MECHANICAL FASTENERS FOR ADVANCED COMPOSITE MATERIALS

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ABSTRACT

Advanced composite materials, which are increasingly being used to build aircraft, have different properties than the metals they replace. Fasteners intended for composite-material joints must be designed and selected to allow for these differences. For example, blind fasteners (one-sided access) used to assemble composite-to-composite joints have been redesigned to expand to larger diameters to resist pull-through and cocking failures.

This paper reviews the fastener designs needed for composite materials. Topics discussed are galvanic corrosion, pull-through resistance, fastener rotation, installation damage, fastener galling and conductivity. A blind fastener recently developed by SPS Technologies is described to show how these requirements are incorporated.

Introduction

Commercial and military aircraft are now being built using advanced composites such as graphite-epoxy materials. Although these materials often reduce the number of structural components and offer alternative joining methods, mechanical fasteners play a vital role in aircraft assembly. In the commercial sector, composite materials are used in secondary structures; the NASA Aircraft Energy Efficiceny (ACEE) Program illustrates some typical applications (Figure 1). These ACEE structures were fabricated from separate graphite-epoxy spars, ribs and skins that were assembled with mechanical fasteners.

Composite materials differ from the metals they replace because they are not as ductile and their properties are directional. Fasteners develop clamping forces and resist joint loads which act in the through-the-thickness direction in a joint; this is also the weakest direction in a composite laminate. Experience with composite joints has identified some potential problems related to fastener design and selection.

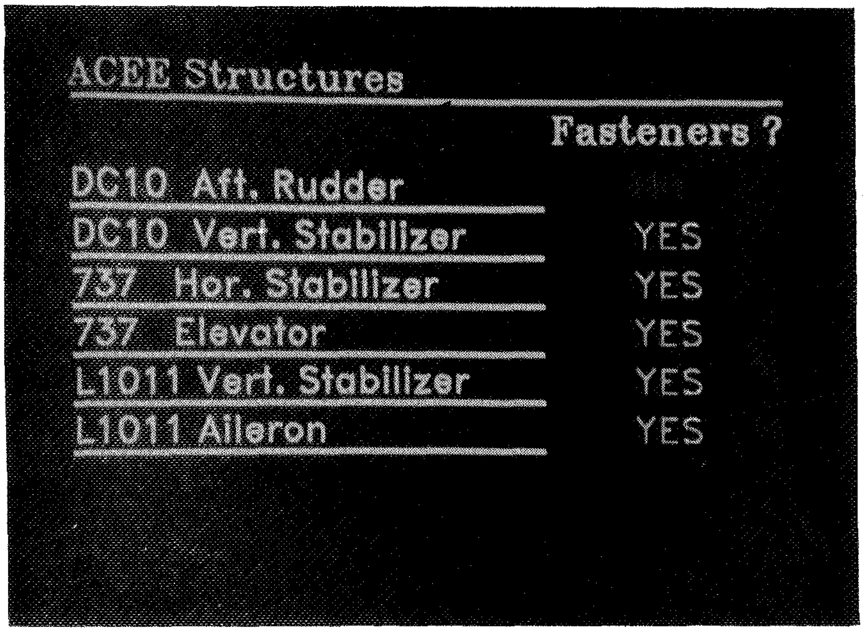

Figure 1. NASA ACEE program structures.

Galvanic Compatibility

When metal fasteners are coupled with graphite-fiber composites in a corrosive environment, graphite's low electrical potential causes the fastener to act as an anode and corrode. The rate at which corrosion proceeds is measured by the current density. Figures 2 and 3 rank the electrical potentials and current densities for various metals coupled with graphite. Current density is the better indicator of compatibility; 6Al-4V titanium alloy, for example, forms a

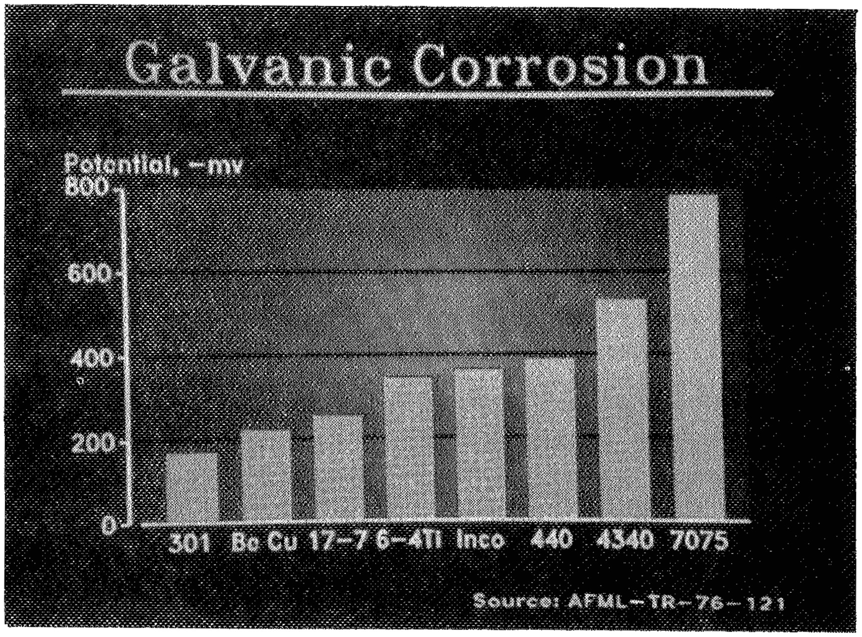

Figure 2. Potential of metals coupled with graphite (ref. 1).

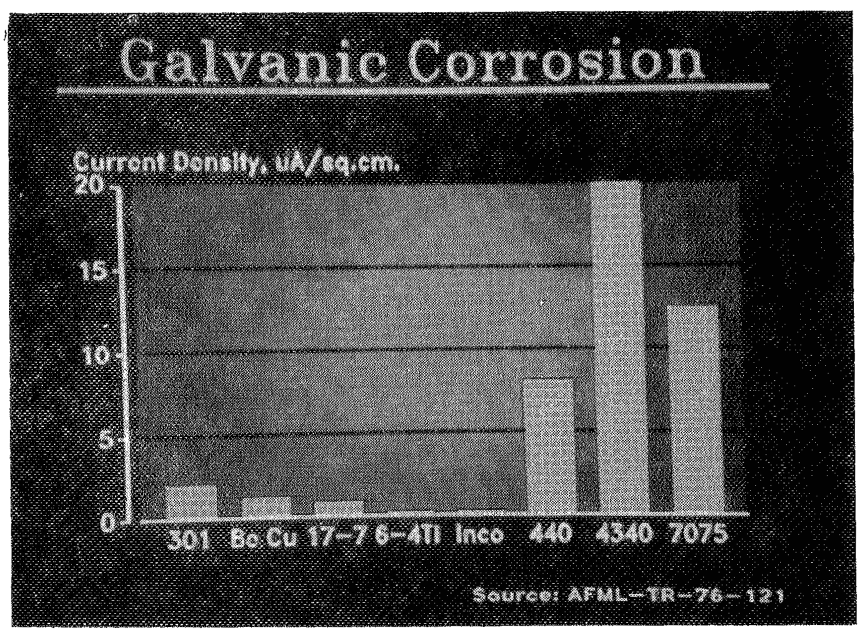

Figure 3. Current density of metals coupled with graphite (ref. 1).

tightly adhering protective oxide film which resists further corrosion. Titanium and its alloys, MULTIPHASE® alloys MP159® and MP35N®; and Inconel alloys 600 and 718 are compatible with graphite-fiber composites. These materials show no evidence of corrosion after 500 hours of 5% salt-spray testing. Corrrosion-resistant steels A-286, Ph13-8Mo, Ph17-7, 301, 304 and 316 are accepted for use with graphite-fiber composites. Occasionally these stain in salt-spray tests, therefore fasteners of these material are usually installed with sealant. Monel 400 and 405 materials will pit and rapidly corrode and are not recommended for graphite composites. Corrosion-resistant steel 440, alloy steels and aluminum alloys are not compatible with graphite. Even when fastener materials are compatible, sealants are generally applied to deny access by the corrosive environment.

Pull-Through Failures

Figure 4 illustrates the pull-through failure mode. The joint fails when through-plane shear forces pull the fastener through the laminate. The failure load is influenced by bending moments, in-plane stresses and dynamic effects that act in combination with the through-plane shear stress to lower the failure load.

Structures joined with shear, flush-head fasteners and blind fasteners are particularly susceptible to this type of failure. Pull-through strength can be improved by using fasteners with larger bearing circumferences because they develop higher through-plane shear loads. Current design practice is to use tension- rather than shear-head fasteners if pull-through strength is critical. Blind fastener applications have required washers under the blind head to provide desired strengths.

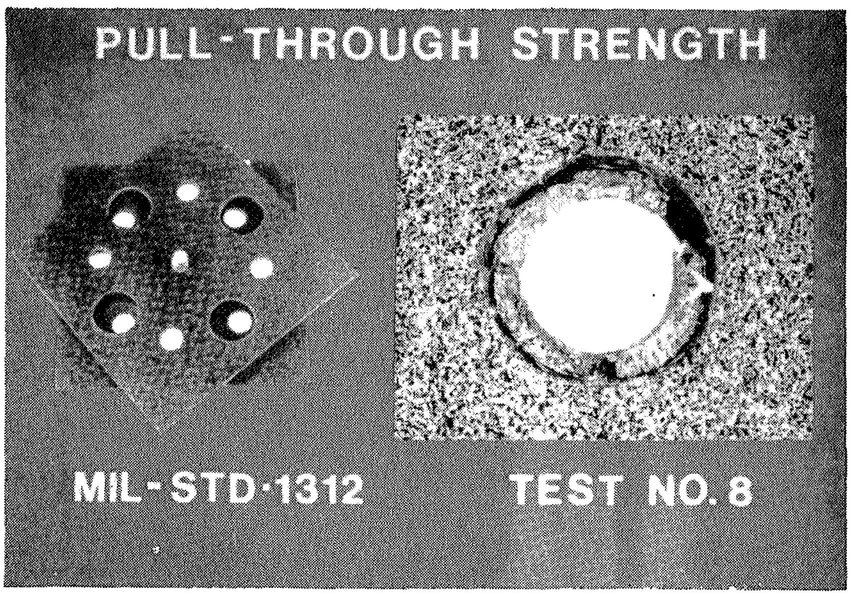

Figure 4. Pull-through failure in joint tensile strength test.

Fastener Rotation

Fastener rotation refers to a fastener cocking in the joint, not the turning action that occurs when a fastener is torqued. Shear loaded joints develop non-uniform bearing contact between the fastener shank and hole. At these highly stressed contact points, the composite structure fails and the fastener rotates into the laminate. Figure 5 illustrates a failed single-lap shear joint. Eventually, the fastener embeds or pulls through the laminate.

Fasteners with large bearing diameters resist cocking forces and retard rotation. Figure 6 summarizes joint tensile strength data for experimental 3/16" diameter, 130^{0} flush-head, titanium bolts with stainless-steel nuts. By increasing the nut flange diameter from .250" to .600" (1.3 to 3.2 shank diameters), the ultimate joint strength improved 36%. However, as Figure 7 shows, increasing flange diameter limitlessly will add weight and not improve joint strength. Based on weight efficiency (ultimate load/fastener weight) a flange diameter of 2X shank diameter optimizes this joint's strength.

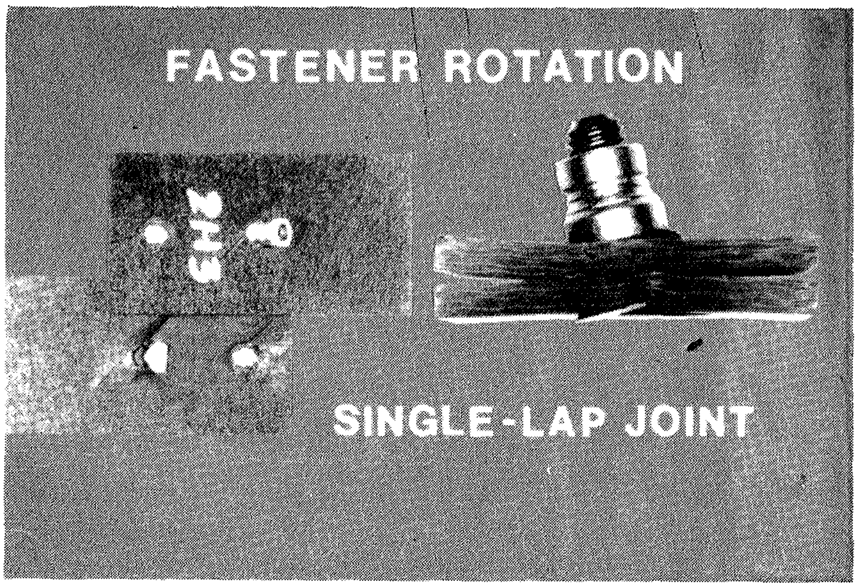

Figure 5. Single-lap joint illustrating fastener rotation failure.

Threaded Fastener Galling

Titanium bolts are widely used with graphite-fiber composites because they are galvanically compatible and lightweight. Airframe manufacturers have reported that galling (seizing) may occur when using titanium or stainless-steel prevailing-torque nuts with these bolts. This effectively destroys the bolt and nut.

To prevent galling, A-286 and 300-series stainless nuts must be coated with a dry-film lubricant and in some cases, first plated with cadmium or coated with aluminum. These finishes are not compatible and would be consumed in service but lubricate the nut or bolt for the initial assembly operation.

An alternative to the threaded fastener is a nonthreaded lockbolt with a swaged collar.

Installation Damage

Some fasteners developed for use in metallic structures will damage composite structures. Damage occurs when the clamping stress exceeds the compressive strength of the laminate; radial expansion in the fastener hole delaminates or buckles plies, impact forces delaminate the structure, or turning fasteners abrade or splinter the composite surface.

Current design practice is to avoid interference fits without using a protective sleeve, fasteners with inadequate bearing area, or rivets and blind fasteners that expand radially, and using rivet guns to install fasteners.

Conductivity

An electrically conductive path between the fastener and the structure is needed to protect graphite-epoxy structures during lightning strikes. Damage can occur at the attachment, exit and transition points (joints), with arcing a danger near fuel cells.

Measures to prevent galvanic corrosion often isolate the fastener with nonconductive sealants, coatings and lubricants. Improved fastener-to-hole contact and conductive coatings must be developed to solve this problem.

Blind Fasteners

Blind fasteners with their special design requirements challenge the fastener designer concerned with composites. Because blind fasteners can be installed from one side of the structure, large bearing diameters are difficult to achieve. In forming the "blind head" these fasteners must not damage the composite structure. Typical applications for blind fasteners include cover-to-spar joints in closing-out stabilizers, ailerons and rudders. These applications are truly "blind" since the fastener bearing surface created inside the structure cannot be seen and inspected. Therefore a blind fastener must be reliable. More recently, airframe manufacturers are evaluating honeycomb sandwich-to-composite joints containing blind fasteners where the fastener's blind head forms inside the core material against the sandwich face sheet.

The aerospace fastener industry is offering a variety of new fasteners for composite materials. One of these is the COMP-TITE™ blind fastener. Shown in Figure 8, it is comprised of four elements: a nut, corebolt, coiled washer and sleeve. During installation (Figure 9) the coiled washer and sleeve are driven over the tapered end of the nut and expanded to their final diameters. The formed washer is then seated against the joint surface as the corebolt advances.

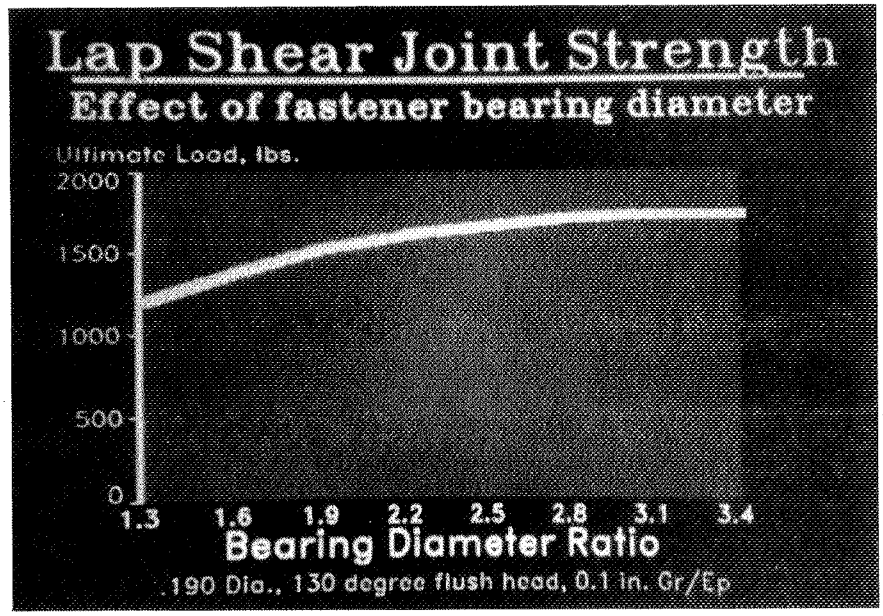

Figure 6. Effect of nut bearing diameter on joint strength.

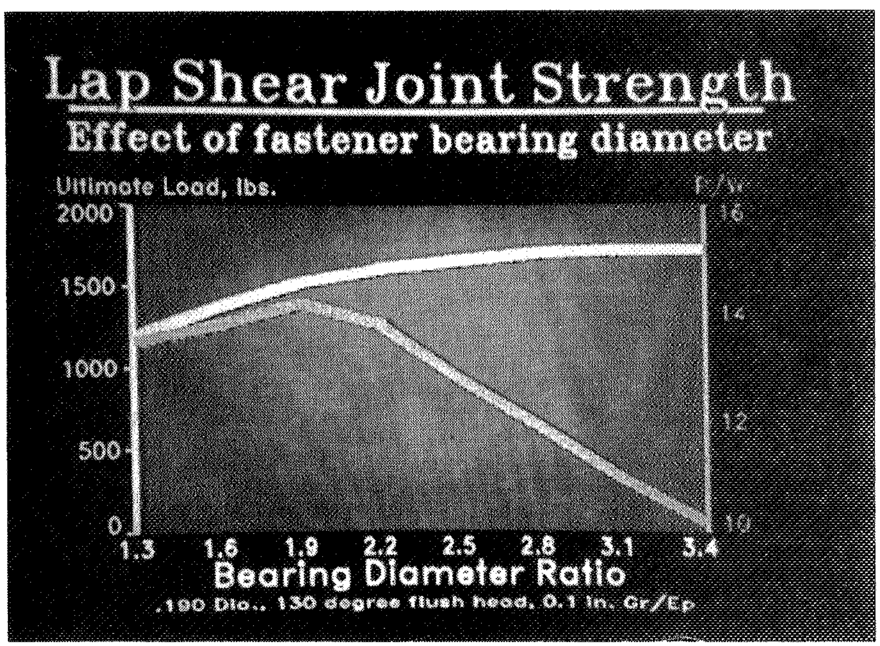

Figure 7. Effect of nut bearing diameter on joint strength versus joint efficiency.

The corebolt drive stem shears at a torque-limiting groove after the joint is clamped. This design approach achieves a large blind-side bearing diameter while minimizing the possibility of joint damage due to excessive bearing stress. A separate washer element also protects the composite surface should the sleeve turn during installation.

Other design advantages are a flat washer bearing surface, consistent blind-head diameters, no fastener hole expansion, and improved installation tolerance of hole condition.

The 6Al-4V titanium nut, MULTIPHASE® alloy MP159® corebolt, 304 S/S sleeve and 316 S/S washer satisfy galvanic compatibility requirements.

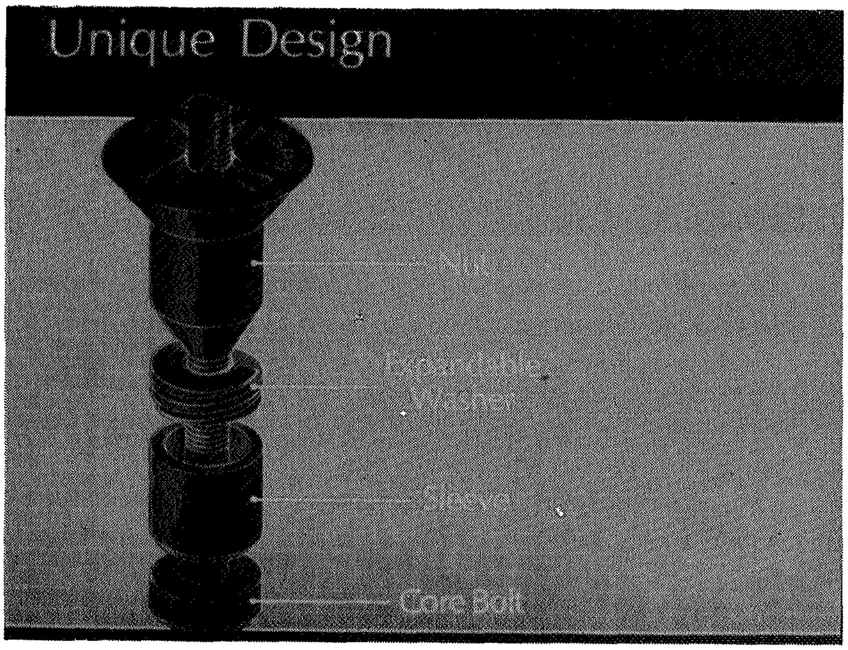

Figure 8. COMP-TITE™ blind fastener.

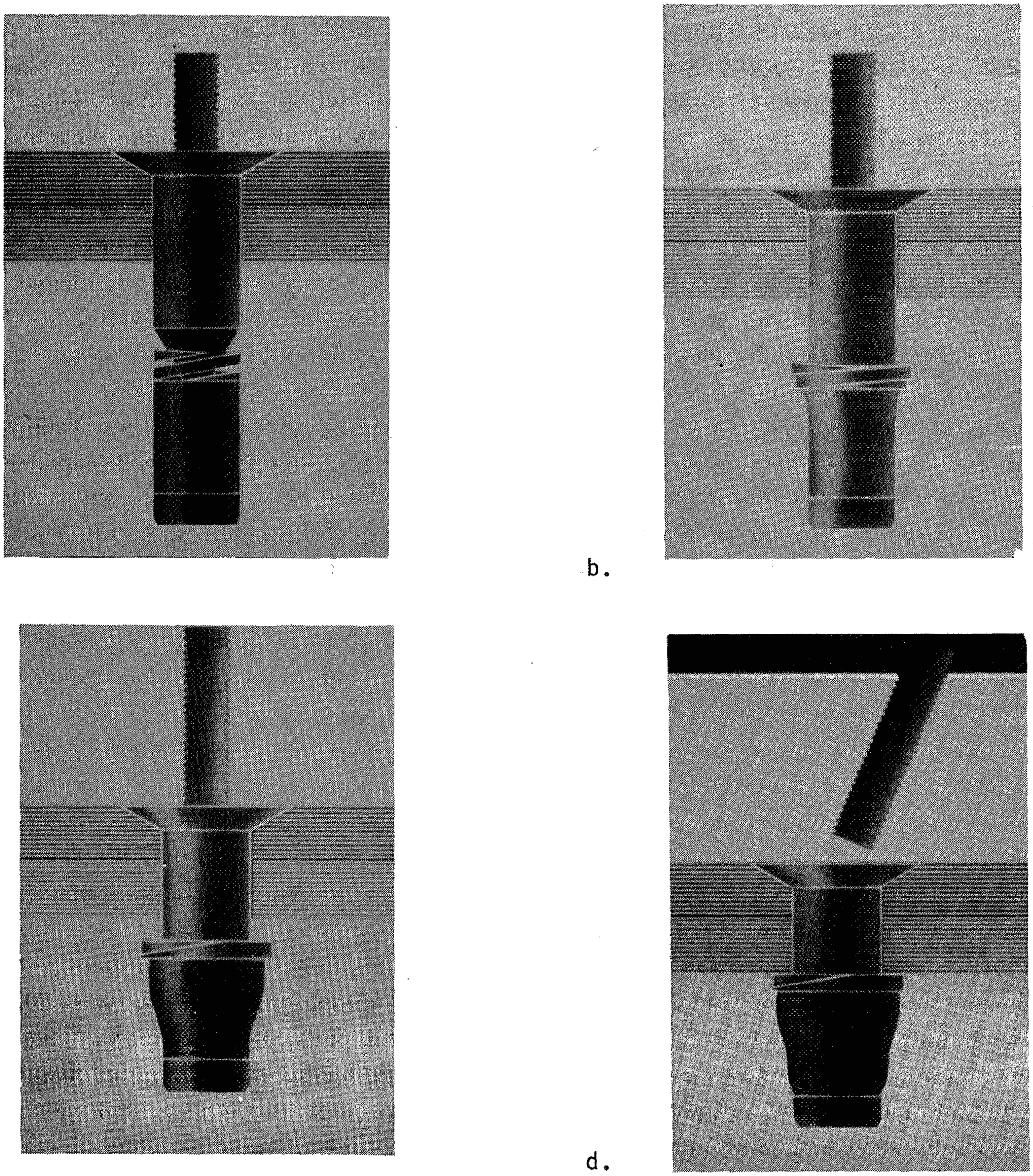

Figure 9. COMP-TITE™ blind fastener installation.

Concluding Remarks

Fastener selection for bolted composite joints should involve a review of the considerations addressed in this paper. The fastener industry is providing new fastener designs which can improve joint strength and reduce corrosion problems. One of these is the COMP-TITE™ blind fastener which was designed for improved pull-through strength and cocking resistance.

Reference

1. B. A. Miller and S. G. Lee: "The Effect of Graphite-Epoxy Composites on the Galvanic Corrosion of Aerospace Alloys", Six Force Materials Laboratory (AFML); Wright Patterson Air Force Base, Ohio, TR-76-121, September 1976.