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(R) Sealing of Integral Fuel Tanks

RATIONALE

This SAE Aerospace Information Report (AIR) revision updates engineering designs including current practical and conservative methods for producing a reliable aircraft integral fuel tank sealing system.

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1. SCOPE

This SAE Aerospace Information Report (AIR) presents preferred practices for sealing of aircraft integral fuel tanks, including rework of applied fuel tank seals. It addresses engineering designs for integral fuel tanks as they are currently found in practice; and discusses the most practical and conservative methods for producing a reliable, sealed system.

Although this AIR presents practices for sealing of integral fuel tanks, the practices presented within this report are practices that are carried throughout sealing that include both pressure and environmental aircraft sealing.

Design preferences for optimum sealing are not within the scope of this document. Such discussions can be found in the Air Force sponsored report, entitled Aircraft Integral Fuel Tank Design Handbook, AFWAL-TR-87-3078.

Key objectives of the fuel tank sealing process are to produce a sealing plane that is leak-free and corrosion resistant, especially at fastener locations, at environmental and operational conditions expected for the life of each air aircraft. Factors that can influence the outcome of this process are:

a. How well the basic design lends itself to good sealing (key design factors to consider include accessibility and minimal movement, among others).

b. The choice of sealant; where it is applied; how it is applied.

c. How well the substrate surface is prepared.

d. Whether sealant fillet dimensions are optimum for aircraft configuration and flight dynamics.

e. The degree of resistance of the sealant to the fluid and thermal environment.

f. The degree of engineering insurance — i.e., application of adhesion promoters to sealant bond surfaces, application of organic topcoats over sealants, proper drainage of the fuel tank, etc. — employed for technical risk reduction.

Effective and efficient sealing of aircraft fuel tanks are prime considerations in both commercial and military aircraft designs. Sealant fillets inside the tanks are considered to be primary seals.

Of nearly equal importance is corrosion control. Sealants are used for fuel containment and corrosion protection, but the purpose of use should never be confused. It is generally accepted, for example, that a major objective of faying-surface sealing is corrosion control. The faying-surface seal is not considered to be a primary seal, except in adhesive-bonded systems; the faying surface seal, however, plays an extremely important role as a secondary seal. It limits the length of a leak path and is a permanent, stable, protected, and essentially non-dislodgeable seal that is sandwiched between two mating surfaces. Extensive use of faying-surface sealing is highly recommended.

Sealing philosophies differ within industry and government. However, as stated in 3.1, there is much greater agreement than dispute. If a particular fuel tank sealing approach appears to be clearly more reliable, keeping production cycle time and costs in mind, it will be identified as a preferred method.

This report is based on technical opinions from a broad cross-section of engineering experts who specialize in aircraft sealing.

The user should consider the engineering requirements and options provided by this report; then develop an individual course (or plan) of action from a somewhat more informed position.

2. REFERENCES

See Appendix A.

3. SEALING PHILOSOPHY

3.1 Sealing Objectives and Basic Categories

The main objectives in aircraft fuel tank sealing are to preclude fuel leaks for the long term and to avoid the intrusion of moisture that can cause corrosion, especially at fastener locations.

Integral fuel tank designs fall into two basic categories: those with full access to the interior of the tank and those with limited access. Those in the latter category are repaired by: (1) injection of channel sealants from the exterior; or (2) retightening or replacing certain types of fasteners from the exterior; or (3) gaining access to the interior of the tank through disassembly of structure, as necessary, to reach the leak source (see Section 12).

Except for channel sealing, all sealing is done inside the fuel tank. Factors to be considered in sealing integral fuel tanks for the two basic categories are given in the following paragraphs.

3.1.1 Designs Providing Interior Access

Leak paths found in interior access designs originate from skin splice joints, spar-to-web joints, dry-to-wet bay interfaces, and access doors. Faying surfaces, lap joints, butt joints, fastener holes, and any other possible path from wet-to-dry side represent opportunities for fuel leakage and for moisture intrusion, which may produce corrosion. (Moisture from water that has combined with fuel inside the tank also is a potential source of corrosion.) It is generally accepted by the industry that the primary seal plane is formed by sealant applied inside the fuel tanks at butt joints, lap edges, and fasteners.

Fay-surface sealing is also considered to be an important type of sealing because it limits the length of leak paths, contains the fuel, and prevents corrosion. Fay-surface sealing is an essential adjunct to fillet sealing to produce a reliable, sealed fuel tank that does not leak during the operational life of the aircraft.

3.1.1.1 Fasteners and Joints

All fasteners and rivets (even interference fit fasteners) at fuel tank boundaries should be wet installed and overcoated to ensure that the tank does not leak. All fasteners that penetrate dissimilar metals must be wet installed with fuel tank sealant; for example, see Figure 2 of ARP4118. If pre-cleaned fasteners are not available, the fasteners to be wet installed shall be cleaned, using AMS3167 or AMS3168, prior to installation. Dry film lubricants need not be removed but adhesion promoters should be applied before wet installation. It is mandatory that cadmium-plated permanent fasteners be coated with a fuel-resistant epoxy primer before adhesion promoter is applied. Solid-film lubricants that meet the engineering material property requirements of MIL-PRF-46010 need not be removed provided adhesion promoter is used. MIL-L-23398 coating, on the other hand, must be removed and adhesion promoter should be applied before sealant application.

Corners and joggles shall be injected or pre-packed with fuel tank sealant, except at a junction where three planes meet. Such a location shall be fitted with suitable reinforcement such as corner fittings or screens. Surge boxes and vent boxes should be sealed on both sides. Both sides of common fuel and pressure bulkheads should be sealed. All butt joints, lap joints, and seams should be sealed with full fillets.

3.1.1.2 Faying Surfaces

Fay-surface sealing should be employed on all lap joint surfaces in fuel tank boundaries and under all attachments to the fuel tank. Major examples of fay-surface sealing applications include:

a. Skin-to-stringer interfaces.

b. Web-to-spar chord.

c. Spar chord-to-wing skin.

d. Surface under any attachment to aircraft skin.

e. Shims installed in faying surfaces.

After faying-surface sealant is applied, the two surfaces are joined (or clamped-up) to attain 100% extrusion, or squeeze-out of the faying surface sealant. Squeeze-out of the fay seal must be continuous around the entire periphery of mated fuel tank structures. Next, excess sealant is removed (while sealant is still wet), the surface is cleaned, and a full fillet of fuel tank sealant is applied around the periphery.

To simplify the manufacturing process, pre-assembly sealing should be done to the greatest extent possible. This includes application of fillets around faying surfaces on sub-assemblies so that 90% of the sealing is complete on assembly.

Some sub-assemblies that are often pre-assembly sealed include:

a. Upper and lower wing panels.

b. Front and rear spars.

c. All intermediate bulkheads and webs, and

d. Boost pump cover plates.

Remaining fillets are then applied.

Injection sealing (or non-pressurized groove-injection sealing) can also be a form of sealing that is accomplished during assembly. Where possible, sealants should be injected while the faying-surface sealant in these locations is still uncured.

Final assembly sealing includes injection seals, hole and slot seals, brushcoat (when specified), and fillet seals. All leak path entry edges should be covered with a minimum of 0.15 in (3.8 mm) of sealant. The minimum sealant bondline on all fuel tank structure should be 0.250 in (6.35 mm).

Pressure testing of faying surfaces of an assembled tank before fillets are applied reveal the effectiveness of the faying-surface seal. Some original equipment manufacturers (OEMs) do not fillet seal sub-components until after final assembly pressure test, in order to monitor sealing effectiveness.

Generally, repairs should be made by fillet sealing the edges of assembled faying surfaces (see 12.4.1.3), and not by disassembly of the faying surfaces. Faying surface seals can be repaired with a high-pressure injection gun and hollow injection bolts; the aircraft manufacturing industry refers to this method as “pressurized groove-injection sealing.”

3.1.1.3 Considerations in the Adhesive Sealing of Tanks

Adhesive sealing of faying surfaces of an integral fuel tank with a structural film adhesive requires particular design characteristics and special processes and equipment. Mating surfaces must not mismatch by more than 0.015 in (0.38 mm). Tooling must be inspected and verified periodically. After application of film adhesive, full clamp-up of structural fasteners must be accomplished to produce the necessary mechanical force (or pressure) to ensure satisfactory adhesive bonding. Lockbolts, threaded fasteners, and crimp pins installed with non-metallic seal washers must be located in wet-to-wet areas of the fuel tank. The entire assembly must be placed in an oven to cure the adhesive per manufacturer instructions. Usually, structural voids at fuel tank boundaries are filled with polysulfide or polythioether sealant after oven cure is completed. Sometimes a high-temperature sealant (conforming to AMS3276, AMS3277) can be used to prepack voids.

3.1.2 Designs with Limited Access

Designs with limited (or no) access should use pressurized groove sealing or channel sealing to facilitate fuel tank sealing rework or repair.

3.1.2.1 Considerations in Groove-Sealing or Channel-Sealing

Groove-sealed or channel-sealed designs incorporate a continuous groove or channel in the faying surface around the entire seal plane. This allows injection of non-curing sealant from the outside by means of a series of ports spaced at 3 to 5 in (76 to 127 mm) intervals. Some groove designs have the groove adjacent to a row of fasteners, or between two rows of fasteners; while others have the groove in-line with the fasteners, so that sealant will surround each fastener.

The groove design offers distinct advantages in thin-winged aircraft, such as military fighters, where internal access is extremely limited or impossible. This design offers a major advantage to this type of aircraft, since repairs can be made quickly under battle conditions using a high-pressure sealant injection gun and an adapter. Fuel tanks need not be emptied to repair a leak. This design is selected for other aircraft due to the simplicity of maintenance and repair.

Grooves are machined into aluminum or titanium alloy component parts of the fuel tank faying surfaces; they are molded into carbon-reinforced epoxy, carbon-reinforced bismaleimide, or other composite parts. In the channel for pressurized, non-curing groove-injection sealant, fastener spacing is a maximum of six times the diameter of the fastener. The minimum diameter of fastener used in channel seal grooves is 0.250 in (6.35 mm).

Ribs that do not assemble to skin splices, but which form the internal structure, do not normally require channel sealing. Self-sealing fasteners are used (Figure 1). Fasteners not located in the groove path are of self-sealing and can be tightened or replaced from the outside.

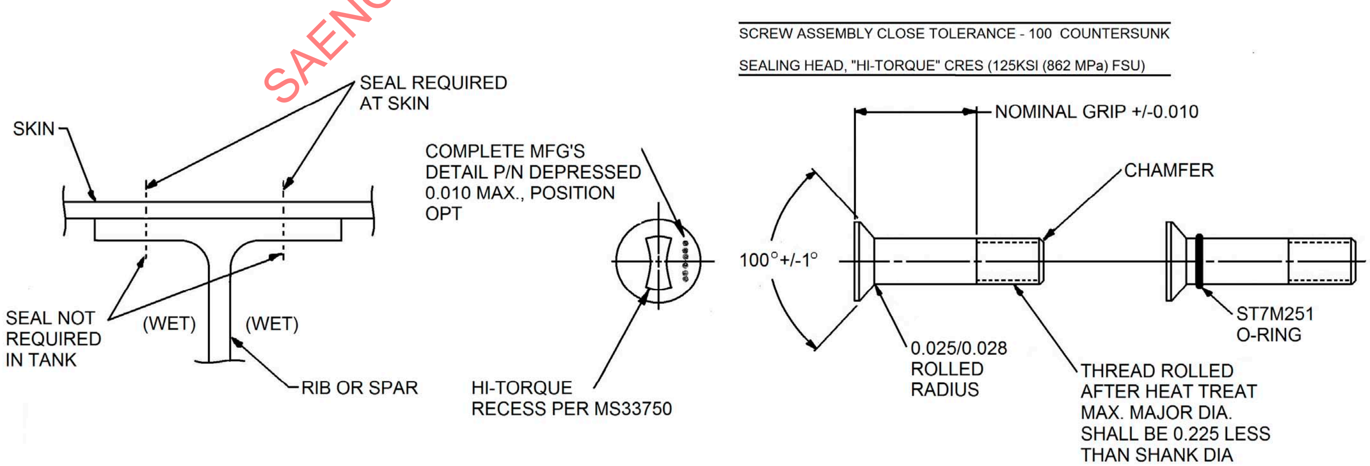

FIGURE 1 - RIB/SKIN ASSEMBLY WITH SELF SEALING FASTENER

The size of the groove, the distance between the injection ports, and design features that can inhibit the flow of sealant through the groove are factors related to design that greatly affect the ease of sealing and, eventually, seal integrity. In many groove designs, joint intersections produce voids or open spaces in the groove line. Restrictions, called dams, made of polysulfide or polythioether sealant (AMS-S-8802, AMS3276 or AMS3277) or epoxy adhesive (such as Fusor 309) are formed-in-place to preserve the continuity of the groove. Dam configuration includes chamfered lands at the ends (or terminations) of each dam. Metal clips (or retainers) may also be used to hold the dams in place.

It is best to fay surface seal around the grooves to provide the best seal. Shims should be avoided as much as possible. Should a shim be required, it should not go across the groove and should be faying surface sealed.

Liquid shims made of epoxy, or adhesively bonded solid or laminated shims, are used to improve the basic structural fit-up. Except for all fuel tank boundary locations, liquid shims may be used in integral fuel tanks, unless specifically prohibited by the engineering drawing. Note: flexibilized liquid shims may be used in fuel tank boundaries provided testing is performed to determine thickness requirements and have been approved for use by appropriate engineering.

The use of shims should be controlled by engineering drawings or applicable specifications for allowable thickness and number of shims in accordance with the aircraft manufacturer's documents.

Sealant-related factors concern application (processing) and operational performance. Flow characteristics are important. Non-curing, groove sealant must seal all gaps and stay in place, yet be injectable. If the viscosity is too low, separation of filler material from the sealant can occur, especially under high-injection pressures, resulting in sealant flowing into the tank. Bead-filled channel sealants are designed to be effective in filling larger gaps; but these bead-filled sealants can be more difficult to extrude because of their relatively-high viscosity. One technique that may be used to alleviate this problem is to warm the channel sealant to approximately 95 °F (35 °C) maximum, to improve the extrudability (or flow) of this sealant.

Sealant is injected at pressures of several thousand psi by sealant guns designed to augment the incoming plant air pressure of 80 to100 psi (552 to 690 kPa) by approximately 40 to 50 times. It is possible to damage the structure, or to distort the aircraft wing skin, losing sealant into the tank if pressures exceeding design structural limits are applied. Minimum design thicknesses for tank components in the area of the channel seal shall be able to withstand the maximum load pressures induced by the groove injection gun.

Pressure regulators on high-pressure channel sealant injection guns are essential. Sealers must be made aware of injection pressure restrictions for the particular design they are servicing. Groove sealant can be extruded with as little as 40 psi (276 kPa) input pressure from plant air, using a 70:1 ratio.

Common failure mechanisms causing leaks in channel-sealed aircraft include:

a. Excessive mismatch of parts [i.e., greater than 0.005 in (0.127 mm)].

b. Large joint deflections.

Particular attention must be given to selection of a channel sealant that ensures good performance, consistent with the aircrafts design configuration and expected operational environment.

3.2 Redundancy in Sealing to Mitigate Technical Risk

Fuel leaks have been one of the most serious of integral fuel tank problems and a very expensive item of operational maintenance and repair. A sealing plan that maximizes redundancy can be a source of great savings during the operational life of the aircraft. Several methods for introducing redundancy into aircraft fuel tank sealing engineering requirements are provided in the following paragraphs.

3.2.1 Faying-Surface Sealing

This type of fuel tank sealing should be used to the greatest extent possible. Faying surface sealing reduces risks of incurring fuel tank leaks and corrosion, especially at fastener locations. Fay seals also fill potential leak paths, thus, making repairs easier and less expensive.

3.2.2 Wet Installation and Overcoating of Fasteners

Fasteners are the principal sources of leaks. An investigation by the U.S. Air Force's Flight Dynamics Laboratory in 1983 revealed that even with interference fit fasteners, unless an interference of at least 0.003 in (0.08 mm) is present, acceptable sealing by the fastener alone could not be expected (see report number AFWAL-TR-83-3089). Additionally, if one considers the possibility of incurring out-of-round holes and other potential manufacturing errors, it becomes evident that there is significant value in wet installing and overcoating fasteners in aircraft fuel tank structure. Overcoating can be accomplished by applying multiple brushcoats (when specified), by applying a brushcoat followed with an extrudable Class B overcoat, or by the application of a single, continuous coat of Class B coat alone.

3.2.3 Fillet Sealing - Extrudable Sealant (Class B) Over Brushable (Class A or Class C) Fuel Tank Sealant

A thin layer of Class A or Class C sealant is worked into the seams and around fasteners with a brush to ensure all leak paths are closed. Prior to when the Class A brushcoat becomes tack-free, Class B material is applied to form fillet and fastener seals. If the brushcoat reaches tack-free before Class B sealant is applied, the brushcoat must be allowed to cure; then the brushcoat is scuff sanded, cleaned, and adhesion promoted prior to application of Class B material. The more viscous Class B sealant provides sealant dimensions necessary for protection against joint movement, temperature cycling, and possible mechanical impact.

3.2.4 Topcoats (AMS-S-4383 Buna-N) Over Fuel Tank Sealant

Topcoats designed for long-term protection of sealant surfaces (and used by some OEMs) are applied over fuel tank sealant inside the tanks as a protective shield between sealant and metal ions in the fuel. An extensive industry-Air Force investigation on sealant chalking discovered that metal ions in fuel can cause heavy chalking of fuel tank sealant. Chalking was observed primarily on the surface of the sealant; but heavy chalking can result in deterioration of the sealant. Use of Buna-N topcoats has largely been discontinued due to improvements in fuel and chalking resistance of present polysulfide/polythioether sealants.

3.2.5 Adhesion Promoters for Polysulfide/Polythioether Sealants

The use of adhesion promoters with polysulfide/polythioether sealants for post-assembly seals in fuel tanks and in-service repairs have proven to be particularly effective. Studies by the U.S. Air Force and private industry have demonstrated good adhesive bonding of fuel tank sealant to substrates that are properly cleaned and adhesion promoted. This positive outcome occurred regardless of whether the surface was aged polyurethane or some other material to which it is normally difficult to obtain a good adhesive bond. Extensive use of adhesion promoters in initial manufacture and any repair operations is highly recommended.

3.2.6 Redundancy in Sealing Groove Designs and Adhesively Sealed Designs

Polysulfide/polythioether fillet sealing of all joints, structural voids, etc. in the aircrafts lower skin area (before the fuel tank is finally assembled) is strongly recommended. This is a one-time opportunity to add redundancy to sealing of that portion of the tank that will be continuously wet with fuel.

Some companies treat difficult-to-seal areas in the upper skin by applying polysulfide/polythioether sealant to upper faying surfaces of groove-designed tanks as a back up to the non-curing channel sealant. The channel must not be blocked with curing-type fay surface sealant. In such cases, it is prudent to assume that faying-surface sealant squeeze-out is performed successfully and completely when the residual faying-surface sealant -- in between the mating surfaces -- occupies a space not greater than a 0.000 to 0.003 in (0.00 to 0.08 mm).

3.3 Composite Construction - Sealing Philosophy

An increasing percentage of aircraft structure consists of composite parts to reduce aircraft weight. Composites usually are carbon-fiber-reinforced thermosetting materials; but, in some cases, composite structure with a thermoplastic matrix is used. Extensive round robin testing has demonstrated that thermoset composites should be scuff sanded prior to sealing (to remove surface gloss), due to difficulty in obtaining good sealant adhesion to these materials.

Composite-to-metal joints must be fay-surface sealed and fillet sealed after assembly. Non-interference fit fasteners are used with composites; therefore, all permanent fasteners penetrating composite structure must be wet installed and overcoated with fuel tank sealant. Fuel tank sealant performs an important secondary role as a non-conductor between carbon fiber and aluminum, thereby helping to prevent galvanic corrosion (see ARP4118).

4. SUBSTRATES

Possible metal surfaces present within an integral fuel tank include corrosion-resistant (stainless) steel, cadmium (must be coated), titanium, nickel-based alloys, such as Inconel, and aluminum (bare or treated). These surfaces, however, are almost always coated by a polyurethane or epoxy corrosion-preventive coating, (exception: titanium is not coated); thus, fuel tank sealant will be required to bond to the polymeric surface. When the corrosion-preventive coating on aluminum structure is scratched or damaged, the surface is cleaned, and a chemical conversion coating is applied to the aluminum. If sealant will entirely cover the area, it is not necessary to reapply the polyurethane or epoxy coating before applying the sealant; otherwise, after chemical conversion coating application, the polymeric corrosion-preventing coating is reapplied. If only the polyurethane coating has been damaged, it can be touched up with an epoxy. Polysulfide/polythioether sealants bond well to most surfaces that will be encountered.

Composite substrates might not be coated with a corrosion-preventive coating. This surface is scuff sanded and cleaned with a solvent blend conforming to AMS3167 or AMS3168 in areas where sealant will be applied.

4.1 Corrosion-Preventive Coatings

AMS-C-27725 fuel-resistant and microbial-resistant polyurethane corrosion-preventive coating is a widely-used primer for coating the entire interior surface of the integral fuel tank. It is applied before accomplishing any sealing processing, such as filleting, overcoating, or void filling. It will cure sufficiently for handling in approximately 24 h at 77 °F (25 °C) and 50% relative humidity (RH), but it will not be fuel resistant for 3-1/2 days. It takes approximately 14 days for this coating to become resistant to methyl ethyl ketone (MEK).

The exterior of the fuel tank is usually covered with an epoxy-based corrosion-preventive primer such as epoxy-polyamide (MIL-PRF-23377).

4.2 Titanium

Titanium parts are usually treated with an inorganic chemical conversion coating; however, organic primer or topcoat is not generally required on titanium parts. Proper sealant adhesion to titanium parts can only be achieved by scuff sanding and the use of an adhesion promoter prior to sealant application.

4.3 Composite Surfaces

Composites will be prevalent in aircraft fuel tanks produced in the future. It is beyond the scope of this document to review the status of present investigations regarding application of sealants to composite surfaces; however, it is well known that current composite structural materials essentially present an epoxy or bismaleimide surface for bonding. Polysulfide/polythioether sealants bond well to these surfaces. It has been established, however, that composite surfaces must be scuff sanded, then solvent cleaned. Fuel tank sealant should be applied as soon as possible after completion of solvent cleaning, abrading, and adhesion promoting.

4.4 Dry Film Lubricants

In 1984, Air Force Material Lab at Wright-Patterson AFB (AFML) tested seventeen dry film lubricants with polysulfide sealants for bonding characteristics with and without the use of dry film lubricants. It was concluded that adhesion promoters are required in fuel tank structure surface preparation when using manganese-dioxide-cured polysulfide sealants. Adhesion promoters are required to ensure 100% cohesive failure [tested after aging 7 days followed by 70 days at 140 °F (60 °C) in jet reference fluid (JRF-1) (JRF)/salt water]. While the results were not as clear cut with dichromate-cured polysulfides, it left no doubt that it is highly desirable to use polysulfide adhesion promoters (conforming to AMS3100) on parts containing dry film lubricant before application of fuel tank sealant for satisfactory bonding of sealant to structure.

AMS3090 has been prepared for dry film lubricants to which sealants will adhere; the appropriate adhesion promoter is still needed when AMS3090 dry film lubricant is on the surface to be sealed.

5. SURFACE PREPARATION

5.1 Cleaning

It is impossible to achieve a good sealant bond if the substrate has not been adequately cleaned, abraded, and protected against contamination. Fuel tank sealant bond surfaces are cleaned as follows:

a. Remove all chips and foreign material, using vacuum cleaners; do not blow off with air pressure.

b. Prepare an aerospace cleaning compound that conforms to engineering material property requirements of MIL-PRF-87937, Type optional, or AMS3166.

c. Pour the cleaning compound (or squirt the cleaning compound) from bottles onto low-linting wipe cloths (AMS3819, Class 1 or 2, Grade A) and scrub the surface transversely -- for example, starting from the top down, followed by left to right. Stiff bristle brushes can be used to facilitate cleaning if necessary.

d. Rinse the cloth or brush frequently in water (not in the cleaning compound) to avoid build-up of contaminants.

e. Re-wet the cloth or brush with cleaning compound; and wipe the surface until it is clean.

f. Using a fresh low-linting cloth, thoroughly rinse with water and perform a final wipe down.

g. Wipe dry with a dry cloth. Do not allow the cleaner to air-dry; evaporation of surface cleaners will redeposit dissolved materials on the surface.

h. Repeat the cleaning process as follows using an approved organic solvent blend, such as AMS3167 or AMS3168:

   1. Dispense the solvent mixture from a polyethylene squeeze-bottle onto a clean low-linting cloth (AMS3819, Class 1 or 2, Grade A). Do not dip the wiper into the solvent.

   2. Clean the surface thoroughly with the cloth, turning it frequently. Change to a new cloth as soil becomes evident.

   3. Clean from the top down and from the inside out.

   4. Continue cleaning. A brush may be used to apply solvent or to promote rapid cleaning. Rinse the brush by squirting bristles with solvent, not by dipping the brush into the solvent.

   5. Before the solvent has a chance to evaporate, rinse the structure using a clean, solvent- wetted cloth.

   6. Finally, when there is no further evidence of soil, wipe the surface dry with a clean and dry cloth.

Re-clean the surface, in accordance with the above procedure, if the surface is not sealed within 24 h.

5.1.1 Important Points to Remember Concerning Surface Cleaning

a. Cleaning cloths should be low-linting and snag resistant and contain less than 0.5% extractable (or nonfibrous) material (see ASTM D2257). The cloths should be open weave or non-woven to allow for easier absorption of bulk contamination. AMS3819 defines the properties and the allowable contamination levels of cleaning cloths.

b. All solvents shall be free of particulate matter and shall leave no residue upon evaporation. Solvents shall be dispensed from clean, oil-free containers. Container design should preclude the possibility of dipping cleaning cloths and brushes into clean solvent.

c. Chlorinated cleaners generally should not be used on titanium structures.

d. Titanium surfaces should be cleaned using both an aqueous alkaline detergent cleaner and an approved organic solvent blend.

e. General Cautions

Be aware of possible sources of surface contamination in the sealing area; these should be eliminated. Wind blown dust, unfiltered air from ventilators, air conditioners, fans, metal chips and metal or plastic dust from nearby drilling or sanding, are potential sources of contamination. Additional sources of contamination include:

1. Personnel transmitting soaps, oils, grease from hands and clothing; a key engineering requirement related to this is that sealant bond surfaces must not be touched with bare hands;

2. Contamination from equipment;

3. Moisture condensation on sealant bond surfaces, which will occur if temperatures are allowed to drop while humidity is high;

f. Never dispense silicone materials in the vicinity of sealing operations.

g. Filtered air should be used when forced into integral fuel tanks for ventilation, curing, drying or purging.

h. Very Important

If adhesion promoter or sealant is not applied within 4 h, reclean the sealant bond surface. Only one surface cleaning does not mean that the bond surface will remain clean. When in doubt, reclean the sealant bond surface.

5.2 Special Considerations Regarding Surface Preparation

Following are engineering requirements which directly affect the cleanliness of fuel tank sealant bond surfaces:

a. Lubricants containing silicones, molybdenum disulfide or graphite shall not be used in drilling, reaming, riveting, in machine operations, swaging, or in lubricating fasteners on any component of the integral fuel tank.

b. The preparation and use of silicone material should be isolated from the sealing area and from the area where sealants are prepared and handled.

c. Where fasteners are installed on automatic fastening machines or where tapered fasteners are used and detail parts cannot be disassembled after drilling of holes, the detail parts should be cleaned first, sealant applied to faying surfaces, and the parts assembled and held together with sufficient clamping force to ensure intimate contact of detail parts prior to and during the drilling or fastener holes. The permanent fasteners should be wet installed.

d. It is acceptable to apply sealant for wet installation to fasteners lubricated with cetyl alcohol or lauric acid lubricants.

5.3 Adhesion Promoters

Adhesion promoters for polysulfide/polythioether sealants were developed primarily to ensure adhesion to aged, fuel soaked AMS-C-27725 polyurethane fuel tank corrosion coatings; however, they are extremely important in several applications and must be used properly in order to be effective, as indicated below:

a. They provide additional insurance for guaranteeing the integrity of sealant adhesion; and they are strongly recommended for this purpose.

b. Their use should be considered mandatory in making in-service repairs to fuel tanks.

In new aircraft production, some OEMs consider it mandatory to use adhesion promoters after cleaning and prior to post-assembly fillet and brushcoat polysulfide/polythioether sealing of joints in integral fuel tanks. Adhesion promoters may also be used during assembly for faying-surface sealing, and on surfaces under fasteners.

Repair of in-service aircraft dictates the mandatory use of adhesion promoters because, as a result of long-term aging and fuel soaking, the surface of the corrosion-protective fuel tank coating loses chemically active groups, which augment sealant adhesion. Sealants, therefore, do not bond well when these chemically active groups are removed from the fuel tank coated surface. Adhesion promoters ensure excellent chemical bonding and provide an added degree of insurance of good adhesive bonding of the fuel tank sealant.

Adhesion promoters that are qualified to AMS3100 must be kept in closed, sealed containers at all times except when being used. Certain adhesion promoters will absorb moisture from the air readily and will thereby become ineffective. If the material is transferred to smaller bottles for use on the production line, transfer of material should be accomplished as quickly as possible; then the bottles must be sealed. Small bottles with screw caps, once opened and in use on the line, should be discarded at the end of shelf life.

Always keep the container tightly capped when not removing material.

It is important to know that, while absorption of moisture eventually renders the adhesion promoter ineffective, it is mandatory that some moisture be absorbed by the applied adhesion promoter to activate it. For this reason, applied adhesion promoter should stand for a minimum of 30 min before sealant is applied. If the humidity level is excessively low, allow 1 h before sealant application. A thin, continuous coat of adhesion promoter should be applied without a subsequent wipe-off. Excessive amounts of applied adhesion promoter can reduce sealant adhesion and, therefore, must be removed from (by wiping) the sealant bond surface.

If the sealant is not applied over the adhesion promoter within 4 h, reclean the surface and reapply the adhesion promoter.

6. SEALANT SELECTION

Integral fuel tank sealants are available in several polymer types: polysulfides, polyurethanes, nitrile, fluoro-or cyano-silicones, and polythioethers. Within the polymer types they are available in several forms: sprayable, brushable, extrudable, rollable, and in a number of cure rates, providing short or extended work lives and cure times. Nearly all of the sealants found within integral fuel tanks are either polysulfide or polythioether.

Fuel resistant fluorosilicones are used in fairly rare instances where temperatures above 300 °F (149 °C) are expected on a fuel tank wall in high performance aircraft. Only fluorosilicones can be used to repair fluorosilicones because other sealants will not bond well to the fluorosilicone rubber surface.

6.1 Polymer Types (Curing-Type Systems)

6.1.1 Polysulfide and Polythioether Sealants

Formulations used in integral fuel tanks are two-part materials consisting of a separately packaged base compound and a curing agent (catalyst). The base compound contains the prepolymer and additives that influence viscosity, thixotropy, reaction rate, wettability, adhesion, tensile and peel strength, hardness, and, in some cases, the ability of the sealant to inhibit corrosion when moisture intrudes. The base compound may also contain a pigment or small amounts of solvents, or both pigment and solvents. The curing agent side contains the curing agent and its solvent or its inert carrier. Polysulfide curing agent may either be manganese dioxide (a black powder) or a dichromate mixture. Polythioether curing agents are typically epoxy-based resin mixtures.

The manganese dioxide is suspended in an inert organic plasticizer. The dichromate carrier contains water to solubilize some of the reactive materials. The curing agent side may also contain reaction modifiers and viscosity modifiers.

The base compound and curing agent are combined in accordance with the prescribed weight ratio to produce a sealant with the expected rheological and physical/mechanical properties. Some polysulfide sealants contain corrosion inhibitors and are so identified in their accompanying data sheets and recognized by specifications designed for them (for example, see MIL-PRF-81733). Corrosion inhibited sealants are used, primarily, in faying sealing of aluminum surfaces of integral fuel tanks and in wet installation of fasteners. Polysulfide and polythioether based sealing compounds are available in several basic types for fuel tank application as listed in Table 1 and Table 2:

TABLE 1 - POLYSULFIDE TYPE FUEL TANK SEALANTS

Polysulfide Type Sealant	Specification	Operating Temperature
Integral Fuel Tank & General Sealant	AMS-S-8802	-65 to +250 °F (-54 to 121 ºC)
Integral Fuel Tank & General Sealant	AMS3276	-65 to +250 °F (-54 to 121 ºC)
Integral Fuel Tank & General Sealant	AMS3281	-65 to +250 °F (-54 to 121 ºC)
Corrosion Inhibiting Sealant	MIL-PRF-81733	-65 to +250 °F (-54 to 121 ºC)
Non-chromate Corrosion Inhibiting Sealant	AMS3265	-65 to +250 °F (-54 to 121 ºC)
Integral Fuel Tank & General sealant (High Strength)	AMS3269	-65 to +250 °F (-54 to 121 ºC)
One Part, Fuel Resistant Fluoro-silicone Adhesive/Sealant	AMS3375	-65 to +400 °F (-54 to 204 ºC)
Quick Repair Sealant	AMS-S-83318	-65 to +250 °F (-54 to 121 ºC)
Corrosion Inhibiting Access Door Sealant	AMS3284	-65 to +250 °F (-54 to 121 ºC)
Adhesion Promoter for use with Polysulfide Sealants or mfg's recommendation	AMS3100, Class 1, 2, or 3	

TABLE 2 - POLYTHIOETHER TYPE FUEL TANK SEALANTS

Polythioether Type Sealant	Specification	Operating Temperature
Integral Fuel Tank & General Sealant	AMS3277	-85 to +250 ºF (-62 to 160 ºC)
Integral Fuel Tank (Sprayable) Sealant	AMS3279	-65 to +250 ºF (-54 to 121 ºC)
Adhesion Promoter for use with Polythioether Sealant or mfg's recommendation	AMS3100, Class 2 or 3	

The different viscosities of polysulfide or polythioether based fuel tank sealants are designed for specific applications as indicated in Table 3:

TABLE 3 - POLYSULFIDE AND POLYTHIOETHER BASE COMPOUND VISCOSITIES

Base Compound	Viscosity Range at 77 °F (25 °C) (Poise)
Sprayable	50 to 150
Brushable (Class A)	100 to 600
Rollable (Faying Surface, Class C)	1000 to 4000
Extrudable/Trowelable (Class B)	6000 to 18 000

6.1.1.1 Class A - Brushable Sealants

Class A and Class C sealants are brushable. They contain approximately 12 to 16% volatiles and flow more than Class B sealants. Class A and Class C brushable sealants are used around metal fasteners and over seams and often as a pre-coat before application of Class B sealant. Class A sealants are available in application times ranging from 1/6 to 4 h; application times for Class C sealants typically range from 2 to 48 h. Brushable fuel tank sealants are applied with a stiff, short brush. Since brushable sealants can contain as much as 16% volatile solvent, at least 1/2 h must be allowed after application for evaporation (or flash-off) of solvent before a top coat of any kind is applied; this flash-off time is based on a recommended Class A or Class C sealant thickness of not greater than 0.125 in (3.18 mm).

6.1.1.2 Class B - Extrudable Sealants

Class B thixotropic fuel tank sealants have no more than 8% of volatile materials and are used primarily for fillets; these sealants are also used for a wide variety of other applications, such as hole filling, prepacking, injection sealing, and for topcoating of fasteners after the Class A material has been applied. Class B fuel tank sealant are available in application times ranging from 10 min to 12 h. The short (10 to 15 min) application time sealants, which conforms to AMS-S-83318 or AMS3277, are highly useful for quick repairs especially at low temperatures; at lower temperatures, the application and cure times are longer. Most of the fuel tank sealing is accomplished with the 2 h application time (Class B-2) material. For repairs, the 1/2 h application time (Class B-1/2) sealant is used. Class B-1/2 sealant is sometimes used during the winter when plant temperatures fall below 70 °F (21 °C).

It is important to note that polysulfide sealants, depending on the type and application life, are strongly affected by humidity and temperature in its application time, tack-free time, and curing rate. As temperature and humidity rise, polysulfide sealant tack-free times and cure rates decrease. However, polythioether sealants are, on the other hand, typically less sensitive to temperature and humidity variations and several, i.e., AMS3277, will cure at temperatures of 20 to 40 °F.

6.1.1.3 Class C - Rollable Sealants (long work life and open time)

Class C fuel tank sealants contain about 10% or less of volatiles with longer application times (2 to 48 h) and very long assembly times (ranging from 12 to 336 h); and Class C sealants are generally used for faying surfaces where, after sealant application, other work must be done before the two surfaces can be drawn together. At the time the two surfaces are pulled together tightly with fasteners, the sealant must still be sufficiently uncured to enable the sealant to flow and extrude, or squeeze out. Generally, a 0.010 to 0.015 in (0.25 to 0.38 mm) thick coating is applied and is subsequently squeezed out to approximately 0.000 to 0.003 in (0.00 to 0.08 mm). Class C fuel tank sealant cure time can range from 5 to 14 weeks depending upon the assembly time of the product selected. Moisture cured, one-part sealants are not used as Class C faying-surface sealants, since moisture would not be available to activate cure once the two surfaces are brought together.

6.1.2 Polyurethanes

Polyurethanes (AMS3278) have only recently been used as integral fuel tank sealants. They are high-strength, high adhesion sealants particularly useful in high-strain fuel tank areas/applications. Highly crosslinked and rigid urethane-based primers are fuel resistant and are used almost exclusively in the form of a corrosion-protective coatings over structure inside the fuel tank. Engineering material property requirements applicable to such a product are defined in AMS-C-27725. This material has been discussed in 4.1.

6.1.3 Fuel Resistant Fluorosilicones (Curing Type)

Fuel resistant fluorosilicones are used where aircraft service temperatures of up to 375 °F (191 °C) are expected. Peel strengths for these sealants are significantly lower than those associated with polysulfides and polythioethers (approximately 10 lb/in width (1.79 kg/cm width) versus 20 to 40 lb/in width (3.6 to 7.2 kg/cm width). For certain locations in the design of aircraft fuel tanks, these lower peel strengths are adequate. The peel strength is reduced to approximately 2 to 5 lb/in-width (0.36 to 0.90 kg/cm-width) at 400 °F (204 °C), but the bond remains intact. A silicone primer material must be used with the fluorosilicone sealant to produce good adhesion.

Two types of fluorosilicone sealants are available:

a. A one part, moisture-curing sealant that produces acetic acid upon cure; and

b. A two-part moisture-curing and condensation-curing sealant that does not release acetic acid during the curing process.

Adhesive bonding tests on various surfaces and fluid immersion tests of samples bonded to different surfaces were conducted between 1984 and 1985; these studies were sponsored and conducted by the U.S. Air Force Materials Laboratory at Wright-Patterson Air Force Base (Dayton, Ohio).

6.1.4 Buna-N Polymers

These polymers systems are used infrequently, and only as a protective overcoat (AMS-S-4383) over integral fuel tank sealants. A totally different use of Buna-N coatings is represented by fill-and-drain sealants. A fuel tank is filled with a medium viscosity, high volatile content Buna-N-based sealant. It is then drained from the tank, leaving a coating over the entire surface of the interior. Solvents evaporate leaving a tough, durable coating. It is seldom used in large aircraft sealing due to lack of thickness control and weight and because of difficulty in removing cured materials for other work, such as sealant rework or repair jobs. Weight penalties resulting from coating surfaces in the tank that need no protection are also a factor.

6.2 Non-curing Polymer Systems for Groove Design

Fuel-resistant channel or groove sealants are putty-like, one-part, formulations that are non-vulcanizing (non-curing). They must be fuel resistant and possess a tacky-type adhesion to groove surfaces that prevents fuel from migrating through the groove and out of the fuel tank. These sealants are produced from fluorosilicones, cyanosilicones, and polysulfides. Sealants currently chosen by aircraft design engineers for this application are usually fluorosilicone-based. AMS3376 is a specification that addresses fluorosilicone-based channel sealants. Engineering requirements for qualification and acceptance of polysulfide-based non-curing groove-injection sealants are provided by AMS3283.

Fillers (often microspheres) are used in channel sealants for several reasons:

a. to minimize thermal expansion;

b. to modify viscosity, and

c. to serve as a gap plugger by producing a log-jamming effect.

6.3 Selection of Polysulfide or Polythioether Sealant Types and Classes Versus Application

As mentioned previously, there is a wide variety of available polysulfide and polythioether based fuel tank sealants to choose from. Table 4 gives examples of the appropriate matching of sealant to each specific application. It is not suggested that other types and classes cannot be used. Those given below are appropriate to the application indicated:

TABLE 4 - SEALANT TYPE AND CLASS VERSUS USE

Use/Application	Class	Method	Time (hours) Application	Assembly (hours)
Brushing of Fasteners, Seams	A-1/2, A-2, A-4, C-2	Brush	1/2, 2, and 4	2 (Class C only)
Fillets and Overcoating of Fasteners	B-1/2, B-2, B-4, B-12	Extrude	1/2, 2, 4, and 12	None
Repair of Fillets and Fasteners	B-1/2	Extrude	1/2	None
Faying Surfaces	B-2	Roll or Spread	2	None
	B-4		4	None
	B-12		4	None
	C-20		8	20
	C-80		8	80
	C-168		48	168
	C-336		96	336

NOTE: It is important that application and assembly times will vary with temperature and relative humidity at the manufacturing facility. Verify application and assembly times from applicable sealant material specification and manufacturers technical data literature.

6.4 Key Points Concerning Curing of Manganese Dioxide Type Polysulfide Sealant

The cure rates of polysulfide sealants are significantly influenced by temperature and humidity. At 55 °F (13 °C) and 40% RH an AMS3276 Class B-2 sealant requires nearly 100 h to cure; whereas, at 85 °F (29 °C) and 80% RH, the same material will cure in approximately 24 h.

Work lives assigned to particular fuel tank sealants are stated for a reaction temperature of 77 °F (25 °C) and 50% relative humidity (standard conditions). Factory conditions are seldom at standard conditions; thus, sealant cure rates will be faster or slower than the stated ideal.

Experiments with variations in humidity, holding the temperature at 77 °F (25 °C) showed that a Class B-2 sealant (i.e., 2 h worklife) acted like a Class B-1 when the humidity was raised to 65% RH, and acted like a Class B-3 when the humidity was lowered to 35% RH.

Anticipation of weather conditions can enhance selection of faster or slower curing sealants as appropriate. Moderate acceleration of cure after sealant application can be accomplished by the use of heat lamps if surface temperatures are monitored closely to 130 °F (57 °C) or less. Increasing the humidity will also increase the cure rate.

Changing the ratio of curing agent to base compound is expressly forbidden. Large increases in the quantity of manganese dioxide curing agent can result in softening of the sealant, which is caused by the sealant's organic plasticizer carrier and makes adhesion more difficult.

7. SEALANT PACKAGING

Two-part polysulfide and polythioether sealants can be purchased from suppliers in a variety of package sizes. The sizes are: 1/2 pt (0.24 L), pint (0.47 L), quart (0.9 L) can kits. Can kits include three-fourths of the total quantity of base compound; this is to allow room for addition of the curing agent and mixing within the base compound container. When mixing two-part can kits the entire contents of the can shall be mixed and used within the work life of the sealant.

Sealant is also available in two-component plastic injection kits with the 2-1/2 fl oz (74 mL) and 6 fl oz (177 mL) sizes being the most popular. It is convenient to use two-component plastic injection kits for both production plant and field repairs. These two-component plastic injection kits meet the engineering requirements of MIL-S-38714. The base compound is contained in the cartridge, and the curing agent in a hollow dasher rod that extends into the cartridge. The rod serves as a shaft for a dasher (agitator blade) for mixing the base and curing agent once they are combined. The curing agent is forced out of the dasher rod and into the base compound through the use of a ram rod. After mixing is complete, the dasher rod is removed, and the nozzle is installed on the end of the cartridge. The cartridge is then placed in a pneumatic or manual sealant gun for use by the sealer. These kits have the following advantages:

a. They eliminate mix/freezing cartridges of sealant and storing frozen cartridges;

b. They eliminate the need for weighing out sealant base compound and curing agent in the proper ratio from a larger quantity in a two-part kit.

c. Reduce personal exposure.

d. Reduce sealant waste.

Sealants can also be purchased from the sealant manufacturer in pre-mixed and quick-frozen form with the sealant packaged in 2-1/2 fl oz (74 mL) and 6 fl oz (177 mL) polyethylene cartridges. Purchasing sealant in this form is a cost-saving convenience for end-users who have no facilities or equipment for meter mixing and freezing of the sealant. Responsibility for supplying a properly mixed and frozen product is also shifted to the sealant manufacturer when the sealant is purchased directly from the supplier in pre-mixed and quick-frozen form.

8. STORAGE OF SEALANT

8.1 Uncured Two-Part Sealant Kits

Uncured sealants are chemically reactive and perishable systems. Both the sealant manufacturer and the user share a responsibility for protecting the fuel tank sealant's shelf life. The manufacturer will formulate a chemically compatible and stable system; then the manufacturer packages it in sealed containers under an inert atmosphere to maximize the sealant's shelf life. The user must recognize the activating effect of temperature and relative humidity on aircraft sealants. Appropriate temperature and humidity controls should be implemented during storage to ensure that the rated shelf life is not reduced. The user must also appreciate the fact that when containers are opened (cans, foil bags, drums), the inert atmosphere is lost.

The shelf life quoted on labels of most sealant suppliers are based on a recommended storage temperature of no more than 80 °F (27 °C). Many user storage facilities have no air conditioning. Temperatures can reach 130 to 150 °F (54 to 66 °C) in the summer months. As a result of these high storage temperatures, both base compound and curing agent will increase in viscosity; this can result in skinning on the surface of the base compound, and the resultant changes will cause rejection upon inspection.

Users may significantly extend the useful life of unmixed sealant by storage at 60 °F (16 °C) rather than 80 °F (27 °C). A broad rule of thumb with chemically reactive systems states that an 18 °F (10 °C) reduction in temperature reduces reaction rates by 50%. It is obvious then that the lower the storage temperature, the less change will occur in the unmixed kits in storage. Storage of unmixed kits at 32 °F (0 °C) or below should be done only in accordance with instructions from the sealant manufacturer.

8.2 Storage of Premixed and Frozen Cartridges

The reactivity of premixed and frozen polysulfide sealant can be essentially suspended by storage at -40 °F (-40 °C) or below. The reactivity of premixed and frozen polythioether sealant can also be essentially suspended by storage at -80 °F (-62 °C) or below. Such is not the case for mixed and frozen polyurethanes, which will begin to show significant loss of work life after 30 days at -40 °F (-40 °C). Storage life of premixed and frozen sealants is established by the manufacturer based on sealant type and chemistry.

Frequent opening of the freezer will adversely affect the inside storage temperature. It should be noted that setting racks of frozen cartridges outside the freezer to rearrange inventories will cause sealant cartridges to increase in temperature beginning the sealant slow thawing process that is non-reversable and will result if the lose of the sealant if temperature is not maintained.

Awareness and good practice will protect the sealant's shelf life. Most users of frozen cartridges have established shelf life limits for frozen cartridges; many use 30 days as the limit for polysulfide type sealants or 42 days as a limit for polythioether type sealants. Rather than scrap the cartridges at the end of the period, it is practical and worthwhile to conduct a worklife test (or retest) to determine acceptability. Based on retest results, the user determines if shelf life should be extended. Generally, when supported by satisfactory retest data, sealant shelf life extensions enhance continuity of manufacturing operations and contribute to reduction of hazardous waste.

8.3 Storage of Elastomeric One-Part Fluorosilicones (Fuel Resistant)

Significant quantities of Dow-Corning Q4-2817, a one-part, fuel-resistant, moisture-curing fluorosilicone, integral fuel tank sealant have been used on certain military aircraft. Its shelf life is 1 year from date of manufacture; no storage conditions (temperature and relative humidity) are specified for this product. Momentive Performance Inc. produces a similar material, FRV1106; and its shelf life is six months when stored at temperatures that do not exceed 110 °F (43 °C). Dow-Corning 5-8733 is a one-part fluorosilicone that cures by condensation and by a reaction with moisture; and its shelf life is 1 year from date of maufacturer when stored at temperatures that do not exceed 100 ºF (38 ºC). Dow-Corning 5-8733 has been applied on a military fighter aircraft for bonding a premolded fluorosilicone gasket into a titanium groove machined into the entryway structure of one of this aircrafts fuel tanks.

8.4 Storage of Channel Sealants

Both the non-curing high viscosity fluorosilicones and the non-curing polysulfide channel sealants are stored at ambient temperature and have the manufacturer's recommended shelf life indicated in Table 5. The channel sealants referred to in this group are:

TABLE 5 – CHANNEL TYPE SEALANT

Material	Spec	Manufacturer	Product #	Comment
Polysulfide (non-curing)	None	PPG Aerospace PRC-DeSoto Int.	PR-705 and PR-706	PR-705 and PR-706 contain both silica and plastic beads
Fluorosilicones	None	Dow-Corning	94-031[1]	Contains plastic beads
	MIL-S-85334	General Electric	G-651	Contains plastic beads
	MIL-S-85334	Dow Corning	Q4-2805[1]	Contains plastic beads
	AMS3376	(Currently No Qualified Products Listed)		

[1]Shelf life is 36 months (or 3 years) from date of shipment.

9. SEALANT MIXING

Each individual batch of a two-part polysulfide or polythioether integral fuel tank sealant has a custom matched curing agent - to produce the properties required by the applicable sealant specification. A particular batch of base compound must be used only with its matched batch of curing agent if the expected properties are to be realized. Curing agent from different batches of the same product shall not be interchanged.

Thoroughly mix the base compound and curing agent to produce the engineering sealant properties required for the cured fuel tank sealant. Effective blending of fuel tank sealants is an important factor in producing a uniform mixture without entrapping air in the sealants. In all cases, no swirling motion should be produced through stirring (to aid in mixing), in order to prevent air entrapment. All of the base compound (Part B) and curing agent (Part A) must be moved physically by the stirrer. The container walls should be scraped frequently during mixing to blend the two parts together.

9.1 Hand Mixing

Small two-part can kits (up to and including gallon sizes) provide enough space above the base compound in the container to permit all of the curing agent to be transferred into the base container for blending. A sufficient amount of curing agent -- including some excess -- is included to accommodate normal transfer losses and still produce the correct ratio of base to curing agent in the mixed sealant.

It is recommended that the full kit be catalyzed to ensure that the proper mix ratio is obtained, rather than using small portions of a kit, weighing out partial amounts, and encountering the dangers of incorrect weighing. Transfer of curing agent can be more readily accomplished by inverting the closed can and cutting out the bottom with a can opener. This produces a continuous opening -- which allows the material to flow, lengthwise, through the can. The latter procedure also eliminates the need to manually transfer curing agent that tends to accumulate around the rim of the can when the can is positioned right-side up with the bottom of the can left intact. It also precludes other sources of error, such as removal of non-uniform amounts of curing agent from the container by failing to stir before removal. There is added danger of not purging the remainder with an inert gas, nor sealing the lid tightly.

Hand mix the base compound and curing agent thoroughly for 5 min with frequent scrape down of the walls. Fold the sealant over itself. Don't whip it, incorporating air. If the warehouse storage temperature is greatly different from standard temperature — i.e., 77 °F (25 °C) — bring kits into this standard temperature range well in advance of mixing to assure that application time and extrusion rates will be in the range expected.

Hand mixing does not necessarily mean that all mixing is achieved by hand with a spatula. It also refers to mixing with hand held or mounted lighting mixers or similar motor driven agitators. In all cases the movement of the mixer blade throughout the sealant and frequent scrape down will aid immeasurably in producing a uniform mix.

WARNING: Extremely fast stirring can cause vortexing, resulting in the incorporation of air; it can also heat up the sealant, which will change its viscosity and shorten its work life.

9.2 Two-component Injection Kit Mixing

Hand mixing of small quantities of two part sealants in two-component polyethylene plastic injection kits is described in 11.1.2.1.

10. THAWING OF PREMIXED SEALANT CARTRIDGES

10.1 Thawing

Frozen cartridges of premixed sealant are thawed by two approved methods.

10.1.1 Ambient Air

Frozen cartridges are laid on a bench or table top and allowed to warm at room temperature. The rate of warm-up is variable depending upon the temperature of the cartridge, the temperature of the ambient air, the closeness of one cartridge to another, and whether they are standing vertically or lying horizontally. Ambient thaw usually takes about 30 min. The core of the cartridge should reach 60 °F (16 °C) before sealant application is started.

10.1.2 Enclosed or Open Water Bath

Two approaches are used with hot water baths:

a. An enclosed metal water bath with metal sleeves welded in place top and bottom provides a dry cylinder into which the cartridges fit snugly. Heat transfer from the water through the metal sleeve and polyethylene cartridge is good. With the water bath at 120 °F (49 °C), thawing takes about 4 minutes.

b. Frozen cartridges are placed directly into heated or unheated water. The cartridges are closed with caps on both ends. As the cartridge warms, the sealant inside expands slightly, and water is not drawn into the cartridge. Thus, the approach is acceptable.

11. SEALANT APPLICATION

Aircraft designs produce a variety of configurations of integral fuel tanks and a variety of sub-assemblies, attachments, and fit ups associated with each design. In all cases, two-part, curing- type sealants (polysulfide or polythioether based) are utilized in several of three general forms: brushable, extrudable, and rollable.

This report cannot specifically address each of the many individual designs. However, this report recommends preferred practices in the application of brushable extrudable, and rollable sealants; it also points out the more desirable contours and thicknesses to be used in the application of sealant in seams, joints, fastener heads, voids, in faying surfaces, and in types of configurations that are common to all designs.

This section on two-part sealant application will, therefore, address first the techniques for applying various forms of sealant; then it discusses several specific configurations where additional comment is appropriate. It also mentions specific methods of protecting applied sealant in its early, tacky state of cure. The application of groove/channel sealant (non-curing type) will be discussed, focusing on key factors necessary for proper application.

11.1 Two-part Curing-Type Sealant

Sealant is applied in accordance with the following purposes:

a. To achieve a good adhesive bond with the substrate, and

b. To produce a long-term seal through proper thickness and contour.

The following are required to achieve a good bond:

a. A clean surface;

b. Sealant with the proper adhesion characteristics for that surface (or use of an appropriate adhesion promoter); and

c. Application of the sealant during its worklife, when it is still capable of wetting the surface.

It is appropriate to reiterate that the use of adhesion promoters for polysulfide and polythioether sealants during the initial production as well as in later repair is highly recommended. Experience has shown that even though acceptance tests are conducted on every batch of sealant and on a variety of coated panels, the production surface can be different and the production cleaning may not be as thorough or complete as that produced under laboratory conditions.

Engineering testing and evaluation of adhesion promoters have proven that whether the surface is old or new, clean or partially dirty, and whether it consists of acrylic, polyurethane or treated aluminum, a good bond is produced through its use with polysulfide or polythioether fuel tank sealants. A discussion of adhesion promoters is given in 5.3.

The adhesion promoter may be applied by aerosol spray, brush, or by wiping it on with a clean cloth saturated with the materials. It is preferred that a thin coat be applied without a subsequent wipe-off of excess adhesion promoter. The adhesion promoter is slightly colored, permitting visual examination to ensure that the entire surface has been coated.

The applied adhesion promoter should be allowed to stand for at least 30 min (especially when humidity is low) to permit activation of the promoter and evaporation of the solvent; then the fuel tank sealant can be applied. If sealant is not applied to the adhesion promoted surface within 4 h, the surface should be recleaned and the adhesion promoter reapplied.

Adhesion promoters are available in both chlorinated and non-chlorinated solvents and are also available in water-based formaulations. Local company policies dictate which can be used. Adhesion promoters with chlorinated solvents should never be used on titanium or titanium alloy surfaces.

Whenever sealant application is delayed, the cleaned and adhesion promoted bond surfaces must be protected from contamination -- which includes, but is not limited to, shop machining fluids, fingerprints, dust, and other particulate matter.

11.1.1 Brushable Sealant Application

Class A brushable sealants are applied as brushcoat seals on fasteners, and in locations where a flowable material is needed. The first coat is worked in and around all leak source areas with a short and stiff brush. The second brush coat is applied after the first coat is tack-free. Overcoats on fasteners are built up to a thickness of 0.030 to 0.060 in (0.76 to 1.52 mm), depending upon the location of the fasteners.

Brushable sealant is used around crevices, holes, seams, fasteners, and, in some cases, as a pre-coat on seams and surfaces to be covered later with the thicker Class B extruded fillet of sealant.

It is important that, during application, brushable sealant be applied thoroughly into crevices and seams; some use a circular motion on the fuel tank structure surface to ensure adequate wetting by the sealant. This prevents voids; and it minimizes the formation of air bubbles.

Figures 2 and 3 illustrate application of the Class A brushcoat sealant over rows of fasteners prior to the application of Class B extrudable material.

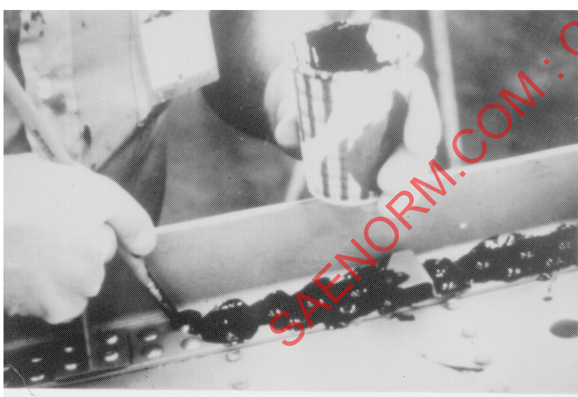

FIGURE 2 - APPLICATION OF BRUSHABLE SEALANT

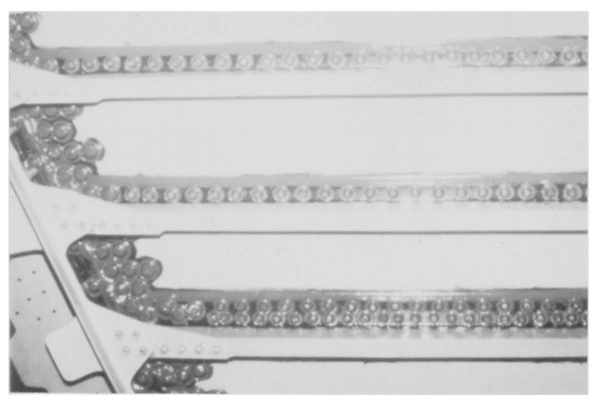

FIGURE 3 - BRUSHABLE SEALANT APPLIED AS SHOWN IN FIGURE 2

Class B fuel tank sealant should be applied only within its application time (worklife) to ensure good wetting of the surface. It is not acceptable to have air bubbles in the Class B fuel tank sealant. The width of the brushcoat should exceed the width of the fillet to be applied by at least 0.10 in (2.5 mm) on each side. Thinning of brushable sealant should not be attempted unless the sealant manufacturer provides specific instructions regarding the type and grade of solvent to be used and the allowable amount of solvent to add. An adhesion promoter shall be applied to cleaned fuel tank structure surfaces before sealant is applied, whether initial production or repair is being accomplished. A brushcoat is considered to be a primary seal only when applied in more than one layer, such as in overcoating of fasteners with a double brushcoat.

11.1.2 Extrudable Sealant Application

11.1.2.1 General

Extrudable Class B sealants are used for the following types of sealing:

a. Filleting over joints, splices, seams, and shims.

b. Prepack/injecting slots and joggles.

c. Filling corner close-out cups.

d. Overcoating fastener heads, bolts, and rivets.

e. Hole filling.

f. Faying surface sealing.

g. Aerodynamic smoothing and gap filling.

Class B fuel tank sealants are known for their low slump (thixotropic or low blockflow) characteristics. The latter engineering properties directly contribute to the extrudability of these viscous materials.

While Class A and Class B integral fuel tank sealants are resistant to jet fuel, the Class B material, which contains fewer volatile solvents, is used in providing the required sealant dimensions (or thickness) without entrapment of air or solvents.

The mixed sealant is generally applied from a 2-1/2, 6, or 12 fl oz (74, 177, or 355 mL) low-density polyethylene cartridge contained in a sealant gun powered by plant air 80 to 90 psi (552 to 621 kPa). Manual guns are also available. Use of greater pressure may cause a high incidence of the cartridge plunger flipping (overturning), resulting in air being blown directly through the cartridge. A sealant gun with cartridge and nozzle is shown in Figures 4 and 5.

FIGURE 4 - SEALANT GUN

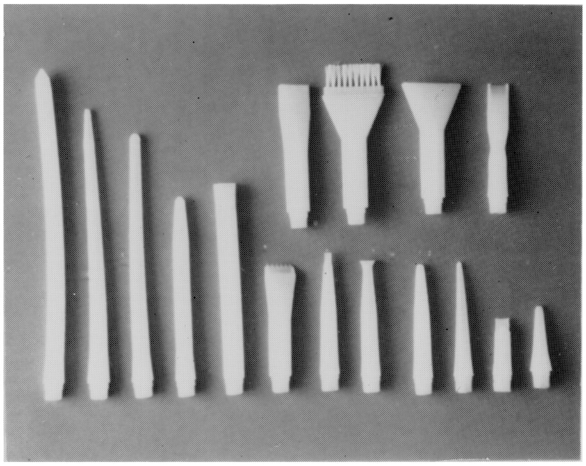

FIGURE 5 - SEVERAL SIZES AND SHAPES OF NOZZLES

The handle of the sealant gun is removable. A trigger mechanism, which extends parallel with the barrel, is available for use in restricted areas. More than fifty nozzle shapes and sizes are available from several manufacturers to accommodate most sealing situations. For another view of the gun and nozzle, see Appendix B, Figure B2.

For field repair, and for repairs or sealing where frozen cartridges of mixed sealant are not available, small quantities of sealant [2-1/2 or 6 fl oz (74 or 177 mL)] can be mixed on site using the two-component polyethylene plastic injection kit illustrated in Figure 6.

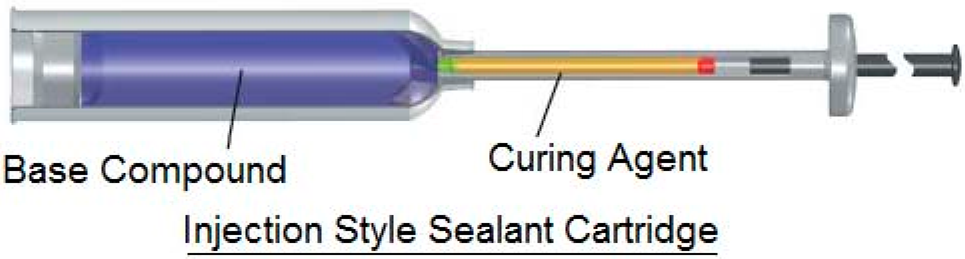

FIGURE 6 - TWO-COMPONENT PLASTIC INJECTION KIT

The sealant base compound is contained in the cartridge, the curing agent in the hollow stem (dasher rod). A ram rod is used to force the curing agent into the body of the base compound as shown in Figure 7.

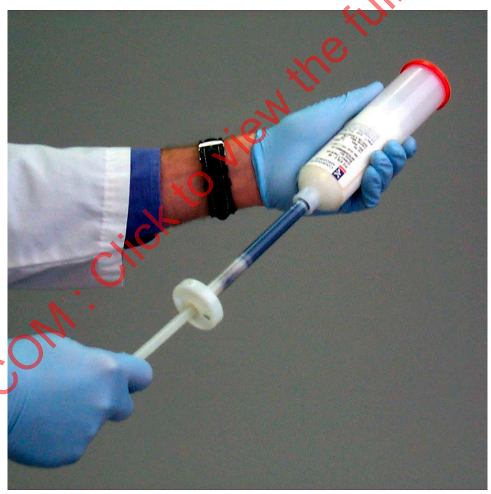

FIGURE 7 - INJECTING CURING AGENT INTO BASE COMPOUND:
(Two-Component Plastic Injection Kit)

An open spoke agitator on the end of the dasher rod is used for mixing the curing agent with the base compound as the dasher rod is pushed and pulled, rotating clockwise slightly each time. Automated equipment is also available to do the mixing (see Figure 8).

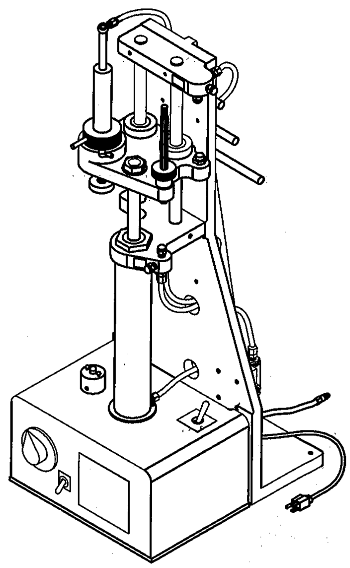

FIGURE 8 - AUTOMATED MIXER FOR THE TWO-COMPONENT INJECTION KIT

The stroking of the dasher rod is accomplished by means of a reversing air cylinder, and rotation of the dasher rod is accomplished by a low speed electric gear motor. The service requirements are compressed air [approximately 90 psi (621 kPa)] and 110 V AC, 60 cycle (or 220 V, 50 cycle). The most effective stroking speed is between 16 and 22 strokes per minute. When the sealant has been mixed to produce a uniform (or homogeneous) compound, the dasher rod is unscrewed from the agitator and removed. The cartridge is fitted with a nozzle and placed in a pneumatic or hand operated sealant gun for application.

Dispensing the fillet from the nozzle (i.e., applying the fillet to a seam or joint) in aerospace work is done in a different manner than caulking in the architectural (commercial building construction) industry. When the architect's method is used — where a trail of sealant is deposited as the delivery tip of the gun points behind the direction of travel — air can be trapped under the sealant bead as it is applied to structure.

The preferred technique is to hold the gun approximately 30 degree off-perpendicular, and point the nozzle in the direction of travel as the fillet is extruded into the joint or seam. This forces sealant into the crevice and minimizes the possibility of air entrapment. Some hold the gun nearly perpendicular to the work. Do not apply sealant with the tip pointing opposite the direction of travel.

After the bead of sealant is applied, the sealant is tooled as shown in Figures 9 and 10. This produces a faired configuration that eliminates the possibility of reentrant edges and trapped air and ensures satisfactory contact with the fuel tank structure surface.

If a large fillet bead is specified, it is not necessary to apply an undersized fillet, followed by application of another fillet over the undersized fillet. While this technique is practiced by some, it introduces an unnecessary step and creates yet another interface where a new bond line must be established. It is preferred that a larger nozzle orifice be used initially and that only one fillet be applied, then tooled (or faired) to dimensions required by engineering.

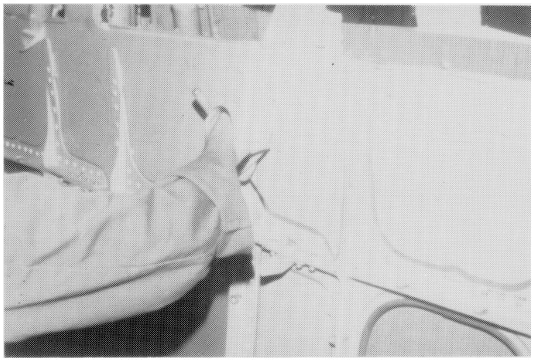

FIGURE 9 - TOOLING (OR FAIRING) A FILLET

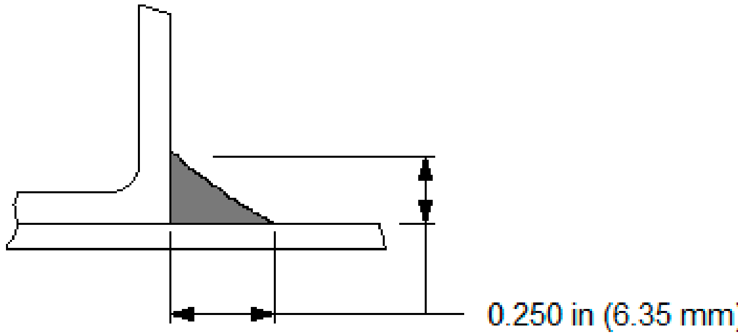

FIGURE 10 - FILLET CONTOUR

The principal goal in applying the appropriate thickness and contour of sealant at any potential leak source is to use a thickness, relative to sealant elongation, that will allow joint movement under operational conditions without tearing the sealant. For example, if a sealant with an elongation of 100% were used to seal a joint, and the thickness of the sealant at the joint were only 0.001 in (0.025 mm), the maximum allowable movement at that interface would be only 0.001 in after which sealant failure would occur. A thickness of 0.003 in (0.08 mm) on the other hand, with the same 100% elongation, would permit 3 times that amount — i.e., 0.003 in — of joint movement without failure.

There are numerous joint and gap configurations and a preferred sealant configuration for each. The major types are illustrated in Figures 11 and 12.

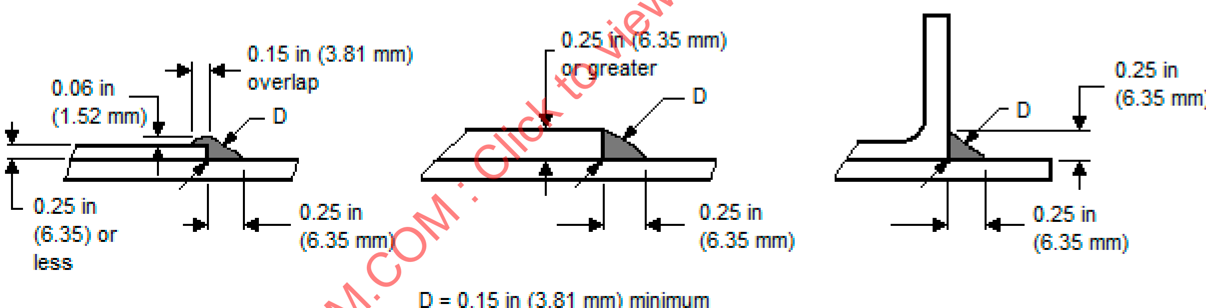

FIGURE 11 - SEALING OFFSETS AND JOINTS

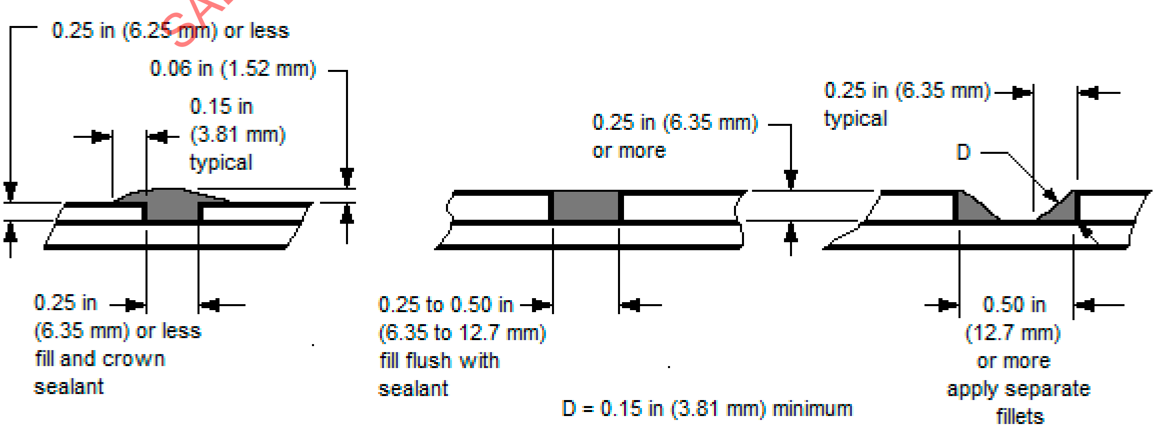

FIGURE 12 - SEALING BUTT GAPS

11.1.2.2 Sealing Offsets and Joints

The application of fillets to offsets and joints is illustrated in Figure 11.

11.1.2.3 Sealing Butt Gaps

Butt gaps vary in width and height. The preferred method for sealing them is shown in Figure 12.

Preferred sealant configurations vary company-to-company and with various government documents. The dimensions given in Figures 11 and 12 present a safe average.

Two major factors govern sealant contour:

a. Sealant should extend at least 0.250 in (6.35 mm) from the potential leak source;

b. The diagonal thickness (also called the throat) from the leak source should be at least 0.150 in (3.81 mm).

If the thickness of a plate or offset is less than 0.250 in (6.35 mm), it should be crowned.

Extreme care must be taken to ensure that butt gaps are filled and not bridged. When a butt gap is wider than 0.500 in (12.7 mm), two separate fillets can be laid, each extending from its potential leak path by 0.250 in (6.35 mm).

11.1.2.4 Holes and Slots

Holes and slots in the integral fuel tank may be sealed with Class B extrudable sealant alone if the opening is less than 0.125 in (3.18 mm). Larger openings to 0.250 in (6.35 mm) may be accommodated if the slot is sufficient to give adequate surface area for adhesion. The Class B fuel tank sealant should protrude through the hole and be tooled on both sides to dimensions shown in Figure 13.

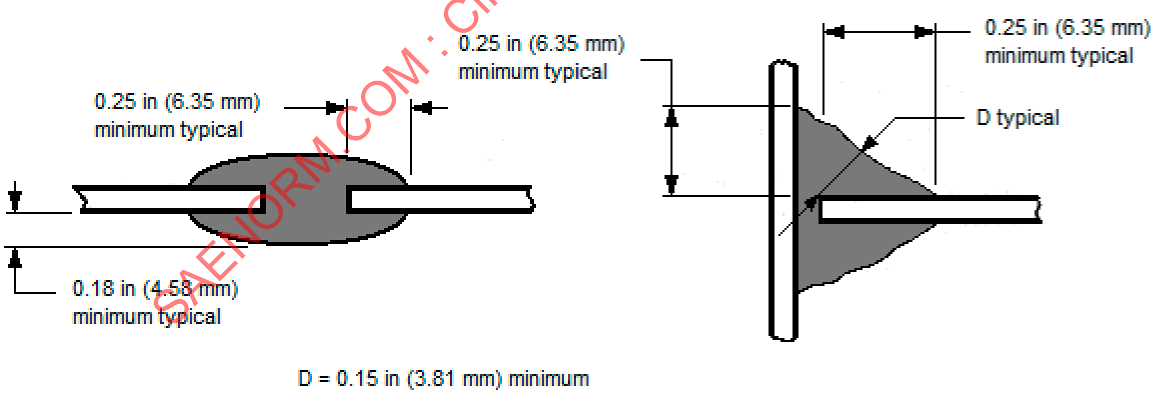

FIGURE 13 - SEALING SMALL HOLES AND SLOTS

If the opening is between 0.125 in (3.2 mm) and 0.500 in (; 12.7 mm), it can be sealed with a combination of sealant plug and sealant (see Figure 14), or a combination of annealed aluminum wire screen and sealant.

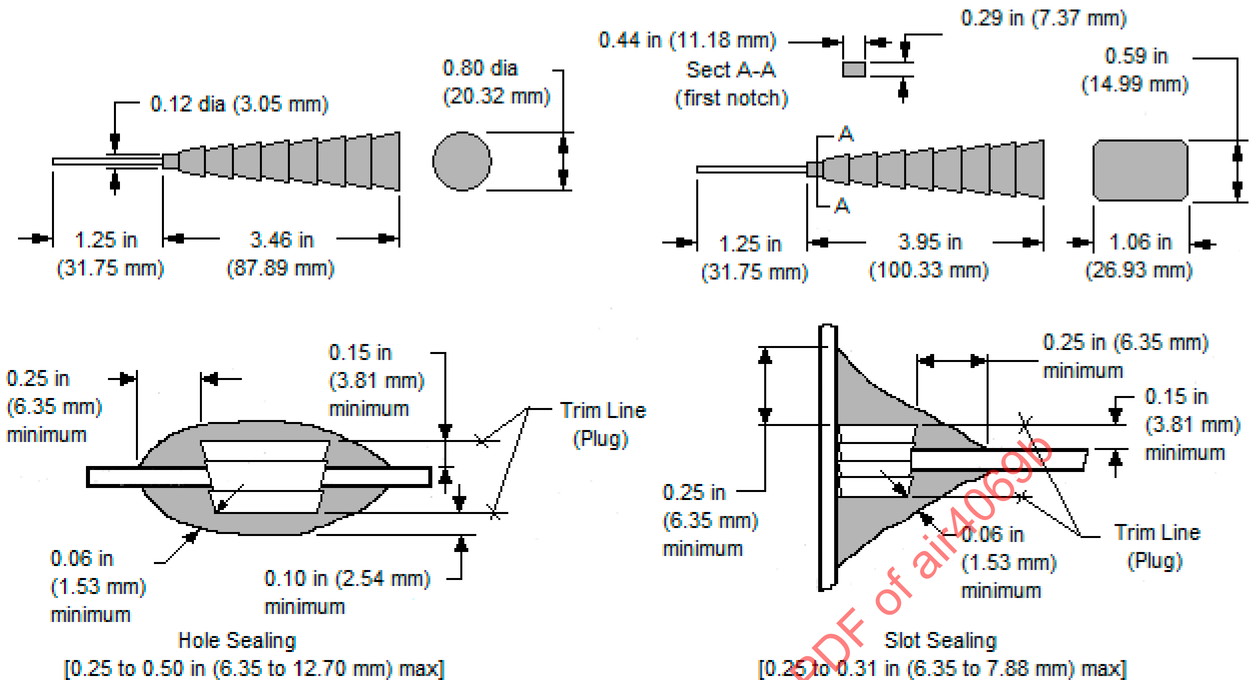

FIGURE 14 - SEALING A LARGE HOLE OR SLOT WITH A PLUG AND SEALANT

Metal clips or plastic blocks can be used to reduce the hole size before sealing. When a wire screen (or mesh) is used (Figure 15) it must be trimmed to overlap the hole or slot by approximately 0.250 in (6.35 mm).

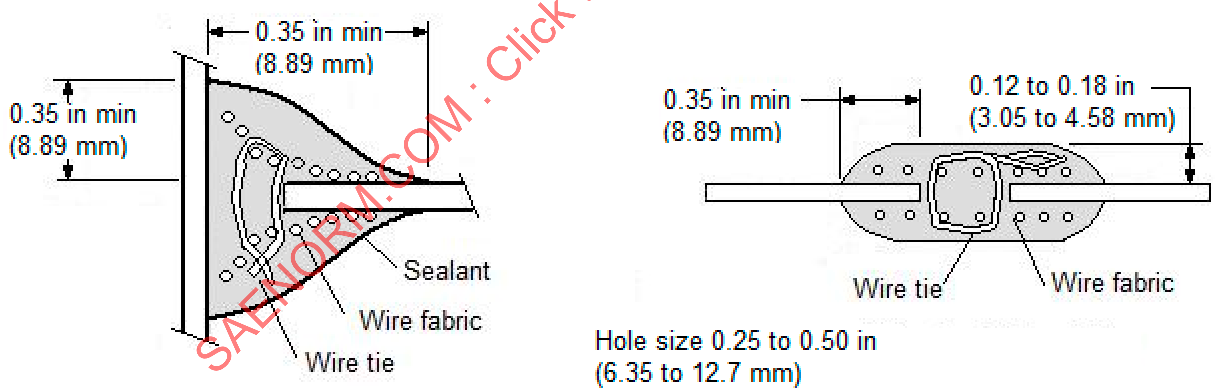

FIGURE 15 - SEALING A LARGE HOLE OR SLOT WITH SCREEN AND SEALANT

A thin layer — i.e., approximately 0.062 in (1.6 mm) — of sealant is applied around the opening first. The screen is then embedded in the sealant. A tie wire is laced to the screen and put through the hole. The hole is then filled with sealant from the opposite side. A second piece of screen of similar size is similarly positioned in the sealant over the hole on the opposite side. The tie wire is laced to the second screen. The screens are then further impregnated with sealant, and the seal is completed by crowning both sides of the screens and fairing the sealant approximately 0.250 in (6.35 mm) beyond the edge of the screen.

11.1.2.5 Fastener Sealing

All fasteners penetrating the fuel tank boundary (or sealing plane) must be wet installed. Sealant can be extruded onto the fastener or into the hole and on the surface under the head of fastener. An alternate approach is to use a special floating plug nozzle on the sealant gun, injecting sealant into the hole as shown in Figure16.

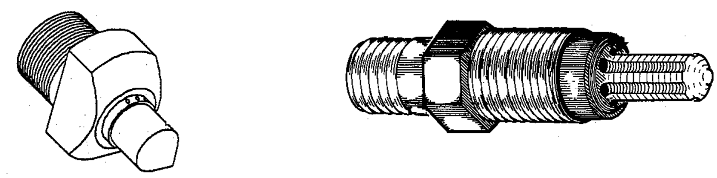

FIGURE 16 - FLOATING PLUG NOZZLE

Once permanent fasteners and bolts are installed and tightened, they must be overcoated with sealant. An overcoat of sealant can be formed using only Class B sealant, by applying multiple layers of Class A sealant, or from a Class A single brushcoat followed by an overcoat of Class B sealant.

When multiple layers of sealant brushcoats are applied, wait until the surface is tack-free before applying the next layer of sealant.

Note that multiple layers of Class A can be considered a primary seal. Slug rivets, on the other hand, are considered absolute seals and, therefore, overcoating of these parts is not required.

Fasteners are overcoated by several techniques:

a. Artist's Brush - Starting at the base of the fastener, rotate the brush around the head and adjacent surface until it is coated and surrounded by faired fillet, as shown in Figures 17 and 18.

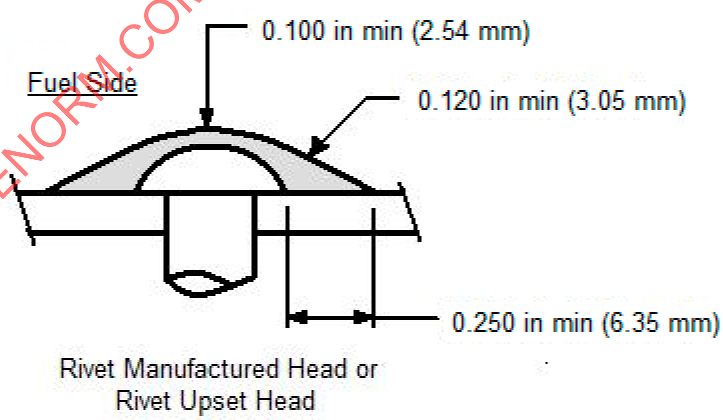

FIGURE 17 - OVERCOATING A RIVET

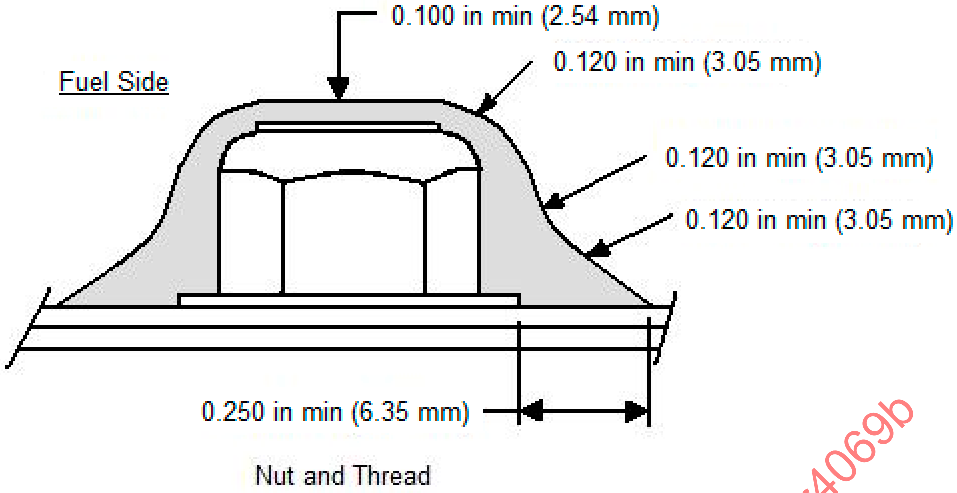

FIGURE 18 - OVERCOATING A FASTENER

b. Beehive Technique - Start the application of sealant from the nozzle of the sealant gun at the base of the fastener head. Rotate the nozzle in a spiral motion until the head is completely covered. Tool to the proper configuration.

c. Flared Tube Applicator (Daubing) - The flared tube applicator is a beveled or flared copper or aluminum tube (see Figure 19) that is closed at one end. It is filled with sealant from the sealant gun, pressed over the fastener head to the surface, and slowly rotated as it is withdrawn.

FIGURE 19 - FLARED TUBE APPLICATOR

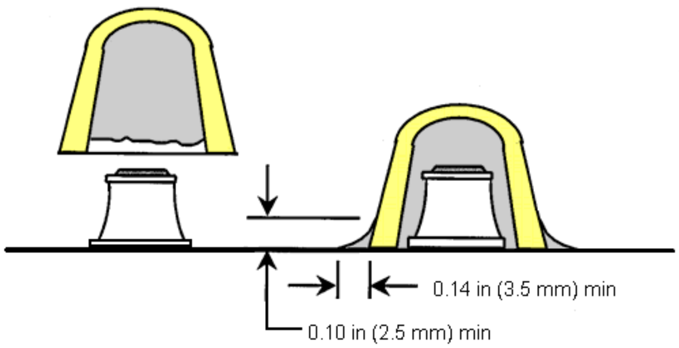

FIGURE 20 – PRE-MOLDED AND ALUMINUM SEAL CAPS

d. Seal Caps - A variety of sizes of premolded seal caps cast from polysulfide or polythioether sealant, and aluminum seal caps are available (see Figure 20). Caps of the proper size are selected, filled with Class B sealant, and pressed into place — directly over the fastener head and collar. Excess sealant squeezes out at the base of the cap and is formed into a fillet. The cap is left in place permanently.

Some companies use seal caps only at lower levels where foot traffic during production operations may bump and scuff coated fasteners. Others use seal caps because they are quick and convenient and do not limit their use to special areas.

Nylon caps are not recommended, due to difficulty in bonding to the surface and lack of a sufficiently broad data base to recommend this type of seal cap.

e. Miscellaneous - All of the techniques mentioned herein are acceptable if care is taken to exclude air bubbles, to avoid air entrapment, to avoid bridging, and to tool — i.e., to shape or fair — the configuration to provide the dimensional thickness required by engineering. When fasteners are overcoated or filleted near a vertical obstruction, care must be taken that no bridging of sealant will occur. If the fastener is closer than 0.250 in (6.35 mm) to the vertical structure, apply sealant completely around the fastener. Wait until the sealant becomes tack-free; then fill in the space between the fastener and the vertical structure, and fair the sealant up the side as shown in Figure 21.

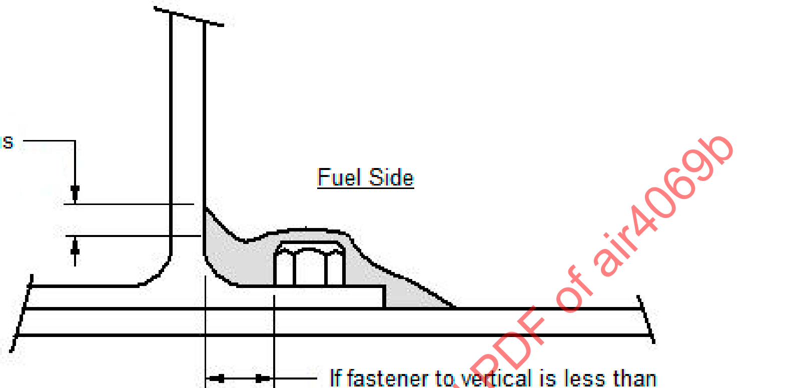

FIGURE 21 - SEALING FASTENER NEAR A VERTICAL SURFACE

If fasteners are widely separated — i.e., greater than 0.500 in (12.7 mm) apart — they can be overcoated (filleted) individually as shown in Figure 22.

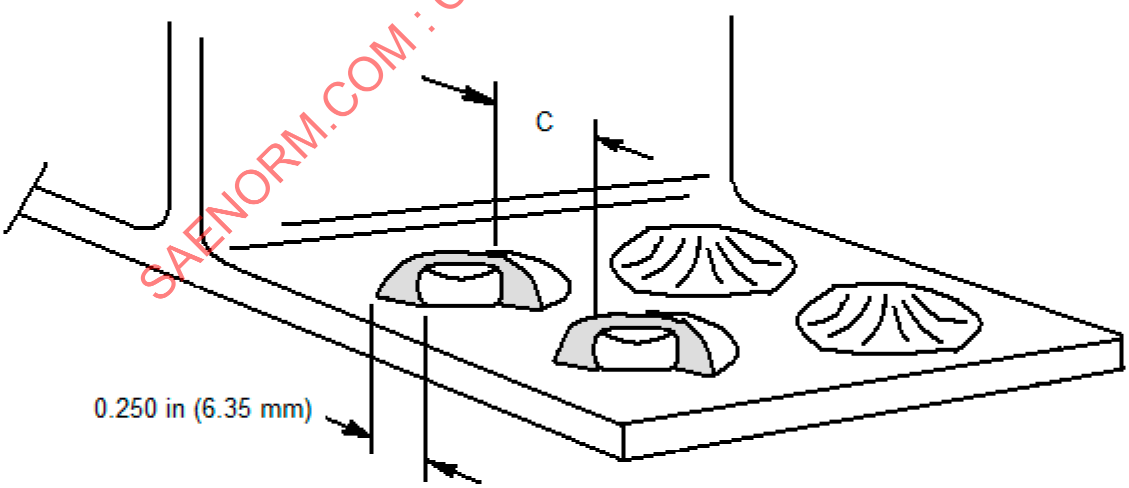

FIGURE 22 - SEALING INDIVIDUAL FASTENERS

11.1.2.6 Dome Nut Sealing

Extrudable sealant is applied around the base of dome nuts as shown in Figure 23. Completely encapsulate the dome nut, including the base and fasteners, holding the dome nut in place and using Class B sealant, or by applying two coats of Class A brushable sealant. Thicknesses of sealant and tooling (or fairing) requirements described earlier apply to this sealing operation.

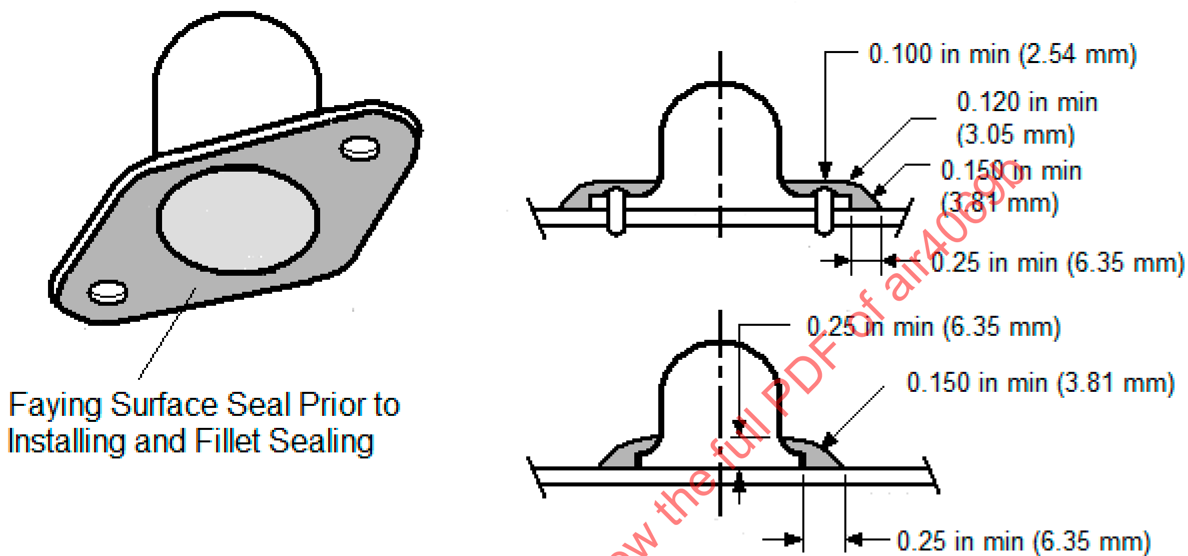

FIGURE 23 - DOME NUT SEALING

11.1.2.7 Prepacking

Extrudable (i.e., Class B) sealant is also used for prepacking voids created at structural intersections. Sealant is packed into the void area and onto fuel tank structure surfaces that will enclose it. The parts are then joined together, avoiding entrapment of air.

Sealant must squeeze out from all edges of the part. After assembly of these parts, remove excess sealant using a non-metallic tool and fair the sealant to form fillets at structure edges.

An example of prepacking is given in Figure 24. When prepacking a gap is impossible or inappropriate, use injection sealing (see 11.1.3.8).

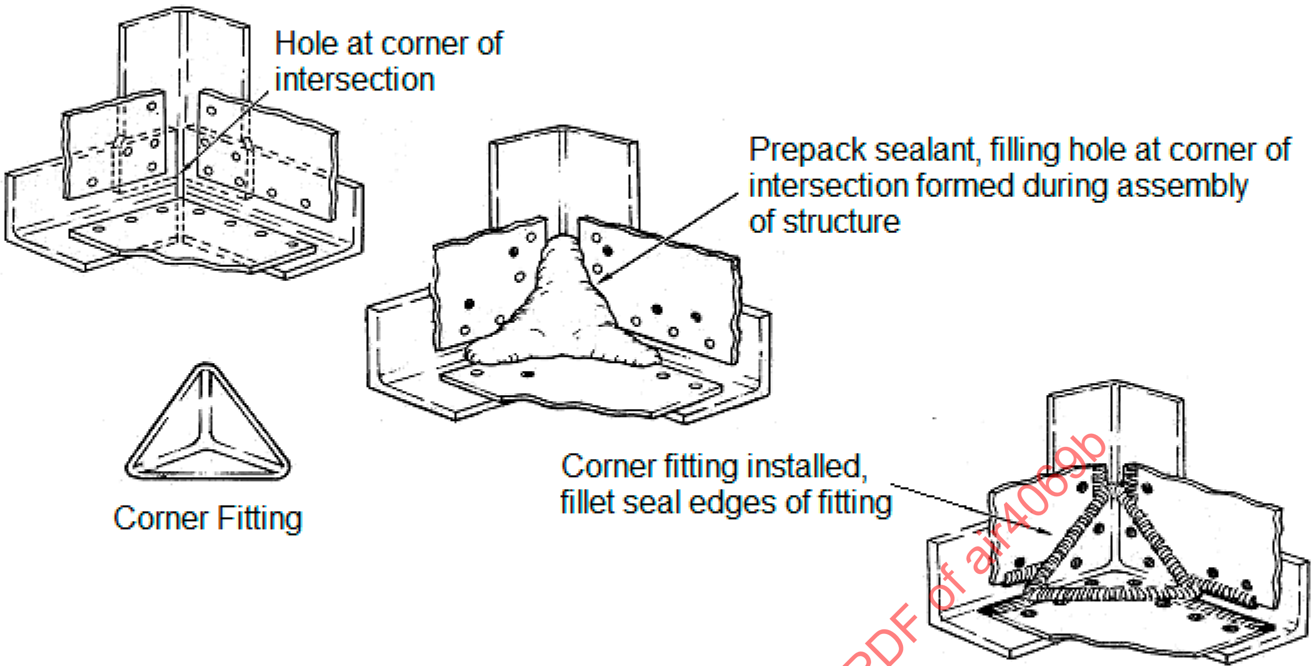

FIGURE 24 - PREPACK SEALING

11.1.2.8 Injection Sealing

After assembly, various channels, crevices, and holes result from assembly of sections and subassemblies of integral fuel tanks. It is preferred to prepack these voids, but this is not always possible. Such voids cannot be left open to collect debris or to become unobserved areas for degradation. All voids and channels must be filled. Pipe cleaners can be used with solvent cleaners to clean and apply adhesion promote in these areas.

Finally, Class B extrudable sealant is injected, using an appropriate nozzle shape and length. Inject sealant until it extrudes from the opposite side. Extrusion of sealant from a structural opening opposite to where sealant injection begins is an indication that the opening is completely filled. Block the opposite side of the void with a spatula and continue to inject until assured the void is completely filled.

If there is more than one opening, plug the other openings (or exits) until sealant has extruded from the first opening; then sequentially unplug each of the other openings. When sealant has extruded from each opening, withdraw the nozzle and ensure that the entrance is filled with sealant. Remove excess sealant with a non-metallic tool; and fair the sealant at each exit area. Injection sealing is illustrated in Figure 25.

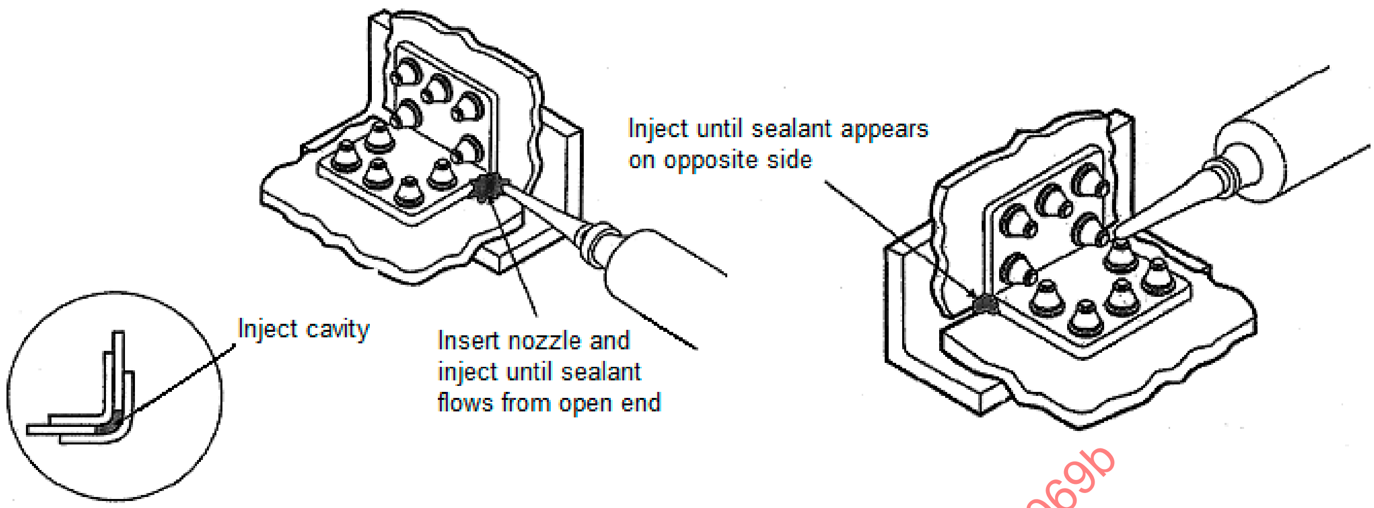

FIGURE 25 - INJECTION SEALING

11.1.2.9 Access Door

There are three types of access door seals:

a. Molded seal.

b. Bonded-in-place seal.

c. Formed-in-place seal, which are also called formed-in-place gaskets.

The following types of sealant are used for sealing of access doors:

a. Low peel strength [2 lb/in (350 N/m) of width], in accordance with AMS3284.

b. AMS-S-8802, AMS3276 and AMS3277 sealants with a non-silicone parting agent on the door. The sealant (Class B) is applied to the door frame and smoothed uniformly over the surface to a thickness of approximately 0.020 in (0.51 mm). The door is installed while sealant is still wet. The fastener should be tightened sufficiently to obtain continuous squeeze-out of the sealant. After the sealant has become tack-free, which requires approximately 24 h (or less) at standard conditions, the specified torque can be applied for installation of the fasteners. The faying surface should be wide enough [i.e., greater than 0.25 in (6.4 mm)] to form a good seal.

11.1.3 Faying-Surface Sealant Application

Faying-surface sealants are applied between overlapping surfaces (see 3.1.1.2 and 3.2.1). Since those surfaces will be drawn tightly together by fasteners, rivets, bolts, and screws, most of the applied sealant will be squeezed out. Squeeze-out must occur during the assembly time (or squeeze-out life) of the faying surface sealant.

After surface cleaning and application of adhesion promoter, the sealant is applied by extruding several beads across the surface to be coated. Generally the sealant is only applied to one surface of the mating surfaces. The sealant is then spread to a uniform thickness of approximately 0.010 in (0.25 mm) by a spreader or roller, as shown in Figure 26.

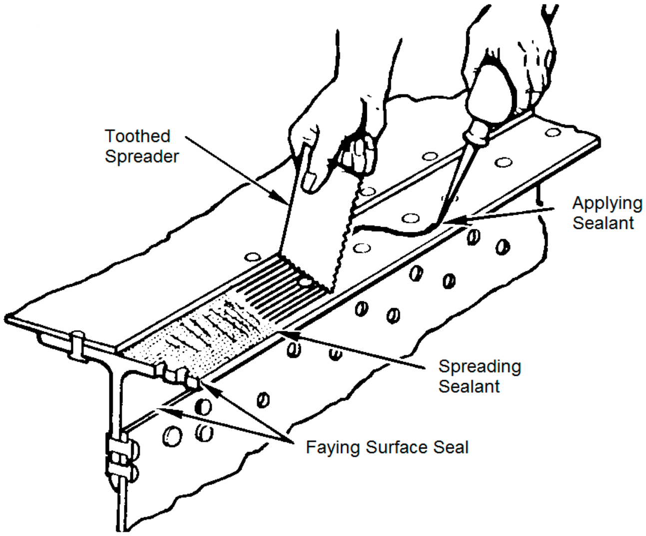

FIGURE 26 - APPLICATION OF SEALANT TO FAYING SURFACE

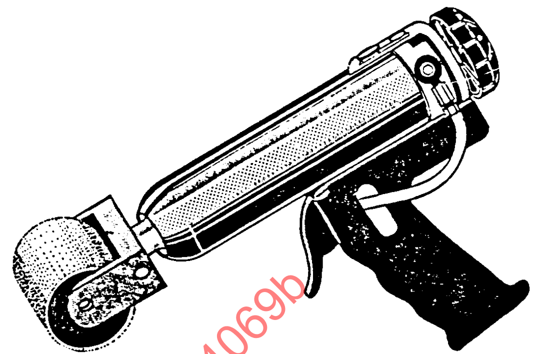

FIGURE 27 - ROLLER NOZZLE FOR FAYING-SURFACE SEALING APPLICATION

An alternative method of application is through use of a roller nozzle assembly that attaches to the threaded end of a standard cartridge in a sealant gun (see Figure 27).

When the two surfaces are fastened together, the sealant squeezes out uniformly around the periphery of the overlap. (If permanent fasteners are not installed within the assembly time, temporary fasteners should be installed in every other hole and tightened to appropriate torque value within the sealant's assembly time.)

If a continuous squeeze out is not achieved, the panels must be opened; and the sealant must be reapplied. For maximum structural strength, and to minimize later metal fatigue, the two faying surfaces are fastened together with the objective of achieving metal to metal contact. The sealant remaining is a thin film, approximately 0.003 to 0.005 in (0.08 to 0.13 mm) thick, and only a stain in the immediate area of the fastener.

Several alternative approaches are taken after obtaining fay seal squeeze out, depending upon the company:

a. Wipe off excess sealant and apply a fillet;

b. Wipe off the excess sealant, and do not apply a fillet until after final assembly and pressure testing for faying-surface leaks;

c. Wipe off the excess sealant, retaining enough sealant for forming and fairing of a fillet; apply a tack-free time accelerator to avoid entrapment and accumulation of debris — i.e., chips, dirt, and other particulate matter — in the applied sealant.

d. If the faying-surface sealant is corrosion-inhibiting, wipe off the excess sealant and apply a fillet of sealant that conforms to the engineering requirements of AMS-S-8802, AMS3276 or AMS3277.

Most companies favor application of the fillet at the subassembly stage, during close-out of the faying surfaces.

11.1.4 Protection of Sealant During the Tacky State

After sealant application — i.e., brushcoating, fillet sealing, or faying-surface sealing — the sealant surface is quite tacky, eventually becoming tack-free (usually within the first 7 to 24 h). During this period, it is vulnerable to collection of metal chips, dust, and other debris from manufacturing operations in the area. Too much surface contamination will require that fuel tank sealant be removed, the sealant bond surface recleaned, and sealant reapplied.

Four techniques are used for protecting the tacky sealant:

a. Physical protection by polyethylene plastic sheet, paper, cardboard, etc.;

b. Application of a quick-drying overcoat;

c. Application of an organic, chemical and corrosion-resistant fuel tank coating, such as a coating that conforms to requirements of AMS-C-27725;

d. Application of a tack-free time accelerator (or detakifier).

Sealing should be performed in a facility where the air is filtered. It is also desirable that no drilling or sanding, or other machining operations, be done in the area during the tacky period. Since this is not always possible, protection must be provided. Draping plastic sheets over applied fuel tank sealant is not without problems including the risk of marring the sealant surface.

A quick-drying, sprayable overcoat (see item b., above), such as PRC-DeSoto PR-715, will protect the surface of the fuel tank sealant. PR-715 is a sprayable, one-part, water-based polyurethane, which becomes tack-free in approximately 30 min at standard conditions. It is applied with a soft, camel hair brush to avoid disturbing the surface of the sealant. Do not apply by spraying and restrict overlap to 0.25 in (6.4 mm).

The last method mentioned above (item d) — a tack-free time accelerator (or detakifier) — is not a coating; it is applied from an aerosol can as a mist-coat to the surface, and it accelerates the polymeric reaction on the surface of the sealant, producing a thin and tough skin in 1 to 2 h. The sealant under the surface continues to cure at its normal rate. It is preferred because it does not introduce a foreign substance or change surface characteristics in any way.

The tack-free time accelerator (or detakifier) does not cure the fuel tank sealant sufficiently for pressure testing or fueling of the aircraft; thus, when a sealant is made tack-free by the tack- free time accelerator, it should be done only for surface protection — not for quicker refueling or pressure testing.

11.2 Application of Groove-Injection (Channel)-Sealant

Groove and channel design and sealants were discussed in 3.1.2.1 and 6.2.

This section discusses preparation of surfaces and application of sealant, including equipment used during sealant application.

11.2.1 Surface Preparation and Pretreatment

11.2.1.1 Substrates

Substrates may be aluminum alloys, titanium, or composites. Aluminum alloys are finished with one of the following coatings:

a. MIL-A-8625, Type I, Class 1 (chromic acid anodize);

b. MIL-A-8625, Type II, Class 1 (sulfuric acid anodize);

c. Ion vapor deposited aluminum, in accordance with MIL-C-83488, Type II, Class 1.

Ion vapor deposition of aluminum is used mostly for fatigue and fracture critical parts. Occasionally, MIL-C-5541, Type 1A, chromate conversion coating will be employed for fatigue-critical reasons, but this is actually less desirable because of reduced corrosion resistance.

The fuel-wetted aluminum surfaces and the aluminum faying surfaces are normally coated with the AMS-C-27725 polyurethane-based fuel tank primer to a thickness of approximately 0.001 in (0.025 mm). Injection grooves in carbon-epoxy, carbon-bismaleimide, and other composite laminates do not normally require finish treatments other than cleaning to remove parting agents. Titanium and composite surfaces are coated only if they interface with galvanically dissimilar materials.

Application of fuel tank primer to detail parts can be performed either before or after fitting, drilling, and reaming operations, provided the surfaces are clean, scratch-free, and chip-free prior to assembly. Subsequently, any scratched or damaged areas of this coating can be locally repaired.

11.2.1.2 Substrate Cleaning

After initial assembly of all parts forming the fuel containment area and all fitting, filling, drilling, reaming, and countersinking is completed, parts are disassembled and chips and burrs removed.

Prior to reassembly of aircraft wing skins to substructure, faying surfaces and channel grooves, and all interior surfaces of the fuel tank, are cleaned using an approved cleaning solvent.

Protect the surface from recontamination after cleaning. Paper masking tape or masking discs can be applied to the exterior of all fastener holes designated as injection or observation ports if they are to be left open for any length of time.

Wherever there are discontinuities in the channel, such as openings or mismatches, these discontinuities must be closed using solid shims or moldable plastic shims. No gaps in the fuel tank should exceed 0.005 in (0.13 mm).

11.2.1.3 Prepacking and Cleaning

The grooves may be prepacked with channel sealant before assembly, or the structure can be assembled then injected with channel sealant. In the former case, it is still necessary to inject after assembly to ensure that no voids remain.

Dams made of AMS-S-8802, AMS3276, AMS3277, Fusor 309 or other approved materials can be installed during the prepacking operation (if the manufacturing plan calls for prepacking the grooves prior to assembly), or later. Install the dam by injecting AMS-S-8802, AMS3276 or AMS3277 sealant using a standard sealant extrusion gun fitted with a plastic nozzle. The injection is accomplished by inserting the nozzle into the dam area with the initial nozzle position at the edge of the channel, withdrawing it slowly as sealant is extruded, filling the dam area. No sealant should enter the channel groove itself.

Once the sealant has cured completely, the prepacking with channel sealant can be completed (or can be started if the dam is built first, before any prepacking has been accomplished).

To prepack the grooves, place a plastic cartridge of channel sealant in a standard (not high pressure) sealant extrusion gun. Do not fit the cartridge with a nozzle. Hold the gun perpendicular to the surface with the cartridge opening pressed against the groove edges. Inject the sealant, moving the gun along the groove at a rate sufficient to continuously fill the channel groove. If the dam has not yet been installed, terminate prepacking within 1 in (25 mm) of area(s) where a sealant dam will be installed.

Once the channel has been filled, trowel the prepacked sealant level with the groove edges using a plastic (or other nonmetallic) scraper. If necessary, fill voids or low spots with channel sealant. Ensure that all corners are filled. Solvent clean excess sealant from adjacent mating surfaces.

Appropriate sealing operations, including (but not limited to) fillet sealing and faying-surface sealing, must be accomplished on joints and overlap edges of lower skins, using fuel tank sealant conforming to AMS-S-8802, AMS3276, AMS3277 or approved sealant.

Once all fasteners and fittings are installed in accordance with applicable engineering drawing requirements, the assembly is ready for injection of channel sealant. Channel sealant is injected with a high-pressure injection gun through external ports spaced at intervals of approximately 3 to 5 in (76 to 127 mm).

11.2.2 Equipment for Groove Injection

Equipment used for injecting channel sealant is radically different from standard sealant extrusion guns used in fillet sealing applications. Several brand names and models are mentioned as examples of the aerospace industry's most-widely-used types of equipment necessary to perform this task. Although this equipment is the most-widely-used, it is not the only equipment that is available and capable of accomplishing groove-injection sealing operations.

The Grover #223 injection gun (see Figure 28) magnifies the plant air pressure by a ratio of 70-to-1. Since tip injection pressures required for the various groove sealants range from 2000 to 6000 psi (13 790 to 41 369 kPa), factory air pressure must be regulated to a lower pressure range — from approximately 80 to 90 psi (552 to 621 kPa) to approximately 25 to 60 psi (172 to 414 kPa). The regulator component of the Grover injection gun allows full-line pressure to accumulate within the chamber; and it regulates the pressure for controlled injection of noncuring groove sealant.

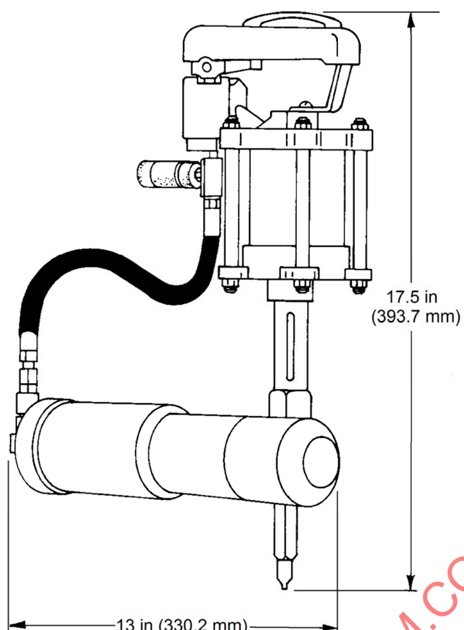

FIGURE 28 - GROVER #223 HIGH PRESSURE INJECTION GUN

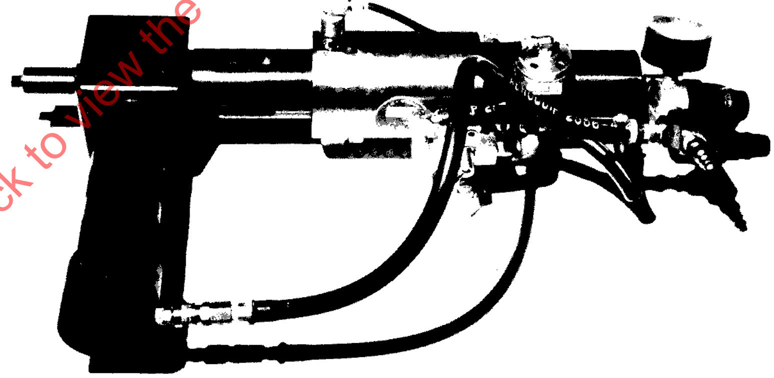

FIGURE 29 - SEMCO MODEL #510 HIGH-PRESSURE INJECTION GUN

Tip pressures are kept under 2000 psi (13 790 kPa) [air pressure at 27 to 29 psi (186 to 200 kPa)] for thin-skinned aircraft, but can be as high as 6000 psi (41 369 kPa) for heavier-winged aircraft. It is critical to the success of sealant application that the operator be acutely aware of the limitation on line pressure since the structure can be damaged, panels can be distorted or rippled, and sealant can be forced into the tank itself.

The Grover #223 gun utilizes a #226358 SEMCO cartridge adapter to permit use of a 6-fl oz (177 mL) plastic cartridge of channel sealant. The PRC-DeSoto SEMCO Model #510 injection gun (see Figure 29) provides a 110-to-1 ratio of line pressure magnification. The Model #510 injection gun is fitted with a regulator for adjusting to viscosities of various channel sealants and for controlling tip pressure; it can accept 6, 8, or 20 fl oz (177, 237, or 591 mL) cartridges of channel sealant, and it provides a continuous bead of material when actuated. Line pressure limits must be a part of the process instructions to ensure that design structure channel width and cross- section, sealant viscosity, and injection gun pressure are compatible.

The Pyles Dispenser System Model 710018-462-000 is connected to shop air pressure supply. The equipment has a 38-to-1 pressure multiplier ratio. When the air pressure setting is 100 psi (689 kPa) the tip pressure will be on the order of 3700 psi (25 511 kPa); when the air pressure is 50 psi (345 kPa) the injection pressure is approximately 1900 psi (13 100 kPa). The lower pressure is used for injection sealing of thin carbon-fiber-reinforced epoxy (composite) skins to metal or carbon-epoxy substructure.

11.2.3 Injection of Channel Sealant

The injection procedure can be started at any point on the fuel tank. Applicable materials and processes specifications or engineering drawings indicate where the injection procedure begins. The starting point is not critical. It is critical, however, that the port adjacent to the port in which the injection fitting is installed is open for the sealant to exit, indicating that the channel in between has been filled.

It is necessary to provide proper clamp up of the seal-groove structure during injection of the channel sealant. Only fasteners from the injection port in use and its adjacent port are removed. All other fasteners must be installed and tightened to specified torque values.

When removable (or temporary) fasteners are involved, injection fittings should be installed into injection and exit holes. It is necessary to measure the depth of the sealant groove and match it to the size (depth) of the port's injection fitting. Some permanent fasteners have a set screw in the fastener; this set screw can be removed when attaching the injection fitting.

Injection fittings are installed and torqued so that the slot in the fitting is aligned with the direction of the sealant groove, being careful not to exceed the torque range for the fitting. With the adjacent exit hole open, the gun is attached to the injection fitting and the sealant flow started. When sealant appears at the level of the skin or spar, or at the bottom of the countersink, the sealant flow is stopped. The injection fitting is then installed in the hole previously used for sealant exit and the next adjacent fastener is removed to permit exit of sealant when the process is systematically repeated. Continuity is thus ensured, port to port.

The sealant gun is hand held and pressed against the injection fitting while sealant is injected. Fixtures are also available for supporting the weight of the gun when overhead parts are injected.

Some noncuring sealants are stiff when cold and extrude at a much lower rate, producing more back pressure. Local heating of the structure with heating pads will aid in movement of the sealant. Once the sealing operation is completed, all accessible excess sealant should be removed from the tank's interior and exterior surfaces.

Fasteners used in addition to those in the groove path must be of the self-sealing type (O-rings) and capable of being replaced from the outside of the tank.

12. LEAK REPAIR

12.1 Repair Philosophy

During initial manufacture, leaks are repaired when discovered. During the aircraft's service life, repairs may be noted; but they may be deferred for action at the time of scheduled maintenance. If the leak is significant, it may be downgraded by use of a temporary repair, with permanent repair deferred until the time of scheduled maintenance. If a significant leak cannot be downgraded to a no leak or small leak condition, the aircraft must be grounded.

Temporary repairs are made to the outside of the integral fuel tank sometimes without defueling. Such a repair can never be accepted as a permanent repair. Permanent repairs are made inside the tank.

Leaks are caused by design deficiencies, material deficiencies, poor workmanship, and flight environment which can produce bond failures, structural cracks, corrosion, and loosening of fasteners. The most common leak sources are non-self-sealing fasteners penetrating fuel tank barrier structure. Proper initial sealing of all fasteners is imperative. Repairing leaking fasteners in the field is more difficult, since some types may require somewhat different sealing contours and dimensions; and repair personnel must recognize the differences in the sealing requirements of each type of fastener.

Fuel tank leaks have been classified by military and commercial industry in much the same way. Internal, non-vented leaks are more serious than internal vented ones, which are more serious than external leaks. Rate of leaking is another element used for determining the seriousness of the leak.

12.2 Leak Classification

The severity of aircraft fuel tank leaks are categorized by the U.S. Air Force as follows:

a. Class “A” - slow seep - 0.00 to 0.25 in (0.00 to 6.35 mm);

b. Class “B” - seep - greater than 0.25 to 0.75 in (6.35 to 19.05 mm);

c. Class “C” - heavy seep (Note 1);

d. Class “D” - running leak (Note 2).

Notes

1. For AVGAS, greater than 0.75 to 2.50 in (6.35 to 63.50 mm) without dripping; for JP-4, greater than 0.75 to 6.00 in (6.35 to 152.40 mm) without dripping; for JP-5 and JP-8, greater than 0.75 to 8.00 in (6.35 to 203.20 mm) and/or 4 drips/minute.

2. For AVGAS, greater than 2.50 in (63.50 mm) or drips or runs from surface; for JP-4, greater than 6.00 inches (152.40 mm) or drips or runs from surface; for JP-5 and JP-8 greater than 8.00 in (203.20 mm) or 8 drops/minutes

These leaks are classified as described in the following paragraphs. The level of action to be taken depends upon the magnitude and location of the leak.

Following are the three levels of action:

a. Classes A and B are essentially the same - the small leak is documented to be periodically inspected for leak growth. Under Class A, it is not mandatory to repair when the tank is opened for inspection or other repair.

b. Under Class B, repair should be scheduled when the aircraft is down for maintenance or when it is opened for another inspection or repair.

c. Class C requires documentation and repair to a no-leakage or small- leakage condition — i.e., to Class A or Class B.

Further information concerning fuel tank leak classifications can be obtained from the following document:

Mahoney, J. W., et. al., AFWAL-TR-87-3078, "Aircraft Integral Fuel Tank Design Handbook," Rockwell North American Aircraft Operations, Los Angeles, CA, December 1987.

12.3 Temporary Repairs

External repairs are considered temporary. Groove-injection repairs are permanent. Temporary repairs are designed to downgrade the leak classification to a flyable condition until scheduled permanent repairs can be accomplished. Several types of patch kits are available.

12.3.1 Aluminum Foil Patch Kit

Leaking fasteners are repaired most effectively by applying an aluminum foil patch. This patch is bonded with an extra-fast-setting epoxy or polysulfide/polythioether sealant. All of the necessary items are provided in a kit (see Figure 30).

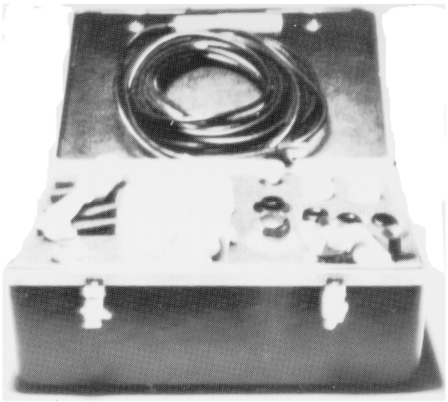

FIGURE 30 - ALUMINUM FOIL PATCH KIT
(NATIONAL STOCK NO. 4920-450-6925)

Defueling the aircraft is not necessary if a fast-setting epoxy is used. The procedure for use is as follows:

1. Clean the fastener area with AMS3167 or AMS3168 cleaner.

   NOTE: Do not remove the original sealant topcoat on the fastener before applying the patch.

2. Use a patch cut from the 0.002 in (0.05 mm) thick aluminum foil supplied in the repair kit. The diameter should cover the head of the fastener and extend 0.50 in (12.7 mm) beyond the head of the fastener.

3. Clean the surface of the foil patch with AMS3167 or AMS3168 cleaner.

4. Mix and apply the quick setting epoxy to the cleaned side of the aluminum patch. Apply it to a thickness 0.015 to 0.020 in (0.38 to 0.51 mm).

5. Press the patch into place over the fastener head. Hold in place with the kit fixture provided. Cure time: approximately 15 min at 75 °F (24 °C).

6. CAUTION: Do not heat to accelerate cure. Heat curing causes the epoxy to become brittle and fail.

7. To remove the patch (when a permanent repair is to be made, heat the patch to 200 to 250 °F (93 to 121 °C) with a heat gun. Use a plastic scraper to pry up the patch. Use needle-nosed pliers to remove the patch. Heat and scrape until epoxy is removed.

NOTE: If a two-component polysulfide or polythioether sealant is used in place of fast setting epoxy, the aircraft must be defueled to a level below that of the leak. Proceed as above. After the patch is applied, apply heat to the patch using the heat applicator in the repair kit. Cure for approximately 30 min at 140 °F (60 °C). At temperatures below 50 °F (10 °C), preheat the surface around the fasteners for approximately 3 to 5 min before applying the patch.

12.3.2 Injection of Sealant Around Flush Fasteners

Temporary repair of fuel tank sealant on flush fasteners can be accomplished, without defueling the air vehicle, by injection of a single-component, anaerobic, thread-locking compound that conforms to the requirements of MIL-S-46163. After the area surrounding the fastener has been cleaned, including removal of any paint, injection is performed at a pressure of approximately 900 psi (6205 kPa).

After the Compressed Air Injector Kit has been used, the head of the fastener is covered with aluminum tape and the sealant is heat-cured to stop the leak. Heat-curing is performed for approximately 5 to 10 min, with the heating iron set at 140 °F (60 °C).

NOTE: When the aircraft employs Buna-N seals in faying surfaces, high-pressure injection repair should not be used.

The equipment required is a part of the kit and includes a position locator, suction cups, cylinders, and jacks for holding the assembly to lower-wing surfaces. After the sealant is cured, the tape is removed.

12.3.3 Application of Quick Hardening Material

A simple method for temporary repair of fastener leaks requires cleaning the surface around the fastener with methyl ethyl ketone (MEK) or methyl propyl ketone (MPK), then applying a material that will harden over the fastener head.

a. Use Oyltite Stik (Air Force ID is D-103). Soften it by dipping the end into MEK;

b. Firmly apply the quick-hardening material around the fastener head until the leak stops;

c. Remove excess material with a plastic scraper or spatula.

12.4 Permanent Repairs

Depending on the degree to which access into the fuel tank is possible, permanent sealant repairs can be made with polysulfide or polythioether sealants. Other repairs not achievable by groove-injection or by access into the tank can be done only by disassembly.

Permanent repairs are generally made from inside the tank; exception to this is groove-injection sealing. Designs on some military aircraft include a channel (or groove) between double rows of fasteners around the perimeter of the fuel tank to allow future repair by injection. In wing tanks, depending on design, seal channels may be between double rows of fasteners or adjacent to the fasteners on the fuel tank side.

Each leak requires a leak path analysis to identify the leak exit point, the leak path, and the leak source. The appropriate aircraft sealing engineering materials and processes specification, technical manual, or technical order will identify sealants used on the structure, fasteners, access doors, and components.

Types of fuel tank seals made with curing-type sealant are:

a. Prepack and injection seals - Inject if possible and add a fillet seal around the periphery and at any other opening.

b. Faying surface - Disassembly would be necessary. Normally leaks are repaired using fillet seals. In some cases hollow bolts can be used for injecting faying-surface sealant to effect repair. Apply manual pressure to prevent panel distortion. The fastener is then reinstalled and sealed.

c. Fillet Seals - Repaired by removal of the fillet in the affected area, then tapering the remaining ends to an angle of approximately 30 degree. Abrade 0.50 in (12.7 mm) on each end, clean, apply adhesion promoter, apply brushcoat Class A sealant, then apply the fillet.

d. Brushcoats - The brush coat is recommended for fillets; and it is applied before the application of the fillet seal. It is never applied over fillet seals as a leak repair.

e. Hole and slot - Repaired by removing old sealant and seals, then reapplying sealant.

f. Overcoat Seals - As previously mentioned, the following three approaches are acceptable:

    1. Multiple layers of Class A material if each layer is applied after the prior layer surface is tack free.

    2. Class A sealant layer followed by a layer of Class B sealant. The layer of Class B material is applied after the Class A sealant is tack-free.

    3. Class B material applied alone.

With any of these approaches, it is recommended that adhesion promoter be applied prior to resealing.

12.4.1 Permanent Repairs with Two-Part Curing Sealant

12.4.1.1 Prepacked Seals

Without disassembly, remove peripheral sealant, clean, apply adhesion promoter, and repair with a fillet. Then tool (or fair) the fillet.

12.4.1.2 Injection Seals

Without disassembly, remove peripheral sealant, clean, apply adhesion promoter (use a pipe cleaner if necessary), reinject, tool the outer surface.

12.4.1.3 Faying-Surface Seals

Remove the fillet to be repaired, clean, apply adhesion promoter, apply brushcoat, apply and fair the new fillet. More extensive repair — i.e., replacement of the faying-surface sealant — would require disassembly, involving significant time and cost. In some cases hollow bolts can be used for injecting faying-surface sealant during repair operations.

12.4.1.4 Fillet Seals

The repair of a fillet seal involves the following steps:

a. Remove the defective sealant using nonmetallic tools. Steel knives or scrapers must not be used.

b. Cut the remaining ends of fillets, tapering them to approximately a 30 degree angle. At least 0.5 in (12.7 mm) on each fillet end should be abraded.

c. Clean the surface (see Section 5).

d. Repair the corrosion-protective coating with an epoxy-based primer, such as a coating that meets the engineering requirements of MIL-PRF-23377 (see Section 4).

e. Apply adhesion promoter (allow approximately 30 min, maximum, for activation). At this point, there are two methods for proceeding; both methods are acceptable.

Method I - Apply a brushcoat of Class A polysulfide or polythioether sealant at a sufficient width along the seam or joint such that, after the fillet is applied and tooled, the Class A material extends 0.10 in (2.54 mm) wider on each side of the fillet. The Class A brushcoat must be applied after at least 30 min of adhesion promoter application, and not greater than 4 h after application of adhesion promoter.

Apply the Class B extrudable fillet sealant and tool it. In those companies which use this technique, the Class B sealant is applied any time after the Class A material becomes tack free. If more than 4 h passes without applying Class B material, the Class A surface must be cleaned and abraded.

Method 2 - Apply Class B extrudable polysulfide or polythioether sealant directly to freshly applied adhesion promoter. The Class B fillet must be applied after at least 30 min of adhesion promoter application, and not greater than 4 h after application of adhesion promoter. Tool, or fair, the fillet.

12.4.1.5 Brushcoating

Brushcoats of Class A polysulfide and polythioether sealants are applied using a stiff brush, working in a close circular motion into and around crevices, holes, seams, around and over fasteners and on surfaces to be sealed with a fillet of Class B material. It is recommended that adhesion promoter be applied after cleaning the surface, before the brushcoat is applied.

12.4.1.6 Fasteners

Since there are several types of fasteners, the major types are addressed in this section.

a. Interference Fit Fasteners - Leaks in interference fit fasteners are repaired by:

   1. Removing the sealant fillet or overcoat if any;

   2. Cleaning the surface;

   3. Applying adhesion promoter;

   4. Overcoating with Class B polysulfide or polythioether sealant, using either a brush or an extrusion gun (other techniques previously mentioned in 11.1.3.5 are acceptable); and fairing (or feathering) the edges.

b. Fasteners with Sealing Washer or O-Ring - Retighten these fasteners to the appropriate torque value. If the leak persists, remove the fastener, clean the surface, replace the sealing washer, replace the fastener, and tighten to the appropriate torque value. Alternative method: after retightening the existing fastener if leaking persists, clean the surface of the fastener thoroughly (inside the tank) with an acceptable solvent cleaner, such as AMS3167 or AMS3168, Type I, and overcoat with a Class B extrudable sealant, observing sealant thickness and dimensions specified in 11.1.2.5.

c. Fasteners Sealed with a Brushcoat/Fillet - Repair as in 12.4.1.6a.

12.4.1.7 Access Doors Previously Sealed with Polysulfide or Polythioether Sealant

a. Retighten the fasteners;

b. Remove leaking screw or bolt, clean it, apply Class A or B sealant to the shank and under the screw or bolt head; then reinstall.

c. If the fuel leak persists, remove the access door, remove the applied sealant, clean, and reapply the access door sealant as described in 11.1.2.9.

12.4.2 Permanent Repairs with Groove/Channel Sealant

Leaks occur at times in difficult-to-reach areas, requiring the removal of equipment before repairs can be made. The most common failure mode is gap extrusion from pressure build-up due to thermal expansion, fuel swell, and other factors.

Thermal expansion, and contraction can also cause void formation. Other causes of leaks include leaching of lower molecular weight polymers by the fuel, polymer chain scission from vibration and shearing action, and hydrolysis of the polymer from absorbed water in the fuel.

Finding the leak source is of paramount importance; this may require removal of access panels to identify the suspected leak source. Once the leak is found, the channel in that area must be reinjected.

Repair personnel must be alert to the aircraft's operational environment — specifically, temperature and humidity — due to the potential for variation of sealant extrudability and groove-injection pressures. It may be necessary, in some cases, to apply heat to aircraft structure near the injection ports.

Starting with the first and second cover screws to the left of the leak exit, inject channel sealant until it exits the second port in a length equivalent to the distance between the ports [3 to 5 in (76 to 127 mm)] or until no voids, or fuel, are observed. Close the first port, open the third port. Inject into the second port. Again, observe sealant exiting the third port until the segment between these ports has been filled with new channel sealant. Close the second port and inject into the third port, opening the fourth port for release of old sealant. Close the third and fourth ports.