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# An experimental study of the compression response of fluted-core composite panels with joints

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ABSTRACT

Fluted-core sandwich composites consist of integral angled web members spaced between laminate facesheets, and may have the potential to provide benefits over traditional sandwich composites for certain aerospace applications. However, fabrication of large autoclave-cured fluted-core cylindrical shells with existing autoclaves will require that the shells be fabricated in segments, and joined longitudinally to form a complete barrel. Experiments on two different fluted-core longitudinal joint designs were considered in this study. In particular, jointed fluted-core-composite panels were tested in longitudinal compression because this is the primary loading condition in dry launch-vehicle barrel sections. One of the joint designs performed well in comparison with unjointed test articles, and the other joint design failed at loads approximately 14% lower than unjointed test articles. The compression-after-impact (CAI) performance of jointed fluted-core composites was also investigated with test articles that had been subjected to 6 ft-lb impacts from a 1/2-in. hemispherical indenter. It was found that such impacts reduced the load-carrying capability by 9–40%. This reduction was dependent on the joint concept.



## 1. Introduction

Launch-vehicle shell structures, such as those in tanks, intertanks, skirts, and frustums, must resist both strength and stability failures when subjected to launch loads. Metallic launch-vehicle shell structures typically use a stiffened-skin construction. However, composite launch-vehicle shell structures often use sandwich construction, which typically consists of thin facesheets separated by a lightweight core such as polymer foam, or aluminum or aramid/phenolic honeycomb. These traditional sandwich composites have a number of manufacturing and in-service issues [1] that may be ameliorated with other sandwich composite constructions such as the fluted-core sandwich composite [2]. The fluted-core sandwich consists of integral angled web members spaced between laminate facesheets (Fig. 1). A discussion of the perceived advantages and disadvantages of honeycomb-core and fluted-core composite structures is given in [2].

Launch-vehicle shell structures can have diameters as large as 33 ft, and at this size cannot be autoclave cured as unitized structures in existing autoclave facilities. Because of the associated costs of building and operating new autoclaves, longitudinal joints will be required if sections of the barrels are to be autoclave cured. That is, it is proposed that such large cylinders can be fabricated by first building autoclave-cured panels and then assembling them into a complete barrel using longitudinal joints. Additionally, the primary loading condition in dry launch-vehicle cylindrical-shell structures is longitudinal compression. Therefore, an experimental study to better understand the longitudinal compression behavior and failure modes of fluted-core composite structures with longitudinal joints is detailed herein. Two different fluted-core composite joint designs were considered. Test articles representing both joint designs were tested in pristine and impact-damaged states. Impacted test articles were tested to provide preliminary data on the impact damage resistance and tolerance of fluted-core composite joints.

A brief discussion of sandwich composite joints and the particular joints to be examined in the present paper is provided in Section 2. Descriptions of the test articles are given in Section 3, and representative experimental results are given and discussed in Section 4. Closing remarks are provided in Section 5.

## 2. Sandwich composite joints

Many joint designs for composite sandwich structures (for several examples, see [3–5]) consist of large, often metallic, splice plates that are bolted, bonded, or bolted and bonded across the joint. In addition, densification of the core in the region of the joint is often necessary. These joint designs can add significant weight to

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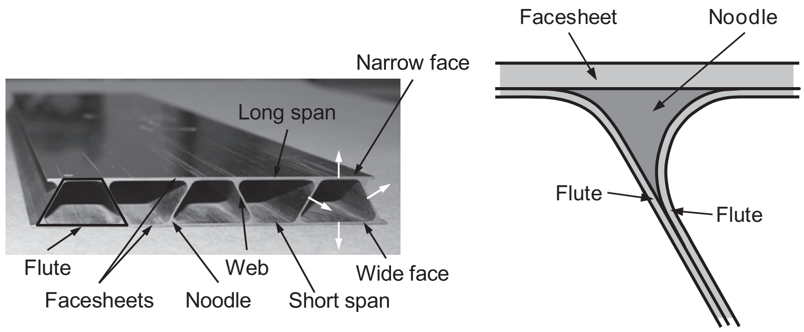



(a) Cross section and nomenclature (b) Cross-sectional sketch

**Fig. 1.** Cross section of an unjointed fluted-core composite panel.

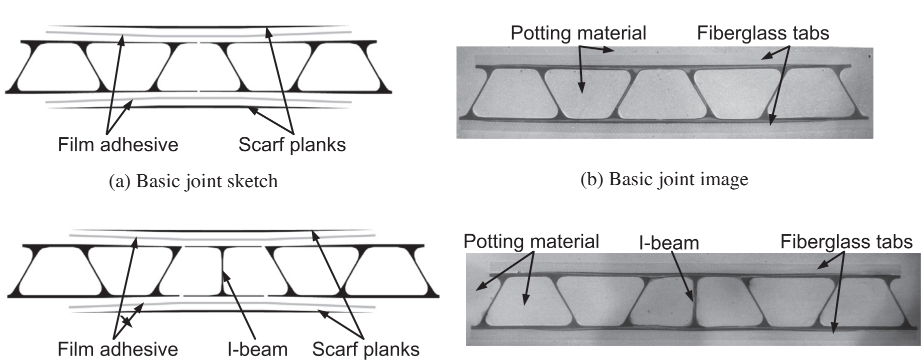
an otherwise lightweight structure. Additionally, the added stiffness of the splice plates and the core densification will draw load into the joint region and can reduce the buckling performance and structural efficiency of the structure. Another typical sandwich-composite joint design has the cores tapered to solid laminates and splice plates bolting the butted solid laminates. These joints can be particularly problematic in buckling- or stiffness-critical structures because not only is more load drawn into the joint by the high longitudinal stiffness, but the bending stiffness is significantly reduced (for a discussion of some of these joint issues for welded orthogrid metallic structures, see [6]).

The fluted-core composite panels considered herein were produced by The Boeing Company and were joined using two types of scarf joints, as shown in Fig. 2. In both joint designs, adjacent shell sections are butted together, the facesheets are scarfed (tapered), and scarf planks that are similar to the removed facesheet material are bonded over the scarfed region. The first joint design, herein termed the *basic* joint, consists of only the scarfed shells, adhesive, and the scarf planks. The second joint design, herein termed the *I-beam* joint, is similar but has the addition of a perpendicular web and noodles between the two separate panels. Potential advantages of these joint designs are that they add very little additional weight to the structure, they are close to stiffness neutral in relation to the surrounding structure, and they can be applied in an out-of-autoclave process. The I-beam joint was explored because it allows for more variation in how the panels of a closed shell fit together; that is, the flanges on the I-beam can be sized as needed to fill the gap between the outermost noodles (unidirectional radius fillers where the webs meet the facesheets) of the separate panels. For both joint types, the scarf plank was 4.5-in. wide with a 1.5-in.-wide flat region. The joint width was sized primarily by the facesheet thickness, and the conservative taper ratio of 0.3-in. per ply.

## 3. Test article description

The objective of the experimental effort described herein is to investigate localized compression failures of fluted-core composite panels with longitudinal scarf joints. The test articles were designed so that they would fail in compression without large global out-of-plane deformations. Test articles with both of the joint designs were tested in pristine and impact-damaged states.

The fluted-core composite cross section that was used in this study was termed the *subscale* cross section in [2], and the test-article geometries were similar to those in [2]. The test articles were made from autoclave co-cured unidirectional intermediate modulus, 350-F toughened carbon-epoxy prepreg, consisted of five flutes (not including the joint), and were nominally 0.74-in. thick. The fluted-core manufacturing method consisted of wrapping prepreg plies around trapezoidal mandrels, arranging the wrapped mandrels with pultruded unidirectional-prepreg radius fillers (noodles), and applying prepreg facesheets on both faces of the wrapped mandrels, autoclave co-curing, and then removing the mandrels after cure. The facesheet layup (including the plies originally wrapped around the mandrels) was $[\pm 45/0/90]_S$, and the web layup was $[\pm 45/\pm 45]_T$ (where the "T" subscript denotes total layup). (The coordinate systems for describing the ply angles are right handed, use the normals as shown by the white arrows in Fig. 1, have the 0-deg direction as the longitudinal test-article direction, and the 90-deg direction as in plane and perpendicular to the 0-deg direction). To make a jointed test article, a cut was made down the middle of the center flute, the facesheets were scarfed, and then the scarf planks were applied. The scarf planks were bonded to the scarfed panels using 0.015-in.-thick 250-F-cure film adhesive under autoclave heat and pressure. Though the considered test-article joints were manufactured using an autoclave, it




(a) Basic joint sketch (b) Basic joint image

(c) I- beam joint sketch (d) I-beam joint image

**Fig. 2.** Joint configurations. The grey lines in (a) and (c) represent film adhesive.