

Submitted for recognition as an American National Standard

COMMERCIAL AIRCRAFT AUXILIARY POWER UNIT INSTALLATIONS

FOREWORD

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1. SCOPE:

This Aerospace Information Report (AIR) reviews the factors to be considered in determining the location and arrangement for auxiliary power unit (APU) installations for airborne applications and reviews requirements for flight suitability.

As treated in this discussion, the APU normally includes a power section (or engine), a starting system, an electronic control unit (ECU), a gearbox with accessory mounting pads, and an oil cooling system. The accessories that are driven by the APU, such as CSD's (constant speed drives), alternating current (AC) generators, hydraulic pumps, or air compressors, are not covered here except insofar as they make demands on the APU. The various installation components and systems that are covered here are outlined by the table of contents.

Turbine-type APU's are by far the most highly developed and universally used airborne units, so their installation will dominate the discussion in this document. And, though there have been some APU's developed for military applications, many military transports are adaptations of commercial carrier aircraft. The bulk of the discussion will, therefore, be oriented toward APU installation requirements as developed by the civilian sector. Discussions of the internal design aspects of the APU itself are not within the scope of this document.

1.1 Purpose:

The purpose of this document is to aid APU installation designers by assuring that no important design aspect of the installation will be overlooked. References 2.1 and 2.2 are also documents published by APU manufacturers for this purpose. Reference 2.3 is a useful design handbook published by the U.S. Air Force.

2. REFERENCES:

- 2.1 Installation Handbook - Airborne Auxiliary Power Units. Garrett Turbine Engine Company. Second edition - 1983.
- 2.2 Installation Manual - Turbine Driven Auxiliary Power Units. Turbomach July 1980.
- 2.3 AFSC Design Handbook 2-3 Propulsion and Power, ASD/ENESS, Wright Patterson AFB, Ohio 45433: Phone (513)255-6281
- 2.4 TSO-C77a, 7/20/81 (Technical Standard Order) Subject: Gas Turbine Auxiliary Power Units. Department of Transportation, FAA.
- 2.5 FAA ORDER 8430.6 C: Susceptor's Handbook: Section 6. Master Minimum Equipment List (MMEL). 2 July 1984.
- 2.6 MIL-P-85573 (AS): Power Unit, Aircraft Auxiliary, Gas Turbine, General Specification for: 15 Nov. 1983.

- 2.7 ASD Technical Report 61-381, "Guide to Design of Mechanical Equipment for Maintainability." Armed Services Technical Information Agency, Arlington Hall Station, Arlington, Virginia.
- 2.8 FAR 25: Federal Aviation Regulations, Part 25 - Airworthiness Standards: Transport Category Airplanes, June, 1974.
- 2.9 "Design Manual on Aircraft Fire Protection for Reciprocating and Gas Turbine Engines." Aerospace Industries Association. Obtainable from National Standards Association, Inc., 5161 River Road, Bethesda, Maryland 20816, Phone: (800)638-8094.
- 2.10 SAE AIR1191, Performance of Low Pressure Ratio Ejectors for Engine Nacelle Cooling, November 1971.
- 2.11 SAE AIR1174, Index of Starting System Specifications and Standards, Revised April 1987.
- 2.12 Paper No. 841571, "Pressurized Air Start System (PASS) for Small Gas Turbine Engines", Jon P. Rominek: Presented at the 1984 Aerotech in Long Beach, Calif. 1984.
- 2.13 ICAO Document of Internal Standards and Recommended Practices "Environmental Protection" - Annex 16, Volume I - "Aircraft Noise" First edition 1981. (Attachment D to Annex 16.)

3. GENERAL BACKGROUND:

3.1 Uses:

The uses that an APU might be put to on a commercial aircraft are as follows:

- a. Drive an AC generator for lights and power on the ground either during passenger occupation or during routine cabin cleaning and servicing.
- b. Provide bleed air for air-conditioning on the ground.
- c. Supply bleed air or electric power for engine starting.
- d. Provide a backup in-flight system (such as electrical) in case one of the engine-driven systems becomes inoperative.

Most utility power requirements on transport aircraft are supplied in flight by engine-mounted accessories such as electric generators or hydraulic pumps. Air for anti-icing and air-conditioning is bled from the engine compressors. With the introduction of the first generation of turbine-engined commercial aircraft such as the DC-8 and B-707, the airlines acquired ground power equipment to supply the pneumatic and electrical power required at all airline terminals in order to maintain passenger comfort and convenience levels and to start the engines.

3.1 (Continued):

By the time the second generation of jet aircraft were on the drawing boards, there was a desire to avoid dependence on ground power equipment for many reasons, including ramp congestion, operational performance, and availability/convenience limitations on flight planning. Fuel cost was a minor item in that period (approximately 10 cents per gallon), and small-turbine-engined APU equipment was available for these new aircraft. Thus, the second generation and subsequent wide-bodied commercial transports (the DC-9 and DC-10, the B-727, 737, and 747, the A-300, the L-1011, the BAC 1-11 and Trident) all had integral onboard APU systems.

The FAA (Federal Aviation Administration) makes a distinction between Category I "Essential" and Category II "Nonessential" APU's. Their definitions, appearing in Reference 2.4, are as follows:

- a. 4.8 Essential APU: An APU which produces bleed air or power, or both, to drive accessories necessary for the dispatch of the aircraft to maintain safe aircraft operation.
- b. 4.15 Nonessential APU: An APU which may be used on the aircraft as a matter of convenience, either on the ground or in flight, and may be shut down without jeopardizing safe aircraft operations.

The dispatchability of a particular commercial airplane is constrained by the MEL (Minimum Equipment List) which defines the alternate equipment or systems that must be operable before the airplane can take off with passengers on board (Reference 2.5). As an example, on a two-engine aircraft, if one engine-driven electric generator is inoperative and an APU-driven generator is on board, then normally the aircraft can be dispatched if the APU is qualified as "essential" but not if it is "nonessential".

In order for an APU to qualify as essential, it must meet certain additional requirements such as ice protection, resistance to foreign object damage, and the survival of a rigorous endurance test. Those requirements are defined in Reference 2.4.

Military transports don't necessarily meet the FAA requirements or vice versa, although military conversions of commercial aircraft may utilize the same equipment. Airborne APU's developed directly for military application may have to meet the requirements of Reference 2.6.

3.2 Description:

Modern APU's are powered by internal combustion turbines with either a centrifugal or axial flow compressor or both. There may be an integral "load compressor" driven by the same shaft as the engine compressor. Where a load compressor is not supplied with the power unit, air is obtained for starting the main engines and for cabin conditioning by bleeding the APU compressor.

An APU usually comes equipped with a gearbox as a means to drive accessories such as an electric generator and hydraulic pumps if required.

3.2 (Continued):

Other than the APU itself, the bulkiest items related to the APU installation are the air inlet (induction) system and the turbine exhaust system. Both the inlet and exhaust ducting may require an acoustically absorbent liner to keep APU noise to acceptable levels. Cooling air must be supplied to the generator, the oil cooler, the compartment in general and, in some cases, to a shroud enclosing the exhaust duct.

Lines are required to carry high-pressure air from the APU compressor to the engine starters and the air-conditioning system. Where compressor bleed is used, the compressor is matched to the turbine assuming a normal quantity of bleed. However, some operating conditions may not require enough bleed to keep the compressor operating within the surge limits. Therefore, a "surge valve" with an overboard line is provided to bleed additional air to keep the APU operating within the stable envelope.

If hydraulic power is to be supplied directly by the APU, a pad can be provided on the gearbox. However, most modern transports do not require a direct hydraulic drive on the APU. Hydraulic power in flight is provided by engine-mounted pumps under all normal flight conditions, and on the ground by electric-driven pumps. The APU gearbox typically has a pad for the generator and possibly one for a cooling-air fan. The hydraulic power requirements during ground operations are normally satisfied by the APU via the electrical generator.

Though it is possible to provide pneumatic power from a compressor mounted on the gearbox, it is seldom done because of the reduced efficiency and additional weight. Centrifugal compressors can run at the same speed as the APU engine compressor so it is not necessary to go through a gear train to reduce the speed. An example of an APU with an integral load compressor is shown by Figure 1. Two configurations using compressor bleed are shown by Figures 2 and 3.

Since, in any APU installation, fuel must be present in close proximity to potential sources of ignition, the APU is considered a fire zone and must be designed as such, separated from other areas of the airplane by firewalls. An example of an APU installation, showing most items that require appreciable space, is shown by Figure 4.

4. INSTALLATION CONSIDERATIONS:

A primary consideration in location and design of the APU installation must be safety. Proper consideration for the possibility of fires and rotor failures must be included to preclude failure of: (1) aircraft primary structure, (2) fuel tanks, and (3) operability of aircraft systems. These topics are discussed in 4.2.1 and 5.1.

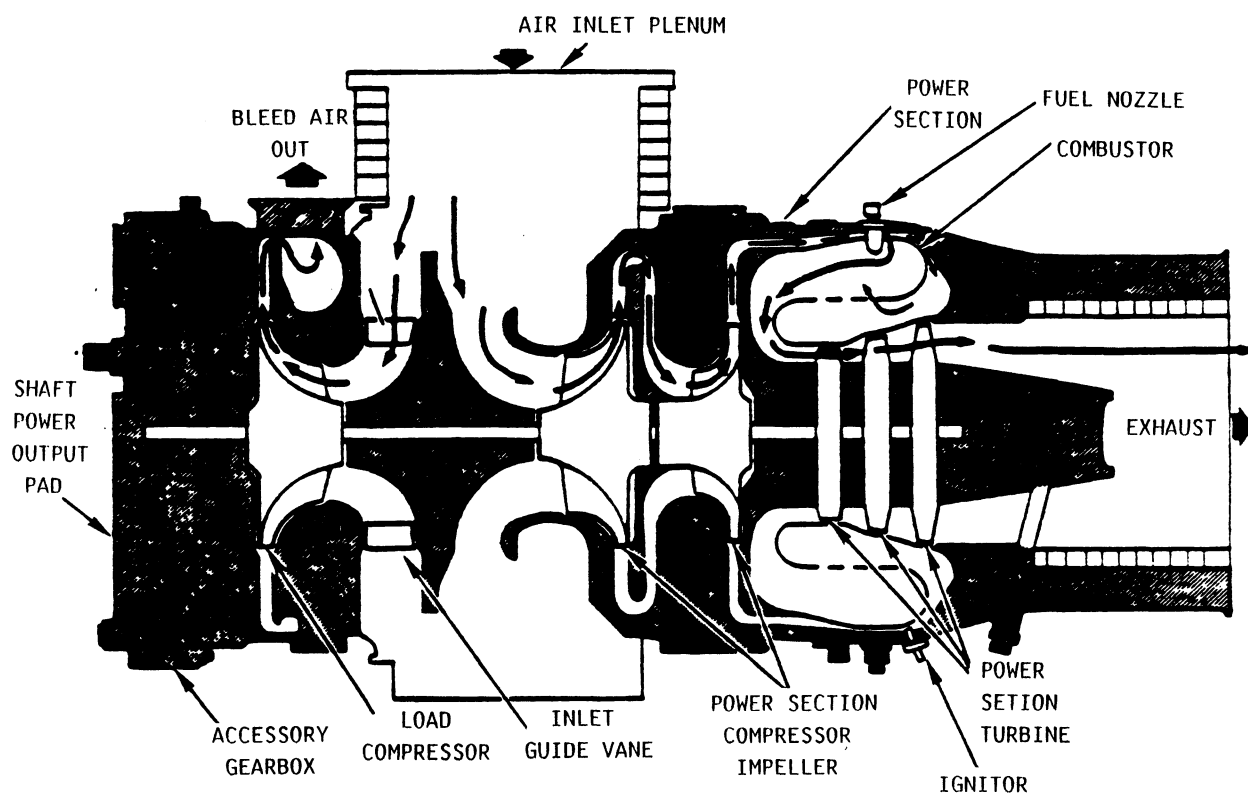


FIGURE 1 - Cross Section of APU with a Bleed Load Compressor

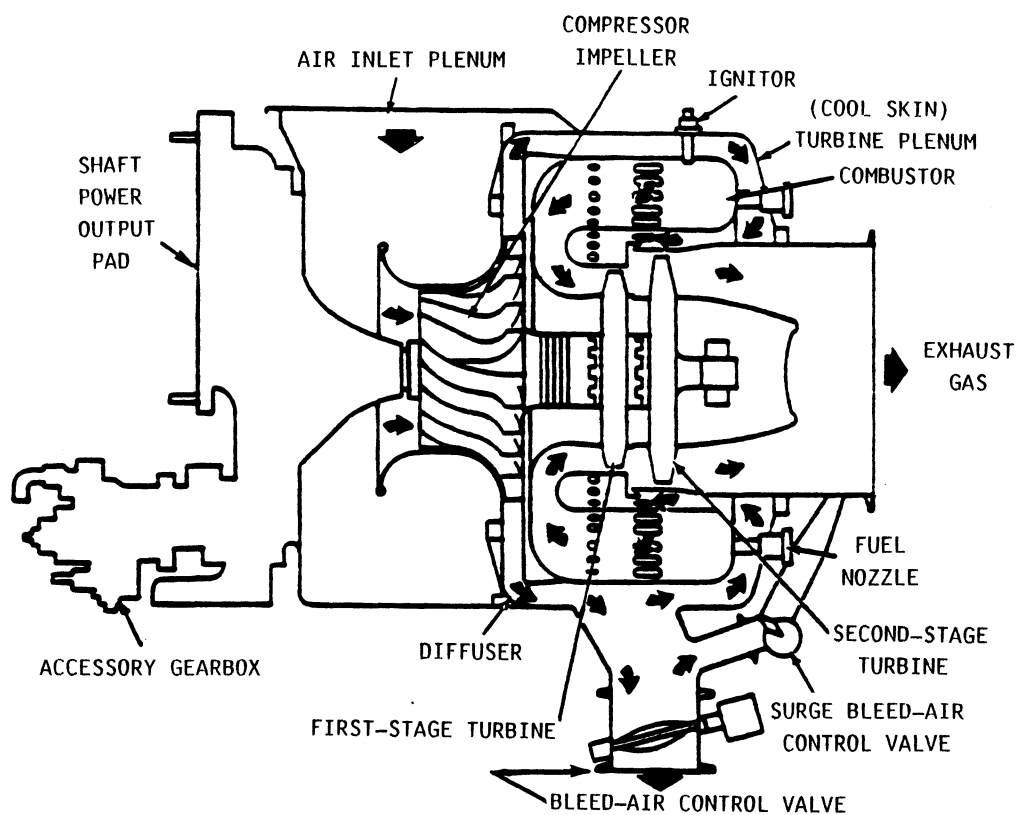


FIGURE 2 - Cross Section of an Integral Bleed Air APU

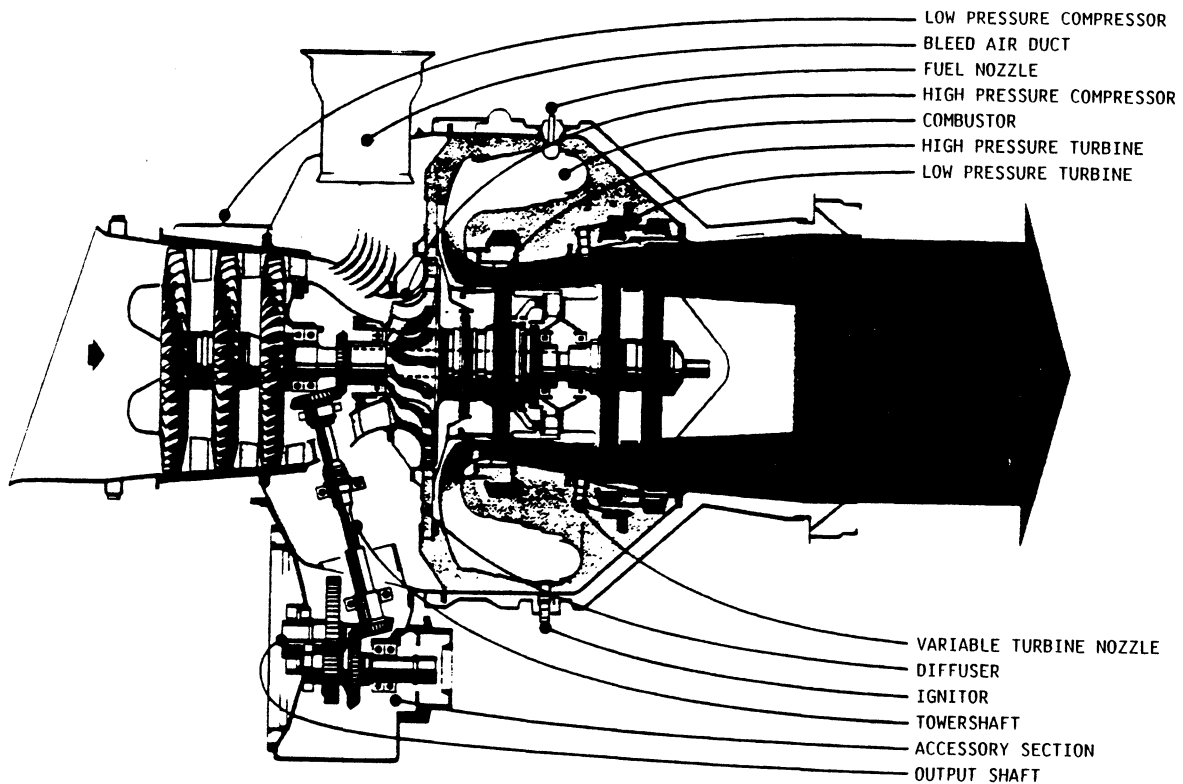


FIGURE 3 - Operating Principles of a Twin-Spool APU



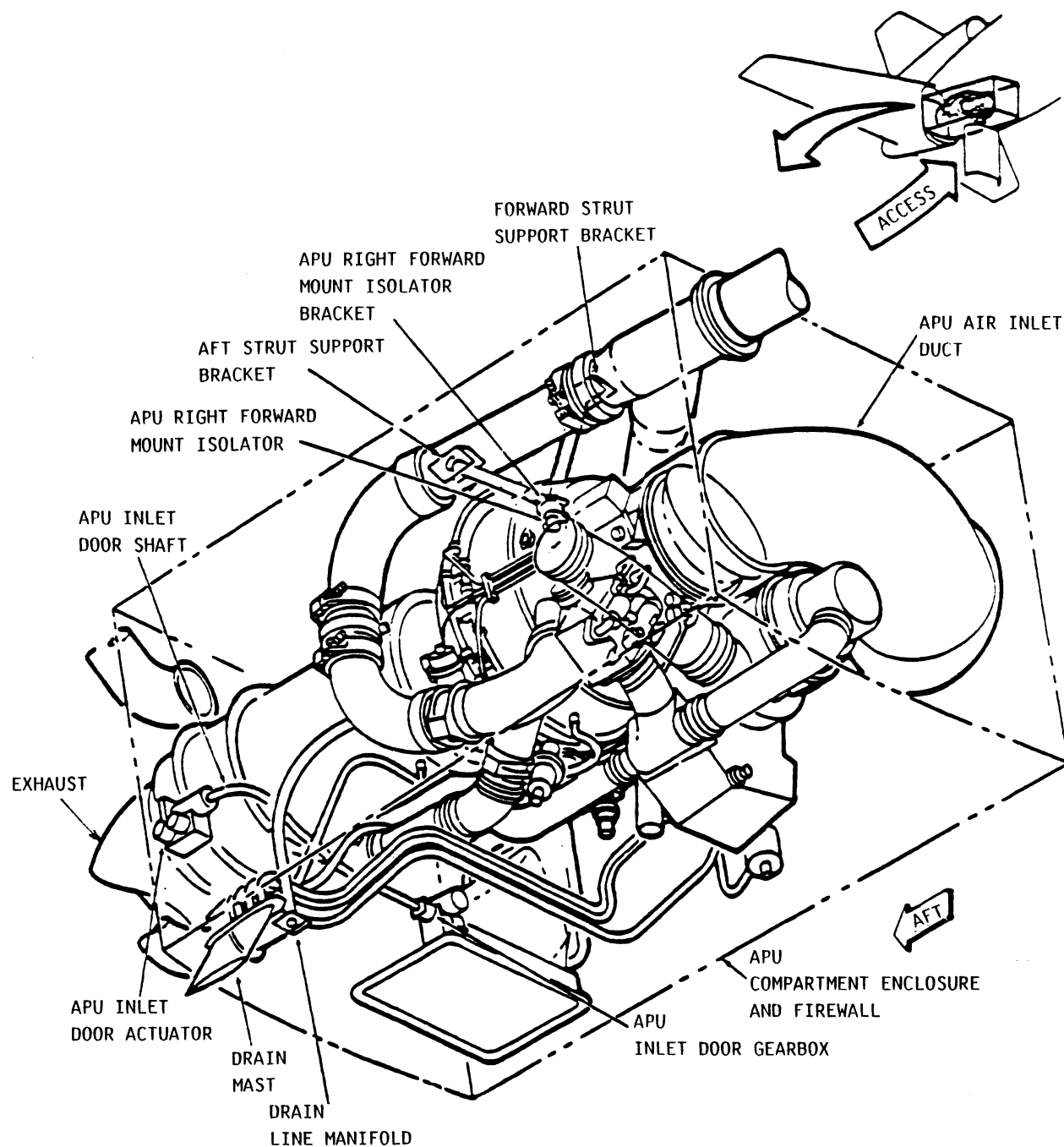


FIGURE 4 - Example APU Installation

4.1 Output:

The initial determination for an APU installation is the size of the unit to be installed. That means determining the power requirements to be satisfied. The general load categories are as follows:

- a. Electrical
- b. Pneumatic
- c. Hydraulic

Hydraulic operations on the ground are usually powered by electric motors, so with respect to APU sizing they become part of the electrical load.

- 4.1.1 Electrical: The electrical load which will be required of the APU generator is calculated from the electrical requirements of the airplane while on the ground and in certain flight conditions, such as short-circuit or fault-clearing loads. A list of typical loads is shown in Table 1. The total of the connected loads is unrealistically high for design purposes because it assumes that all the individual loads peak at the same time. The total of the average loads is not necessarily a good criterion for sizing the generator either. The generator capacity normally must be determined as a matter of judgement and may come out somewhere between connected and average loads.

Where possible, the APU generator capacity will be made to match that of the generators on the main engines so that common parts can be stocked. However, before that is done, a careful analysis of the electrical loads should be made and the possibility of electrical growth should be considered to assure that future versions of the airplane will not be restricted by the APU generator. An example of the electrical load requirement for a large commercial transport is shown in Table 1.

- 4.1.2 Pneumatic: Pneumatic power is required for engine starting and air-conditioning on the ground and may be required for air-conditioning in flight and also anti-icing where bleed air is used for that purpose. The total capacity of the system must be sized to accommodate both electrical and pneumatic loads under the most severe condition. Table 2 shows a typical set of ground pneumatic requirements at three environmental conditions for a large commercial transport. It is assumed that full electrical load is applied at the same time.

TABLE 1 – Example Electrical Load Analysis (KVA)

System	Connected Load	Average Flight Load	Average Ground Load
Avionics	16.9	6.9	2.1
Electrical	28.5	7.4	7.1
Hydraulics	63.0	0.4	15.6
Interiors	29.0	15.0	4.5
Mission	2.6	1.1	1.3
Lighting	22.0	8.0	6.1
Power Plant	48.0	26.7	3.9
Environmental	54.0	33.8	26.3
Totals	263.8	99.3	66.9

NOTE: Direct current (DC) loads are included as a function of transformer rectifier input loads.

TABLE 2 – Example Pneumatic Ground Requirements

Altitude	Inlet Total Temp °F	Minimum Bleed Air Flow lb/min	Bleed Air Total Pressure psia	Bleed Air Total Temp °F
Sea Level	103	350	41	430 max
8 500	90	270	32	430 max
Sea Level	-40	410	41	185 min

4.1.3 Allowances for Growth and Installation Losses: The APU must be sized to accommodate losses that are characteristic of a particular installation and the APU manufacturer will provide corrections to be applied to the APU performance for inlet and exhaust losses. Typically the losses will amount to a few percent of ambient static pressure. Gearboxes are relatively efficient devices. If a separate gearbox is required, a good rule-of-thumb is 0.5% loss per gear mesh. That places the usual gearbox for a generator at better than 98% efficiency. AC generators will run at approximately 85% efficiency at full load. However the biggest factor to make allowance for is the unknown future growth in demands to be put on the APU. Both airline and military customers will request additional on-board services that require more electrical power and nearly all commercial aircraft, when first designed, have potential to add fuselage length for greater passenger-carrying capability. That increases the air-conditioning load so more pneumatic capacity will be required. An APU installation that is designed near its load limit may create future problems, depending partly on the potential of the APU for future uprating. In the early stages of design, judgement must be exercised concerning the amount of excess weight to be carried in order to accommodate future growth.

4.2 APU Location:

Early in the design phase of an airplane a judgement decision must be made concerning the location of the APU. The following factors should be taken into account:

4.2.1 Safety: Safety is the primary and overriding requirement in the location of the APU. The APU compartment contains both fuel and sources of ignition and is, therefore, classified as a fire zone by the FAA. Though it may be technically possible to locate the APU in the cabin pressurized area, it is seldom done for obvious safety reasons. APU's are, therefore, almost always located in an unpressurized area. In addition, consideration should be given to the potential for uncontained rotor failure resulting in high energy debris projectiles.

4.2.2 Center of Gravity: During the progress of an aircraft design, the center of gravity sometimes has a tendency to creep aft resulting in a degradation of pitching stability. For a number of reasons, many commercial transports locate the APU in the aft fuselage behind the rear pressure bulkhead, which may be the best compromise but doesn't alleviate the center of gravity problem. Alternate locations might be in a wing fillet or wheel well, or in the case of a retrofit for a military purpose, even a separate pod or blister attached to the fuselage or mounted under the wing.

4.2.3 In-Flight Pressure Differential: This item must be considered for all altitudes, airspeeds, and aircraft attitudes. In general, the air inlet should be located in a region of pressure slightly higher than that at the exhaust outlet. The opposite condition (negative ΔP) will decrease the performance of the APU and will make in-flight starting difficult if not impossible. Further, if the negative pressure gradient is high enough, it can produce overheating of the APU and other adverse conditions. When the APU is inoperative in flight, a negative ΔP can produce reverse windmilling if the installation is not provided with suitable inlet or exhaust doors. Windmilling either forward or reverse will add airplane drag and unnecessary wear on the APU seals and bearings, but reverse windmilling can also damage generator brushes that are designed to trail the rotation. Forward windmilling can cause oil accumulation in the sump, thereby giving an erroneous quantity reading.

4.2.4 Location of Air Inlet: The inlet should be in a location that will prevent ingestion of exhaust either from the APU itself or from a main engine. In addition to exhaust ingestion, the probability of both liquid and solid particle ingestion, in flight and on the ground, must be considered.

One of the least favorable locations for an inlet is well aft on the bottom surface of the fuselage. Liquids likely to be ingested with this type inlet include those that may be spilled within the aircraft fuselage, fuel-tank leakage and vent-system discharge, leakage from the hydraulic system, etc. Water, mud, and ice thrown up by the tires or sucked into the inlet during maximum rotation of the airplane at takeoff or landing may also be ingested with the APU in operation. However upward-flow inlets are assisted by gravity in excluding the heavier dust and debris particles.

For acoustical reasons, APU inlets should be directed generally upward and away from the passenger cabin. The sound generated by the APU compressor is dominated by the high-pitch blade-passage frequency, which is highly directional, and can be extremely uncomfortable to the human ear if not properly directed. Elimination of a line-of-sight between the sound source and the ear is a fundamental means of minimizing noise exposure. The upward orientation thus minimizes noise exposure of ground crews. Location of the inlet near a cabin service door should also be avoided.

4.2.5 Location of Exhaust Outlet: Placement of the exhaust outlet immediately forward of the landing gear wheel wells should be avoided to preclude the possibility of hot APU exhaust gases entering these sensitive areas during any operating condition. This would be especially adverse in the event of exhaust torching that could result from such things as ingestion of flammable fluids or malfunctioning fuel system. The exhaust outlet should not be located in a way that would allow its exhaust to be ingested by a main engine.

As with air inlets, exhaust discharge should be directed generally upward and away from the passenger cabin to minimize noise effects to passengers and ground crew.

4.2.6 Weight of Connecting Systems: Wherever possible, the APU should be installed at a location that minimizes the length of the following:

- a. Pneumatic lines to air-conditioning packs and engine starters. These lines can be large diameter and extra length will add substantially to aircraft weight.
- b. Fuel supply lines to the APU, if too long, may demand an extra boost pump to overcome the line pressure drop in order to satisfy the APU suction head requirement.
- c. Electrical leads from the generator to aircraft systems and electric power supply to the APU starter can require heavy wires and constitute a substantial weight increment. They should be kept as short as possible.

4.2.7 Accessibility: Location of the APU in the aircraft should be greatly influenced by the need for accessibility. Easy access to the areas requiring regular servicing or inspection, or both, enhances the maintainability of the airplane. Good accessibility for removal and replacement of line replaceable units (LRU's) and driven-accessories also facilitates maintenance. The location should permit easy removal and reinstallation of the complete APU or quick engine change (QEC) unit, with a minimum of special tools or workstands, or both.

4.3 Maintainability:

One of the highest cost items in operation is maintenance. Anything the airframe designer can do to reduce maintenance provides a competitive advantage beneficial to the customer. At one or more stages in the design of the airplane a mockup of the APU in the APU compartment will be a valuable aid in determining accessibility and removal characteristics of the installation design.

4.3.1 Accessibility Requirements: Proper planning for accessibility of the installed engine enhances visual inspection, servicing and cleaning, checking and correcting control adjustments, ground testing, APU removal, and parts replacement. This involves, among other things, providing adequate access doors or openings, or both. The following instructions are offered as a checklist for improving accessibility.

4.3.1.1 Quick Installation and Removal Capability: The following requirements are practical for most installations:

- a. Provide lift or support equipment for installing and removing the APU and other relatively heavy or bulky components.
- b. Provide adequate room for wrenching and safetying at attach points; also good visibility for inspecting mount points in "open" and "secured" positions.
- c. Use quick-attach-detach (QAD) fasteners wherever practical.

4.3.1.1 (Continued):

- d. Ensure that all disconnect points and connections are located for ready accessibility and easy visual inspection for security.
- e. Minimize possibility of reverse installation by using different sizes of connections or connectors. Develop piping, hose runs, and wiring routing so that cross-connecting to wrong points is impossible.
- f. Use standard type fittings (AN, MS, and NAS).
- g. Eliminate hidden pockets in the compartment where small items could be lost.
- h. Provide compartment service drains (scuppers) for easy draining of spilled fuel, oil, cleaning fluids, etc.
- i. Provide adequate clearances for the removal of filters and other LRU's. The necessary clearance for such equipment should be shown on the applicable APU installation drawing. Additional clearance should be allowed beyond the standard removal clearance to permit "wobble" of the LRU or accessory--sometimes necessary for installation or removal. To ensure proper access, an early decision should be made regarding which LRU's must be removable with the APU installed in the aircraft.

4.3.1.2 Quick Engine Change Concept: The capability of quickly removing or installing major components of an aircraft (such as main engine or APU) to minimize downtime is a standard requirement. Generally, a kit of parts assembled on the APU prior to installation in the aircraft permits faster installation and removal.

Quick engine change (QEC) kits are usually composed of items that are necessary to accommodate an interface between the power plant, APU, and the airframe. The QEC kit should include the APU-mounted, aircraft-furnished accessories, such as tachometer-generator, alternator, hydraulic pump, etc. The kit-to-airframe interface connections should be identified by color-coding (international orange) to preclude inadvertent separation at the wrong end and to assure that only items belonging to the APU and QEC kit are removed from the airplane at APU change. Whenever possible, these connections should be designed to minimize interference with predictable maintenance items, such as filters, servicing points, etc.

4.3.1.3 Accessibility for Regular Servicing, Inspection, and Maintenance: Servicing, inspection, and maintenance time can be minimized by providing proper access to components requiring regular attention. The following items will usually require regular service, inspection, and maintenance:

- a. Fuel filters
- b. Oil filters
- c. Fuel nozzles
- d. Ignition system, including ignitor plugs
- e. Chip detectors (if used)
- f. Drain and fill ports
- g. Borescope ports
- h. Fuel control
- j. Exhaust duct and coupling
- k. Bleed-air ducts and couplings
- l. Fluid level indicators, pressure-differential (ΔP) indicators, hour meter, and start counter, should all be in prominent locations, clearly visible from quick-opening doors
- m. All fuel and lubricating oil lines, drain lines, and line connections
- n. Electrical harnesses and thermocouples
- o. APU-driven equipment (alternator or hydraulic pump)
- p. Fire extinguisher bottles
- q. Fire detector elements
- r. Starter
- s. Thermostats
- t. ECU
- u. Speed switch or monopole speed sensing system
- v. Combustor
- w. Bleed-air load control valve (LCV)
- x. Door actuators and linkage

4.3.1.3 (Continued):

Large multiscrew-fastened access panels or hinged doors should not be used where small sizes are adequate. Stressed skin panels for access doors should be avoided where possible. All access door fasteners should be a captive quick-release/fasten type.

4.3.1.4 Accessibility of LRU's: The following requirements pertain to the accessibility of LRU's:

- a. Adequate space for wrenching clearances and tools necessary for inspection and removal or replacement
- b. Minimum removal of other system components and hardware to gain access to LRU's
- c. Priority of accessibility to items requiring the most frequent attention

4.3.2 Compartment Lighting: Compartment lighting (lamps) should be provided for adequate illumination of service points, fluid level indicators, and warning indicators. Lamps should be powered from the battery bus through a door-actuated switch or "prevent-close" switch arrangement.

4.3.3 Wiring, Piping, and Hoses: The following instructions are generally applicable for good installation practice:

- a. Use standard connections.
- b. Avoid crossing lines to eliminate chafing. Provide different size adjacent lines to avoid cross connections.
- c. To the extent possible, route fluid and electrical lines through quick-release, ganged, antichafing clamps.
- d. Label all hoses and wiring to avoid errors in connections; color-code disconnect points.
- e. Ensure that hoses are long enough to prevent stretching and are adequate for the given operating pressure.
- f. Where possible, route electrical wiring above fluid lines and reservoirs to minimize possibility of fluid leakage or spillage onto the wires and connectors; also provide drip loops in wiring harnesses at the connectors. Electrical leads and fuel lines must be separated. Do not attach electrical power leads to fuel lines.
- g. Do not use left-hand threaded connectors unless obviously identified. Most technicians expect connectors to be right-handed. In the past, forced turning of left-hand threaded connectors has resulted in damage beyond routine maintenance.
- h. Route fire/overheat detector loops clear of access doors and service areas, if possible, to minimize probability of damage during routine maintenance.

4.3.4 Maintenance Placards: Where possible, prominent placards should be provided for equipment in or near the APU compartment, with the following type of information to assist in maintenance and to avoid errors and personnel injury:

- a. Manufacturer's name
- b. Part number
- c. Working pressure
- d. Type of fluid
- e. Fluid quantity (gallons and liters)
- f. Special instructions or limitations
- f. Information helpful in troubleshooting; such as, adjustment information

Locate placards so that they are easily seen; instructions should be simple and printed in bold, easily legible letters. In addition to safety placards, adequate personnel safety guards should be provided at areas such as the inlet and exhaust to prevent personnel injuries.

4.3.5 Self-Locking Devices: Self-locking fasteners and attachments are strongly recommended, where possible, and safety wire only when absolutely necessary. Self-locking devices (nuts, bolts, screws) in place of lockwire are particularly desirable in all areas of difficult access, because the effectiveness of lockwire is compromised if it cannot be properly installed. Self-locking fluid couplings may be desirable at QEC disconnect points if space permits.

4.3.6 Compartment Intercom Connection or Remote Control Panel, or Both: An intercom is necessary if the mechanic is not visible to, or within audible range of, the operator at the cockpit controls during "power on" or controls adjustments. This is considered, first, a safety factor and, second, a convenience factor. A remote control panel located in the vicinity of the APU is also recommended, especially if the APU is to be used for ground maintenance or checkout, or both.

4.3.7 Fault Isolation: To facilitate troubleshooting the APU and its associated systems as expeditiously as possible, the installation designer should provide for fault isolation. This capability can be provided in three ways:

- a. Cockpit annunciator panel lights and APU indicating-instruments.
- b. A fault isolation module in or near the APU compartment. (This may be part of the APU ECU).
- c. A fault isolation connection panel in or near the APU compartment, suitable for use with an aerospace ground equipment (AGE) analyzer, and providing sufficient analyzer interfaces to minimize the need for disconnecting APU fluid, air, and electrical systems control lines.

4.3.7 (Continued):

The various parameters that need indication in a fault isolation system will vary with the APU model and the installation involved. For this reason, they are presented in detail in the appropriate series installation manual or in the model specification.

4.3.8 Design for Maintainability: Many details in the design of an APU installation can have an important impact on the overall maintainability of the final product. Such details are treated in Reference 2.7.

Design suggestions for electrical equipment are presented in 5.8.8.

5. INSTALLATION REQUIREMENTS:

Safety requirements for transport category commercial aircraft certificated in the U.S. are governed by Federal Air Regulations (FAR) Part 25 (Reference 2.8). The APU itself is certificated under the FAA Technical Standard Order TSO-C77a (Reference 2.3). The installation in the airframe is certificated under FAR Part 25 and FAA Advisory Circulars provide the commonly used bases for compliance.

5.1 Safety:

5.1.1 Compartment Design:

5.1.1.1 Selection of Compartment or Enclosure, or Both: The installation designer must be aware at the outset that any APU compartment or enclosure is designated a fire zone per Reference 2.8, paragraph 25.1181, and must meet the requirements of paragraphs 25.901(d) and 25.903(d)(1) for rotor failures. A means of compliance with paragraphs 25.901(d) and 25.903(d)(1) is presented in Advisory Circular No. 20-128.

After selection of the APU location, another option must be decided before proceeding with details of the compartment design. If the APU is in a compartment within the aircraft, it must be isolated from the remainder of the aircraft by a firewall. This may be in the form of a fireproof shroud within the compartment, or the compartment walls may be fireproofed.

Installations that utilize a fireproof shroud are sometimes configured as tightly wrapped "cocoon", while others are simply fireproof boxes within the compartment; both are equally capable of achieving fireproof status. Usually, the cocoon is used only when the selected compartment is too small for a fireproof box, and the compartment structure is unsuitable for fireproofing the complete compartment. The cocoon-type shroud, is a much less desirable approach, since it imposes numerous disadvantages, including the following:

- a. It is difficult and expensive to fabricate, due to the irregular shape.
- b. There is poor accessibility for installation, maintenance, and servicing.

5.1.1.1 (Continued):

- c. Suitable entry and egress for wiring, piping, or ducting are difficult to provide.
- d. It is difficult to attach, support, and handle.
- e. It is difficult to cool properly.

A regular shaped enclosure within the compartment also exhibits some of the same disadvantages as the cocoon arrangement. Nevertheless, occasionally when the APU is installed in an existing airframe, a box or cocoon is the only satisfactory method of achieving a fireproof enclosure without extremely expensive structural modifications. Also, a fireproof enclosure within the compartment requires less fire suppressant for the smaller volume.

In general, the optimum APU installation will utilize a compartment with fireproof walls, where structural considerations permit. Again, selection of the APU location early in the design of a new aircraft facilitates the necessary structural arrangement for this purpose.

Another approach to fire protection is the use of fireproof shrouds around the individual components or systems; that is, the fuel control systems, compressor/turbine assembly, reduction drive unit, and combustor/tailpipe assembly. This type of shrouding has been used on numerous commercial APU installations and has been certified as meeting all the fire prevention/protection criteria, regulations, and requirements of the FAA, CAA, and the Canadian Department of Transportation.

- 5.1.1.2 Typical Installations: Examples of existing installations are shown in Figures 5, 6, and 7. The first is intended for ground operation only, and is located in the aft wheel well. The design was constrained because the aircraft had been previously released to production. As a result, a close form-fitting fireproof shroud is used as the fireproof compartment. The second example (Figure 6) is an APU installation designed for airborne operation in which the whole APU compartment is fireproof. The third and fourth examples (Figure 7) are regular shaped enclosures designed for installation within an existing compartment.

The compartment must be designed with fireproof materials. It must maintain its integrity in the event of a fire in the same manner as that of a firewall. The enclosure must withstand pressure and temperature rises resulting from a compartment fire, a ruptured pneumatic duct or plenum, or discharge of fire extinguishers. Access doors, hinges, and latches must be constructed of materials that are as fireproof as the enclosure. Drainage provisions for the enclosure must be sufficient to accommodate significant fuel leaks.

The interior surfaces of the compartment should be as free as possible of standing frames, bulkheads, or other structures that could trap burning fluids and prevent extinguishment by the fire suppressant.

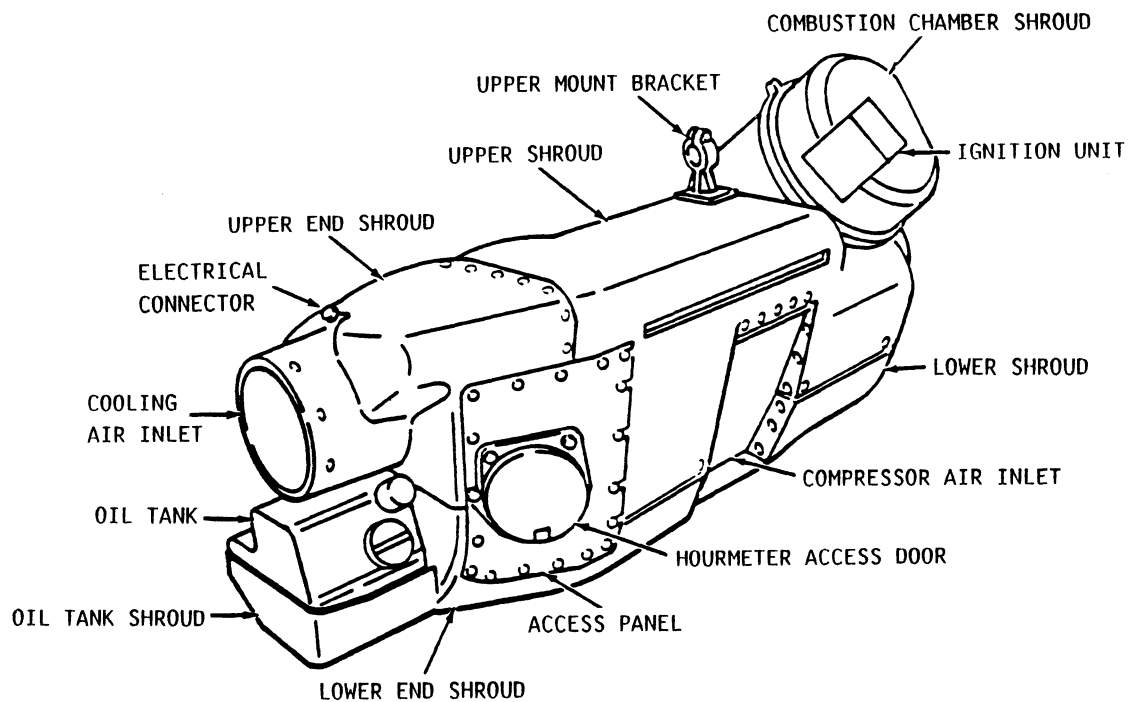


FIGURE 5 - Example of Cocoon-Type Fireproof APU Enclosure



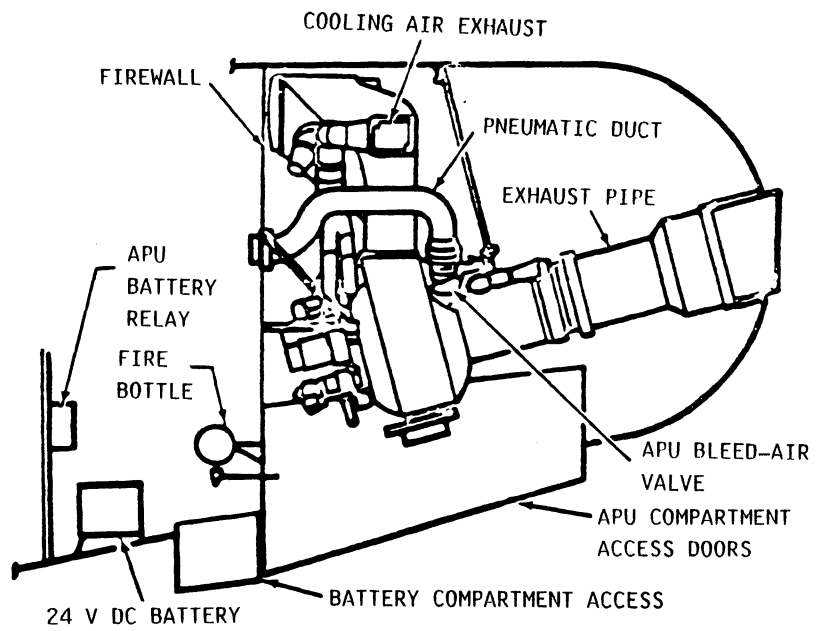


FIGURE 6 - Example of Fireproof APU Compartment



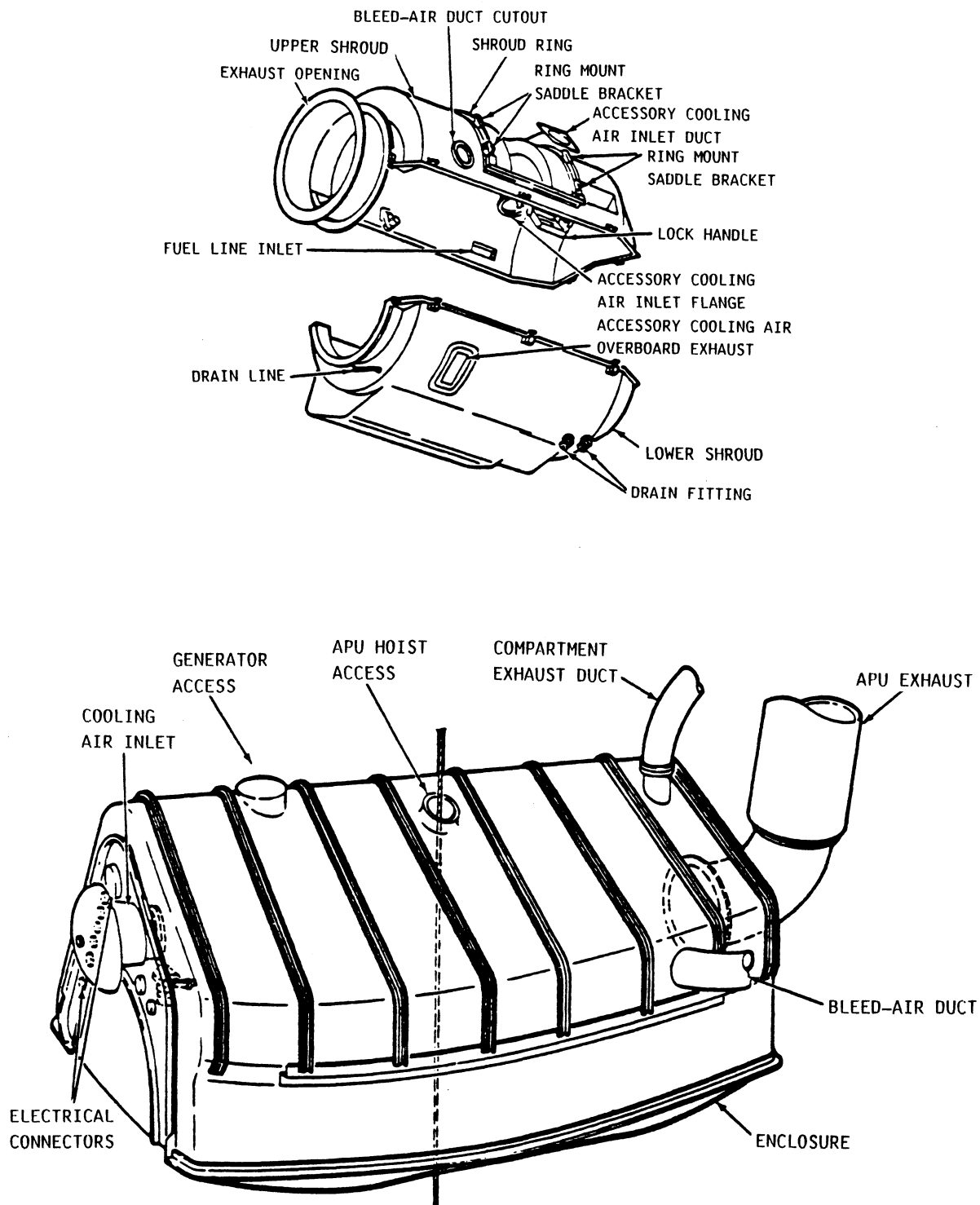


FIGURE 7 - Examples of Regular Shaped Fireproof Enclosures for Installation Within an Existing Compartment

5.1.1.3 Compartment Wiring:

Normally, an APU compartment contains the following kinds of wiring, categorized by function:

- a. APU control
- b. DC power to or from APU starting system
- c. AC power from APU-driven alternator
- d. Fire and overheat detection

Wiring within the compartment or enclosure should meet the minimum requirement for main-engine nacelle installations. Wiring should be routed above fluid-carrying lines and below or sufficiently remote from high-temperature pneumatic ducts, turbine plenum, exhaust duct, and other hot surfaces to preclude early aging and deterioration of wiring insulation.

In event of a compartment fire, heavy electrical leads, such as battery and generator cables, will conduct very high temperatures through the copper construction for a considerable distance past the compartment wall. Flammable materials and critical equipment should be located clear of such leads in the area outside the compartment. Fire-detector wiring, if exposed to compartment interior, should have high-temperature insulation or be protected against open flame. Use only fireproof electrical connectors where wiring passes through the compartment wall.

An electrical schematic for the APU defines the electrical requirements and shows the location of the required connections to aircraft circuits. This schematic is included in the applicable APU model specification.

5.1.1.4 Compartment Piping: For commercial aircraft, all piping and hoses within the APU compartment must meet the requirements of TSO-C53 and FAR 25. The best guidelines for APU installation piping are those for main-engine nacelles; these are as follows:

- a. All fluid piping should be corrosion-resistant steel.
- b. Minimum wall thickness must meet FAR 25 and AFSC Design Handbook 2-3 requirements.
- c. All fittings should be steel.
- d. All hoses must be at least fire-resistant and comply with TSO-C53.
- e. No piping smaller than 1/4-in diameter should be used.
- f. Piping and hoses for liquids should be routed below electrical wiring, and hoses should be located away from high-temperature surfaces (pneumatic ducts, turbine plenums, exhaust system, etc.)

- 5.1.1.5 **Compartment or Enclosure Materials:** APU compartments or enclosures must be fireproof and be able to withstand a fire test, as defined by FAR 25 or AFSC Design Handbook 2-3. Therefore, they must be fabricated of fireproof coatings.

Stainless steel at least 0.015-in thick or titanium at least 0.020-in thick are considered suitable firewall materials. Where stainless steel or titanium cannot be used, alternate materials may be substituted, usually at greater weight. However, unless there are compelling reasons to deviate, corrosion-resistant steel is strongly recommended because of its demonstrated record of integrity, relative cost, and ease of fabrication.

Some installations have achieved fireproof status by lining the compartment with fireproof batting. Other installations have achieved this status by applying flame-resistant coatings that can be troweled or painted on the compartment walls. Some of these coatings expand in thickness during the curing cycle and form a nonabsorbent, resilient, fireproof barrier.

No wicking or absorbent materials are permitted within, or immediately adjacent to, the compartment.

Fasteners used in compartment design should be steel, titanium, or monel. Do not use aluminum or other low-melting-point metals for fasteners.

Enclosures that also serve as firewalls must be sealed to make them vapor and liquid-tight. A high-temperature, fire-resistant, mastic sealing-compound should be used for this purpose.

- 5.1.1.6 **Pressure Relief Provisions:** An increase in compartment ambient pressure may occur, as a result of a compartment fire, fire-extinguisher discharge, or failure of a pneumatic component. Consequently, pressure relief is necessary to prevent a compartment wall rupture that would allow a compartment fire to migrate into unprotected areas of the airplane. Pressure relief doors or panels should be provided. Relief doors should be hinged at the leading edge for aerodynamic damping when blown open. The main access door to the compartment, if located on the outer surface of the airplane, can be designed to deflect and, thus, relieve the internal pressure buildup.
- 5.1.1.7 **Ground Fire Door:** In case of an APU compartment fire on the ground, when it could be beneficial, a spring-in door may be provided large enough to accommodate a fire extinguisher thrust in from the outside.

5.1.2 Ventilation and Cooling: The following items should be considered:

- a. The cooling air for a cooling fan can be either a separate inlet duct or draw from the APU inlet plenum. Protection against fire propagation is required when the cooling fan inlet draws air from the APU inlet plenum.
- b. Cooling air ducting should be fireproof along its entire length outside of the compartment and at least fire-resistant inside the compartment. On installations where compartment-cooling air is exhausted overboard, the duct and the aircraft surface aft of the outlet should be constructed of fireproof materials (meeting firewall requirements). This is necessary since a compartment fire could be exhausted overboard through the cooling-air-outlet duct.
- c. If cooling air is obtained from, or traverses, another aircraft compartment, a fireproof check valve and, dependent on the specific installation, shutoff valve should be installed at the APU compartment wall through which the cooling-air duct enters. This will prevent migration of a fire in the APU compartment to other areas of the aircraft, and the loss of fire-extinguishing agent.
- d. An air-cooled generator or alternator, if installed, should be fitted with a muff or shroud to conduct the spent cooling air either directly overboard or into the exhaust system. This muff and ducting should be constructed of fireproof materials.
- e. The oil cooler discharge air can be ducted directly overboard, into the APU compartment, or into the APU exhaust/exhaust shroud. Considerations in selection of the design approach include the effect on the need for shutoff valves in the event of a fire, the quantity of fire extinguishing agent required, and the effects of oil cooler leaks.

As with the compressor air inlet, a positive ΔP (inlet pressure higher than outlet pressure) must be maintained between the cooling-air inlet and outlet ports.

5.1.3 Fire-Detection and Extinguishing System: The interior of an APU compartment or enclosure is a designated "fire zone" per Reference 2.8 and, as such, must be equipped with fire-detection and extinguishing apparatus. The system should be designed for the highest reliability, and the detector system should respond to an unacceptable or abnormally high average temperature throughout the compartment, as well as a compartment fire.

Systems that meet this requirement and are in current use are of the dual continuous-element type, which are logarithmic averaging. When set to actuate at approximately 150°F over the normal average compartment temperature, they will detect either an unacceptably high compartment average temperature or a local hot spot. Continuous element systems will detect local hot spots, but will not identify specifically where they are.

5.1.3 (Continued):

With this type of system, the aircraft is protected against the APU compartment walls ever reaching a surface temperature that could become a source of ignition to combustibles external to the APU compartment, as well as detecting a fire within the compartment. A fire-detection system should be reserved for a condition requiring immediate APU shutdown and release of extinguishing agent.

5.1.3.1 Fire-Detection and -Extinguishing Provisions: The FAA requirements for fire detection and extinguishing may be found in Reference 2.8, paragraphs 25.1195 to 25.1203.

There are three general types of detection-procedure systems that can be used:

- a. Manual: This type of system utilizes warning lights to alert the crew, who then follow prescribed cockpit procedures as a countermeasure.
- b. Semiautomatic: This system may be employed when an airplane is sufficiently complex that fire procedures may be considered too demanding. Here the pilot is warned of a fire by cockpit lights, but a multiple-function switch or "emergency" handle simplifies the fire-fighting procedure to perhaps a single action by a crew member. Actuating the "fire" or "emergency" handle should initiate the following functions:
 - (1) Selection of Fire Bottle No. 1 or 2
 - (2) APU shutdown and bleed-air valve closure
 - (3) Firewall (or wing tank) fuel shutoff
 - (4) Switch APU-driven AC generator to OFF
 - (5) Hydraulic system shutoff (if APU-driven)
 - (6) Door actuation to closed position (if used)
 - (7) Discharge of extinguishing agent.

Versions of the semiautomatic system described here are in general use on most transport-category airplanes and are based on years of satisfactory experience. This system is recommended for all airplane applications.

- c. Automatic: The automatic system not only senses the fire and warns the crew but also performs other necessary actions in proper sequence without pilot action. The automatic system should initiate the same functions listed in b above for the semiautomatic system.

Details of the features and installation requirements of a number of detection and extinguishing systems can be obtained from Reference 2.9.

5.2 Air Inlet:

The air inlet discussed here supplies air to the APU compressor. The air inlet for ventilating the APU compartment is discussed under 5.11. Those two air inlets should be kept separate for the following reasons:

- a. With a combined inlet it might be possible to propagate a fire from the compressor inlet to the general APU compartment. Therefore, incorporation of a fireproof shutoff valve or fireproof ducting, or both, are essential if a common inlet is used.
- b. Depending on the APU air requirements and the inlet design, it is possible for the APU compressor to draw enough air to starve the compartment cooling system.
- c. Closing a door at the inlet port to prevent windmilling would also shut off ventilation to the APU compartment.
- d. Closing the APU air inlet door immediately after APU operations may result in a thermal soakback situation causing compartment temperatures to rise. In this case, a delay in the inlet door closing is required.

5.2.1 Location: The following should be considered in locating the APU inlet:

- a. The location should minimize the ingestion of solid foreign objects. Normally that means avoiding the bottom of the fuselage.
- b. Locate the inlet in an area where it is unlikely to ingest hazardous liquids from drainage discharge or possible leakage.
- c. Locate the inlet far enough from the APU exhaust to assure that there will be no reingestion of exhaust gases.
- d. Locations that could be exposed to main engine exhaust buffeting or shock waves may cause erratic APU operation and should be avoided.
- e. The inlet should be located so that, in flight, the pressure at the inlet will always be greater than the pressure at the exhaust to prevent reverse windmilling.
- f. The effect of compressor noise should be minimized, which usually means locating the inlet on the right-hand side of the airplane, away from the passenger-loading doors.

5.2.2 Ingestion: Large solid objects such as rocks, bolts or nuts can cause serious damage to compressor blades. So can chunks of ice. However, a screen can protect the APU from such objects as long as they are ingested upstream of the screen. If the hole size in the screen is 0.2 x 0.2 in or less, the objects that get through will normally be below the threshold of serious damage. However, it should be noted that hole sizes smaller than 0.75 in are significantly more vulnerable to icing than holes larger than that size.

5.2.2 (Continued):

Care must be taken to avoid ingestion of hazardous fluids, which include combustibles such as fuel, oil, or hydraulic fluid. If there is a leak ahead of the APU, it could cause a runaway and catastrophic failure. Analysis or test may be required to determine the amount of ingestion of combustible liquids that the APU can withstand. The overspeed control cuts back on the fuel supply, but if the amount ingested exceeds the normal supply, the overspeed control will be powerless to keep the rotor from spinning out of control.

However, the more usual case is drainage fluid ingested in small quantities, too small to affect the rotor rpm but significant in terms of the bleed air quality delivered to the passenger cabin via the air-conditioning system. If other design considerations dictate an adverse inlet location in that respect, such as the lower surface of the tail cone, then it is sometimes possible to remedy the situation by installing a diverter similar to that shown by Figure 8. It is intended to divert the fluid that washes along the skin in flight and has proven in some cases to be an effective fix.

5.2.3 Performance: The inlet can affect the performance in two ways:

- a. Losses in pressure.
- b. Nonuniform velocity over the face of the compressor.

The gas turbine compressor, like any other internal combustion engine, can produce power roughly in proportion to the amount of air it can take in. Any resistance to airflow in the inlet will therefore reduce the maximum power output of the APU. How important that is depends on the individual installation. Normally APU capacity is not tailored exactly to the requirements of a particular airplane and should not be if any additional capacity is provided for future growth of the airplane. The additional capacity available may influence the care that is taken in designing the inlet for aerodynamic efficiency.

However, where feasible, it is desirable to keep the losses to a minimum because losses mean reduced efficiency. Therefore, the velocities should be kept as low as possible and the surfaces should be smooth and free of protruding connectors. Abrupt expansions or sharp turns should be avoided. Where sharp turns are unavoidable, turning vanes may be considered. If the turning vanes are upstream of the screen and accumulate ice that breaks loose, it will not damage the compressor. Unavoidable restrictions such as screens should have as much through-flow area as possible to reduce the pressure loss, particularly during icing conditions.

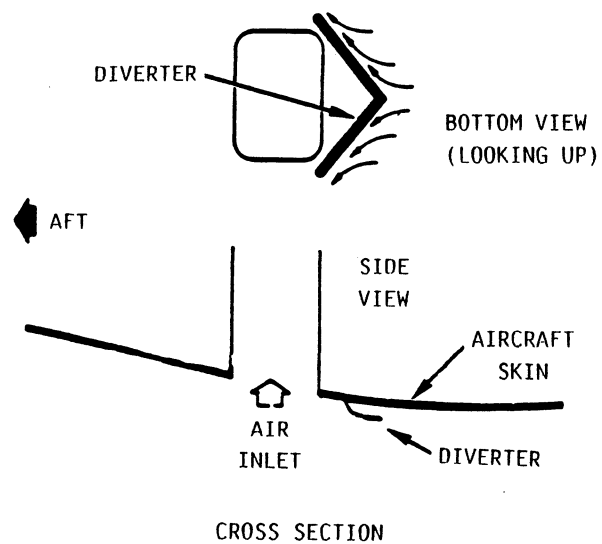


FIGURE 8 - Fluid Diverters

5.2.3 (Continued):

The subject of acoustics is brought up here because it is related to the inlet performance in an inverse manner. In order to have an inlet that suppresses APU-generated noise, it should be long enough to provide sufficient surface for noise-absorbing lining in the duct. The longer and more tortuous the inlet duct, the better acoustic absorption potential it has, just the opposite of the requirement for performance. Modern APU's can't avoid generating high-pitched noise, so when an APU is selected for an airplane, allowance should be made for inlet pressure drop sufficient to provide for reasonable noise attenuation.

Distortions of the airflow, that is, nonuniformity of velocity at the compressor inlet may cause unacceptable vibrations, and swirl of the incoming air may reduce the surge margin. That is particularly true of axial flow compressors. Centrifugal compressors are not so sensitive. The inlet distortion limits are usually specified in the APU model specification but the amount of distortion and its effect are difficult to determine during the design phase. A full-scale test with a representative APU should be incorporated in the program at the earliest possible date.

- 5.2.4 Icing: Ice accumulation in the inlet can have two effects. It can accumulate on obstructions such as screens and restrict the airflow, causing a reduction in APU power output. Or, if it melts partially and refreezes, chunks of ice can form, which if downstream from the screen, can break off and damage the APU compressor.

FAR 25 states the following:

a. 25.1091 Air Induction:

(1) The air induction system for each engine and APU must supply:

(a) The air required by that engine and auxiliary power unit under each operating condition for which certification is requested.

b. 25.1093 Induction System Icing Protection:

(1) Turbine Engines: (1) Each turbine engine and its air inlet system must operate throughout the flight power range of the engine (including idling), with the limitations established for the airplane, without the accumulation of ice on engine or inlet system components that would adversely affect engine operation or cause a serious loss of power or thrust.

(a) Under icing conditions specified in FAR Part 25 (Reference 2.8) Appendix C;

(b) In snow, both falling and blowing.

Flush inlets do not usually require anti-icing and ram inlets usually do unless they are retractable and are extended only to get the APU started in flight.

5.2.4 (Continued):

Screens should be downstream from any protuberance that could collect ice that might break off and damage the APU compressor. Screens themselves can collect ice or snow, though experience has shown that one with a large area such as a z-screen can usually be subjected to the specified icing tests without choking the engine.

Icing tests are discussed in FAR 25 and Advisory Circular AC NO: 20-73.

Three general types of anti-icing systems may be considered:

- a. Injection of anti-icing liquids
- b. Electrical resistance heating
- c. Injection of compressor bleed air

The use of anti-icing liquids is not usually considered in cases where compressor bleed air is used for air-conditioning because of contamination of cabin air. Electrical heating requires large amounts of electrical energy and poses difficult insulation problems in the presence of ice and water.

The use of bleed air for anti-icing reduces the APU power available, but commonly is the most practical solution. The installation of an anti-icing system should be done only if it is necessary to meet FAR requirements.

- 5.2.5 Air Inlet Port: An air inlet with a full-ram scoop cannot usually be justified in a modern transport aircraft because of the additional drag and the requirement for ice protection. Usually a flush inlet works out to be the best compromise, with a door at the aircraft mold line to prevent excessive in-flight windmilling of the APU rotor and related aircraft drag. However, in some cases an articulated scoop has been used to pick up enough ram pressure so that the APU can be started in flight. Such a scoop can be made to retract flush with the mold line once the APU has been started, to reduce drag and to prevent ice accumulation.

Aircraft requirements for transports will often indicate in-flight starting which normally requires a positive ΔP across the APU. The positive ΔP will cause forward windmilling and substantial drag loss if the air is allowed to vent through the system unimpeded. It is the usual case with transport aircraft, that the loss in fuel burned to overcome the drag, or the risk of not meeting performance guarantees dictate the use of controllable doors. For those installations where the use of doors is doubtful, a trade study may be made to determine whether doors can be omitted to avoid the cost, weight, and additional maintenance.