

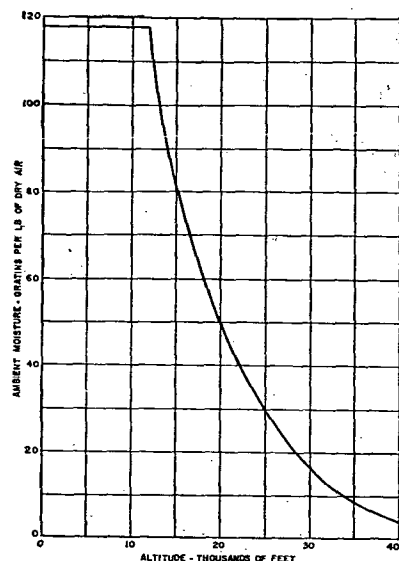


Fig. 2 Design Ambient Moisture Conditions

of the solar and internal heat from occupants and electrical equipment. The heat transfer study should consider all of the possible flow paths through the usually complex aircraft structure. Air film coefficients vary with altitude and this also should be considered.

Ground and flight requirements may be quite different. An aircraft sitting on the ground in bright sunlight will have local skin temperatures as much as 60 F deg higher than the ambient, where the surface is unpainted and perpendicular to the sun's rays. Painting the upper portion of the fuselage with white paint will reduce this effect considerably, as will a breeze blowing across the airplane. The average skin temperature for an unpainted fuselage should be taken as about 20 F deg above ambient, and about 15 F deg above ambient for a painted fuselage.

Other considerations for ground operation are: pulldown or warmup requirements, time that doors are open for loading, and whether ground heating and cooling is to be provided from the installed equipment or from an external source.

CABIN AIR SOURCES AND DISTRIBUTION

The source for cabin pressurization and ventilation may be engine or air turbine driven compressors or, if the airplane is powered by gas turbine engines, air may be bled directly from the engine compressor. Engine driven or turbocompressors provide a more certain source of fresh air than direct engine bleed, and at a pressure adequate to maintain cabin pressure over a wider range of operating conditions than engine air bled from an intermediate stage of compression. The temperature of the air supplied by turbocompressors is lower under

most conditions than that of engine bleed air. High pressure bleed air has certain advantages for pressurizing, heating and ventilating, but care must be exercised to assure that this air is free from engine oil contamination, or the associated breakdown products of the oil when exposed to high temperatures. Turbocompressors have disadvantages over direct bleed in that they add cost and weight, are less reliable, and are less efficient.

A portion of the cabin air may be recirculated, but it should be filtered and purified if it is a large percentage of the total ventilation, or unless it is recirculated for limited times only. The recommended ventilation rate is 20 cfm per passenger and 30 cfm for cockpit crew members.

The distribution system should be designed to give lowest restriction compatible with space and weight limitations. The transmission of objectionable air noise to the cabin should be avoided. Since a transport cabin is essentially a long, narrow room, the airflow must be balanced properly to avoid large temperature gradients from one end to the other. In an airplane that cruises for several hours at high altitudes where the ambient temperature is extremely low, it may be desirable to direct all or part of the air through passages in the walls to eliminate uncomfortable body radiation to a cold wall.

Many airplanes now in service are equipped with a supplementary air distribution system that allows each passenger individual control of a relatively high velocity stream of air delivered to his seat area. The passenger can open, close, or modulate a small outlet, which also can be swiveled to direct the air on his face or other parts of his body. This allows the passenger to obtain an effective temperature lower than the general cabin ambient, to clear cigarette smoke, and help relieve air sickness.

AIR-CYCLE REFRIGERATION SYSTEM

In the air-cycle system, compressed air is cooled by expanding it through a turbine which performs work. The turbine may drive a fan which draws cooling air across an air-to-air heat exchanger (simple cycle), or it may drive a compressor which raises the pressure of the air before it enters the turbine. (bootstrap cycle), or it may do both (compound cycle).

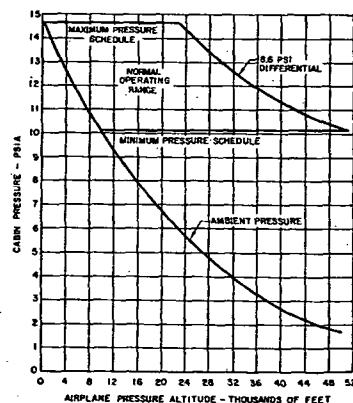


Fig. 3 Typical Cabin Pressure Schedule

Air-cycle refrigeration systems are discussed in detail in Chapter 31 of the 1961 GUIDE AND DATA BOOK.

A capacity for an air-cycle refrigeration system has little meaning if given in terms of Btu/h or tons, based on the change in air temperature through the pack, since the system imposes an extra restriction on the air source (except for direct engine bleed) which causes a higher system inlet air temperature. The quantity of air delivered and the temperature at which the air is supplied to the cabin are more significant indications of capacity. For a modern jet transport, typical values, on a hot day, would be about 240 lb per min at 50 F dry-bulb just after takeoff, and 190 lb per min at 55 F dry-bulb during cruise.

The main advantage of an air-cycle refrigeration system is its light weight, while the main disadvantages are low efficiency and poorer ground cooling. Ground cooling is normally provided for an airplane equipped with an air-cycle system by using an external air-conditioning cart. Cooling capacities of these carts range up to 35 tons for the larger transports. Cooling with the installed equipment can be obtained by use of an auxiliary power unit, usually a gas turbine engine, to supply large quantities of high pressure air. The auxiliary power unit may be carried aboard the aircraft. It is not practical to run the jet engines of an airplane on the ground simply to obtain cooling because of the higher power required and the associated noise and high rate of fuel consumption.

VAPOR-CYCLE REFRIGERATION SYSTEM

The vapor-cycle system has a higher efficiency than the air-cycle system but it is generally heavier. It can be used at higher speed ranges than the air-cycle system because it pumps heat to a higher level before rejecting it to the sink. It has the additional advantage, perhaps the most important, of providing ground cooling with just an electrical power source. The vapor compressor and fans also may be driven by air turbines, but in this case lesser quantities of high pressure air are required than for the air-cycle system.

Modern airplanes are equipped with alternators providing 400 cps power, which permits relatively high rotational speeds and results in considerably lighter equipment than was possible with earlier 60 cps or direct current. Vapor compressors driven by air turbines have also been developed which operate at speeds up to 80,000 rpm and above. Shaft sealing and speed control are the main problems with these compressors. Jet transports now in passenger service have an installed vapor-cycle refrigeration capacity ranging from 4 to 26 tons. Smaller capacity units are also in service for galley refrigerators and electronic equipment cooling.

A typical aircraft vapor-cycle system is shown in Fig. 4. In

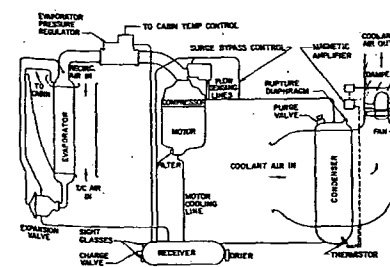


Fig. 4 Vapor-Cycle Refrigeration Unit

this system cabin air is normally recirculated by an electric fan through the evaporator when the airplane is on the ground. Turbocompressor air from outside may be manually selected after engines are started, and is switched on automatically at takeoff for cabin pressurization. Capacity modulation is accomplished by means of an evaporator pressure regulator which raises or lowers the temperature level at which the refrigerant is evaporated. The expansion valve is thermostatic and must control to enough superheat to assure that no liquid enters the compressor. As flow is throttled at the evaporator pressure regulator or expansion valve, the surge control valve must open to bypass refrigerant and keep a minimum flow through the compressor. Since the position of each valve is dependent on the other valves in the loop, such a control system may tend to be unstable.

Other methods of capacity modulation include bypassing air around the evaporator, throttling refrigerant at the evaporator inlet, varying compressor speed, or unloading the compressor. In the case of evaporator inlet throttling with a motorized expansion valve and a centrifugal compressor, the function of the valve may be combined with the surge control on the same shaft, so that as the expansion valve closes the bypass circuit opens.

The hot turbocompressor or engine bleed air is first passed through an air-to-air heat exchanger where it is partially cooled before entering the evaporator. One reason for precooling is to match the required in-flight capacity to that required on the ground. A second reason is to improve the system reliability.

The condenser fan provides cooling air on the ground and can also be turned on in flight to supplement ram air at low speeds and low altitude. In this system the fan windmills in flight when turned off, but a separate circuit is provided for ram air on some airplanes. The cooling air is automatically modulated to maintain a minimum condensing pressure, both to reduce drag and to maintain pressure across the expansion valve at the low ambient temperature encountered at high altitude.

Many vapor cycle equipped airplanes also have electrical resistance heaters for ground heating and complete self-containment of the air conditioning system. If heaters, electric driven compressors and fans are combined with galley, electronic, water injection pump, and similar equipment, the total airplane electrical load may be excessive for the installed alternator capacity and some monitoring of the loads may be required. This may be more practical than increasing the alternator size if it is not necessary that all of these loads be on simultaneously. The monitoring may be done manually with mechanically interlocked switches, or with relays. Motorized timing switches may be used to assure that two large motors do not start simultaneously.

The refrigerant used must be non-toxic, odorless, and non-flammable. Refrigerants 12 and 114 are now widely used in airplane systems, and other refrigerants of this family may have specific advantages.

COMBINATION VAPOR- AND AIR-CYCLE SYSTEMS

Installations combining these two types of systems either in parallel or series may gain some of the advantages of each while eliminating some of the disadvantages. For example, such a system provides some ground cooling but it is not as heavy as a vapor-cycle system.

If the systems are in series, the engine bleed or turbocompressor air will probably pass through the air-cycle system before entering the vapor-cycle unit. If they are in parallel, recirculated cabin air would best be used for the vapor-cycle