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Design and Fabrication of a Tank-Applied Broad Area Cooling Shield Coupon

J.J. Wood and M.R. Middlemas
Yetispace, Huntsville, Alabama

Prepared for Marshall Space Flight Center
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LIST OF ACRONYMS

BAC	broad area cooling
CFM	cryogenic fluid management
CPST	cryogenic propellant storage and transfer
GTA	ground test article
MLI	multilayer insulation
MSFC	Marshall Space Flight Center
SOFI	spray-on foam insulation

CONTRACTOR REPORT

DESIGN AND FABRICATION OF A TANK-APPLIED BROAD AREA COOLING SHIELD COUPON

1. INTRODUCTION

1.1 Background

The NASA Cryogenic Propellant Storage and Transfer (CPST) project is developing a flight test article to assess cryogenic fluid management (CFM) technologies in a low-gravity environment. Multilayer insulation (MLI) and broad area cooling (BAC) shield systems are among the key technologies planned for evaluation. BAC shield technology has been developed to aid in reducing heat leak through the wall of cryogenic tanks in recent years. Several studies[1,2,3] have demonstrated the potential thermal benefit of BAC shields; however, the BAC shield subsystem has had limited thermal testing and no structural analysis or testing prior to this effort. A BAC shield is a tube and fin heat exchanger that wraps around a cryogenic tank to provide active cooling. In the case of a hydrogen tank and 90 K cryocooler, the BAC shield is imbedded in the MLI blanket's approximate midpoint. The MLI/BAC shield system must be designed to withstand launch dynamic loads. Leaks introduce a conductive heat transport mechanism inside the MLI blankets. Seals, fittings, welds, or fractures can be leak sources that result in loss of mission. Physical damage to the MLI would reduce its effectiveness and shorten mission duration by increasing heat load. The threat of a leak in BAC shield tubing or physical damage to MLI during launch is a major risk to a successful CPST mission.

Prior to fielding the CPST flight article, a fully integrated ground test article (GTA) based on the anticipated flight article design is being developed. The GTA will include a fully integrated MLI/BAC shield system designed for flight.

1.2 Objectives

The overall objective of the small-scale BAC shield acoustic test was to evaluate the structural performance of the BAC shield coupon in a simulated launch dynamic environment. Specific design and test goals are as follows:

1. Develop a preliminary design for restraining an integrated MLI/BAC shield system to withstand launch loads.
2. Evaluate varied unsupported BAC shield tube lengths in a simulated launch dynamic environment.
3. Assess the interface between the BAC shield tube and the BAC shield support standoff in a simulated launch dynamic environment.

1.3 Approach

Two structural evaluations of the BAC shield were initially considered: an acoustic test in an acoustic chamber, and a random vibration test on a shaker table. The BAC shield is lightweight and has a large surface area. These two characteristics suggest that the dominant dynamic load on the BAC shield will be due to the launch acoustic loads, rather than dynamic loads transmitted through structure, as would be the case for smaller, heavier components attached to structure. Acoustic testing will likely provide a worst-case environment for evaluating the BAC shield design.

The small-scale BAC shield test is a precursor to a fully tank-integrated system on a flight-scale tank. The panel was sized for quick, inexpensive build to gain insight and identify issues as quickly as possible. It was designed to be similar to a section taken out of the CPST GTA, without the complex curve of the end caps. This approach allowed for multiple BAC tubes to be represented with manifolds on either end. The presence of three vertical tubes allowed for three different spacings between standoffs to be tested. Unsupported tube lengths between standoffs ranged from 18 in to 36 in. Fewer standoffs were desirable to minimize heat leak between the 90 K shield and 20 K tank in application. This heat leak decreased the benefit of the BAC shield.

2. TEST ARTICLE ELEMENTS

2.1 Tank Surface and Priming

The CPST GTA tank is a thin-walled, 5-ft-diameter, aluminum pressure vessel. The test panel represented the tank shell with a 1/8-in-thick aluminum sheet that was rolled to a 5-ft-diameter curve. The panel, shown in Figure 1, was cut to a 3-ft-wide by 5-ft-long shape. The aluminum was cleaned, wash primed, and epoxy primed. This priming process was required for the proper adhesion of spray-on foam insulation (SOFI) to the tank surface. Two pieces of angle aluminum were bolted to the lateral edges of the panel to maintain the true shape and to add stiffness.

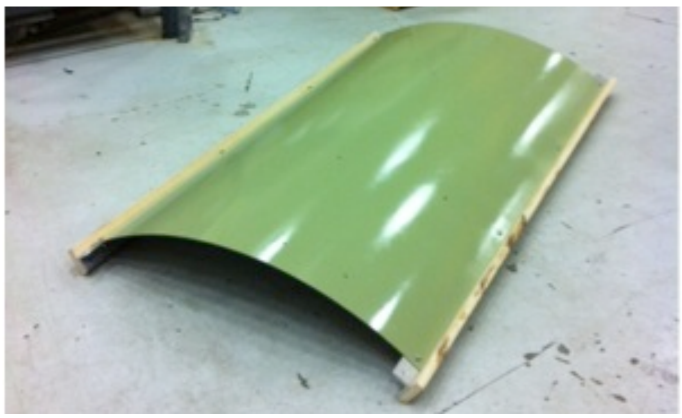
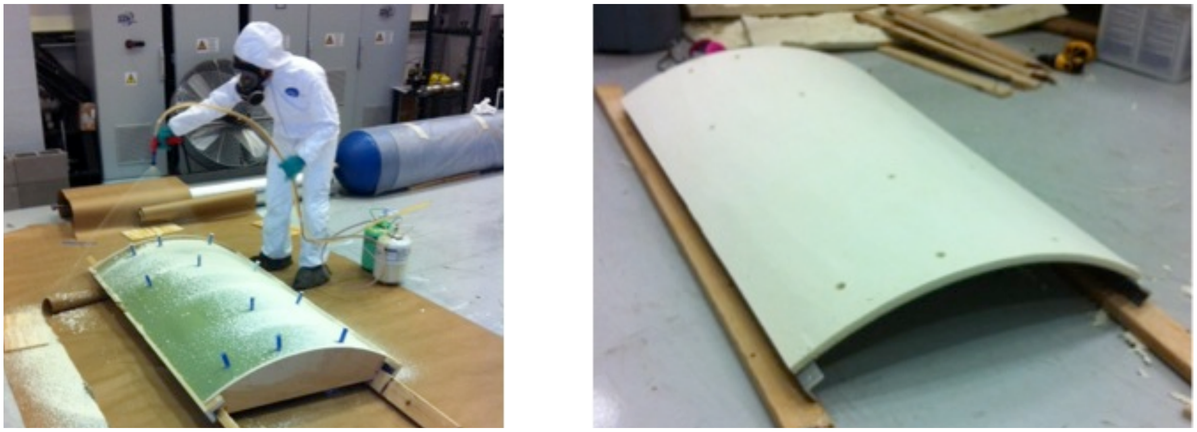


Figure 1. Primed aluminum panel.

2.2 Spray-On Foam Insulation

SOFI installed on hydrogen tanks prevents condensation on the surface of the tank in the absence of a complex helium purge bag subsystem normally required with MLI on cryogenic tanks during ground hold periods. The SOFI thickness was determined analytically based on the system configuration, primarily the number of MLI layers. Applying the minimum allowable amount of SOFI was desirable because the SOFI has little benefit in a vacuum and is added mass.

The primed aluminum panel was covered with a 1/2-in (+1/4-in-tolerance) layer of Versi-Foam System 10, an off-the-shelf high-density foam suitable for cryogenic applications. The BAC shield standoffs were mounted to the panel and masked during SOFI application to provide needed cavities in the SOFI. After the foam cured, the standoffs were removed and the foam was trimmed to the proper dimension. The process is shown in Figure 2a and Figure 2b.



a) b)

Figure 2. Application of Versi-Foam System 10.

2.3 Multilayer Insulation

MLI provides thermal protection for cryogenic tanks from radiation in vacuum. The CPST MLI system consisted of two blankets: a 30-layer inner MLI blanket of a 10-layer/cm density that was situated between the outer surface of the SOFI and the bottom of the BAC shield, and a 30-layer outer MLI blanket of a 20-layer/cm density that was configured on top of the BAC shield. The cross-sectional layup of the system is illustrated in Figure 3. The blankets were constructed out of the following materials based on the recommendations given in the MSFC MLI material guidelines[4]:

- Reflector layers: Double-aluminized 0.25-mil polyester (Mylar) film coated with 1000Å of aluminum
- Separator layers: B4A (0.2 oz/yd^2) polyester (Dacron) netting
- Bumper strips: B2A (0.4 oz/yd^2) polyester (Dacron) netting
- Inner covers: Nomex-reinforced polyimide (Kapton) film, aluminized on both sides and porolated with ~120 needle perforations per square inch
- Outer cover: Beta cloth
- Blanket edges: Aluminized Kapton tape sewn with Kevlar thread

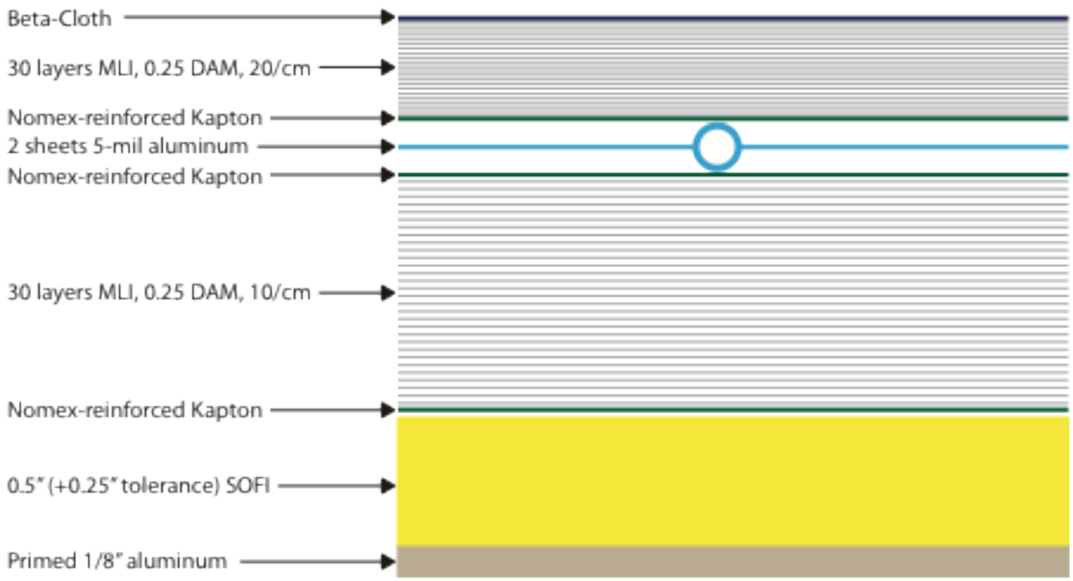


Figure 3. Insulation system cross-sectional layup.

Bumper strips made from folded layers of Dacron netting were used to increase the spacing between the reflector layers to achieve the desired density for the inner blanket, shown in Figure 4a. Inner covers were added to increase handling strength and to protect the MLI blankets from the BAC shield. The Nomex-reinforced Kapton cover is shown in Figure 4b. Beta cloth was selected as the outermost blanket layer to represent a flight-like configuration, as shown in Figure 5.

a)

b)

Figure 4. Inner MLI blanket: a) side view, and b) overhead view.

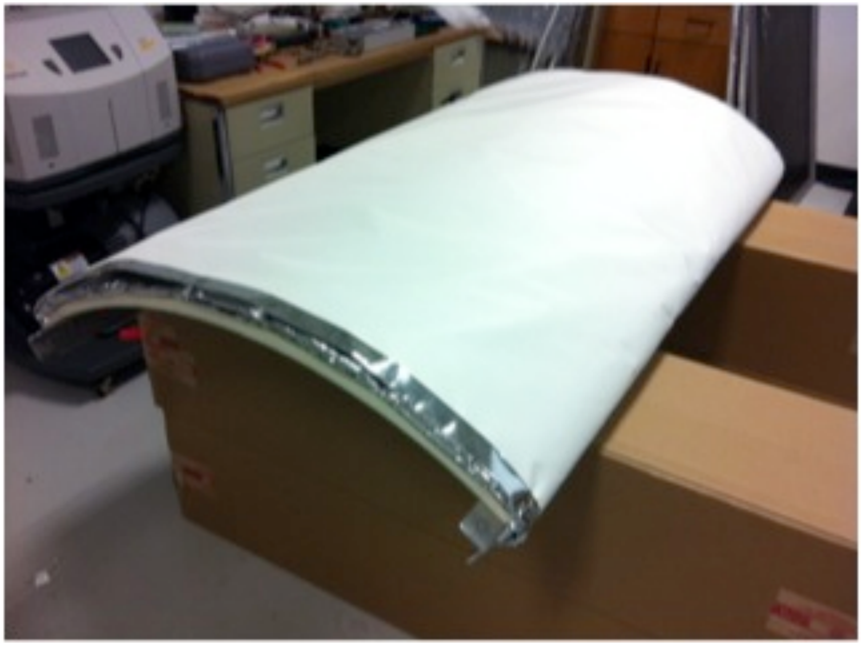


Figure 5. Outer MLI blanket with Beta cloth cover.

The blankets' layers were draped over the test panel to incorporate the curvature of the panel prior to sewing. All of the blanket edges were wrapped with Kapton tape. Strips of Velcro loop were sewn along the underside of the long edges of the blankets. Corresponding strips of Velcro hook were adhesively attached to the aluminum extrusions used to stiffen the test panel. The top and bottom edges of the blankets were not attached to the panel. This reduced the constraint of the blanket and better represented a tank-integrated blanket.

2.4 Broad Area Cooling Shield

The BAC shield is a tube array used to circulate chilled gas around the cryogenic tank. Aluminum panels were bonded to the tubes (Figure 6) to maintain a constant temperature across the entire BAC shield. The test panel was configured with the dimensions shown in Figure 6. The upper and lower manifolds were formed from 3/8-in 316L stainless steel tubing. The cooling lines were formed from 1/4-in tubing. Orbital welding using Swagelok automatic tube weld fittings was used to connect the tubing to minimize the risk of leaks. After welding, the assembly was helium leak checked and no detectable leaks were found.

To maximize heat transfer from the stainless steel tubing, aluminum foil panels were bonded to both sides of the tubing, shown in Figure 6. The edges of the foil were folded over to eliminate any sharp edges that could damage the MLI or cause a safety hazard during installation. Beads were formed in the foil to increase the bonding area. The beads were sized to allow for a 15-mil-thick bond line between the foil and the tubes. The foil panels were bonded to the tubes using an epoxy adhesive (Hysol 9430). The adhesive was cured at 180°F for 2 hr per the manufacturer's instructions.

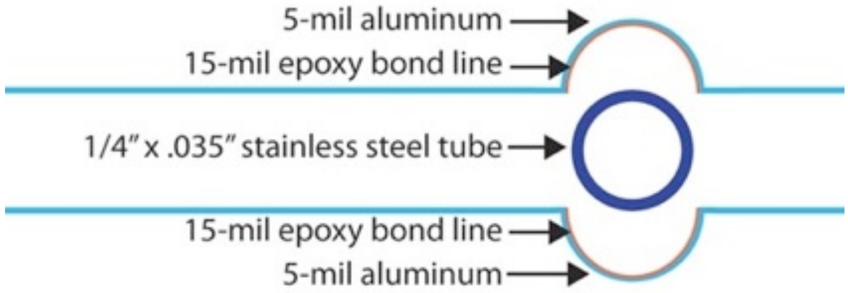


Figure 6. BAC shield layup.

2.5 Broad Area Cooling Shield Standoffs

The BAC shield was supported by 11 standoffs designed and analyzed by ER34, ER43/Tec-Masters, and ER41/Dynamic Concepts at MSFC, shown in Figure 7. The standoff concept was a proposed solution to balance the thermal and structural requirements of the system. In implementation on an LH2 tank, the standoffs extended from the surface of the tank at a temperature of approximately 20 K to the BAC shield at a temperature of approximately 90 K. This dramatic temperature difference resulted in a nontrivial heat leak through the standoff, which was undesirable. However, structural instability in the system was also highly undesirable due to the risk of a shortened mission or loss of mission or resulting from damage to the BAC tubes or MLI.

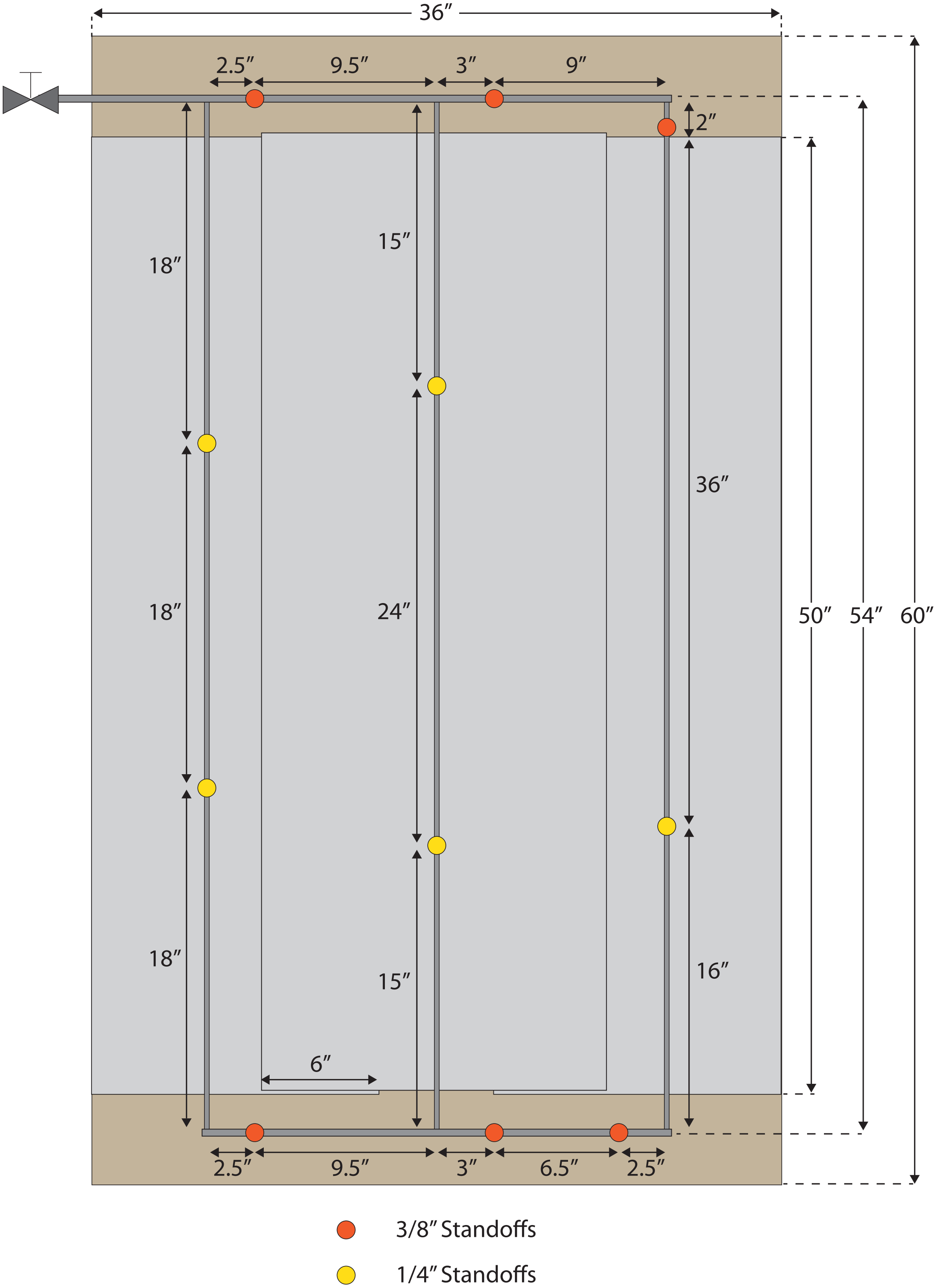


Figure 7. Test article configuration.

The standoffs were 2.5 in tall to properly position the BAC shield in the MLI blanket. They were machined from the polyetherimide material Ultem 1000. Ultem 1000 was selected for its low thermal conductivity, acceptable mechanical properties at cryogenic temperatures, availability, and cost. The BAC tubes were supported in a cradle at the head of the standoffs and held in place by a cap secured with two opposed retaining rings, shown in Figure 8 and Figure 9. The standoffs were bolted to the aluminum panel with the locations situated to give different unsupported tube lengths in the BAC shield, as seen in Figure 7.

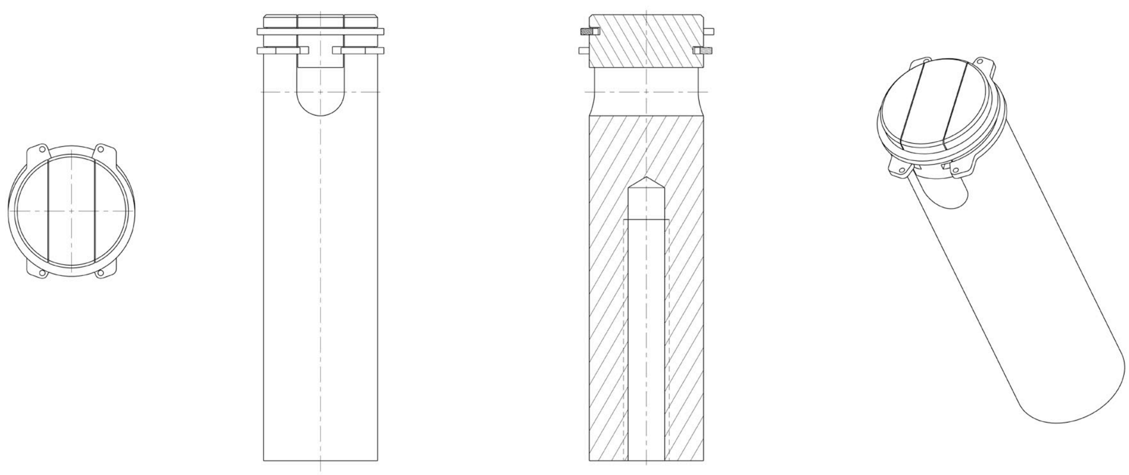


Figure 8. BAC shield standoff assembly.

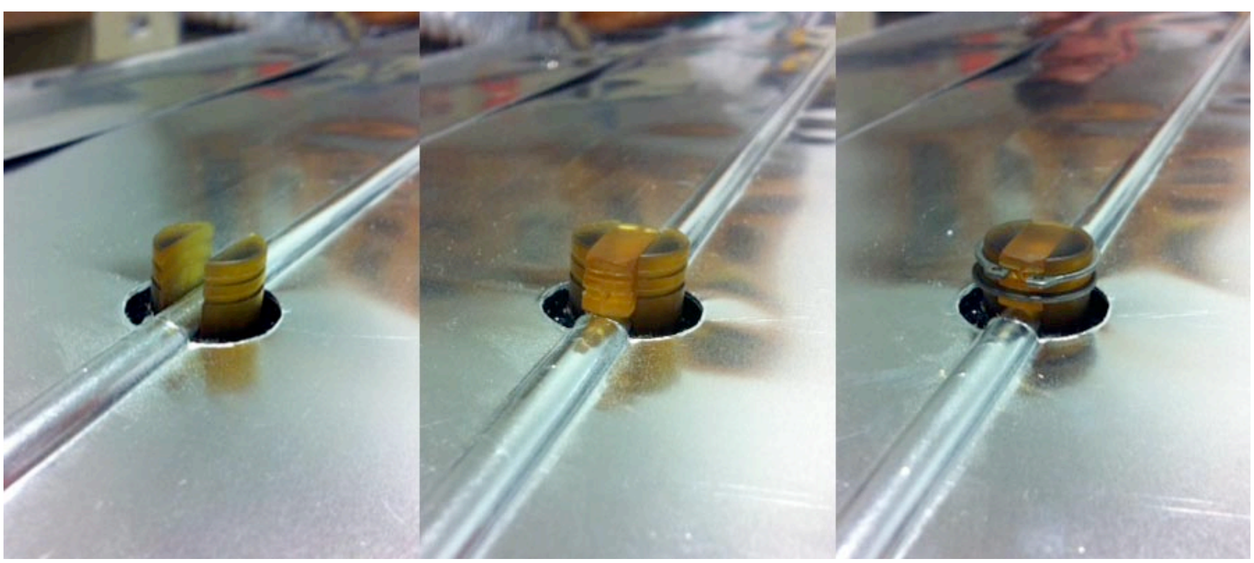
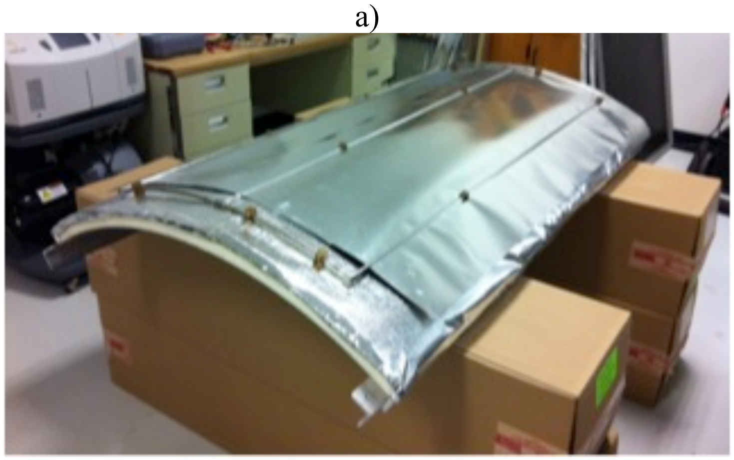


Figure 9. BAC shield standoff cap assembly.

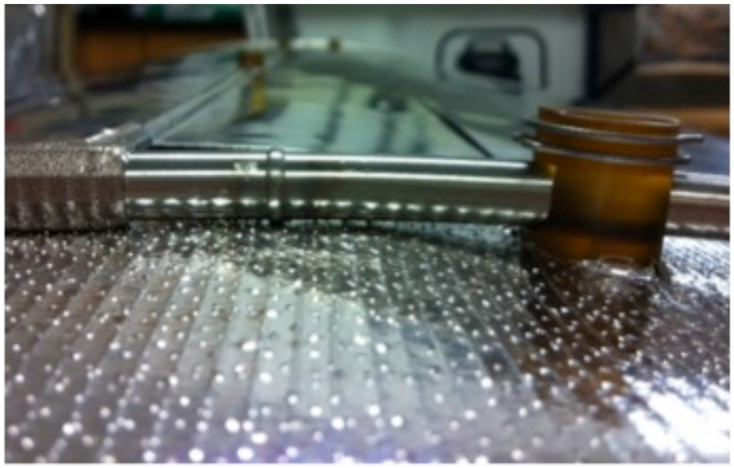
Assessing the tube condition during and after testing as a function of the unsupported tube length was a primary goal of the test. Unsupported 1/4-in tube lengths of 18-, 24-, and 36-in were evaluated in this configuration. The 3/8-in tube manifold lines were also supported by standoffs, but these lines were less consequential to the GTA application because the manifold lengths were relatively short and existed only at the top of the tank. The 1/4-in tubes spanned the entire length of the tank and required more supports; thus, the test setup was focused on evaluating the 1/4-inch tube lengths.

Integration of the standoffs into the MLI/BAC shield system was approached in such a way as to inflict minimal impact on the existing system. The standoffs were mounted directly to the primed aluminum panel, with the SOFI conforming to the bottom 1/2 in of each standoff. The inner MLI blanket was perforated at each standoff interface location to allow the MLI blanket to lie naturally on the SOFI surface. Holes were punched in the BAC shield material at each standoff interface point, but the shield material was otherwise left undisturbed. The outer MLI blanket remained completely intact with no impact as a result of the standoffs. The standoff integration process is illustrated in Figure 10.

a)



b)



c)

Figure 10. BAC shield: a) without MLI blanket, b) with inner MLI blanket, and c) standoff attachment detail.

3. TEST RESULTS

3.1 Test Setup

The test panel was delivered to the MSFC Acoustic Test Facility located in Building 4619. The outer MLI blanket was briefly removed to install instrumentation. Before testing, the tubes were evacuated and then pressurized with 100 psia neon, which is the gas expected to be used in the BAC shield for the GTA. The panel was suspended from the ceiling in the acoustic chamber for testing, shown in Figure 11.

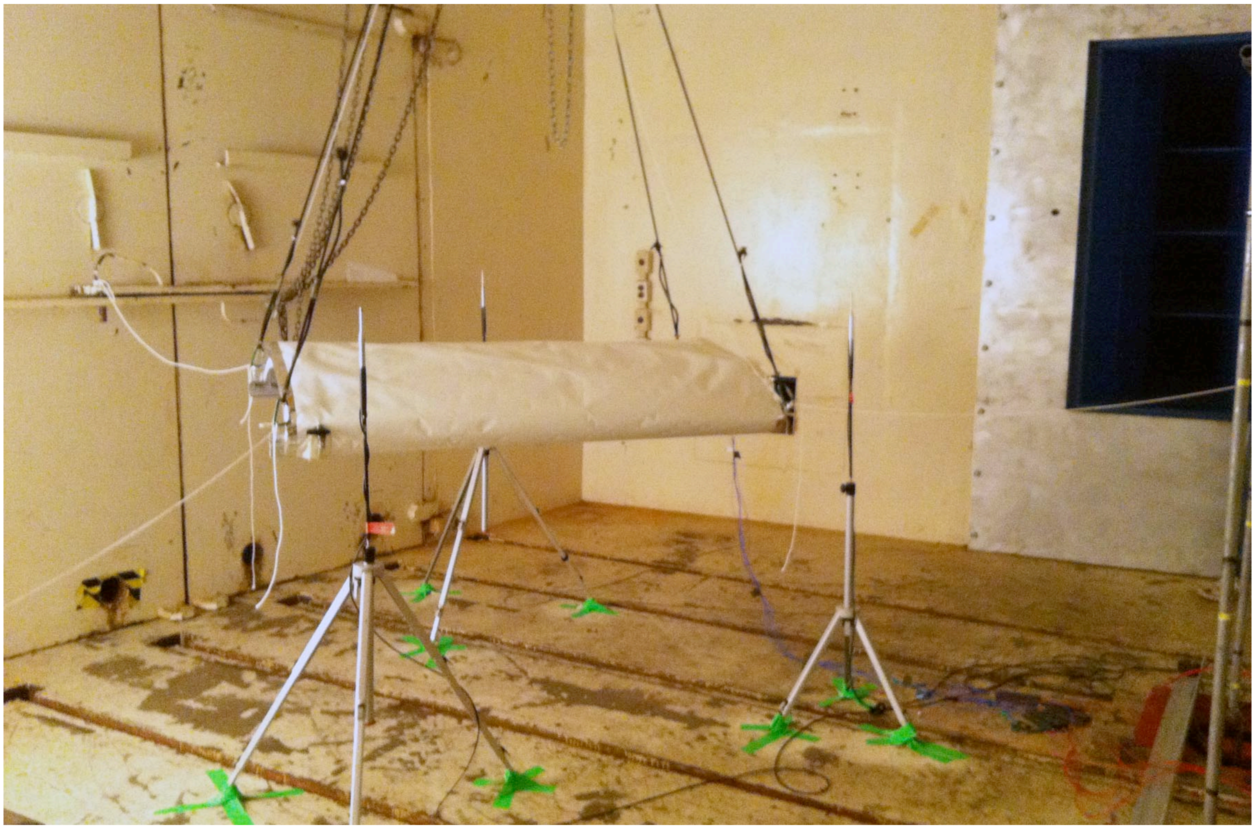


Figure 11. Test panel in acoustic chamber.

3.2 Post-Test Evaluation

Immediately following the acoustic test, the pressure in the BAC shield was measured to verify that no leaks in the tubing or welds formed as a result of the test. No pressure drop was observed. The test panel was disassembled and visually inspected for damage. The inner and outer MLI blankets were inspected for tears or abrasion. The BAC shield was inspected for cracks or bends in the aluminum foil, or bends in the tube array. No damage was evident in the MLI blankets or the BAC shield assembly. Further details regarding the acoustic analysis and testing may be found in Reference 5.

4. CONCLUSIONS

The small-scale BAC shield acoustic test article was designed and assembled as a coupon representation of the CPST GTA tank-integrated BAC shield. The tank material, primer, SOFI, inner MLI blanket, BAC shield, and outer MLI blanket made up the test article per the current GTA configuration. This test panel was assembled and delivered to the MSFC Acoustic Test Facility for testing in a simulated worst-case launch acoustic environment. Prior to testing, the BAC shield tubes were pressurized with 100 psia of gaseous neon. After testing, the pressure in the tubes was measured to determine whether a pressure drop occurred during testing. No pressure drop was noted, and no damage to the BAC shield or MLI was found during detailed visual examination.

This test article development effort focused on the structural element of the BAC shield. A preliminary design for a standoff to support the BAC shield tube and constrain its movement was developed and physically implemented. The interface between this standoff and tube was carefully examined to detect any evidence of stress or damage to the tube or standoff; none was noted. The unsupported tube length between standoffs was also of interest during testing. Distances of 18, 24, and 36 in were tested, and all three unsupported tube lengths appeared acceptable. A longer unsupported line length was desirable because fewer standoffs were required, resulting in less total conductive heat transfer through the standoffs to the tank surface. Future testing should be performed using an MLI/BAC shield system integrated onto a flight-scale tank.

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14. ABSTRACT
The small-scale broad area cooling (BAC) shield test panel represents a section of the cryogenic propellant storage and transfer ground test article, a flight-like cryogenic propellant storage tank. The test panel design includes an aluminum tank shell, primer, spray-on foam insulation, multilayer insulation (MLI), and BAC shield hardware. This assembly was sized to accurately represent the character of the MLI/BAC shield system, be quickly and inexpensively assembled, and be tested in the Marshall Space Flight Center Acoustic Test Facility. Investigating the BAC shield response to a worst-case launch dynamic load was the key purpose for developing the test article and performing the test. A preliminary method for structurally supporting the BAC shield using low-conductivity standoffs was designed, manufactured, and evaluated as part of the test. The BAC tube-standoff interface and unsupported BAC tube lengths were key parameters for evaluation. No noticeable damage to any system hardware element was observed after acoustic testing.

15. SUBJECT TERMS
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