry-coupled contact, low-frequency (25 kHz), ultrasound has been successfully demonstrated

in our facility in the pulse-echo mode. Neither method, however, was successful in locating unbonds when applied to strain isolated panels.<sup>(21)</sup> Further effort is required in this area and is proceeding as a company sponsored effort.

Acoustic Emission.- For many years, scientists have observed the emission of stress waves by material undergoing plastic deformation. This energy is emitted whether the deformation is in the micro- or the macro-range. One of the earliest observations was described as "tin cry"; the audible sounds emitted by tin during deformation. In recent years, refinements in observation and recording techniques have shown that progressive yielding of a material under stress can be detected and related to the integrity (among other qualities) of the material involved. For example, micro-failure at a bond line can not only be detected but, through the use of triangulation methods, can be located with a high degree of accuracy. One promising feature of the method is its amenability to on-board, or in-service, monitoring with permanently installed sensors.

Acoustic emission techniques show great promise for bond evaluation, but have been little developed thus far. Work by Schmitz, et al <sup>(22-24)</sup> found this method, when applied to bonds under stress, to be a reliable indicator of bond quality. Proof loading to 90 percent of ultimate tensile strength gave repeatable indications of impending failure without degradation of bond quality. They reported, however, that a development effort was required to achieve an easily controlled method for stressing bonds.

The advantages of the acoustic emission method are:

- (1) detection of weak bonds
- (2) large structures can be interrogated without scanning
- (3) useful for "before and after" evaluation such as in degrading environment investigations.

Disadvantages are:

- (1) bond line must be stressed
- (2) difficult to locate poor bond in large structures. (Subsequent work by Dunnegan, Nortec, Battelle-N.W. and others <sup>(25)</sup> in flaw location is well documented and largely overcomes this factor as a deterrent.)
- (3) operator-dependent, to some degree.

The National Materials Advisory Board <sup>(26)</sup> lists bond quality as a significant problem area for NDE and urges work on acoustic emission studies to achieve solutions.

Proof Testing.- As the name implies, proof testing involves the mechanical loading of a part. Its interface with the science of NDE requires that the loading be monitored in some fashion, such as by acoustic emission, to prevent actual damage to the part under investigation. The method is important to the

investigation of bond integrity because, without it, the current state of the art is limited. Common NDE technology allows the measurement of cohesive bond quality with an acceptable degree of assurance. On the other hand, there is no known means of assessing adhesive bond quality short of the combination of NDE and proof loading.

Hendrickson and Phelps (27) have reported the development of a proof loading device which operates on the electromagnetic principle, and overcomes most shortcomings of previously used methods. The approach is analogous to that used for electromagnetic forming, but the driving pulse is shaped to produce a tensile, rather than a compressive, force. By controlling the pulse fall time and coil current, highly reproducible results are achieved. Tensile levels of over 20,684 kilonewtons per square meter (3000 pounds per square inch) can be achieved with a high degree of accuracy.

A major drawback to practical use of acoustic emission for bond evaluation has been a suitable means of providing the required stress in a controlled manner. It is felt that an investigation of acoustic signature variations with bond quality should be undertaken, using a stressing approach similar to that described above. This subject has been discussed with others working in each field.(25, 28) They agree that the approach deserves investigation. The method, however, requires internal access to the panel or part.

Holography.- Holography produces a three dimensional, stereographic view of an object. Rather than recording an image as in conventional photography, the process records the information produced by interference patterns formed by the superposition of coherent light from a reference source and from reflection by the object. The resulting hologram contains complete phase and amplitude information and can then be used to reconstruct the view in a completely natural and three dimensional fashion. The required coherent light is most easily obtained from a laser source.

Holographic interferometry can take advantage of this phenomenon in three modes of operation:

Real-time - The process hologram is mounted in the exact position in which it was exposed and the object viewed through the hologram while it is illuminated by coherent light. If the object is moved or deformed, the change will be manifested by the appearance of fringes (light and dark bands). The location and spacing of these fringes are a measure of the motion or deformation of the surface.

Time-lapse (double exposure) - This mode is similar to real-time interferometry except that two holograms are made on the same plate; one with the object in its normal state and the other while it is being stressed. The resulting hologram when viewed with coherent light reveals a static fringe pattern from which microscopic surface deformations may be measured.

Time-average - In this mode the object is stressed in a periodic fashion (e.g., vibration). The hologram is exposed and, when viewed with coherent light, the reconstructed image displays fringes which are a measure of vibration amplitudes at its surface.

The reconstructed holographic images may be enlarged or reduced in scale by viewing under illumination by light of a different wavelength than that by which they were produced.

The holographic method shows promise for use on TPS. Subsurface defects are manifested at the surface and produce fringe irregularities when the object is stressed. The present MDAC-E program cited in reference (6) will investigate the use of holographic interferometry to evaluate RSI for voids, cracks, delaminations, and unbonds. The work is scheduled for late in the program; thus, results are not yet available. The literature is devoid of references to work of this nature. One manufacturer of holographic systems (29) reports success in detecting bond defects in panels or cork, Teflon, and RTV bonded to aluminum substrates. There is reason, therefore, for optimism concerning the applicability of the method to honeycomb ablator panels. A feasibility study is underway at this time.

Because the holographic method is relatively new, first being practically applied in 1965, much further development will be required before the method can leave the laboratory for routine shop or field application. Since displacements in the order of the wavelength of light - approximately  $5 \times 10^{-5}$  centimeter ( $1.27 \times 10^{-5}$  inch), small ambient vibration levels and slight changes in the index of refraction of air in the optical path (e.g., that produced by thermal convection currents) render the method unusable unless conditions are carefully controlled.

Visual Inspection.- Visual inspection, within its obvious limitations, is applicable and recommended by Dervy. (30) After achieving no success in detecting heat shield bond defects using X-ray, sonic resonance, infrared, and microwave methods, he developed a visual inspection method which may have merit. It consists of leaving certain honeycomb cells unfilled until after the bonding operation is completed. This allows the use of suitable optical equipment to verify the bond condition around those cells. While this method relies on sampling, it is believed to offer a valuable adjunct to the tensile testing of the in-process control coupons. After bond quality verification, the empty cells are filled with a repair ablator mix.

NDE Method Comparison and Evaluation.- Each of the NDE methods discussed above has a possible place in the inspection and bond certification of the bonded-on ablator panels. X-ray requires access to both sides of the panels. Acoustic emission and ultrasonics may require two sided access unless provisions are made for access through the ablator at various points in each panel for the application of suitable transducers. Such access would permit obtaining acoustic signatures from the substrate as the bond line is stressed. The introduction of Lamb waves (31, 32) into the substrate through these access ports would provide a reliable assessment of bond quality.

Depending upon the method of applying the necessary stress to the panels, holography may or may not require access to both surfaces.

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Depending upon the method of applying the necessary stress to the panels, holography may or may not require access to both surfaces.

A 50.8 by 76.2-centimeter (20 by 30-inch) panel, shown in figure 17, was fabricated as described in the "Ablator Panel Fabrication" section. Artificial unbonded areas were introduced on each side of each bond line as indicated. These were accomplished by placing 0.012-centimeter (0.005-inch) Mylar discs at appropriate locations while bonding the ablator panels to the aluminum sheet. One-half of the panel included a 0.318-centimeter (0.125-inch) silicone sponge strain isolator. The other half was bonded directly to an aluminum sheet, 0.081 centimeter (0.032 inch) thick. The location of the Mylar discs with respect to the various bond lines is described below and keyed to figure 17.

- A. Top of bond line between the ablator and the strain isolator.
- B. Bottom of bond line between the ablator and the strain isolator.
- C. Top of bond line between the aluminum sheet and the strain isolator (or the ablator, where the strain isolator was omitted).
- D. Bottom of bond line between the aluminum sheet and the strain isolator (or the ablator where the strain isolator was omitted).

Using both the Fokker Bondtester and the Model S-1 Sondicator in the dry-coupled contact mode, we were able to detect all unbonds in the area where the panel was bonded directly to the aluminum. Neither of the instruments responded to the unbonds in the strain isolated area, and both instruments required access to the aluminum face of the panel. The Fokker instrument was judged to give more reliable indications and to be less susceptible to operator-induced false indications.

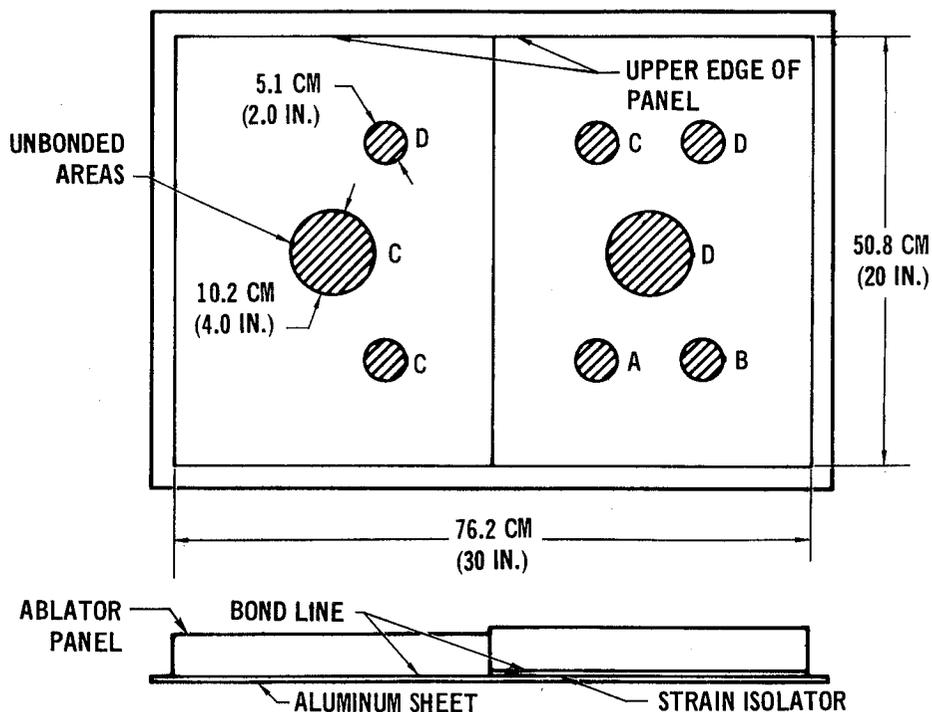


FIGURE 17 NDE ABLATOR PANEL

The Sondicator was used in its air-coupled mode. A pitch-catch technique from the ablator side was unsuccessful. Using the through-transmission setup shown in figures 18 and 19, line scans were made which detected all artificial unbonds in the section of the panel without the strain isolator. The added attenuation of the foam isolator exceeded the capability of the instrumentation. Figure 20 shows the resulting scans. All three artificial unbonds, and some apparently natural unbonds, are detected. With some modification, this equipment and approach would be capable of characterizing bond defects in areas both with and without a strain isolator.

The panel was sealed to allow its immersion in water. Ultrasonic C-scans were performed from the aluminum face using the pulse-echo mode. The panel was immersed for convenience only. In practice, proper fixturing would allow the use of a bubbler and eliminate panel sealing and immersion.

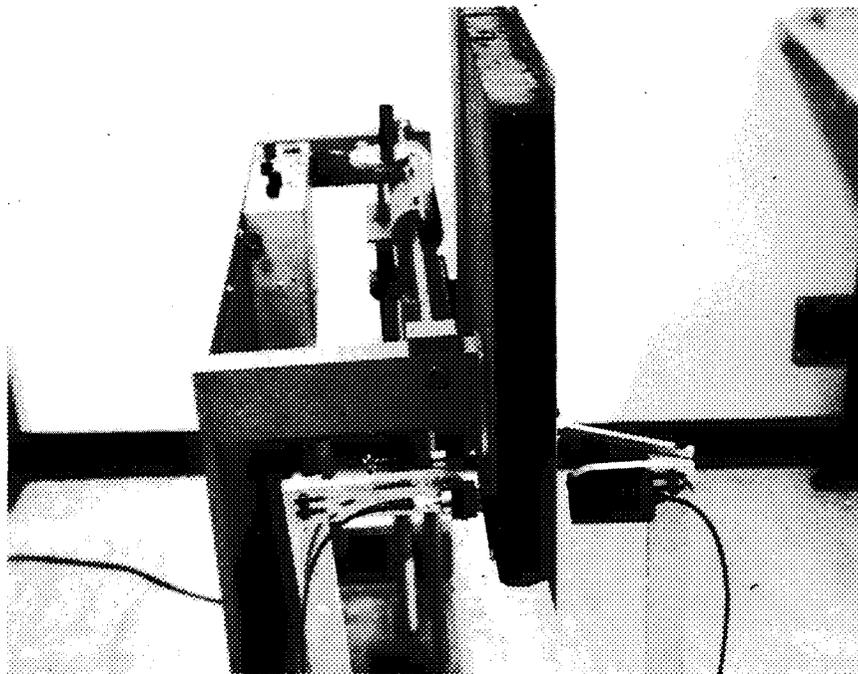
Basically, the inspection parameters were selected to display a "ringing" signal pattern which was established using the bare aluminum sheet extending from under the bonded-on ablator. The signal pattern consists of multiple echoes from the far side of the face sheet. Over bonded areas, the pattern is severely damped. Scans were made at 2.25, 5, 15 and 25 MHz using search units of varying focal lengths. All artificial unbonds were detected except those associated with the bond line between the ablator panel and the strain isolator. This is attributed to the high damping coefficient of the silicone sponge material masking the defect responses. Typical scans made using a 15 MHz search unit, pulsed at 2.25 MHz, are shown in figures 21 and 22. Note that the natural unbonds appearing in the lower left in figure 21 correspond well with those shown in figure 20.

The panel was radiographed using very high sensitivity, ultra fine grain film (Kodak R) and low energy. The resulting radiograph showed, as expected, no significant defects. The panel is currently undergoing a holography feasibility study and further company sponsored work is planned.

Other than visual examination, no NDE method has yet proved effective where access is available only to the ablator surface. Both ultrasonic immersion pulse-echo and air-coupled low frequency examinations show correlation with known artificial unbonds, except those associated with the bond line between the ablator and the strain isolator. Both methods indicate natural unbonds in the panel. Each has been shown feasible where access to the aluminum face may be obtained, and each has a good potential for use in production inspection. The examination of bonds and of low density materials have each been difficult NDE problems for many years. The solution to these problems by certain NDE methods just described appear feasible based on laboratory experimentation. However, the use of these methods on a large scale basis, such as for Space Shuttle application, will require far more development and refinement before they can become standard methods for bond verification and certification. The work being accomplished under NASA contract NAS 9-12180 (6) and other on-going studies must be continued and intensified. We recommend that NASA fund such work at a higher level.



**FIGURE 18 SONDICATOR SETUP FOR THROUGH TRANSMISSION  
EXAMINATION OF NDE TEST PANEL**



**FIGURE 19 CLOSEUP OF SCANNING MECHANISM AND SONDICATOR TRANSDUCERS**

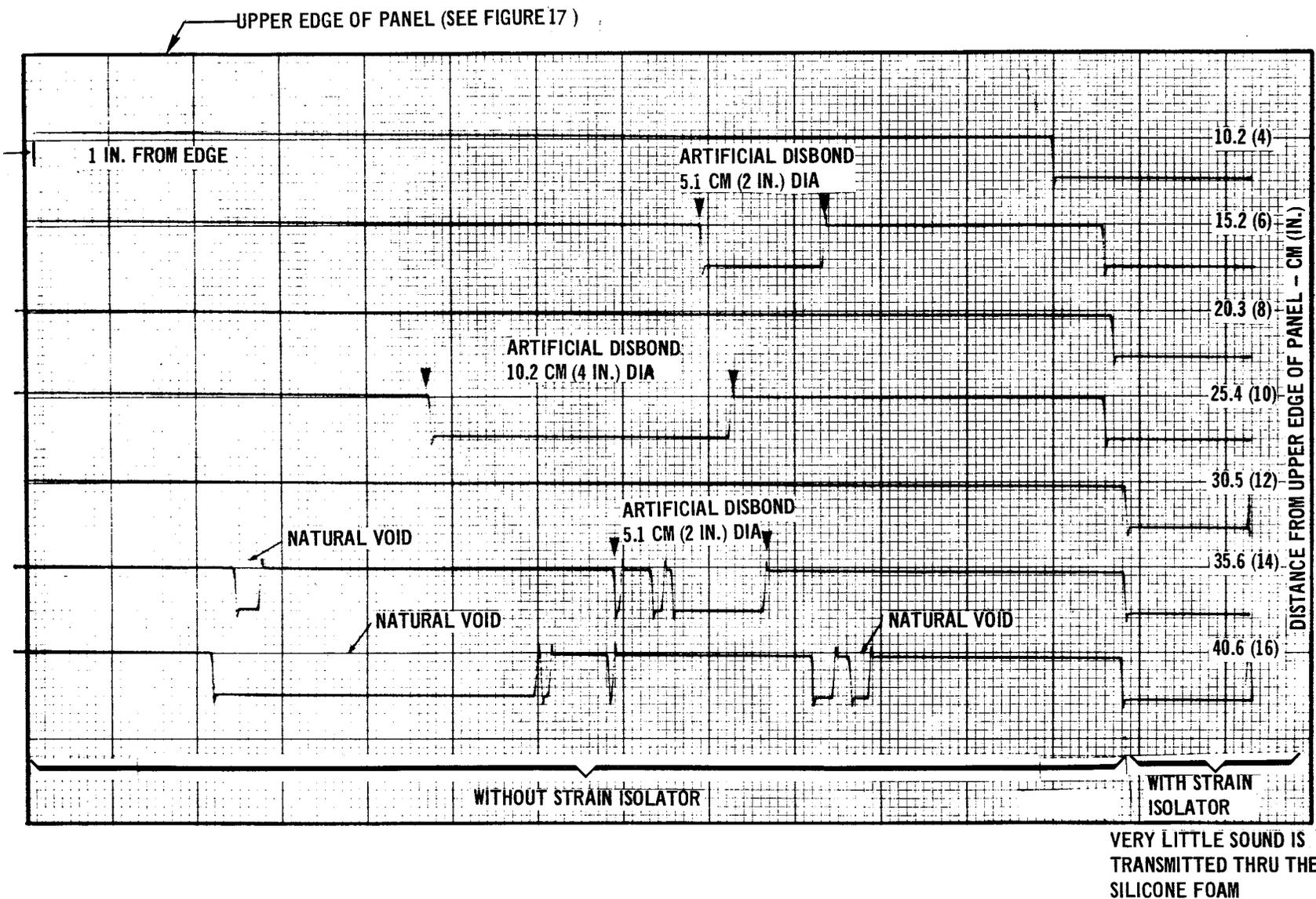
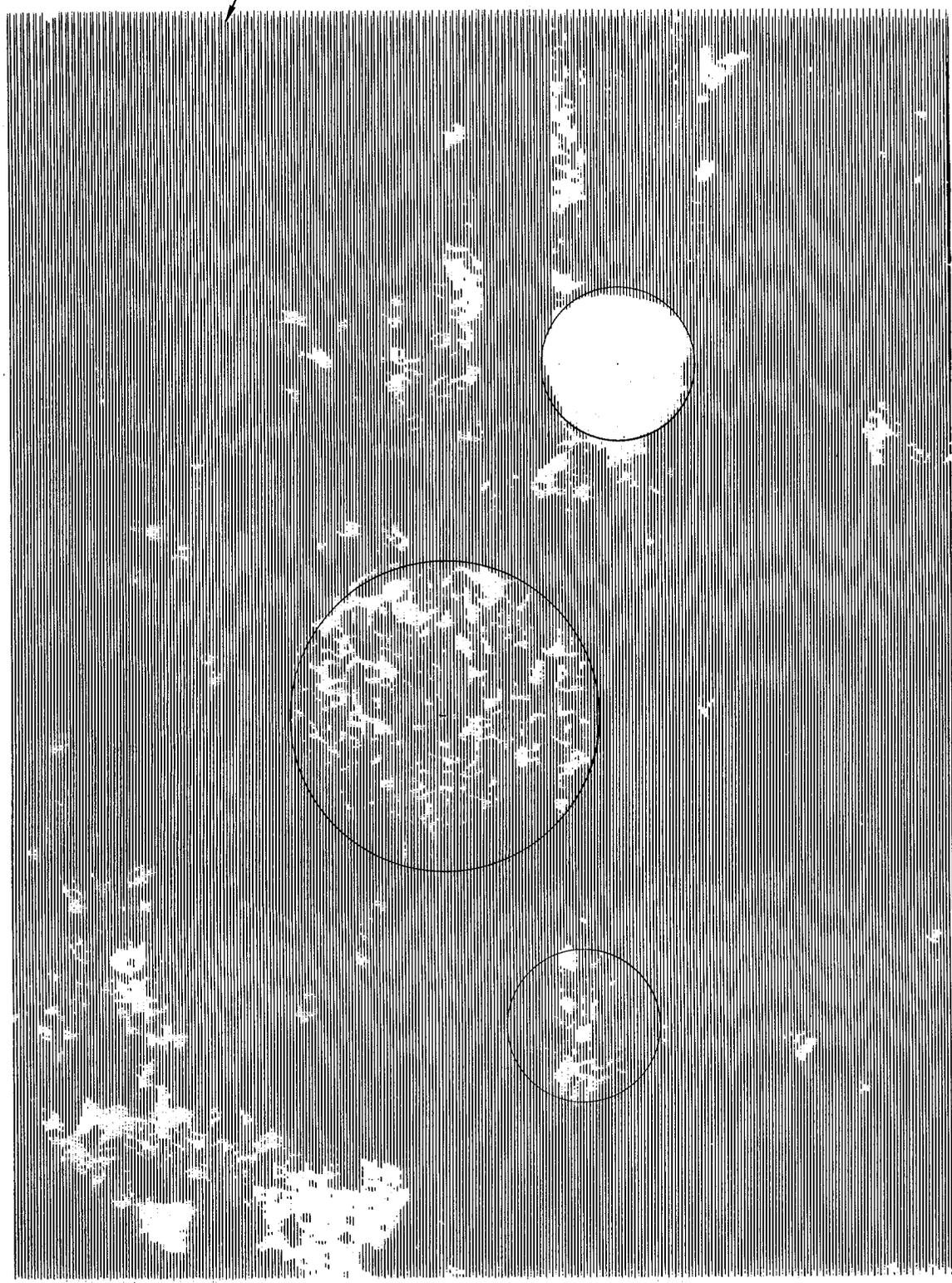


FIGURE 20 SONDICATOR LINE SCAN OF NDE TEST PANEL

E  
DE  
UE

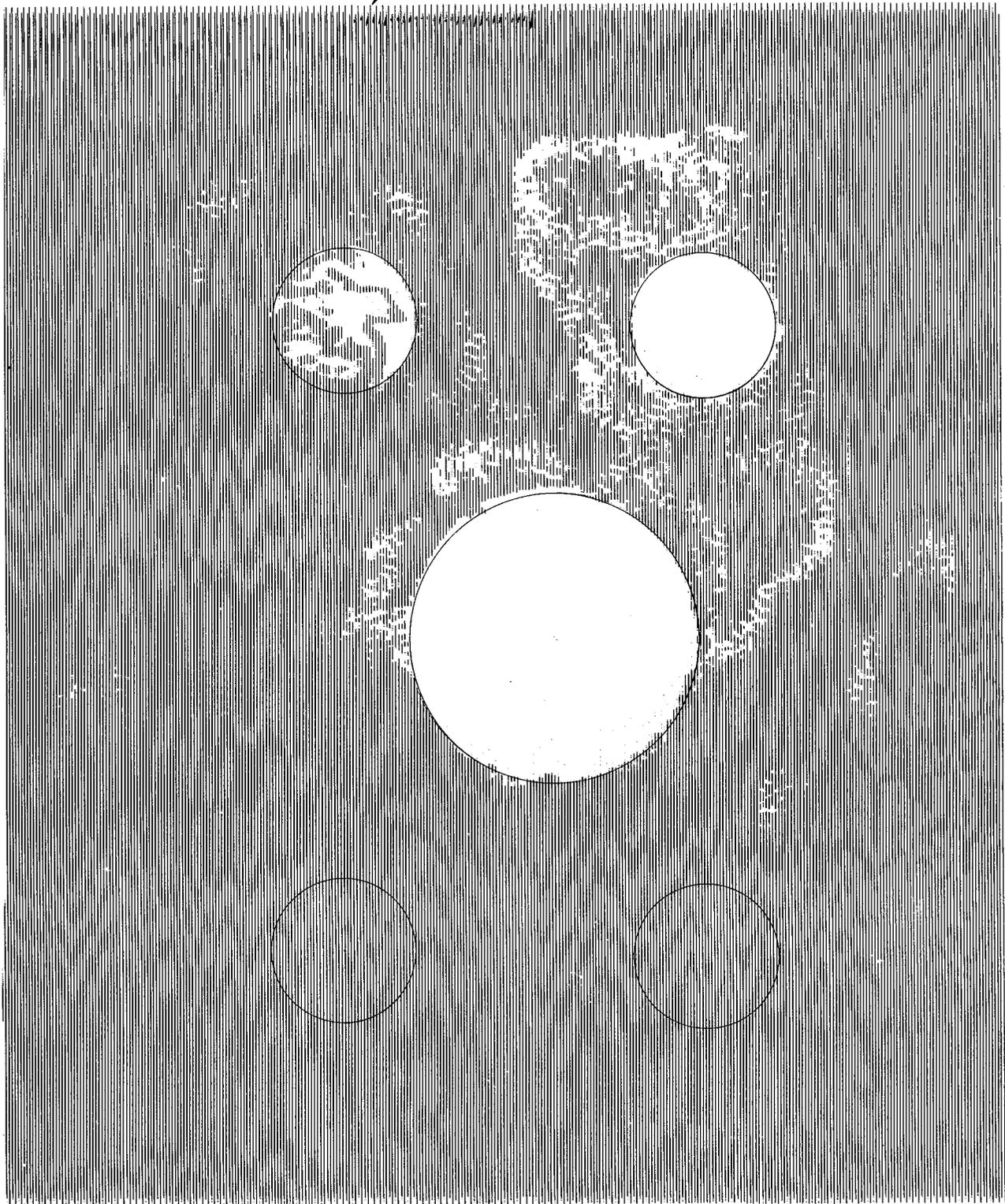
UPPER EDGE OF PANEL (SEE FIGURE 17)



- CIRCULAR AREAS DENOTE INTENTIONAL UNBONDED AREAS
- LIGHT AREAS SIGNIFY UNBOND

FIGURE 21 ULTRASONIC C-SCAN OF NDE TEST PANEL (WITHOUT STRAIN ISOLATOR)

UPPER EDGE OF PANEL (SEE FIGURE 17)



- CIRCULAR AREAS DENOTE INTENTIONAL UNBONDED AREAS
- LIGHT AREAS SIGNIFY UNBOND

FIGURE 22 ULTRASONIC C-SCAN OF NDE TEST PANEL (WITH STRAIN ISOLATOR)

## Static Testing

As noted previously, one of the NDE methods currently under evaluation in the aerospace industry to determine bond integrity for the direct bond-on TPS panels, involves proof or static testing. Tests which develop bond stresses of 1.76 kilograms per square centimeter (25 pounds per square inch) are thought to be adequate for determining bond integrity. During Task II, several static test concepts were investigated. Strength tests of two of these concepts were conducted in the laboratory to aid in their evaluation. These two concepts were later used in a time and motion study of the ablator panels on the mockup. In addition, mechanical properties were determined for the ablator material being considered. This section of the report, therefore, describes the results of the laboratory screening studies and strength tests.

Bond Test Concepts.- The various bond test concepts investigated included the insert, bonded-on fittings, suction cup, protruding honeycomb cells, and cork screw techniques shown schematically in figure 23. All concepts investigated utilized NASA 80/20 ablator in a honeycomb core.

The "insert" concept consists of an aluminum insert potted in the honeycomb core. The insert is not bonded to the substructure but is used to load the ablator and test the ablator panel to substructure bond. After the ablator panel is bonded to the substructure, a plug is machined in the ablator panel with the insert at its center. To test the bond, a tool is threaded into the insert and prescribed tension load is applied. After testing, the tool is removed while the insert is left in the ablator. This is a simple concept, but inserts of this type add weight to the TPS and provide heat shorts to the structure.

The "bonded-on fitting" concept consists of an aluminum fitting bonded to a plug machined in the ablator panel after the panel is bonded to the substructure. A tool is attached to the bonded fitting for strength testing. The fitting is later removed either by severing the bond between fitting and ablator panel or by heating the bond locally (or both). Removing the fitting could be facilitated by placing small wires in the bond which are pulled to cut the adhesive. This is a reliable concept which has the advantage of applying uniform stresses to the bondline; however, it has a disadvantage in that the fittings have to be removed prior to flight.

The "suction cup" concept consists of applying a vacuum to pull on the machined plugs. Differential pressure is probably difficult to achieve because of ablator porosity, and the maximum differential pressure of 96.6 kilonewtons per square meter (14.7 pounds per square inch) is not high enough to properly test the bond.

In the "protruding honeycomb cells" concept the honeycomb cell walls protrude beyond the ablator surface. Loads are applied to the cell walls to determine the integrity of the ablator-to-structure bond. This concept has

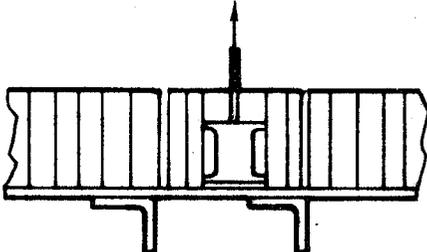
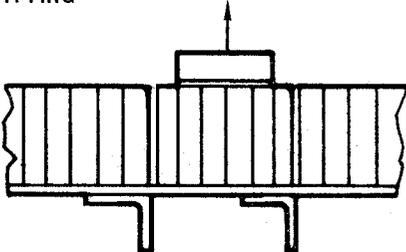
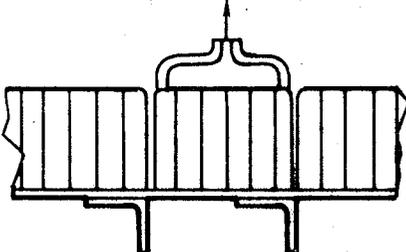
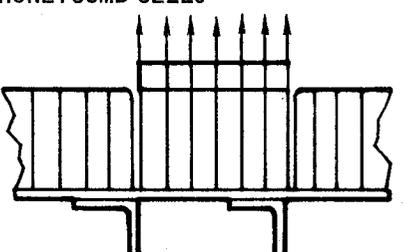
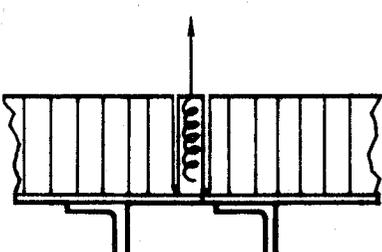
CONCEPT	COMMENTS
<p>1) INSERT</p> 	<ul style="list-style-type: none"> <li>• SIMPLE CONCEPT</li> <li>• INSERTS ADD WEIGHT TO TPS</li> <li>• INSERTS PROVIDE HEAT SHORTS TO STRUCTURE</li> </ul>
<p>2) BONDED ON FITTING</p> 	<ul style="list-style-type: none"> <li>• SIMPLE CONCEPT</li> <li>• REQUIRES REMOVAL OF FITTING</li> <li>• REPAIRS MAY BE REQUIRED</li> </ul>
<p>3) SUCTION CUP</p> 	<ul style="list-style-type: none"> <li>• MAY BE DIFFICULT TO OBTAIN DIFFERENTIAL PRESSURE BECAUSE OF POROSITY OF ABLATOR</li> <li>• APPLIED BOND STRESS LIMITED TO 1.03 Kg/CM<sup>2</sup> (14.7 PSI)</li> </ul>
<p>4) PROTRUDING HONEYCOMB CELLS</p> 	<ul style="list-style-type: none"> <li>• DIFFICULT TO FABRICATE</li> <li>• DIFFICULT TO APPLY UNIFORM LOAD</li> </ul>
<p>5) CORK SCREW</p> 	<ul style="list-style-type: none"> <li>• DIFFICULT TO ACHIEVE HIGH LOADS BECAUSE OF LOW STRENGTH OF ABLATOR</li> <li>• REQUIRES REPAIR</li> </ul>

FIGURE 23 BOND TEST CONCEPTS

two disadvantages; the ablator panels are difficult to fabricate, and it would be hard to apply uniform loads to the cell walls.

The "cork screw" concept consists of a cork-screw-type device inserted into a cell of the honeycomb core, and then cutting the ablator loose from the cell wall. This concept has two disadvantages; it is difficult to insert a tool into one cell and cut the ablator loose from the cell wall, and the low strength of the ablator would probably limit the applied load and the resulting bond stress to low values.

The "insert" and "bonded-on fitting" concepts were selected for further evaluation and are discussed in more detail later in this section.

Ablator Mechanical Properties.- Tensile tests were conducted to determine mechanical properties of the NASA 80/20 ablator blend material with and without honeycomb core. These tests were necessary for evaluating the merits of the two selected static bond test concepts. It was assumed that since the honeycomb core has a 1,379 kilonewtons per square meter (200 pounds per square inch) tensile strength and modulus of 158,578 kilonewtons per square meters (23,000 pounds per square inch), the tensile properties of the ablator specimens would approach these values. The full 1,379 kilonewtons per square meter (200 pounds per square inch) tensile strength was not expected since the ablator prevented good fillet action of the adhesive to the cells of the honeycomb core. Cylindrical shaped specimens, 2.54 centimeters (1.0 inch) long by 3.18 centimeters (1.29 inches) in diameter, were tested at room temperature with the test setup illustrated in figure 24. Aluminum loading blocks were bonded to the cylindrical specimens with Scotchweld 2716 adhesive, with loads applied to the aluminum blocks through universal joints which assured that pure axial loads were applied to the specimens.

Specimen strains were determined by using two double cantilever clip-on displacement gages, illustrated in figure 24. Strain gages were bonded to the cantilever arms of the displacement gages. Displacement gages were calibrated by relating strain gage output to displacement of the cantilever arms. The gages were clamped between knife edges attached to the aluminum blocks with set screws. Gages were attached to two sides of each specimen to compensate for differential strains due to specimen misalignment or nonuniform specimen density. Gages were accurate to within  $\pm 0.00076$  centimeter/centimeter ( $\pm 0.0003$  in/in).

Four tensile mechanical property tests were conducted including two on specimens of the NASA 80/20 blend material alone and two on specimens having the same material filled in honeycomb core having 0.953 centimeter (0.375 inch) wide cells. Results of these strength tests are summarized in table 4. Ultimate tensile strengths, strains at failure, and elastic moduli are listed along with average properties. Tensile strength of the ablator material alone is 233 kilonewtons per square meter (33.9 pounds per square inch) and the modulus is 17,926 kilonewtons per square meter (2600 pounds per square inch). As expected, strength and modulus of the composite ablator and honeycomb core were significantly higher than that of the ablator alone, being 896 kilonewtons per square meter (130.0 pounds per square inch) and 234,420 kilonewtons per square meters (34,000 pounds per square inch), respectively. These data indicate that

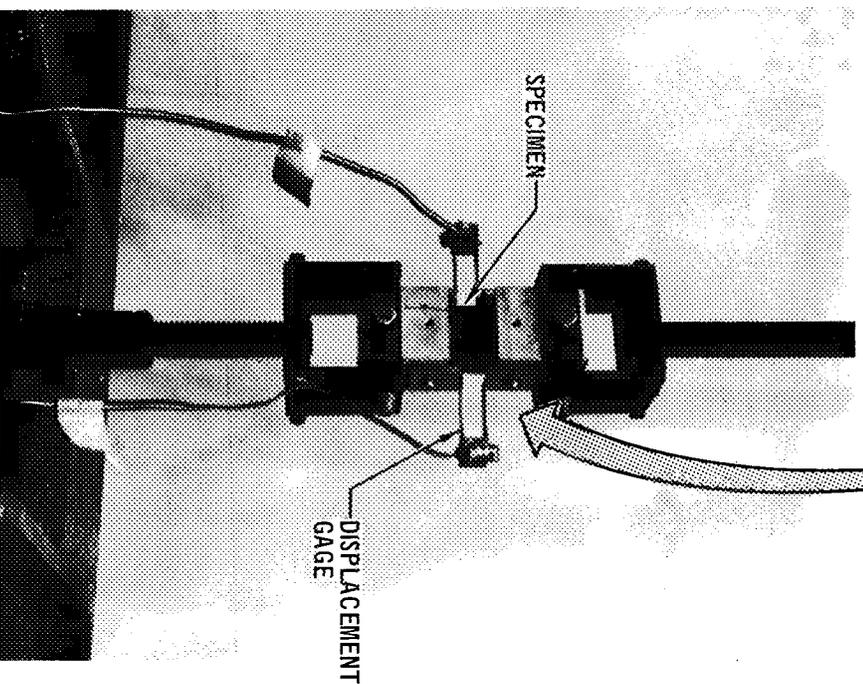
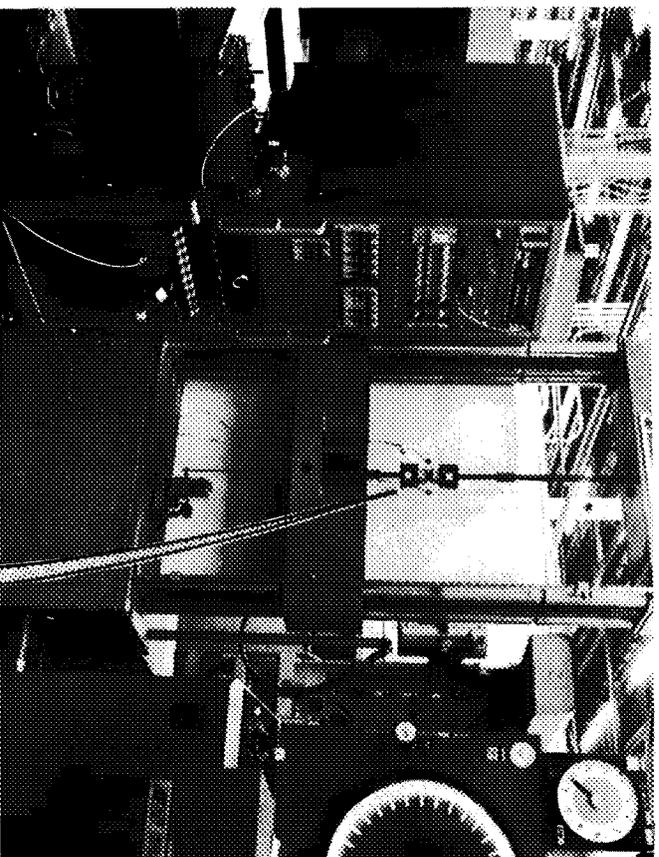


FIGURE 24 ABLATOR MECHANICAL PROPERTY TEST SETUP

**TABLE 4**  
**ABLATOR TENSILE STRENGTH TEST RESULTS**

SPECIMEN	SPECIMEN NUMBER	DENSITY Kg/m <sup>3</sup> (LB/FT <sup>3</sup> )	ULTIMATE TENSILE STRENGTH kN/m <sup>2</sup> (LB/IN. <sup>2</sup> )	STRAIN AT FAILURE (PERCENT)	ELASTIC MODULUS kN/m <sup>2</sup> (LB/IN. <sup>2</sup> )
NASA 80/20 ABLATOR BLEND	A	211.0 (13.2)	265 (38.5)	1.65	18,547 (2,690)
	B	205.0 (12.8)	202 (29.3)	1.82	17,306 (2,510)
	AVERAGE	208.0 (13.0)	234 (33.9)	1.74	17,926 (2,600)
NASA 80/20 ABLATOR BLEND IN HONEYCOMB CORE	C	284.0 (17.7)	958 (139.0)	0.45	233,041 (33,800)
	D	250.0 (15.6)	834 (121.0)	0.41	235,799 (34,200)
	AVERAGE	268.0 (16.7)	896 (130.0)	0.43	234,420 (34,000)

the honeycomb core contributes considerably to the composite ablator/honeycomb mechanical properties. Typical failed specimens are illustrated in figure 25.

Bond Tests.- Strength tests of the "insert" and "bonded-on fitting" concepts were conducted to aid in the evaluation. Both concepts are illustrated in figure 26. The test setup used to test three "insert" specimens is illustrated in figure 27, while the test results are summarized in figure 28. Specimen No. 1 failed at a low load because of a poor bond between the ablator plug and substructure. Specimen No. 2 also failed at a low load because the ablator was nonuniform and soft near the bondline. Specimen No. 3 failed at the bondline at a load of 400 newtons (92 pounds) or 302 kilonewtons per square meter (43.8 pounds per square inch). The failure stress is less than the strength of the ablator/honeycomb core composite of 896 kilonewtons per square meter (130.0 pounds per square inch) discussed previously. This is attributed to the design of the specimen, which loads the bond in peel.

The setup for testing six "bonded-on fitting" specimens was similar to that used for the "insert" specimens. Test results are summarized in figure 29. All specimens except Specimen No. 3 failed between the ablator and substructure. The three adhesives used to bond the fittings to the ablator panels included RTV 560, EC 2216 and EPON 828. Since the RTV 560 adhesive produced the highest failure loads and was also the easiest to remove from the ablator, it was selected for subsequent testing on the mockup at NASA-LRC.

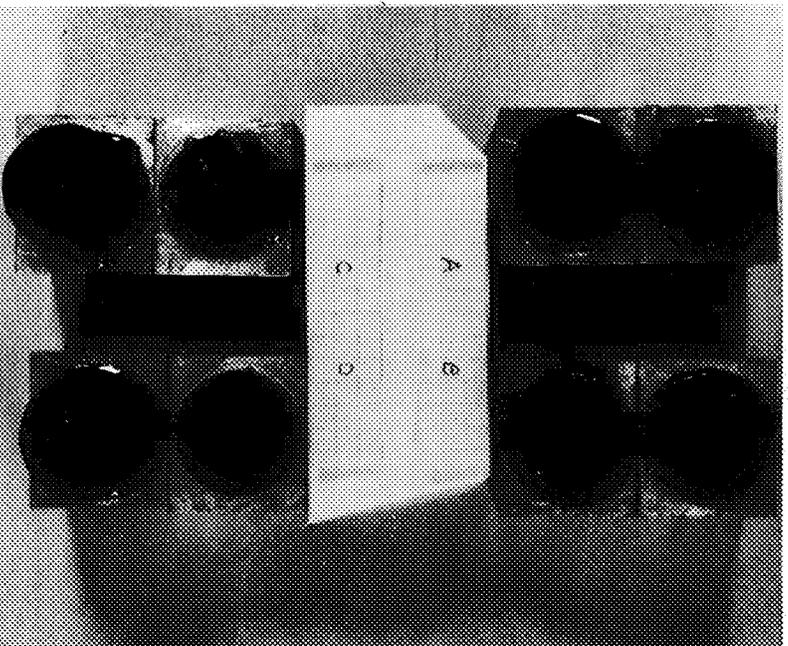
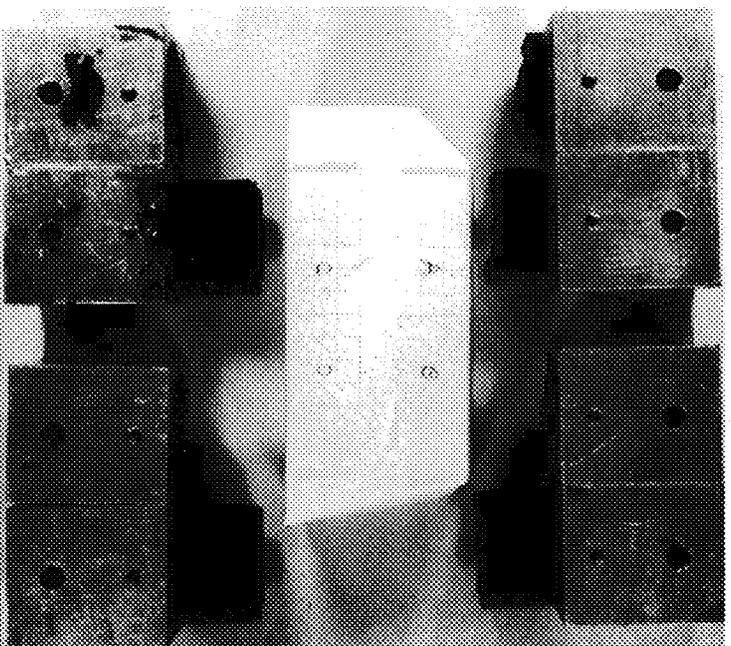
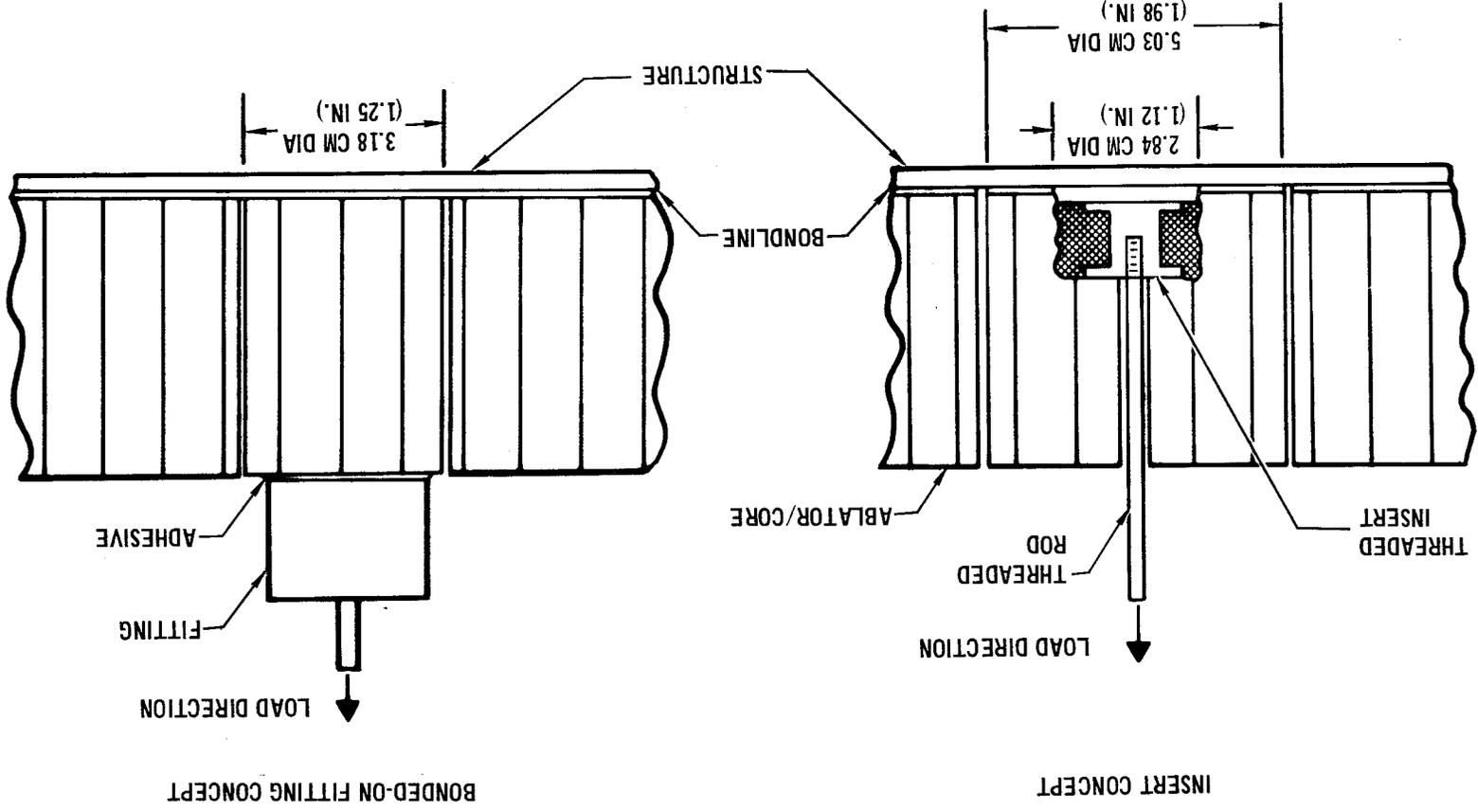


FIGURE 25 FAILED TEST SPECIMENS

FIGURE 26 SPECIMENS USED FOR BOND STRENGTH EVALUATION



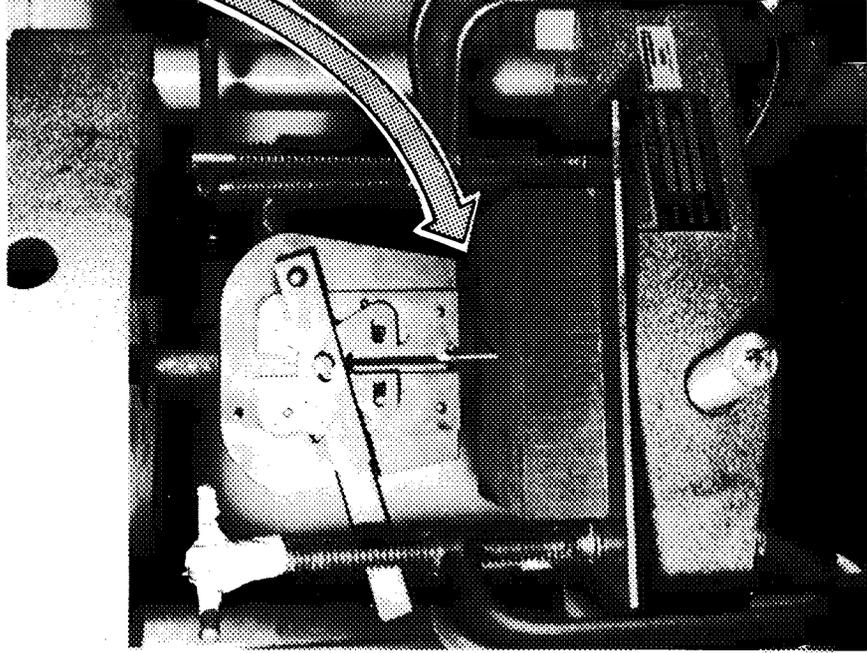
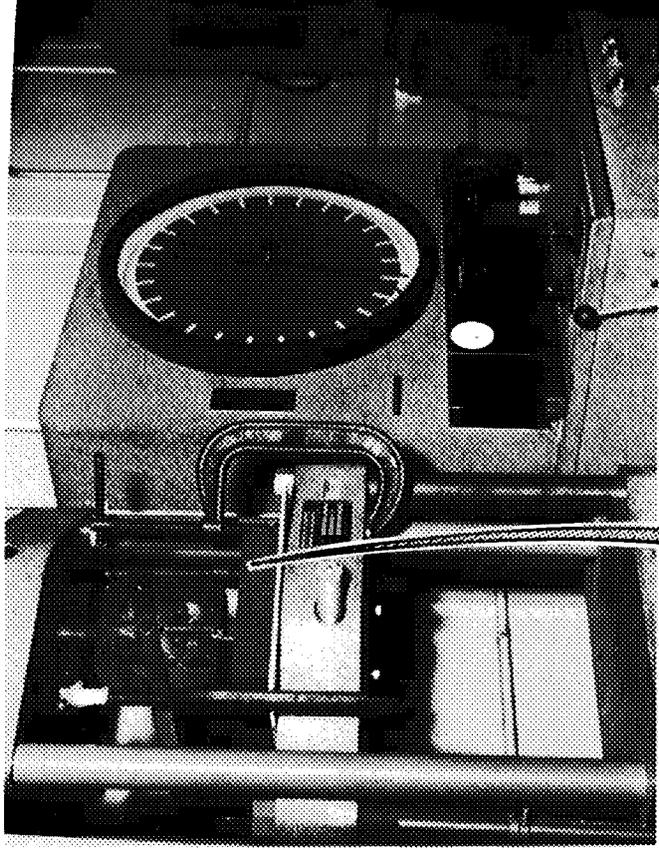


FIGURE 27 INSERT TEST SETUP

PLUG DESCRIPTION	SPECIMEN NUMBER	D <sub>1</sub> CM (IN.)	D <sub>2</sub> CM (IN.)	BOND AREA CM <sup>2</sup> (IN. <sup>2</sup> )	FAILING LOAD N (LB)	ULTIMATE TENSILE STRENGTH kN/m <sup>2</sup> (LB/IN. <sup>2</sup> )
	1 (A)	2.84 (1.12)	5.02 (1.98)	13.55 (2.10)	240 (54.0)	-
	2 (B)	2.84 (1.12)	5.02 (1.98)	13.55 (2.10)	276 (62.0)	-
	3	2.84 (1.12)	5.02 (1.98)	13.55 (2.10)	409 (92.0)	302 (43.8)

(A) POOR BOND

(B) SOFT ABLATOR MATERIAL

**FIGURE 28 MACHINED PLUG TENSILE TEST RESULTS  
(With Insert)**

With the limited tests conducted on the "insert" and "bonded-on fitting" concepts, both concepts were found to be feasible and neither concept had a clear advantage over the other. The bonded fitting concept is lighter and produces uniform stresses at the bondline. However, the insert concept requires less time to test and reduces the possibility of having to repair the ablator panels after testing. Both concepts were selected for the refurbishment tests discussed in the next section.

#### Quality Assurance

None of the NDE methods described previously has been developed to the extent that it provides positive NDE approach to establishing bond integrity. Thus, bond integrity verification currently represents a major problem in the development of a reliable Space Shuttle TPS. Much more extensive work must, therefore, be done in this area by industry and the government to achieve a reliable technique(s) for bond inspection and certification.

The most reliable bond verification method to date involves proof or static testing. However, this approach has some significant limitations. The adequacy of proof testing the TPS on the vehicle, although demonstrated in this study to be a feasible approach, is questionable since no statistical means can be applied to determine the number of such tests which should be performed per square meter (square foot) of surface area. During the test program, static testing of machined plugs in the installed ablator panels showed, in most cases, that the bond in the areas tested were adequate. However, subsequent removal of the ablator showed large areas of disbond in regions immediately adjacent to the areas tested. Thus, the current method of static testing on the vehicle would be a matter of chance. Therefore static testing of machined plugs on the vehicle is not recommended at this time.

PLUG DESCRIPTION	ADHESIVE	SPECIMEN NUMBER	FAILING LOAD N (LB)	ULTIMATE TENSILE STRENGTH AT FAILURE ZONE $\text{kN/m}^2$ (LB/IN. <sup>2</sup> )	ABLATOR/STRUCTURE BOND STRESS $\text{kN/m}^2$ (LB/IN. <sup>2</sup> )	
	RTV-560	1	489 (110.0)	965 (140.0)	6617 (89.5)	
		2	400 (90.0)	793 (115.0)	507 (73.6)	
		AVERAGE	445 (100.0)	879 (127.5)	562 (81.5)	
	EC 2216	3 (A)	53 (12.0)	-	-	-
		4	356 (80.0)	703 (102.0)	450 (65.3)	
		AVERAGE	356 (80.0)	703 (102.0)	450 (65.3)	
	EPON 828	5	400 (90.0)	789 (114.5)	505 (73.3)	
		6	285 (64.0)	562 (81.5)	359 (52.1)	
		AVERAGE	343 (77.0)	676 (98.0)	432 (62.7)	

(A) POOR BOND TO STRUCTURE

**FIGURE 29 MACHINED PLUG TENSILE TEST RESULTS  
(With External Fitting)**

Because of the above results, the quality assurance plan described in subsequent text for external access bond verification recommends tensile testing of process control coupons fabricated in parallel with the bonded-on ablator panels. This, coupled with carefully executed and fully documented material and process controls, is considered to be the only available bond quality assurance approach at this time. The in-process control method of bond certification implements traceability and qualification of raw materials, proven state-of-the-art fabrication and bonding techniques, and the fabrication of in-process control coupons, which are fabricated in parallel with each production run. Destruct and/or nondestruct test results of the in-process control coupons is indicative of the bond integrity of the bonded-on ablative panels. A typical quality assurance plan based on the above stated approach is as follows:

Quality Assurance Plan (External Access Only)

A. Receive Raw Material From Vendor

1. Receiving Inspection checks material for obvious damage, proper packaging and quantity. Verify that a copy of vendor certification (including actual test data) accompanies each shipment. A Receiving Inspection Operating Sheet (RIOS) shall be initiated and processed for each shipment of material. Traceability of material by lot number, batch number, and purchase order number shall be maintained and recorded on each RIOS.
2. Forward the raw material to the fabrication bond room, accompanied by one copy of the vendor certification.
3. Forward the completed RIOS and one copy of the vendor certification to the Quality Assurance Record Center (QARC) for filing as a permanent record.

B. In-House Qualification Testing of Raw Material by MDAC-E Bond Room and Quality Assurance Laboratory

1. Each raw material shall be tested per applicable Quality Planning Instruction Sheet (QPIS), implementing the requirements of the engineering drawing, Process Specification (P.S.) or MAC Material Specification (MMS).
2. Each QPIS shall provide complete material traceability, actual test values of each specimen tested, test instructions, and rejection number of the rejecting document in the event of a specimen failure.
3. The following tests will be considered during in-house qualification.
  - o ablator - tensile strength and elongation, hardness (shore "A"), density and thermal expansion
  - o primer/adhesive - lap shear and cure characteristics
  - o honeycomb core - bare compression dry.

C. Raw Material Storage

1. Store the qualified raw material in controlled storage (if required) until ready for use.

D. Fabrication and Bonding

Each procedural operation shall be verified by inspection on QPIS. All ovens, furnaces, and temperature and pressure control systems shall be certified and shall have a current quality assurance calibration tag affixed. All temperature recorder sheets shall be attached to, and made part of, this inspection and certification procedure. All variations from established tolerances must be summarized on applicable rejection documents.

1. An in-process control coupon shall be fabricated in parallel with each production panel or series of panels constituting a production run.

MFG. SUPERVISOR \_\_\_\_\_ INSP. \_\_\_\_\_ DATE \_\_\_\_\_

2. Manufacturing and inspection verify that enough qualified raw material exists to fabricate quantities specified for the production run.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_ MFG. SUPERVISOR \_\_\_\_\_ DATE \_\_\_\_\_

3. Verify nesting the honeycomb core on a wire structure (for adequate support) and prepare for TURCO cleaning per PS 11321.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

4. If the cleaned honeycomb core is not used immediately, protect from dust by wrapping in wax-free Kraft paper.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

5. Flush cleaned honeycomb with phenolic resin primer (SC 1008). Collect primer runoff in a clean, degreased primer collection pan. Reclaim primer immediately after honeycomb is primed. Allow honeycomb to drain in pan for 5 minutes. Place primed honeycomb on clean absorbent paper towels for additional 5 minutes to remove excess primer.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

6. Cure ('B'-stage) the primer honeycomb in an air-circulating oven for 2 hours at 355° to 361°K (180° to 190°F).

RECORD CURE START TIME \_\_\_\_\_ CURE COMPLETE TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

7. After priming operations, cover honeycomb with clean Mylar film until ready for ablator fill operations (not more than 8 hours after priming).

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

8. Position the primed honeycomb core in a mold fixture.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

9. Weigh and mix the ablator materials (microballoons and sylgard 182 resin).

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

10. Fill the honeycomb core with the ablator mix.

RECORD FILLING START TIME \_\_\_\_\_ FILLING COMPLETE TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

11. Vacuum bag the filled ablative core and draw vacuum equal to 88.05 kilonewtons per square meter (26 inches of mercury) (minimum). Check vacuum bag for leaks. After vacuum has been achieved, cure the part at 422 ± 6°K (300 ± 10°F) for

8 hours. Vacuum and temperature shall be monitored on tape recorder sheets during the entire cure cycle.

RECORD TIME VACUUM WAS ACHIEVED \_\_\_ TIME OVEN WAS TURNED ON \_\_\_

TIME OVEN REACHED 422°K (300°F) \_\_\_ TIME CURE CYCLE COMP. \_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

12. Cool part to room temperature and remove from oven.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

13. Machine the part to required thickness - reference applicable drawing.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

14. Trim the part to required dimensions shown on the applicable drawing.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

15. Radiograph part per MDAC P.S. 21206.3 using beryllium window tube at lowest practical kilovoltage. Use ASTM Type 1 film with no front screen. A copy of records required by MDAC P.S. 21206 will accompany the part. Interpretation will cover foreign inclusions, voids, density variation, cracks, and core damage. Penetrimeters are not required. The interpreter's report will accompany the part.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

REMARKS \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

16. Fill voids and/or repair the ablator as determined by x-ray results.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

NOTE: Items 17 through 23 apply to ablator panels that will be bonded to the metal substructure with a strain isolator installed between the ablator panel and substructure.

17. Clean the bond side of the strain isolator with isopropyl alcohol and air dry for a minimum of one hour.

RECORD DRYING START TIME \_\_\_\_\_

DRYING COMPLETE TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

18. At least 1 hour prior to bonding, lightly wipe the surface of the ablator panel (side to be bonded only) with cheesecloth slightly dampened with isopropyl alcohol. Air dry. Do not apply adhesive if there is strong odor of alcohol.

RECORD DRYING START TIME \_\_\_\_\_ DRYING COMPLETE TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

19. Using a clean, degreased (MEK) and dry stiff paint brush and and/or metal spatula, apply approximately 0.013 to 0.025 centimeters (0.005 to 0.010 inches) of catalyzed RTV 560 to the strain isolator and to the cleaned side of the ablator panel.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

20. Immediately bond the strain isolator to the ablator panel. Apply 13.8 to 34.6 kilonewtons per square meter (2 to 5 pounds per square inch) pressure to the isolator during cure cycle.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

21. Cure the bonded assembly for a minimum of 24 hours at room temperature. Do not attempt to remove excess adhesive with solvent.

RECORD CURE START TIME \_\_\_\_\_ CURE COMPLETE TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

22. After cure, trim excess adhesive from bonded assembly with sharpened putty knife or razor blade-type scraper.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

23. Inspect bonded assembly per engineering drawing.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

24. Wipe metal substructure with MEK dampened cloth. Allow to air dry.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

25. Scrub the metal surface with nylon/silicon carbide abrasive pads and water. Alternate scrubbing the surface with clean abrasive pads and wiping with water soaked clean cheesecloth until all oxide film and contamination are removed. Change abrasive pads frequently. Continue cleaning, using clean cloths until the wiping cloth shows no removable contamination.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

26. Rinse with deionized water. Check for "water-break" free surface, If a "water-break" free surface is not obtained, repeat the cleaning procedure starting with 25 above.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

27. Dry clean surface with clean cheesecloth.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

28. Apply silicone primer General Electric (SS 4155) with clean paint brush or sprayer. Apply the primer in a uniform coating over the entire surface to be bonded. Allow primer to cure for minimum of 3-1/2 to 4 hours at a relative humidity of 40 to 70 percent. Do not prime if relative humidity is above or below these limits. Keep primed surface clear and free from contaminants.

RECORD DRYING START TIME \_\_\_\_\_

DRYING COMPLETE TIME \_\_\_\_\_

RECORD ACTUAL RELATIVE HUMIDITY \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

29. At least 1 hour prior to bonding, lightly wipe the surface of the ablator panel (side to be bonded only) or the strain isolator with cheesecloth lightly dampened with isopropyl alcohol. Air dry. Do not apply adhesive if there is a strong odor of alcohol.

RECORD DRYING START TIME \_\_\_\_\_ DRYING STOP TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

30. Using a clean, degreased (MEK) and dry stiff paint brush and/or metal spatula, apply approximately 0.013 to 0.025 centimeters (0.005 to 0.010 inches) of catalyzed RTV 560 to primed metal and to the cleaned side of ablator panel or strain isolator.

RECORD COMPLETION TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

31. Within 30 minutes of applying adhesive position ablator panel to adhesive covered metal surface per engineering drawing. Apply 13.8 to 34.6 kilonewtons per square meter (2 to 5 pounds per square inch) pressure to panel during cure cycle.

RECORD TIME ABLATOR PANEL WAS POSITIONED \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

32. Cure the bonded assembly for minimum of 24 hours at room temperature. Do not attempt to remove excess adhesive with solvent.

RECORD CURE START TIME \_\_\_\_\_ CURE COMPLETE TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

33. After cure, trim excess adhesive from bonded assembly with sharpened putty knife or razor blade-type scraper.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

34. Inspect bonded assembly per engineering drawing.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

35. Fill gap between the ablator panels with caulking compound.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

E. Process Control Coupon Testing

1. Wipe static test fitting with MEK-dampened cloth. Allow to air dry.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

2. Scrub the bonding surface of the static test fitting with nylon/silicon carbide abrasive pads and water. Alternate scrubbing the surface with clean abrasive pads

and wiping with water soaked clean cheesecloth until all oxide film and contamination are removed. Change abrasive pads frequently. Continue cleaning, using clean cloths, until the wiping cloth shows no removable contamination.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

3. Rinse with deionized water. Check for "water-break" free surface. If a "water-break" free surface is not obtained, repeat the cleaning procedure starting with 2 above.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

4. Apply a uniform coating of silicone primer SS 4155 to fitting. Allow primer to cure for minimum of 3-1/2 to 4 hours at a relative humidity of 40 to 70 percent. Do not prime if relative humidity is above or below these limits.

RECORD DRYING START TIME \_\_\_\_\_

DRYING COMPLETE TIME \_\_\_\_\_

RECORD ACTUAL RELATIVE HUMIDITY \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

5. At least 1 hour prior to bonding, lightly wipe the surface of the process control coupon with cheesecloth lightly dampened with isopropyl alcohol. Air dry. Do not apply adhesive if there is a strong odor of alcohol.

RECORD DRYING START TIME \_\_\_\_\_ DRYING STOP TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

6. Using a clean, degreased (MEK) and dry stiff paint brush apply approximately 0.013 to 0.025 centimeters (0.005 to 0.010 inches) of catalyzed RTV 560 to the fitting and to the process control coupon.

RECORD COMPLETION TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

7. Within 30 minutes of applying adhesive, position fitting on adhesive covered process control coupon. Apply 13.8 to 34.6 kilonewtons per square meter (2 to 5 pounds per square inch) pressure to fitting during cure cycle.

RECORD TIME FITTING WAS POSITIONED \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

8. Cure the bonded assembly for minimum of 24 hours at room temperature.

RECORD CURE START TIME \_\_\_\_\_ CURE COMPLETE TIME \_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

9. Machine a 4.75-centimeter (1.87-inch) diameter plug in the process control coupon, concentric with the bonded-on fitting.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

10. Using a spring scale or equal, apply a tension load to each fitting until failure occurs. Record actual load applied and condition of bond failure.

REMARKS \_\_\_\_\_  
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\_\_\_\_\_

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

F. Refurbishment Phase Fabrication and Bonding

1. Remove the charred ablator material from skin of structure.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

2. Repeat Section D.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

G. Refurbishment Phase Process Control Coupon Testing

1. Repeat Section E.

INSP. \_\_\_\_\_ DATE \_\_\_\_\_

Quality Assurance Plan (Internal & External Access).-- In addition to the inspection plan described for external access, the internal face of each direct bonded-on panel (applicable for panels without strain isolators only) shall be inspected on 5.1-centimeter (2.0-inch) grid centers, using the Fokker Bondtester with the 5410 probe. Calibrate on the setup standard and examine the panel per MDAC P.S. 21233.2. Areas of indicated weak bond of over to be determined (TBD) centimeter (TBD inch) in major dimension and TBD centimeter (TBD inch) in minor dimension will be cause for rejection.

## TEST PROGRAM

All of the refurbishment testing of the direct bond-on ablator attachment concept considered in this program was conducted on the full-scale mockup located at the NASA-LRC, Hampton, Virginia. These tests included installation of ablator panels with strain isolators; installation of ablator panels without strain isolators; caulking of the gaps between ablator panels; removal of ablator panels after charring; replacing the charred ablator panels with new units; static testing of cored plugs with external fittings; static testing of cored plugs having inserts; and static testing of process control coupons. The testing was performed from 12 April through 3 May 1972.

Synoptic descriptions of the various refurbishment tasks associated with a particular maintenance function (removal, replacement, inspection, etc) are listed in a series of tables in appendix A. These tables provide the actual, as well as the estimated, productive (active) time, in manhours, required to perform a specific maintenance task function. In addition to the foregoing, video tape recordings were made to provide a pictorial summary of the actual work effort required for the various refurbishment tasks.

## Testing Procedure

Test Documents.-- Prior to conducting tests at NASA-LRC, MDAC prepared Maintenance Task Schedules and Test Plans. The format used for these schedules was identical to that used during Task I. This provided for real-time recording of each task, as well as serving as a guideline for duties to be performed.

Completed forms for each series of tests conducted are contained in appendix A.

Test Personnel.-- The personnel involved in the testing represented the disciplines of design engineering, maintenance engineering, and manufacturing. Design engineering personnel directed the overall test program. Maintenance task functions were performed by two manufacturing mechanics and one manufacturing inspector, while maintenance engineering monitored and recorded (video taped) the various task functions.

Monitoring Equipment.- The equipment used during the testing operation was the same as that used during Task I, except that the 8-channel strip chart recorder was not used. It was determined from the Task I studies that it was less time consuming to refer to the Maintenance Task Schedules for the real-time efforts for specific Refurbishment Tasks than it was to extract such times from the strip chart recordings. Following is a listing of equipment used:

video camera (Sony AVC-4000A)

video tape recorder (Sony AV-5000A)

T-V monitor (Ampex 9)

5-channel electronic timer and event control box

The monitoring equipment was used to perform two separate functions: it (1) provided video tapes in real time of all tasks, and (2) accurately timed each step of each maintenance task.

The operation of the monitoring equipment required the full-time effort of a camera operator as well as an event recorder operator.

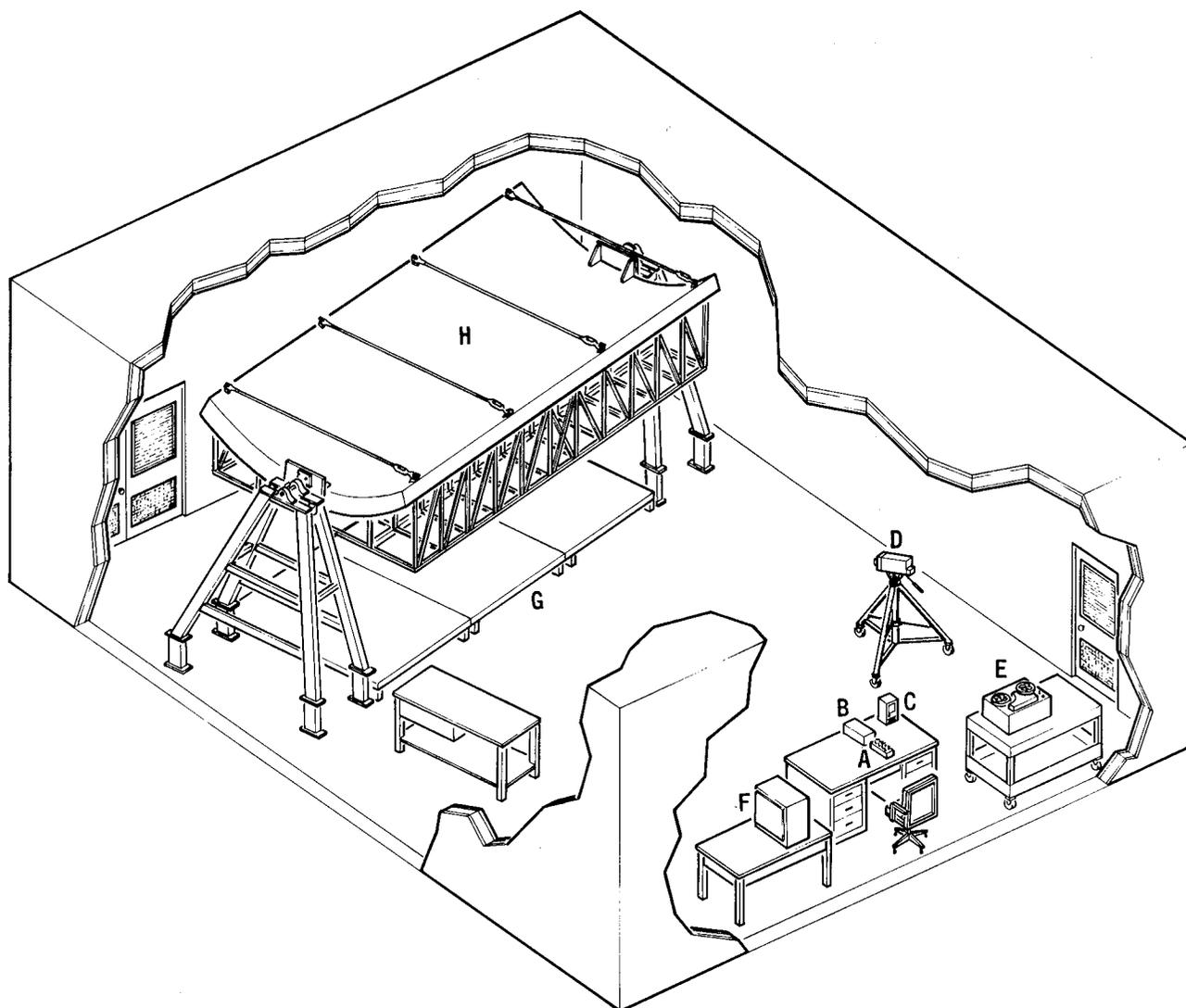
Test Setup.- The test setup used during Task II, shown in figure 30, enabled the event recorder operator to have full view of the mockup and the working area surrounding the mockup. Thus, he could accurately time and record the work effort of each particular member of the team for each test or function.

The five-channel electronic timer, comprised of five separate counters, provided real-time monitoring for each team member whenever that particular team member was involved with a productive effort. The time accumulated on the counters was then entered on the maintenance task schedules at the end of a particular sequence or test. Each channel of the electronic timer was controlled by a separate on/off switch on the event control box. This provided for the individual activation or deactivation of each counter commensurate with the productive effort of a team member.

The camera operator who made real-time video tape recordings of all work efforts was also responsible for signaling the start of each step listed on the maintenance task schedules.

The video camera was connected to the tape recorder. The camera/tripod was mounted on a dolly to enable the camera operator to move over the general area in front of the mockup, as necessary, to obtain good coverage of the function being performed. The TV monitor received the video signal from the video tape recorder and provided the camera operator with a quick-look evaluation of the picture being recorded.

As indicated in figure 30, all panels were installed with the test fixture rotated to simulate the bottom surface of a Shuttle vehicle with the maintenance personnel standing on work platforms. The work platforms used



- A - EVENT CONTROL BOX
- B - ELECTRONICS COUNTERS
- C - EVENT RECORDER
- D - VIDEO CAMERA
- E - VIDEO TAPE RECORDER
- F - TV MONITOR
- G - WORK PLATFORMS
- H - FULL-SCALE MOCKUP

**FIGURE 30 TEST SETUP**

during the tests were designed to provide satisfactory overhead-height working conditions for 95 percent of the work force (per Maintainability Design Guide, Report E501-10, McDonnell Douglas Corporation, dated 26 June 1970).

Test Objectives.- The overall objectives of the test effort were to resolve the uncertainties associated with the installation, inspection, removal, replacement, and bond integrity evaluation of representative direct bond-on ablator panels. Specifically, the objectives of each individual test were:

Installation - Determine and resolve problems involved in the initial and subsequent installation of ablator panels on the vehicle, particularly with regard to handling, positioning, bonding, and sealing of joints.

Inspection - Establish procedures and equipment requirements for the inspection of the installed ablator panels before flight.

Removal and Replacement - Resolve the problems involved in removing either damaged or flight-expended panels and replacing them with new panels.

Bond Integrity Evaluation (Static Testing) - Determine bond integrity by applying a load to plugs cored in the ablator panels as well as in process control coupons.

Test Criteria.- In order that the testing be performed in as close to an actual shop environment as practical, a set of conditions under which each test would be run had to be established. These include, but are not necessarily limited to, the following:

all test personnel were required to wear white coats and white gloves when handling ablator material to minimize contamination

all hand tools required for the maintenance task to be located in the immediate work area, either in a tool box or on a work bench

all special tools, such as saws, scales, air drills, etc, to be located on the work bench

work stands arranged prior to the start of test

ablator panels unpacked and placed in a ready state prior to the test where they were to be used (the actual time required to unpack the ablators was not used in the data analysis since in an operational environment the actual time required to perform this simple task would vary considerably depending on storage location)

performance time considered to be that time in which the particular personnel was actively participating in the test (waiting or watching was not considered active time; however, getting or setting up tools was considered active time)

no time allotted for writing up inspection discrepancies

no time allotted for the cleaning of tools (brushes, scrapers, etc) after completion of the individual step.

These conditions provided a common basis from which each test was conducted, evaluated, and compared.

Each manufacturing test personnel had identifying numbers attached to the back of his white coat. These numbers corresponded to the electronic timer channels on which his productive time was measured. Total duration of a particular task or maintenance function was also recorded. The tests were video taped on 1-hour rolls of tape. At the beginning of each new roll of tape an identification card which had the test title and sequence reel number on it was recorded. This was done to prevent any mixup in the tapes after the test had been run. Once the monitoring equipment was ready and the identification card had been taped, the camera operator would give the command READY and after a few seconds START. On START, the event recorder operator would start the task duration timer, and the other appropriate channel timers, depending on which test personnel were actively participating.

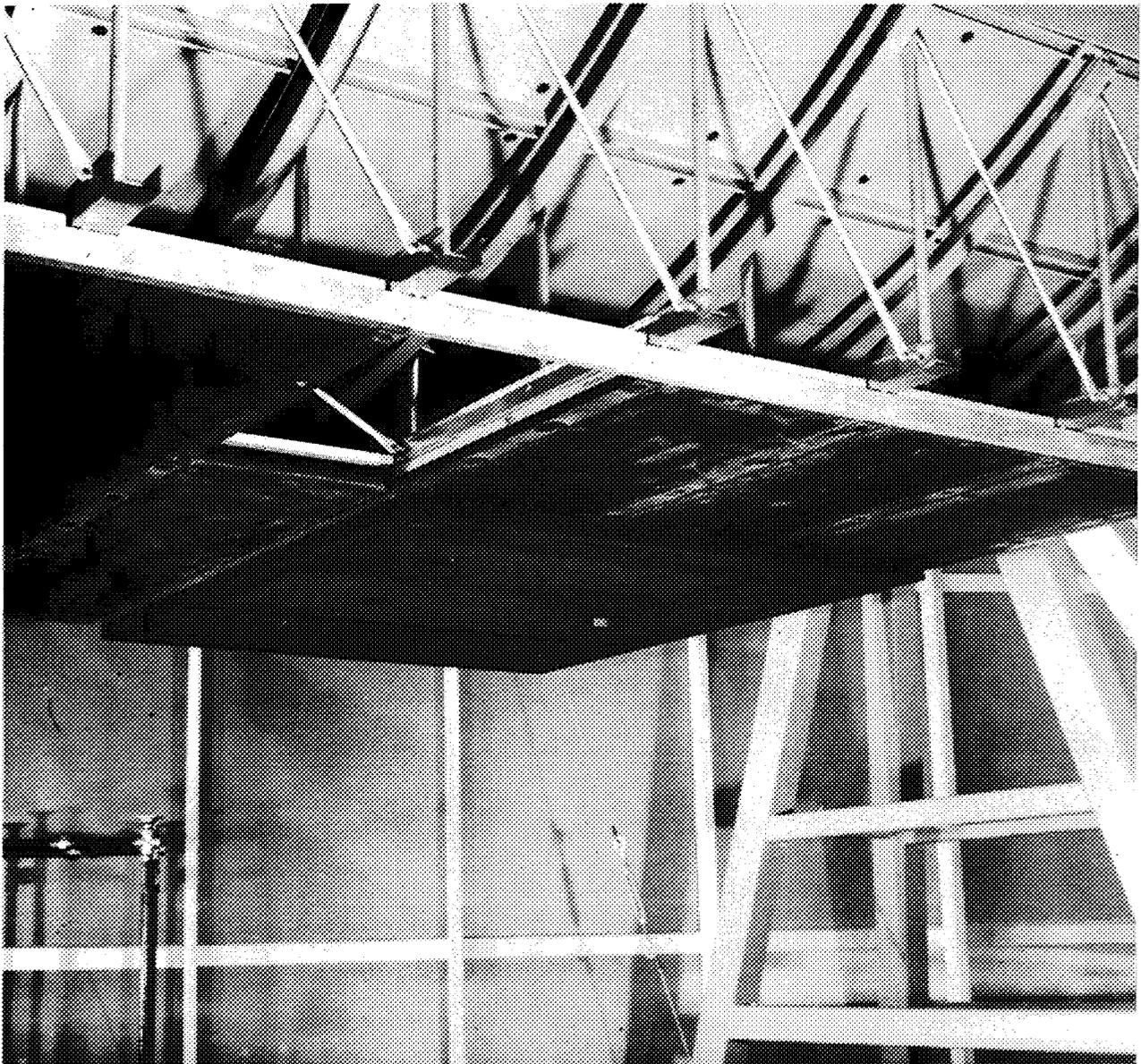
Tests Performed.- The test program consisted of investigating the direct bond-on ablator attachment technique and the various refurbishment functions associated with installing and removing flat, constant thickness, panels. Two bonding concepts were evaluated:

- (1) direct bonding of ablator panels to a metallic panel support
- (2) bonding of ablator panels to a strain isolator (silicone sponge) which itself was bonded to the panel support.

An evaluation of bond strength was obtained by the static testing of cored plugs in both bonded-on ablator panels and process control coupons. Loads were applied to fittings that were externally bonded to the ablator panels and to inserts that were internally imbedded in the ablator during the manufacturing process. Refurbishment functions investigated included all tasks associated with the initial installation, caulking, inspection, removal, replacement (final installation), and bond integrity evaluation of the bonded-on ablator panels.

Prior to bonding the ablator panels to the panel support, a trial fit was made on the full-scale mockup. This trial fit permitted nondimensionally conforming panels to be modified to provide the desired fit between panels. A specified gap between panels was required to permit injection of a silicone RTV compound. The average longitudinal and lateral spacing between ablator panels was 0.477 centimeter (0.180 inch). A total of eight TPS ablator panels were used in the tests, including four 55.1 by 141.4-centimeter (21.70 by 55.66-inch) and four 55.1 by 70.5-centimeter (21.70 by 27.74-inch) panels.

The ablator panels were bonded to the panel support assembly, shown in figure 31. The individual step-by-step procedure, including the tools required to perform the individual tasks, is tabulated in the Maintenance Task Schedules included in appendix A.



**FIGURE 31 ABLATOR PANEL INSTALLATION**

A brief summary of the test sequence follows:

1. clean and prime panel support assembly
2. apply adhesive to approximately 1/3 of the panel support assembly
3. Place strain isolator against the above area and support same during the adhesive cure cycle.
4. Apply Adhesive to remainder of panel support assembly and to the exposed surface of the strain isolator.

5. Apply adhesive to the ablator panels, install panels and support same during the adhesive cure cycle.
6. Caulk all gaps between the ablator panels.
7. Remove panel support assembly (including the bonded-on ablator panels) from the full-scale mockup.
8. Char the ablator using oxygen/acetylene equipment.
9. Reinstall panel support assembly on the full-scale mockup.
10. Remove charred ablator from panel support assembly.
11. Scrape strain isolator and adhesive from panel support assembly.
12. Clean surface of panel support assembly to obtain "water-break" free surface.
13. Repeat strain isolator and ablator panel installation sequences.
14. Machine 4.75-centimeter (1.87-inch) diameter plugs in each ablator panel. Bond fittings to each plug.
15. Locate imbedded inserts in ablator panels and machine 4.75-centimeter (1.87-inch) diameter plugs, concentric with inserts.
16. Bond fittings to process control coupons.
17. Apply static load to each machined coupon; record results on data sheet.
18. Remove fittings from ablator panels.
19. Repair ablator panels.

#### Test Data Results

This section presents a synopsis of the refurbishment test data given in tables A1 through A13 of appendix A.

This synopsis is given in tables 5 through 12. Descriptions of the various refurbishment tasks associated with a particular maintenance function (i.e., initial installation, caulking gaps, inspection, static testing, removal, and final installation) are presented in capsule form. For purposes of comparison, these tables give the actual and estimated productive (active) time, in manhours, required to perform a specific maintenance task function.

In addition, the actual task duration of each individual refurbishment task is given. More detail information (i.e., materials, tools, and equipment used, and comments as to the nature of specific refurbishment tasks) concerning the results of a specific refurbishment task, can be obtained from tables A1 through A13 of appendix A. The intent of this section of the report is solely to present the basic data in the manner in which it was obtained. Manipulation and analysis of the data to conform to specific operational possibilities is discussed in the Refurbishment Analysis section.

Initial Installation.- The first series of tests involved the initial installation on the mockup of two large 55.1 by 141.4-centimeter (21.70 by 55.66-inch) and two small 55.1 by 70.5-centimeter (21.70 by 55.66-inch) ablator panel assemblies. One of the large panels was installed with a foam rubber pad (strain isolator) while the other was bonded directly to the aluminum substructure. The difference in task duration and productive time between these two installations is shown in table 5. Both of the small ablator panel assemblies were installed without a strain isolator. The installation results of these later assemblies are shown in table 6.

Caulking Gaps.- Once the ablator panels were installed, the remaining task to complete the initial installation was to caulk the gaps between panels with a silicone elastomeric compound. The task duration and productive times to accomplish this task are shown in table 7. For comparison purposes the same data for the final installation at the end of the test program are also given in this table. The average task duration and productive times to caulk the gaps on a linear meter (foot) basis is 0.131 hour per meter (0.040 hour per foot) and 0.319 manhour per meter (0.097 manhour per foot), respectively.

Inspection.- Upon completion of the caulking procedure, the entire installation was visually inspected for dents, abrasions, pitmarks, and mismatch. This function was performed by a fully qualified inspector; results of which are shown in table 8.

Ablator Removal.- The entire TPS assembly (ablator panel/panel support composite) was then removed from the mockup and exposed to a thermal environment in the NASA-LRC test facility. After the ablator had been charred, the entire TPS assembly was remounted on the mockup and the removal cycle of the ablator panels was begun. The results of the removal cycle are shown in table 9. The removal cycle was considered complete when none or no more than approximately 0.005 centimeter (0.002 inch) of adhesive remained on the panel support assembly.

Ablator Replacement.- This function started with removing the residual adhesive, remaining after the ablator removal function was completed, by scouring the panel support assembly using nylon/silicon carbide abrasive pads and water until a "water-break" free surface was obtained. After proper cleaning another set of ablator panels were installed on the mockup for subsequent static testing and final display purposes. The results of this task are shown in table 10. In this instance the two small 55.1 by 70.5-

TABLE 5  
TEST DATA

- TASK FUNCTION - INSTALLATION (INITIAL)
- HEAT SHIELD TYPE - ABLATOR
- ATTACH CONCEPT - BONDED
- PANEL SIZE - 55.1 x 141.4 CM  
- (21.70 x 55.66 IN.)

TASK NO.	DESCRIPTION	ONE PANEL WITH STRAIN ISOLATOR			ONE PANEL WITHOUT STRAIN ISOLATOR		
		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)	
			ACTUAL	ESTIMATED		ACTUAL	ESTIMATED
1 (1)	WIPE PANEL SUPPORT (P/S) WITH SOLVENT	0.034	0.034	0.033	0.034	0.034	0.033
2 (2)	WIPE PROCESS CONTROL COUPON (PCC) WITH SOLVENT	0.013	0.013	0.004	0.009	0.009	0.004
3	TRIAL FIT STRAIN ISOLATOR	0.032	0.086	0.050	-	-	-
4 (3)	SCOUR PANEL SUPPORT	0.106	0.212	0.200	0.164	0.302	0.200
5 (4)	SCOUR PROCESS CONTROL COUPON	0.034	0.034	0.008	0.028	0.028	0.008
6 (5)	INSPECT P/S FOR WATER BREAK FREE SURFACE	0.028	0.054	0.067	0.026	0.051	0.067
7 (6)	INSPECT PCC FOR WATER BREAK FREE SURFACE	0.014	0.024	0.008	0.008	0.016	0.008
8 (7)	DRY P/S	0.021	0.021	0.033	0.016	0.016	0.033
9 (8)	DRY PCC	0.006	0.006	0.004	0.005	0.005	0.004
10 (9)	CHECK HUMIDITY	0.006	0.006	-	0.007	0.007	-
11(10)	PRIME P/S	0.046	0.046	0.089	0.033	0.033	0.089
12(11)	PRIME PCC	0.009	0.009	0.004	0.006	0.006	0.004
13(12)	INSPECT PRIMER APPLICATION ON P/S	0.026	0.026	0.033	0.021	0.021	0.033
14(13)	INSPECT PRIMER APPLICATION ON PCC	0.012	0.012	0.007	0.008	0.008	0.007
15(-)	MIX ADHESIVE	0.220	0.438	0.500	-	-	-
16(-)	APPLY ADHESIVE TO P/S	0.192	0.192	0.356	-	-	-
17(-)	APPLY ADHESIVE TO PCC	0.025	0.025	0.009	-	-	-
18(-)	INSPECT ADHESIVE APPLICATION ON P/S	0.012	0.012	0.033	-	-	-
19(-)	INSPECT ADHESIVE APPLICATION ON PCC	0.006	0.006	0.007	-	-	-
20(-)	INSPECT STRAIN ISOLATOR	0.015	0.015	0.017	-	-	-
21(-)	INSPECT STRAIN ISOLATOR FOR PCC	0.005	0.005	0.004	-	-	-
22(-)	BOND STRAIN ISOLATOR TO P/S	0.040	0.121	0.133	-	-	-
23(-)	BOND STRAIN ISOLATOR TO PCC	0.014	0.014	0.008	-	-	-
24(-)	INSPECT PRESSURE FIXTURE AND VERIFY CURE CYCLE	0.020	0.020	0.017	-	-	-
25(-)	INSPECT PRESSURE SETUP AND VERIFY CURE CYCLE FOR PCC	0.011	0.011	0.007	-	-	-
26(-)	REMOVE PRESSURE FIXTURE	0.034	0.069	0.050	-	-	-
27(-)	REMOVE PRESSURE PLATE FROM PCC	0.003	0.003	0.004	-	-	-
28(-)	INSPECT STRAIN ISOLATOR INSTALLATION	0.011	0.011	0.033	-	-	-
29(-)	INSPECT STRAIN ISOLATOR INSTALLATION ON PCC	0.006	0.006	0.007	-	-	-
30(14)	INSPECT ABLATOR PANEL	0.018	0.023	0.033	0.015	0.021	0.033
31(15)	INSPECT ABLATOR PANEL FOR PCC	0.005	0.005	0.004	0.006	0.006	0.004
32(16)	TRAIL FIT ABLATOR PANEL	0.014	0.038	0.600	0.014	0.041	0.600

( ) TASK NUMBERS APPLY TO PANEL WITHOUT STRAIN ISOLATOR DATA

TABLE 5  
TEST DATA (Continued)

TASK NO.	DESCRIPTION	ONE PANEL WITH STRAIN ISOLATOR			ONE PANEL WITHOUT STRAIN ISOLATOR		
		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)	
			ACTUAL	ESTIMATED		ACTUAL	ESTIMATED
33(-)	CLEAN STRAIN ISOLATOR WITH ALCOHOL	0.031	0.031	0.033	-	-	-
34(-)	CLEAN STRAIN ISOLATOR ON PCC WITH ALCOHOL	0.005	0.005	0.004	-	-	-
35(-)	INSPECT STRAIN ISOLATOR FOR CLEANLINESS	0.013	0.013	0.017	-	-	-
36(-)	INSPECT STRAIN ISOLATOR ON PCC FOR CLEANLINESS	0.007	0.007	0.007	-	-	-
37(17)	CLEAN ABLATOR PANEL WITH ALCOHOL	0.026	0.026	0.033	0.031	0.031	0.033
38(18)	CLEAN ABLATOR PANEL FOR PCC WITH ALCOHOL	0.005	0.005	0.004	0.005	0.005	0.004
39(19)	INSPECT ABLATOR PANEL FOR CLEANLINESS	0.009	0.009	0.017	0.013	0.013	0.017
40(20)	INSPECT ABLATOR PANEL FOR PCC FOR CLEANLINESS	0.003	0.003	0.007	0.007	0.007	0.007
41(21)	MIX ADHESIVE	0.208	0.416	0.500	0.258	0.512	0.500
42(22)	APPLY TAPE TO EDGES OF INSTALLED ABLATOR PANELS	0.024	0.024	-	0.023	0.023	-
43(23)	APPLY ADHESIVE TO STRAIN ISOLATOR ON P/S (OR P/S)	0.134	0.267	0.356	0.106	0.211	0.356
44(24)	APPLY ADHESIVE TO PCC OR STRAIN ISOLATOR ON PCC	0.008	0.008	0.009	0.023	0.042	0.009
45(25)	REMOVE TAPE FROM ABLATOR PANELS	0.012	0.012	-	0.018	0.018	-
46(26)	INSPECT ADHESIVE APPLICATION	0.010	0.010	0.033	0.013	0.013	0.033
47(27)	INSPECT ADHESIVE APPLICATION ON PCC	0.004	0.004	0.007	0.004	0.004	0.007
48(28)	APPLY ADHESIVE TO ABLATOR PANEL	0.080	0.160	0.356	0.105	0.210	0.356
49(29)	APPLY ADHESIVE TO ABLATOR PANEL FOR PCC	0.013	0.023	0.009	0.017	0.034	0.009
50(30)	INSPECT ADHESIVE APPLICATION	0.007	0.007	0.033	0.013	0.013	0.033
51(31)	INSPECT ADHESIVE APPLICATION FOR PCC	0.004	0.004	0.007	0.003	0.003	0.007
- (32)	INSTALL SPACERS	-	-	-	0.033	0.033	-
52(33)	INSTALL ABLATOR PANEL	0.104	0.365	0.133	0.057	0.189	0.133
53(34)	INSTALL ABLATOR PANEL ON PCC	0.011	0.011	0.008	0.010	0.010	0.008
54(35)	INSPECT PRESSURE FIXTURE AND VERIFY CURE CYCLE	0.016	0.016	0.017	0.016	0.016	0.017
55(36)	INSPECT PRESSURE SETUP AND VERIFY CURE CYCLE FOR PCC	0.012	0.012	0.007	0.004	0.004	0.007
56(37)	REMOVE PRESSURE FIXTURE	0.035	0.069	0.067	0.043	0.085	0.067
57(38)	REMOVE PRESSURE PLATE FROM PCC	0.006	0.006	0.004	0.004	0.004	0.004
58(39)	INSPECT ABLATOR PANEL INSTALLATION	0.019	0.019	0.033	0.020	0.020	0.033
59(40)	INSPECT ABLATOR PANEL INSTALLATION ON PCC	0.006	0.006	0.007	0.006	0.006	0.007
	TOTAL	1.850	3.135	4.070	1.232	2.110	2.774

TABLE 6.

## TEST DATA

- TASK FUNCTION - INSTALLATION (INITIAL)
- HEAT SHIELD TYPE - ABLATOR
- ATTACH CONCEPT - BONDED
- PANEL SIZE - 55.1 x 70.5 CM (21.70 x 27.74 IN.)

TASK NO.	TASK DESCRIPTION	TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)	
			ACTUAL	ESTIMATED
1	INSPECT ABLATOR PANELS	0.021	0.021	0.017
2	INSPECT ABLATOR PANEL FOR PROCESS CONTROL COUPON (PCC)	0.007	0.007	0.004
3	TRIAL FIT ABLATOR PANELS	0.019	0.036	0.600
4	WIPE PANEL SUPPORT (P/S) WITH SOLVENT	0.024	0.024	0.033
5	WIPE PCC WITH SOLVENT	0.008	0.008	0.004
6	SCOUR P/S	0.161	0.288	0.200
7	SCOUR PCC	0.035	0.035	0.008
8	INSPECT P/S FOR WATER BREAK FREE SURFACE	0.031	0.062	0.067
8A	REPEAT TASK NO. 6	0.105	0.210	-
	REPEAT TASK NO. 8	0.029	0.056	-
9	INSPECT PCC FOR WATER BREAK FREE SURFACE	0.005	0.009	0.008
10	DRY P/S	0.013	0.013	0.033
11	DRY PCC	0.004	0.004	0.004
12	CHECK HUMIDITY	0.008	0.008	-
13	PRIME P/S	0.041	0.041	0.089
14	PRIME PCC	0.003	0.003	0.004
15	INSPECT PRIMER APPLICATION ON P/S	0.014	0.014	0.033
16	INSPECT PRIMER APPLICATION ON PCC	0.006	0.006	0.007
17	CLEAN ABLATOR PANELS (2) WITH ALCOHOL	0.028	0.028	0.033
18	CLEAN ABLATOR PANEL FOR PCC WITH ALCOHOL	0.008	0.008	0.004
19	INSPECT ABLATOR PANELS FOR CLEANLINESS	0.015	0.015	0.017
20	INSPECT ABLATOR PANEL ON PCC FOR CLEANLINESS	0.009	0.009	0.007
21	MIX ADHESIVE	0.235	0.466	0.500
22	APPLY TAPE TO EDGES OF INSTALLED ABLATOR PANELS	0.030	0.030	-
23	APPLY ADHESIVE TO P/S	0.116	0.231	0.356
24	APPLY ADHESIVE TO PCC	0.016	0.029	0.009
25	REMOVE TAPE FROM ABLATOR PANELS	0.009	0.009	-
26	INSPECT ADHESIVE APPLICATION	0.011	0.011	0.033
27	INSPECT ADHESIVE APPLICATION ON PCC	0.005	0.005	0.007
28	APPLY ADHESIVE TO ABLATOR PANELS	0.092	0.184	0.356
29	APPLY ADHESIVE TO ABLATOR PANEL FOR PCC	0.013	0.022	0.009
30	INSPECT ADHESIVE APPLICATION	0.010	0.010	0.033
31	INSPECT ADHESIVE APPLICATION FOR PCC	0.003	0.003	0.007
32	INSTALL SPACERS	0.041	0.041	-
33	INSTALL ABLATOR PANELS	0.075	0.219	0.133
34	INSTALL ABLATOR PANEL ON PCC	0.010	0.010	0.008
35	INSPECT PRESSURE FIXTURE AND VERIFY CURE CYCLE	0.017	0.017	0.017
36	INSPECT PRESSURE SETUP AND VERIFY CURE CYCLE FOR PCC	0.005	0.005	0.007
37	REMOVE PRESSURE FIXTURE	0.068	0.137	0.067
38	REMOVE PRESSURE PLATE FROM PCC	0.004	0.004	0.004
39	INSPECT ABLATOR PANEL INSTAL.	0.024	0.024	0.033
40	INSPECT ABLATOR PANEL INSTAL. ON PCC	0.006	0.006	0.007
TOTAL		1.384	2.368	2.758

TABLE 7  
TEST DATA

- TASK FUNCTION - CAULK GAPS
- HEAT SHIELD TYPE - ABLATOR
- ATTACH CONCEPT - BONDED
- PANEL SIZE - 55.1 x 70.5 CM (21.70 x 27.74 IN.) - (2 PANELS)  
- 55.1 x 141.4 CM (21.70 x 55.66 IN.) - (2 PANELS)
- GAP SIZE - 0.46 x 5.08 x 955 CM (0.18 x 2.0 x 376 IN.)

TASK NO.	TASK DESCRIPTION	INITIAL INSTALLATION			FINAL INSTALLATION		
		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)	
			ACTUAL	ESTIMATED		ACTUAL	ESTIMATED
1	INSTALL TAPE ADJACENT TO GAPS	0.247	0.494	-	0.177	0.355	-
2	MIX CAULKING COMPOUND AND FILL GAPS	0.926	2.492	1.000	0.980	2.580	1.000
3	VERIFY CURE CYCLE	0.026	0.026	0.030	0.015	0.015	0.030
4	INSPECT FOR VOIDS AND MISMATCH	0.035	0.035	0.100	0.023	0.023	0.100
5	REPAIR CAULKED AREA (LARGE PANEL ONLY)	-	-	-	0.059	0.059	-
6	INSPECT REPAIRED AREAS	-	-	-	0.011	0.011	-
	TOTAL	1.234	3.047	1.130	1.265	3.043	1.130

TABLE 8  
TEST DATA

- TASK FUNCTION - INSPECTION
- HEAT SHIELD TYPE - ABLATOR
- ATTACH CONCEPT - BONDED
- TOTAL AREA - 2.65 METER<sup>2</sup> (29.0 FT<sup>2</sup>)

TASK NO.	TASK DESCRIPTION	TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)	
			ACTUAL	ESTIMATED
1	VISUALLY INSPECT INSTALLED ABLATOR PANELS	0.027	0.027	0.025

centimeter (21.70 by 27.74-inch) ablator panels were installed with a strain isolator whereas the two large 55.1 by 141.4-centimeter (21.70 by 55.66-inch) ablator panels were bonded directly to the substructure.

Static Testing.- Times associated with static tests for verifying bond integrity are shown in tables 11 and 12. Table 11 gives the results of testing four "insert" type plugs as noted in figure 26. A load of 15.9 kilograms (35 pounds) was applied to each plug, except the plug in the large panel, located in the middle of the assembly, which failed at 7.2 kilograms (16 pounds). This premature failure was due to a large unbonded area. The average task duration

**TABLE 9  
TEST DATA**

- TASK FUNCTION - REMOVE
- HEAT SHIELD TYPE - ABLATOR
- ATTACH CONCEPT - BONDED
- PANEL SIZES - 55.1 x 70.5 CM (21.70 x 27.74 IN.)  
- 55.1 x 141.4 CM (21.70 x 55.66 IN.)

TASK NO.	TASK DESCRIPTION	ONE LARGE PANEL (WITH STRAIN ISOLATOR)			1 LARGE PLUS 2 SMALL PANELS (WITHOUT STRAIN ISOLATOR)		
		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)	
			ACTUAL	ESTIMATED		ACTUAL	ESTIMATED
1	SAW SLOTS IN CHARRED ABLATOR	0.101	0.202	-	0.197	0.393	-
2	REMOVE CHARRED ABLATOR	0.236	0.471	2.000	0.169	0.338	3.000
3	REMOVE ADHESIVE AND STRAIN ISOLATOR	0.658	1.521	1.200	-	-	-
4	REMOVE ADHESIVE	-	-	-	1.043	2.528	1.200
5	INSPECT PANEL SUPPORT FOR SCRATCHES AND RESIDUAL ADHESIVE	0.015	0.015	0.067	0.019	0.019	0.083
	<b>TOTAL</b>	<b>1.010</b>	<b>2.209</b>	<b>3.267</b>	<b>1.428</b>	<b>3.278</b>	<b>4.283</b>

and productive time to perform each individual test was approximately two and three minutes, respectively. When using the bonded-on-type fittings (figure 26) to perform the static tests, either on the installed panels or process control coupons, the results in table 12 were obtained. A load of 24.9 kilograms (55 pounds) was applied to each plug machined in both the ablator panels and the process control coupons, without failure. The average task duration and productive times using the fittings installed on the panels were approximately 18 and 27 minutes, respectively. Of the four fittings installed, only three were removed. Of these three, only two were repaired after testing. The test data, shown in table 12, however (which were taken from table A-13) were modified to include four fittings for all task assignments.

In like fashion the task duration and productive times for static testing the process control coupons were 11 and 17 minutes, respectively. It should be noted that, although times are given for mixing the ablator repair material (Task No. 27 of table 12), these values were not added to the totals since, during a normal refurbishment, this material would be premixed and refrigerated until ready for use.

#### REFURBISHMENT ANALYSIS

This section analyses the maintenance requirements and techniques associated with refurbishment of the bonded-on ablator panels. This analysis includes, first, manipulation of the data presented in tables 5 through 12 to conform to specific operational refurbishment situations that could be encountered in maintaining an operational TPS. Secondly, these data are compared with similar

TABLE 10  
TEST DATA

- TASK FUNCTION - INSTALLATION (FINAL DISPLAY)
- HEAT SHIELD TYPE - ABLATOR
- ATTACH CONCEPT - BONDED
- PANEL SIZES - 55.1 x 70.5 CM (21.70 x 27.74 IN.)  
- 55.1 x 141.4 CM (21.70 x 55.66 IN.)

TASK NO.	TASK DESCRIPTION	TWO SMALL PANELS WITH STRAIN ISOLATOR			TWO LARGE PANELS WITHOUT STRAIN ISOLATOR		
		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)	
			ACTUAL	ESTIMATED		ACTUAL	ESTIMATED
1 (1)	WIPE PANEL SUPPORT (P/S) WITH SOLVENT	0.023	0.023	0.033	0.034	0.034	0.067
2 (2)	SCOUR P/S	0.972	1.943	2.000	1.245	2.491	0.400
3 (3)	INSPECT P/S FOR WATER BREAK FREE SURFACE	0.018	0.034	0.067	0.029	0.054	0.133
4 (4)	DRY P/S	0.018	0.018	0.033	0.021	0.021	0.067
5 (5)	INSPECT P/S FOR SCRATCHES	0.015	0.015	0.050	0.015	0.015	0.050
6 (-)	INSPECT STRAIN ISOLATOR	0.019	0.019	0.017	-	-	-
- (6)	INSPECT ABLATOR PANELS	-	-	-	0.029	0.045	0.067
7 (-)	TRIAL FIT STRAIN ISOLATOR	0.022	0.064	0.050	-	-	-
- (7)	TRIAL FIT ABLATOR PANELS	-	-	-	0.027	0.080	1.200
8 (8)	CHECK HUMIDITY	0.009	0.009	-	0.010	0.010	-
9 (9)	PRIME P/S	0.036	0.036	0.089	0.068	0.068	0.178
10(10)	INSPECT PRIMER APPLICATION	0.027	0.027	0.033	0.026	0.026	0.067
11(-)	MIX ADHESIVE	0.185	0.366	0.500	-	-	-
12(-)	APPLY MASKING TAPE	0.027	0.027	-	-	-	-
13(-)	APPLY ADHESIVE TO P/S	0.114	0.227	0.356	-	-	-
14(-)	REMOVE MASKING TAPE	0.022	-	-	-	-	-
15(-)	INSPECT ADHESIVE APPLICATION	0.010	0.010	0.033	-	-	-
16(-)	BOND STRAIN ISOLATOR TO P/S	0.040	0.137	0.133	-	-	-
17(-)	INSPECT PRESSURE FIXTURE AND VERIFY CURE CYCLE	0.019	0.019	0.017	-	-	-
18(-)	REMOVE PRESSURE FIXTURE	0.029	0.059	0.050	-	-	-
19(-)	INSPECT STRAIN ISOLATOR INSTAL	0.011	0.011	0.033	-	-	-
20(-)	INSPECT SMALL ABLATOR PANELS	0.017	0.017	0.017	-	-	-
21(-)	TRIAL FIT SMALL ABLATOR PANELS	0.026	0.048	0.600	-	-	-
22(-)	CLEAN INSTAL. STRAIN ISOLATOR WITH ALCOHOL	0.030	0.030	0.033	-	-	-
23(-)	INSPECT STRAIN ISOLATOR FOR CLEANLINESS	0.011	0.011	0.017	-	-	-
24(11)	CLEAN ABLATOR PANELS WITH ALCOHOL	0.023	0.023	0.033	0.041	0.041	0.067
25(12)	INSPECT PANELS FOR CLEANLINESS	0.013	0.013	0.017	0.015	0.015	0.033
26(13)	MIX ADHESIVE	0.249	0.498	0.500	0.201	0.402	0.500
27(14)	APPLY MASKING TAPE	0.044	0.044	-	0.026	0.026	-
28(15)	APPLY ADHESIVE TO STRAIN ISOLATOR AND P/S	0.113	0.227	0.356	0.122	0.244	0.356
29(16)	REMOVE MASKING TAPE	0.010	0.010	-	0.021	0.021	-
30(17)	INSPECT ADHESIVE APPLICATION	0.009	0.009	0.033	0.011	0.011	0.034
31(18)	APPLY ADHESIVE TO ABLATOR PANELS	0.126	0.252	0.356	0.078	0.157	0.366
32(19)	INSPECT ADHESIVE APPLICATION	0.010	0.010	0.033	0.008	0.008	0.034
33(20)	INSTALL ABLATOR PANELS	0.126	0.378	0.133	0.081	0.277	0.133
34(21)	INSPECT PRESSURE FIXTURE AND VERIFY CURE CYCLE	0.019	0.019	0.017	0.018	0.018	0.017
- (22)	INSTALL SECOND LARGE PANEL	-	-	-	-	-	-
	REPEAT TASK NO. (14)	-	-	-	0.027	0.027	-
	REPEAT TASK NO. (15)	-	-	-	0.091	0.182	0.356
	REPEAT TASK NO. (16)	-	-	-	0.016	0.016	-
	REPEAT TASK NO. (17)	-	-	-	0.010	0.010	0.034
	REPEAT TASK NO. (18)	-	-	-	0.092	0.183	0.366
	REPEAT TASK NO. (19)	-	-	-	0.008	0.008	0.034
	REPEAT TASK NO. (20)	-	-	-	0.081	0.277	0.133
	REPEAT TASK NO. (21)	-	-	-	0.018	0.018	0.017
35(23)	REMOVE PRESSURE FIXTURES	0.052	0.104	0.067	0.067	0.134	0.133
36(24)	INSPECT ABLATOR PANEL INSTAL	0.032	0.032	0.033	0.023	0.023	0.067
	TOTAL	2.526	4.791	5.739	2.559	4.942	4.909

( ) TASK NO'S APPLY TO LARGE PANELS WITHOUT STRAIN ISOLATOR DATA

test data obtained for the TPS concepts investigated during Task I. Finally, an evaluation is made of the maintenance techniques associated with various operational situations.

**TABLE 11  
TEST DATA**

- TASK FUNCTION - STATIC TESTING (INSERTS)
- HEAT SHIELD TYPE - ABLATOR
- ATTACH CONCEPT - BONDED
- NUMBER OF INSERTS - ONE PER PANEL (4)

TASK NO.	TASK DESCRIPTION	TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)	
			ACTUAL	ESTIMATED
1	INSPECT TOOL SETUP	0.008	0.008	-
2	MACHINE CYLINDRICAL PLUGS	0.046	0.134	0.233
3	INSTALL EYE BOLTS	0.013	0.013	0.033
4	APPLY STATIC TEST LOAD	0.020	0.040	0.067
5	REMOVE EYEBOLTS	0.008	0.008	-
	TOTAL	0.095	0.203	0.333

The possible operational refurbishment situations are best classified as either scheduled or unscheduled maintenance. Scheduled maintenance, as defined here, would involve 100 percent removal and replacement of TPS panels associated with vehicle maintainability after the vehicle has experienced its normal flight environment(s). Unscheduled maintenance, on the other hand, involves partial removal and replacement of the TPS panels prior to flight. Activities which would affect unscheduled maintenance include, but are not necessarily limited to, handling, transportation, prelaunch operation, aborts, etc. As in the case of Task I, it is not the intention of this report to cite or analyze all the possibilities which might occur in the maintenance of a vehicle's TPS; rather, there is enough basic information given concerning refurbishment to permit the reader to evaluate his own particular situations and to estimate similar or related systems.

#### Refurbishment Labor and Performance Requirements

Refurbishment manpower and duration performance time values quoted herein represent the active times to perform specific maintenance task functions. To obtain overall refurbishment manpower and elapsed time requirements, one must add to these values such critical refurbishment-related items as procurement, packaging, transportation, acquisition of tools and equipment, cure cycles, idle times, and times to write dispositions. These items vary depending upon the environment under which the task is performed, the type and skills of the personnel involved, the logistics of the vehicle, the company involved and its method of operation, etc. To consider all these factors was beyond the scope

TABLE 12  
TEST DATA

- TASK FUNCTION - STATIC TESTING (BONDED-ON FITTINGS)
- HEAT SHIELD TYPE - ABLATOR
- ATTACH CONCEPT - BONDED

TASK NO.	TASK DESCRIPTION	INSTALLED PANELS (4 FITTINGS)			PROCESS CONTROL COUPONS (3 FITTINGS)		
		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)		TASK DURATION (HOUR)	PRODUCTIVE TIME (MAN-HOUR)	
			ACTUAL	ESTIMATED		ACTUAL	ESTIMATED
1 (1)	WIPE FITTING WITH SOLVENT	0.032	0.032	0.007	0.026	0.026	0.005
2 (2)	SCOUR FITTINGS	0.037	0.037	-	0.042	0.042	-
3 (3)	INSPECT FOR WATER-BREAK FREE SURFACE	0.025	0.046	-	0.021	0.039	-
4 (4)	DRY FITTINGS	0.012	0.012	-	0.013	0.013	-
5 (5)	CHECK HUMIDITY	0.012	0.012	-	0.009	0.009	-
6 (6)	APPLY PRIMER TO FITTINGS	0.015	0.015	-	0.015	0.015	-
7 (7)	INSPECT PRIMER APPLICATION	0.012	0.012	-	0.012	0.012	-
8 (-)	SELECT AND MARK LOCATION FOR FITTINGS	0.010	0.010	-	-	-	-
9(17)	INSPECT TOOL SETUP	0.007	0.007	-	0.010	0.010	0.017
10(18)	MACHINE CYLINDRICAL PLUGS	0.057	0.171	0.233	0.066	0.133	0.175
11 (8)	CLEAN ABLATOR SURFACE WITH ALCOHOL	0.018	0.018	0.007	0.016	0.016	0.005
12 (9)	INSPECT SURFACE FOR CLEANLINESS	0.016	0.016	0.006	0.015	0.015	0.006
13(10)	MIX ADHESIVE	0.185	0.363	0.500	0.195	0.387	0.500
14(11)	APPLY ADHESIVE TO PLUGS	0.076	0.076	0.008	0.019	0.019	0.006
15(12)	APPLY ADHESIVE TO FITTINGS	0.038	0.038	0.008	0.018	0.018	0.006
16(13)	INSPECT ADHESIVE APPLICATION	0.013	0.013	0.017	0.008	0.008	0.013
17(14)	INSTALL FITTINGS	0.029	0.057	0.400	0.036	0.036	0.050
18(15)	INSPECT PRESSURE SETUP AND VERIFY CURE CYCLE	0.016	0.016	0.050	0.016	0.016	0.017
19(16)	REMOVE PRESSURE SETUP	0.067	0.130	0.150	0.015	0.015	0.013
20(19)	APPLY STATIC TEST LOAD	0.024	0.044	0.033	0.055	0.055	0.017
21(-)	REMOVE FITTINGS	0.043	0.043	0.067	-	-	-
22(-)	INSPECT FOR DAMAGE	0.010	0.010	0.017	-	-	-
23(-)	REMOVE LOOSE ABLATOR	0.102	0.203	0.133	-	-	-
24(-)	WIPE REPAIR AREA WITH ALCOHOL	0.028	0.028	0.033	-	-	-
25(-)	INSPECT AREA FOR CLEANLINESS	0.027	0.027	0.017	-	-	-
26(-)	MIX SYLGARD RESIN	0.104	0.209	0.139	-	-	-
27(-)	MIX ABLATOR REPAIR MATERIAL	(0.225)	(0.449)	(0.489)	-	-	-
28(-)	PRIME REPAIR AREAS	0.041	0.041	0.033	-	-	-
29(-)	INSPECT PRIMED AREAS	0.017	0.017	0.017	-	-	-
30(-)	FILL REPAIR AREAS WITH ABLATOR MATERIAL	0.082	0.082	0.167	-	-	-
31(-)	INSPECT REPAIRED AREAS	0.025	0.025	0.017	-	-	-
32(-)	SAND REPAIRED AREAS	0.023	0.023	0.167	-	-	-
33(-)	INSPECT REPAIRED AREAS	0.011	0.011	0.033	-	-	-
TOTAL		1.214	1.844	2.259	0.607	0.884	0.830

( ) TASK NO'S APPLY TO PROCESS CONTROL COUPON DATA

of the current study. Several of these factors, however, are more apparent than others and, therefore, were filtered into the analysis of a typical Space Shuttle refurbishment example cited later in the report.

In the following paragraphs the various elements of the refurbishment cycle, namely, initial installation, scheduled and unscheduled removal and replacement, inspection, and bond integrity evaluation (static testing) are discussed. Data for task duration time are stated in terms of hours per square meter (foot) while the manpower requirements are given in terms of manhours per square meter (foot).

Initial Installation.- Task duration and productive time requirements for the initial installation of the ablator panels, including caulking of gaps, are given in table 13. The table shows the initial installation of a small (55.1 by 70.5-centimeter (21.70 by 27.74-inch)) and a large (55.1 by 141.4-centimeter (21.70 by 55.66-inch)) panel both with and without the use of a strain isolator. Analysis of the data shows that installation of either size panel with a strain isolator increases the task duration and productive times by approximately 38 percent over the installation without a strain isolator. Task duration and productive times were increased by approximately 17 percent for installing the small panels versus the large panels, for the case with and without a strain isolator. To assist in visualizing these trends this data is presented in bar chart form in figure 32. Prior to installation of the ablator panels, the aluminum substrate was thoroughly cleaned to provide a "water-break" free surface. The degree of difficulty in obtaining a "water-break" free surface is, of course, dependent on the initial condition of the surface at the time of bonding. The difference in obtaining a "water-break" free surface initially versus one which has had adhesive applied to it is evident in comparing the data of table 13 with those shown in table 14.

Scheduled Removal and Replacement.- Scheduled removal and replacement task duration and performance time requirements for the small and large ablator panels with and without the use of a strain isolator are given in table 14. The table also makes a comparison between a situation in which the aluminum structure has a "water-break" free surface versus one which has some residual adhesive remaining prior to replacement.

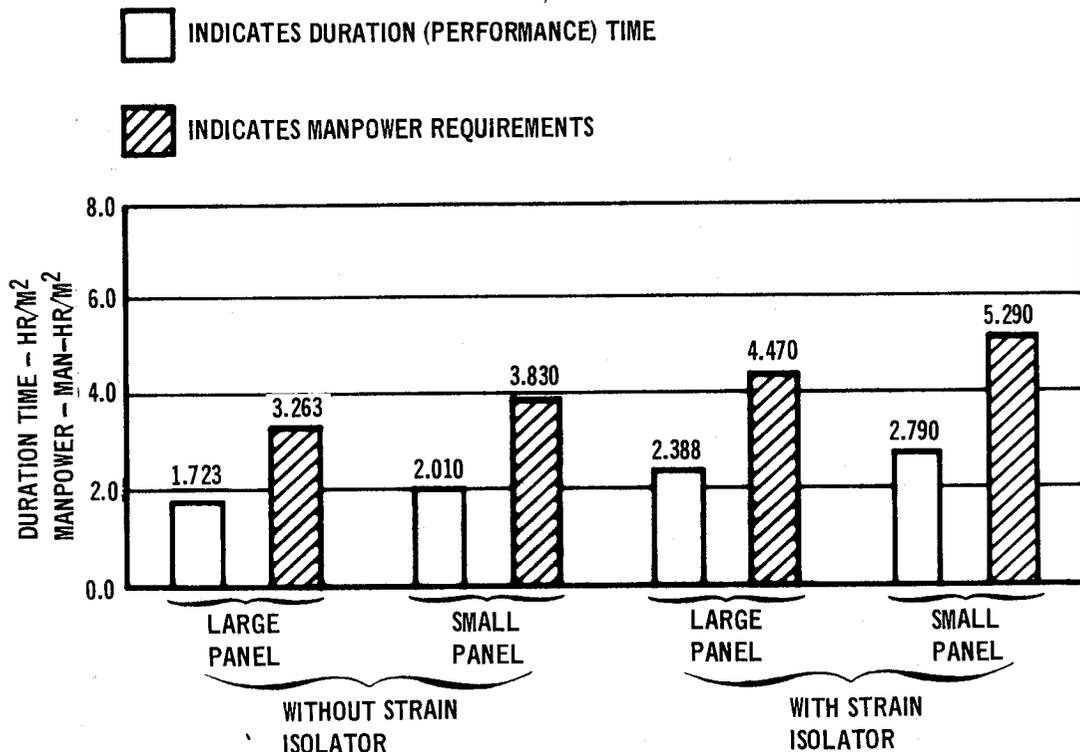
The data presented in these tables assume that the TPS has gone through an entry environment after which the ablator panels are not reusable and must be replaced with new units. In order to obtain a representative refurbishment situation, the ablator panels underwent a simulated thermal environment to develop a significant char layer. The removal cycle was considered complete when none or no more than approximately 0.005 centimeters (0.002 inches) of adhesive remained on the panel support assembly.

As noted, the task duration and performance times to remove the large panels was approximately the same as that to remove the small panels. However, it took about 35 percent more time to remove the panels with the strain isolator than without the strain isolator. This increase in time is primarily due to cleaning around the universal head rivets that were located in the area having the strain isolator, whereas flush head rivets were located in the area

TABLE 13

**ABLATOR DIRECT BOND-ON ATTACH CONCEPT**  
**Scope: Initial Installation**

FUNCTION	PANEL SIZE: 55.1 x 70.5 CM (21.70 x 27.74 IN.)				PANEL SIZE: 55.1 x 141.4 CM (21.70 x 55.66 IN.)			
	WITH STRAIN ISOLATOR		WITHOUT STRAIN ISOLATOR		WITH STRAIN ISOLATOR		WITHOUT STRAIN ISOLATOR	
	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )
INITIAL INSTAL.	2.790(0.260)	5.290(0.492)	2.010(0.186)	3.830(0.355)	2.388(0.222)	4.470(0.416)	1.723(0.160)	3.263(0.303)



**FIGURE 32 INITIAL INSTALLATION COMPARISON**

without the strain isolator. The effect of a "water-break" versus a "non-water-break" free surface is reflected in the replacement data. To effect a "water-break" free surface for the area with and without a strain isolator took between 54 and 73 percent more time for the small and the large panels respectively than required for a "non-water-break" free surface. The manpower requirements to replace the smaller panels (with strain isolator) was approximately 24 and 40 percent greater than for the larger panels (with strain isolator) for the "water-break" free and the "non-water-break" free condition respectively. This data is presented in bar chart form in figures 33 and 34.

Unscheduled Removal and Replacement.- Unscheduled removal and replacement maintenance task duration and productive time requirements are presented in table 15. These data represent situations in which a random TPS panel would be removed and replaced prior to flight for one, or a combination, of the following reasons:

- (1) damage has occurred to the basic ablator and/or substructure
- (2) access to internal insulation or equipment is required

This table gives the requirements to remove and replace a selected ablator panel surrounded by similar components of the same design. The primary difference between the scheduled and unscheduled situations in this instance is in

TABLE 14

**ABLATOR DIRECT BOND-ON ATTACH CONCEPT**  
**Scope: Scheduled Removal and Replacement**

FUNCTION		PANEL SIZE: 55.1 x 70.5 CM (21.70 x 27.74 IN.)				PANEL SIZE: 55.1 x 141.4 CM (21.70 x 55.66 IN.)			
		WITH STRAIN ISOLATOR		WITHOUT STRAIN ISOLATOR		WITH STRAIN ISOLATOR		WITHOUT STRAIN ISOLATOR	
		TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )
NON-WATER BREAK FREE SURFACE	REMOVE	1.287(0.120)	2.807(0.261)	0.912(0.085)	2.089(0.194)	1.282(0.119)	2.805(0.261)	0.909(0.084)	2.081(0.193)
	REPLACE	2.321(0.216)	4.538(0.422)	1.635(0.152)	3.264(0.303)	1.629(0.151)	3.227(0.300)	1.154(0.107)	2.324(0.216)
	TOTAL	3.621(0.337)	7.345(0.683)	2.544(0.237)	5.352(0.497)	2.911(0.270)	6.032(0.561)	2.063(0.191)	4.406(0.409)
WATER BREAK FREE SURFACE	REMOVE	1.287(0.120)	2.807(0.261)	0.912(0.085)	2.089(0.194)	1.282(0.119)	2.805(0.261)	0.909(0.084)	2.081(0.193)
	REPLACE	3.619(0.336)	7.089(0.659)	2.486(0.231)	4.921(0.457)	2.918(0.271)	5.771(0.536)	1.985(0.262)	3.962(0.368)
	TOTAL	4.906(0.456)	9.896(0.920)	3.398(0.316)	7.010(0.651)	4.200(0.390)	8.576(0.797)	2.894(0.346)	6.043(0.561)

□ INDICATES DURATION (PERFORMANCE) TIME

▨ INDICATES MANPOWER REQUIREMENTS

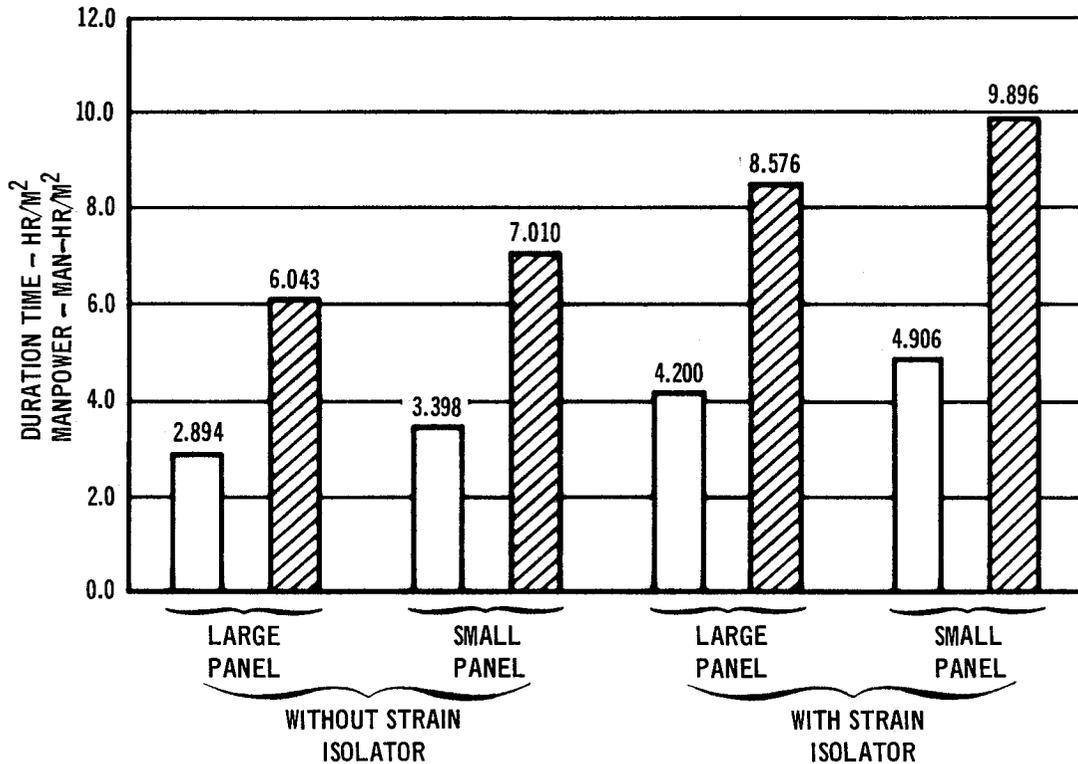
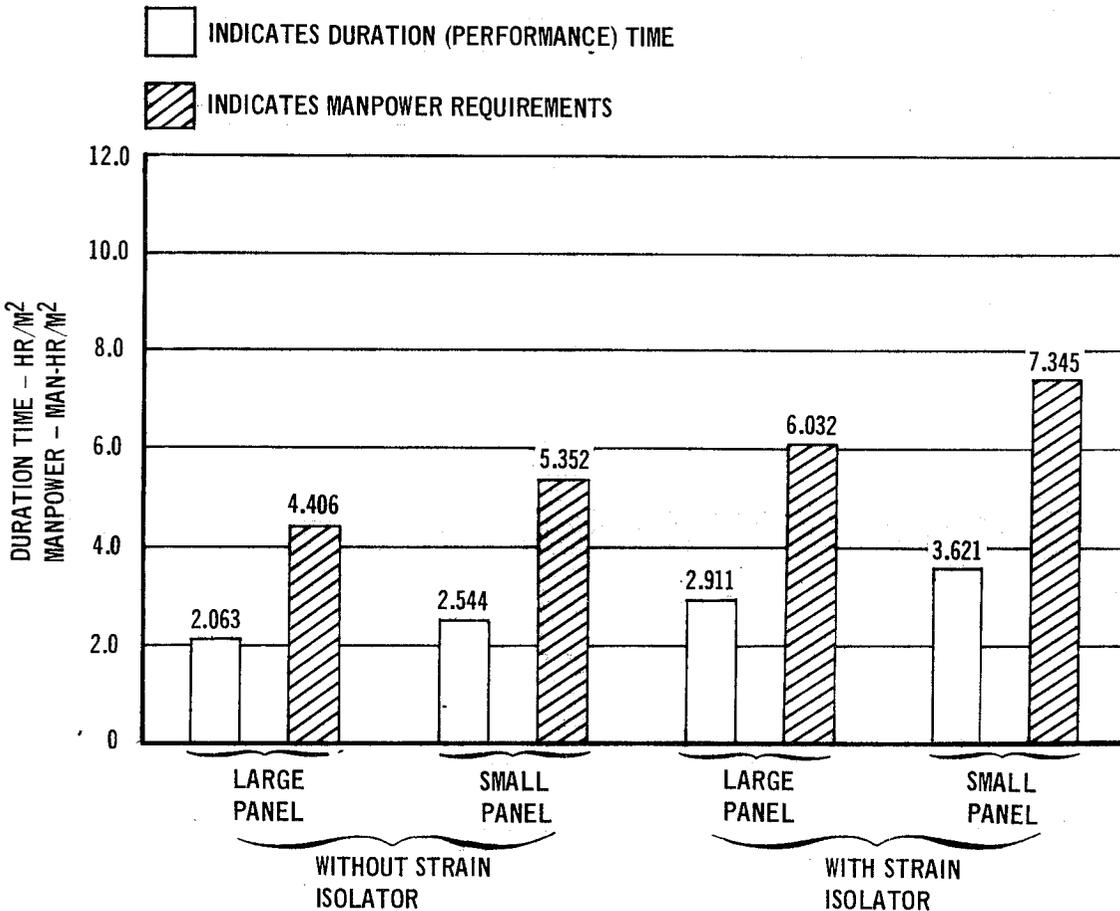


FIGURE 33 SCHEDULED REMOVAL AND REPLACEMENT COMPARISON (WITH WATER-BREAK FREE SURFACE)

the boundary conditions between panels at the time of removal and/or replacement. In the case of the scheduled removal and replacement exercise, successive removal of the panels is made easier by not having to worry about damaging an adjacent panel since all panels are removed. On the other hand, during the unscheduled maintenance situation panels must be removed or fitted in place between adjacent panels (with all four edges of the panel coming into play).

It should be noted that the unscheduled removal and replacement data are an extrapolation of the scheduled removal and replacement data. Based on experience gained in the removal and replacement of the RSI direct bond approach investigated during Task I, it was felt that a percentage increase in task duration and productive time of certain task functions would be justifiable because of the added care that must be exercised in this situation to prevent damage to adjacent panels. In the case of the removal function, a 20-percent increase was made to the tasks of sawing slots in the ablator, removal of the ablator and removal of the adhesive/strain isolator. Likewise, a 20-percent increase was made to the replacement functions involving scouring the panel support, priming the panel support, applying masking tape, removal of masking



**FIGURE 34**  
**SCHEDULED REMOVAL AND REPLACEMENT COMPARISON**  
**(Without Water Break Free Surface)**

tape, applying adhesive, and inspection of voids and mismatches. However, the times to install tape adjacent to gaps and mixing caulking compound and filling gaps was increased 100 percent. With these exceptions the trends noted in table 14 relative to panel size (with and without a strain isolator) are essentially the same for the unscheduled removal and replacement functions. These trends are illustrated in bar chart form in figures 35 and 36.

Inspection (Quality Assurance).- The inspection (quality assurance) required for accomplishing Space Shuttle TPS refurbishment would essentially consist of two functions. The first can be identified as "individual maintenance task inspection" while the second is identified as "final inspection."

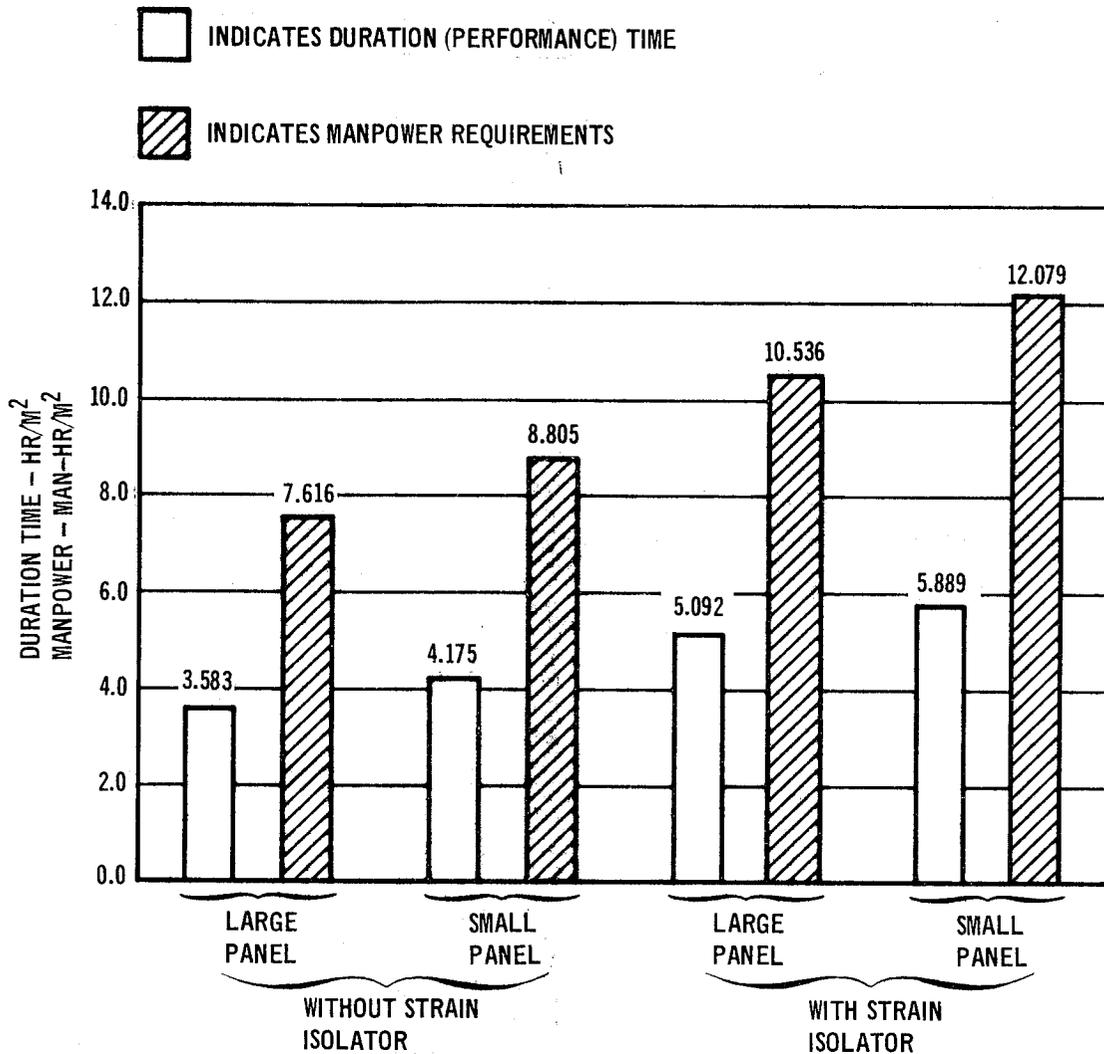
Individual maintenance task inspection starts with the postlanding phase of Shuttle operation. An overall visual inspection is first made to determine which panels need to be either removed and replaced, and/or repaired. This is then followed by detail inspection of completed sequential maintenance tasks associated with the refurbishment of the damaged TPS panels.

Final inspection consists of a prelaunch check, in which all of the external TPS surfaces are reexamined to assure that no damages have

TABLE 15

**ABLATOR DIRECT BOND-ON ATTACH CONCEPT**  
**Scope: Unscheduled Removal and Replacement**

FUNCTION		PANEL SIZE: 55.1 x 70.5 CM (21.70 x 27.74 IN.)				PANEL SIZE: 55.1 x 141.4 CM (21.70 x 55.66 IN.)			
		WITH STRAIN ISOLATOR		WITHOUT STRAIN ISOLATOR		WITH STRAIN ISOLATOR		WITHOUT STRAIN ISOLATOR	
		TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )
NON-WATER BREAK FREE SURFACE	REMOVE	1.541(0.143)	3.363(0.313)	1.089(0.101)	2.503(0.233)	1.534(0.143)	3.359(0.312)	1.088(0.101)	2.495(0.232)
	REPLACE	2.803(0.260)	5.671(0.527)	2.076(0.193)	4.329(0.402)	2.022(0.188)	4.140(0.385)	1.506(0.140)	3.167(0.294)
	TOTAL	4.344(0.403)	9.034(0.840)	3.165(0.294)	6.832(0.635)	3.556(0.331)	7.499(0.697)	2.594(0.241)	5.662(0.526)
WATER BREAK FREE SURFACE	REMOVE	1.541(0.143)	3.363(0.313)	1.089(0.101)	2.503(0.233)	1.534(0.143)	3.359(0.312)	1.008(0.101)	2.495(0.232)
	REPLACE	4.348(0.404)	8.716(0.810)	3.086(0.287)	6.302(0.586)	3.558(0.331)	7.177(0.667)	2.495(0.232)	5.121(0.476)
	TOTAL	5.889(0.547)	12.079(1.123)	4.175(0.388)	8.805(0.819)	5.092(0.474)	10.536(0.979)	3.583(0.333)	7.616(0.708)

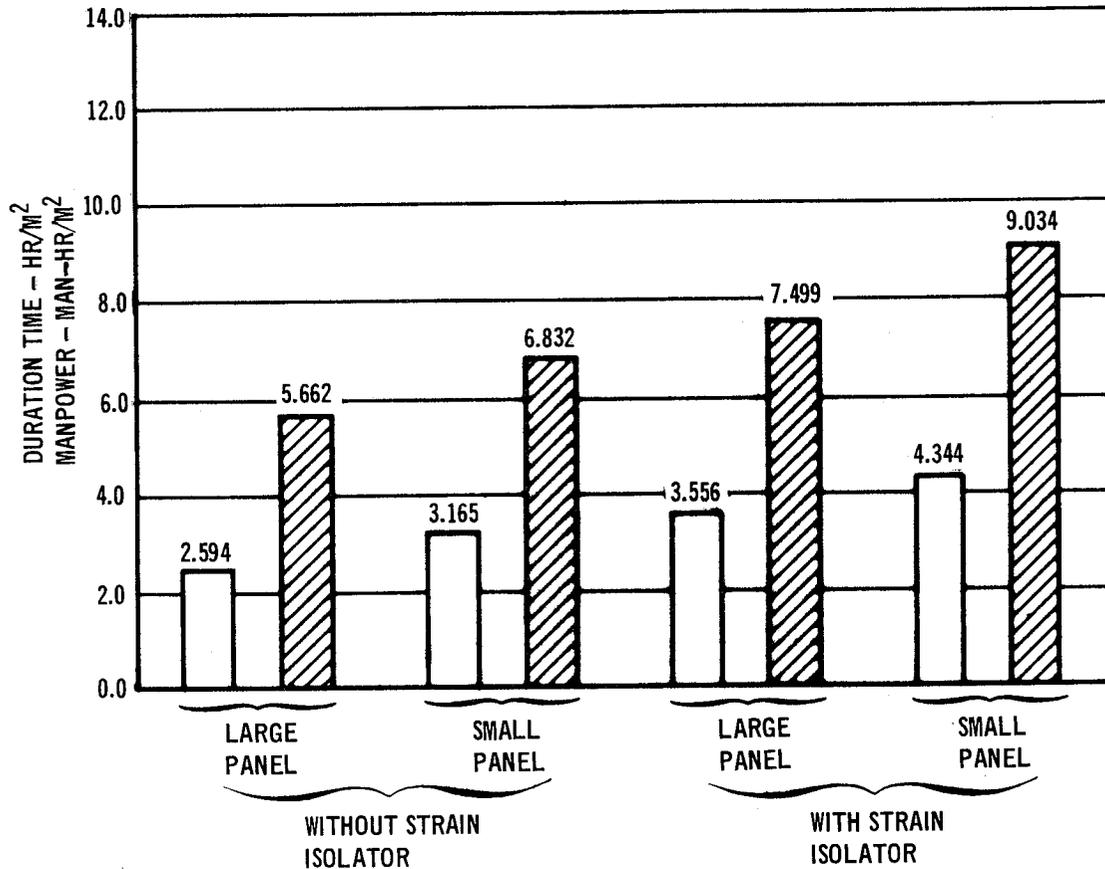


**FIGURE 35 UNSCHEDULED REMOVAL AND REPLACEMENT COMPARISON  
(WITH WATER-BREAK FREE SURFACE)**

occurred to the TPS panels while the vehicle, including all of its subsystems, is being functionally checked and serviced for the next launch. This inspection is primarily a visual examination of the components involved.

During the testing phase of this study, inspection was conducted, as required, to verify the satisfactory completion of the individual refurbishment tasks which were performed (i.e., panel installation, removal, and replacement). These inspection functions fell under the category of individual maintenance task inspection. That portion of the manpower requirements presented in tables 13 and 14, which were devoted to inspection, were extracted and are analyzed in more detail in this section of the report. These inspection data are presented in table 16 for the scheduled removal and replacement of the attach concept tested.

- INDICATES DURATION (PERFORMANCE) TIME
- INDICATES MANPOWER REQUIREMENTS



**FIGURE 36 UNSCHEDULED REMOVAL AND REPLACEMENT COMPARISON (WITHOUT WATER-BREAK FREE SURFACE)**

As shown in table 16, the inspection requirements for the small panels with a strain isolator are 53 percent greater than for the large panels with a strain isolator, whereas those of the small panels without a strain isolator are 36 percent greater than those of the large panels without a strain isolator. Simulation of a typical final inspection exercise was also performed after all the ablator panels had been installed on the mockup. These data are presented in table 17. Since only one man performed this inspection, task duration and productive times are identical and on a square meter (square foot) basis, found to be 0.0102 hours per square meter (0.0009 hours per square foot).

Bond Integrity Evaluation (Static Testing).— The task duration and productive times to perform static tests to verify the integrity of the adhesive bond are given in table 18. As noted, three different methods were employed including the process control coupon technique (with and without a strain isolator), imbedded panel inserts, and bonded-on fittings (to the installed panels)

TABLE 16  
**INSPECTION (QUALITY ASSURANCE)**  
**Scheduled Removal and Replacement**

CHARACTERISTICS PANEL SIZE	TOTAL MANPOWER MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	INSPECTION MANPOWER MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	INSPECTION PERCENTAGE OF TOTAL MANPOWER	INSPECTION PERCENTAGE OF PRODUCTION MANPOWER
SMALL PANELS (WITH STRAIN ISOLATOR)	9.896(0.920)	1.622(0.151)	16.4	19.6
SMALL PANELS (WITHOUT STRAIN ISOLATOR)	7.010(0.651)	1.000(0.093)	14.3	16.6
LARGE PANELS (WITH STRAIN ISOLATOR)	8.576(0.797)	1.057(0.098)	12.3	14.1
LARGE PANELS (WITHOUT STRAIN ISOLATOR)	6.043(0.561)	0.737(0.069)	12.2	13.9

TABLE 17  
**ABLATOR DIRECT BOND-ON ATTACH CONCEPT**  
**Scope: Final Inspection**

FUNCTION	TASK DURATION HR/M <sup>2</sup> (HR/FT <sup>2</sup> )	ACTUAL PRODUCTIVE TIME MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )
FINAL INSPECTION	0.0102(0.0009)	0.0102(0.0009)

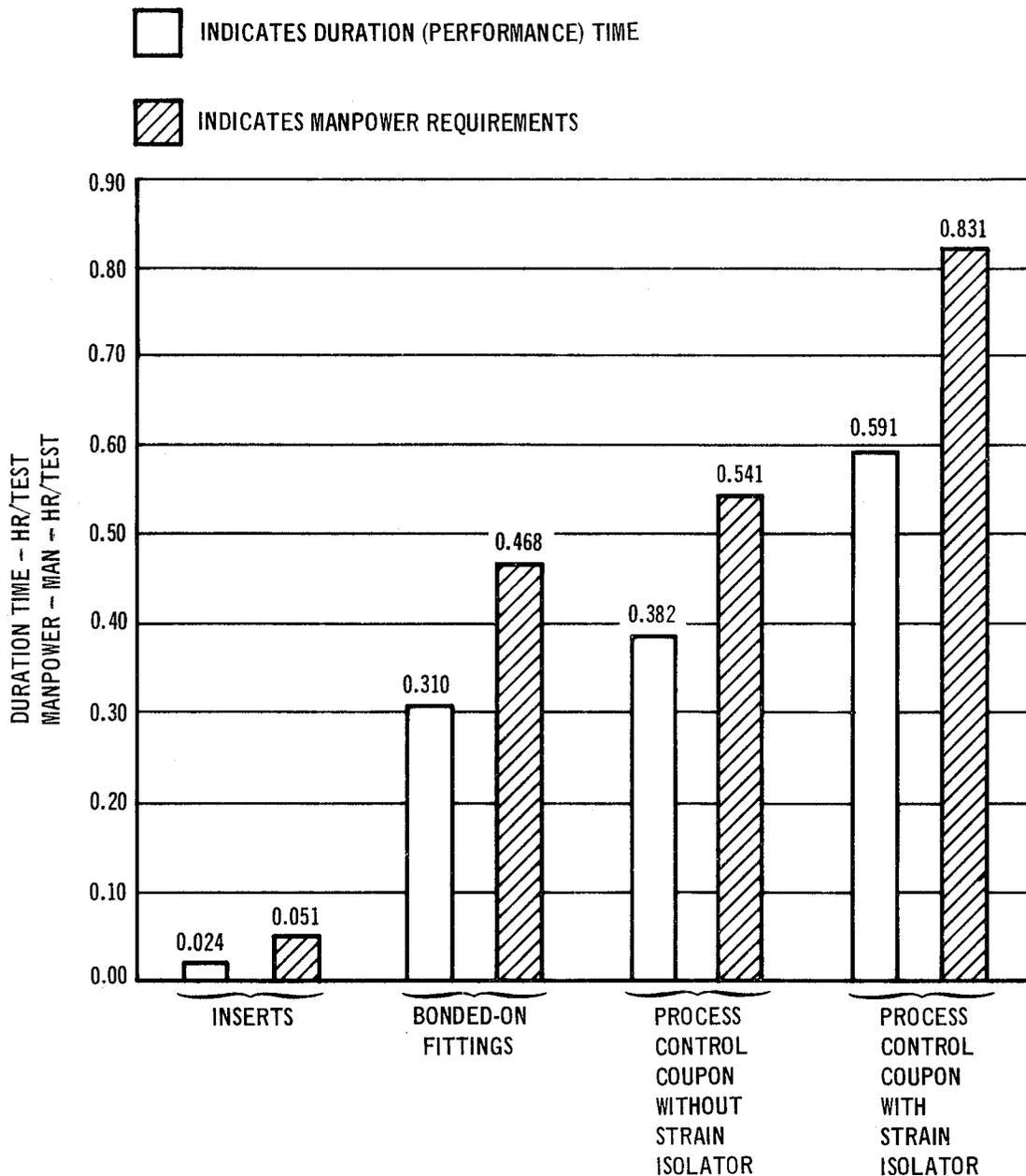
described previously under the section labeled "Static Testing." It should be noted that the task duration and productive times for the process control coupons (with and without a strain isolator) include the requirements for manufacturing the coupons in parallel with bonding on the ablator panel. Process control coupon testing would of course be performed off the vehicle, whereas the imbedded inserts and bonded-on fittings would be performed on installed ablator panels. As noted, there is an order of magnitude difference among insert concept, the bonded-on fittings, and the process control coupon techniques (as shown in the bar chart of figure 37). Although the times to perform the static tests using the "insert" type fitting, the former method is more restrictive to preselected locations whereas the latter method allows for random sampling. Depending upon the number and type of static tests required per square meter (square foot) of surface area this facet of the refurbishment operation could be significant or irrelevant.

Converting the data given in table 18 and plotting them on a number of tests per square meter basis gives the manpower requirements as shown in figure 38. Based on the data presented in tasks 42, 43, 45, 46, 48, 50, 52, and 54 of table 5, we find that 5.1 square meters of ablator panels (i.e., 6.8 large ablator panels) can be installed using an adhesive with a pot life of 2.5 hours. This area was calculated using the following equation:

**ABLATOR DIRECT BOND-ON ATTACH CONCEPT**  
**Scope: Bond Integrity Evaluation (Static Testing)**

TABLE 18

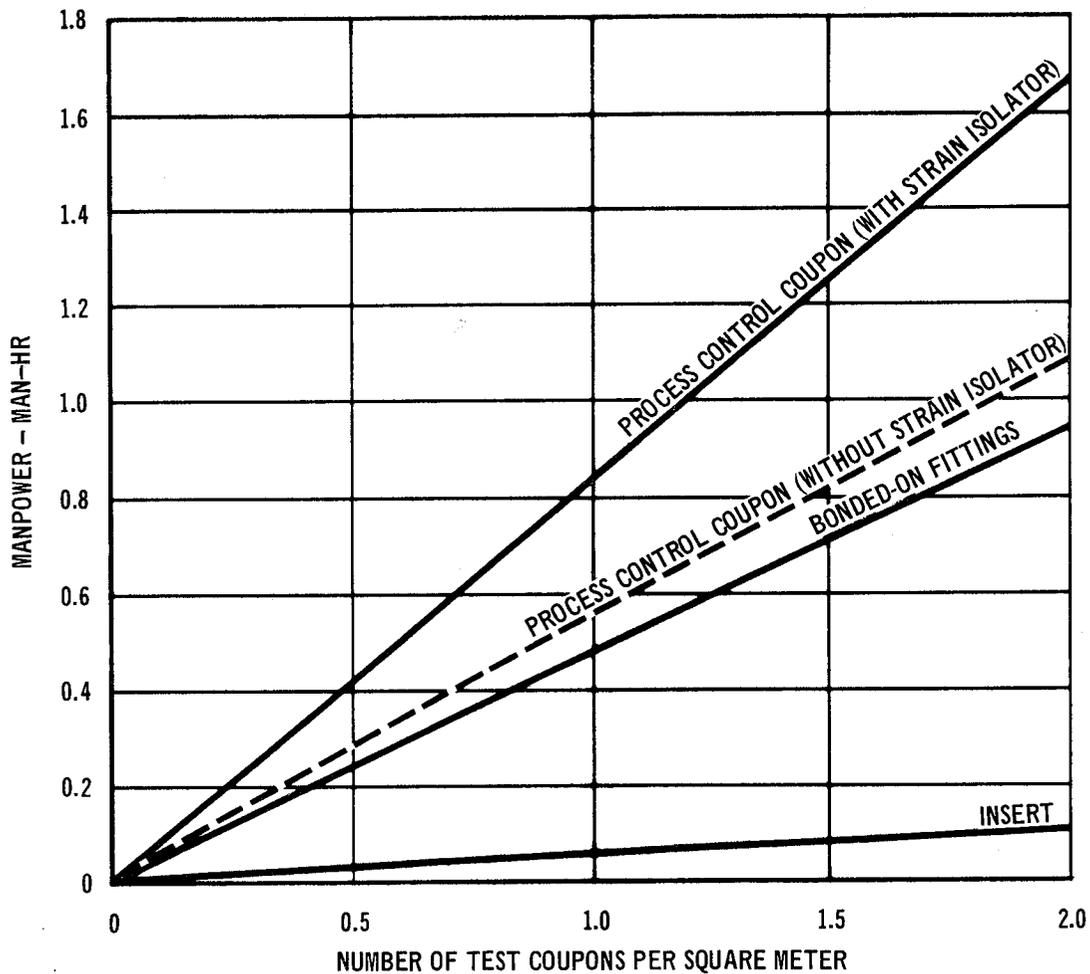
FUNCTION	PROCESS CONTROL COUPON		IMBEDDED PANEL INSERTS		BONDED-ON FITTING	
	WITH STRAIN ISOLATOR	WITHOUT STRAIN ISOLATOR	ACTUAL PRODUCTIVE TIME MAN-HR/COUPON	TASK DURATION HR/INSERT	ACTUAL PRODUCTIVE TIME MAN-HR/INSERT	TASK DURATION HR/FITTING
INSTALL AND/OR LOAD	0.591	0.831	0.541	0.024	0.051	0.175
	-	-	-	-	-	0.135
REMOVE AND REPAIR	-	-	-	-	-	0.187
TOTAL	0.591	0.831	0.541	0.024	0.051	0.468



**FIGURE 37 BOND INTEGRITY EVALUATION COMPARISON  
(STATIC TESTING)**

$\frac{\text{Area in square meters/panel}}{\text{Task duration installation time (HRS)/panel}} \times \text{pot life of adhesive} = \text{total area}$

Using the data presented in figure 38 and assuming that one process control coupon would be manufactured and tested for each 5.1 square meters of area, the cost in manhours to verify the bond by this technique is equal to 0.157 and 0.102 manhours per square meter, respectively, for the configuration with and without the use of a strain isolator. The effect of this method of bond certification is filtered into the analysis of a representative Space Shuttle configuration cited later in the report.



**FIGURE 38 MANPOWER VS. TEST COUPON REQUIREMENTS**

Refurbishment Labor and Performance TPS Attach Concept Comparison

The real significance of the data presented for the direct bond-on ablator panels becomes apparent when these data are compared with the data associated with the TPS attach concepts tested in Task I. This comparison is presented in figures 39 and 40 for the scheduled and unscheduled removal and replacement functions, respectively.

From these figures one can see that a sizable difference exists not only among attach concepts having different heat shield materials but also among identical attach concepts having different heat shield materials. On a scheduled removal and replacement basis (figure 39) the ablator key/keyway attach concept is the lowest maintenance cost approach; whereas the ablator direct bond-on concept is the highest maintenance cost approach, the difference being

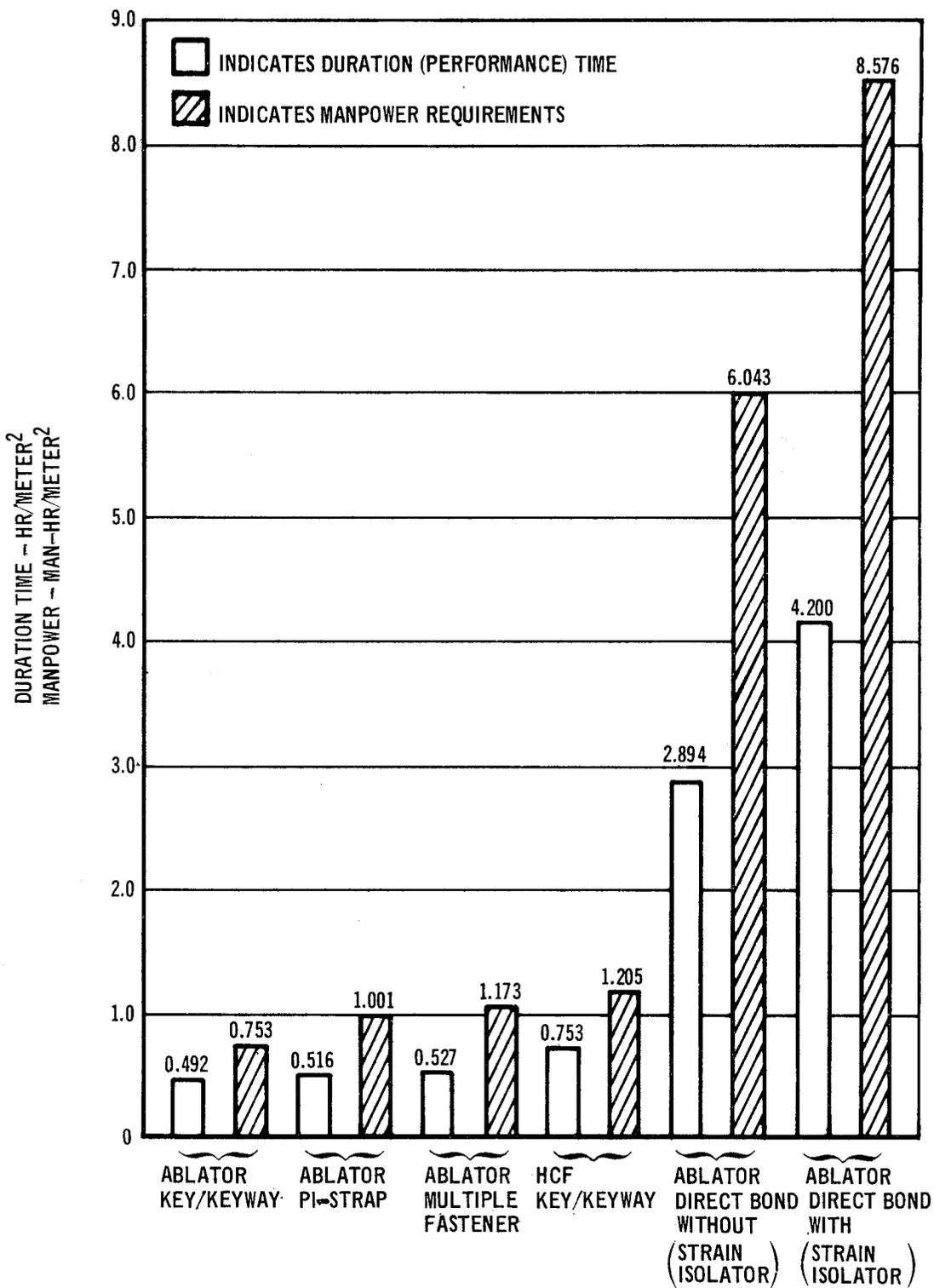
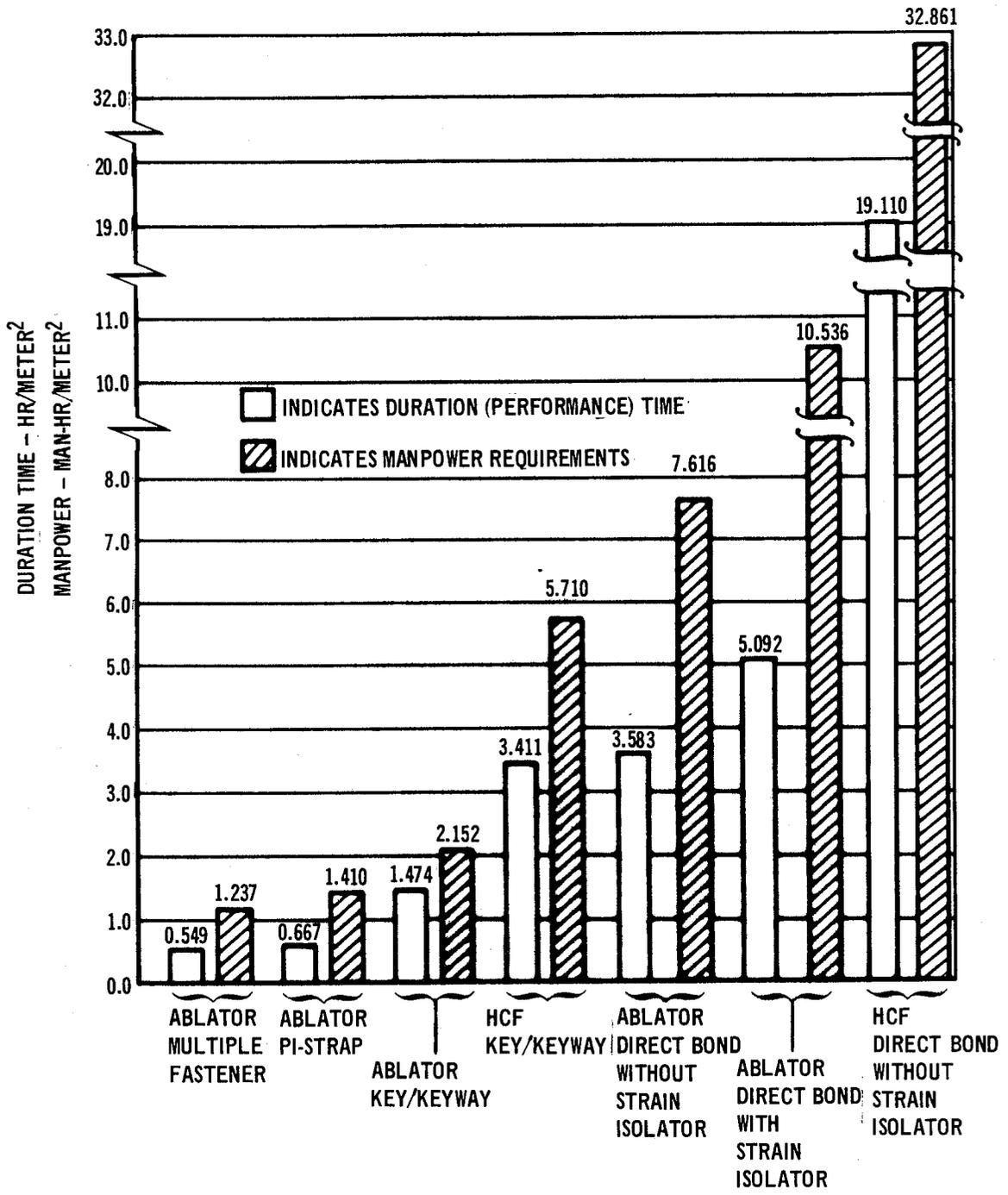


FIGURE 39 SCHEDULED REMOVAL AND REPLACEMENT ATTACH CONCEPT COMPARISON



**FIGURE 40 UNSCHEDULED REMOVAL AND REPLACEMENT ATTACH CONCEPT COMPARISON**

over 1000 percent. It should be noted that the ablator direct bonded-on approach cited assumes the larger of the two size panels investigated with the use of a strain isolator on a "water-break" free surface.

Comparison among the unscheduled removal and replacement duration times and manpower requirements for the individual attach concepts are shown in figure 40. As noted a greater difference exists between the various attach concepts than for the scheduled maintenance situation. In this instance both the ablator and HCF direct bond-on approach are greater than the ablator multiple fastener attach concept by approximately 750 and 2550 percent, respectively. The HCF direct bond-on approach is greater than the ablator direct bond-on approach primarily due to the added care which must be taken in handling HCF because of its more fragile nature and to the larger size ablator panels tested.

### Maintenance Techniques

In addition to obtaining and analyzing performance time data, another objective of the program was to evaluate the techniques used in performing the various maintenance operations. This was accomplished by examining the various maintenance procedures (i.e., handling, tools, fixtures, materials, etc) used during the installation, inspection, static testing, and removal of the ablator panels. For the most part, all procedures employed were state-of-the-art. In addition, we note some of the major problem areas associated with these procedures, the design to which they were applied, and the ways in which the problems affected the test data.

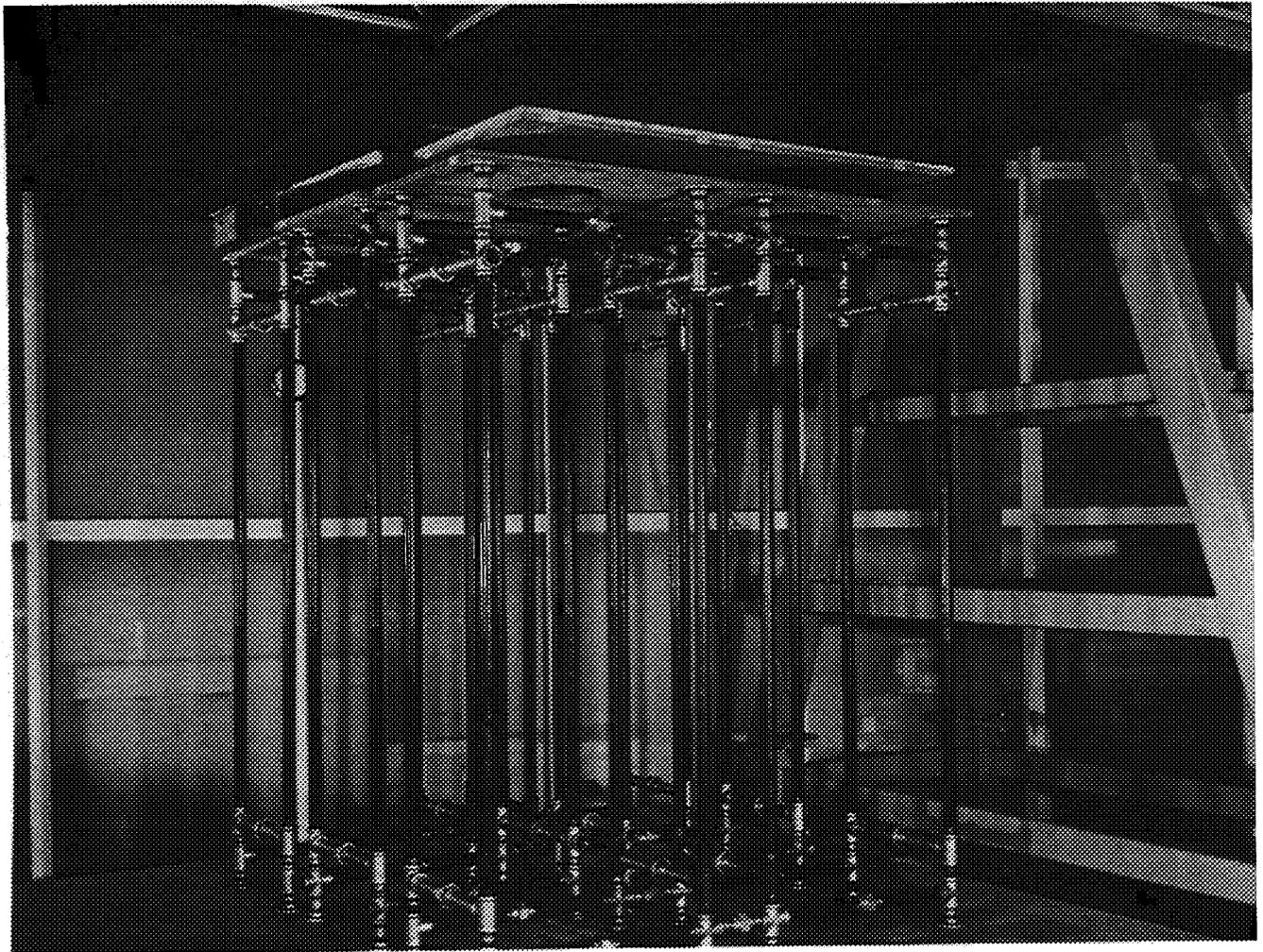
Handling.- Handling of both the small and the large ablator panels while inspecting, applying adhesive, or installing the panels on the panel support assembly was readily accomplished, without any obvious damage to the panels. Installation of the large and small ablator panels was accomplished in essentially the same manner. One man was required to support the small panel, whereas two men supported the large panel, while the pressure plate, pressure bags, and support stand were positioned beneath the panel assembly as shown in figure 41. The manpower allocations required for installing both the small and large ablator panels followed the sequence of operations below:

two men were required for carrying the adhesive coated panels and positioning same to the panel support assembly

two men handled and positioned the support stand, used for supporting the panel during the adhesive cure cycle

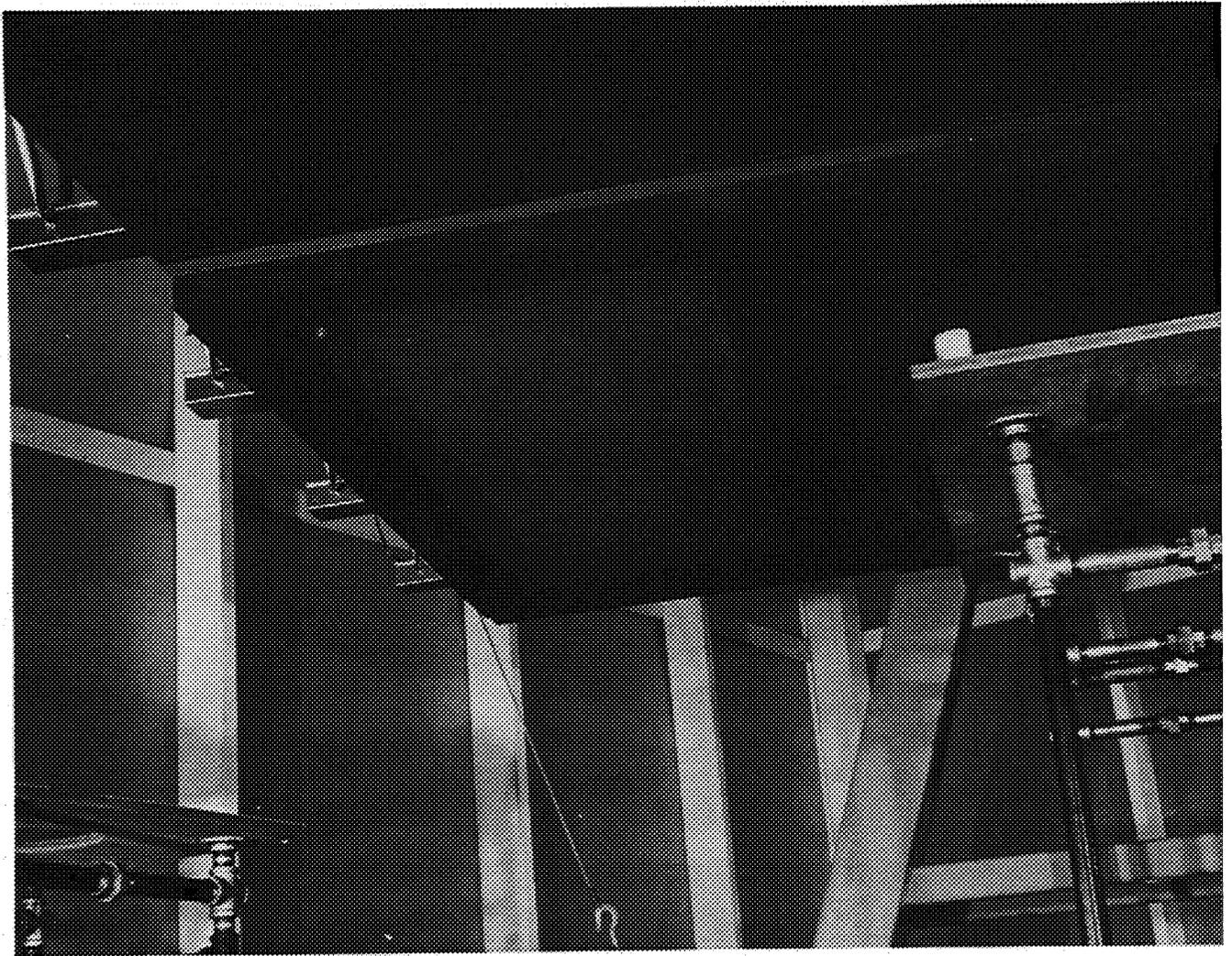
one man handled and positioned a cushioned pressure plate between the support stand and the small panel, whereas two men were required for handling the larger plate

positioning and inflating the pressure bags, between the support stand and the pressure plate, for the small panel was accomplished by one man, whereas two men were employed while performing this task for the large panels.



**FIGURE 41 PANEL SUPPORT STAND**

Bonding the strain isolator, figure 7, to the panel support assembly, figure 42, with RTV 560 adhesive created several problems. The lack of tackiness of the adhesive made it mandatory that the thin, limp, isolator pad be supported with a rigid backup plate while it was being positioned and applied to the adhesive coated panel support assembly. Once the strain isolator was placed in position, the same procedure described in the previous paragraph for installing the large ablator panel was used for applying a uniform pressure to the strain isolator during the adhesive cure cycle. Trying to accurately position the strain isolator on the backup plate and subsequently to the panel support assembly proved a challenge. Although the actual time required for bonding the strain isolator to the panel support assembly is included in the final refurbishment cost data, we strongly recommend that the strain isolator be bonded to the TPS panels as a bench operation, and that the isolator and the TPS panel be bonded to the panel support assembly as an integral unit.



**FIGURE 42 INSTALLED STRAIN ISOLATOR**

Support Stand.- The support stand, (figure 41), manufactured from 2.54-centimeter (1.0-inch) diameter pipe and corresponding tees, crosses, unions and floor pads (although over-designed) worked well for supporting the panels during the adhesive cure cycles. The 1.91-centimeter (0.75-inch) thick plywood pressure plate on the other hand was not rigid enough to provide a uniform pressure to the entire ablator panel area. This condition, however, would not have occurred if a single rectangular shaped pressure bag, covering the entire area of the pressure plate, had been used instead of two 38.1-centimeter (15-inch) outside diameter inertubes.

Adhesive Application.- The RTV 560 adhesive used for bonding the ablator panels to the panel support assembly was applied to both the panel and to the metallic skin of the panel support (or to the previously bonded-on strain isolator). Approximately 0.038 to 0.051 centimeters (0.015 to 0.020 inches) of adhesive was applied to each surface using a semistiff brush. A paint roller

was then used to uniformly spread the adhesive over the entire surface. A plastic serrated comb, with flats between each groove, was used on the initial installation for controlling the thickness of the adhesive. This, however, was replaced in favor of a paint roller, since the comb removed all of the adhesive in the flat areas. A redesign of the tool, incorporating small runners along each end of the comb, would help to control the thickness and minimize the bare areas.

While removing the charred ablator panels from the panel support assembly, a large void in the bond area was discovered under the middle large ablator panel, as shown in figure 43. Since this void occurred along the splice joining the two skins used in manufacturing the panel support assembly, it is conceivable that excessive waviness existed in this area. This theory was further strengthened by the fact that bond failure occurred while static testing the plug (machined in the second set of panels) located in this same area.

Caulking.- The two parts of the RTV 88 silicone compound, described in the "Ablator Panel Fabrication" section and prepackaged in 0.227-kilogram (8-ounce) cartridges, were mixed together by two men while two additional men were performing the actual caulking. Although the setup used for mixing the compound (figure 44) required two men, the performance time for only one man was recorded, since normally a special mixing machine, available from the vendor, would be used, making the mixing a one man operation. As illustrated in the figure, one man stroked the plunger back and forth, while the other man merely held the trigger on the air motor, which rotated the plunger as the compound was being mixed. Filling the 0.46-centimeter (0.18-inch) wide gaps between adjacent panels was accomplished by using an air-pressure-operated caulking gun, as shown in Figure 45. To minimize cost the width of the gap was selected to correspond with the availability of stocked, plastic nozzles. The depth of the gaps made it mandatory to use nozzles with a long constant cross section to assure that the entire gap was being filled. The nozzles were extended close to the bondline and held in that position until the caulking compound extruded to the outer surface of the panel, thus filling the entire gap. As illustrated in the figure, a man followed the filling operation with a putty knife removing all excess material and smoothing the surface of the filled gap. This had to be accomplished shortly after the gap was filled because the compound had a relatively short pot life.

It should be pointed out that the time recorded for caulking the gaps was extremely high, due to the nozzles becoming clogged or stopped up with lumpy material as the material was extruded through the nozzle. Approximately 30 percent of the cartridges had some cured, hard material distributed throughout the cartridge. In several cartridges, curing had proceeded to the extent that the mixing plunger could not be moved at all, and, consequently, the entire cartridge had to be thrown away. Another time delay evolved from having to apply approximately 541.6 kilonewtons per square meter (80 pounds per square inch) of pressure instead of the recommended 270.8 kilonewtons per square meter (40 pounds per square inch). This higher pressure ruptured several of the rectangular cross sectional plastic nozzles.

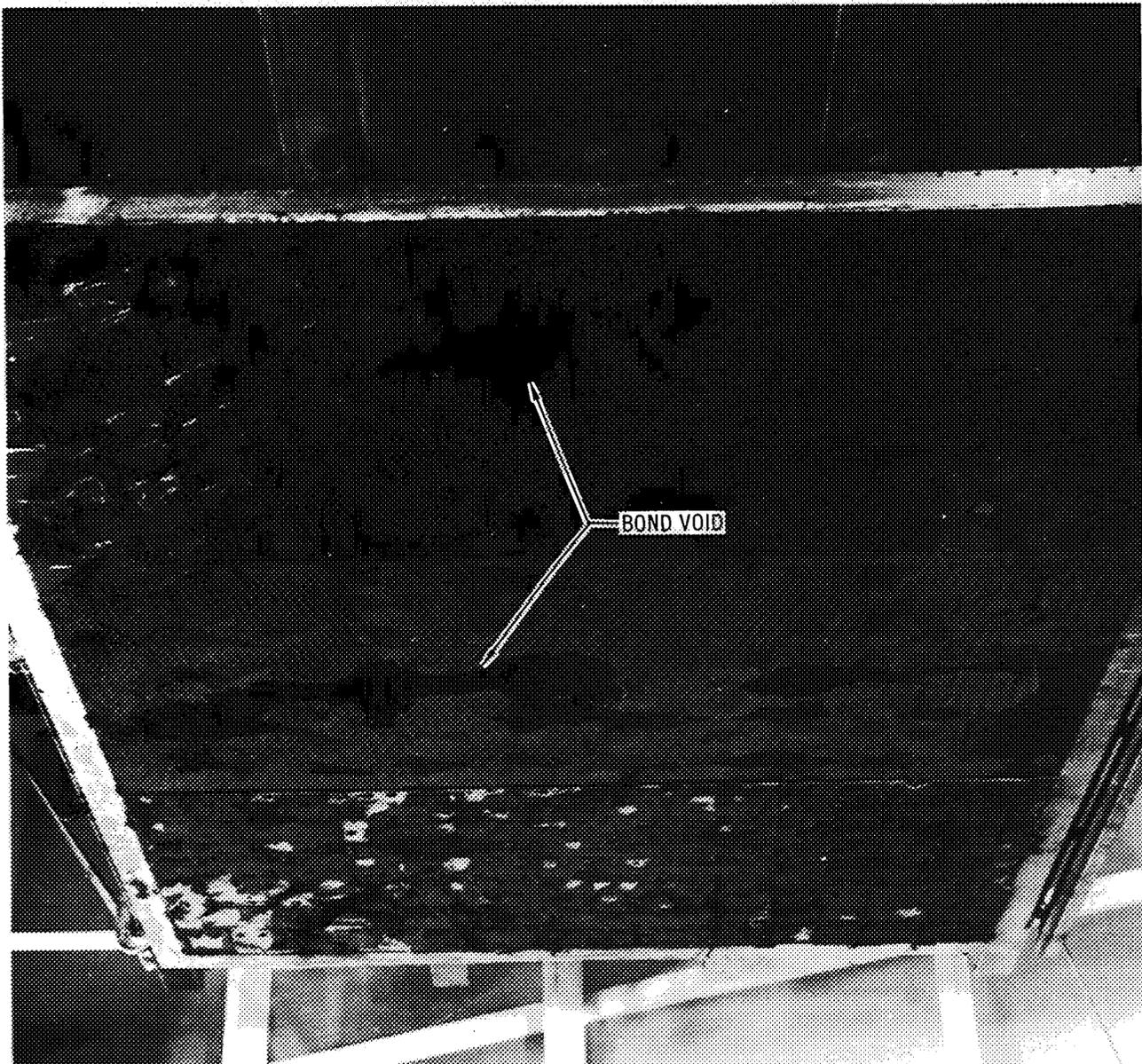
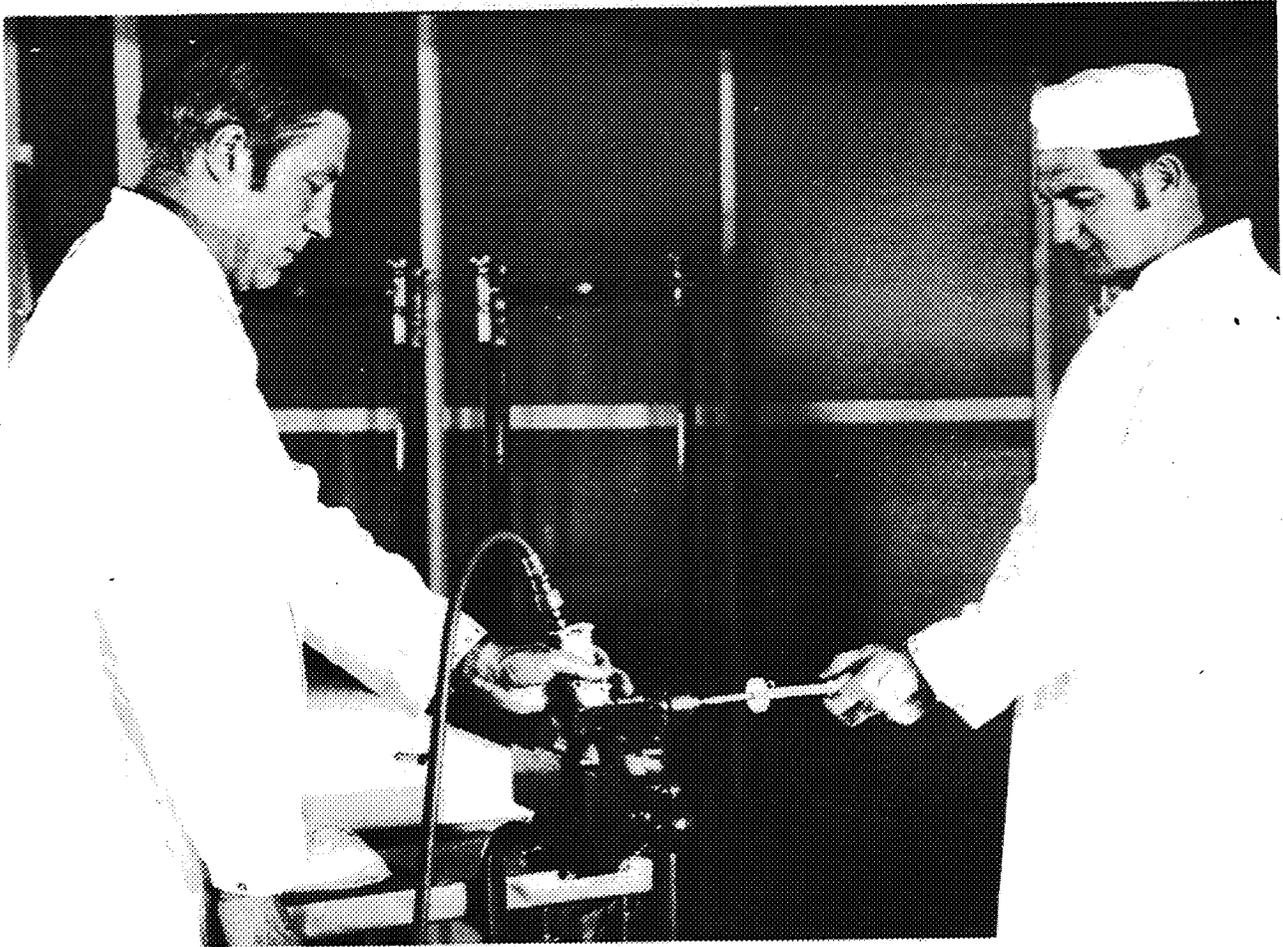


FIGURE 43 BOND CONDITION

Removing Charred Ablator Material.— The charred ablator panels (figure 46) were sectioned into small strips by machining intersecting grooves in the ablator panels with a circular saw, as shown in figure 47. The circular saw was set to a predetermined depth to assure that the blade would not bear on, or come in contact with, the aluminum skin. The sawing of these grooves proved to be a messy task. Although a strong shop vacuum, reinforced with a large exhaust fan, was used adjacent to the sawing operation, the entire room was heavily contaminated with dust particles. These sections, approximately 5.1 x 17.8 centimeters (2 by 7 inches), were removed by using a putty knife to cut and pry each section away from the bondline, as shown in figure 48.



**FIGURE 44 MIXING CAULKING COMPOUND**

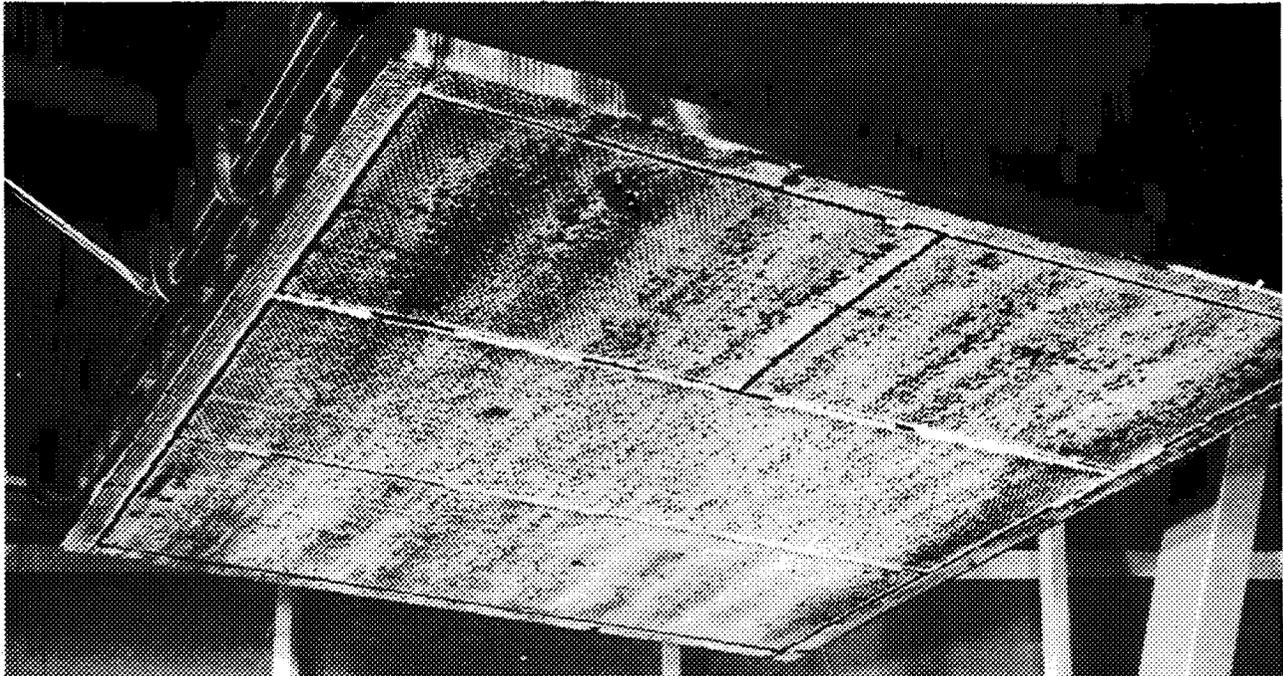
Removing Adhesive.- Removal of the cured adhesive from the aluminum skin of the panel support assembly was accomplished in two steps.

First, the remaining ablator material, the strain isolator (if applicable) and most of the adhesive were removed. This task was accomplished by using sharp plastic scrapers, as shown in figure 49. These scrapers had to be extremely sharp in order to be effective; consequently, one man was assigned to sharpen the scrapers, while two men were using them to scrape off the adhesive. Our goal was to allow no more than 0.005 centimeters (0.002 inches) of residual adhesive to remain on the skins of the panel support assembly.

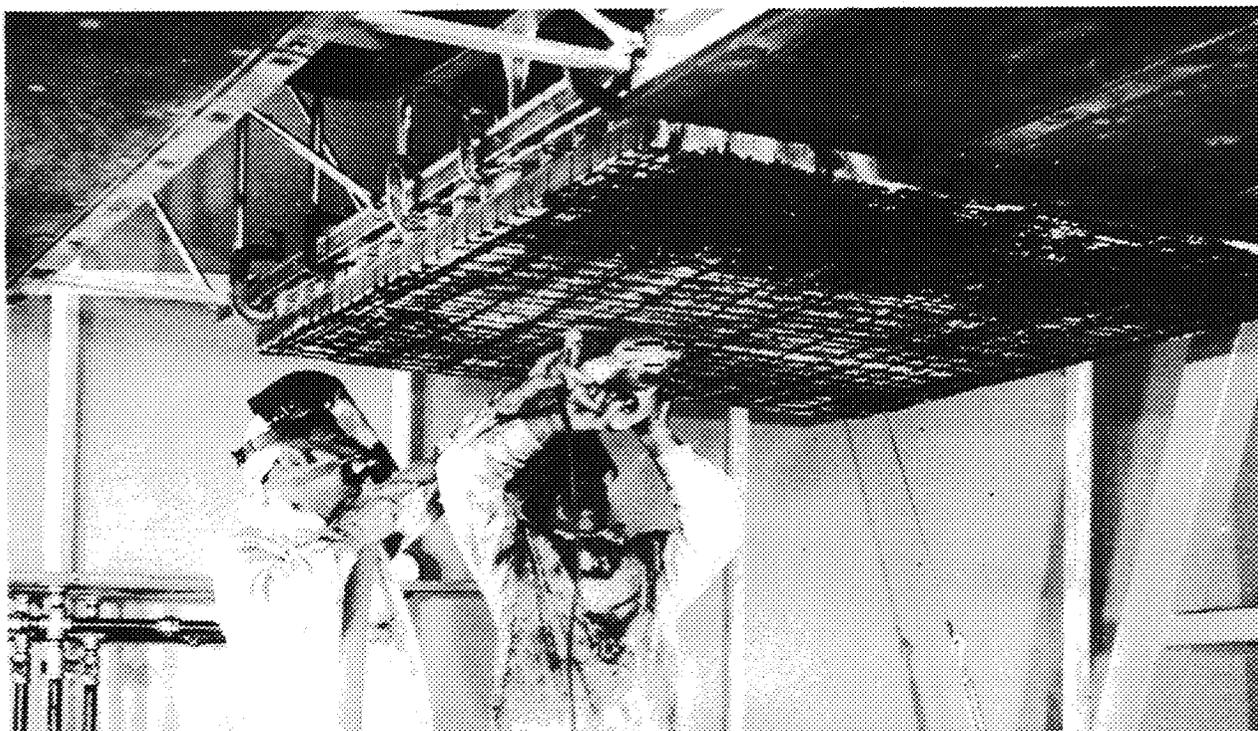
Removing the bonded-on strain isolator was such an easy operation that we suspect that the bond may not have cured properly. The strain isolator peeled off readily by applying a steady downward pull to the outer edges of the pad, as shown in figure 50. Initially this pad was bonded to the panel support assembly, with a single face adhesive application approximately 0.013 to 0.02 centimeters (0.005 to 0.008 inches) thick. During the final installation operation, the thickness of the adhesive was increased to approximately 0.038 to 0.051 centimeters (0.015 to 0.020 inches). Subsequent static testing of two machined plugs in the small bonded-on ablator panels revealed an adequate bond.



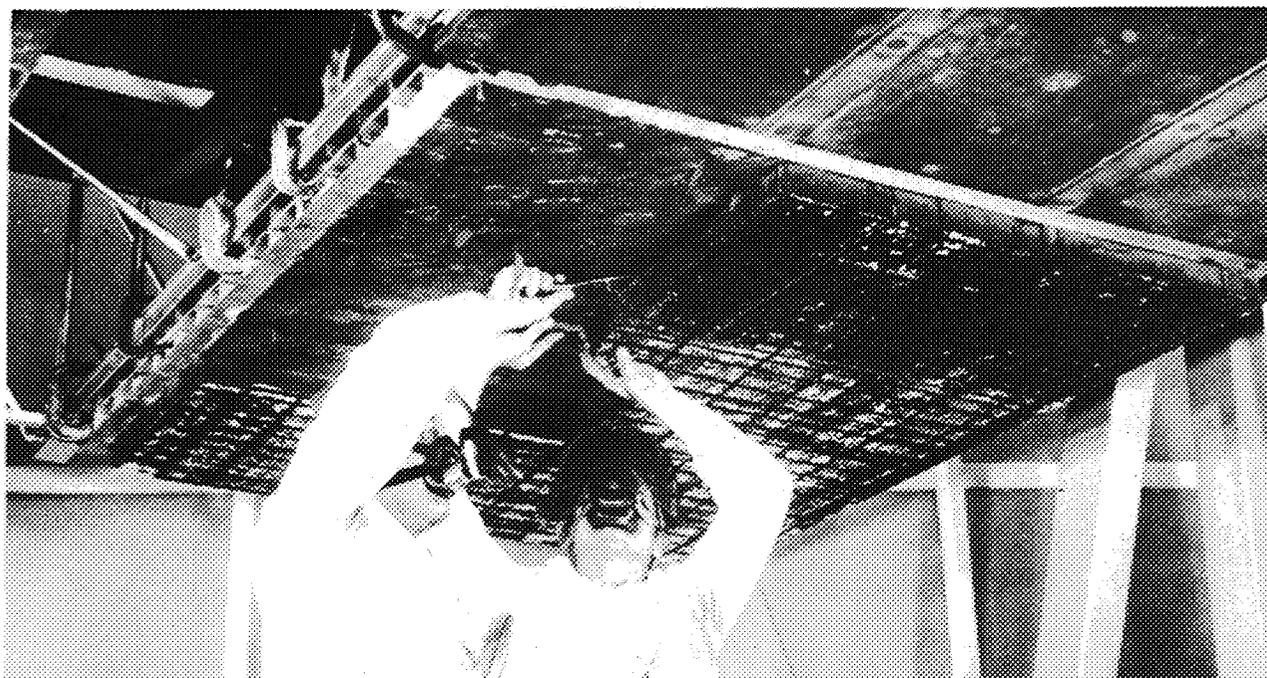
**FIGURE 45 CAULKING OPERATION**



**FIGURE 46 CHARRED ABLATOR PANELS**



**FIGURE 47 SECTIONING CHARRED ABLATOR**



**FIGURE 48 REMOVING CHARRED ABLATOR**

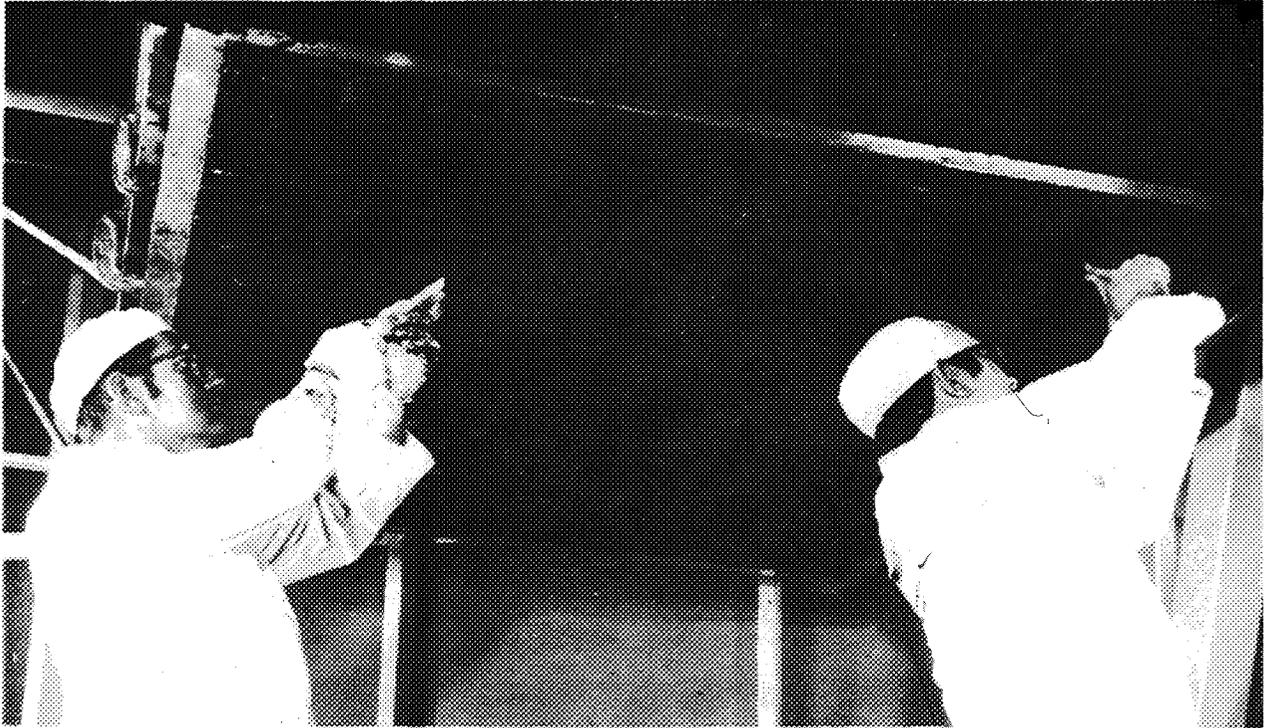


FIGURE 49 SCRAPING OFF ADHESIVE



FIGURE 50 REMOVING STRAIN ISOLATOR

The second step for the adhesive removal procedure consisted of removing the remaining residual adhesive until a "water-break" free surface was obtained. This was done by scrubbing the surface with nylon/silicone carbide abrasive cloths and rinsing with deionized water. The abrasive pads were attached to a 11.4-centimeter (4.5-inch) diameter disk sander, as shown in figure 51. Use of an abrasive material for obtaining a "water-break" free surface is highly questionable, since it scratches the aluminum surface (as illustrated in figure 52).

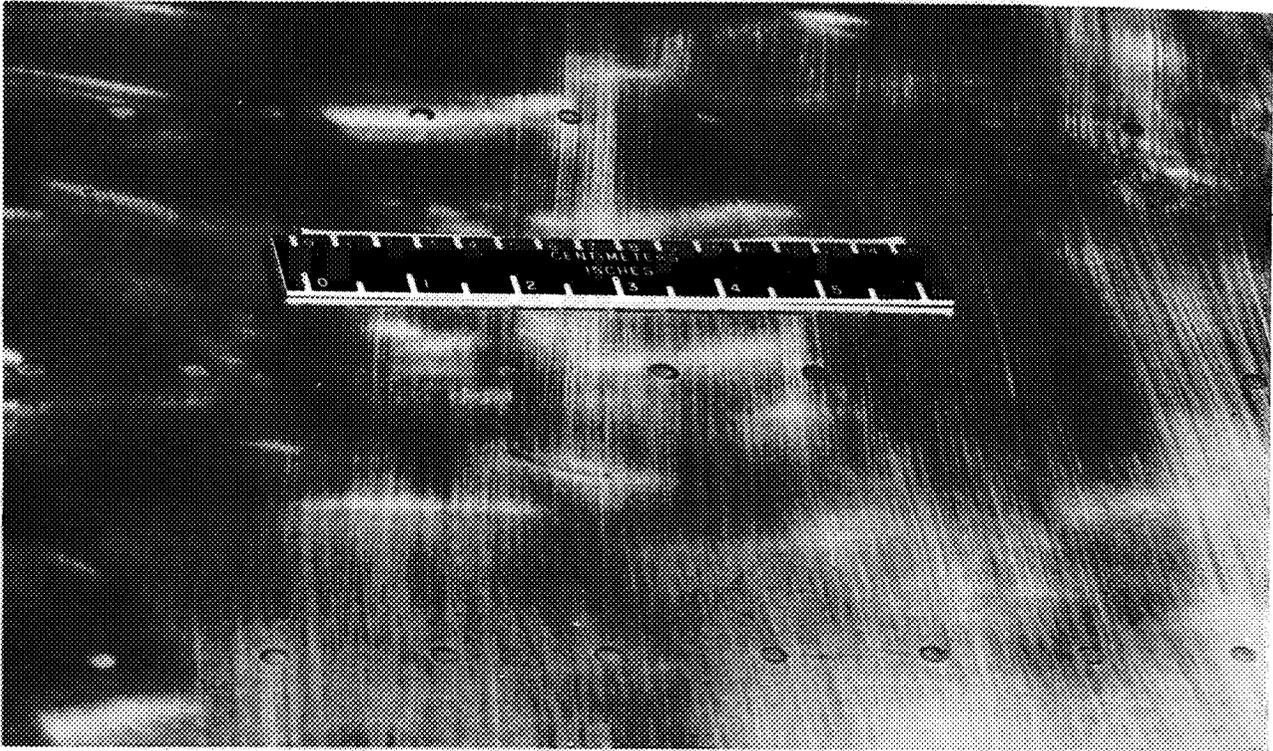
Obtaining a "water-break" free surface was readily accomplished in the area where flush head rivets were used for attaching the stiffeners to the skin of the panel support assembly. This was not the case where universal head rivets were installed. Although considerable time was spent, to remove the adhesive around each rivet head, using plastic scrapers, a small disk sander with abrasive pads, and much hand scrubbing, the surface would not wet around the periphery of the rivets. These areas were approximately 1.65 centimeters (0.65 inch) in diameter.

Static Testing.- As mentioned previously, three different static testing approaches were investigated for bond integrity evaluation. All of these approaches involved machining a plug (as shown in figure 53) in either the bonded-on ablator panels or in the process control coupons.

The first approach, by far the simplest, consisted of applying a pre-determined load to an eyebolt that had been screwed into an imbedded insert in the center of each ablator panel (figure 54). Since the width of the groove surrounding the machined plug is very narrow and the hole leading to the



FIGURE 51 REMOVING RESIDUAL ADHESIVE



**FIGURE 52 CLEANED ALUMINUM SURFACE CONDITION**



**FIGURE 53 MACHINING ABLATOR PLUGS**

imbedded insert is small, no repair is required unless damage occurs while machining the plug.



**FIGURE 54 STATIC TESTING MACHINED PLUGS (INSERTS)**

The second approach used for checking the bond consisted of bonding on a fitting at a random location(s) on the external surface of the ablator panel. After waiting the necessary time to insure that the adhesive had cured, a pre-determined load of 24.9 kilograms (55 pounds) was applied to the fitting. If no failure occurred the fittings were removed by using a sharp, thin, flexible putty knife to cut through the adhesive layer (figure 55 ). This procedure resulted in damaging the ablator panel in each area where the fittings had been attached (figure 56 ). Each damaged area was repaired locally.

The third approach tested was identical to the second, except that a process control coupon was used. Application of the static load is illustrated in figure 57. For this approach the plugs can be tested to failure, since damage to the coupons need not be repaired.

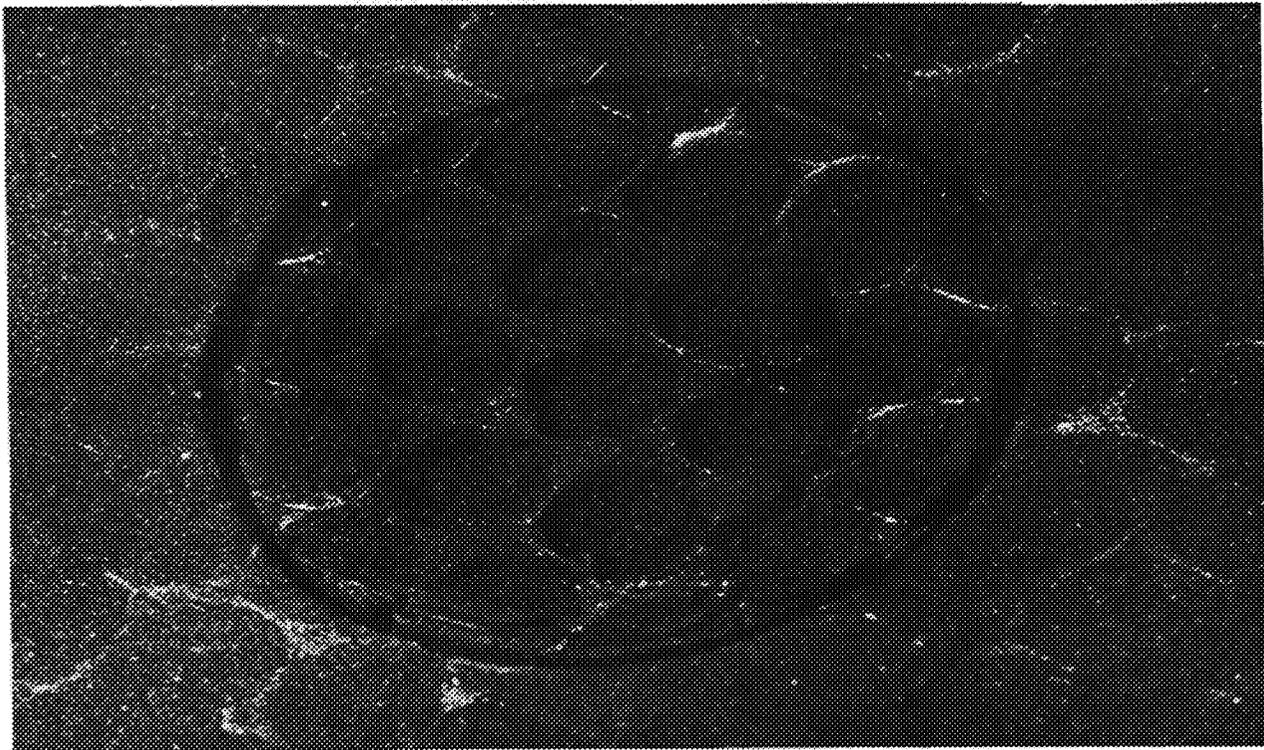
Maintenance Technique Conclusions and Recommendations.- In reviewing some of the factors observed while performing the various maintenance operations, and the performance time data associated with specific tasks, the following conclusions and/or recommendations can be made.

Handling the 5.1-centimeter (2.0-inch) thick ablator panels, manufactured without facesheets, was readily accomplished without any obvious damage to the panels.

The strain isolators should be bonded to the TPS panels, as a bench operation, instead of bonding them to the substructure. In addition



**FIGURE 55 REMOVING BONDED-ON FITTING**



**FIGURE 56 PANEL CONDITION AFTER FITTING REMOVAL**

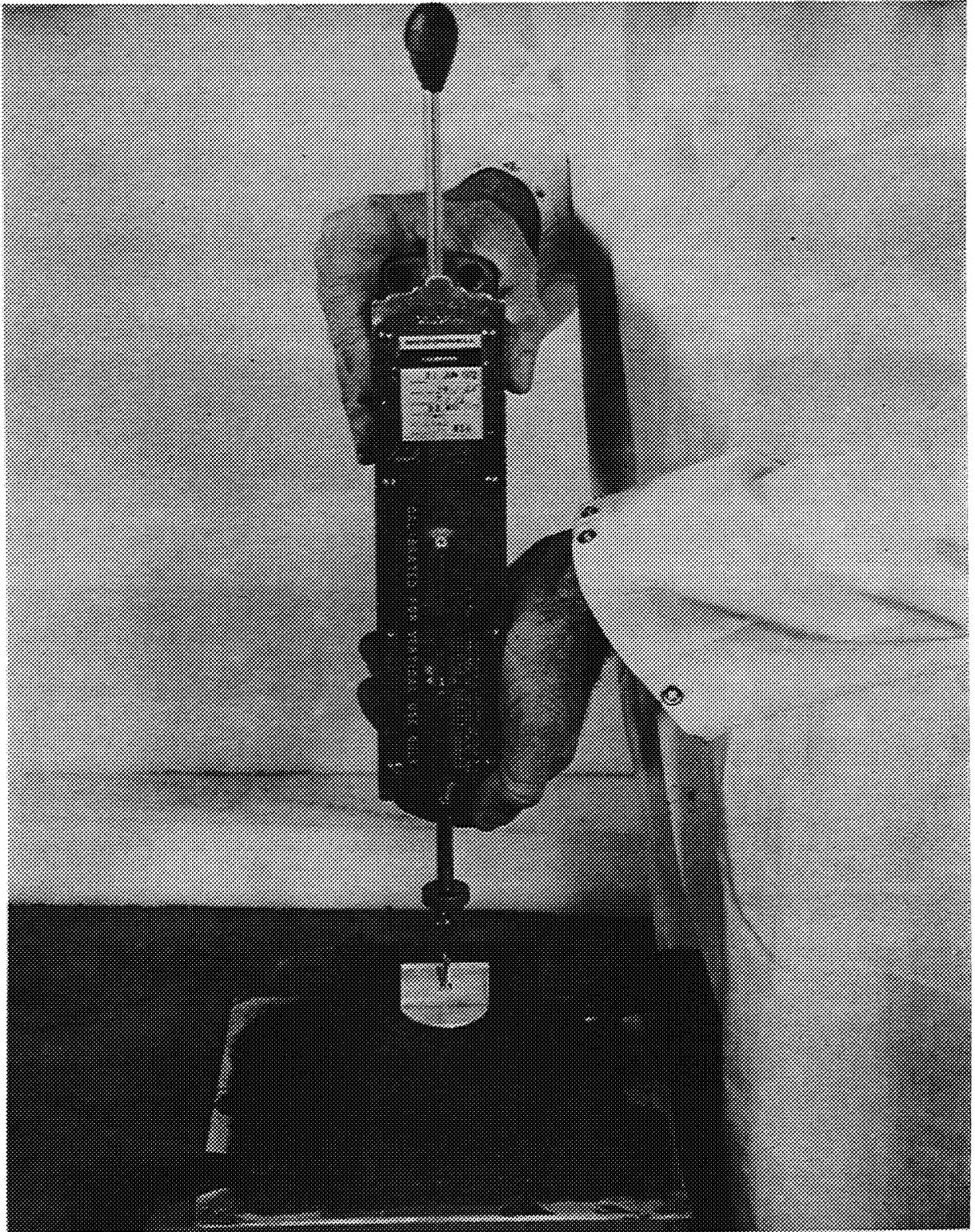


FIGURE 57 STATIC TESTING PROCESS CONTROL COUPON

to eliminating the problems associated with positioning the silicone sponge pads, it also greatly reduces refurbishment time.

In order to reduce the performance time associated with applying a uniform pressure to the bonded-on ablator panels during the adhesive cure cycle, special pressure bags, designed to cover the entire area of the panel, should be used.

Pressure plates, if required, must provide uniform loading of the panels during the adhesive cure cycle.

Waviness of the TPS panels and/or the support structure will have to be minimized in order to help eliminate bonding voids. This is especially true if the TPS panels are bonded directly to the support structure (without strain isolator), with thin layers of adhesive.

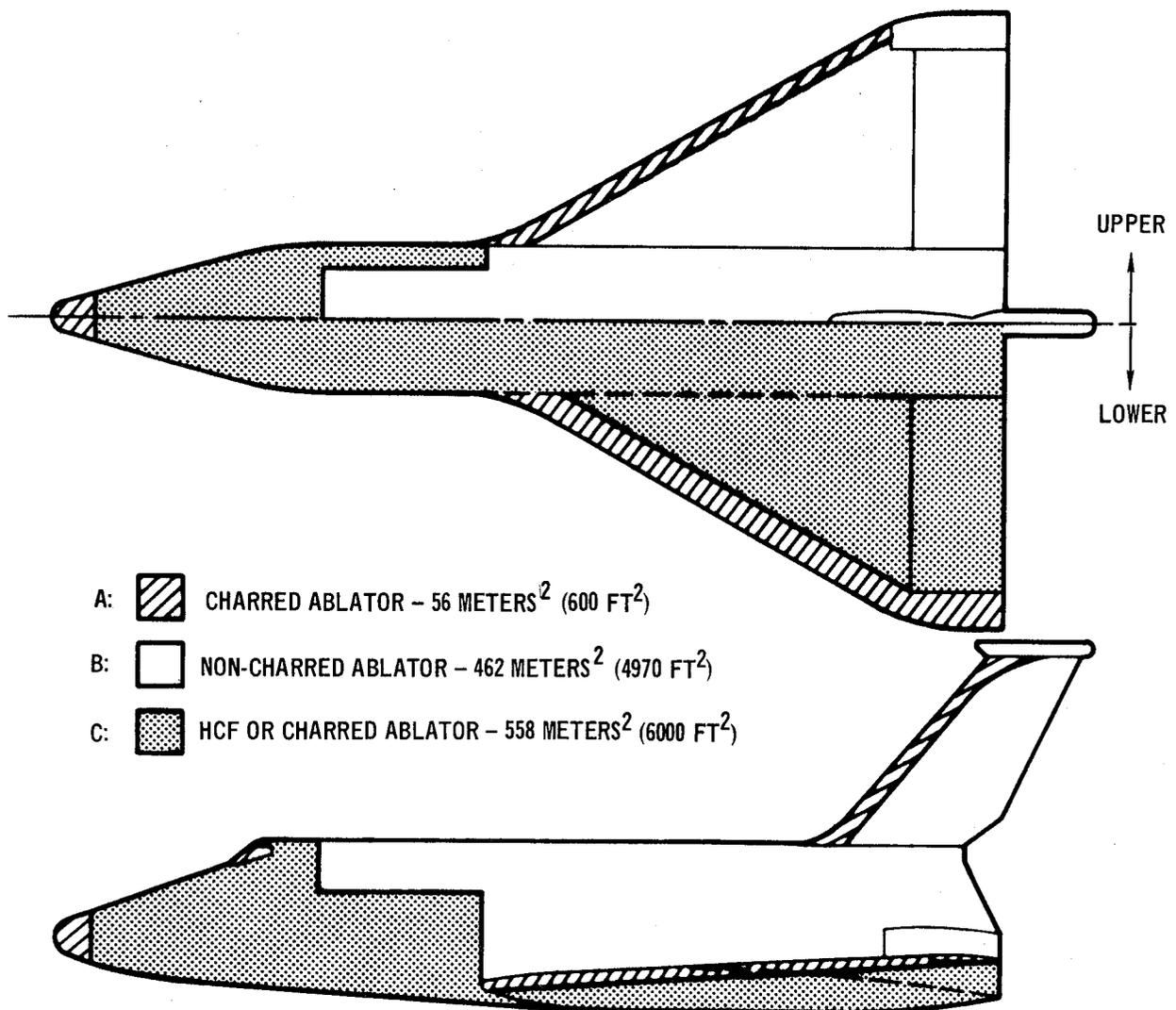
The recorded performance time associated with caulking the gaps between the panels was abnormally high, due to partially cured caulking compound clogging the nozzles.

#### SPACE SHUTTLE REFURBISHMENT

To illustrate the effect of refurbishing the bonded-on ablator concept when applied to a Space Shuttle vehicle, a representative vehicle configuration was analyzed using the test data obtained. The configuration, temperatures, and material distribution used in the analysis were identical to those used in Task I and reported in NASA CR-112034. These results were compared with the results obtained in Task I and are discussed herein.

The material distribution used in the analysis is shown in figure 58. The term "charred" ablator refers to that portion of the vehicle which would require refurbishment after every flight. The term "noncharred" ablator refers to that portion of the vehicle which would not experience temperatures greater than 675°K (750°F) and would, therefore, have a use-life greater than one flight. In the case of the noncharred ablator, variable use-life estimates were assumed. In the one instance it was assumed that the materials would have a use-life equal to the life of the vehicle, namely 100 flights. In addition, data were derived assuming total refurbishment once every 100 flights and twice every 100 flights.

For the case analyzed, 57 percent of the total surface area would be refurbished after every flight, while the remaining 43 percent would be covered with noncharring ablator which would be totally refurbished in accordance with the use-life assumptions quoted previously. Refurbishment labor costs for the highly curved nose section, and for the leading edges of the wing and tail surfaces, were not calculated since all test data were derived from flat panels and, as such, may not be directly proportional (since it is assumed it would be more difficult to refurbish these sections).



**FIGURE 58 ORBITER TPS DISTRIBUTION**

The results of the analysis are presented in tables 19 and 20. In deriving these data, the following cost model was used:

$$C_F = (A_F) (M) (L_R) (P) (Y)$$

- where:
- $C_F$  = average cost/flight (\$)
  - $A_F$  = average area/flight replaced measured in meters squared (feet squared)
  - $M$  = refurbishment manhours/meters<sup>2</sup> (feet<sup>2</sup>)
  - $L_R$  = labor rate @ \$15/manhour

TABLE 19  
NONCHARRED ABLATOR COST DATA

Area B = 462 M<sup>2</sup> (4970 Ft<sup>2</sup>)

ATTACH CONCEPT	TYPE MAINTENANCE	% AREA REFURBISHED	AREA REFURBISHED M <sup>2</sup> (FT <sup>2</sup> )	MANHOURS REQUIRED MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	COST/FLIGHT FOR PARTIAL REFURBISHMENT (\$)	COST/FLIGHT FOR TOTAL REFURBISHMENT (\$)	COST (\$) FOR 100 FLIGHTS WITH TPS FLIGHT LIFE OF:		
							100	50-99	34-49
DIRECT BOND-ON (WITH STRAIN ISOLATOR)	INITIAL INSTALLATION	100	462 (4970)	4.635 (0.431)	-	-	52,856	52,856	52,856
	SCHEDULED	100	462 (4970)	8.741 (0.812)	-	99,170	-	99,170	198,340
	UNSCHEDULED	3	13.86 ( 149)	10.701 (0.994)	3,642	-	360,558	356,916	353,274
	UNSCHEDULED	1	4.62 (49.7)	10.701 (0.994)	-	1,214	1,214	2,428	3,642
	TOTAL				3,642	100,384	414,628	511,370	608,112
DIRECT BOND-ON (WITHOUT STRAIN ISOLATOR)	INITIAL INSTALLATION	100	462 (4970)	3.370 (0.313)	-	-	38,234	38,234	38,234
	SCHEDULED	100	462 (4970)	6.150 (0.571)	-	69,774	-	69,774	139,548
	UNSCHEDULED	3	13.86 ( 149)	7.723 (0.718)	2,629	-	260,271	257,642	255,013
	UNSCHEDULED	1	4.62 (49.7)	7.723 (0.718)	-	876	876	1,752	2,628
	TOTAL				2,629	70,650	299,381	367,402	435,423

TABLE 20

**CHARRED ABLATOR COST DATA**  
**Area C = 558 M<sup>2</sup> (6000 Ft<sup>2</sup>)**

ATTACH CONCEPT	TYPE MAINTENANCE	% AREA REFURBISHED	AREA REFURBISHED M <sup>2</sup> (FT <sup>2</sup> )	MANHOURS REQUIRED MAN-HR/M <sup>2</sup> (MAN-HR/FT <sup>2</sup> )	COST/FLIGHT FOR TOTAL REFURBISHMENT (\$)	COST FOR 100 FLIGHTS (TPS FLIGHT LIFE = 1) (\$)
DIRECT BOND-ON (WITH STRAIN ISOLATOR)	INITIAL INSTALLATION	100	558 (6000)	4.635 (0.431)	-	63,513
	SCHEDULED	100	558 (6000)	8.741 (0.812)	119,776	11,857,824
	UNSCHEDULED	1	5.58 ( 60)	10.701 (0.994)	1,466	146,600
	TOTAL				121,242	12,067,937
DIRECT BOND-ON (WITHOUT STRAIN ISOLATOR)	INITIAL INSTALLATION	100	558 (6000)	3.370 (0.313)	-	46,178
	SCHEDULED	100	558 (6000)	6.150 (0.571)	84,272	8,342,928
	UNSCHEDULED	1	5.58 ( 60)	7.723 (0.718)	1,058	105,800
	TOTAL				85,330	8,494,906

P = productivity factor equal to 1.53

Y = planning and engineering support at 1.07

Therefore:

$$C_F = (A_F) (M) (15) (1.53) (1.07)$$

The factor Y is used to account for the required effort of planning and engineering personnel to support the maintenance personnel during the refurbishment activity. The factor P is used to account for unproductive time incurred during installation and removal of the TPS panels. Examples of unproductive time would include having the personnel available but not able to perform their function due to parts or equipment delay, equipment breakdown, failure to complete on time a prerequisite task, etc. Included in the refurbishment of each area are the initial installation costs and the costs for both scheduled and unscheduled maintenance functions. Scheduled maintenance refers to heat shield removal and replacement after exposure to the entry environment, while unscheduled maintenance refers to the removal and replacement of the damaged heat shields due to ground operations and/or entry environment.

Unscheduled percentage factors of 1 and 3 were assumed. The 1 percent applies to the unscheduled maintenance required due to damage of the virgin material during normal ground operations attendant upon initial installation and complete refurbishment of the area, while the 3 percent factor is applied each and every flight for use-life values greater than one. It should be noted that these percentage factors are purely estimates and are not based on any historical data. Such factors can only be verified after sufficient experience has been obtained on actual operational-type hardware.

The manhours quoted for the unscheduled maintenance were extrapolated from the scheduled removal and replacement data. The scheduled data were obtained under actual test conditions. When removing and replacing a particular panel during unscheduled maintenance, extreme care must be taken in order not to damage an adjacent panel or close out member. During a regularly scheduled removal of panels, such care would not be necessary, since many panels would be removed and replaced at one time.

The data presented in tables 19 and 20 are the results of a combination of several important parameters, such as the labor cost per square meter (square foot) to remove and replace the ablator panels, total area refurbished after each flight, and the expected use-life of the basic heat shield material. Maintenance labor costs for areas B and C of the vehicle (reference figure 58) are given for the configuration with and without a strain isolator, with the panel support assembly being cleaned and checked for a "water-break free" surface condition. In addition they also include the manhours required for manufacturing and static testing the process control coupons as described in the previous section. As stated previously the cost for area A was not projected because it was felt that the flat panel test data is not directly applicable to those highly curved regions of the vehicle.

The significance of the bonded-on ablator concept in relation to the other TPS concepts investigated during Task I is illustrated by comparing the various TPS concepts on an average \$/square meter (\$/square foot) and \$/flight basis as shown in tables 21 through 23. The \$/square meter (\$/square foot) parameter indicated the relative ease or difficulty associated with refurbishing the various TPS concepts considered. Based on this parameter, the various TPS concepts are compared for areas B and C of the vehicle investigated. As stated previously, the cost for area A was not projected because it was felt that the flat panel test data are not directly applicable to these highly curved regions of the vehicle.

In reviewing the maintenance labor cost data for the noncharred ablator (area B) shown in table 21, it is noted that the average bonded-on ablator concept costs are approximately 525 percent higher than those concepts employing an externally removable panel. When reviewing the maintenance labor cost data for the ablator attach concept for area C, table 22, we see that there is an order of magnitude difference between ablator key/keyway and direct bond-on (with strain isolator) attach concepts. Comparing the RSI (HCF) attach concepts for area C, it is clearly evident that the direct bond maintenance labor costs are greater than those for the key/keyway attach concept by between 450 and 500 percent.

Maintenance labor cost comparison for the various TPS attach concepts considering the refurbishment of the entire vehicle shown in figure 58, except for the nose section and leading edges of the wing and tail, is given in table 23. As indicated, the TPS flight life for the ablator attach concepts was considered to be 1 for the charred ablator area (area C), while flight lives of 100, 50 to 99, and 34 to 49 were considered for the noncharred ablator area (area B). For the vehicle whose basic TPS incorporated RSI (HCF) the cost data was derived by covering area C with RSI (HCF) and area B with ablator (attached by means of pi-straps). Flight lives of 100, 50 to 99, and 34 to 49 were assumed for both areas B and C. From these data, it is clearly evident that of all the variables considered, use-life of the heat shield material is by far the most significant. Current state-of-the-art ablators have for the most part a use-life of one flight. However, if the ablator material does not experience temperatures above 672°K (750°F), it is assumed that its use-life could be extended to 100 flights. The current goal in the development of RSI (HCF) is to have a use-life of at least 100 flights. If such a goal is obtained the use of RSI (HCF), in combination with a removable panel attach concept, could prove to be most cost effective from a maintenance labor point of view. If, on the other hand, the RSI (HCF) is bonded directly to primary structure, then ablator panel attach concepts become competitive with RSI (HCF) even though the ablators have a limited use-life of one flight for those areas where the higher temperatures are obtained. As noted, the direct bond-on ablator concepts are considerably higher in labor costs than any of the other TPS attach concepts, and are, therefore, the least cost effective.

## CONCLUSIONS AND RECOMMENDATIONS

Several significant conclusions and recommendations summarized below, may be drawn from Task II.

TABLE 21

**NON-CHARRED ABLATOR ATTACH CONCEPT COST DATA COMPARISON**  
**Area B = 462 M<sup>2</sup> (4970 Ft<sup>2</sup>)**

(VEHICLE LIFE = 100 FLIGHTS)

TPS ATTACH CONCEPT	AVERAGE COST WITH TPS FLIGHT LIFE OF:					
	100		50-99		34-49	
	\$/M <sup>2</sup> (\$/FT <sup>2</sup> )	\$/FLIGHT	\$/M <sup>2</sup> (\$/FT <sup>2</sup> )	\$/FLIGHT	\$/M <sup>2</sup> (\$/FT <sup>2</sup> )	\$/FLIGHT
ABLATOR PI-STRAP	1.22 (0.11)	562	1.46 (0.14)	673	1.69 (0.16)	783
ABLATOR MULTIPLE FASTENER	1.16 (0.11)	535	1.44 (0.13)	666	1.72 (0.16)	796
ABLATOR KEY/KEYWAY	1.71 (0.16)	791	1.89 (0.18)	871	2.06 (0.19)	952
ABLATOR DIRECT BOND-ON (WITHOUT STRAIN ISOLATOR)	6.48 (0.60)	2,994	7.95 (0.74)	3,674	9.42 (0.88)	4,354
ABLATOR DIRECT BOND-ON (WITH STRAIN ISOLATOR)	8.97 (0.83)	4,146	11.07 (1.03)	5,114	13.16 (1.22)	6,081

TABLE 22

## TABLE 11.0-4 MAINTENANCE LABOR COST COMPARISON

Area C = 558 M<sup>2</sup> (6000 Ft<sup>2</sup>)

(VEHICLE LIFE = 100 FLIGHTS)

TPS ATTACH CONCEPT	AVERAGE COST WITH TPS FLIGHT LIFE OF:							
	100		50-99		34-49		1	
	\$/M <sup>2</sup> (\$/FT <sup>2</sup> )	\$/FLIGHT						
ABLATOR KEY/KEYWAY	-	-	-	-	-	-	18.96 ( 1.76)	10,582
ABLATOR PI-STRAP	-	-	-	-	-	-	24.67 ( 2.31)	13,864
ABLATOR MULTIPLE FASTENER	-	-	-	-	-	-	29.05 ( 2.70)	16,210
ABLATOR DIRECT BOND-ON (WITHOUT STRAIN ISOLATOR)	-	-	-	-	-	-	152.24 (14.16)	84,949
ABLATOR DIRECT BOND-ON (WITH STRAIN ISOLATOR)	-	-	-	-	-	-	216.27 (20.11)	120,679
HCF KEY/KEYWAY								
• 1.5 AND 3%*	4.50 (0.42)	2,509	4.78 (0.45)	2,669	5.07 (0.47)	2,830	-	-
• 2.5 AND 5%*	7.33 (0.68)	4,090	7.60 (0.71)	4,242	7.88 (0.73)	4,395	-	-
• 5 AND 10%*	14.41 (1.34)	8,041	14.65 (1.36)	8,173	14.89 (1.38)	8,306	-	-
HCF DIRECT BOND								
• 1.5 AND 3%*	25.61 (2.38)	14,293	28.18 (2.62)	15,726	30.75 (2.86)	17,158	-	-
• 2.5 AND 5%*	41.66 (3.87)	23,248	44.15 (4.11)	24,636	46.64 (4.33)	26,023	-	-
• 5 AND 10%*	81.78 (7.61)	45,634	82.27 (7.82)	46,909	86.35 (8.03)	48,184	-	-

\*UNSCHEDULED REFURBISHMENT

TABLE 23  
**MAINTENANCE LABOR COST COMPARISON**  
**Area B + C = 1020 M<sup>2</sup> (10,970 Ft<sup>2</sup>)**

(VEHICLE LIFE = 100 FLIGHTS)

TPS ATTACH CONCEPT	AVERAGE COST WITH TPS FLIGHT LIFE OF:					
	C = 1, B = 100		C = 1, B = 50-99		C = 1, B = 34-49	
	\$/M <sup>2</sup> (\$/FT <sup>2</sup> )	\$/FLIGHT	\$/M <sup>2</sup> (\$/FT <sup>2</sup> )	\$/FLIGHT	\$/M <sup>2</sup> (\$/FT <sup>2</sup> )	\$/FLIGHT
ABLATOR KEY/KEYWAY	11.15 ( 1.04)	11,373	11.23 ( 1.04)	11,453	11.31 ( 1.05)	11,534
ABLATOR PI-STRAP	14.14 ( 1.32)	14,426	14.25 ( 1.33)	14,536	14.36 ( 1.34)	14,647
ABLATOR MULTIPLE FASTENER	16.42 ( 1.53)	16,745	16.55 ( 1.54)	16,876	16.67 ( 1.55)	17,006
ABLATOR DIRECT BOND-ON (WITHOUT STRAIN ISOLATOR)	86.22 ( 8.02)	87,943	86.89 ( 8.08)	88,623	87.55 ( 8.14)	89,303
ABLATOR DIRECT BOND-ON (WITH STRAIN ISOLATOR)	122.38(11.38)	124,825	123.33(11.47)	125,793	124.27(11.56)	126,760
	B & C = 100		B & C = 50-99		B & C = 34-49	
HCF KEY/KEYWAY						
• 1.5 AND 3%*	3.01 ( 0.28)	3,071	3.28 ( 0.30)	3,342	3.54 ( 0.33)	3,612
• 2.5 AND 5%*	4.56 ( 0.42)	4,652	4.82 ( 0.45)	4,915	5.08 ( 0.47)	5,178
• 5 AND 10%*	8.43 ( 0.78)	8,603	8.67 ( 0.81)	8,846	8.91 ( 0.83)	9,089
HCF DIRECT BOND						
• 1.5 AND 3%*	14.56 ( 1.35)	14,856	16.08 ( 1.49)	16,398	17.59 ( 1.64)	17,941
• 2.5 AND 5%*	23.34 ( 2.17)	23,811	24.81 ( 2.31)	25,308	26.28 ( 2.44)	26,806
• 5 AND 10%*	45.29 ( 4.21)	46,196	46.65 ( 4.34)	47,581	48.01 ( 4.46)	48,967

**\*UNSCHEDULED REFURBISHMENT**

1. Fabrication and handling of large size ablator panels presented no serious problems. Additional studies should be made to establish upper size limits from a handling and fabrication standpoint.

2. Control of humidity at temperature is required for acceptable hydrolyzation of current state-of-the-art primers used in prebonding operations. Such requirements may create the need for special facilities for Space Shuttle application. Further development of primers which are less susceptible to humidity and temperature control is desirable.

3. Development of film type adhesives for Shuttle application would provide easier adhesive application, better control of adhesive thickness with resulting lower weight, and reduced maintenance labor costs.

4. Verification of bond integrity presents a major problem for the Space Shuttle TPS. Although candidate NDE methods exist, no one technique has yet been proven to be fool proof. Further detail development of NDE methods should be initiated as soon as possible.

5. In the absence of any positive NDE technique(s) it is felt that a carefully executed and fully documented material and process control procedure, together with tensile testing of process control coupons, is the best inspection and certification approach available at this time to establish bond integrity.

6. During the removal and replacement of the ablator panels, dust particles contaminated the test area. Such contamination on a large-scale basis could affect the health of personnel working in the refurbishment area and the electronic equipment around and within the spacecraft. It is, therefore, recommended that vacuum techniques that would be amenable to large-scale Space Shuttle effort be evaluated.

7. Comparison of the bonded-on ablator concept with the TPS attach concepts investigated during Task I show the bonded-on ablator concept to be the least cost effective approach from a maintenance labor cost viewpoint, when projected to Space Shuttle refurbishment.

8. The strain isolator should be bonded to the TPS panel as a bench operation to reduce the refurbishment manhours with the isolator and the TPS panel subsequently being bonded to the substructure as an integral unit.

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## APPENDIX A

### MAINTENANCE TASK SCHEDULES

All time data obtained while performing the refurbishment tests of the direct bond-on attach ablator panels are contained in this appendix (tables A1 through A13 in the form of maintenance task schedules). In order to help identify the data, the specific task functions, heat shield type, attach concept, and size of panels involved are identified in each table. The task functions are divided into initial installation, caulking of gaps, inspection, removal, final display installation, and static testing. The test data in these maintenance task schedules include the task descriptions, individual task times, cumulative production time, cumulative task duration plus cure time, equipment and parts required, and a general comments column. The task descriptions are set up in a sequential step by step arrangement, allowing each specific task to be timed separately. In addition to the total duration time, the actual performance time expended by each individual was recorded in seconds. Actual and estimated total productive times required for performing each individual task are expressed in manhours. Cumulative times in terms of manhours and hours are tabulated for the productive times and task durations (including cure time requirements), respectively. All specific tools, equipment, materials, and parts required to perform the specific tasks are identified. General comments, as applicable, are also included.



Table A-1 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR (WITH STRAIN ISOLATOR)</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
5	Scrub the surface of aluminum process control coupon as specified per Task No. 4	122	122	-	-	-	.034	.008	.379	.295	.219		
6	Rinse surface of ablator panel support with deionized water. Apply with saturated cheesecloth. Check for water break free surface.	102	92	-	102	-	.054	.067	.433	.362	.247	Cheesecloth Deionized Water Rubber Gloves	
6A	If a water break free surface is not obtained, repeat the cleaning procedure. Repeat Task No. 4 Repeat Task No. 6	-	-	-	-	-	-	-	-	-	-		
7	Rinse surface of aluminum process control coupon as specified per Task No. 6.	49	39	-	49	-	.024	.008	.457	.370	.261		
7A	If a water break free surface is not obtained, repeat the cleaning procedure. Repeat Task No. 5 Repeat Task No. 7	-	-	-	-	-	-	-	-	-	-		
8	Dry surface of panel support with cheesecloth.	75	75	-	-	-	.021	.033	.478	.403	.282	Cheesecloth	
9	Dry surface of process control coupon with cheesecloth.	22	22	-	-	-	.006	.004	.484	.407	.288	Cheesecloth	
10	Check humidity.	22	-	-	22	-	.006	-	.490	-	.294	Humidity Gage	
11	Apply a thin film of silicone primer to the ablator panel support. Apply primer in a uniform coating over the entire surface to be bonded. Allow primer to cure for minimum of 3 1/2 to 4 hours at a relative humidity of 40 to 70 percent.	164	164	-	-	-	.046	.089	.536	.496	.340	GE SS4155 Primer Protective Goggles or Eyeshields Rubber Gloves Paint Brush	
NOTE:													
Do not prime if relative humidity exceeds these limits. Keep primer surface free from contaminants.													

Table A-1 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR (WITH STRAIN ISOLATOR)</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL				EST
							ACTUAL	EST					
12	Apply a thin film of silicone primer over the surface of process control coupon as specified per Task No. 11.	31	31	-	-	-	.009	.004	.545	.500	.349		
13	Inspect primer application on panel support and verify cure cycle.	92	-	-	92	-	.026	.033	.571	.533	4.125	Flashlight	
14	Inspect primer application on process control coupon and verify cure cycle.	44	-	-	44	-	.012	.007	.583	.540	4.137		
15	Mix silicone adhesive in the following ratio: 100 grams of resin - RTV 560 and 0.3 grams (30 drops) of catalyst thermo-lite (T-12). Mix RTV 560 in its container by hand, using a metal spatula. Mix well for 2 to 3 minutes. Weigh out required quantity of RTV-560 for bonding operation. Use clean, degreased (MER) container. Measure the required amount of catalyst over the surface of the RTV-560 in accordance with the indicated ratio. Gently blend the catalyst into the RTV-560 by hand with metal spatula only. Continue mixing for minimum of 5 minutes. Scrape sides of container intermittently to assure no catalyst has migrated to walls of container.	791	-	783	791	-	.438	.500	1.021	1.040	-	RTV 560 Adhesive T-12 Catalyst Spatulas (Metal Only) Gram Scale (Balance) Rubber Gloves Mixing Container	
16	Using a clean, degreased and dry stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to the primed panel support.	690	690	-	-	-	.192	.356	1.213	1.396	4.329	RTV 560 Adhesive Paint Roller Stiff Paint Brush Rubber Gloves Protective Goggles or Eyeshields	

Table A-1 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR (WITH STRAIN ISOLATOR)</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL				EST
							ACTUAL	EST					
17	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to primed process control coupon.	90	90	-	-	-	.025	.009	1.238	1.405	4.354		
18	Inspect adhesive on panel support for proper application.	44	-	-	44	-	.012	.033	1.250	1.438	4.366	Flashlight	
19	Inspect adhesive on process control coupon for proper application.	21	-	-	21	-	.006	.007	1.256	1.445	4.372		
20	Visually inspect strain isolator for obvious damage and cleanliness.	53	-	-	53	-	.015	.017	1.271	1.462	4.387		
21	Visually inspect strain isolator for process control coupon for obvious damage and cleanliness.	19	-	-	19	-	.005	.004	1.276	1.466	4.392		
22	Place strain isolator on pressure plate and bond to panel support. Position pressure support stand and pressure bag beneath pressure plate. Slowly inflate pressure bag until the pressure plate evenly supports the strain isolator with 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	143	104	133	143	56	.121	.133	1.397	1.599	4.432	1 Strain Isolator 64T020018-2001 Support Stand Air Pressure Bag (Inner Tube) Pressure Plate Air Pressure Source Air Pressure Regulator	Man No. 2 & 3 positioned isolator on Pad, using same to position isolator on panel support Man No. 1 & 4 positioned support stand and pressure bags
23	Bond strain isolator to process control coupon. Add pressure plate and weights to evenly apply 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	51	51	-	-	-	.014	.008	1.411	1.607	4.446	Strain Isolator Pressure Plate Weights	
24	Check pressure support setup and verify cure cycle.	71	-	-	71	-	.020	.017	1.431	1.624	28.466		

Table A-1 (Continued)

MAINTENANCE TASK SCHEDULE

- TASK FUNCTION INSTALLATION (INITIAL)
- HEAT SHIELD TYPE ABLATOR (WITH STRAIN ISOLATOR)
- ATTACH CONCEPT BONDED
- PANEL SIZE 55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)

TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL				EST
							ACTUAL	EST					
44	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to strain isolator bonded on process control coupon.	27	27	-	-	-	.008	.009	2.411	3.349	30.041		
45	Remove tape from edges of ablator panels.	44	-	44	-	-	.012	-	2.423	-	30.053		
46	Inspect adhesive on strain isolator bonded to panel support for proper application.	35	-	-	35	-	.010	.033	2.433	3.382	30.063	Flashlight	
47	Inspect adhesive on strain isolator bonded to process control coupon for proper application.	14	-	-	14	-	.004	.007	2.437	3.389	30.067		
48	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to process control ablator panel.	288	288	288	-	-	.160	.356	2.597	3.745	30.147	1 Ablator Panel 64T020016-1007 RTV 560 Adhesive Paint Roller Stiff Paint Brush Rubber Gloves	Man No. 1 applied Adhesive with Brush Man No. 2 Spread Adhesive with Roller
49	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to process control ablator panel.	47	36	47	-	-	.023	.009	2.620	3.754	30.160		
50	Inspect adhesive on ablator panel for proper application.	26	-	-	26	-	.007	.033	2.627	3.787	30.167		
51	Inspect adhesive on process control ablator panel for proper application.	14	-	-	14	-	.004	.007	2.631	3.794	30.171		

Table A-1 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR (WITH STRAIN ISOLATOR)</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)						
							ACTUAL	EST					
52	Position and align the ablator panel on the strain isolator. Install spacers to insure proper gap control. Position support stand, air pressure bag, and pressure plate. Slowly inflate pressure bag, until pressure plate evenly supports the ablator panel with approximately 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	374	374	374	374	195	.365	.133	2.995	3.927	30.275	Support Stand Air Pressure Bag Pressure Plate Cotton Gloves Air Pressure Source	No. 1 & 2 positioned panel assy. No. 3 & 4 positioned pressure plate, air bags & support stand
53	Bond ablator panel on process control coupon. Add pressure plate and weights to evenly apply 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	39	39	-	-	-	.011	.008	3.007	3.935	30.286	Pressure Plate Weights Cotton Gloves	
54	Check pressure support setup and verify cure cycle.	57	-	-	57	-	.016	.017	3.023	3.952	54.302		
55	Check pressure setup on process control coupon and verify cure cycle.	44	-	-	44	-	.012	.007	3.035	3.959	54.314		
56	Deflate pressure bag, remove pressure plate, pressure bag, support stand, and gap spacers.	125	125	125	-	-	.069	.067	3.104	4.026	54.349		
57	Remove weights and pressure plate from process control coupon.	20	20	-	-	-	.006	.004	3.110	4.030	54.355		
58	Inspect ablator panel for proper installation, mismatch and gap dimensions.	69	-	-	69	-	.019	.033	3.129	4.063	54.374	Flashlight Gap Gage	
58A	If mismatch exceeds design requirements, sand edges of ablator panel to eliminate excessive mismatch.	-	-	-	-	-	-	-	-	-	-		

Table A-1 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR (WITH STRAIN ISOLATOR)</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
58B	Inspect reworked areas for mismatch conditions and obvious damage.	-	-	-	-	-	-	-	-	-	-		
59	Inspect process control ablator panel for proper installation.	20	-	-	20	-	.006	.007	3.135	4.070	54.380		



Table A-2 (Continued)

MAINTENANCE TASK SCHEDULE													
		<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETER (21.70 X 55.66 INCHES)</u></li> </ul>											
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
5.	Rinse surface of ablator panel support with deionized water. Apply with saturated cheesecloth. Check for water break free surface.	92	92	-	92	-	.051	.067	.424	.312	.261	Cheesecloth Deionized Water Rubber Gloves	
5A	If a water break free surface is not obtained, repeat the cleaning procedure.	322	322	322	-	-	.179	-	.603	-	.351		
	Repeat Task No. 3	107	97	-	107	-	.057	-	.660	-	.381		
	Repeat Task No. 5												
6.	Rinse surface of aluminum process control coupon as specified per Task No. 5.	29	29	-	29	-	.016	.008	.676	.320	.389		
6A	If a water break free surface is not obtained, repeat the cleaning procedure.	-	-	-	-	-	-	-	-	-	-		
	Repeat Task No. 3												
	Repeat Task No. 5												
7.	Dry surface of panel support with cheesecloth.	56	56	-	-	-	.016	.033	.692	.353	.405	Cheesecloth	
8.	Dry surface of process control coupon with cheesecloth.	19	19	-	-	-	.005	.004	.697	.357	.410		
9.	Check Humidity	24	-	-	24	-	.007	-	.704	-	.417	Humidity Gage	
10.	Apply a thin film of silicone primer to the ablator panel support. Apply primer in a uniform coating over the entire surface to be bonded. Allow primer to cure for minimum of 3 1/2 to 4 hours at a relative humidity of 40 to 70 percent.	123	123	-	-	-	.033	.089	.737	.446	.450	Protective Goggles or Eyeshields Rubber Gloves GE SS4155 Primer Paint Brush	
		NOTE: Do not prime if relative humidity exceeds these limits. Keep primed surface free from contaminants.											

Table A-2 (Continued)

## MAINTENANCE TASK SCHEDULE

- TASK FUNCTION INSTALLATION (INITIAL)
- HEAT SHIELD TYPE ABLATOR
- ATTACH CONCEPT BONDED
- PANEL SIZE 55.1 X 141.4 CENTIMETER (21.70 X 55.66 INCHES)

TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)						
							ACTUAL	EST					
11.	Apply a thin film of silicone primer over the surface of process control coupon as specified per Task No. 10.	21	21	-	-	-	.006	.004	.743	.450	.456		
12.	Inspect primer application on panel support and verify cure cycle.	77	-	-	77	-	.021	.033	.764	.483	4.227	Flashlight	
13.	Inspect primer application on process control coupon and verify cure cycle.	28	-	-	28	-	.008	.007	.772	.490	4.235		
14.	Visually inspect ablator panel for obvious damage and cleanliness.	54	21	-	54	-	.021	.033	.793	.523	4.250	Ablator Panel 64T020016-1005	Man No. 1 & 3 Handled Panel Assembly Man No. 3 Performed Inspection
15.	Visually inspect process control ablator panel for obvious damage and cleanliness.	20	-	-	20	-	.006	.004	.799	.527	4.256		
16.	Trial fit ablator panel. Check mismatch and gap condition.	51	49	49	51	-	.041	.600	.840	1.127	4.270	Cotton Gloves	
17.	Clean surface of ablator panel by wiping with cheesecloth dampened with isopropyl alcohol. Allow to air dry for 1 hour (min).	111	111	-	-	-	.031	.033	.871	1.160	4.301	Isopropyl Alcohol Cheesecloth Rubber Gloves	
18.	Clean surface of process control ablator panel by wiping with cheesecloth dampened with isopropyl alcohol. Allow to air dry for 1 hour (min).	18	18	-	-	-	.005	.004	.876	1.164	4.306		
19.	Inspect ablator panel for cleanliness and verify drying time.	46	-	-	46	-	.013	.017	.889	1.181	5.319		

Table A-2 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETER (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL				EST
							ACTUAL	EST					
20.	Inspect process control ablator panel for cleanliness and verify drying time.	24	-	-	24	-	.007	.007	.896	1.188	5.326		
21.	Mix silicone adhesive in the following ratio: 100 grams of resin - RTV 560 and 0.3 grams (30 drops) of catalyst thermolite (T-12). Mix RTV 560 in its container by hand using a metal spatula. Mix well for 2 to 3 minutes. Weigh out required quantity of RTV-560 for bonding operation. Use clean, degreased (MEK) container. Measure the required amount of catalyst over the surface of the TRV-560 in accordance with the indicated ratio. Gently blend the catalyst into the RTV-560 by hand with metal spatula only. Continue mixing for minimum of 5 minutes. Scrape sides of container intermittently to assure no catalyst has migrated to walls of container.	928	-	915	928	-	.512	.500	1.408	1.688	-	RTV 560 Adhesive T-12 Catalyst Spatulas (Metal Only) Gram Scale (Balance) Rubber Gloves Mixing Container	
22.	Apply tape to edges of installed ablator panels.	82	-	-	82	-	.023	-	1.431	-	5.349	Masking Tape	
23.	Using a clean, degreased and dry stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to the primed panel support.	380	380	380	-	-	.211	.356	1.642	2.044	5.455	RTV 560 adhesive Paint Roller Stiff Paint Brush Rubber Gloves Protective Goggles or Eyeshields	
24.	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to surface of process control coupon.	81	70	81	-	-	.042	.009	1.684	2.053	5.478		

Table A-2 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETER (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL				EST
							ACTUAL	EST					
25.	Remove tape from edges of ablator panels.	66	-	-	66	-	.018	-	1.702	-	5.496		
26.	Inspect adhesive on surface of panel support for proper application.	48	-	-	48	-	.013	.033	1.715	2.086	5.509	Flashlight	
27.	Inspect adhesive on surface of process control coupon for proper application.	13	-	-	13	-	.004	.007	1.719	2.093	5.513		
28.	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to ablator panel.	378	378	378	-	-	.210	.356	1.929	2.449	5.618	1 Ablator Panel 64T020016-1005 Paint Roller Stiff Paint Brush Rubber Gloves RTV 560 Adhesive	
29.	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to process control ablator panel.	62	62	62	-	-	.034	.009	1.963	2.458	5.635		
30.	Inspect adhesive on ablator panel for proper application.	45	-	-	45	-	.013	.033	1.976	2.491	5.648		
31.	Inspect adhesive on process control ablator panel for proper application.	12	-	-	12	-	.003	.007	1.979	2.498	5.651		
32.	Install spacers for gap control.	119	119	-	-	-	.033	-	2.012	-	5.684	Spacers Masking Tape	
33.	Position and align the ablator panel on the panel support. Position support stand; air pressure bag and pressure plate. Slowly inflate pressure bag, until pressure plate evenly supports the ablator panel with approximately 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	206	185	206	206	82	.189	.133	2.201	2.631	5.741	Support Stand Air Pressure Bag Pressure Plate Air Pressure Source Cotton Gloves	Man No. 2 & 3 positioned panel Man No. 1 & 4 positioned pressure plate, air bags and support stand

Table A-3 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
6	Scrub the surface of the ablator panel support with nylon silicone carbide abrasive pads and deionized water. Alternately, scrub the surface with clean abrasive pads and wipe with clean water soaked cheesecloth until all oxide film and contamination are removed. Change abrasive pads frequently. Continue cleaning, using clean cloths, until the wiping cloths shows no removable oxide film.	579	579	454	-	-	.288	.200	.384	.858	.240	Protective Goggles or Eyeshields Rubber Gloves Bear-Tex Abrasive Pads Cheesecloth Deionized Water	
7	Scrub surface of aluminum process control coupon as specified per Task No. 6.	125	125	-	-	-	.035	.008	.419	.866	.275		
8	Rinse surface of ablator panel support with deionized water. Apply with saturated cheesecloth. Check for water break free surface.	112	112	-	112	-	.062	.067	.481	.933	.306	Cheesecloth Deionized Water Rubber Gloves	
8A	If a water break free surface is not obtained, repeat the cleaning procedure.	-	-	-	-	-	-	-	-	-	-		
	Repeat Task No. 6	378	378	378	-	-	.210	-	.691	-	.411		
	Repeat Task No. 8	106	94	-	106	-	.056	-	.747	-	.440		
9	Rinse surface of aluminum process control coupon as specified per Task No. 8.	17	17	-	17	-	.009	.008	.756	.941	.445		
10	Dry surface of ablator panel support with cheesecloth.	46	46	-	-	-	.013	.033	.769	.974	.458	Cheesecloth	
11	Dry surface of process control coupon with cheesecloth.	14	14	-	-	-	.004	.004	.773	.978	.462		
12	Check humidity gage.	29	-	-	29	-	.008	-	.781	-	.470		

Table A-3 (Continued)

MAINTENANCE TASK SCHEDULE													
• TASK FUNCTION <u>INSTALLATION (INITIAL)</u> • HEAT SHIELD TYPE <u>ABLATOR</u> • ATTACH CONCEPT <u>BONDED</u> • PANEL SIZE <u>55.1 X 70.5 CENTIMETER (21.70 X 27.74 INCHES)</u>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
13	Apply a thin film of silicone primer. Apply primer in a uniform coating over the entire surface to be bonded. Allow primer to cure for minimum of 3 1/2 to 4 hours at a relative humidity of 40 to 70 percent.	148	148	-	-	-	.041	.089	.822	1.067	.511	Protective Goggles or Eyeshields Rubber Gloves GE SS 4155 Primer Paint Brush	
NOTE: Do not prime if relative humidity exceeds these limits. Keep primed surface free from contaminants.													
14	Apply a thin film of silicone primer over the surface of process control coupon as specified per Task No. 13.	12	12	-	-	-	.003	.004	.825	1.071	.514		
15	Inspect primer application on panel support and verify cure cycle.	52	-	-	52	-	.014	.033	.839	1.104	4.278	Flashlight	
16	Inspect primer application on process control coupon and verify cure cycle.	22	-	-	22	-	.006	.007	.845	1.111	4.284		
17	Clean surface of (2) ablator panels by wiping with cheesecloth dampened with isopropyl alcohol. Allow to air dry for 1 hour (min.).	99	99	-	-	-	.028	.033	.873	1.144	4.312	Isopropyl Alcohol Cheesecloth Rubber Gloves 2 Ablator Panels 64T020016-1001	
18	Clean surface of process control ablator panel by wiping with cheesecloth dampened with isopropyl alcohol. Allow to air dry for 1 hour.	28	28	-	-	-	.008	.004	.881	1.148	4.320		
19	Inspect ablator panels for cleanliness and verify drying time.	53	-	-	53	-	.015	.017	.896	1.165	4.335		

Table A-3 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 70.5 CENTIMETER (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	PRODUCTIVE TIME (MAN-HR)						
							ACTUAL	EST					
20	Inspect process control ablator panel for cleanliness and verify drying time.	31	-	-	31	-	.009	.007	.905	1.172	4.344		
21	Mix silicone adhesive in the following ratio: 100 grams of resin - RTV 560 and 0.3 grams (30 drops) of catalyst thermolite (T-12). Mix RTV 560 in its container by hand using a metal spatula. Mix well for 2 to 3 minutes. Weigh out required quantity of RTV-560 for bonding operation. Use clean, degreased (MEK) container. Measure the required amount of catalyst over the surface of the RTV-560 in accordance with the indicated ratio. Gently blend the catalyst into the RTV-560 by hand with metal spatula only. Continue mixing for minimum of 5 minutes. Scrape sides of container intermittently to assure no catalyst has migrated to walls of container.	846	-	832	846	-	.466	.500	1.371	1.672	4.579	RTV 560 Adhesive T-12 Catalyst Spatulas (Metal Only) Gram Scale (Balance) Rubber Gloves Mixing Container	
22	Apply tape to edges of installed ablator panel.	108	-	-	108	-	.030	-	1.401	-	4.609	Masking Tape	
23	Using a clean, degreased and dry stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to the primed panel support.	416	416	416	-	-	.231	.356	1.632	2.028	4.725	RTV 560 adhesive Paint Roller Stiff Paint Brush Rubber Gloves Protective Goggles or Eyeshields	
24	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to surface of process control coupon.	59	45	59	-	-	.029	.009	1.661	2.037	4.741		

Table A-3 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 70.5 CENTIMETER (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
25	Remove tape from edges of ablator panels.	33	-	-	33	-	.009	-	1.670	-	4.750		
26	Inspect adhesive on surface of panel support for proper application.	40	-	-	40	-	.011	.033	1.680	2.070	4.761	Flashlight	
27	Inspect adhesive on surface of process control coupon for proper application.	17	-	-	17	-	.005	.007	1.685	2.077	4.766		
28	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to process control ablator panel.	330	330	330	-	-	.184	.356	1.869	2.433	4.858	RTV 560 Adhesive Paint Roller Stiff Paint Brush Rubber Gloves	
29	Using a stiff paint brush or metal spatula, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to ablator panels.	47	31	47	-	-	.022	.009	1.891	2.442	4.871		
30	Inspect adhesive on ablator panels for proper application.	35	-	-	35	-	.010	.033	1.901	2.475	4.881		
31	Inspect adhesive on process control ablator panel for proper application.	10	-	-	10	-	.003	.007	1.904	2.482	4.884		
32	Install spacers for gap control.	148	148	-	-	-	.041	-	1.945	-	4.925		
33	Position and align each ablator panel on the panel support. Install spacers to insure proper gap control. Position support stand; air pressure bag and pressure plate. Slowly inflate pressure bag, until pressure plate evenly supports the ablator panel with approximately 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	275	275	275	239	-	.219	.133	2.164	2.615	5.001	Support Stand Air Pressure Bag Pressure Plate Air Pressure Source Cotton Gloves	Man No. 1 & 3 positioned panels Man No. 2 positioned pressure plate Man No. 1 & 2 positioned support stand

Table A-3 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (INITIAL)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 70.5 CENTIMETER (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	PRODUCTIVE TIME (MAN-HR)		ACTUAL				EST
							ACTUAL	EST					
34	Bond ablator panel on process control coupon. Add pressure plate and weights to evenly apply 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	35	35	-	-	-	.010	.008	2.174	2.623	5.011	Pressure Plate Weights Cotton Gloves     Flashlight Gap Gage	
35	Check pressure support setup and verify cure cycle.	61	-	-	61	-	.017	.017	2.191	2.640	29.028		
36	Check pressure setup on process control coupon and verify cure cycle.	17	-	-	17	-	.005	.007	2.196	2.647	29.033		
37	Deflate pressure bag. Remove pressure plate, pressure bag, support stand and gap spacers.	246	246	246	-	-	.137	.067	2.333	2.714	29.101		
38	Remove weights and pressure plate from process control coupon.	15	15	-	-	-	.004	.004	2.337	2.718	29.105		
39	Inspect ablator panels for proper installation, mismatch and gap dimensions.	58	-	-	58	-	.024	.033	2.361	2.751	29.129		
39A	If mismatch exceeds design requirements, sand edges of ablator panel to eliminate excessive mismatch.	-	-	-	-	-	-	-	-	-	-		
39B	Inspect reworked areas for mismatch conditions and obvious damage.	-	-	-	-	-	-	-	-	-	-		
40	Inspect process control ablator panel for proper installation.	22	-	-	22	-	.006	.007	2.367	2.758	29.135		

Table A-4

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>CAULK GAPS (INITIAL INSTALLATION)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>.46 X 5.08 X .955 CENTIMETERS (.18 X 2.0 X .376 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL				EST
							ACTUAL	EST					
1	Install tape on ablator panels adjacent to gaps.	890	-	890	890	-	.494	-	.494	-	.247	Masking Tape Scissors Rubber Gloves	
2	Mix caulking compound in the prepackaged cartridges. Fill gaps between ablator panels with silicone caulking compound. Smooth bead and remove excess material. Remove masking tape.	3335	3239	3335	2398	-	2.492	1.000	2.986	1.000	1.173	RTV 88 Caulking Compound Semco Caulking Gun Air Pressure Source Air Pressure Regulator Putty Knife Cheesecloth	Man No. 1 used caulking gun Man No. 2 followed caulking nozzle with putty knife, smoothed out beads and removed tape Man No. 3 mixed compound in cartridges.
3	Verify cure cycle.	92	-	-	92	-	.026	0.030	3.012	1.030	25.199		
4	After cure, inspect caulking for voids and mismatch condition.	125	-	-	125	-	.035	0.100	3.047	1.130	25.234	Flashlight Feeler Gage	
4A	Repair voids as required.	-	-	-	-	-	-	-	-	-	-		
4B	Inspect repaired areas.	-	-	-	-	-	-	-	-	-	-		

Table A-5

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSPECTION</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u> <u>55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
1	Visually inspect the entire area of the installed panels for dents, abrasions, and pit-marks. Visually inspect the caulking around the periphery of each panel for obvious damage.	97	-	-	97	-	.027	.025	.027	.025	.027	Flashlight	

NOTE:  
Any damage of a magnitude affecting the integrity of the ablator panel and the aluminum support structure will warrant removal of ablator panel to permit further inspection and repair.







Table A-8 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (FINAL DISPLAY)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETER (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
5	Inspect panel support for nicks and scratches.	53	-	-	53	-	.015	.050	2.615	.717	1.344		
6	Visually inspect (2) ablator panels for obvious damage and cleanliness.	103	59	-	103	-	.045	.067	2.660	.784	1.373	2 Ablator Panels 64T020016-1005	Man No. 1 & 2 handled panels Man No. 3 performed inspection
7	Trial fit ablator panels. Check mismatch and gap condition.	97	97	97	93	-	.080	1.200	2.740	1.984	1.400	Cotton Gloves	
8	Check humidity	36	-	-	36	-	.010	-	2.750	-	1.410	Humidity Gage	
9	Apply a thin film of silicone primer to the ablator panel support. Apply primer in a uniform coating over the entire surface to be bonded. Allow primer to cure for minimum of 3 1/2 to 4 hours at a relative humidity of 40 to 70 percent.	243	243	-	-	-	.068	.178	2.818	2.162	1.478	Protective Goggles or Eyeshields Rubber Gloves GE SS4155 Primer Paint Brush	
NOTE:													
Do not prime if relative humidity exceeds these limits. Keep primed surface free from contaminants.													
10	Inspect primer application on panel support and verify cure cycle.	95	-	-	95	-	.026	.067	2.844	2.229	5.254	Flashlight	
11	Clean surface of ablator panels by wiping with cheesecloth dampened with isopropyl alcohol. Allow to air dry for 1 hour (min.).	146	146	-	-	-	.041	.067	2.885	2.296	-	Isopropyl Alcohol Cheesecloth Rubber Gloves	
12	Inspect ablator panels for cleanliness and verify drying time.	54	-	-	54	-	.015	.033	2.900	2.329	-		

Table A-8 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (FINAL DISPLAY)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETER (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
13	Mix silicone adhesive in the following ratio: 100 grams of resin - RTV 560 and 0.3 grams (30 drops) of catalyst thermolite (T-12). Mix RTV 560 in its container by hand using a metal spatula. Mix well for 2 to 3 minutes. Weigh out required quantity of RTV 560 for bonding operation. Use clean, degreased (MEK) container. Measure the required amount of catalyst over the surface of the RTV-560 in accordance with the indicated ratio. Gently blend the catalyst into the RTV-560 by hand with metal spatula only. Continue mixing for minimum of 5 minutes. Scrape sides of container intermittently to assure no catalyst has migrated to walls of container.	724	-	724	724	-	.402	.500	3.302	2.829	-	RTV 560 Adhesive T-12 Catalyst Spatulas (Metal Only) Gram Scale (Balance) Rubber Gloves Mixing Container	
14	Apply tape to edges of installed ablator panels.	95	95	-	-	-	.026	-	3.328	-	-	Masking Tape	
15	Using a clean, degreased and dry stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to the panel primed support.	440	440	440	-	-	.244	.356	3.572	3.185	5.376	RTV 560 Adhesive Paint Roller Stiff Paint Brush Rubber Gloves Protective Goggles or Eyeshields	
16	Remove tape from edges of ablator panels.	74	74	-	-	-	.021	-	3.593	-	5.397		
17	Inspect adhesive on surface of panel support for proper application.	39	-	-	39	-	.011	.034	3.604	3.219	5.408	Flashlight	

Table A-8 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (FINAL DISPLAY)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETER (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
18	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to ablator panel.	282	282	282	-	-	.157	.366	3.761	3.585	5.487	1 Ablator Panel 64T020016-1005 RTV 560 Adhesive Paint Roller Stiff Paint Brush Rubber Gloves	
19	Inspect adhesive on ablator panel for proper application.	29	-	-	29	-	.008	.034	3.769	3.619	5.495	Flashlight	
20	Position and align the ablator panel on the panel support. Position support stand; air pressure bag and pressure plate. Slowly inflate pressure bag, until pressure plate evenly supports the ablator panel with approximately 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	292	292	292	292	120	.277	.133	4.046	3.752	5.576	Support Stand Air Pressure Bag Pressure Plate Air Pressure Source Air Pressure Regulator	Man No. 2 & 3 positioned panel Man No. 1 installed spacers Man No. 1 & 4 positioned pressure plate, pressure bags and support stand
21	Check pressure support setup and verify cure cycle.	66	-	-	66	-	.018	.017	4.064	3.769	29.594		
22	Install second, large ablator panel.												
	Repeat Task No. 14	96	96	-	-	-	.027	-	4.091	-	-		
	Repeat Task No. 15	328	328	328	-	-	.182	.356	4.273	4.125	-		
	Repeat Task No. 16	59	59	-	-	-	.016	-	4.289	-	-		
	Repeat Task No. 17	35	-	-	35	-	.010	.034	4.299	4.159	-		
	Repeat Task No. 18	330	330	330	-	-	.183	.366	4.482	4.525	-		
	Repeat Task No. 19	28	-	-	28	-	.008	.034	4.490	4.559	-		
	Repeat Task No. 20	304	304	304	304	138	.292	.133	4.782	4.692	-		
	Repeat Task No. 21	61	-	-	61	-	.017	.017	4.799	4.709	29.940		
23	Deflate pressure bag. Remove pressure plate, pressure bag, support stand and gap spacers.	242	242	242	-	-	.134	.133	4.933	4.842	30.007		
24	Inspect ablator panels for proper installation, mismatch and gap dimensions.	82	-	-	82	-	.023	.067	4.956	4.909	30.030	Flashlight	

Table A-8 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (FINAL DISPLAY)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETER (21.70 X 55.66 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL				EST
							ACTUAL	EST					
24A	If mismatch exceeds design requirements, sand edges of ablator panels to eliminate excessive mismatch.	-	-	-	-	-	-	-	-	-	-		
24B	Inspect reworked areas for mismatch conditions and obvious damage.	-	-	-	-	-	-	-	-	-	-		



Table A-9 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (FINAL DISPLAY)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR (WITH STRAIN ISOLATOR)</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
4	Dry surface of ablator panel support with cheesecloth.	65	65	-	-	-	.018	.033	2.018	2.133	1.031	Cheesecloth	
5	Inspect panel support for nicks and scratches.	53	-	-	53	-	.015	.050	2.033	2.183	1.046	Flashlight	
6	Visually inspect strain isolator for obvious damage and cleanliness.	69	-	-	69	-	.019	.017	2.052	2.200	1.065		
7	Place strain isolator on surface of panel support and check for proper fit. Remove strain isolator and place in plastic bag.	79	79	79	73	-	.064	.050	2.116	2.250	1.087	1 Strain Isolator 64T020018-2001 Cotton Gloves	
8	Check humidity	31	-	-	31	-	.009	-	2.125	-	1.096	Humidity Gage	
9	Apply a thin film of silicone primer to the ablator panel support. Apply primer in a uniform coating over the entire surface to be bonded. Allow primer to cure for minimum of 3 1/2 to 4 hours at a relative humidity of 40 to 70 percent.	128	128	-	-	-	.036	.089	2.161	2.339	1.132	GE SS4155 Primer Protective Goggles or Eyeshields Rubber Gloves Paint Brush	
							NOTE: Do not prime if relative humidity exceeds these limits. Keep primed surface free from contaminants.						
10	Inspect primer application on panel support and verify cure cycle.	96	-	-	96	-	.027	.033	2.188	2.372	4.909	Flashlight	

Table A-9 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (FINAL DISPLAY)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR (WITH STRAIN ISOLATOR)</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
11	Mix silicone adhesive in the following ratio: 100 grams of resin - RTV 560 and 0.3 grams (30 drops) of catalyst thermolite (T-12). Mix RTV 560 in its container by hand, using a metal spatula. Mix well for 2 to 3 minutes. Weigh out required quantity of RTV-560 for bonding operation. Use clean degreased (MEK) container. Measure the required amount of catalyst over the surface of the RTV-560 in accordance with the indicated ratio. Gently blend the catalyst into the RTV-560 by hand with metal spatula only. Continue mixing for minimum of 5 minutes. Scrape sides of container intermittently to assure no catalyst has migrated to walls of container.	665	-	653	665	-	.366	.500	2.554	2.872	-	RTV 560 Adhesive T-12 Catalyst Spatulas (Metal Only) Gram Scale (Balance) Rubber Gloves Mixing Container	
12	Apply tape to edges of installed ablator panels.	98	-	-	98	-	.027	-	2.581	-	-	Masking Tape	
13	Using a clean, degreased and dry stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to the primed metal support panel.	408	408	408	-	-	.227	.356	2.808	3.228	5.022	RTV 560 Adhesive Paint Roller Stiff Paint Brush Rubber Gloves Protective Goggles or Eyeshields	
14	Remove tape from edges of ablator panels.	80	80	-	-	-	.022	-	2.830	-	5.044		
15	Inspect adhesive on panel support for proper application.	37	-	-	37	-	.010	.033	2.840	3.261	5.054	Flashlight	

Table A-9 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (FINAL DISPLAY)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR (WITH STRAIN ISOLATOR)</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)						
							ACTUAL	EST					
16	Place strain isolator on pressure plate and bond to support panel. Position pressure support stand and pressure bag beneath pressure plate. Slowly inflate pressure bag until the pressure plate evenly supports the strain isolator with approximately 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	144	144	144	137	67	.137	.133	2.977	3.394	5.094	1 Strain Isolator 64T020018-2001 Support Stand Air Pressure Bag (Inner Tube) Pressure Plate Air Pressure Source Air Pressure Regulator  2 Ablator Panels 64T020016-1003  Cotton Gloves  Isopropyl Alcohol Cheesecloth Rubber Gloves  Flashlight	Man No. 1 and 2 positioned isolator on pad, using same to position isolator on panel support. Man No. 3 and 4 positioned support stand and pressure bags.
17	Check pressure support setup and verify cure cycle.	68	-	-	68	-	.019	.017	2.996	3.411	29.113		
18	Deflate pressure bag. Remove pressure plate, pressure bags, and pressure support stand.	106	106	106	-	-	.059	.050	3.055	3.461	29.142		
19	Inspect strain isolator for proper installation.	39	-	-	39	-	.011	.033	3.066	3.494	29.153		
20	Visually inspect (2) ablator panels for obvious damage and cleanliness.	60	-	-	60	-	.017	.017	3.083	3.511	29.170		
21	Trial fit ablator panels. Check mismatch and gap condition.	93	81	-	93	-	.048	.600	3.131	4.111	29.196		
22	Clean surface of strain isolator bonded on panel support by wiping with cheesecloth dampened with isopropyl alcohol. Allow to air dry for 1 hour (min.)	108	108	-	-	-	.030	.033	3.161	4.144	29.226		
23	Inspect strain isolator bonded on panel support for cleanliness and verify drying time.	39	-	-	39	-	.011	.017	3.172	4.161	29.237		

Table A-9 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (FINAL DISPLAY)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR (WITH STRAIN ISOLATOR)</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
24	Clean surface of ablator panels by wiping with cheesecloth dampened with isopropyl alcohol. Allow to air dry for 1 hour (min.).	83	83	-	-	-	.023	.033	3.195	4.194	29.260	Isopropyl Alcohol Cheesecloth Rubber Gloves	
25	Inspect ablator panels for cleanliness and verify drying time.	48	-	-	48	-	.013	.017	3.208	4.211	30.273		
26	Mix silicone adhesive as specified per Task No. 11.	896	-	896	896	-	.498	.500	3.706	4.711	-	RTV 560 Adhesive T-12 Catalyst Spatulas (Metal Only) Gram Scale (Balance) Rubber Gloves	
27	Apply tape to edges of installed ablator panels.	159	159	-	-	-	.044	-	3.750	-	-	Masking Tape	
28	Using a clean, degreased and dry stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to strain isolator bonded to panel support.	408	408	408	-	-	.227	.356	3.977	5.067	30.386	RTV 560 Adhesive Paint Roller Stiff Paint Brush Rubber Gloves Protective Goggles or Eyeshields	
29	Remove tape from edges of ablator panels.	36	36	-	-	-	.010	-	3.987	-	30.396		
30	Inspect adhesive on strain isolator bonded to panel support for proper application.	34	-	-	34	-	.009	.033	3.996	5.100	30.405	Flashlight	
31	Using a stiff paint brush and paint roller, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to (2) ablator panels.	453	453	453	-	-	.252	.356	4.248	5.456	30.531	2 Ablator Panel 64T020016-1003 RTV 560 Adhesive Paint Roller Stiff Paint Brush Rubber Gloves	
32	Inspect adhesive on ablator panels for proper application.	37	-	-	37	-	.010	.033	4.158	5.489	30.541		

Table A-9 (Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>INSTALLATION (FINAL DISPLAY)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR (WITH STRAIN ISOLATION)</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
33	Position and align the ablator panel on the strain isolator. Install spacers to insure proper gap control. Position support stand, air pressure bag, and pressure plate. Slowly inflate pressure bag, until pressure plate evenly supports the ablator panel with approximately 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	453	453	453	453	-	.378	.133	4.636	5.622	30.667	Support Stand Air Pressure Bag Pressure Plate Cotton Gloves Air Pressure Source	
34	Check pressure support setup and verify cure cycle.	70	-	-	70	-	.019	.017	4.655	5.639	54.686		
35	Deflate pressure bag, remove pressure plate, pressure bag, support stand, and gap spacers.	188	188	188	-	-	.104	.067	4.759	5.706	54.738		
36	Inspect ablator panels for proper installation, mismatch and gap dimensions.	114	-	-	114	-	.032	.033	4.791	5.739	54.770	Flashlight Gap Gage	
36A	If mismatch exceeds design requirements, sand edges of ablator panel to eliminate excessive mismatch.	-	-	-	-	-	-	-	-	-	-		
36B	Inspect reworked areas for mismatch conditions and obvious damage.	-	-	-	-	-	-	-	-	-	-		

Table A-10

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>CAULK GAPS (FINAL DISPLAY)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>.46 X 5.08 X 955 CENTIMETERS (.18 X 2.0 X 376 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
1	Install tape on ablator panels adjacent to gaps.	638	638	638	-	-	.355	-	.355	-	.177	Masking Tape Scissors Rubber Gloves	
2	Mix caulking compound in the prepackaged cartridges. Fill gaps between ablator panels with silicone caulking compound. Smooth bead and remove excess material. Remove masking tape.	3530	3492	3530	2265	-	2.580	1.000	2.935	1.000	1.158	RTV 88 Caulking Compound Semco Caulking Gun Air Pressure Source Air Pressure Regulator Putty Knife Cheesecloth	Man No. 1 used caulking gun Man No. 2 followed caulking nozzle with putty knife, smoothed out beads and removed tape Man No. 3 mixed compound in cartridges
3	Verify cure cycle	54	-	-	54	-	.015	0.030	2.950	1.030	25.173		
4	After cure, inspect caulking for voids and mismatch condition.	83	-	-	83	-	.023	0.100	2.973	1.130	25.196	Flashlight Feeler Gage	
4A	Repair as required.	213	213	-	-	-	.059	-	3.032	-	25.255	X-Acto Knife Rubber Gloves	Cut off local protruding beads
4B	Inspect repaired areas.	38	-	-	38	-	.011	-	3.043	-	24.266		

MAINTENANCE TASK SCHEDULE

- \* TASK FUNCTION — STATIC TESTING (INSERTS)
- \* HEAT SHIELD TYPE — ABLATOR
- \* ATTACH CONCEPT — BONDED
- \* PANEL SIZE — 55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)
- \* 55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)

TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME										GENERAL COMMENTS		
		TASK DUR	MAN NO. 1	MAN NO. 2	MAN NO. 3	MAN NO. 4	2 PRODUCTIVE	EST	ACTUAL	EST	ACTUAL			
		(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(MAN-HR)	(HR)	(MAN-HR)	(HR)	(MAN-HR)			
		CUMULATIVE	CUMULATIVE	CUMULATIVE	CUMULATIVE	CUMULATIVE	PRODUCTIVE	TASK	+CURE TIME	PARTS REQUIRED	MATERIAL AND/OR			
1	Inspect tool setup for machine-ing core coupons.	28	-	-	-	28	-	.008	-	.008	-	.008	Core Cutter	Man No. 1 used vacuum
2	Locate .48 cm (.190 in) diameter holes in center of panels. Using these holes as center points, machine a 4.75 cm (1.87 in) diameter plug in each ablator panel.	166	166	166	149	-	.134	.233	.142	.233	.054	Core Cutter	Man No. 2 machined core coupon or Eyeshields Protective Goggles Vacuum	
3	Insert eyebolts in .48 cm (.190 in) diameter holes and imbedded inserts.	46	46	-	-	-	.013	.033	.155	.266	.067	4 AN42B17A Eyebolts	Man No. 3 verified depth of cut	
4	Using a spring scale, load each insert to a predetermined load. Record actual load applied, if bond failure occurred, or any damage to ablator or aluminum support panel.	72	72	-	72	-	.040	.067	.195	.333	.087	Spring Scale	Man No. 1 used vacuum	
5	Remove eyebolts.	29	29	-	-	-	.008	-	.203	-	.095		Man No. 2 machined core coupon or Eyeshields Protective Goggles Vacuum	

Table A-11

Table A-12

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>STATIC TESTING (FITTING)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR PROCESS CONTROL COUPON</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>15.24 X 15.24 CENTIMETERS (6 X 6 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN HR)		ACTUAL				EST
							ACTUAL	EST					
1	Clean surface of static test fittings by wiping with cheesecloth dampened with solvent. Allow to air dry for 5 minutes.	94	94	-	-	-	.026	.005	.026	.005	.026	3 Fittings 64T020019-2001 Methyl Ethyl Ketone (MEK) Cheesecloth Rubber Gloves	
2	Scrub surface of static test fittings with nylon silicone carbide abrasive pads and deionized water.	151	151	-	-	-	.042	-	.068	-	.068	Protective Goggles or Eyeshields Rubber Gloves Bear-Tex Abrasive Pads Cheesecloth Deionized Water	
3	Rinse cleaned surfaces with deionized water. Check for water break free surface.	74	66	-	74	-	.039	-	.107	-	.089	Cheesecloth Deionized Water Rubber Gloves	
4	Dry surfaces with cheesecloth.	48	48	-	-	-	.013	-	.120	-	.102	Cheesecloth	
5	Check humidity.	32	-	-	32	-	.009	-	.129	-	.111	Humidity Gage	
6	Apply a thin film of silicone primer to surface of static test fittings. Allow primer to cure for a minimum of 3 1/2 to 4 hours at a relative humidity of 40 to 70 per cent.	53	53	-	-	-	.015	-	.144	-	.126	GE SS 4155 Primer Rubber Gloves Paint Brush	
NOTE:													
Do not prime if relative humidity exceeds these limits. Keep primed surface free from contaminants.													
7	Inspect primer application and verify cure cycle.	43	-	-	43	-	.012	-	.156	-	3.888		
8	Clean ablator surface on process control coupons by wiping with cheesecloth dampened with isopropyl alcohol. Allow to air dry for 1 hour (min).	57	57	-	-	-	.016	.005	.172	.010	-	Isopropyl Alcohol Cheesecloth	
9	Inspect process control coupons for cleanliness and verify drying time.	53	-	-	53	-	.015	.006	.187	.016	-		

Table A-12(Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>STATIC TESTING (FITTING)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR PROCESS CONTROL COUPON</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>15.24 X 15.24 CENTIMETERS (6 X 6 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
10	Mix silicone adhesive in the following ratio: 100 grams of resin - RTV 560 and 0.3 grams (30 drops) of catalyst thermolite (T-12). Mix RTV 560 in its container by hand using a metal spatula. Mix well for 2 to 3 minutes. Weigh out required quantity of RTV-560 for bonding operation. Use clean, degreased container. Measure the required amount of catalyst over the surface of the RTV-560 in accordance with the indicated ratio. Gently blend the catalyst into the RTV-560 by hand with metal spatula only. Continue mixing for a minimum of 5 minutes. Scrape side of container intermittently to assure no catalyst has migrated to walls of container.	702	-	694	702	-	.387	.500	.574	.516	-	RTV 560 Adhesive T-12 Catalyst Metal Spatula Gram Scale (Balance) Rubber Gloves Mixing Container	
11	Using a clean, degreased, and dry stiff brush apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to process control coupons.	69	69	-	-	-	.019	.006	.593	.522	3.907	RTV 560 Adhesive Stiff Paint Brush Rubber Gloves	
12	Using a stiff brush, apply approximately 0.038 to 0.051 cm (0.015 to 0.020 in) of catalyzed RTV 560 to surface of static test fittings.	65	65	-	-	-	.018	.006	.611	.528	3.925	3 Static Test Fittings 64T020019-2001	
13	Inspect adhesive on process control coupons and static test fittings for proper application.	28	-	-	28	-	.008	.013	.619	.541	3.933		

Table A-12(Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>STATIC TESTING (FITTING)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR PROCESS CONTROL COUPON</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>15.24 X 15.24 CENTIMETERS (6 X 6 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL				EST
							ACTUAL	EST					
14	Position and align the static test fittings on the process control coupons. Add pressure block, pressure plate, and weights to apply 13.8 to 34.6 kN/m <sup>2</sup> (2 to 5 PSI) for 24 hours.	129	129	-	-	-	.036	.050	.655	.591	3.969	Styro Foam Pressure Blocks Pressure Plates Weights	
15	Check pressure setup and verify cure cycle.	58	-	-	58	-	.016	.017	.671	.608	27.985		
16	Remove weights, pressure plate, and pressure block from process control coupon.	54	54	-	-	-	.015	.013	.686	.621	28.000		
17	Inspect tool setup for machining plugs in the process control coupons.	35	-	-	35	-	.010	.017	.696	.638	28.010		
18	Machine a 4.75 cm (1.87 in) diameter plug in each process control coupon.	239	-	-	239	-	.133	.175	.829	.813	28.076	Core Cutter Cotton Gloves	Man No. 1 machined the plugs Man No. 3 verified depth of cut
NOTE: Exercise care not to touch or nick aluminum support panel with core cutter. Check for aluminum filings.													
19	After clamping process control coupons to work bench, apply a tension load to each static test fitting. Uniformly increase the load until failure. Record max load applied and describe type of failure and damage.	197	197	-	-	-	.055	.025	.884	.838	28.131	Spring Scale C Clamps	Two Coupons without strain isolator withstood 35.4 kg (80 lb) tension load One Coupon with strain isolator failed at 31.8 kg (70 lb)

Table A-13

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>STATIC TESTING (FITTING)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)</u> <u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)						
							ACTUAL	EST	ACTUAL				EST
1	Clean surface of static test fittings by wiping with cheese cloth dampened with solvent. Allow to air dry for 5 minutes.	116	116	-	-	-	.032	.007	.032	.007	.032	Methyl Ethyl Ketone (MEK) Cheesecloth Rubber Gloves 4 Fittings 64T020019-2001	
2	Scrub surface of static test fittings with nylon silicone carbide abrasive pads and deionized water.	133	133	-	-	-	.037	-	.069	-	.069	Protective Goggles or Eyeshields Rubber Gloves Bear-Tex Abrasive Pads Cheesecloth Deionized Water	
3	Rinse cleaned surface with deionized water. Check for water break free surface.	89	77	-	89	-	.046	-	.115	-	.094	Cheesecloth Deionized Water Rubber Gloves	
4	Dry surface with cheesecloth.	42	42	-	-	-	.012	-	.127	-	.106	Cheesecloth	
5	Check humidity	43	-	-	43	-	.012	-	.139	-	.118	Humidity Gage	
6	Apply a thin film of silicone primer to surface of static test fittings. Allow primer to cure for a minimum of 3 1/2 to 4 hours at a relative humidity of 40 to 70 per cent.	55	55	-	-	-	.015	-	.154	-	.133	GE SS 4155 Primer Rubber Gloves Paint Brush	
NOTE:													
Do not prime if relative humidity exceeds these limits. Keep primed surface free from contaminants.													
7	Inspect primer application and verify cure cycle.	42	-	-	42	-	.012	-	.166	-	3.895		
8	Select and mark areas on installed ablator panels were static test fittings are to be located.	37	37	-	-	-	.010	-	.176	-	-		
9	Inspect tool setup for machining plugs in the ablator panels.	25	-	-	25	-	.007	-	.183	-	-		

Table A-13(Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>STATIC TESTING (FITTING)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)</u> <u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
10	Machine 4.75 cm (1.87 in) diameter plug in each ablator panel.	205	205	205	205	-	.171	.233	.354	.240	-	Core Cutter Vacuum Protective Goggles or Eyeshields  Respirators Cotton Gloves	Man No. 1 machined the plugs Man No. 2 used vacuum Man No. 3 verified depth of cut
							NOTE: Exercise care not to touch or nick aluminum support panel with core cutter.						
11	Clean ablator surface of plugs by wiping with cheese-cloth dampened with isopropyl alcohol. Allow to air dry for 1 hour (min).	63	63	-	-	-	.018	.007	.372	.247	-	Isopropyl alcohol Cheesecloth	
12	Inspect plugs for cleanliness and verify drying time.	59	-	-	59	-	.016	.006	.388	.253	-		
13	Mix silicone adhesive in the following ratio:  100 grams of resin - RTV-560 and 0.3 grams (30 drops) of catalyst thermolite (T-12). Mix RTV-560 in its container by hand, using a metal spatula. Mix well for 2 to 3 minutes. Weigh out required quantity of RTV-560 for bonding operation. Use clean, degreased container. Measure the required amount of catalyst over the surface of the RTV-560 in accordance with the indicated ratio. Gently blend the catalyst into the RTV-560 by hand with metal spatula only. Continue mixing for minimum of 5 minutes. Scrape side of container intermittently to	664	-	644	664	-	.363	.500	.751	.753	-	RTV-560 Adhesive T-12 Catalyst Metal Spatula Gram Scale (Balance) Rubber Gloves Mixing Container	

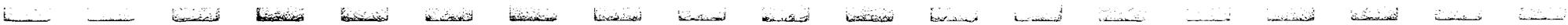
Table A-13(Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>STATIC TESTING (FITTING)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)</u> <u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME							CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)		ACTUAL	EST			
							ACTUAL	EST					
13 Cont.	assure no catalyst has migrated to walls of container.												
14	Using a clean, degreased, and dry stiff brush, apply approximately 0.051 to 0.076 cm (0.020 to 0.030 in) of catalyzed RTV 560 to the plugs. Insert coil of release cloth in cored holes.	273	273	-	-	-	.076	.008	.827	.761	3.971	RTV-560 Adhesive Paint Brush Rubber Gloves Release Cloth	
15	Using a stiff brush, apply approximately 0.051 to 0.076 cm (0.020 to 0.030 in) of Catalyzed RTV 560 to surface of 4 static test fittings.	135	135	-	-	-	.038	.008	.865	.769	4.009	4 Static Test Fittings 64T020019-2001	
16	Inspect adhesive on plugs and static test fittings for proper application.	48	-	-	48	-	.013	.017	.878	.786	4.022		
17	Position the support stand. Position and align the static test fittings (4) and the pressure plates under the plugs.	103	103	103	-	-	.057	.400	.935	1.186	4.051	Support Stand Pressure Plates	
18	Check pressure support set up and verify cure cycle.	59	-	-	59	-	.016	.050	.951	1.236	28.067		
19	Remove pressure plates, support stands and release cloth.	242	242	225	-	-	.130	.150	1.081	1.386	28.134		
20	Using a spring scale, load each fitting to a predetermined load. Record the actual load applied. If bond failure occurred, or any damage to ablator or aluminum support panel.	85	73	-	85	-	.044	.033	1.125	1.419	28.159	Spring Scale	No failures occurred while applying a load of 24.9 kg (55 lb) to each fitting
21	Using a sharp bladed knife, remove static test fittings from surface of the ablator panels by cutting into the adhesive between the fitting and the panels.	117	117	-	-	-	.033	.067	1.158	1.486	28.191	Sharp Bladed Putty Knife	Removed 3 fittings only



Table A-13(Continued)

MAINTENANCE TASK SCHEDULE													
<ul style="list-style-type: none"> <li>• TASK FUNCTION <u>STATIC TESTING (FITTING)</u></li> <li>• HEAT SHIELD TYPE <u>ABLATOR</u></li> <li>• ATTACH CONCEPT <u>BONDED</u></li> <li>• PANEL SIZE <u>55.1 X 141.4 CENTIMETERS (21.70 X 55.66 INCHES)</u></li> <li style="padding-left: 20px;"><u>55.1 X 70.5 CENTIMETERS (21.70 X 27.74 INCHES)</u></li> </ul>													
TASK NO.	TASK DESCRIPTION	INDIVIDUAL TASK TIME						CUMULATIVE PRODUCTIVE TIME (MAN-HR)		CUMULATIVE TASK DURATION + CURE TIME (HR)	TOOLS, EQUIPMENT, MATERIAL AND/OR PARTS REQUIRED	GENERAL COMMENTS	
		TASK DUR (SEC)	MAN NO. 1 (SEC)	MAN NO. 2 (SEC)	MAN NO. 3 (SEC)	MAN NO. 4 (SEC)	Σ PRODUCTIVE TIME (MAN-HR)						
							ACTUAL	EST					
28	Prime repair area with 2 to 5 MILS of mixed Sylgard 184. Sylgard 184 can be used for priming to 1 hour after mixing.	73	73	-	-	-	.020	.033	1.527	1.858	29.301	Mixed Sylgard 184 Paint Brush	
29	Inspect primer area and record time.	41	-	-	41	-	.011	.017	1.538	1.875	29.312		
30	Within 10 minutes after priming, trowel and compact ablator repair material into the repair holes. Ablator repair material can be used up to 2 hours after mixing.	148	148	-	-	-	.041	.167	1.579	2.042	29.353	Putty Knife	
31	Inspect repair and verify cure cycle.	55	-	-	55	-	.015	.017	1.594	2.059	37.368		
32	After repair material has cured remove excess material by sanding with abrasive cloth. Vacuum loose ablator particles.	42	42	42	-	-	.023	.167	1.617	2.226	37.381	Protective Goggles or Eyeshields Respirators Vacuum Cotton Gloves Abrasive Cloth	Man No. 1 sanded the repaired areas Man No. 2 used vacuum
33	Inspect repair areas for smoothness.	29	-	-	29	-	.008	.033	1.625	2.234	37.389		



## APPENDIX B

### TOOLS, EQUIPMENT, AND MATERIALS

The tools, equipment and materials used to fabricate the direct bond attach ablator panel assemblies are listed in tables B-1 and B-2, respectively.

TABLE B-1

#### TOOLS AND EQUIPMENT

- |  |   |
|--|---|
| <ul style="list-style-type: none"> <li>o AIR CIRCULATING OVENS</li> <li>o THERMOCOUPLES</li> <li>o THERMOMETERS</li> <li>o TEMPERATURE RECORDER</li> <li>o MANOMETERS (HG)</li> <li>o VACUUM PUMPS</li> <li>o VACUUM PLATES</li> <li>o ALUMINUM MOLDS (EDGE MEMBERS)</li> <li>o ALUMINIZED MYLAR TAPE</li> <li>o BAND SAW</li> <li>o PNEUMATIC DRILLS</li> <li>o DRILL AND EDGE TEMPLATES</li> </ul> | <ul style="list-style-type: none"> <li>o HEAT LAMPS</li> <li>o VACUUM LEAK DETECTOR</li> <li>o PRIMING PLAN (WITH DRAIN VALVE)</li> <li>o HOBART MIXER, MODEL V-1401</li> <li>o TROWELS (WOOD OR METAL)</li> <li>o TAMPER (METAL)</li> <li>o METAL TUBE ROLLERS</li> <li>o PUTTY KNIVES</li> <li>o BRISTLE BRUSHES</li> <li>o VISE GRIPS (LOCK-TYPE PLIERS)</li> <li>o GRAM BALANCE</li> <li>o POUND BALANCE</li> </ul> |
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TABLE B-2

#### MATERIALS

TYPE	SOURCE
o STRUCTURAL HONEYCOMB CORE, HEXAGON CELL, HRP-3/8-GF11-2.2,	HEXCEL PROD. INC.
o MYLAR FILM, TYPE A	E.I. DUPONT DE NEMOURS
o MOLD RELEASE, FLUOROCARBON DISPERSION, CAMIE 1000	CAMIE CORP.
o BLEEDER/RELEASE CLOTH, PINK SILICONE FINISH 1B-301-F54	COAST MFG. CO. HEXCEL CORP.
o BLEEDER(BREATHER) CLOTH, GLASS, STYLE 162	VOLAN FINISH; UNIGLASS IND.
o EXTRUDED SEALING TAPE, PRESTITE NO. 582 OR 587.3	INTERCHEMICAL CORP.
o PHENOLIC MICROBALLOONS GRADE BJO-0930	UNION CARBIDE CORP.
o SILICONE RESIN (WITH CURING AGENT) SYLGARD 182 AND 184	DON CORNING CORP.
o PHENOLIC RESIN PRIMER (RESINOX SC 1008)	MONSANTO CORP.
o EPON 828 POTTING COMPOUND	SHELL CORP.
o METHYL-ETHYL-KETONE (MEK)	FEDERAL SPECIFICATION TT-M-261
o ISOPROPYL ALCOHOL	COMMERCIAL GRADE
o POLYETHYLENE BAGS	OPEN STOCK

