MSFC-766

Application of Pi Preform Composite Joints in Fabrication of NASA Composite Crew Module Demonstration Structure (Abstract)

John E. Higgins[1]
Air Force Research Laboratory (AFRL), Space Vehicles Directorate, Kirtland AFB, NM, 87114

Larry Pelham[2]
Material and Processes Laboratory, NASA/MSFC, Huntsville, AL, 35812

I. Introduction

THIS paper will describe unique and extensive use of pre-woven and impregnated pi cross-sections in fabrication of a carbon composite demonstration structure for the Composite Crew Module (CCM) Program. The program is managed by the NASA Safety and Engineering Center with participants from ten NASA Centers and AFRL. Multiple aerospace contractors are participating in the design development, tooling and fabrication effort as well. The goal of the program is to develop an agency wide design team for composite habitable spacecraft. The specific goals for this development project are:

a) To gain hands on experience in design, building and testing a composite crew module.

b) To validate key assumptions by resolving composite spacecraft design details through fabrication and testing of hardware.

This paper will focus on the design and fabrication issues supporting selection of the Lockheed Martin patented Pi pre-form to provide sound composite joints a numerous locations in the structure. This abstract is based on Preliminary Design data. The final design will continue to evolve through the fall of 2007 with fabrication mostly completed by conference date.

II. Pi-Preform Background

The Pi pre-form has been extensively evaluated by both industry and DoD leading to internal assessment of B-basis joint properties as a function of relevant boundary conditions. While these properties can not be describe here in numerical detail, it is useful to consider the range of applications for intended use in the NASA CCM and their impacts on design options as well as fabrication methods.

The Pi-preform is a woven carbon composite material which provided in prepreg form and frozen for long term storage. The cross-section shape allows the top of the pi to be bonded to a flat or curved surface with a second flat plate composite section bonded between the two legs of the Pi (see Figure 1.)

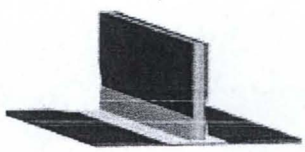

Figure 1. Typical Pi pre-form joint.

The joint can procured in a range of dimensions and is intended to resist pull-off and shear forces (nominally cited in lbs/in) depending upon the nature for the fixity and stiffness of the plates framing into the joint.

---

[1] Insert Job Title, Department Name, Address/Mail Stop, and AIAA Member Grade for first author.
[2] Insert Job Title, Department Name, Address/Mail Stop, and AIAA Member Grade for third author.

III. CCM Structural Configuration

From a structures perspective the CCM can be viewed as a pressure shell with variable pressure time histories and a series of both impact and quasi-static, high intensity point, line, and area distributed loads. In fact the point and line loads are distributed to the pressure shell through application of Pi pre-forms and a fewer number of bolted aluminum fitting only for the highest loads. The portion of the overall space vehicle being designed by the CCM team is illustrated figures 2 and 3.

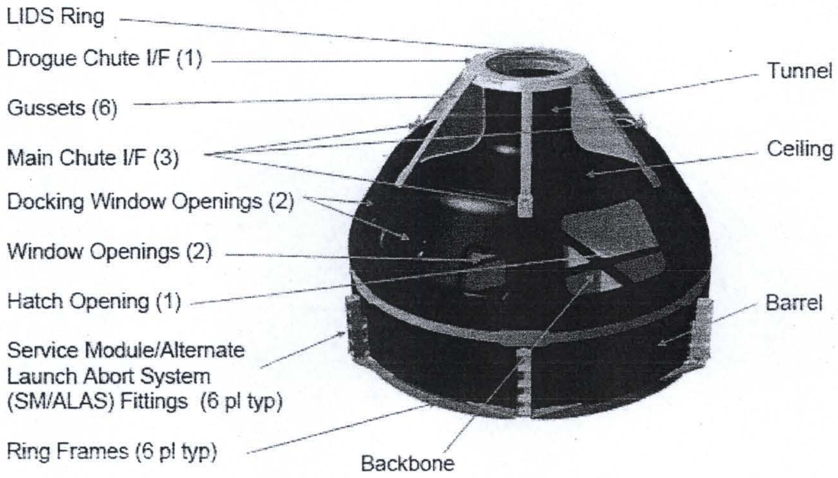

Figure 2. Top view of CCM.

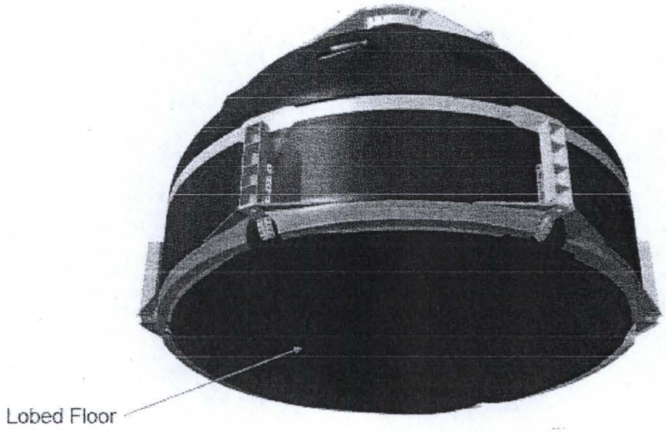

Figure 3. Bottom view of CCM.

Following the nomenclature of these figures the heaviest point loads are applied and distributed to the pressure shell at the aluminum Service Module/Alternate Launch Abort System (SM/ALAS) fittings and the Main and Drogue Chute fittings. Significant line load with metal to metal impact is applied at the Lids ring. These major external point and line loads as well as pressure impact loads (blast and water impact) are applied to the lobed floor though the reentry shield and crushable materials. As these loads are distributed further into the structure lower capacity connections are made almost exclusively with Pi Pre-forms.

As we look at the region of the tunnel, six plate like gussets are found about the exterior of the tunnel. These gussets are bonded to the tunnel and a reinforcing strap by Pi-Pre-forms, as shown in Figure 4.

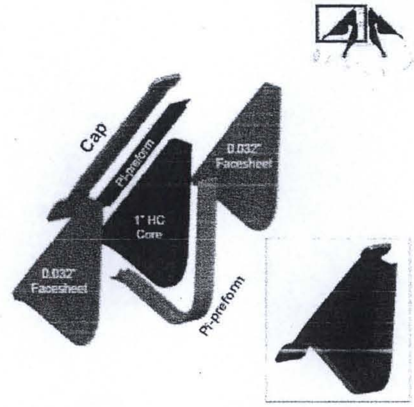

Figure 4. Pi pre-form joint bonding of gussets at tunnel.

The Pi pre-form legs can be cut to form curved surfaces relatively to form bonded joints to tight curvature surfaces or can be terminated as two separate pieces at relatively acute angled features without detrimental bond strength loss.

Another major region relying upon the merits of the Pi pre-form is the backbone (partially visible though the main hatch in Figure 2. The backbone is used to support a large amount of stowed equipment and so has high distributed inertial loads. It also resists pressure loads distributed to the peculiar lobed surface at the base of the pressure shell and to the SM/ALAS fittings. Additionally the backbone provides load sharing to the external heat shield for critical impact loads. All connections among plates of the backbone structure, including the upper flanges, and to the lobe base of the pressure shell are currently joined by Pi pre-forms (see Figures 6).

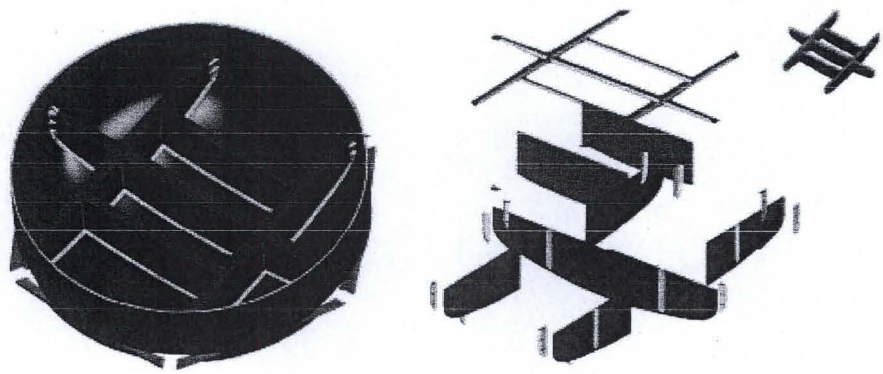

Figure 6. Backbone fabrication views.

The intersection of backbone composite plates is formed by application of two Pi pre-forms, top flanges and lobed surfaces are bonded with one Pi pre-form as illustrated in Figures 7. In particular, the shape of the Pi pre-form as applied to the lobe joints is an extension prior application and must yet be supported by careful substructure testing before acceptance into the final design for the CCM. These joints experience both high shear and tensile loads resulting from the non-cylindrical symmetry of the backbone and resulting lobes and the applied internal pressure and other loads. The resulting line loads are seen to be relatively high at a few regions of the lobed structure (reference Figure 7). The durability and capacity of the Pi pre-forms are essential to the success of the lobed surface design. This feature alone can result in very significant mass saving for the pressure shell. Without them the CCM will probably employ a conventional, heavier, domed bottom. Final detail configuration, test data and analysis are not available at this time but should be by paper final submission.

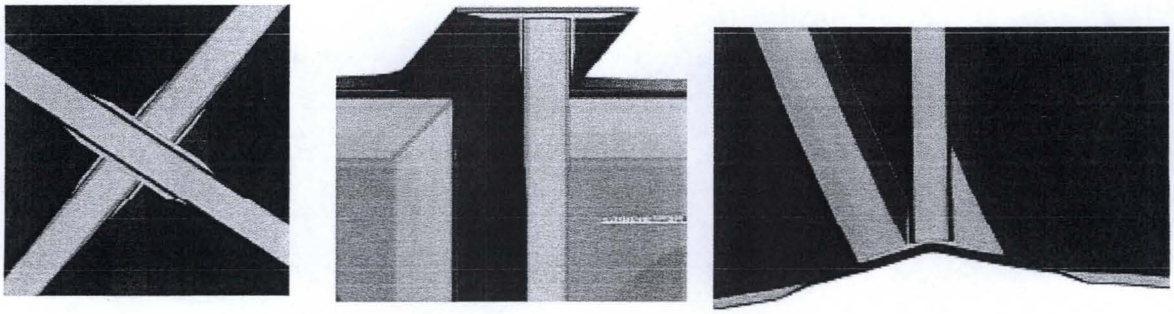

Figure 6. Backbone joints at plate intersections, flange and lobed-surface.

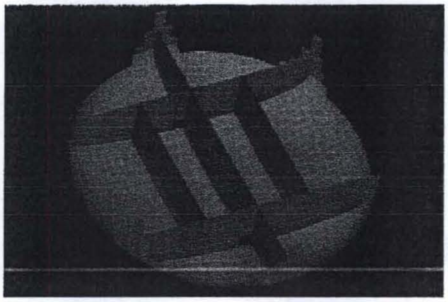

Figure 7. Joint regions controlled by tension/compress (red) and shear (blue).

IV. Pi Pre-forms Aid Fabrication

Because the learning experience nature of the program, and for purposes on maintaining a constrained schedule, and experienced team of government and contract personnel have been maintained as coequal players in the design team to advise as to practicality of detail fabrication, durability and likely performance of details approaching failure load. Consequently the design process is not guided solely by least weight or other simple factors, but by the judgment of numerous disciplines. The current sequence of fabrication for the gussets and backbone are illustrated in Figures 8 and 9. The gussets will be co-bonded to the tunnel prior to bonding in of the aluminum Lids ring.

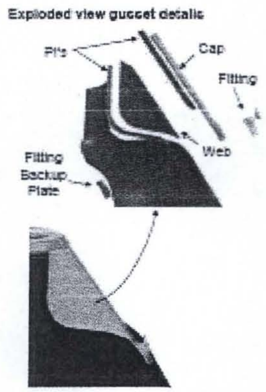

Figure 8. Gusset Fabrication

The backbone will be co-bonded to the bottom half of the pressure shell prior to assembly of the top and bottom halves of the pressure shell. This process will allow good access to the interior of the shell throughout backbone fabrication and can also potentially permit extensive installation of equipment and crew facilities prior to final assembly of the two shell halves.

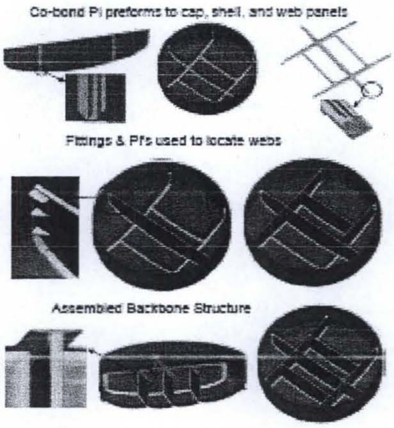

Figure 8. Backbone fabrication sequence

V. Summary

This paper will document a critical composite technology (composite jointing) for the CCM at a non-proprietary and non-sensitive level. This means that useful features and limitations will be discussed qualitatively. The regions of highest loading nature of critical joint stresses will be discussed without recourse to test data results or more than identification of regions of maximum stress from analysis. Test configuration may be shown, but not test results except for go/no go conditions. It is the intent of the authors to pass on to the public the general approach to design integration using Pi pre-forms and the relative ease afford to fabrication by this technology with out compromising NASA, DOD, or proprietary interests.