compression to extract heat from the vapor, and thereby cause the overall compression process to approach more closely the ideal condition of isothermal compression. Essentially, such intercoolers serve the same purpose as a cooling jacket, but with greater effectiveness because of the more satisfactory heat transfer conditions.

In the simple saturation cycle the saturated liquid entering the expansion valve commences to vaporize as soon as its pressure starts to drop. The vapor produced during the expansion process has no further use, in terms of refrigerating effect, since it has already picked up its latent heat of vaporization as a result of heat which it has extracted from the unvaporized residue. Thus the instant such vapor forms, its usefulness is at an end, and to allow such material to undergo a further drop in pressure is uneconomical. With compound compression, there is at least one intermediate pressure at which flash vapor can be extracted. In such cases several expansion valves can be utilized with all of the refrigerant from the condenser passed through a first expansion valve to the higher suction pressure, and the flash vapor then extracted and returned to the condenser through the high compression stage. The remaining refrigerant can then pass through a second expansion valve where the pressure is dropped to that corresponding to the low-pressure evaporator. The number of expansion valves is limited by the number of stages of compression.

Further cycle complications may arise if more than one evaporator is to be operated with a single compressor, and particularly, if the pressures in these evaporators are to differ. The most common solution is to operate the compressor at the suction pressure of the lowest pressure evaporator, and to equip all other evaporators with back-pressure regulating valves or throttling devices between the evaporator and the compressor suction. This permits these evaporators to operate at higher pressures and, therefore, higher temperatures than those corresponding to the compressor suction conditions. However, this is accomplished only with a loss of power, since all of the refrigerant from all of the evaporators must be compressed through the maximum lift from the lowest pressure in the system.

The Air Cycle System

Air cycle refrigeration, one of the earliest forms of cooling, became obsolete for many years because of its low coefficient of performance and high operating costs. Recently, however, it has been applied with success to aircraft cooling systems where, with low equipment weight, it can utilize a portion of the cabin air supercharger capacity. It is unique among refrigeration systems in that the refrigerant remains in the gaseous phase throughout the cycle.

Fundamentally, the air cycle is essentially the same as the vapor cycle. Compression is accomplished by a reciprocating or centrifugal compressor, and, since there is no change of phase of the refrigerant upon expansion, an *air cooler* replaces the condenser, and a *refrigerator*, the evaporator. Although some cooling would result from the expansion of the gas through an ordinary expansion valve, a much greater drop in air temperature is accomplished if the expansion is controlled to approach the isentropic by replacing the valve with an expansion engine or turbine. Furthermore, the work recovered by such an expansion engine can be utilized to supply part of the work of compression or to drive other devices.

It is a common misconception that aircraft flown at high altitudes do

not require comfort cooling. With pressurized cabins the work of compression results in an air temperature increase which, when added to the heat supplied by ram effect, solar radiation, electrical and mechanical equipment and the occupants of the plane, may make the conditions intolerable without comfort cooling. At 600 mph, the ram temperature effect of stopping the air relative to the plane will result in an entering air temperature of 164 F when the ambient air is at the standard Army summer sea level design temperature of 100 F. At 1000 mph, the entering air temperature is almost 280 F.

Air cycle systems are used in practically every jet fighter and many modern commercial passenger planes flying today. In comparative studies[1] made during the design of the cooling system for one large commercial airliner, it was shown that an air cycle system was much lower in both weight and space requirements than either a vapor compression or dry ice system. It had the further advantages of ease of repair and the use of a completely non-toxic refrigerant. The weight, for example, was reduced from approximately 60 lb per ton for a vapor compression system, or an initial weight of 130 lb per ton for a dry ice system, to approximately 25 lb per ton for an air cycle system. The usual disadvantage of high power requirements for the operation of the air cycle system was shown to be more than offset by the reduction in fuel requirements for transporting the bulk and weight of the cooling system through the air. Quite possibly, with continued development and further experience, air cycle refrigeration systems may be used economically for other applications, particularly in the transportation field.

The Steam Jet System

The *steam jet* system, under certain circumstances, is desirable for use in air conditioning.[2] Steam supplies directly the power used for compressing the refrigerant, thus eliminating the losses connected with other methods of supplying energy. As the compression ratio between the evaporator and condenser under normal circumstances is large, the mechanical efficiency of the equipment is somewhat lower than that of the positive mechanical type compressor. The condensing water requirements are considerably greater, as both the refrigerant and the impelling steam must be condensed.

The steam jet system functions on the principle that water under high vacuum will vaporize at low temperatures. Steam jet boosters or compressors of the type commonly used in power plants for various processes, will produce the necessary low absolute pressure to cause evaporation of the water.

A diagrammatic representation of a typical steam ejector water cooling system is shown in Fig. 5. The figures correspond to an average representative system. The water to be cooled enters the evaporator and is cooled to a temperature corresponding to the vacuum maintained. Because of the high vacuum, a small amount of the water introduced in the evaporator is flashed into steam. As this requires heat, and the only source of heat is the rest of the water in the evaporator tank, this other water is almost instantly cooled to a temperature corresponding to the boiling point determined by the vacuum maintained. The amount of water flashed into steam is a small percentage of the total water circulated through the evaporator, amounting to approximately 11 lb per (hr) (ton) of refrigeration developed. The remainder of the water at the desired