established based on previous service experience of equipment installed in the same environment. If previous experience on similar or identical components is not available, conservative initial inspection/test intervals should be established until design maturity can be assured.

5.3.5 External environment

The severity of the external environmental conditions that should be considered when showing compliance with CS 25.981 is that of the conditions established by the certification specifications.

5.3.6 External sources of tank auto-ignition

The possibility of fuel tank ignition due to surface-ignition sources created by external tank heating should be considered. This includes heating of the tank due to the operation or failure of systems outside the tank within both the pressurised and unpressurised areas of the aeroplane, such as overloaded electric motors or transformers, failures in the pneumatic system, and/or ducting that could cause localised heating of tank surfaces. In addition, the possibility of localised heating due to external fires should be considered.

5.3.6.1 CS 25.967(e) requires that, 'Each fuel tank must be isolated from personnel compartments by a fumeproof and fuelproof enclosure.'

5.3.6.1.1 Leakage of fuel or vapour into spaces adjacent to the fuel tank, where a secondary fuelproof and fumeproof barrier is not provided, has typically been assumed for areas such as:

— The wing leading edges (including any adjacent compartment such as the strut) and trailing edges,

— Fairings located below the fuel tanks,

— Fuel pump enclosures, and

— Unpressurised areas of the fuselage surrounding fuel tanks located in the empennage.

5.3.6.1.2 Components located in these areas have been required to meet the explosion-proof requirements. These components or systems should be included in the analysis. Examples of such equipment include, but are not limited to, environmental control system (ECS) air conditioning packs, motors, power assisted valves, fuel pumps, hydraulic pumps/motors, certain flight control actuators, ECS controls, and wiring and valves.

5.3.6.2 A safety review of the flammable fluid leakage zones adjacent to fuel tanks should be conducted to determine whether the design complies with the requirements of CS 25.863(a) and CS 25.981. In general, the fire protection philosophy for any area considered a flammable fluid leakage zone is to assume that flammable vapour may be present in the zone and to minimise the probability of ignition of the vapour (CS 25.863(a)). This has typically been accomplished by using combinations of the following design considerations:

— Grounding and bonding of electrical equipment,

— Qualification of electrical equipment as explosion proof,

— Sealing of electrical connectors,

— Proper support, protection, and separation of wiring,

— Drainage provisions in the leakage zone,

— Ventilation of the leakage zone in flight and of areas around the auxiliary tanks, and

— Immediate maintenance action to correct leaks in these areas.

5.3.6.3 Surface temperatures in areas adjacent to fuel tanks

While EASA (and previously the JAA (Joint Aviation Authorities)) has accepted the use of maximum acceptable surface temperatures 27.8 °C (50 °F) below the applicable auto-ignition temperature of the fuel-air mixture (i.e. a surface temperature of 204 °C (400° F) for fuel tanks filled with kerosene), some higher temperatures have been accepted in certain cases if adequately substantiated by the applicant. Some manufacturers have substantiated that the conditions (ambient pressure, dwell time, fuel type, etc.) within certain flammable fluid leakage zones are such that a higher value may be used.

For example, maximum allowable pneumatic bleed duct surface temperatures of 232°C (450°F), with a transient excursion up to 260°C (500°F) for a maximum of two minutes, have been approved. The excursion above 232°C (450°F) occurs only during failure conditions such as an engine pneumatic high stage bleed valve failure or duct rupture. The approval of these elevated temperatures has been based on compensating design features such as a cockpit indication of over-temperature combined with associated procedures to shutoff the overheated system, insulated ducts, zone ventilation airflow which produces a lean fuel-air mixture, and an automatic over-temperature shutoff of the pneumatic system so that the temperature cannot exceed the accepted 232°C (450°F) temperature for more than two minutes. The internal tank surface temperatures resulting from the failure should not exceed the surface temperature limit for the fuel type used, as described in paragraph 3.5 of this AMC.

5.3.7 Electrical ignition sources

The applicant should perform a failure analysis of all the fuel systems and subsystems that have wiring routed into fuel tanks. Systems that should be considered include those for fuel pump power and control and indication, fuel quantity indication, fuel temperature indication, fuel level sensors, and any other wiring routed into or adjacent to fuel tanks. The analysis should consider system level failures, failures within LRUs, and the component level failures discussed below. The analysis should include the existence of latent failures and subsequent failures that may lead to an ignition source within the fuel tank. Examples include undetected failures of tank components or wiring, the undetected presence of conductive debris, damage to FQIS or level sensor probes, or corrosion, in combination with external failures such as hot shorts or electromagnetic effects. In addition, the applicant should provide a description of the protective means employed in the fuel system wiring. This should include a description of features such as separation/segregation, transient suppression devices, shielding of wiring, and methods employed to maintain configuration control of critical wiring throughout the life of the aeroplane.

5.3.8 Electrical short-circuits

5.3.8.1 One method that may provide protection of circuits that enter fuel tanks is the incorporation of a transient suppression device (TSD) in the circuit close to the point where those wires enter the fuel tanks. Consideration should also be given to protection of the wiring between the TSDs and the tank if the protection devices are not located at the tank entrance, and also to the possibility of transients being induced in the wiring between the TSDs and the electrical devices in the fuel tanks. Caution should be exercised when using a TSD to ensure that the TSD addresses both voltage and current suppression in order to limit the energy and current below the limits provided in Section 3.2 of this AMC.

5.3.8.2 Another method of protection that has been used to provide a fail-safe design with respect to electrical shorts is the separation of the wiring to electrical devices in the fuel tanks from other electrical power wires and circuits, combined with shielding between the wiring that enters the fuel tanks and any other electrical power-carrying wires in the aircraft installation. The effects of electrical short circuits, including hot shorts, on the equipment and wiring that enters the fuel tanks should be considered, particularly for the FQIS wiring, fuel level sensors, and probes. Latent failures from factors such as contamination, damage/pinching of wires during installation, or corrosion on the probes, connectors, or wiring should be considered when evaluating the effects of short circuits. The wire routing, shielding, and segregation outside the fuel tanks, including within the FQIS components (e.g., gauging units), should also be considered when evaluating the effects of short circuits. The evaluation should consider both the electrical arcing and localised heating that may result from short circuits on equipment, FQIS probes, and wiring. The evaluation of electrical short circuits should include consideration of shorts within electrical equipment, and the wiring from the equipment into the fuel tank. Prevention of fuel ignition from electrical shorts to the wiring that enters the fuel tanks may require specific wire and circuit separation and wire bundle shielding.

5.3.9 LRU design evaluation

The design review should include an evaluation of the separation and protective features incorporated into any fuel system LRU whose failure could result in high-level electrical power (i.e., above the intrinsically safe levels) entering the fuel tank. For example, circuit board failures could cause the LRU power supply circuits for the fuel quantity gauging system to come into contact with the circuits that lead into the fuel tank, resulting in a possible ignition source. Failures that can lead to violating the separation features within the LRU can be external or internal events. External failures include overvoltage or overcurrent, high humidity, temperature, vibration, shock, and contamination. Internal failures include manufacturing defects or flaws in the conductor, substrate, or coating. To address these failures, the design should either provide isolation and physical separation between the critical circuits, such as the circuits that enter a fuel tank, or adequate protective features, such as the transient suppression devices as discussed earlier, to protect the circuits that enter the fuel tank. Any LRU that meets the design requirements identified in Underwriters Laboratories Inc., UL 913, Intrinsically Safe Apparatus and Associated Apparatus for use in Class I, II, III, Division 1, Hazardous (Classified) Locations, is considered acceptable, provided the following issues are addressed:

— Ideally, higher power circuits within the LRU should not be located on the same circuit board or in a wire harness or electrical connector with intrinsically safe circuits or wiring;

— There should be a physical barrier between circuit boards to isolate the intrinsically safe circuits from the effects of broken components or fire within the LRU; and

— If limiting devices are installed on the same circuit board in series with the system circuitry to limit the amount of power or current transmitted to the fuel tank, there should be 7.62 cm (3 inches) between the traces, unless the manufacturer can justify a smaller separation on the basis that the effects of fire on the circuit board will not compromise the intrinsically safe circuit(s).

5.3.10 Electromagnetic effects including HIRF

See AMC 25.954 for guidelines on establishing compliance with the requirements for fuel system protection from lightning effects.

5.3.10.1 The evaluation should consider the electromagnetic effects due to HIRF, electrical transients, and RF emissions on the fuel system conductors (e.g. fuel tank plumbing, structure, fuel, equipment and wiring) within the fuel tanks, particularly for the FQIS wiring and probes. The applicant should also consider the latent failures from factors such as contamination, damage, or corrosion on the probes or wiring when evaluating the effects of electrical transients. The wire routing, shielding, and segregation of conductors (e.g., plumbing, component casings, wiring, etc.) outside the fuel tanks should also be considered when evaluating the effects of electrical transients because the generation of the transient and the coupling to conductors may occur outside the fuel tanks. The evaluation should consider both electrical sparks and arcs, and localised heating, which may result from electromagnetic effects on the fuel tank system, FQIS probes, and wiring.

5.3.10.2 The evaluation should consider latent failures of electromagnetic protection features, such as shielding termination corrosion, shield damage, and transient limiting device failures, and the applicant should establish appropriate indications or inspection intervals to prevent the existence of latent failure conditions. The failure of other system components may also affect the protection against electromagnetic effects. Consequently, the evaluation should consider the effect of any anticipated failure on the continued environmental protection.

5.3.10.3 The evaluation of electromagnetic effects should be based on the specific electromagnetic environment of a particular aeroplane model. Standardised tests, such as those in EUROCAE ED-14G Change 1 dated January 2015, 'Environmental Conditions and Test Procedures for Airborne Equipment', and the equivalent RTCA, Inc., Document No DO-160G dated December 2010, Sections 19 and 20, are not sufficient alone to show that the appropriate standardised test categories, procedures, and test levels of EUROCAE ED-14G/RTCA DO-160G are selected, without an evaluation of the characteristics of the specific electromagnetic environment and the induced transient levels assigned to systems installed within a particular aeroplane model. Simulation of various latent failures of fuel system components within the tanks may be needed to show the effectiveness of the transient protection. The effectiveness of these features should be verified using the appropriate test procedures and test levels of EUROCAE ED-14G/RTCA DO-160G, determined above.

5.3.10.4 Prevention of fuel ignition due to electromagnetic effects may require specific wire segregation and separation, wire bundle shielding, or transient suppression for wires entering fuel tanks. The effectiveness of the transient protection features should be verified using the appropriate test procedures and test levels of EUROCAE ED-14G/RTCA DO-160G, determined above.

5.3.10.5 Redundancy of bond paths

A failure of bonding jumpers is generally considered a latent failure, since there is no annunciation or indication of the bonding failure. The aeroplane fleet fuel tank inspections that occurred as a result of the TWA 800 investigation (National Transportation Safety Board Aircraft Accident Report NTSB/AAR-00/03, 'In-flight Breakup Over the Atlantic Ocean Trans World Airlines Flight 800, Boeing 747-131, N93119, Near East Moriches, New York,' dated July 17, 1996) showed that failures of bonding jumpers, due to damage, wear, or manufacturing errors, were not unusual. Based on this, it would be difficult to show that the probability of a failure of a single bonding jumper is extremely remote or extremely improbable. Therefore, electrical bonding jumpers or other bonding provisions would need to consider the consequences of these latent failures. This may result in designs that incorporate electrical bonding redundancy, if the failure of a single electrical bonding feature could create a fuel tank ignition source. Additionally, manufacturers would need to consider the use of appropriate maintenance to detect failed bonding jumpers. An example of such maintenance might include periodic inspections to limit latency.

5.3.10.6 Self-bonding couplers

Early generation, self-bonding, flexible fuel couplers did not have multiple bonding paths. Thus, these bonding couplers exhibited single-point failures that caused a loss of function. These self-bonding flexible couplers failed because of missing bonding springs, anodising on bonding surfaces, and incorrect installation. The safety assessment of designs incorporating multiple bonding paths must consider these failure modes, and qualification testing should show that no ignition sources are present in the full-up (non-degraded condition) and possible degraded condition with failure modes present within the couplings. For example, failure assessments of clamshell-type, self-bonding metallic couplings in composite fuel tanks have shown that arcing could occur if a coupling was improperly latched, or became unlatched and fell to the bottom of the fuel tank. The design of the coupling would need to address these failure modes. Improper latching could be addressed through positive latching features with tactile and visual indications that the coupling is properly latched. Redundant fail-safe features, such as redundant hinge and latching features, redundant bonding features, etc., may be needed to address other possible failure modes.

5.3.10.7 Resistance or impedance limits of aeroplane electrical bonding provisions

5.3.10.7.1 There is no specific EASA guidance on the maximum resistance or impedance of aeroplane electrical bonding provisions because electrical bonding within a fuel system should be tailored to the performance requirements of a particular aeroplane design. The electrical bonding should consider the electrical sources, electrical faults, and electrostatic charges. The electrical bonding should also consider the fuel system design of the specific aeroplane, which would include the structure material used (aluminium, carbon-fibre composites, fibreglass composites, etc.), the configuration of the fuel system (routing of fuel tubes, wires, and hydraulic tubes), and the electrical bonding concept (intentional isolation, self-bonding fittings, separate bonding jumpers, etc.). Given the large variation in design approaches and the close relationship between the design approach and the electrical bonding requirements, it is not practical for EASA to provide specific guidance on the maximum bonding resistance or impedance.

5.3.10.7.2 Some type certificate (TC) holders have performed tests on their aeroplanes to determine the specific requirements for electrical bonding. Others, in the absence of specific aeroplane test data, have chosen conservative electrical bonding approaches. The approach is a decision each TC holder should make based on the specific situation for that TC holder's aeroplane models.

5.3.10.8 Bonding integrity checks

Past experience has shown that measurement of bond resistance is the desired method of ensuring bond path integrity. During bonding resistance measurements, the protective finish of components might be damaged in order to penetrate the insulating anodised surface layer, which may lead to subsequent corrosion damage. This concern has resulted in some TC holders defining non-intrusive inspections for electrical bonding. These inspections may include detailed visual inspections provided that the quality of the electrical bonding feature can be adequately assessed by visual cues, such as visible corrosion, breakage, tightness, or missing bonding provisions. For critical bonds, this method would not by itself be adequate. Other inspection methods include inductively coupled loop resistance measurements that eliminate the need to disconnect bonding jumpers, or to penetrate corrosion-prevention coatings. The need for bonding inspections, the frequency of the inspections, and the determination as to whether the inspections must be an Airworthiness Limitation should be established under the fuel tank SSA.

5.3.10.9 Bond corrosion and integrity

5.3.10.9.1 Degradation of electrical bonding provisions, such as bonding jumpers, has occurred on in-service aeroplanes. Results from aeroplane fuel tank inspections conducted on a sample of aeroplanes by manufacturers and operators showed discolouration, corrosion, and damage to bonding jumpers. It is not clear whether the discolouration indicates that corrosion that will become more severe with time, or whether it is simply a surface colour change. The applicant should define the bonding feature characteristics — such as visible corrosion, discolouration, jumper strand separation, and jumper strand breakage — that will be used to distinguish discrepant bonding provisions.

5.3.10.9.2 The level of corrosion observed on bonding features, specifically on bonding jumpers, varies greatly across aeroplane fleets. While some aeroplanes within a fleet and certain locations within the fuel tanks showed no evidence of corrosion, other aeroplanes and locations exhibited higher levels of corrosion. Inspection results indicate that the materials used in certain bonding jumpers (tin-plated copper) may be more prone to corrosion. Nickel-plated copper wire does not experience similar corrosion. Corrosion programs for aeroplane structures have long recognised the variability of corrosion within the fleet. Factors that influence the level of corrosion of bonding jumpers include the fuel type (sulphur content, etc.), the presence of water in the fuel tank, installation effects such as cracking of the tin plating when the jumper is installed, the temperature, humidity, and chemicals used for preparation of the fuel tanks prior to aeroplane storage, etc. While certain levels of corrosion or discolouration may be acceptable between inspection intervals, the showing of compliance should include substantiation that the materials used in the bonding jumpers are appropriate for use in the fuel tanks in consideration of the proposed inspection intervals. This substantiation should consider the variability in corrosive environments and the factors noted above that may exist on in-service and stored aeroplanes in the fleet.

5.3.10.10 CS 25.981 states: '(a) No ignition source may be present at each point in the fuel tank or fuel tank system where catastrophic failure could occur due to ignition of fuel or vapours.' Fuel tube flexible couplings and components as small as nuts, bolts, and washers may develop sufficient charge to cause arcing due to electrostatic conditions if not properly accounted for in the design. Electrical bonding would need to be considered if these couplings are identified as ignition sources during the ignition source evaluation and assessment.

5.3.11 Friction sparks

The failure modes and effects analysis (FMEA) should include an evaluation of the effects of debris entering the fuel pumps, including any debris that could be generated internally, such as any components upstream of the pump inlet. Industry practices for fuel tank cleanliness, and design features intended to preclude debris entering the fuel pumps, have not been effective at eliminating debris. Service experience has shown that pump inlet check valves, inducers, nuts, bolts, rivets, fasteners, sealant, lockwire, and so forth have been drawn into fuel pumps and contacted the impeller. This condition could result in the creation of friction sparks, and it should be an assumed failure condition when conducting the SSA. Fail-safe features should be incorporated into the fuel pump design to address this condition. Examples of means that may be incorporated into the fuel pump design to address this concern include:

— the installation of inlet flame arrestors,

— the use of reticulated foam,

— the use/installation of ejector fuel pumps without impellers to scavenge fuel, or

— maintaining fuel over the pump inlet throughout the aeroplane flight attitude envelope.

6 COMPONENT FAILURE MODE CONSIDERATIONS

6.1 Component qualification review

The qualification of components, such as fuel pumps, has not always accounted for unforeseen failures, wear, or inappropriate overhaul or maintenance. Failures to account for these failure modes and testing the pump using the procedures defined in Military Standard MIL-STD-810H, Method 511.6, Explosive Atmosphere, have led to some fuel pumps entering airline service having never been tested to demonstrate whether they have explosion-proof capabilities. This combined experience suggests that more needs to be done to establish the capabilities of fuel pumps and other fuel system components to operate safely in an explosive environment. Such a capability should be substantiated considering these factors in addition to the conditions noted in paragraph 3.3 of this AMC. The amount of qualification review can be significantly reduced if the fail-safe features noted earlier in this AMC are followed (e.g. not operating pumps in the vapour spaces of the tank, incorporating arc fault or ground fault protection on the electrical circuit, etc.). Therefore, an extensive evaluation of the qualification of components may be required if a qualitative assessment of the component and installation features does not eliminate the component as a potential ignition source.

6.2 Maximum component temperature for qualification of fuel system components

The maximum component temperatures may be determined experimentally. Tests should be conducted that are long enough for the component to reach the maximum temperature. All the foreseeable failures and malfunctions of the fuel tank components (including those failures and malfunctions that could be undetected by the flight crew and maintenance personnel) should be considered when determining the maximum temperatures.

6.2.1 Components mounted adjacent to the exterior surface of the fuel tank can create a high localised temperature on the inner surface of the tank. This can be investigated by laboratory tests that duplicate the installation, or by a validated heat transfer analysis using the maximum potential temperature of the component.

6.2.2 When aeroplane equipment or system components such as engine bleed air ducting or ECS are located near fuel tanks, an FMEA should be performed to determine the failures of adjacent systems or components that could cause elevated surface temperatures. The maximum internal tank temperatures that can occur during normal and failure conditions should be determined. Systems, such as over-temperature protection devices, should be evaluated to determine whether periodic health checks are necessary to ensure that latent failures do not exist.

6.3 Possible failure modes for determination of maximum component temperatures

The following list identifies some possible failure modes, but not all the conditions, that should be explored in determining the maximum temperature expected for fuel tank components:

6.3.1 Fuel pumps

6.3.1.1 Normal fuel pump operation considering the highest hot day ambient and fuel tank temperatures: in many cases, fuel pump motors are protected by a (single) three-phase thermal circuit breaker. In several instances, the resetting of circuit breakers has resulted in arcing inside the fuel tank and the development of an ignition source from an existing failure. Therefore, the fuel pump circuit should also preclude the development of an ignition source if the breaker is reset or forced in by a mechanic. Methods that may be used to address this foreseeable failure condition include the use of circuit-protective features such as non-resettable, fast-acting AFCB or GFI circuit breakers.

6.3.1.2 Two-phase operation of three-phase electrical fuel pumps: a failure of a single phase of a multiple-phase fuel pump will significantly increase the load on the remaining phases of the pump and the generation of heat in the pump. In many cases, thermal protection features within the pump have been incorporated to address this failure condition, but these means have not been effective at preventing continued operation of a pump with a failed electrical phase. Another failure condition that should be considered is the subsequent failure of a second phase of the pump and possible arcing or heat damage. In general, pumps should not be allowed to operate following a failure of a single electrical phase of the pump if such operation could result in the development of an ignition source. Automatic protective means, such as AFCBs or GFIs or other means, should be provided to shut down the pump when a single electrical phase failure occurs. Periodic inspections or maintenance of these features may be required.

6.3.1.3 Dry operation of fuel pumps, including lack of lubrication: service history has shown that flight crews and maintenance personnel have inadvertently operated fuel pumps for long periods of time without fuel in the fuel tank. Fuel pumps are typically qualified for dry run operation for periods of time based upon assumptions made about the possible duration of inadvertent operation, or the failure conditions, which could result in dry running of the pump. For example, some pumps were operated during qualification testing up to a maximum of 8 hours continuously, with total accumulated dry run operation of 24 hours. These qualification tests were accomplished in order to show that the fuel pump performance was still adequate following the dry pump operation. The tests were not conducted in an explosive environment and, hence, were not intended to qualify the pumps for such operation. In other cases, previous approvals were predicated on the assumption that the fuel pump would not be dry run operated because the pump would be turned off by the flight/ground crew following a pump low-pressure indication. Extended dry operation of pumps may result in surface temperatures above the auto-ignition temperature of the fuel, or may expose the pump to dry run operation where debris from the fuel tank could enter the impeller and cause sparks. Manufacturers' recommended procedures have not been shown to be adequate in preventing dry run operation. Therefore, additional fail-safe features are necessary to preclude ignition sources caused by the dry run operation of aeroplane fuel pumps. One or more of the following fail-safe means should be considered for the protection of fuel pumps:

1. Incorporating design features to keep the fuel pump inlet submerged in jet fuel to prevent dry running of the pump under all operating conditions.

2. Incorporating automatic pump shutoff features into the fuel pump or aeroplane to preclude dry run operation.

3. Other means such as the installation of flame arrestors in the fuel pump inlet to preclude flame propagation into the fuel tank.

6.3.1.4 The temperatures associated with the fuel pump following wet operation with wet mechanical components both at zero and reduced fluid flow.

6.3.1.5 The temperatures associated with moving mechanisms that are locked or seized.

6.3.1.6 The temperatures generated as a consequence of pump impeller slippage.

6.3.1.7 High temperatures or high currents due to a broken shaft. The design has to contain the broken shaft, and the pump and its control system must consider the high currents and temperatures that would follow.

6.3.1.8 Failed bearings: the effects of wear on the fuel pump features incorporated into the design to maintain explosion-proof characteristics should be evaluated. For example, the wear of bearings or failures, including spinning of any bushings, and the possible effects on quenching orifices should be evaluated. In many cases, the fuel pump explosion-proof features are not redundant, and the failure or degradation of the features is latent. If single or probable combinations of failures in the fuel pump can cause an ignition source, CS 25.981 requires the incorporation of the fail-safe features noted previously. If wear of the pump can cause the degradation of fail-safe features, appropriate inspections, overhaul, or life limiting of the pump should be included in the Airworthiness Limitations Section of the ICA, per CS 25.981(d) and Appendix H to CS-25, paragraph H25.4.

6.3.2 FQIS

6.3.2.1 FQIS wiring in the tank, with maximum voltage and current applied, considering normal and failure conditions, including the effects of high-voltage systems outside the tank in proximity to the FQIS wires.

6.3.2.2 FQIS components in the normal and failed state with the above associated maximum voltages and fault currents applied.

6.3.3 Float switch system

Float switch system temperatures should be determined considering the maximum environment temperatures and the application of the applicable maximum voltage and fault currents.