U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: AUXILIARY FUEL SYSTEMS FOR RECIPROCATING AND TURBINE POWERED PART 23 AIRPLANES

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Change:

1. PURPOSE. This advisory circular (AC) provides information and guidance concerning acceptable means, but not the only means, of showing compliance with Part 23 of the Federal Aviation Regulations (FAR), Part 3 of the Civil Air Regulations (CAR), or earlier corresponding regulations applicable to auxiliary fuel system installations. Accordingly, this material is neither mandatory nor regulatory in nature and does not constitute a regulation.

2. SCOPE. This AC provides guidance and criteria for the installation of auxiliary fuel systems in Part 23 airplanes. It is intended to be used for auxiliary fuel system installations in the airplane including fuselage, wing, or external configurations. Installations that involve changes to primary structure, aerodynamics, airspeed, mass distribution (will induce flutter changes), maximum weight, or changes in center of gravity (c.g.) limits require additional substantiation, that is beyond the scope of this AC.

3. APPLICABLE FAR SECTIONS AND RELATED DOCUMENTS.

a. Applicable Sections. Applicable sections of the FAR are shown in specific paragraphs, as well as listed below:

§ 23.561	§ 23.843	§ 23.1337
§ 23.571	§ 23.853	§ 23.1351
§ 23.601	§ 23.863	§ 23.1357
§ 23.603	§ 23.867	§§ 23.1501 through 23.1529
§ 23.609	§ 23.901	§ 23.1541
§ 23.613	§ 23.903	§ 23.1543
§ 23.615	§§ 23.951 through 23.1001	§ 23.1553
		§ 23.1555
§ 23.619	§ 23.1011	§ 23.1557
§ 23.625	§ 23.1183	§§ 23.1581 through 23.1589
§ 23.777	§ 23.1189	
§ 23.787	§ 23.1305	

b. Related Documents. Related AC's and reading material are listed in appendixes 2 and 3 respectively.

4. GENERAL. Before determining the auxiliary fuel system configuration and modifying the airplane, the applicant should become familiar with the existing airplane structural and systems characteristics and functions, and with the applicable certification requirements. To avoid structural and systems compatibility problems, a working knowledge of the airplane is essential. In particular, the applicant should determine the effects of the addition of the auxiliary fuel system on payload, c.g., mass distribution induced flutter changes, system and airplane operations, and structural margins. When in doubt about any certification requirement, the applicant should consult with the FAA aircraft certification office responsible for his project early in the design program to avoid costly changes late in the program.

5. CERTIFICATION BASIS.

a. New Type Certificates. For the issuance of a new type certificate, an airplane must be shown to comply with the certification basis established in accordance with § 21.17 of the Federal Aviation Regulations (FAR). If the regulations do not provide adequate or appropriate standards because of a novel or unusual design feature, special conditions will be prescribed in accordance with § 21.16.

b. Other Design Changes. For other design changes, such as the addition of a new model to an existing type certificate or modification of an existing model, the airplane must be shown to comply with the certification basis established in accordance with § 21.101. Generally, the applicant may choose compliance with the regulations incorporated by reference in the type certificate (the original certification basis) or with the applicable regulations in effect on the date of the application for approval of the auxiliary fuel system (current rules). If the original certification basis does not provide adequate or appropriate safety standards because of novel or unusual design features, compliance with current rules may be prescribed in accordance with § 21.101(b). If neither the original certification basis nor current rules provide adequate or appropriate standards, special conditions will be prescribed in accordance with § 21.16. Although sections of Part 23 are referenced in this AC, the references should be interpreted to be the corresponding sections of the earlier applicable certification basis.

c. Unsafe Features or Characteristics. Notwithstanding compliance with the established certification basis, § 21.21 precludes approval if there is any feature or characteristic that makes the airplane unsafe. The applicant should recognize that it may be necessary, because of such a feature or characteristic, to impose special requirements which exceed the standards of the certification basis, to eliminate the unsafe condition.

6. PROCEDURES. In order to avoid delays and possible expensive redesign, it is strongly recommended that the following procedures be followed. After the applicant has made application for approval of an installation, the applicant should:

a. Submit a proposed overall certification program plan that identifies the essential steps or actions and the sequence anticipated for submitting reports, drawings, process specifications, analyses, tests, and other documentation to complete the installation approval. This program plan should include the proposed or target schedule for the required FAA approval tests and inspections.

b. Generate a certification test plan which describes the analytical procedures or qualification testing to be used to demonstrate the design adequacy. Each plan should list the applicable FAR and describe how each requirement will be met. In addition, the plan should include a description of the airplane or test articles to be used, drawings, method of production simulation (if applicable), and the target date for installation and test. The certification test plan should be submitted for review and concurrence by the appropriate FAA aircraft certification office prior to initiation of tests, to prevent certification delays.

c. After the FAA has reviewed and accepted the test plan, a Type Inspection Authorization (TIA) will be issued to specify the required official ground and flight tests.

d. Schedule FAA conformity inspection of the test installation.

e. Schedule and conduct the ground and flight test(s) with FAA witnessing.

f. Submit final test reports describing all test results and obtain FAA approval.

7. DISCUSSION.

a. General. The addition of auxiliary fuel tanks to an airplane should not compromise the basic integrity of the original fuel system. These installations should comply with the appropriate regulations required by the certification basis of the particular airplane.

The auxiliary fuel system should be evaluated in conjunction with the main fuel system to ensure that no hazardous fuel transfer or feed conditions exist. The criteria used to make this evaluation will depend on the type of auxiliary fuel system selected. The requirements for the two primary types of auxiliary fuel systems, the transfer and the direct feed type, vary considerably. The transfer type system supplies fuel from the auxiliary tank to an existing main tank(s). In at least one operating mode, the direct feed system supplies fuel directly to an engine.

The requirements for a direct feed auxiliary fuel system are considerably more stringent than those for a transfer auxiliary fuel system. In general, these requirements ensure that an uninterrupted flow of fuel at the required pressure and flow rate is provided to each engine for all operating conditions of the airplane. For turbine engine airplanes, these provisions should be automatic to meet the requirements of § 23.955(f)(2). These requirements also address altitude performance effects and low and high temperature fuel aspects as well as providing fuel system independence in at least one configuration. Failure mode and effects analyses (FMEA) are needed to ensure that no hazardous conditions exist due to a failure of the auxiliary system. Continuous engine operation should be verified when the auxiliary tank system is depleted of fuel in order to prevent engine flameout or other unacceptable operating conditions.

Transfer type system requirements are not as stringent but do require basic fuel system considerations such as damage to tank and vent lines due to excessive pressure from overfilling, high and low temperature fuel effects, transfer rates, drainage, altitude effects, etc. The auxiliary tank depletion characteristics should also be evaluated to ensure that air entrainment, etc., do not alter main tank performance. The applicant should determine when transfer to a main system tank should be established and whether the transfer should be in increments or continuous. The auxiliary tank quantity, flow rates, main system tank levels, etc., are considerations for when to initiate the transfer and should be a part of the AFM procedures and limitations. If misconfiguration of the fuel system can result in an unsafe operating condition, cockpit annunciation of the condition should be provided.

b. Structural Considerations (§ 23.561).

(1) Design Criteria and Structural Loads.

(i) The extent of structural substantiation required depends on the magnitude and location of the added fuel and the modifications required to accommodate the fuel tank installation. Evaluation of the tank attachment hardware and local structure may be sufficient; however, installations that involve changes to primary structure, aerodynamics, maximum weight changes, or changes in c.g. limits may require additional substantiation that is beyond the scope of this AC.

(ii) The tank installation design should isolate the tank itself from airframe induced structural loads and from deformation induced by the wing and fuselage, except for integral type tanks.

(iii) The fuel tank and its attachment and support structures should be designed to withstand all design loads, including cabin pressurization and the emergency landing load specified in § 23.561. The requirement for retention of fuel as required by

§ 23.967(e) should also be addressed for these loads as well as dynamic loads. The requirements of § 23.571 should be addressed as required for the fuel tank.

(iv) Fuel loads included in the structural substantiation should be based on the most critical density of the fuels approved for use in the airplane.

(v) The fuselage is limited to design values that cannot be exceeded without resubstantiation. Tradeoffs between passengers, cargo, and fuel may be made provided the allowable floor, bulkhead, and local shell loads are not exceeded.

(vi) The following should be considered in the evaluation of the tank and tank support structure in accordance with the applicable certification basis:

(A) Tank internal pressure developed during malfunction of the pressure type fueling system, if applicable. Tank pressure due to fuel head in combination with gust loads should also be considered.

(B) Except as provided in § 23.625(a) or (b), a fitting factor of at least 1.15 should be applied to all tank support fittings and their attachment to the tank.

(C) All probable combinations of fuel distribution in multiple tanks, including slosh, should be accounted for in defining tank structural loads and airplane weight and balance.

(D) To preclude rupture and provide durability, the face sheet thickness should be sufficient for the applicable load requirements and to prevent accidental damage. Where aluminum is used for these purposes, thicknesses are typically not less than 0.020 inch for the outer face sheets or 0.040 inch for the inner face sheets.

(E) The requirements of §§ 23.963, 23.965, and 23.967 are applicable.

(vii) Installation of wing auxiliary tanks should address the increased wing loads.

(2) <u>Structural Modification</u>.

(i) Where existing structure is being modified for the tank installation, adequate reinforcement should be added as necessary to maintain structural integrity equal to or better than the original structure.

(ii) Modifications such as cutouts, tank support attachments, and service openings through exterior skins, should not degrade structural load capability or lead to reduced fatigue capability. If holes are cut through the pressure vessel for auxiliary fuel system lines, etc., special care should be taken to reseal the penetrations, particularly those affecting the pressure vessel. The fuselage should be pressure tested in accordance with the requirements of § 23.843; and if major modifications are made to the cabin pressure vessel, a fatigue evaluation should be accomplished as required by § 23.571.

(iii) The effect of the modification on the existing maintenance program, including the structural supplemental inspection program, if applicable, should be considered and appropriate changes made in accordance with § 23.1529.

(3) Crash Overload. Hard attachment points between the fuel tank and airframe structure restrict relative motion and, in turn, impose high concentrated loads on both the tank and the airframe. In order to limit the magnitude of these concentrated loads, crash load failure points are typically located between the tank and airframe. In addition:

(i) Attachment point loads should be evenly distributed to minimize the possibility of fuel tank rupture.

(ii) In the event of an overload condition, the failure should occur at some point between the tank attach fitting and the basic airframe and floor structure to minimize potential body tank rupture. Where possible, the design should prevent failure of the tank support from causing failure of the fuel lines, for the maximum tank displacement that could occur. It may be necessary to incorporate redundant supports, flexible secondary supports, or secondary constraint bulkheads to accomplish this.

c. Tank Location Criteria.

(1) Uncontained Engine Rotor and Blade Failure Considerations for Turbine Powered Airplanes (§ 23.903).

(i) The applicant should evaluate the location of fuel tanks and other fuel system components from the standpoint of protection afforded against uncontained engine and auxiliary power unit (APU) rotor or blade failures. For this evaluation, the applicant should review the information and recommendations given in AC 20-128, "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Fan Blade Failures," or any superseding FAA guidance material. The applicant should also obtain information about the containment features which may be incorporated in the particular engines or APU's used on the airplane involved. The energy levels of uncontained rotor/blade fragments specified by the engine/APU manufacturer should be used.

(ii) For certification compliance, a report addressing the above considerations should be prepared and submitted. The report should adequately consider uncontained rotor and blade failures from all engine and APU sources which may affect the integrity of the auxiliary fuel system. The report should also show that design precautions have been taken to minimize hazards to the airplane in the event of these failures and that the airplane safety level has not been degraded by the auxiliary fuel tank/system installation.

(2) Installations in Cargo and Baggage Compartments (§ 23.787).

(i) The various components for the auxiliary fuel system installed in cargo and baggage compartments should be protected from damage caused by shifting cargo. A cargo barrier, either rigid or flexible, should be used to separate the auxiliary fuel system from the cargo. This barrier should be designed to contain the maximum cargo loading for which the compartment is approved under all load conditions including the emergency landing condition. (§ 23.561)

(ii) When the fuel system is installed in cargo and baggage compartments, ensure all material used, including cargo barriers and replacement compartment liners, meet the applicable flammability requirements. As a minimum, a cargo barrier should meet the flammability requirements of cargo and baggage compartment liners. (§ 23.863)

(iii) If holes are cut through cargo and baggage compartment liners for auxiliary fuel system lines, care should be taken to reseal the liner.

(iv) When the auxiliary fuel system is designed to be quickly removed, consideration should be given to the method for resealing or plugging holes while the system is removed. Complete maintenance instructions should be provided detailing the method of removal, resealing, and restoring the airplane essentially to its original configuration. (§ 23.1529)

(v) Auxiliary fuel systems are frequently installed in cargo compartments. If the tank and component secondary barriers are capable of withstanding a cargo compartment fire so that the safety of the airplane is maintained, then the secondary barrier materials are acceptable. These fire resistant characteristics should be equivalent to the liner materials of the compartment where they are located. The system should also be evaluated with respect to materials from the standpoint of toxic gas release under fire conditions. No materials should be used which act as a fuel for fires. Avoid the use of magnesium or flammable resins, sealants, and coatings.

(3) Design and Location. Section 23.967(e) is applicable and should be addressed.

d. Airplane Fuel System Compatibility (§§ 23.901(b)(1), 23.951, 23.953, 23.955, 23.957, 23.961, 23.995, and 23.1189).

(1) Interface Considerations.

(i) The interface of the auxiliary fuel system and the existing airplane fuel system should be evaluated. Use of existing fuel system lines and manifolds can provide considerable weight savings; however, the functions of these lines should be checked to ensure that the added usage does not conflict with other requirements.

NOTE: Should existing fuel lines and manifolds be used, special care should be taken to ensure that air is not introduced into the main fuel system during normal and abnormal use of an auxiliary system.

(ii) Interface with the existing airplane vent system for venting of the auxiliary tank(s) should be evaluated. The existing vents have been sized to maintain acceptable pressure levels during refueling and flight maneuvers. When combining the systems, unless it is obvious by analysis, the applicant should verify that no failure conditions result in an overpressure condition, i.e., during refueling or emergency descent. Some systems may require two-phase flow analysis (air venting from one tank and liquid fuel venting from another tank through a combined vent system). If the main fuel system tanks use flexible tank liners, it may be necessary to show by analysis or test that the combined vent system does not cause any hazardous bladder collapse in the main system tanks due to rapid descent or other operating condition.

(iii) When the auxiliary fuel system arrangement has been determined and the interfaces with the main fuel system have been established, a total system analysis should be conducted to ensure that no hidden failures in the system could lead to an unsafe operating condition. Analyze the system for all modes of operation, including venting, pressure fueling, defueling, transfer, engine feed, crossfeed, and emergency fuel dumping. For example, the auxiliary tank system should be designed so that failure of the system could not result in undetected or uncontrollable transfer of fuel from the main tank to the auxiliary tank when the main tank system is in its normal operating configuration.

(2) Other Considerations. Other systems should also be evaluated for compatibility with the auxiliary fuel system. Ensure that the auxiliary fuel system electrical power demands do not overtax the airplane electrical system. Use auxiliary fuel system cockpit indicators and nomenclature which are compatible with the existing cockpit displays. Adequate cockpit display to indicate auxiliary tank

depletion or improper fuel scheduling should be provided and cockpit indication of low fuel state, c.g., unbalance or other unsafe condition should be considered for the particular installation. It should not be possible to select fuel from more than one tank at a time unless the tank vents are interconnected.

(3) Control and Shutoff (§§ 23.995 and 23.1189). Sections 23.995 and 23.1189 should be complied with for valves, controls, and shutoffs.

e. General Arrangement Evaluation.

(1) System Layout. In addition to the criteria described in the previous section, consideration should be given to the following:

(i) Line Routing, Flexibility, and Support (§§ 23.863 and 23.993). General fuel system practices should be adhered to in installing fuel and vent lines (refer to AC 43.13-1A). All flexible lines should be adequately supported along the entire line installation length. Ensure that lines cannot chafe against control cables, airframe structure, or other equipment items. Avoid locating lines near high temperature sources or near electrical wiring. Where close proximity of a fuel line to electric wiring is unavoidable, locate the fuel line so that leakage cannot drip onto the wiring. Ensure that the fuel line is adequately clamped to structure to maintain the required spacing. Do not support wire bundles from fuel or vent lines. If adequate compartment ventilation or fuel line shrouding cannot be provided, isolation of electrical wiring from fuel lines may require a vapor barrier or a conduit for the wiring. Undrainable low spots in vent and fuel lines should be avoided.

(ii) Fuel Tank and Component Location, Access, Mounting, and Protection (§§ 23.901, 23.963, 23.965, 23.993, and 23.994).

(A) Each auxiliary fuel tank or tank module design should be evaluated for the basic requirements of §§ 23.963 and 23.965. These requirements address, for example, the basic integrity of the tank, bladder cell requirements, and the tank tests, such as slosh and vibration, that may be required.

(B) As a general rule, all components, such as valves, pressure transmitters or switches, filters, etc., should be directly mounted to the airplane structure or to supports which are directly attached to the structure. However, components may be mounted to the fuel tank to minimize relative motion.

If fuel or other system lines or fittings are used to support auxiliary fuel system "in-line" small/lightweight components, it should be shown that this practice does not result in excessive structural stresses when subjected to the vibration and other loads expected in service.

(C) Although function should dictate the appropriate location of components in the airplane, there is usually some latitude which can allow selection of a specific area which is more suitable than others. Component location should be considered from the aspects of both access and protection. Access is especially important for components which may require routine periodic inspection and maintenance such as strainers, filters, and drain valves or components with known short service life expectancy. Where possible, such components should be located in areas where there are currently existing access doors and openings on the airplane. When new access provisions are required, lightning and crashworthiness vulnerability as well as structural security should be considered.

(D) For components which are located inside the fuel tanks, the crashworthiness aspects of the installation should be considered. Means should be provided to prevent component sharp edges from penetrating the tank surface due to deflection of the surface under crash load conditions should be provided, especially where flexible tank bladder cells are used.

(iii) Tank Penetration Points (Access, Quantity Probes, Float Switches, and Fuel Fittings) (§§ 23.963, 23.973, 23.975, 23.977).

(A) The location and arrangement of all tank penetration points should be considered. Tank penetration points are all locations where openings exist in the tank walls for access (inspection or repairs), for mounting fuel quantity probes, float switches, etc., and for tank venting, draining, fuel transfer, or fueling.

(B) Auxiliary tanks should have access openings large enough to permit completion of required inspections. Component and line penetrations may be usable as access/inspection openings, depending on size and location, and should be evaluated for acceptability.

(C) The fuel tank filler, fuel jettison, and vent openings should be designed so that they open external to the airplane and prevent spilled fuel from entering any part of the airplane.

(iv) Electrical Wiring Routing and Support. Refer to AC 43.13-1A, "Acceptable Methods, Techniques and Practices--Aircraft Inspection and Repair," for more details regarding routing and supporting of wires.

(2) Fuel Containment Secondary Barriers (§§ 23.967 and 23.853). For auxiliary fuel systems which are located in the passenger or cargo and baggage compartments (appendix 1), isolation of the fuel and fuel vapors from other areas of the compartment is of critical importance. Tanks, lines (including flexible lines), fittings, connections, and other components, such as valves, pressure

transmitters, regulators, etc., should be shrouded or provided with redundant barriers so that leaks from any of these sources cannot present a hazard. Some of the important characteristics of the secondary barrier system are:

(i) The system should be capable of containing and isolating any leakage.

(ii) Secondary barrier spaces should be vented and drained in accordance with acceptable practices to prevent the accumulation of fuel or fuel vapor. The drain system also serves as a periodic visual means of detecting any leakage in the auxiliary fuel system. For this reason, shroud drains should not be connected to other types of fluid drain systems.

(iii) The secondary barrier drain system materials, construction, and sealing characteristics should be compatible with fuel and capable of long life under the altitude/cabin pressure cycling, vibration, and wear that they may be exposed to in service. It is acceptable, with no further showing of compliance, to use the same materials, construction, and sealing as originally approved in the airplane type design, and specified in the Airplane Maintenance Manual if service experience has been acceptable.

(iv) The drain system should be reviewed from the installation location aspects to preclude the possibility of inadvertent damage by ground personnel or shifting cargo.

(3) <u>Tank, Fuel, and Vent Line and Component Shrouds (§§ 23.853 and 23.967)</u>.

(i) Auxiliary fuel tanks installed in a passenger or cargo and baggage compartment should be completely shrouded. This means that all fittings connected to and through the tank walls should also be provided with secondary barriers.

(ii) All vent and fuel lines, fittings, and connections in a passenger or cargo compartment should also be shrouded.

(iii) Valves and other components, unless otherwise protected, can have possible leak paths through shafts and at control motor and solenoid connections or other seals in addition to their line connections, and should be completely shrouded.

(iv) Electrically operated components are of particular concern because of the possible need to route electrical leads through the secondary barrier spaces. The space should be considered an abnormal vapor zone containing flammable fluid similar to the interior of the fuel tank. Thus, an evaluation of the electrical connector and wiring temperatures should be made for both normal and fault load conditions. It may be necessary from this evaluation to install the wiring in vapor-proof conduit, except where shown to be intrinsically safe.

(4) Fuel Tank Secondary Barrier Cavity Venting (§ 23.967). The changes in tank secondary barrier cavity pressure during all airplane maneuvers, including emergency descent, should be accounted for in the design of the auxiliary fuel tank. Bladder type tanks may be critical under emergency descent conditions, depending on the cavity vent line sizing. The vent/drain configuration should provide the required positive and negative pressure relief between the outer shell and the bladder or inner wall to prevent collapse or overexpansion of the inner tank. Depending on the location of the overboard vent/drain exit and the airflow characteristics around the exit or exit mast, a flight test may be required to evaluate the emergency descent characteristics of the cavity vent system with the airplane in both the "clean" and "wheels and flaps down" configuration.

(5) Other Secondary Barrier Vent and Drain Provision (§§ 23.954 and 23.967).

(i) All secondary barrier spaces should be vented and drained. The spaces in some designs are manifolded for venting and drainage or are independently vented and drained. Eventually, all cavities should vent and drain to an exit external to the airplane. The overboard exit should be located to prevent fluid reingestion into such areas as the wheelwell and other critical areas of the airplane. On many airplanes, there are existing exit drain masts which are used to vent and drain the secondary barrier cavities of the airplane's main fuel tanks. The use of these existing drain masts is recommended. The attachment of the auxiliary system drain to the existing airplane drain should ensure that backflow does not occur in either system.

(ii) For secondary barriers, the cavity vent and drain exit should always be open and vented to ambient pressure. Avoid the use of push-to-drain valves at both ends of the drain to check the cavity condition. Multiple drain outlets utilizing push-to-drain or other type valves should not inhibit venting.

(iii) If a new drain exit is required, consider carefully the location and configuration from the standpoint of lightning vulnerability and conductivity. Drain masts should not be located upstream of air inlets or other openings in the airplane external surface. Physical inspection by the cognizant personnel of all drain locations on the actual airplane should be accomplished to ensure all interfaces are considered. Unless it is obvious by inspection, verification should be accomplished by impingement tests conducted in flight to ensure that liquid discharge from the drain exit will not cause a hazard or reenter at another airplane surface. It should be ensured that freezing does not occur nor does icing buildup cause suction venting during the tests and that the test results are representative of a fuel leak.

f. Fuel System Contamination Prevention Assessment (§§ 23.951, 23.971, 23.977, and 23.997). The primary concerns of fuel contamination with respect to auxiliary fuel system design are water and debris contamination. The certification requirements are quite specific, and the installer should be familiar with the requirements of § 23.971, Fuel Tank Sumps, and § 23.977, Fuel Tank Outlets. There may also be a need to refer to § 23.997, Fuel Strainer or Filter. This regulation would be applicable for auxiliary fuel systems which feed fuel to a positive displacement pump which, in turn, feeds the engine or to some alternate auxiliary fuel tank direct engine feed system. The existing main fuel system design should already satisfy § 23.997 requirements. The installer should, however, verify that these requirements are maintained when an auxiliary fuel system is installed. For turbine powered airplanes, an evaluation of the original and auxiliary fuel system should be done to satisfy the requirements of § 23.951(c). The following features should be considered with respect to auxiliary fuel system contamination.

(1) Fuel Tank Sumps and Fuel Strainers.

(i) Sump Location and Capacity.

(A) Sumps should be installed at the lowest point in the auxiliary fuel system with the airplane in its normal static ground attitude. This should allow water in the system to migrate to the sump where it can be drained before flight. The sump may be an integral part of the tank, providing the bottom of the tank is the lowest point in the system, or may be a single separate tank specifically installed for sumping purposes. If the sump is a separate tank and located within a passenger or cargo compartment, it should be designed to the shrouding criteria set forth previously for fuel tanks including the overboard drain exit requirements.

(B) Sumps and sump tanks should have the capacity specified in § 23.971. If a single sump tank is used for a number of tanks or modules that are interconnected together to function as a single tank system, the required capacity of the sump is based on the capacity of the total tank system. All tanks must be completely drainable to the sump tank.

(ii) Sump Drain Provisions. All sumps should have provisions which allow complete drainage of the sump. These drainage provisions should be carefully designed to provide high reliability in service and protected to prevent the possibility of leakage from damage as a result of a wheels-up landing. Drain valves should be the positive locking type and be reliable. Lightning aspects of the overboard access should be addressed as discussed later. Locate the drain valve at or near the sump. Do not locate drain valves on the bottom surface of the fuselage or other areas where they may be inadvertently damaged or opened. In passenger cargo compartments, sump drains should be shrouded in accordance with the provisions described previously and the shrouds provided with vents per normal shroud procedures.

(iii) Fuel Strainers (§§ 23.951 and 23.977).

(A) One purpose of using a fuel tank outlet strainer is to prevent the intrusion of debris of a size sufficient to damage or jam components downstream of the tank outlet. Fuel strainers of this type should be used in the fuel tank outlets of auxiliary tank systems which transfer fuel by mechanical pump means or which have gravity fuel fillers incorporated, where there is a probability of debris inadvertently entering the tank.

(B) The mesh or size requirements are defined in § 23.977. However, because of the problem of icing, the effective flow area of the strainer should be selected considering also the requirements of § 23.951(c). Fine mesh should not normally be used in this application.

(2) Fuel and Vent System Low Points (§ 23.975). Avoid creating low points in routing fuel and vent lines. It is particularly important to eliminate low points in vent and drain lines, where water may collect and freeze, blocking the lines. Where traps in the vent system are unavoidable, drains should be installed. Depending on the particular design, these drains may allow the fluid to flow back to the tank. Where possible, drain lines should be routed to provide continuous down slope to the drain exit so that complete drainage is accomplished with the airplane in the normal static ground or level flight attitude. If not possible, consider adding sump type drain valves at the applicable low points. Where drain valves are required, use the criteria discussed previously.

g. Ignition Source Isolation Evaluation.

(1) System Electrical Bonding (§§ 23.863 and 23.867). All auxiliary fuel system conductive components such as electrical equipment, fuel tanks, lines, etc., should be electrically bonded to airplane structure. If two or more components are grounded in series, both ends of the ground circuit should be grounded to ensure that the loss of an intermediate ground connection will not leave any component isolated from ground. The bonding jumper should be as short as practicable and installed in such a manner that the resistance of each connection does not exceed .003 ohm. Special emphasis should be placed on bonding when addressing nonmetallic or composite auxiliary fuel tank/systems. The applicable auxiliary fuel system installation drawings should identify the discrete attachment points requiring bonding. The surface treatment(s) required should also be specified by an applicant's specification(s) which should be submitted to the

cognizant certification office during certification. Verification of adequate bonding should be accomplished during installation and when maintenance is performed on the auxiliary fuel system in the airplane.

(i) <u>Wiring Isolation in Fuel or Fuel Vapor Environment</u>.

(A) Electrical wiring in fuel or fuel vapor environment should be adequately protected to prevent damaged wire(s) from igniting fuel/fuel vapor. Installation of the electrical wiring in a sealed metallic conduit is an acceptable method to meet this criteria. The conduit seal should be sufficiently airtight that combustion cannot be maintained.

(B) Flexible conduit conforming to specification <u>MIL-C-6136</u>, Conduit; Electrical, Flexible, Shielded, Aluminum Alloy for Aircraft Installation, Types I or II, or equivalent, may be used where it is impractical to use rigid conduit, such as, areas that have motion between conduit ends or where complex bends are necessary.

(C) Conduit installation considerations include the following:

(<u>1</u>) Metallic conduit should have a low-resistance bond of less than .003 ohm to airplane structure.

(<u>2</u>) To prevent wire chafing at the conduit ends, suitable end fittings should be installed so that a smooth surface comes in contact with the wire(s) inside. When fittings are not used, flare the end of the conduit to prevent wire insulation damage.

(<u>3</u>) The conduit should be supported by clamps along the conduit run to prevent chafing against structure and to avoid stressing the end fittings.

(2) <u>Lightning Vulnerability (§ 23.954)</u>.

(i) <u>System Installation</u>. The auxiliary fuel system installation should be evaluated from the standpoint of lightning vulnerability. Where possible, components, installation practices, and locations should be used that were originally type certificated on the airplane if service experience has been acceptable. Some items and areas that may be susceptible to fuel ignition or indirect effects of lightning include, but are not limited to, the following:

(A) Vent outlets, metal fittings and mechanical fasteners inside fuel tanks, fuel filler caps and access doors, drain plugs, tank skins, fuel transfer lines inside and outside the tanks, and electrical and electronic fuel system components and wiring.

(B) Advisory Circular 20-53A, "Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning," addresses the subject in more detail.

(C) The primary areas of concern for auxiliary systems are all fuselage penetrations, such as protruding masts, access provisions, vents, and drains which can be susceptible to a direct strike or corona effects. Details of all attachments, fittings, etc., should be reviewed to ensure there will be no arcing or sparking and that adequate electrical bonding has been provided. Composites in the basic airplane in areas that involve a portion of the auxiliary fuel system installation should also be evaluated for indirect effects. Indirect effects are induced electromagnetic effects which occur from a lightning strike (such as induced sparking in fuel system components or wiring).

(ii) Protruding Masts.

(A) If the existing vent and drain masts were designed to reduce lightning vulnerability, it is recommended that they be used for the auxiliary fuel system also unless such use would compromise their original intended function.

(B) If additional masts or overboard drain lines are required, an evaluation of lightning protection should be conducted. However, the evaluation may be minimized by using the same design and general location as the previous type design.

(C) Access doors or caps should provide isolation of the fuel system components (drains, etc.) with respect to lightning. This isolation should prevent transfer of electrical discharge into the fuel system component(s) and channel or dissipate the energy into airplane structure.

(iii) Vent and Drain Protection.

(A) Generally, auxiliary fuel tank vent systems are integrated with the existing main fuel tank vent system on the airplane being modified. The main tank vent outlets may have been designed and certified for lightning protection. Where auxiliary tank venting is provided separately, it is advisable to consult the type certificate holder to determine a satisfactory vent exit location and configuration. In general, to improve lightning protection, flush outlets are preferable instead of masts. Vent outlets should not be located in a direct (zone 1) or swept stroke area. Depending on the particular design, flame arresters may also be required in the vent system proper. Vent system exit design is a critical element of airplane safety and requires a considerable background knowledge of the possible lightning strike zones of the particular airplane being modified.

(B) When fuel tanks requiring secondary barriers are adjacent to passenger areas, the vent outlet for the airspace between the barriers should be designed to the same criteria used for tank vents; i.e., assuming that the effluent is a combustible mixture of fuel and air. These cavity vents should not be combined with or directly ported into other main or auxiliary tank venting/drainage systems. Cavity venting and draining provisions can be combined as a single function and routed to a single drain mast, preferably an existing main tank cavity drain on the airplane being modified. However, care must be taken to ensure that the pressure differential will always be such that the cavity will drain.

(C) Drain valves should be located at or in the lines near the tanks to be drained and not installed on the external surface of the airplane. If tunnels or spaces are required to obtain access to drain valves, the use of nonconductive materials to isolate the valves from possible lightning arc-over or conduction into fuel tanks or fuel carrying components should be considered. Each access configuration should be evaluated for conformance to lightning protection criteria.

(iv) Bonding for Lightning Protection (§ 23.867).

(A) A minimum of two bonding jumpers should be installed between a conductive tank and the airplane structure.

(B) Individual bonding jumpers should not be less than no. 12 American Wiring Guide (AWG) for stranded cooper wire or no. 10 AWS for stranded aluminum wire.

(3) Explosion Considerations.

(i) Electrostatic Charge.

(A) The auxiliary fuel system should be evaluated from the standpoint of electrostatic charge build-up. Unless there are means to progressively drain off the charge, electrostatic potential can build up to hazardous levels (sparking discharge levels) in areas of the fuel system where fuel flow velocities are high or where there is a high degree of fuel agitation. Some of the areas of concern are refueling outlets into the fuel tank and long lengths of refueling or fuel transfer hoses where the hose material is highly nonconductive to electrical currents. (For example, teflon hose was a problem in this respect until the teflon was formulated with a graphite or other materials to make it more conductive.) High electrostatic potential can persist for long periods after build-up in some cases. Explosions have occurred many hours after refueling when personnel introduced objects at ground potential into the bladder cells.

(B) Electrostatic potential build-up can be reduced in tanks by locating fuel outlets near the bottom of the tanks and directing outlets away from direct impingement on tank structure (to reduce splashing and sloshing) and expanding the outlet fitting area to reduce the outflow velocity. Electrically bonding the tank fittings to structure may also help by progressively draining off the charge. Sizing hoses and other components to reduce flow velocities may allow more time for charge relaxation. A long run of electrically nonconductive hose can be broken up using metal fittings or lengths of metal tubing, each grounded to structure, to provide additional area for charge relaxation.

(C) The internal tank coatings can influence the degree of fuel electrostatic charge relaxation. The use of dielectric primer, corrosion protective coatings, and painting on internal tank walls should be consistent with the desired overall fuel tank wall conductivity.

(D) Tank foam may be used.

(ii) Component Isolation. Components located in a fuel or a fuel vapor environment should be designed such that there is no fire or explosion hazard during normal operation or under a failure condition. This should be accomplished by ensuring that there is no sparking that could cause ignition.

(iii) Spark Isolation (Explosion Proofing).

(A) Generally, electrical component manufacturers have demonstrated spark isolation or explosion proofing by test similar to MIL STD 810 where a high intensity spark is intentionally set-off inside the component case which is filled with a flammable fuel air mixture and with the component immersed in a flammable fuel-air mixture environment. The external environment is then ignited to prove its flammability. A test of this type does not depend on the failure mode since the cause of the spark is not important in this situation. However, a failure mode analysis should be conducted to ensure that the test is adequate and simulates all the actual conditions anticipated in service. For the particular auxiliary fuel system application intended, service life characteristics (such as the degradation of seals with time, etc.) should be considered to ensure adequate explosion proofing. Auto ignition of fuel vapors due to hot component surfaces resulting from failures such as dragging fuel pump rotors or shorting of electrical motor stator wires to the case should also be considered.

(B) For some components, such as fuel quantity probes, explosion proofing can be shown by demonstrating that the circuit energy is less than 0.2 millijoule under normal or any failed condition. Such components are then considered as intrinsically safe with no further substantiation.

h. Environmental Properties Evaluation.

(1) Normal Environment Properties.

(i) Fuel Resistance. Fuel resistance deficiencies have produced problems in the past.

(A) An aspect which should be evaluated is the prolonged effects of fuel exposure. Some materials, certain plastics in particular, which exhibit short-term fuel resistance have, over a prolonged period, deteriorated under the influence of fuel or fuel vapor.

(B) New innovative material applications, such as composites and new bonding adhesives, should be thoroughly tested to determine the long-term effects of fuel and fuel vapor exposure. Surface treatments, coatings, and sealants intended to reduce weathering and corrosion and seal structural areas should also be substantiated to ensure fuel and fuel vapor resistance, where applicable.

(C) If a component is life limited, the limits due to fuel environmental conditions should be defined, particularly for nonmetallic items.

(ii) Fuel Additive Compatibility. An evaluation should be made of the effects of additives, approved for the airplane, on the components of the auxiliary fuel system. The applicant should substantiate, by suitable methods, that the use of approved additives does not deteriorate these components or restrict the use of specific additives by suitable warning placards on the airplane and notices in the limitations section of the AFM.

(iii) Corrosion and Micro-Organism Resistance. Corrosion in auxiliary fuel systems is primarily due to entrained water in the fuel and the acids produced by the associated microbial contamination. Thus, corrosion protection is especially important for tanks, sumps, and equipment located in sump areas. Metal tanks and components should be made of materials resistant to corrosion or otherwise suitably protected. Metal combinations (dissimilar materials) which are subject to electrolytic corrosion problems should be avoided. Magnesium, copper, cadmium, and brass should not be used in auxiliary fuel systems as these metals are very active chemically. The combination of graphite layers of composite construction attached directly to aluminum may result in intergranular corrosion and should be avoided. Materials used for bladder cells, seals, and composite tanks and fittings should be resistant to microbial contamination. Bladder cells should conform to Technical Standard Order (TSO) C80 or otherwise be shown suitable for the intended application.

(iv) Temperature Range Suitability. Materials and components used in the auxiliary fuel system should have suitable properties and should perform their intended function throughout the approved airplane operating envelope. In some instances, they have been exposed to temperatures as low as -65° F or lower and as high as 250° F, or even higher. Some rubber and plastic materials, for example, have excellent flexure properties at room temperature, but become unacceptably brittle at low temperatures.

(2) Extreme Environment Properties. Extreme environment properties are those properties a material or combination of materials should have under certain conditions which are not encountered during the routine operating life of the materials. Examples are conditions which may be imposed by component failure or crash environments. An evaluation of the extreme environment properties should account for the following:

(i) Flexibility and Resilience. The properties of flexibility and resilience should, to a certain degree, be considered as a part of the normal environmental condition for flexible liners. Materials and parts for rubber fuel lines should provide resilience and flexibility and conform to TSO-C53 or otherwise be shown suitable for the intended application.

(ii) Heat-Strength Characteristics. The high temperature strength properties of materials used in the auxiliary fuel system should be considered for those components which may be subjected to sources of heat due to the failure of some component in another adjacent compartment or adjacent system. In addition, these configurations should be capable of sustaining the critical flight and landing loads and thus the integrity of the system under these conditions.

i. Nonmetallic Material (§§ 23.601, 23.603, 23.609, 23.613, 23.615, 23.619, and 23.867). The suitability and durability of materials used for nonmetallic auxiliary fuel tanks should be established by tests. Advisory Circular 20-107A, "Composite Aircraft Structure," should be reviewed for applicability when composite materials are used. The following elements should be considered in establishing material properties and substantiating the nonmetallic auxiliary fuel tank structure by tests:

(1) Aging of the laminate in the operating environment, including wear, due to temperature, pressure, cavitation, moisture content changes, etc.

(2) Chemical reactions with fuel vapor, cleaning liquids, solvents, salt water vapor, and any other contaminates such as fungus in the tank.

(3) Static electrical charge, bonding, or lightning strike.

(4) Any other elements characteristic of or unique to the type of nonmetallic material, method of processing, and design applications.

(5) A manufacturing process to ensure repeatability of material properties.

(6) Inspection techniques for manufacturing and for continued airworthiness.

(7) Statistically based material strength properties for critical tank structure. Strength, detail design, and fabrication should minimize the probability of fatigue failure. Chapter 9 of MIL-HDBK-5, "Metallic Materials and Elements for Aerospace Vehicle Structures," and MIL-HDBK-17, "Plastics for Flight Vehicles," contain procedures for establishing such properties.

(8) Composite repair procedures defined by the applicant and approved by the FAA.

j. Fuel System Performance. The applicant should evaluate the auxiliary fuel system performance throughout the certified operating envelope of the system. This should include an FAA witnessed functional ground and flight test program. As noted earlier, installations that involve changes in primary structure, airspeed, c.g. limits, aerodynamics, weight limits, or mass distribution require additional substantiation that is beyond the scope of this AC.

k. Normal Operation Evaluation.

(1) Refueling and Transfer Performance.

(i) Refueling and Transfer Flow Rates and Pressures (§§ 23.951, 23.955, 23.957, 23.961, 23.979, and 23.991).

(A) The auxiliary refueling system should be analyzed to determine that the flow rates and pressures are acceptable. Fueling flow rates should also be demonstrated and verified by ground tests. The tank vent system capacity should be verified for the required operations and refueling system malfunctions to ensure that overpressurization of the tanks, including the existing airplane main tanks when applicable, does not occur. Verification is also required that the pressure fueling manual or automatic shutoff means does not produce unacceptable surge pressures which may damage the system or fueling equipment or rupture fueling lines. This verification can be accomplished by ground or laboratory refueling tests using fast response pressure transducers and recorders or submittal of previously accepted similar tests and service history data.

(B) Transfer rates should be determined to show compliance with § 23.955(d) for all flight conditions in which transfer will be permitted to ensure that the receiving tank will be neither overfilled nor depleted before transfer is completed. It should be shown that transfer does not present any hazard, such as unwanted fuel migration, during such flight conditions. Any restrictions on transfer, such as duration or flight operating condition, should be outlined in the limitations section of the AFM. It should be assumed that the transfer system might be left on inadvertently; therefore, it should also be shown that transfer under conditions not permitted by the AFM would not present any hazard. It should be shown that the fuel system complies with § 23.955(d).

(C) Compliance with the hot weather operational performance requirements of § 23.961 should be shown for auxiliary feed systems that feed directly to the engine. This is normally accomplished by conducting a hot fuel test (see AC 23.961-1); however, it may, in some instances, be sufficient to show that the system is similar to a previously approved system or to submit an analysis that is supplemented with component test data.

(ii) Fuel Tank Capacities (Usable Fuel, Sump Capacity, Undrainable Fuel, and Expansion Space) (§§ 23.959, 23.969, and 23.971).

(A) For direct feed auxiliary fuel systems, the unusable fuel requirements of § 23.959, apply (see AC 23.959-1 for method for determination). For transfer type auxiliary fuel systems, the unusable fuel is the quantity of fuel remaining after transfer under the most critical steady state airplane flight attitude and altitude conditions permitted by the AFM.

(B) Sump capacity is a part of the unusable fuel and as previously noted, is defined by § 23.971(a).

(C) The undrainable fuel quantity should be measured, usually during the initial filling of the auxiliary tanks as a part of FAA witnessed ground tests. The undrainable fuel quantity is the fuel remaining in the system after all fuel possible has been sump drained from the system. It is not usually necessary to completely fill the tanks to determine the undrainable fuel, as the undrainable fuel is fuel trapped between stringers, at low points in fuel fittings, etc. Determination of undrainable fuel is typically done by adding a known quantity of fuel to the tank sufficient to cover all potential trapping cavities and then draining the tank. The difference between the amount of fuel added and that which is drained is the undrainable fuel. It is recommended that the undrainable fuel not exceed the capacity of the fuel tank sump.

(D) The maximum tank fueling capacity should take into consideration the expansion space requirements of § 23.969, Fuel Tank Expansion Space. The expansion space volume is the space available for fuel thermal expansion within the tank itself and does not include vent line volume. Basically, the expansion space is the volume from the tank full level to the level where fuel will just begin to enter the vent line.

(E) Figure 1 shows how the expansion space would be defined for three different vent configurations. The expansion space volume should be subtracted from the total volume of fuel at the level at which fuel will just begin to enter the vent line, and does not include the "compression" space above the vent opening. The expansion space should be derived for the airplane in its normal ground attitude. Expansion space capacity is verified during the airplane ground fueling tests conducted as a part of the test program.

(F) Ground tests of the installed system should be conducted in accordance with § 23.979 with the airplane in the correct ground attitude to verify that the expansion space requirements are maintained for pressure fueling to the maximum automatic fuel shutoff level, verify tank(s) pressures during failure of the auto shutoff and also provide the correct values for usable and unusable system fuel.

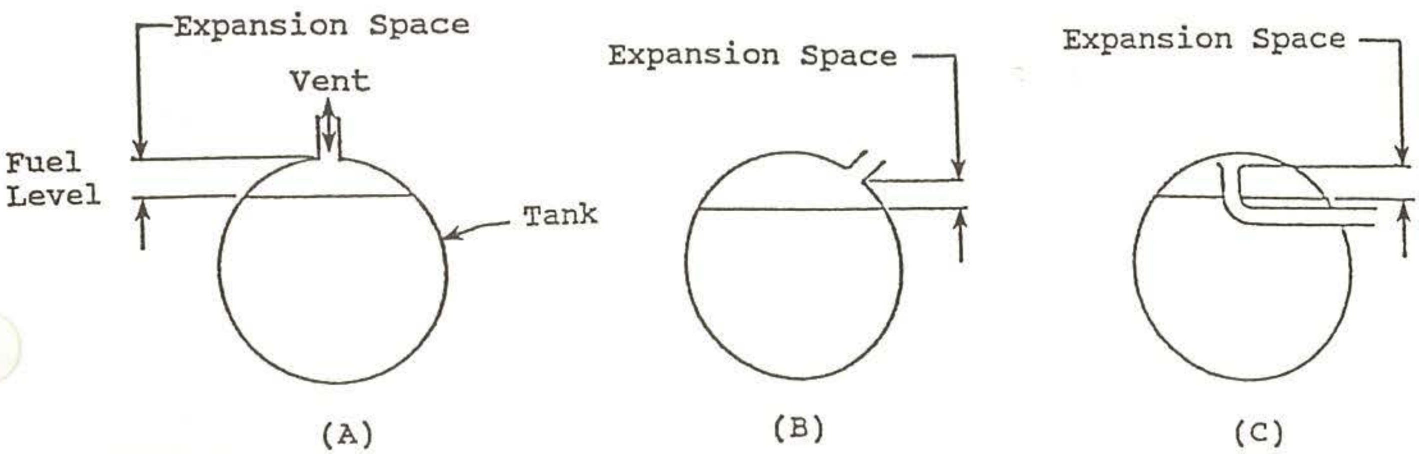

Figure 1 - EXAMPLES OF EXPANSION SPACE DEFINITION

(iii) Pressure Relief (Water Hammer and Thermal Expansion) (§§ 23.995). The designer should evaluate the pressure fueling and transfer or direct feed system operation to ensure that no damaging fuel line pressures will occur during flow shutoff or due to thermal expansion effects. Normally, sufficient flex line length and the use of "slow" shutoff valves or valves with thermal relief features will negate this problem. In some cases, relief valves or other means may need to be incorporated in the system.

(iv) Vent System Anti-Siphoning (§ 23.975). The auxiliary tank vent system should be arranged so that no hazardous quantities of fuel can migrate from one tank to another tank or be discharged overboard during any normal flight attitudes. However, the tank vent design is to ensure that fuel will drain clear of the airplane during fuel discharge conditions. This should also be addressed for a ground attitude with the airplane parked on a ramp with a one percent slope.

(2) Operating Limits (§§ 23.1501 through 23.1529). Assuming that the airspeed, c.g., maximum takeoff weight and maximum landing weight limitations will not be changed as a result of the auxiliary fuel system installation, the applicant's alternatives may be tradeoffs between payload weight and auxiliary fuel system weight at maximum capacity loading. Using these criteria, the applicant should review the requirements of Part 23, subpart G, Operating Limitations and Information, to ensure that the auxiliary fuel system design does not degrade the airplane performance and other requirements stated in this subpart.

(i) Operating Airplane Flight Envelope. The installation of the auxiliary fuel system should not restrict the operating flight envelope of the airplane, or a major recertification effort may be required. This does not mean that the auxiliary fuel system must function (transfer fuel) at all existing extremes of the airplane flight envelope. Envelope limitations on the transfer of auxiliary tank fuel should, however, be stated in the AFM. Using the above criteria, the applicant should ensure that the auxiliary fuel system will not be adversely affected by exposure to the temperatures, pressures, altitude variation, and flight loads encountered in all regions of the airplane flight envelope.

(ii) System Electrical Power Requirements (§§ 23.1351 and 23.1357).

(A) If additional equipment which consumes electrical power is installed in an airplane, the revised total electrical loads should not exceed the generator or alternator output ratings and limits prescribed for the airplane, or the ratings of any airplane bus(s). To ensure that the design meets the criteria, the applicant should provide the following:

(1) Power requirements for each of the equipment items which will be installed.

(2) Wiring diagrams for the equipment installation.

(3) An updated, electrical load analysis for the airplane including the auxiliary fuel system.

(B) An appropriate circuit protective device (circuit breaker of fuse) should be installed as close as possible to the electrical power-source bus. Good engineering practices for selection of circuit breakers should consider the following:

(1) The minimum rating commercially-available airplane circuit breaker size which will power the normal (i.e., intended) load without nuisance trips, thereby minimizing deliverable power to possible fault loads.

(2) Integral three-phase circuit breakers to protect three-phase loads.

(3) The selected circuit protective device should be consistent with the airplane electrical system protection and should protect the smallest wiring in the circuit.

(iii) Fuel Quantity System Calibration and Limitations (§ 23.1337(b)). Part 23 requires that fuel quantity gages read zero when the fuel remaining in the tank is equal to the unusable fuel supply. If a fuel quantity indicator is installed (see § 23.1337(b)(5)), it should be calibrated for usable fuel wet, i.e., with a specific fuel of known density to substantiate that the fuel measurement system, as installed in the airplane, indicates zero in a level flight attitude. The applicant may want to increase the unusable fuel to the zero limit of the gage in some cases where the gage cannot be calibrated down to the actual unusable tank fuel level, in lieu of replacing the gage. The calibration also encompasses additional readings of the fuel quantity gage which are compared against a standard, usually the readings taken from a fueling system having a calibrated accuracy of 0.5 percent.

l. Fail-Safe and Emergency Operation Evaluation (§ 23.903(c)). It is the applicant's responsibility, as a part of the certification compliance program, to analyze and submit a report(s) on the auxiliary fuel system component failure modes and consequences of these failures. It should be shown that the resulting consequence of any single or probable combination of failures will not affect the functional isolation of the engines or jeopardize the safety of the airplane. The fail-safe criteria as defined in appendix 1, Definitions, should be used as a guide in all design and failure mode analyses.

(1) System Failure Modes.

(i) Component Failure Modes.

(A) The applicant should analyze the effects of malfunction or failure of each piece of equipment installed in the auxiliary fuel system and ensure that no malfunction will result in a hazard to the airplane. The analysis should include the effects of failure for all modes of component failure and all modes of auxiliary fuel system operation, such as, pressure fueling and defueling, fuel transfer or engine feed, and emergency fuel jettisoning. The effects of both detectable and undetectable failures should be analyzed.

(B) Wherever possible, the configuration should incorporate means to detect component failure in the system. An example of such detecting means is the momentary "on" position detecting circuit incorporated in electric motor-operated fuel shutoff valves. Valves with this feature are available as off-the-shelf items.

(ii) <u>Component Failure Indication</u>.

(A) As discussed in the previous section, failure indication should be incorporated wherever possible to preclude situations of undetectable failure which can jeopardize airplane safety. Failure indication can be provided in a number of ways. The best from a recognition standpoint is indication which is immediate and draws attention. The momentary "on" position, or in-transit light for a motor-operated shutoff valve, a low fuel state warning light, and an audible warning and light indicating fire or overheat are all examples of this type of indication. Continuous monitoring indicators such as pressure gages, fuel quantity indicators, and temperature gages can also provide failure indication. However, these devices are not as effective because they rely heavily on human judgment and alertness. Where crew workloads are heavy, such indications may go unnoticed for long periods or until the failure produces a critical flight incident.

(B) Periodic inspection, such as the preflight inspection for fuel dripping from the auxiliary fuel system shroud drain (indication of fuel system leakage) is an essential function, but does not preclude the chance of failure occurring during long duration flights. Thus, assuming other means of detecting leakage are not incorporated, design precautions (for example, placing electrical wiring in conduits where it is routed through shroud spaces) may be necessary to preclude the chances that another failure will affect the safety of the airplane.

(2) <u>Operating Limits</u>.

(i) <u>Emergency Electric Power Requirements</u>. There are two conditions where the designer should carefully consider the availability of electrical power in the event of a generator failure:

(A) Direct engine feed auxiliary systems where the loss of pump electrical power could create an unsafe operating condition, such as an engine flame-out.

(B) Direct engine feed or transfer auxiliary systems where fuel management is required to maintain proper airplane c.g. control (such as, fuel used late in the flight).

(C) If, in either of these cases, fail-safe features are used which require the need for emergency electrical power, these needs should be assessed to ensure that sufficient power is available.

(ii) Fuel Jettisoning (§ 23.1001).

(A) If the applicant uses a tradeoff between auxiliary fuel system weight at maximum fuel capacity and payload weight (and thus there is no change in the airplane maximum takeoff and landing weight), the fuel jettisoning requirements of the airplane should be the same as for the original, unmodified airplane. Therefore, there should be no need to jettison auxiliary tank fuel. Addition of fuel capacity which increases the maximum takeoff weight of the airplane would require additional certification efforts which are beyond the scope of this AC. One of these efforts would, however, be to evaluate the need of auxiliary fuel jettisoning.

(B) Regardless of the need for auxiliary fuel jettisoning, the applicant should ensure by failure mode analysis or demonstration that main tank fuel jettisoning can still be accomplished without hazard to the modified airplane.

m. Engine Oil System Capacity (§ 23.1011). The applicant should ensure that the additional fuel capacity of the auxiliary fuel system, thus the added flight duration, does not cause depletion of the engine oil supply under maximum oil consumption conditions and engine out operation. Adequacy of the engine oil capacity should be shown as a part of the compliance for certification of the auxiliary fuel system.

n. Main Fuel System Capacity and Flow Regulation. The applicant should show that there is no condition in which a receiving tank could be overfilled from the auxiliary tank fuel. If necessary, means should be provided in tanks supplied with auxiliary fuel to regulate the fuel level in those tanks. There should be no condition in which a receiving tank could be depleted during auxiliary tank transfer. In some cases, auxiliary tank fuel transfer cannot be initiated until the receiving tank fuel has been used down to a certain quantity. This limitation should be clearly stated in the AFM. The applicant should include in the AFM all limitations on the use of auxiliary tank fuel and any warnings necessary in the operation of the system. Limitations and procedures should be evaluated with regard to practicality and pilot workload.

o. Radio Frequency Interference. The applicant should ensure that the system will not cause objectionable radio frequency interference and not be adversely affected by radio frequency interference from other airplane systems.

p. Airplane Center of Gravity Control.

(1) Since auxiliary fuel tanks are usually installed after initial certification of the airplane and are not part of the basic fuel system, the weight and location of the installation may introduce complex procedures in c.g. control. Several models of auxiliary fuel transfer may be used, requiring c.g. control for each. If a failure can trap fuel in an auxiliary fuel system, there should be a means provided to feed the engines and stay within the c.g. limits for the remainder of the flight (to reach the airport of destination or an alternate airport). Instructions necessary to maintain the airplane within the established c.g. limits are required by the operating regulations and by § 23.1583.

(2) An auxiliary fuel system installed aft of the main gear may affect the airplane ground handling operations. Especially for airplanes which have not normally been ground handling limit critical, special cautions and placards may be required. It may be necessary in some cases to institute refuel sequence controls to prevent tipping of the airplane. Since removal of interiors or other equipment could also aggravate ground aft c.g. problems, maintenance manual supplements should include appropriate procedures and cautions.

(3) A means of controlling the center of gravity may be attained by providing c.g. limit charts with associated limits on airplane gross weight, configuration, zero fuel weight, and fuel schedules in the limitations section of the AFM. In addition, fuel transfer procedures should be provided for all modes of transfer along with instructions for c.g. control if fuel transfer is not available.

q. Airplane Placards and Instrument Marking Evaluation.

(1) Location of Placards, Markings, Gages, and Switches, etc. (§§ 23.1555 and 23.1557).

(i) Cockpit placards, markings, annunciator lights, gages, switches, and controls for the auxiliary fuel system should be located in suitable areas with sufficient illumination to ensure they are easily readable during day and night operations. The switches and controls should be easily accessible to the ground or flight crews as required by the applicable regulations.

(ii) Special placards, located in the cargo compartment, or adjacent to the auxiliary fuel tank installation may be necessary to inform or caution the ground crew about certain aspects of the installation. For example, these placards may state certain cargo compartment loading limits or restrictions, flexible cargo barrier tensioning requirements, or cautionary flammable fluid requirements as required. Suitable markings on the airplane exterior surface are required identifying drain access doors, masts, fuel filler openings, etc.

(2) Instrument, Instrument Identification, Lighting, and Calibration (§§ 23.1305, 23.1337, 23.1381, 23.1541, 23.1543, 23.1553, 23.1555, and 23.1583).

(i) A fuel quantity indicator should be installed for each independent auxiliary fuel tank which provides indication to the flight crew of the quantity, in gallons or pound, of usable fuel in each tank during flight unless § 23.1337(b)(5) is met. Indicators should be as accurate and compatible with the existing airplane fuel quantity indicators as possible and calibrated using the same units of volume.

(ii) Instrument and switch markings should be easily readable with instrument lights.

(iii) Each instrument, indicator, and switch should have markings/placards which permit the crew to easily identify it. Markings and placards should be displayed in conspicuous places and should be such that they cannot be easily erased, disfigured, or obscured.

(iv) If the instrument markings are on the cover glass of the instrument, there should be means to maintain the correct alignment of the glass cover with the face of the dial.

(v) Each fuel tank selector control, if used, should be marked to indicate the position corresponding to each tank.

r. Pilot's Operating Handbook (POH) or Airplane Flight Manual (AFM) (§§ 23.1581 through 23.1587) (reference AC 23-8A).

(1) Auxiliary fuel tanks installed after initial certification of the airplane require an FAA approved AFM supplement or an appendix to the existing basic AFM to provide appropriate operating information, procedures, and limitations. Generally, an appendix to an AFM is appropriate when written by the manufacturer of the basic airplane, and a supplement is appropriate when the applicant for an auxiliary fuel tank installation is other than the manufacturer.

(2) The applicant is responsible for preparing the AFM supplement or appendix which should be incorporated into the basic AFM. The operating procedures and limitations should be evaluated by the FAA flight test crew as part of the flight test evaluations prescribed by the Type Inspection Authorization (TIA). Crew workload should be evaluated to determine whether it is still acceptable with the addition of an auxiliary fuel system. Crew workload should be considered early in the design of the system, with FAA participation, to ensure that all considerations are properly coordinated.

(3) Sufficient information and data should be provided in the AFM to ensure that the flight crew will be able to understand and operate the system during normal, abnormal, and emergency operations of the airplane.

(4) Abnormal procedures are those that are not normal procedures and also are not emergency procedures. They include procedures for foreseeable failure situations where the use of special systems or the use of regular systems may be expected to maintain an acceptable level of airworthiness. Immediate action is not usually required. Since most auxiliary fuel systems are add-on systems, which are not included in the flight training syllabus of the airplane, the AFM supplement or appendix should be complete in providing the required information. To ensure completeness of the AFM supplement (or appendix), the following discussion and format are provided as a guide for the type of information that should be considered.

(i) Limitations.

(A) Fuel Loading Limitations. The maximum allowable fuel in each auxiliary tank should be specified. Loading limitations may be required to maintain weight/c.g. within limits; i.e., certain main fuel tanks may be required to be loaded before the auxiliary tanks and the auxiliary tanks may be required to be loaded in a particular sequence depending on the design of the system.

(B) Fuel Management Limitations.

(1) Specific fuel usage procedures may be required to maintain the weight and balance of the airplane within limits. Additionally, flight planning limitations may be required if a single failure can trap fuel in the auxiliary fuel system; the main fuel system should still provide sufficient fuel to the engines for the remainder of the flight, to reach the airport of destination or to an alternate airport.

(2) A specific sequence of transferring auxiliary fuel may be required as a result of fuel flow rates.

(C) Operating Limitations.

(1) Maneuvering limitations should be specified.

(2) Transfer of fuel during takeoff and landing are usually prohibited because of the crashworthiness fire hazard.

(3) Transfer of fuel during climb or descent may be prohibited because of usable fuel consideration.

(D) Miscellaneous Limitations. Cargo and floor loading restrictions may be required due to the auxiliary fuel tank installation.

(ii) Emergency Procedures.

(A) Ditching. If applicable, procedures should be provided regarding transfer of fuel from auxiliary fuel tanks and placement of controls and switches prior to ditching.

(B) No Fuel Transfer. Should fuel not transfer and become trapped in the auxiliary tanks, procedures should be included to regain transfer capability. If transfer is still not available, management procedures should specify how to maintain weight/c.g. within limits.

(iii) Normal Procedures/Abnormal Procedures.

(A) Fuel Loading. Instructions necessary to enable loading of the airplane within the established limits of weight and center of gravity, and to maintain the loading within these limits in flight should be provided.

(B) External Preflight Check. Detailed procedures should be specified.

(C) Cockpit Preflight Check. Detailed procedures should be specified.

(D) Fuel Management and Transfer Procedures.

(1) Fuel Transfer. Detailed procedures should be specified for each fuel transfer schedule approved and should include normal fuel transfer rates for use.

(2) Flow Check. Procedures to determine that auxiliary fuel transfer is available should be specified, where required.

(3) Fuel Jettison (If installed). Procedures should be established to dump fuel, if desired, listing airspeed, altitude, and configuration.

(E) Unusable Fuel (§ 23.1585(f)). The unusable fuel should be specified.

(F) Usable Fuel (§ 23.1585(g)). Maximum usable fuel should be specified.

(iv) Performance. Any change in airplane performance should be provided.

(v) Auxiliary Fuel System Description. A detailed description and functional schematic arrangement should be provided. This information may be provided in an unapproved section of the AFM supplement (or appendix) or may be included in the approved Section 3, Normal Procedures. A suggested outline includes the following:

(A) Fuel Transfer System.

(B) Control Panel.

(C) Refueling System.

(D) Electrical System.

(E) Schematics.

s. Weight and Balance Manual Information (§ 23.1589). Weight and loading distribution information including loading instructions should be presented either in the AFM supplement or in a separate weight and balance control and loading document which should be referenced in the AFM.

t. Continued Airworthiness (§ 23.1529). The inspections, tests, repairs, and related intervals upon which compliance with the applicable certification basis is based should be included in a maintenance manual supplement supplied by the applicant. The manual should also contain complete servicing information for the auxiliary tanks and systems. If the applicant proposes to have a system where a tank(s) may be removed or made inoperable for maintenance purposes and the remainder of the system remains airworthy (as where more than one tank configuration is an approved configuration) or where the entire system is classified as removable, complete maintenance instructions should also be provided detailing the methods of system modification or removal, resealing and restoring the compartments, and other considerations necessary to make the airplane airworthy. The applicant should refer to Part 23, appendix G, Instructions for Continued Airworthiness, when providing maintenance instructions.

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APPENDIX 1. DEFINITIONS

The following definitions are applicable as used in the text of this AC.

a. Auxiliary Fuel System. An auxiliary fuel system is a system installed within the airplane which makes additional fuel available for increasing the flight range of that airplane. The term "auxiliary" means that this system is secondary to the airplane's main fuel system; i.e., that the functions of the main fuel system are immediately available and operative in the event of failure or inadvertent depletion of fuel in the auxiliary fuel system (reference § 23.955(b)(2)). In essence, an airplane equipped with an auxiliary fuel system is capable of safe flight even when the auxiliary fuel system is not used, i.e., where its fuel storage capacity is not required.

b. Main Fuel System. A main fuel system is a system installed within an airplane which is required for safe operation of the airplane. Its primary function is to provide an independent, uninterrupted flow of fuel to each airplane engine. Main fuel tanks are those tanks which normally supply fuel directly to the engine in at least one operating mode and are necessary to satisfy the independent feed requirements of the airplane (reference § 23.953). These tanks also contain the reserve fuel necessary for all flight diversions and other contingencies.

c. Fail-Safe.

(1) The FAA fail-safe design concept is a design methodology where the effect of failures and failure combinations must be considered in defining a safe design. The following basic rules involving failure events apply:

(i) In any system or subsystem, a single failure of any element or connection during any one flight (brake release through ground deceleration to stop) must be assumed without consideration as to its probability of failing. This single failure event must not prevent the continued safe flight and landing of the airplane.

(ii) Additional independent failure events during any one flight following the first single failure must also be considered when the probability of occurrence is likely (i.e., those combinations of failures not shown to be extremely improbable). If a critical failure event cannot readily be detected, it must be counted as a latent existing failure in addition to the first failure. The probability of these combined failures includes the probability of occurrence of the first failure event.

(2) The following design principles and techniques are generally utilized to prevent single failures and likely combinations of failures from jeopardizing the continued safe flight and landing of the airplane:

(i) Redundancy or backup systems that provide system function after the first failure, i.e., two or more engines, two or more hydraulic systems, dual flight controls, etc.

(ii) Isolation of systems and components, both physically and functionally, so that failure of one element will not cause failure of the other. This is sometimes referred to as system independence.

(iii) Detection of failures or failure indication.

(iv) Functional verification, i.e., the capability for testing or checking the condition of the components.

(v) Proven reliability and integrity to ensure that multiple component or system failures will not occur in the same flight.

(vi) Damage tolerance that limits the safety impact or effect of the failure.

(vii) Design failure path that controls and directs the failure event by design to limit the safety impact.

(viii) Flight crew procedures following the failure event designed to ensure continued safe flight by specific crew actions.

(3) The FAA fail-safe design concept utilizes all of the above eight design principles in whatever combinations are required to produce a fail-safe design. The employment of only one of the above principles is seldom adequate; generally, two or more are used in the design to satisfy the fail-safe design concept, i.e., ensure that catastrophic failures will be extremely improbable.

d. Passenger/Cargo Compartments. All compartments specifically designed to provide a suitable life support environment for people and animals during all operating modes of the airplane. These areas may or may not be pressurized. These areas include, but are not limited to, the cockpit, passenger compartments, and cargo and baggage compartments.

e. Zero/Fuel Weight. Typically, civil airplanes are designed to carry fuel in the wings. In addition to any other advantages, locating the fuel in the wings relieves wing bending stresses and allows a higher maximum weight than would be possible with the same quantity of fuel located within the fuselage. For such airplanes, zero fuel weight is established as a limit to ensure that maximum wing bending stresses are not exceeded by replacing fuel in the wings with an equal weight of payload carried in the fuselage. When an auxiliary fuel tank is installed within the fuselage, the existing zero fuel weight limit is no longer directly applicable because the fuel contained in that tank does not relieve wing bending stresses. It is, therefore, necessary to reduce the zero fuel weight limit by the maximum usable fuel capacity of the auxiliary tank. Alternatively, the zero fuel weight limit may be redefined as the maximum zero wing fuel weight limit. Any fuel contained in the auxiliary tank would then be treated as payload from a weight and balance standpoint. Regardless of which procedure is used, the AFM must clearly state the limit and its meaning.

APPENDIX 2. ADVISORY CIRCULARS

The advisory circulars listed below can be obtained from the U.S. Department of Transportation, Utilization and Storage Section, M-443.2, Washington, D.C. 20590:

a. "Qualification of Fuels, Lubricants, and Additives for Aircraft Engines," Advisory Circular 20-24B, Federal Aviation Administration, December 20, 1985.

b. "Aircraft Fuel Control," Advisory Circular 20-43C, Federal Aviation Administration, October 20, 1976.

c. "Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning," Advisory Circular 20-53A, Federal Aviation Administration, April 12, 1985.

d. "Composite Aircraft Structure," Advisory Circular 20-107A, Federal Aviation Administration, April 25, 1984.

e. "Fuel Drain Valves," Advisory Circular 20-119, Federal Aviation Administration, February 7, 1983.

f. "Water in Aviation Fuels," Advisory Circular 20-125, Federal Aviation Administration, December 10, 1985.

g. "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Fan Blade Failures," Advisory Circular 20-128, Federal Aviation Administration, March 9, 1988.

h. "Flight Test Guide for Certification of Part 23 Airplanes," Advisory Circular 23-8A, Federal Aviation Administration, February 9, 1989.

i. "Substantiating Flow Rates and Pressures in Fuel Systems of Small Airplanes," Advisory Circular 23.955-1, Federal Aviation Administration, June 10, 1985.

j. "Unusable Fuel Test Procedures for Small Airplanes," Advisory Circular 23.959-1, Federal Aviation Administration, January 14, 1985.

k. "Procedures for Conducting Fuel System Hot Weather Operation Tests," Advisory Circular 23.961-1, Federal Aviation Administration, January 14, 1987.

l. "Procedures for Determining Acceptable Fuel/Oil Ratio as Required by FAR 23.1011(b)," Advisory Circular 23.1011-1, Federal Aviation Administration, November 14, 1983.

m. "Installation of Fuel Flowmeters in Small Airplanes with Continuous-Flow, Fuel-Injection, Reciprocating Engines," Advisory Circular 23.1305-1, Federal Aviation Administration, December 21, 1984.

n. "Certification of Non-oxygenated Automobile Gasoline (Autogas) Instead of Aviation Gasoline (Avgas) in Part 23 Airplanes with Reciprocating Engines," Advisory Circular 23.1521-1A, Federal Aviation Administration, January 2, 1991.

o. "Acceptable Methods, Techniques and Practices--Aircraft Inspection and Repair," Advisory Circular 43.13-1A, Federal Aviation Administration, April 17, 1972.

APPENDIX 3. RELATED READING MATERIAL

a. U.S. Army Aircraft Crash Survival Design Guide, USARTL-TR-79-22A

b. MIL-C-6136 - Conduit; Electrical, Flexible Shielded, Aluminum Alloy for Aircraft Installation, Types I or II

c. MIL-HDBK-5 - Metallic Materials and Elements for Aerospace Vehicle Structures

d. MIL-HDBK-17 - Plastics for Flight Vehicles

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