DEVELOPMENT OF DESIGN AND PRODUCTION PROCESSES FOR BLOCK-ABLATOR HEATSHIELDS WITH PRELIMINARY TEST RESULTS

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ABSTRACT

The block-ablator (B-A) concept is based on the milling of high-tolerance ablator blocks and the subsequent adhesive installation of these blocks into precision honeycomb (H/C) already pre-bonded to an aeroshell structure. Intended for use on atmospheric entry, descent, and landing (EDL) vehicles, the concept originated at NASA's Ames Research Center in 2006-07. The ARA Ablatives Laboratory (ABL) was tasked by NASA to mature the concept by developing a producible B-A design and by investigating and developing production processes for a B-A heatshield system. The ABL performed this preliminary one-year study during 2008-09. This paper summarizes the ABL's selected B-A design that is based on trapezoidal-shaped blocks and H/C cells made of silica-phenolic composite. Although not comprehensive, the paper discusses production processes, and primary lessons learned from the fabrication of multiple test units and manufacturing demonstration units (MDUs).

1. INTRODUCTION

The concept of a B-A heatshield was originated at NASA's Ames Research Center in 2006-07 by Peter Zell (Ref.1,2) and the thermal protection engineering staff. During that time, the ARC TPS staff was doing characterization testing and developing heatshield designs made from PICA ablator for the Crew Exploration Vehicle (Orion) and other NASA systems. PICA is a "ceramic" that is produced and applied monolithically for a small EDL vehicle or in large tiles, or "modules," for a larger vehicle. While PICA is reinforced internally with carbon fibers, PICA heatshield designs at that time did not have a secondary reinforcement system such as H/C. The concept of a B-A heatshield was to produce and bond precision H/C to structure and then insert and bond high-tolerance thermal protection blocks into the cells of that H/C. The idea was generated as a means of: 1) reinforcing and strengthening lightweight and perhaps somewhat brittle ablator and ceramic TPS materials; and 2) anchoring the heatshield via H/C bonding and enabling an initial pull-test of bonded, unfilled H/C to validate bond strength. The block-ablator concept was inclusive of a wide range of ablator materials, not just PICA and other lightweight systems. Molded, polymer based ablators in a cured form – such as the phenolic carbon ablator P-28 – might also be milled into precision blocks and bonded into block-ablator H/C. The B-A heatshield requires a faceted aeroshell structure. Shown in Fig. 1, this is a structure with flat faces to which flat H/C can be bonded. However, B-A can accommodate simple curvature at the cone edge as shown.

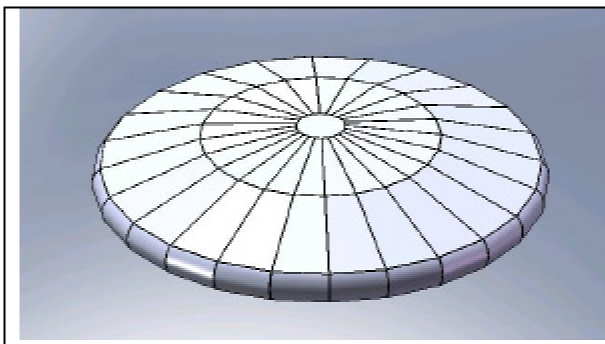
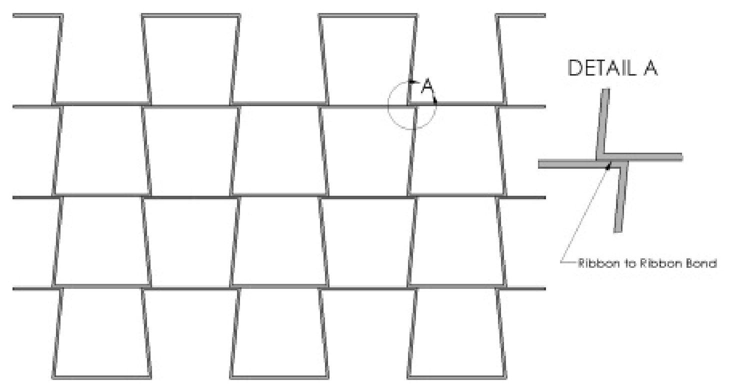


Fig. 1 – Large Faceted Aeroshell Structure (5.0m)

The Ablatives Laboratory (ABL) was tasked to contribute to the B-A effort in the following primary ways: 1) develop a producible design for a block-ablator heatshield system including honeycomb and block configuration and their basic dimensions; 2) select materials and develop a reliable method for producing block-ablator H/C; 3) develop processes and steps for milling blocks from slabs of ablator material; 4) select adhesives and investigate bonding processes for bonding H/C and TPS blocks; 5) produce eight large flexure test samples (i.e., 16.0-in long block-ablator on 30.0-in. long aluminum plates) made from PICA and P-28 ablators for bend testing at NASA/LaRC; 6) produce manufacturing demonstration units (one flat and one curved) of the B-A system using NASA-supplied substrates and PICA ablator billets; and 7) build PICA and P-28 thermal test samples and conduct arc-jet testing (stagnation and aeroshear series) to evaluate block-ablator system performance.



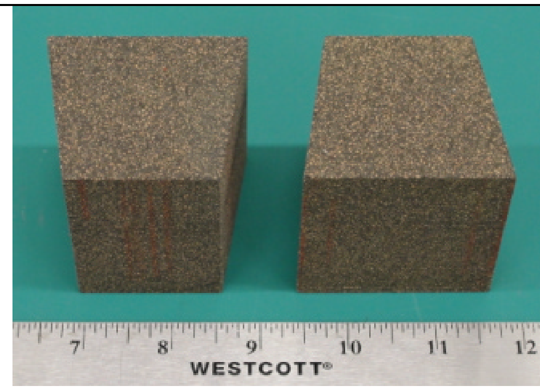


Fig. 2 – Trapezoidal H/C Design for B-A System and Trapezoidal P-28 Ablator Blocks

2.0 SELECTED B-A DESIGN

After study of the NASA/ARC concept, our engineering design for a B-A system had several differences relative to the ideas presented to us. The first was the ABL selection of a trapezoidal ablator block, or TAB, as a better configuration instead of a square or rectangular ablator block. We concluded early on that H/C for a square block is significantly more difficult to produce – and is less robust in lightweight form – than H/C for a trapezoidal block. We determined that we could produce and assemble TAB honeycomb using processes that were already common and proven within the ABL. The trapezoidal processes are comparable to our standard processes for "flexcore" H/C production. This design allows us to produce long, trapezoidal-shaped ribbons that are then easily assembled and bonded to produce H/C panels. Each H/C cell has an average cross dimension of about 2.0 in. (5.1 cm). Each H/C cell is bonded in four places to adjacent H/C cells as shown in the left portion of Fig. 2. We selected ~0.25 in. (0.64 cm) of ribbon overlap at the corners to provide necessary H/C strength. A pair of milled blocks of the P-28 ablator is shown in the right of Fig. 2.

The second ABL difference was that we selected a H/C design with a ribbon thickness of ~0.018-in. (0.46 mm) instead of 0.030-in. originally conceived by NASA/ARC. The reasoning was that a too-robust H/C would increase weight and could lead to differential surface recession during entry, resulting in interference heating. We made TAB H/C from the same basic materials already in use for other H/C. Our standard H/Cs are made from woven broadgoods of fused silica (i.e., high-purity fused quartz). Our selected silica fabric for TAB H/C was 0.012 in. (0.30 mm) thick (un-coated) using a proprietary "formable" weave. The fabric has an area weight of 8.45 oz/yd^2 (0.0287 g/cm^2). When this fabric is phenolic impregnated and B-staged, it has an "expanded" thickness of ~0.018 in.

H/C is produced from long flat ribbons that are slitted from sheets of silica-phenolic prepreg. We designed and produced precision plastic blocks for imparting the trapezoidal shape into the flat silica-phenolic ribbons. The prepreg ribbons (typically either 2.0-in. or 2.75-in. wide) are wrapped around a matched set of these blocks and then oven heated and cured to achieve a permanent thermoplastic set of the precise trapezoidal shape and size.

We designed the trapezoidal ablator blocks and their B-A honeycomb to have a relatively snug fit. The derived requirement was a 0.010-in. (0.25 mm) gap between the block and its adjacent ribbon on all lateral sides, just enough room for bonding adhesive and getting the block inserted into the H/C cells. This snug fit was verified early in the program via a number of fit checks. Standard production runs of B-A honeycomb produce panels with 12 cells on a side for a total of 144 TAB cells each. These panels are produced in two heights of either 2.0 in. (5.1 cm) for most flat test articles and a flat MDU, and 2.75-in. (7.0 cm) for the curved MDU and for two of eight flexure test samples. A photo of production H/C panels is shown in Fig. 3. An array of CNC-milled trapezoidal blocks of the P-28 ablator is shown in Fig 4. Nine molded panels of P-28 yielded 432 blocks for production of test and evaluation samples. (In total, about 600 blocks of PICA ablator were also produced.)

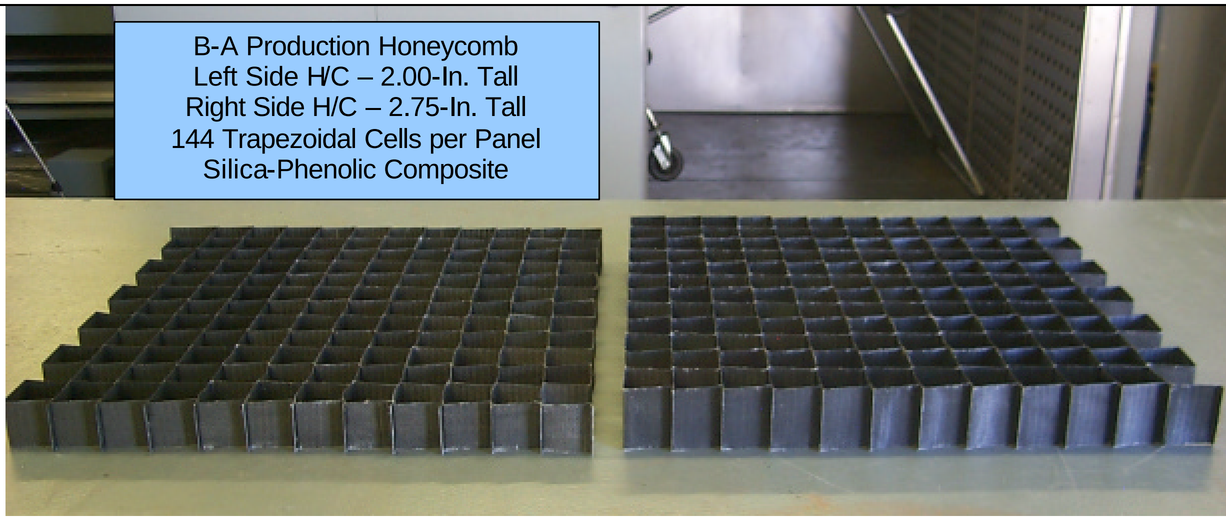


Fig. 3 – Two Production Panels of Unfilled Block-Ablator H/C with 144 Cells Each

Fig. 4 – P-28 Ablator Blocks (384) Milled from Eight of Nine Molded Panels

3.0 B-A PRODUCTION PROCESSES

The following discussion and graphics give insight into the design and manufacturing plan we developed for how a faceted aeroshell structure could be covered with TAB honeycomb and ablator blocks. We primarily stayed with the idea of first bonding down H/C and then bonding ablator blocks into the H/C cells. (However, we also spent design effort on the alternate approach of first bonding ablator blocks in H/C cells and then bonding a complete, final-milled block-ablator module into place on the aeroshell structure.) Fig. 5 shows our TAB H/C design for an inner gore of a sphere-cone aeroshell as an example of our manufacturing plan. An outer gore would be the same except larger in size. An assembled panel of H/C for this aeroshell location is shown in the upper-left quadrant (Part "A") of the figure. In its untrimmed state, this H/C has 104 "whole" trapezoidal cells. This is the starting configuration before trimming of the edge cells to achieve the actual gore shape. The upper right quadrant (Part "B") shows the trimmed configuration in a state that would be ready for bonding to the aeroshell structure. After bonding, this H/C would then be filled with trapezoidal ablator blocks. The lower

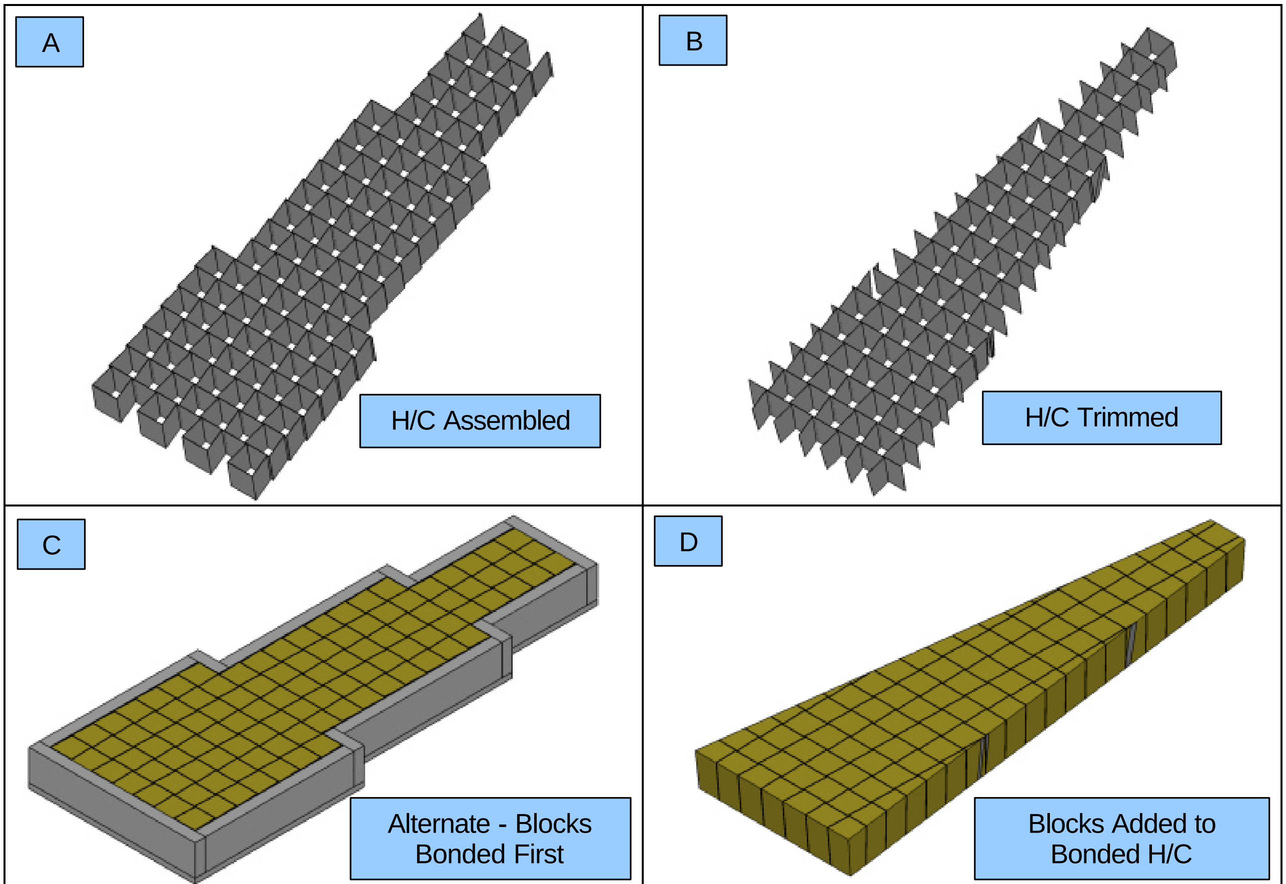


Fig. 5 – TAB H/C Appearance for the Inner Gore with and w/o Ablator Blocks

right quadrant (Part "D") shows the final gore configuration with all the blocks bonded in place with the perimeter blocks having been trimmed already prior to their insertion and bonding. The lower-left quadrant of the figure (Part "C") depicts the alternate approach where the H/C cells (all whole cells) might be filled with ablator blocks prior to H/C bonding. This could be done in a mold, as shown, to facilitate the block-bonding process. After the block adhesive was cured, then this gore configuration would be removed from the mold, precision milled, and then bonded into place as a complete module (with the same appearance as Part "D") on the aeroshell structure.

Additional insight into the B-A process can be gained through a discussion of our production of samples for NASA flexure testing (Ref.3). Six main samples were produced in this series consisting of three PICA samples and three P-28 samples. The overall procedure was to first bond the H/C in place with whole cells, then insert and bond the ablator blocks, and then do a final milling step to achieve required dimensions. This procedure followed the "print bonding" technique. A thin, controlled layer of epoxy-phenolic (E-P) paste adhesive is spread out on a flat plate and the H/C is dipped into this thin layer so that one end of the H/C ribbons picks up an adhesive "fillet." The H/C is applied ("printed") to the test article substrate and then the H/C bonding adhesive is cured at elevated temperature with applied pressure. It's very important to use shape-retainer blocks during curing so that the H/C cells do not become distorted. Our shape retainer blocks were milled from a lightweight plastic foam.

We selected room-temperature-curing RTV-560 silicone adhesive for bonding ablator blocks into honeycomb cells. The adhesive was applied to the cell ribbons and to the cell floor. The adhesive was also applied to five faces of each ablator block. To facilitate ablator block insertion and bonding into H/C cells, each block first received a small bevel on the edges of its base. The bevel does three things: 1) the block enters the cell more readily; 2) the block is less likely to scrape away resin already applied to the cell walls and

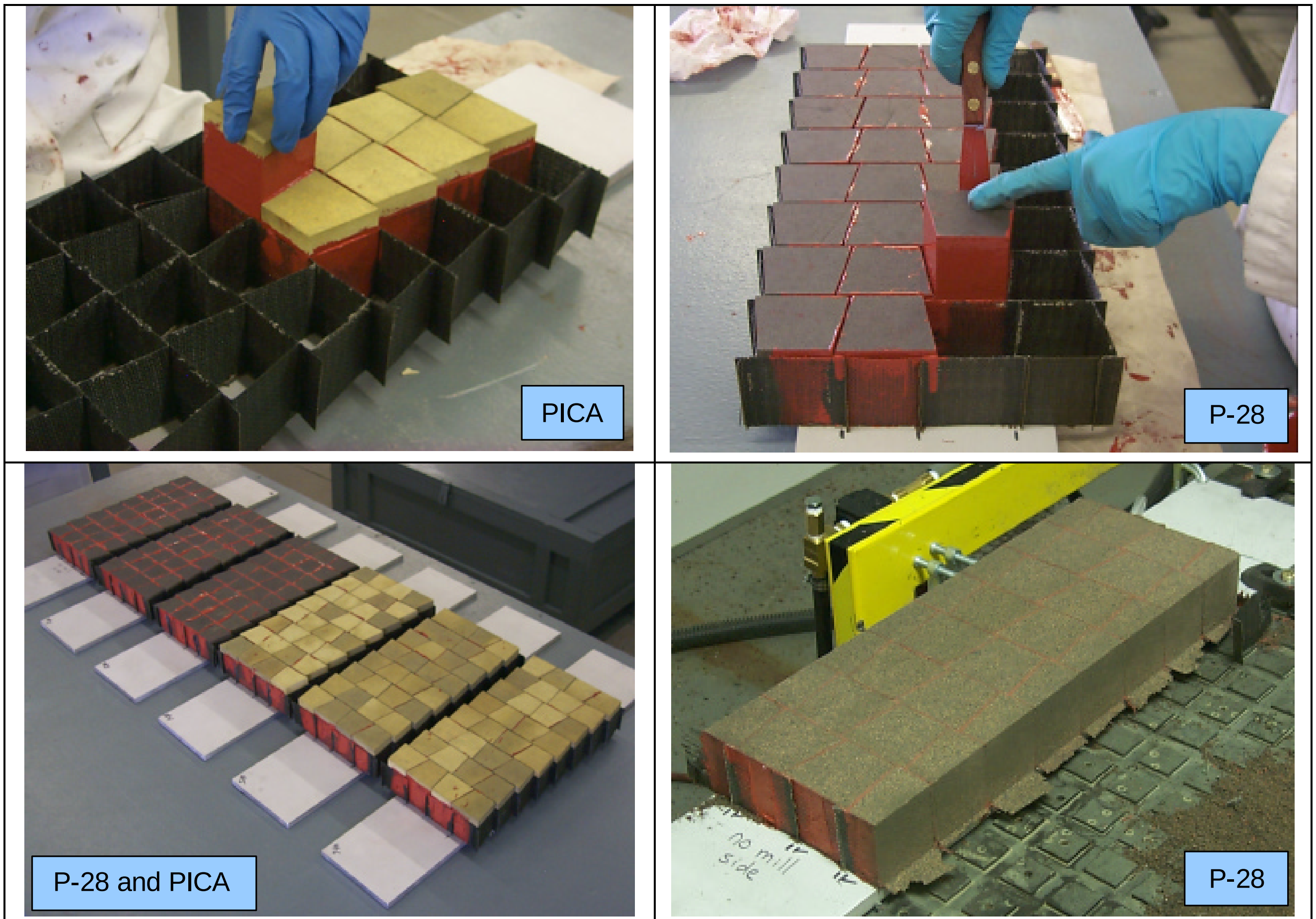


Fig. 6 – Production of PICA and P-28 Flexure Samples Showing Block Bonding and Final Milling

push this resin to the bottom of the cell; and 3) the block accommodates the cured fillet of the E-P paste adhesive at the base of the H/C cell.

Contained in the top row of Figure 6 are photos of the bonding of PICA and P-28 blocks into honeycomb for flexure samples. With a four-by-eight array of blocks, the fully bonded TPS parts on the flexure samples were oversized and had dimensions of about 16.2 x 8.2 x 2.2 in. (41.1 x 20.8 x 5.6 cm). They required final milling to meet the test size requirement of 16.0 x 6.0 x 2.0 in. (40.6 x 15.2 x 5.1 cm). In the bottom left of Fig.6 are shown the six fully assembled PICA and P-28 flexure samples ready for milling. The photo in the bottom right is a fully-milled P-28 sample that is ready for clean-up and final detailing. (Note that these samples were prepared with all *whole cells* and then milled along the sides to create partial cells.)

4.0 FABRICATION OF FLAT MDU

In support of NASA/ARC, we had the requirement to produce two manufacturing demonstration units (MDUs) of the block-ablator system. One, discussed here, was a 24.0 x 24.0-in. (61.0 x 61.0 cm) flat B-A panel on an aeroshell-type, titanium substrate. (The other, discussed below, was a curved panel on a rolled-aluminum substrate.) Shown in Fig. 7, the substrate provided by NASA/ARC for the flat MDU was a 30.0 x 30.0-in. (76.2 x 76.2 cm) titanium honeycomb panel. We were directed to use this panel basically *as is* and not reduce its size to 24.0 x 24.0 in. to match the size of the block-ablator unit. The surface of the titanium panel was abraded to facilitate bonding of the block-ablator honeycomb and ablator blocks.

Using the same processing that was used above for the flexure samples, H/C was bonded to the titanium panel by the print method. A layer of E-P paste adhesive was applied to a flat aluminum plate and the 12-cell by 12-cell H/C panel was dipped into this layer to pick up adhesive at the base of its H/C ribbons. Then the H/C was applied to the prepared titanium surface for bonding. Retainer blocks were inserted into the H/C cells so that the cells would not lose their precise trapezoidal shape during adhesive cure in the oven. The top row of Fig. 7 shows photos of the early steps of bonding PICA ablator blocks into the H/C cells. In the bottom left of the figure, the panel has blocks bonded into eleven of the twelve rows of cells. The photo in the bottom right shows the panel on the CNC milling machine ready to be milled down to final MDU thickness.

5.0 B-A DESIGN WITH CURVATURE

The curved shoulder region of a faceted sphere-cone aeroshell structure (e.g., Orion) is more challenging for applying the B-A honeycomb system. We studied a number of different designs and production concepts for this location. We ended up with a design actually very similar in appearance to the gore regions, although its production process is significantly different. Our selected design uses the same TAB H/C components for the aeroshell's shoulder region as for the gores. The challenge lies in making the flat H/C panels conform to the simple curvature of the shoulder's surface. This is done by H/C milling. (Several H/C panels in different planes are joined together and then milled for curvature.) Due to the milling requirement, it is more difficult to bond H/C to structure first before block bonding at the shoulder. To get the needed curvature, it is easier to bond the blocks in place first, and then mill the bonded assembly. This is because blocks rigidize the H/C ribbons and thereby facilitate their milling. So, if we chose to bond unfilled H/C to the curved shoulder, then *temporary milling blocks* would need to be installed first to allow H/C milling to final shape and dimensions. Then the unfilled, curved H/C could be bonded to structure. (Note that our manufacturing demonstration unit for a shoulder panel, discussed later, was based not on bonding H/C first but, instead, on bonding a completed, fully-milled block-ablator unit to the shoulder structure.)

Assuming a relatively large shoulder radius of curvature – and assuming a process where unfilled H/C is bonded to structure first – our design for an aeroshell-shoulder block-ablator system is shown in Fig. 8. While the standard trapezoidal ablator block remains the same, there are several differences for the shoulder H/C compared to the inner and outer gore regions that were discussed above: 1) the narrow part of the trapezoidal H/C cell points to the left and the right for the shoulder region instead of inboard and outboard as do cells of the gore regions; 2) the

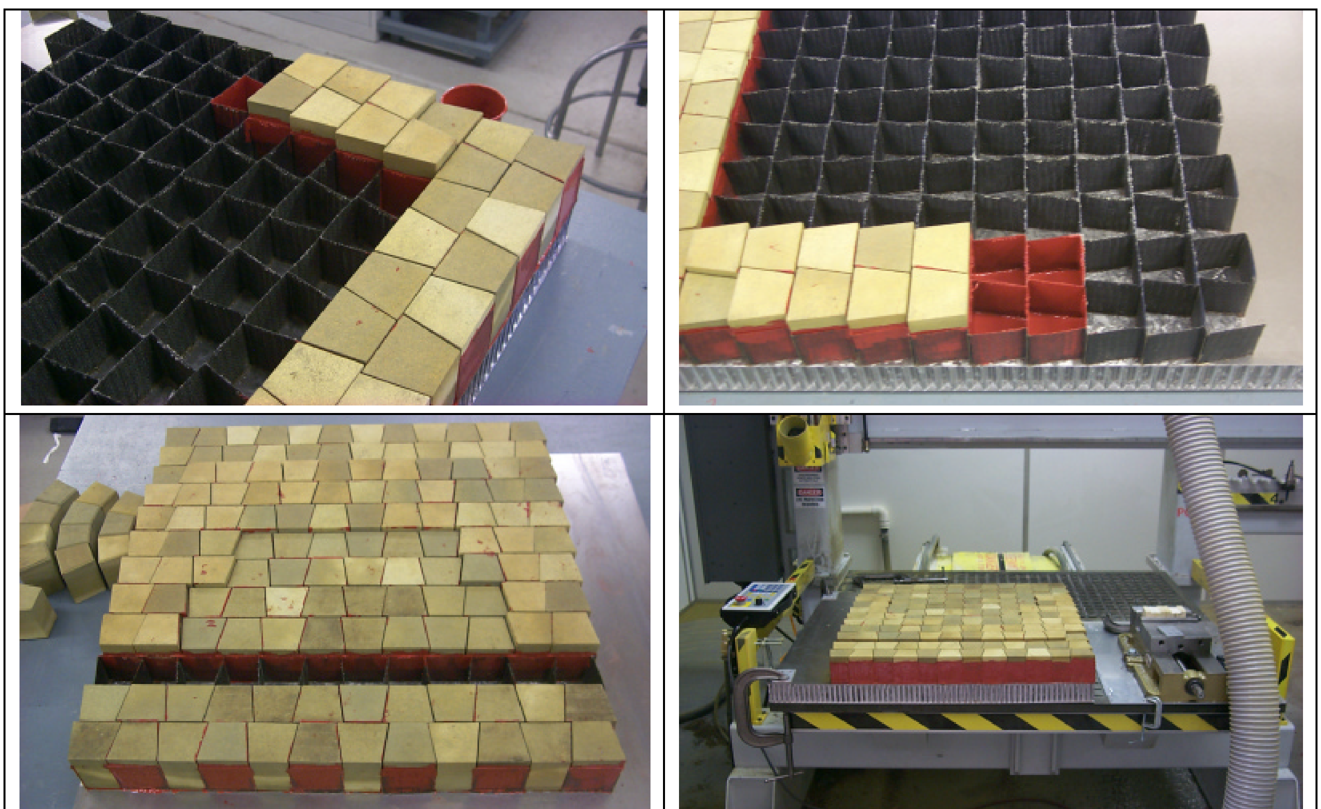


Fig. 7 – Production of the Flat Manufacturing Demonstration Panel Using PICA Blocks

shoulder region H/C shown has two in-board rows with a uniquely shaped cell to accept what we have labeled as a "Joint Ablator Block," or JAB; and 3) the shoulder region H/C at the interface with the outer gore has one row (the top row) with trapezoidal cells that are wider (to accept an "Interface Ablator Block," or IAB) compared to the standard TAB honeycomb cell. The graphics of Fig. 8 make these details easier to grasp as they specifically point out the shoulder locations of TAB, JAB, and IAB cells.

Our shoulder honeycomb design for the faceted aeroshell with large shoulder radius is formed from three flat H/C sub-panels that are shown in side view in Parts A and B of Fig 8. (The interface between the sub-panels is where the angle changes.) The three sub-panels are joined together by *lap joints* of honeycomb ribbon. The assembled H/C shoulder panel has ten rows of cells, but only two of these rows have lap joints. By design, the ribbons of these lap joints are parallel to each other and, to achieve this, the trapezoidal cells had to be rotated 90-deg from their "standard orientation" in the gore regions. Achieving optimally aligned ribbons for strong lap joints was the sole reason for the H/C cell rotation. After the sub-panels have been joined via the lap joints (and the H/C rigidized with ablator blocks or temporary milling blocks), then the resulting assembly would be CNC milled to achieve the inner and outer curvatures of the shoulder region. The amount of material to be milled away is small when three sub-panels are used (i.e., instead of two sub-panels). In Fig. 8, the faint structure line (mold line) shown in Part A indicates the amount of H/C material that needs to be removed in order

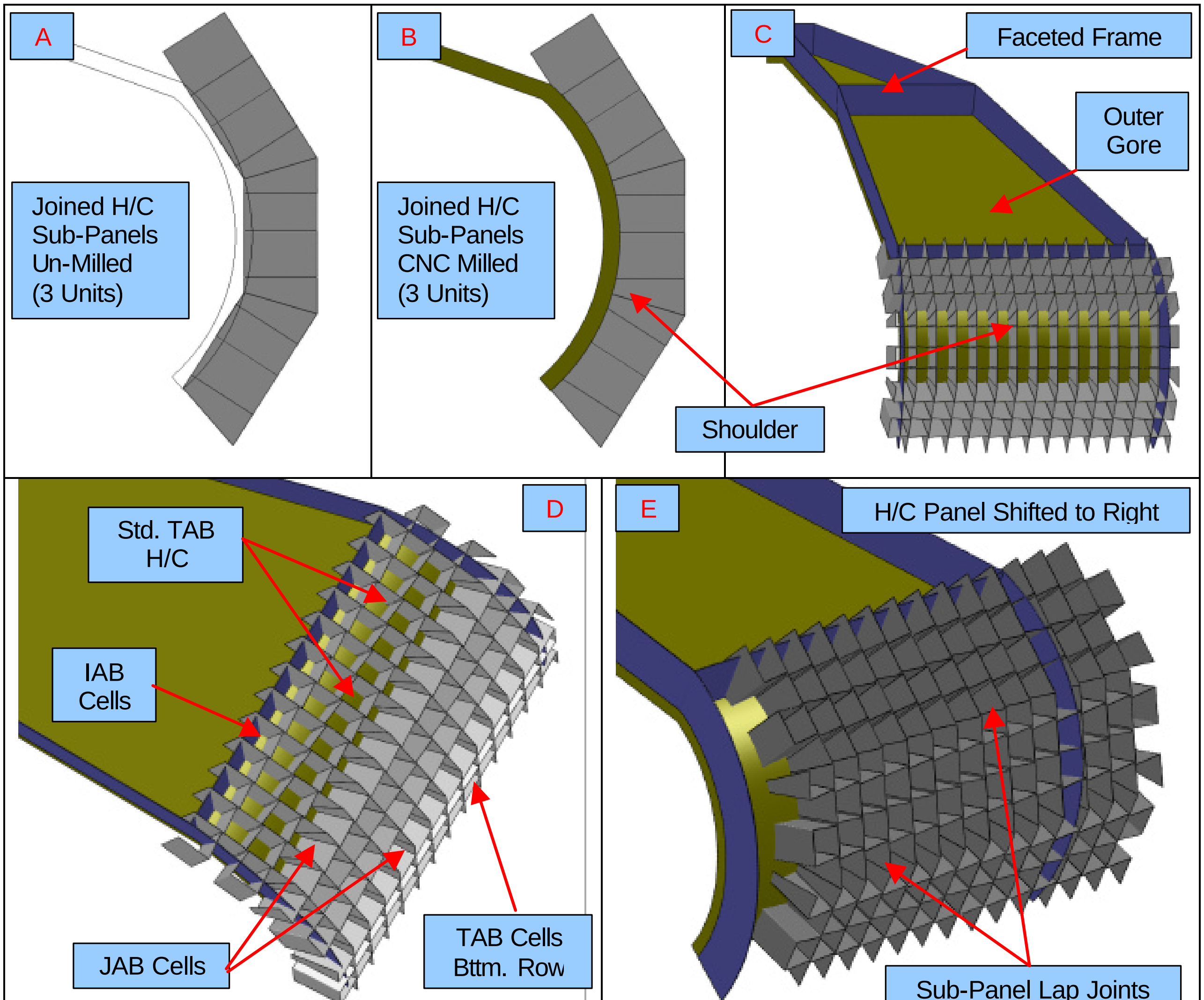


Fig. 8 – Details of Trapezoidal H/C Design for the Aeroshell Shoulder Region

for the honeycomb panels to match the structure's curvature at the shoulder region. Part B shows only the inner surface of the H/C panel having been milled, but the outer surface is also milled in a similar production step. The graphics of Fig. 8 show the lap joints in the center of Rows 4 and 7 to have only small zones of overlap. This was done for visualization purposes only. Our manufacturing plan has maximized overlap of these joint ribbons to increase strength of the shoulder H/C panel. Also, by using maximum overlap we minimize H/C ribbon *stair-steps* on the cell walls and achieve a better fit of the joint ablator block ("JAB") within these cells.

The top row of cells of the shoulder honeycomb panel is filled with a larger trapezoidal ablator block that we have labeled in Fig. 8, Part D, as an "IAB" or interface ablator block. This block has the same left-to-right dimension, and the same thickness, but a greater "top-to-bottom" span (in this view) compared to the standard trapezoidal ablator block. These IAB blocks are tapered on one side so that the blocks fit within the truncated cell at this location. (Our design shows here – but does not require – use of the NASA/ARC latticework or frame discussed in Ref.1. If used, then all the blocks of this row would be bonded on one face to the frame that would abut the shoulder H/C panel.) The bottom row of H/C cells of the shoulder panel has each cell filled with the standard TAB, but these blocks are milled down on one side to fit within the truncated cell structure.

Our selected design for the B-A H/C system is therefore based on only three unique block configurations: 1) the standard TAB that covers the aeroshell gores and nose location; 2) the IAB on the shoulder; and 3) the JAB on the shoulder. However, all blocks used for the shoulder honeycomb region need to have their root face milled to match the structure's curvature (and later their top face milled to the outer design curvature as a final machining step). During root milling, all of the shoulder blocks receive the same curvature, but with an angular relationship that is unique to each row. In other words, the blocks are not all normal to the surface and each row has a somewhat different "off-normal" angle. The different orientations of root curvature are easy to achieve by the type of precision CNC milling upon which our whole design is based. The entire array of ablator blocks for an aeroshell can be mass-produced by automated CNC milling – for which the ABL and most aerospace companies have extensive experience – and small orientation differences in root curvature are readily accommodated.

6.0 FABRICATION OF CURVED MDU

In Section 4.0, the flat MDU that was shown was made to demonstrate how a B-A system (as gores) might be applied to the flank region of a flight aeroshell with a faceted structure. We also produced a demonstration unit to validate our method for how a B-A system could be applied to the curved shoulder region of a faceted aeroshell. The structure of such an aeroshell would have to have, by definition, simple curvature on the shoulder and not compound curvature. The process to produce this unit followed the process described above in Section 5.0. It was the process where ablator blocks were bonded to H/C first, following by milling and then bonding to structure. Because the shoulder radius of the rolled aluminum substrate was relatively small at 6.0 in. (15.2 cm), we assembled just two flat H/C panels to do the shoulder unit instead of three shown in the graphics of Fig. 8. The process we defined in our original technical approach proved to be feasible and worked quite well in making the shoulder MDU.

The ablator unit was built and applied "modularly" (i.e., built as a complete module and then secondarily bonded). The unit was assembled using RTV-560 adhesive to bond blocks to H/C and then fully machined to its final shape and dimensions before it was bonded to structure. Bonding was accomplished with E-P film adhesive, not E-P paste. The GFE shoulder structure was more of a simulated structure (less fidelity than the titanium panel of the flat unit). The structure was 0.5-in. (1.3 cm) thick cold-rolled aluminum. It was shaped to match the approximate shoulder-region curvature of a large, aeroshell unit (i.e., Orion). The block-ablator unit was made from the same type of silica-phenolic H/C panel that was used for the flat MDU. However, here the H/C started out as 2.75-in. (7.0 cm) thick instead of 2.00-in. (5.1 cm) thick. The PICA ablator blocks were mostly the same as the 24.0 x 24.0-in. (61.0 x 61.0 cm) flat MDU blocks, but taller. This unit was made from 32 standard TAB units just like the flat panel, but in addition it required 8 JAB units (a different shaped block, see Fig. 8) for the ridgeline of the MDU. The initial bonding of TAB units is shown in left side of Fig 9. An end view of the completed shoulder module is shown in the right side of Fig. 9. The finished ablator module of this MDU had an exact fit to the rolled aluminum base.

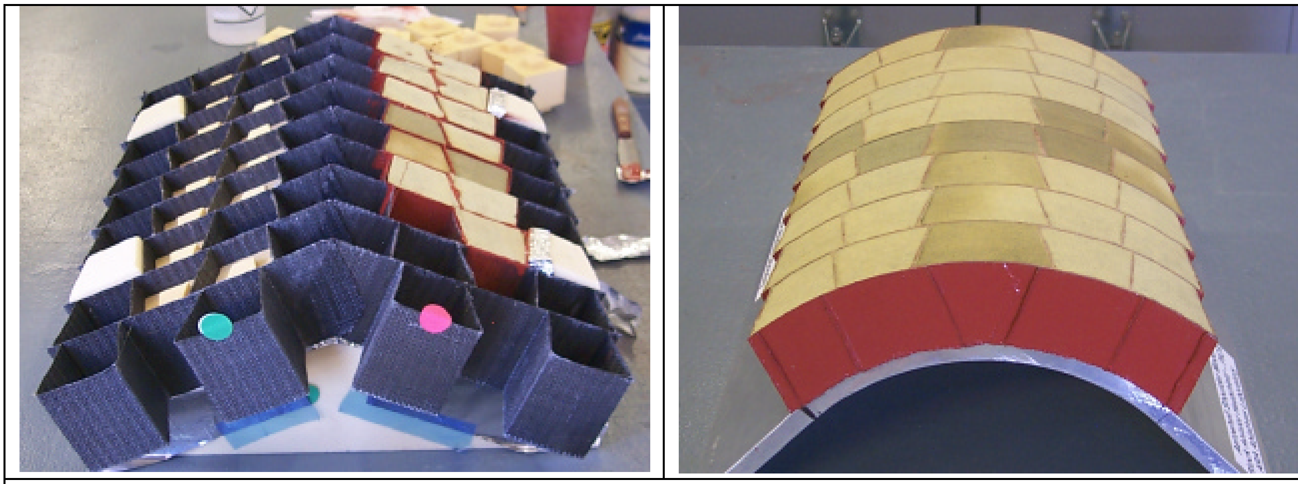


Fig. 9 – Production of the Curved Shoulder Region MDU Using PICA Ablator Blocks

7.0 IHF ARC-JET TEST RESULTS

The figures below show test results for two B-A stagnation samples out of eight that were tested by ABL in 2009. In Fig. 10 is P-28 Sample 3606 and in Fig. 11 is PICA Sample 3619. The test condition for these two samples was 574 W/cm^2 at 0.290 atm for 40 sec. (Other samples were tested at 620 W/cm^2 and 958 W/cm^2 at greater pressures.) The objectives of the ABL tests were to show: 1) that ablator performance in the B-A configuration is consistent with known monolithic performance; 2) that H/C ribbons recede approximately equal to the ablators; and 3) that seams do not open during exposure. Seams did not open and recession was uniform except for some PICA edge roughness, to be expected, where flow spilled over the shoulder of the sample (causing environments to be locally augmented).

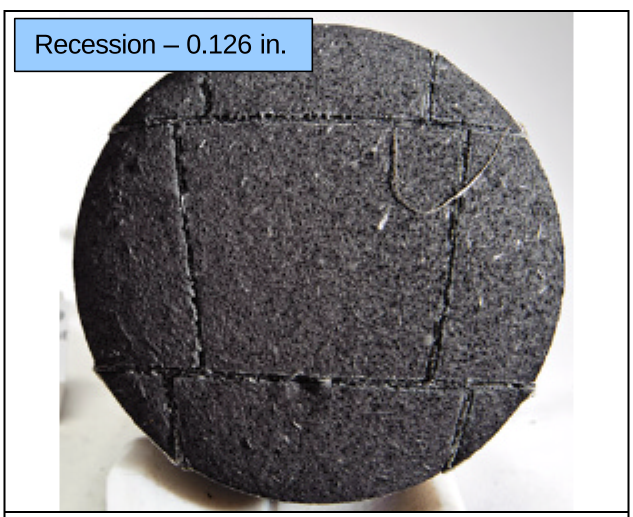


Fig. 10 - P-28 Sample 3606 Tested at 574 W/cm^2

In addition to stagnation samples, we also tested six aeroshear samples at a range of heating, shear, and pressure conditions. The samples again showed very good performance: closed seams and uniform recession. More details for both series of arc-jet tests will be documented in a 2011 AIAA Thermophysics paper.

Fig. 11 - PICA Sample 3619 Tested at 574 W/cm^2

7.0 SUMMARY OF RESULTS

The results and findings of this summary paper should be considered only preliminary regarding the suitability and producibility of B-A heatshield systems for planetary EDL vehicles. Significant progress was made in developing a B-A design and manufacturing processes to produce it. Significant progress was made on preliminary test evaluations of the performance of B-A heatshield systems. More work is still needed and the following points are provided as a means of summarizing conclusions to date, unknowns that remain, and technical effort that is still needed.

• B-A H/C has large cells and therefore limited ribbon to anchor it to structure. It still needs to be determined through testing whether the process of bonding H/C first with E-P paste adhesive (followed by ablator block bonding) produces a stronger heatshield attachment than bonding large-area, completed B-A modules with E-P film.

• H/C by itself, because it is a woven fabric, cannot be milled by conventional processes. It will deform, yield, and fray from end-mill forces. Therefore, H/C for a curved shoulder location must be rigidized via blocks prior to milling. These blocks are either temporary, tightly-fitted milling blocks for the case of bonding H/C first, or permanently-bonded ablator blocks for the case of bonding completed heatshield modules.

• Heatshield-to-structure bond optimization work is still needed. Substrate primer coats may enhance the bonding of H/C to structure, the bonding of blocks to structure, and the bonding of completed modules to structure. However, the epoxy-phenolic adhesive has its own recommended primer, and the silicone adhesive requires a silane-class primer – effectively integrating and using both primers requires study.

• Each ablator block bonded into H/C has five interface bonds, four to the walls of the H/C cell and one to the floor of the H/C cell. For each of these bonds, RTV-560 adhesive is applied to both mating surfaces prior to assembly. Good technique is required to apply sufficient adhesive to eliminate/minimize gaps and voids in the wall bonds, while preventing adhesive from being scraped from the wall and pushed to the bottom of the cell. Sidewall bonding is facilitated by *lateral pressure* from bonded blocks that fill adjacent cells. All bonds, however, are not equally good. Invariably, some seem to be better than others as determined by sample cross sectioning.

• We found that bonding whole ablator blocks into whole H/C cells is very doable. However, bonding partial ablator blocks into partial H/C cells (for example around the perimeter region of a bonded gore of H/C) does not, both from the standpoint of handling and the need to apply bond pressure, and also from the standpoint that unsupported H/C ribbon segments tend to warp significantly during H/C bonding. Warping occurs because partial cells do not (and cannot in practicality) receive shape-retainer blocks, as do the full cells.

• Because of aeroheating and aeroshear forces, a "robust" adhesive is needed (such as RTV-560) for bonding blocks. However, a robust elastomeric adhesive with some expansion characteristics via an "active" additive (e.g., blowing agent) could help eliminate/minimize gaps and voids in the block-to-ribbon bonds.

• A B-A heatshield system can enhance quality assurance from the standpoint that every ablator block can be inspected and verified prior to bonding and use. (However, quality assurance of the five adhesive bonds surrounding each installed ablator block remains a challenge.)

• A B-A heatshield approach allows the use and H/C reinforcement of "non-packable" TPS such as ceramics (e.g., PICA) and stiff, "non-flowing" polymeric ablator compounds (i.e., compounds that can be monolithically molded but not "wet packed" into ordinary honeycomb).

• A B-A approach facilitates the manufacturing and use of dual-layer heatshield systems (i.e., robust top layer over insulating sub-layer), which have the potential of reducing TPS weight and raising heatshield thermal efficiency.

• A B-A system allows the use of dual-layer, polymer-based ablators where the upper and lower layers are "co-packed" and stitched together by fibers that bridge their interface. These dual-layer ablators can be monolithically molded and then CNC milled into blocks just like the PICA and P-28 blocks were milled under this study.

8.0 REFERENCES

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9.0 ABBREVIATIONS AND ACRONYMS

ABL	Ablatives Laboratory (ARA)
ARC	Ames Research Center
B-A	Block-Ablator
CEV	Crew Exploration Vehicle (Orion)
CNC	Computer Numerical Control
EDL	Entry, Descent and Landing
E-P	Epoxy-Phenolic Adhesive
GFE	Government Furnished Equipment
H/C	Honeycomb
IAB	"Interface" Ablator Block
IHF	Interaction Heating Facility (Arc-Jet)
JAB	"Joint" Ablator Block
LaRC	Langley Research Center
MDU	Manufacturing Demonstration Unit
P-28	Phenolic-Carbon Ablator
PICA	Phenolic-Impregnated Carbon Ablator
TAB	"Trapezoidal" Ablator Block
T/C	Thermocouple

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