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Honeycomb Fastening

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THE BEST WAY to begin a presentation of the requirements and influences of fastening honeycomb sandwich is with a brief review of the fundamentals of honeycomb sandwich in general. An appreciation for the advantages of sandwich structure will help put the importance of honeycomb fastening in its proper perspective.

Sandwich panel structure usually consists of two thin facings separated by a stabilizing and shear resistant light-weight core. Relatively wide separation of the stable faces results in extremely high stiffness-to-weight ratios. Material selection for facings and core may be paper, wood, metal, plastic, or most recently, what is called "advanced composite," which is ultra high-performance boron, glass, or graphite fibers in a plastic or metallic matrix. To date, honeycomb sandwich in aerospace use has usually been composed of high-strength aluminum facings with expanded aluminum honeycomb core.

The core-to-facing attachment method as well as the material selection usually depend on the temperature environment in which the panel will operate. Candidate fabrication methods are brazing, welding, soldering, diffusion bonding, and adhesive bonding. Adhesive bonded sandwich, because of its high efficiency, reasonable environmental tolerance, and cost effectiveness, has found wider use than the other types. Fig. 1 illustrates the concept of adhesive bonded sandwich.

Sandwich construction is a relatively new form, having been developed during the World War II for use on the RAF Mosquito bomber. After the war, the B-36 bomber utilized some bonded structure, but not until the development of the B-58 in the early 50's did structural sandwich prove its efficiency and producibility. This supersonic bomber utilized bonded honeycomb structure as cover material for the entire wing and tail surfaces. Since then virtually all military, and an increasing number of commercial aircraft, utilize bonded sandwich extensively as primary aircraft structure (1).* It is also used extensively in boat hulls, mobile homes, shipping containers, and most recently, as a commercial building material. In addition to its efficiency with regard to strength and stiffness, bonded sandwich is fatigue resistant, a good insulator or radiator depending on core material selection, highly serviceable, and presents a smooth, attractive surface.

The application to space vehicles use probably best illustrates the size range of honeycomb sandwich. Studies have been made for sandwich structure using extremely light 1/8-in. thick aluminum honeycomb core with facings of 1-ply woven glass (dubbed "miniwich") for payload regions, to 3-in. thick bonded honeycomb sandwich with 3/8-in. aluminum plate skins for first-stage booster primary structure. Sandwich is currently used in the Saturn space vehicles as the common bulkheads for fuel tanks of the S-II and S-IVB stages, and as stage interconnect structure to which the electronic equipment is mounted, the "Instrument Unit" (Fig. 2).

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*Numbers in parentheses designate References at end of paper.

ABSTRACT

Attachment of honeycomb sandwich structure has been an important design consideration in the aerospace field since the early 50's when bonded sandwich was first used extensively as covering for the wings and tail of the supersonic B-58. Since then, virtually all military and an increasing number of commercial aircraft and space vehicles utilize honeycomb sandwich as primary structure. This paper illustrates the basic approaches to sandwich panel attachment and the variety of typical solutions. Successful honeycomb fastening design concepts from B-58, B-57F, and F-111 production programs at General Dynamics are illustrated. Sealing of sandwich joints for use as integral fuel tanks and application of specialty fasteners for honeycomb sandwich are discussed. Structural efficiency of "fastened" stepped-down edge concepts versus full-depth panel edges is compared. A full-depth panel edge design with a stud and plug with spliceplate is currently an attractive design for fastening both metallic and composite-faced sandwich.

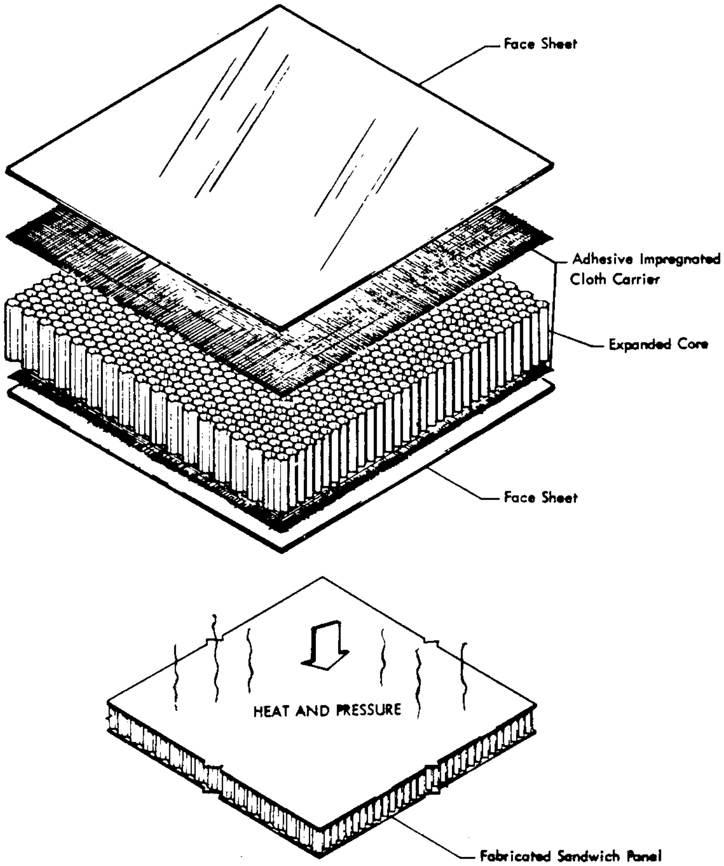


Fig. 1 - Bonded honeycomb sandwich structure

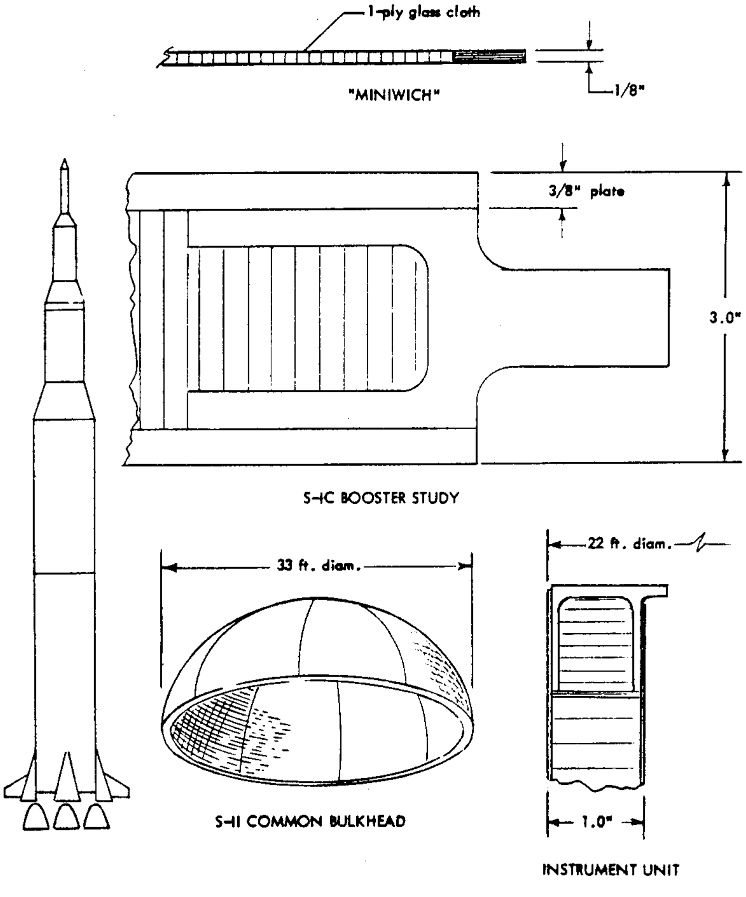
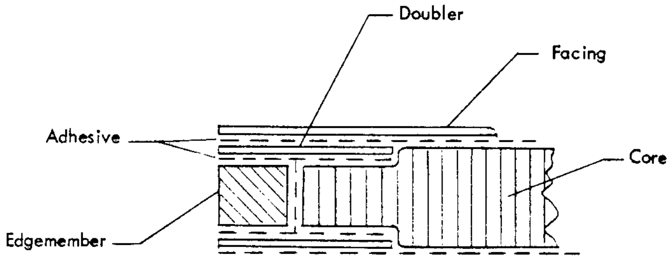
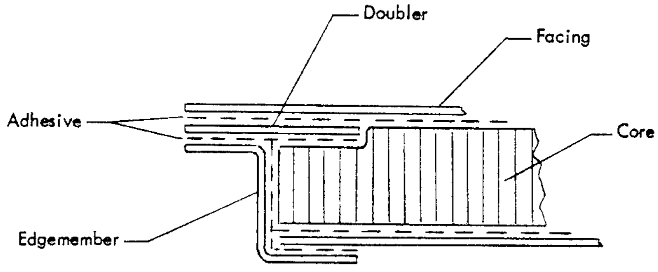


Fig. 2 - Space vehicle applications for honeycomb sandwich



FULL-DEPTH EDGE



STEPPED EDGE

Fig. 3 - Basic approaches to sandwich panel-edge design

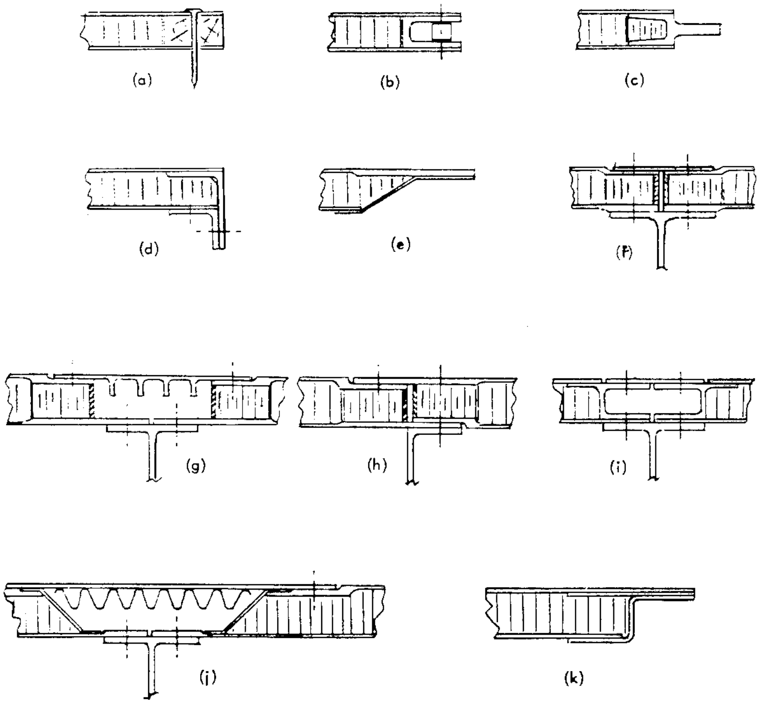


Fig. 4 - Typical edge designs

HONEYCOMB FASTENING REQUIREMENTS AND APPROACHES

Fastening requirements for sandwich fall generally into two categories: Localized load attachment to the center of a panel such as from a support or strut (this situation may be continuous as with attachment to an intermediate wing spar or fuselage frame); and panel-edge fastening.

There are also two basic approaches to sandwich panel-edge design: A full-depth edge approach, and a stepped-down zee-edge type (Fig. 3). The full-depth edge usually contains a separate doubler for each face for added attachment strength and to provide the necessary bolt bearing area. The doubler may be integral with the facing. The other requirement is for a compression-resistant member in the region of the fastener, shown in Fig. 3a as a block. Full-depth edges are stiffer and

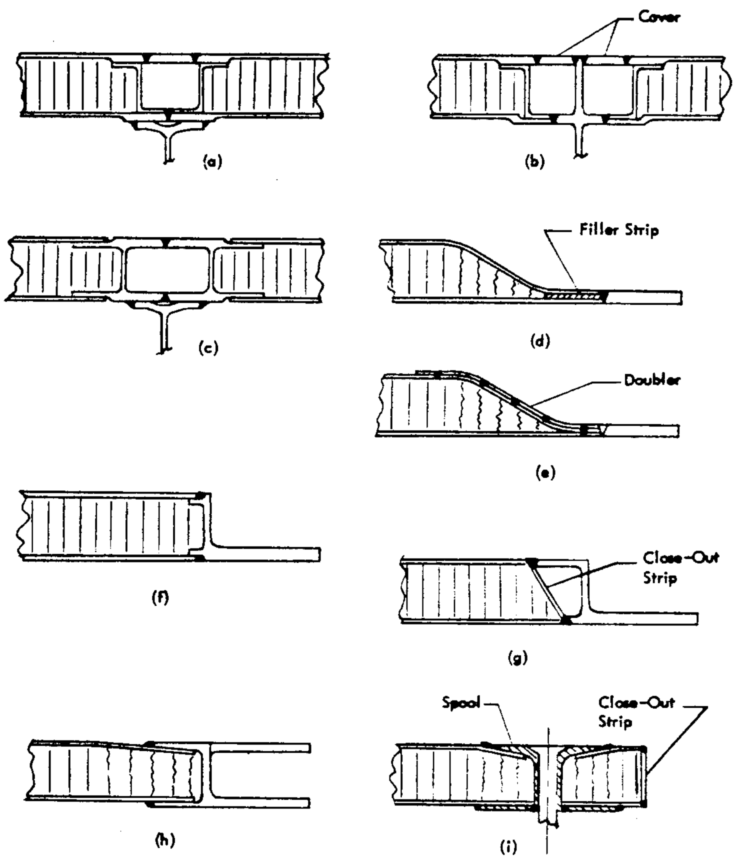


Fig. 5 - Weld attachment joint concepts

stronger because the loading eccentricity is considerably reduced when the structural loads are introduced directly into each facing. The zee-type edge (Fig. 3b), mainly depends on the strength and stiffness of the core to force the structural load out (or in) through one panel facing only. This concept is sometimes simpler and lighter, and results in shorter fasteners.

PANEL EDGE DESIGNS - Panel edge designs seem to be nearly limitless, and this is one feature that makes honeycomb sandwich challenging to a structural designer. Every new use seems to warrant a new edge design. Several edge designs may accomplish the same purpose, but all are not necessarily equally desirable. Fig. 4 illustrates some typical designs gathered from various sources—most of them have been described in technical magazine articles. Concepts 4a, 4b, and 4c are simple but require a good thickness match of edgemember and core for proper fit to eliminate a peel prone condition. Thickness match is a problem sometimes solved by cutting the core several hundredths of an inch thicker than the edgemember, and then sanding the core flush with the edgemember on fabrication "fit up." Concept 4f depends on heavier density core to resist the compression force of the fastener. Since there is no edgemember in this design, the panel raw edge should be protected with a suitable potting (sealing) compound. Success of types 4f and 4i in axial compression depends on the stiffness of the spliceplate for resistance to buckling between fasteners.

Type 4h is a lap splice design which is structurally efficient. It has one bad feature, however; each panel has a protruding edge that would be vulnerable to damage and would require special care in handling to prevent damage to the panel prior to installation. Types 4g and 4j may be good for light loads with high insulation requirements, but would probably show more imagination in design than is warranted.

Welding as a Joining Means - Weld joining is especially applicable to sandwich fabricated by the welding, brazing, or diffusion bonding processes. Welding may be used to attach panels permanently to each other and to understructure, or welding may be used for adding edgemembers to prefabricated welded, brazed, or diffusion bonded honeycomb. Fig. 5 shows several concepts of each type. Concepts 5a, 5b, and 5c illustrate permanent attachment, by welding, of brazed or diffusion bonded panels. Type 5c could also be an adhesive bonded panel since there is no welding of a double thickness of material as in 5a and 5b. Welded joint specimens have been manufactured successfully at General Dynamics which, with proper tool design and cooling techniques, have allowed continuous welding of thin skins less than 1/4 in. from a bonded joint with no apparent degradation of the bond. Edge concepts 5d through 5i have been conceived for adding on to prefabricated welded honeycomb sandwich. Types 5d and 5e have the panel edge crushed and prepared for addition of an attachment member as a secondary welding operation. Types 5f, 5g, and 5h have a separate machined member which attaches to both skins. Type 5i illustrates the welded addition of an insert spool for each individual bolt and a welded-on panel edge closeout strip.

Nearly all the concepts shown so far (bonded, brazed, and

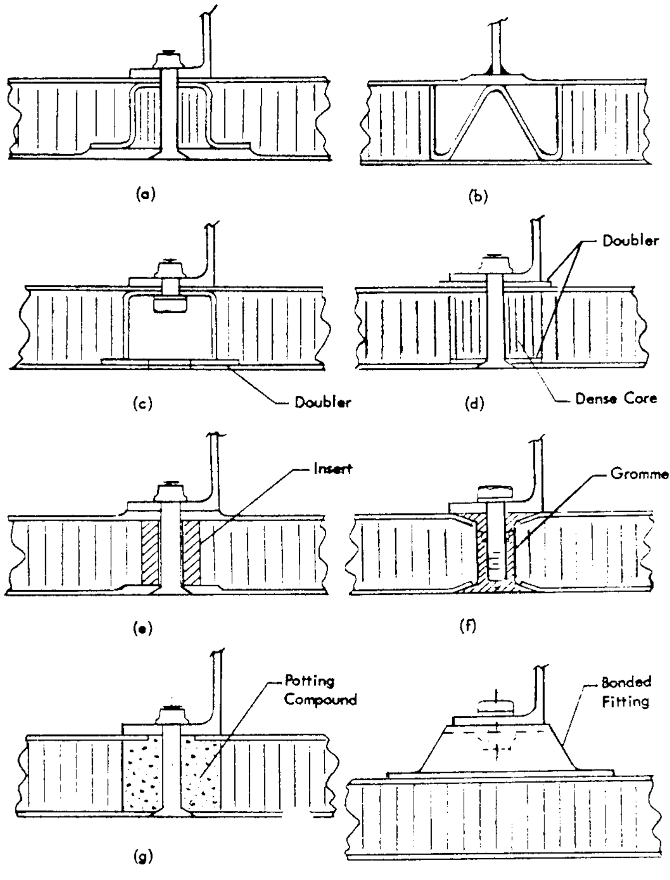
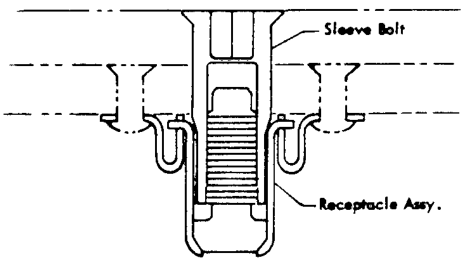
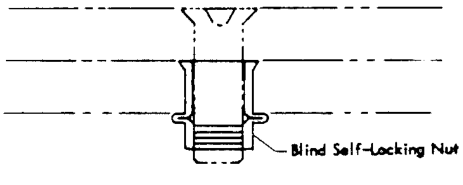


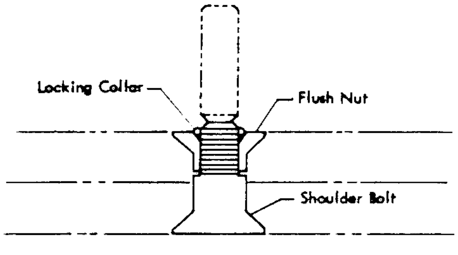
Fig. 6 - Local attachment concepts



MILSON STRUCTURAL ACCESS PANEL FASTENER



DAVIS PRESS NUT



DOUBLE FLUSH LOCKED FASTENER

Fig. 7 - Special fastener examples

welded) have both good and bad features so that the use of nearly all could be argued pro and con individually, but they do serve to illustrate the wide variety of thinking and inventiveness that has gone into sandwich panel edge designs.

LOCAL ATTACHMENT DESIGN CONCEPTS - There seems to be as great a variety of solutions for local attachment as for edge designs. The most common local attachment means is by provisions manufactured into the panel as indicated by concepts a, b, c, d, and e of Fig. 6. The inserts can be continuous if the attachment must be continuous. Many special grommets, illustrated in 6f, are available commercially, can be installed after panel fabrication, and require no previous panel preparation. Some designs make use of a potting compound which can be installed from one side after the panel is fabricated, as illustrated in 6g. Attachment fittings are sometimes bonded to the panel surface as shown in 6h, usually with stronger core in the panel under the fitting.

SPECIAL FASTENERS

Many special devices have been invented applicable to fastening honeycomb sandwich. The Milson access panel fastener, the Davis Press Nut, and the positive mechanical lock double flush fastener are three examples of specialty fasteners which originated at General Dynamics for specific uses (Fig. 7).

The Milson is a high-strength and quick-operating fastener system for attaching access panels which carry high-structural loads. It assures positive hole alignment for stressed panels which, when removed and the stress is relieved, no longer fit the hole pattern for reinstallation. The shoulder on the sleeve bolt allows threads to be engaged on the floating receptacle assembly prior to final alignment. An even torquing-up of fasteners around the perimeter of the panel then forces the structure back into correct alignment.

The Davis Press Nut answered the need for a simple, one-piece, blind nut. It is installed in the understructure by bulging on the back-side under the compressive force of the installing tool. The nut is serrated around the head or else oval-shaped to fit an oval hole for locking in place.

The double flush fastener consists of a countersunk shoulder bolt and a countersunk nut. When the bolt and nut are both installed flush with the structure, a soft-locking collar is pressed into a recess in the nut, the collar-installing stem is removed, and the exposed stub is machined off.

Quite often a special device is required in honeycomb fastening, but the large majority of fasteners used are simple, standard AN or MS nuts and bolts or rivets.

HONEYCOMB FASTENING IN PRODUCTION PROGRAMS

Fig. 8 illustrates examples of panel-edge designs used on production programs at General Dynamics. The B-58 represented the first major use of sandwich as primary structure

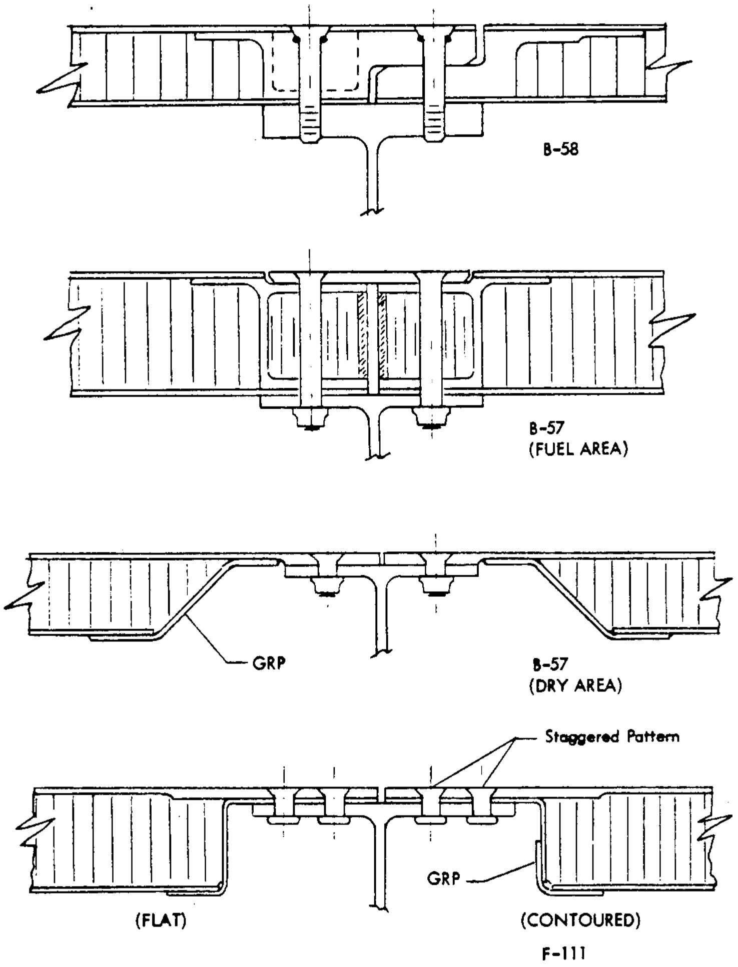


Fig. 8 - Production program designs

in a high-performance aircraft. The basic panel-edge design was a simple lap joint for panels that were 0.58-in. thick. One row of bolts was used to fasten each panel edge with an adjacent row serving as a clamp to help seal the lap splice for fuel containment. The fasteners were specially designed flush-type internal wrenching titanium bolts. The material was titanium for weight savings over steel. The flush heads had a groove around the base to accept an O-ring gasket and were a 60 degree countersink instead of the standard 100 degree. This resulted in a smaller, lighter head and a reduced edge distance requirement. The bolts were coarse thread for threading into tapped aluminum understructure, again a weight savings feature over steel nuts.

The B-57F wing design program used two very different concepts; one for fuel containment and higher loads, the other for dry, lighter-loaded areas. The 1.50-in. thick fuel tank panels had glass honeycomb core in the panel edge to resist compression of the bolts, and the edges were sealed and protected with an epoxy potting compound. The B-57 dry area design used several plies of woven glass cloth impregnated with an epoxy adhesive, commonly called "glass reinforced plastic" (GRP), to seal the edges of the 0.75-in. thick panels. In both cases the fasteners were standard NAS flush countersunk bolts with standard nuts.

The F-111 panel joint designs are also of the stepped-down type. The zee edgemember in the flat-panel design is a soft aluminum formed strip. A two-piece zee was substituted in the contoured panels, made up of a 90 deg angle aluminum edgemember strip which was easier formed to contour plus the addition of a GRP "knee" over the corner. The fasteners for these panels are mostly 2219 aluminum rivets with some standard flush bolts.

FUEL SEALING ASPECTS OF HONEYCOMB FASTENING

Sandwich skin panels are commonly used to form integral fuel tanks. The smooth, unbroken, uncluttered panel inner surface and sealed-cell honeycomb core are fuel tight. Fuel leakage, therefore, exists only at joints and fasteners, a problem which can be handled in a satisfactory manner.

If the fastener is installed coated with sealant, or with an O-ring gasket, or both, the problem is usually solved. On the B-58 program, it was found that installing a bolt with sealant was sufficient, and that also using a rubber gasket, was unnecessary.

Fuel may exist on one or both sides of a continuous intermediate attachment. If fuel exists on both sides as shown in Fig. 9a, a single row of fasteners is sufficient. The fasteners are installed coated with sealant; sealant is spread on the faying surfaces; and sealant fillets are applied over the nut and along the panel edges. In separating a wet area from a dry area with a

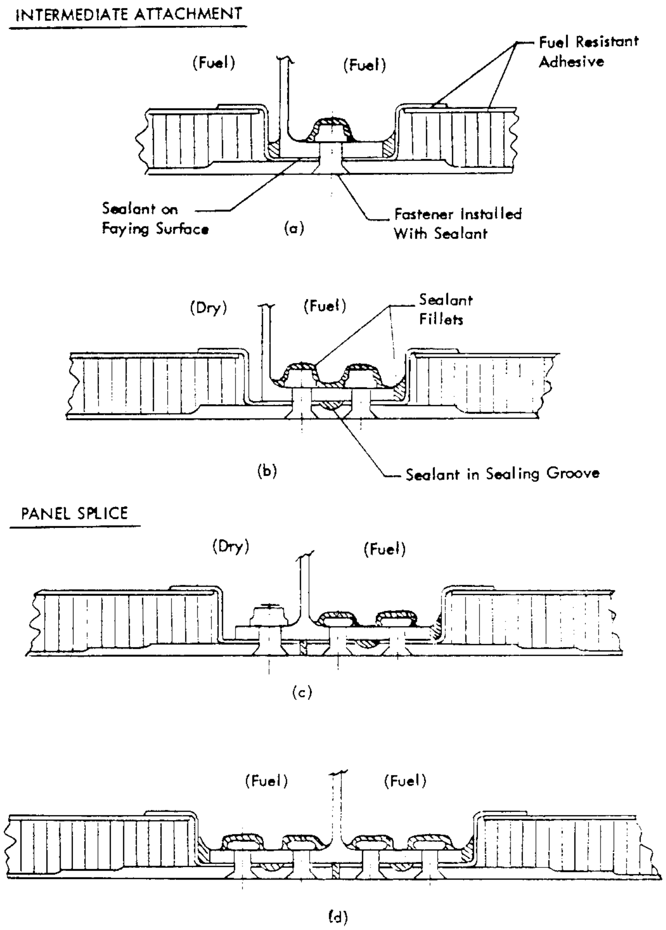


Fig. 9 - Fuel-sealing approaches to honeycomb fastening

continuous panel as shown in concept 9b, successful fuel sealing can be accomplished by a multiple barrier approach: a double row of fasteners for better clamping, a continuous sealant groove (filled through spaced injection holes), sealant on the faying surface, and internal fillets.

If the wet and dry areas are separated with a joint of two separate panel edges, as in concept 9c, the same four sealing aids are necessary for the wet side only. If each of the two panels must seal a wet area then the four sealing aids must be repeated for each edge as shown in concept 9d.

Fuel-sealing problems are believed to be somewhat reduced with full-depth edge sandwich. For an intermediate-type panel attachment, the sealing solution is the same for separating two fuel areas, or a fuel area and a dry area, as shown in Fig. 10a. The requirements are: the fastener coated with sealant, sealant on the faying surfaces, and fillets over the nut and along the understructure edges. The added stiffness of the full-depth edge with the use of an external spliceplate as shown in Fig. 10b is sufficient to require only a single row of fasteners per panel when splicing two panels. Sealant is required as shown only in the fueled area. For two panels separating a fuel and a dry area, and without an external spliceplate as shown in concept 10c, two rows of fasteners are required to clamp the panel edge sealing the fuel area. A continuous sealing groove between the fasteners is also used, as are sealant fillets and potting between the panel edges.

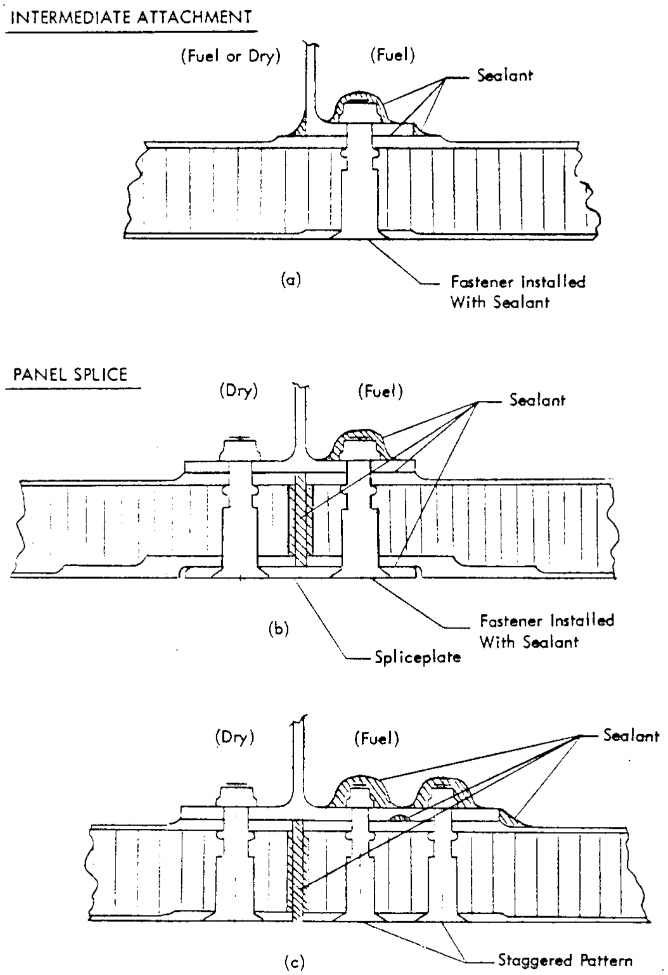


Fig. 10 - Fuel-sealing of full-depth edge sandwich panels

These concepts only illustrate the basics of multiple barrier fuel sealing in panel fastening. There are many more aspects which are also important such as minimum fastener diameter, maximum fastener spacing, minimum flange width and thickness, surface finish, surface mismatch, etc. (2).

RECENT R&D EFFORT IN HONEYCOMB FASTENING

An evaluation of the difference in structural efficiency between a typical bolted zee-edge design and a full-depth edge design using welding as a fastening method was made in a recent General Dynamics study (3). Welding was used for the full-depth edge for maximum attachment weight savings and to eliminate load eccentricity. The sandwich panel joint specimens were tested for shear strength as simple beams and for axial and bending strength as loaded columns plus transverse beam loads. The failing load divided by the specimen weight determined the Relative Efficiency Factor (R.E.F.). As shown in Fig. 11, for the stepped-down edge designs these factors are given as 23.7 (beam) and 21.8 (beam-column) for the standard zee, and 28.9 and 18.8 for the two-piece zee (aluminum and GRP). In comparison, the full-depth edge design specimens welded to the loading member (also in aluminum and designed

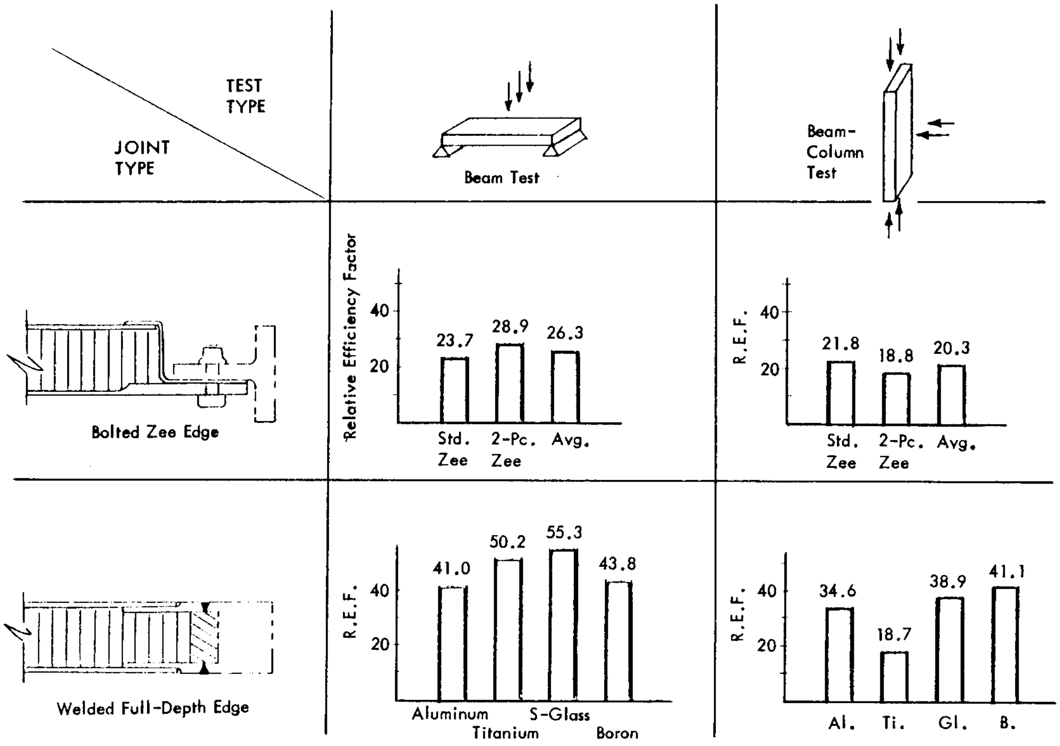


Fig. 11 - Sandwich joint efficiency study results

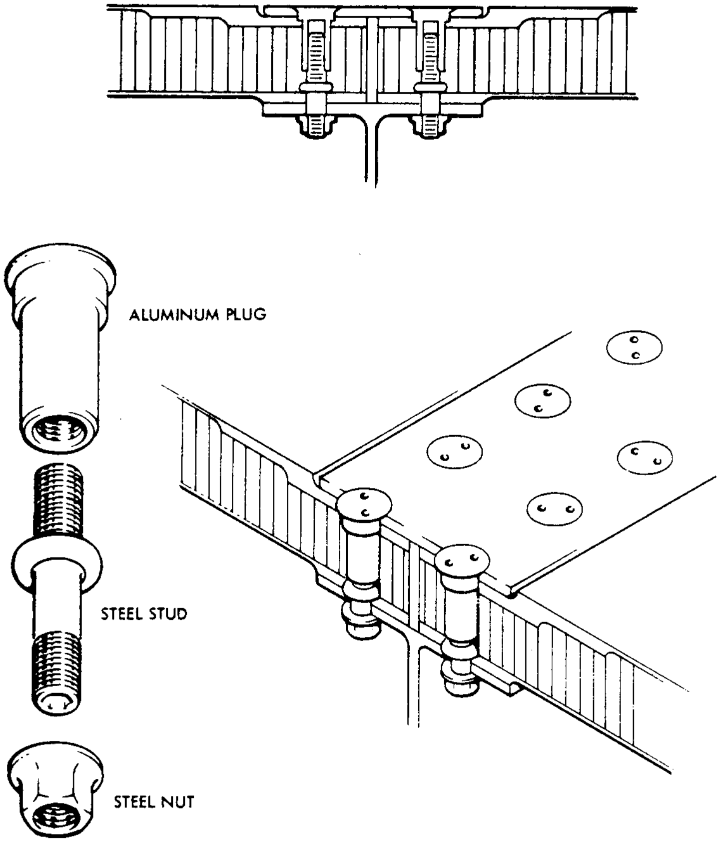


Fig. 12 - Stud and plug fastener for honeycomb structure

to the same load capability) yielded efficiency factors of 41.0 (beam) and 34.6 (beam-column). This represents a 56% improvement over the zee-edge beam design average of 26.3, and a 70% improvement over the zee-edge beam-column design average of 20.3. These results led to an investigation of other facing materials for test specimens, also designed to the same load capacity, for a further efficiency evaluation of the full-depth edge design.

Specimens with unidirectional S-glass facings resulted in efficiency factors of 55.3 and 38.9 for the two test types as

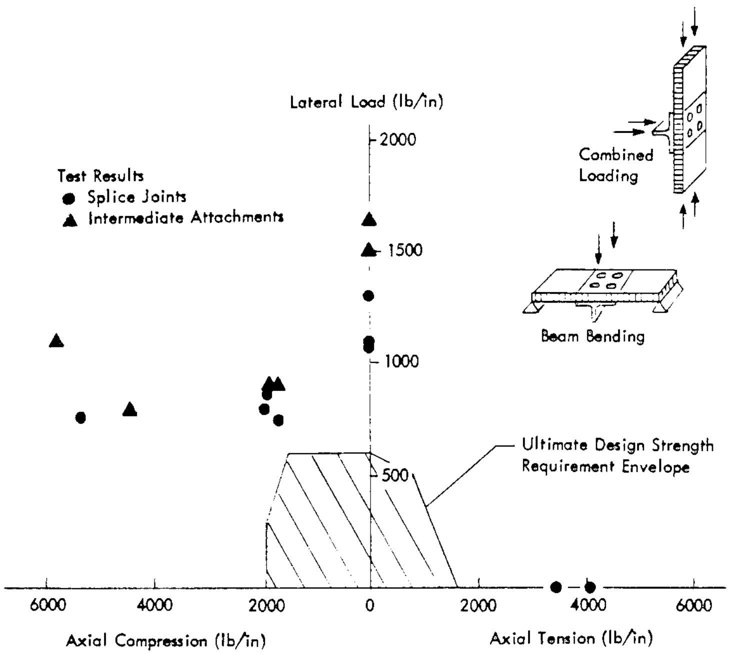


Fig. 13 - Stud and plug fastener–boron sandwich joint test results

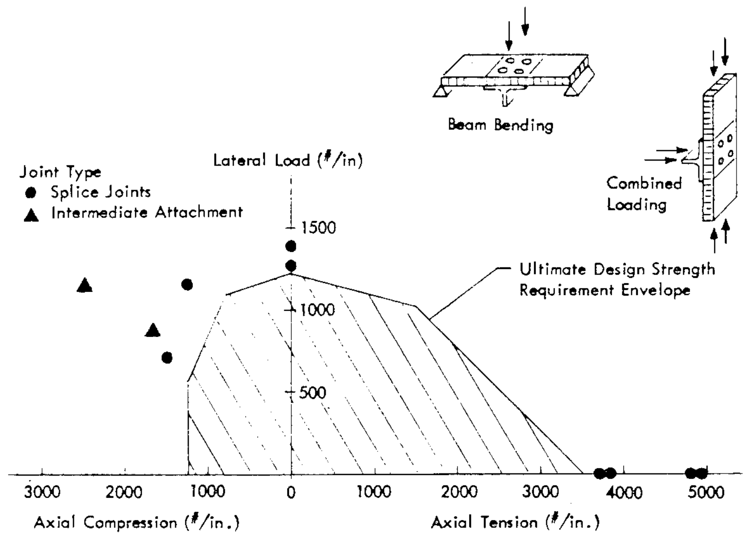


Fig. 14 - Stud and plug fastener–graphite sandwich joint test results

shown in Fig. 11. These are equivalent to a further increase in efficiency over the full-depth aluminum specimens of 35% and 12%, respectively. It should be mentioned that deflection of the glass-faced specimens was twice that of the aluminum ones.

Using titanium facings, efficiency factors of 50.2 and 18.7 were developed. The 50.2 represented a further increase of 22% over the full-depth edge aluminum design. The 18.7 factor was disappointing, however, and was attributed to the facings being welded directly to the stiff loading fixture. With deflection of the panel specimens under load, the facings had no bonded edgemember "slip joint" in which stresses could redistribute. The other full-depth specimens all had nonweldable facings plus bonded weldable edgemembers and, as shown in Fig. 11, the test results were much better. Finally, specimens with boron facings were made and tested (4). The corresponding efficiency factors established for the boron tests were 43.8 and 41.1. From an efficiency standpoint, as simple beams the boron panels by these tests were little better than aluminum and not as efficient as titanium or glass. The boron panels were the most efficient of all, however, when tested as beam-columns: 102% more effective structurally than the bolted stepped-down zee-edge design (in aluminum) and 19% better than the full-depth edge in aluminum.

The conclusion from this study was that use of full-depth edge designs is potentially attractive and that this basic concept with lightweight fastening methods for removable panels was worth pursuing.

As indicated earlier, the welded-edge design concept illustrated in Fig. 11 makes use of a separate bonded edgemember of weldable material when used with composite facings. Even in the case of a welded aluminum design, a higher strength, nonweldable aluminum facing can be used with a thicker, lower strength, weldable aluminum edgemember bonded in. Titanium edgemembers work very well with composite-faced sandwich due to the inherent strength-to-weight efficiency of titanium, and also because of a compatible thermal expansion coefficient.

CURRENT INTEREST IN HONEYCOMB FASTENING AT GENERAL DYNAMICS

The current interest is full-depth edge joints, with a stud-and plug-type fastener as illustrated in Fig. 12. The stud and plug fastener concept allows use of a full-depth panel edge without a separate edgemember or densified core. The full-depth edge results in added stiffness and the elimination of an edgemember saves weight, resulting in an appreciable increase in structural efficiency. The steel stud clamps the inner face and transmits the inner face load to the understructure, and the aluminum plug (and spliceplate) transmit the outer face loads from panel to panel. The joint can be designed in such a way that the stud and plug fastener can be used without a spliceplate for the outer facing; however, the joint concept loses much of its efficiency advantage if both facings are not spliced.

This stud and plug fastener with a full-depth edge sandwich joint has been tested recently in a Fort Worth Div. composite structure development program conducted under Air Force contract.

Using boron-epoxy honeycomb sandwich, six design variations of intermediate attachment and panel splice joints were static tested to failure in tension, three designs were tested in bending, and two designs were tested as beam-columns. Variations in fastener hole spacing, edge distance, and composite laminate thickness were examined as were the effects of load interactions at joints. The results of these fastener tests conducted on the boron composite sandwich specimens are plotted in the interaction diagram of Fig. 13, in which lateral load is plotted versus axial load, and the ultimate strength requirement envelope is shown. The test specimens representing the various designs all failed outside the ultimate strength requirement envelope. The conservatism is due to an unexpectedly high performance of the joint (5).

Graphite-epoxy honeycomb structure was also investigated. Again the stud- and plug-type fastener was tested in applications of full-depth sandwich as intermediate attachments and joint splices. The results of the graphite-epoxy honeycomb fastening tests are plotted in the interaction diagram of Fig. 14. The experience gained from the boron program resulted in a less conservative design approach for the graphite structure joints. As shown in Fig. 14, however, all test specimens sustained loads greater than the requirement of the ultimate design strength envelope (6).

The stud and plug fastener concept appears especially attractive for panel-edge joints, contributing to a higher load carrying capability and a net reduction in weight. This fastener is not considered as the ideal solution though, and ingenious fastening system improvements will doubtlessly come.

Table 1 - Design Influence Factors in Honeycomb Fastening

Category	Influence Factor	Joint/Fastener Consideration
Primary load	Intensity • Low • Intermediate • High	Corresponding joint strength, fastener size
	Direction • Tension • Compression • Shear • Combined loads	Joint material distribution, fastener type
	Internal pressure	Joint thickness, bending resistance, number of fasteners
Primary function	Access panel (frequent removal)	Serviceable joint edge, quick acting, retained fasteners
	Fixed panel • Dry area • Fuel containment	Fastener type, size, spacing
	Insulation • Sound • Heat	Full-depth edge, applicable fasteners
	Aerodynamic Smoothness	Flush joint design, c'sunk fasteners
Cost	Expendable structure	Inexpensive fasteners and edge members
	Value of weight saved	Lightweight material and fastener selection, lightweight edge design
Material selection	Plastics	Low bearing, shear-out strength
	Composites	Difficult hole preparation
	Aluminum	Bonded joint, fastener type
	Steel, titanium	Brazed, welded, diffusion bonded joints, applicable fasteners
	Superalloys	Joint concept complexity, welding, ceramic or other suitable fasteners
Fabrication method	Adhesive bonding	Latitude of design
	Brazing, welding	Limited in material and joint design
	Diffusion bonding	Titanium joint, simple design limitation

CONCLUSION

What are the honeycomb fastening design influences? Certainly, type and magnitude of load, primary function of the structure, allowable cost, choice of structural materials, and fabrication method are all important influences. Each of these categories have requirements which result in joint and fastener selection considerations, as shown in Table 1.

What is foreseen as honeycomb fastening problems of the near future where solutions are needed? First is an acceptable edge and attachment design for brazed and welded sandwich. No such design currently exists which is completely satisfactory. Second is better bonding adhesives for use in temperatures above 500 F. And third, better edge and joint designs and fasteners to go with an increasing use of advanced composite structure.

More sophisticated aerospace designs call for new fastening devices. And as honeycomb panel design applications are continually increasing, the fastening requirements include a multiplicity of functions: fasteners must provide a method of sealing against fuel, be compatible with the other metals, and be easy to install, inspect, remove, and replace. There is always room for improvement.

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