may be an auxiliary gasoline engine or a diesel engine. This engine is usually of large enough capacity so as to be able to drive a generator which provides electric power for operating the evaporator fans. Thus, the air conditioning system is entirely independent of the main bus power plant and its auxiliaries. Because the separate engine drive is independent of the main engine, bus engine speed has no effect on the air conditioning and the air conditioning load does not rob power from the main engine.

The separate engine drive has objections in that it involves initial cost and maintenance of a second engine which is being operated under adverse conditions for best engine performance and requires more space and weight allowance. For the above reasons, the installations which are driven from the main engine have found favor in recent years. These systems have the advantage of cutting down on maintenance, initial cost, weight and space allowances, but they do put an added load on the main engine.

The main engine drive has a disadvantage in that because the refrigeration compressor is tied to the main engine speed, the capacity will vary according to the speed at which the main engine is operating. Thus, when the bus is standing still and the engine is idling, the capacity is very low. When the bus is operating at high speed, the capacity may be too great. In order to give more uniform refrigeration capacity with speed, various means can be used. One of these is the use of an automatic transmission to maintain the compressor at a fairly constant speed regardless of bus speed. Such a device permits the refrigeration compressor to be operated at a reasonable speed, perhaps 50 to 60 percent of the maximum, when the engine is idling in a station.

Another means to regulate capacity is use of a compressor with larger displacement than normal but equipped with automatic capacity control. This arrangement allows use of full compressor displacement when operating at low engine (compressor) rpm and automatic reduction of capacity as the engine (compressor) rpm increases. This type drive requires careful selection of drive ratios and optimum matching of compressor to the main engine.

In addition, a clutch is usually provided to allow the compressor to be disconnected when required and to eliminate this extra power drain at times when full engine horsepower is required. Some installations are provided with a *kick-down* switch arrangement activated by the throttle pedal. By this device, the air conditioning compressor and usually the drive for the condenser fan is automatically disconnected as long as the accelerator pedal is fully depressed. This added refinement, of course, requires very careful design of the drive and clutch as well as the compressor since sudden and very rapid acceleration forces are introduced when the *kick-down* switch is released.

Several current installations employ hydraulic drive for the condenser fan. The hydraulic pump is mounted on the compressor clutch housing and driven by belts from the compressor flywheel while in other installations it is mounted directly on the bus engine. The writers do not know of current bus air-conditioning systems using hydraulic drive for the compressor. However, various truck refrigeration compressors are driven in this manner, and this type drive for bus air conditioning systems has promise for some applications.

Electric motors are used extensively to power the evaporator fans for bus air conditioning units. Power requirements are usually within the capacity of the heavy duty generators and alternators used on bus engines. Electric drive for the condenser fans and compressors is not usually considered, due to the high power requirements for these components.

CONTROLS

The usual safety controls such as high-low pressure switch, oil safety switch and in the case of a separate engine drive, oil failure switch and high temperature switch are employed. However, the switch enclosures are weather-proof and dust tight or the controls are mounted in a separate compartment for this purpose. In most cases, the capillary lines must be replaced with flexible hoses to avoid breakage due to vibration.

Operating controls depend on the system used and are quite simple in some cases.

If a separate engine drive is used, start-stop engine and fan controls are provided for the operator, and temperature is controlled automatically. This is accomplished by pre-setting of the compressor capacity control and in some cases by the automatic water valve on the heating coil which is placed in series with the cooling coils. Ventilation air control is usually pre-set, although in some cases it may be manually adjusted.

Some installations require a separate thermostat to control the cooling system operation. The thermostat can be used to control a liquid line solenoid valve, a clutch, or the air conditioning drive engine in cases where automatic engine stop-start controls are used. The thermostat bulb is usually installed in the air return duct. However, care must be taken to shield this bulb from drafts caused by door openings, etc.

On inter-urban buses, a reheat coil is normally used. This coil, using hot water from the bus engine, is placed in series with the evaporator on the leaving side. In some cases, it is necessary to employ booster pumps to supplement the water pump on the bus engine. The coil is usually fitted with an automatic water control valve with the sensing element of the automatic valve placed so as to respond to air temperature over the coil. In addition, a manual control, which can be used to bypass the automatic control valve, is sometimes employed in order to provide for fast warm-up of the bus in cold weather.

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CHAPTER 18

AIRCRAFT AIR CONDITIONING

Design Conditions, Cabin Air Sources and Distribution, Air-Cycle Refrigeration System, Vapor-Cycle Refrigeration System, Combined Vapor- and Air-Cycle Refrigeration System, Temperature Control, Cabin Pressurization Control, Cargo Compartments, Supersonic Transports

THE introduction of high speed jet transport airplanes in passenger service has greatly increased the importance of aircraft air conditioning in recent years. These aircraft carry as many as 100 people at speeds approaching the speed of sound and at altitudes up to 40,000 ft. The basic principles of air conditioning stores, restaurants, homes, etc. are applicable to airplanes. However, the equipment must meet additional requirements. It must be compact, lightweight, accessible for quick inspection and servicing, vibration free, and unaffected by airplane vibration and landing impact. The temperature control and pressurization control systems must be capable of responding to rapid changes of ambient temperature and pressure as the airplane climbs and descends.

In older non-pressurized airplanes and in light private planes, the air-conditioning systems are comparatively simple, consisting usually of just a heating unit. In faster-than-sound military aircraft the systems are quite complex, with the problems of heat sink, and pressure and temperature control, compounded over those of the present day jet transports.

DESIGN CONDITIONS

Fig. 1 gives a typical design ambient temperature envelope, showing the variation of temperature with altitude for hot, standard, and cold days. The ground static design temperatures may be higher or lower than these values depending on the regions in which the airplane may be operated. Normal rate of change during climb and descent is about 10 F deg per min, but rates as high as 30 F deg per min may be encountered.

A recommended design ambient moisture variation with altitude is shown in Fig. 2. The moisture may be taken as high as 180 grains per lb of dry air at sea level for military aircraft. The moisture given up by the cabin occupants may be determined from the curves in Chapter 8 of the 1961 GUIDE AND DATA BOOK. This factor is particularly important where all or a portion of the cabin air is to be recirculated.

In a pressurized aircraft the minimum amount of outdoor air flowing into the cabin must be equal to the leakage at the particular differential between cabin and outside pressure. The leakage is made up of: (1) structural leakage through door seals and skin joints, and (2) controlled leakage through galley, toilet, and electronic equipment vents. Practically, the inflow should be a considerable margin above the leakage in order to maintain good pressure control and adequate ventilation. A typical pressure control operating range is shown in Fig. 3, where the upper curve represents the maximum pressure differential to which the cabin is designed and the bottom curve represents the maximum cabin altitude which is comfortable for most passengers. The pressure control system will generally be operated somewhere between these two limits. Airplanes flying at high altitudes must be equipped with an oxygen system for use in case of loss of pressurization.

For high speed aircraft the increase in air temperature and pressure due to ram effects is appreciable and may be calculated from Equations 1 and 2:

$$\Delta T_r = 0.2 M^2 T_a \quad (1)$$

$$\Delta P_r = 3.5\ (0.2 M^2 P_a) \quad (2)$$

where

- ΔT_r = increase in temperature due to ram effect, Fahrenheit degrees.
- M = *Mach number*, dimensionless.
- T_a = absolute static temperature of ambient air, Rankine degrees.
- ΔP_r = increase in pressure due to ram effect, pounds per square inch.
- P_a = absolute static pressure of ambient air, pounds per square inch.

The *average* increase in airplane skin temperature is generally assumed to be 0.9 of the ram temperature rise.

The cooling and heating loads for a particular airplane must be determined from a heat transfer study and from an analysis

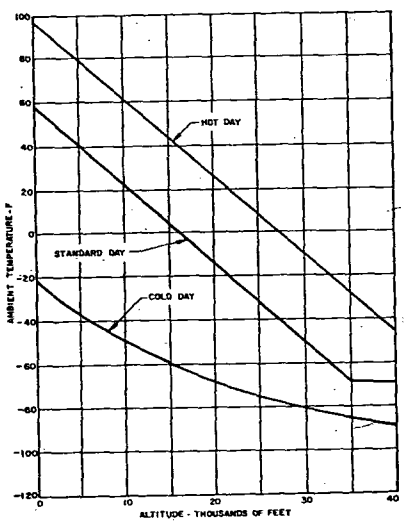


Fig. 1 .... Typical Design Ambient Temperature Conditions