AEROSPACE RECOMMENDED PRACTICE	ARP731™	REV. C
	Issued 1963-05 Revised 2003-01 Reaffirmed 2015-11 Superseding ARP731B	

(R) General Requirements for Application of Vapor Cycle Refrigeration Systems for Aircraft

RATIONALE

ARP731C has been reaffirmed to comply with the SAE five-year review policy.

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1. SCOPE:

The purpose of this SAE Aerospace Recommended Practice (ARP) is to establish recommendations for the design, installation and testing of air vehicle vapor cycle refrigeration systems. These recommendations are representative of the refrigerant cycles.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrrendale, PA 15096-0001.

ARP85	Air Conditioning Systems for Subsonic Airplanes
ARP292	Air Conditioning Systems for Helicopters
ARP987	Control of Excess Humidity in Avionics
AIR1168/3	SAE Aerospace Applied Thermodynamic Manual, Section 3: Aerothermodynamic Systems Engineering and Design

2.1.2 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

A-A-58060	Fluorocarbons and Other Refrigerants, Department of Defense, Washington, DC, September 3, 1996
VV-L-825C	Lubricating Oil, Refrigerant Compressor, Uninhibited, Department of Defense, Washington, DC, March 18, 1997
MIL-STD-461E	Requirements fort the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, Department of Defense, Washington, DC, August 20, 1999
MIL-STD-704E	Aircraft Electric Power Characteristics, Department of Defense, Washington, DC, November 15, 1991
MIL-STD-810F	Environmental Engineering Consideration and Laboratory Test, Department of Defense, Washington, DC, January 1, 2000
MIL- HDBK -310	Global Climatic Data for Developing Military Products, Department of Defense, Washington, DC, June 23, 1997 (supersedes MIL-STD-210)
MIL-HDBK-454	General Guidelines For Electronic Equipment, Department of Defense, Washington, DC, April 28, 1995, Notice 1, May 28, 1997 (supersedes MIL-STD-454M)

2.1.3 ARI Publications: Available from Air-Conditioning & Refrigeration Institute (ARI), 4100 N. Fairfax Drive, Suite 200, Arlington, VA 22203.

ARI 700 Specifications for Fluorocarbon Refrigerants
ARI 740 Standards for Refrigerant Recovery/Recycling Equipment

2.1.4 ASME Publications: Available from ASME, 22 Law Drive, Box 2900, Fairfield, NJ 07007-2900.

ASME Y14.100M Engineering Drawing Practices

2.2 Related Publications:

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

ASHRAE Fundamentals and Application Handbooks, American Society of Heating, Refrigeration and Air-conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329

3. SYSTEM DESIGN RECOMMENDATIONS:

3.1 Introduction:

Vapor cycle refrigeration system design recommendations are presented in this document in the following general areas:

a. System Design Recommendations: (See Section 3)
b. Component Design Recommendations: (See Section 4)
c. Desirable Design Features: (See Section 5)

3.2 System Definition:

3.2.1 Basic System: The basic vapor cycle refrigeration system, as shown in Figure 1, includes the following necessary elements:

a. Refrigerant compressor
b. Evaporator
c. Condenser
d. A heat sink for condensing refrigerant
e. Refrigerant
f. Refrigerant piping
g. System controls
h. Liquid refrigerant receiver
i. Filter drier
j. Expansion device
k. Power source

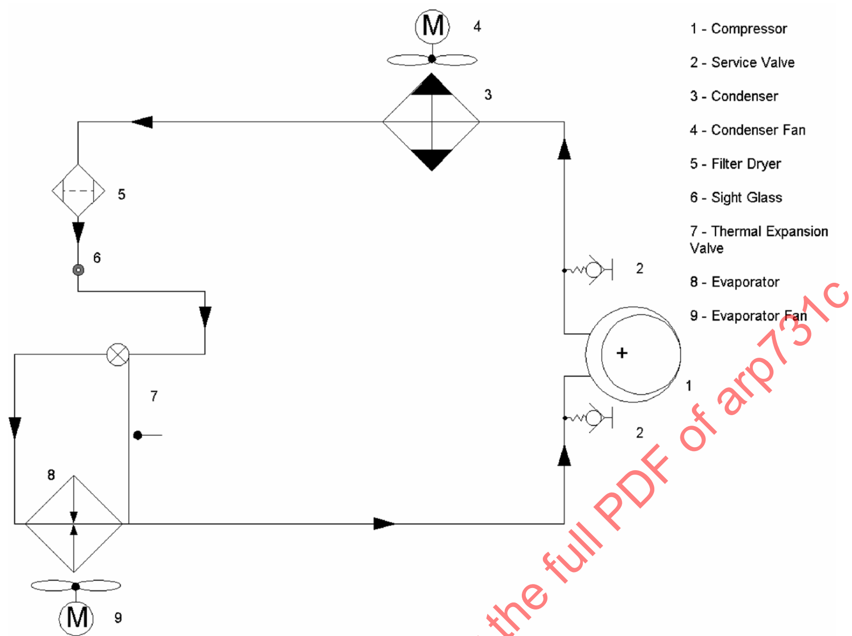

FIGURE 1 - Typical Vapor Cycle Refrigeration System Schematic

3.2.2 Additional Elements: The system may also include the following elements:

a. Protective devices
b. Sight glass
c. Refrigerant quantity gauge or level sensor
d. Condenser flow device for ground or low airspeed operation (such as a fan)
e. A device for removing condensed moisture from the evaporator air (demister)
f. Hot gas bypass valve
g. Head pressure control device
h. Trouble shooting and system monitoring instrumentation
i. Surge control device
j. Compressor bearing lubrication system
k. Cold start provisions
l. Subcooler/superheater
m. Quench valve
n. Economizer
o. Cooling capacity control device

3.3 Performance Characteristics:

3.3.1 Required Performance: The cooling capacity of the system should be sufficient to satisfy the air vehicle cooling requirements established by the required specifications.

3.3.2 Performance Analysis: The cooling requirements of a specific configuration of vapor cycle system may be determined analytically by the methods described in SAE AIR1168/3.

3.3.3 Off Design Performance: The system should be capable of operating at cooling loads ranging from zero to maximum capacity without undesirable effects such as refrigerant compressor surge or system performance instability. Operation at light load and at values below 10 to 20% capacity may require additional refrigeration system control such as a hot gas bypass valve and/or head pressure control valve.

3.3.4 Evaporator Temperature: The evaporating temperature shall be sufficiently high to prevent freezing of condensing moisture in the evaporator, or a method to prevent this shall be incorporated in the refrigeration system. An expansion valve shall be considered to maintain proper superheat in order to ensure proper evaporator/compressor performance.

3.3.5 Optimum System Design Considerations: Considerations should be given to selecting the combination of condenser, evaporator and refrigerant compressor performance which not only provides the required cooling performance, but will impose the least penalties (power, weight, drag) on the air vehicle. Where considerable reduction in cooling capacity and cooling power requirements exists for a large portion of the flight, such as for example, high altitude subsonic cruise, consideration should be given to sink control and power control to minimize air vehicle performance impact.

3.3.6 Evaporator Water Carryover (Reference SAE ARP987): The evaporator air circuit should incorporate adequate water traps and drains to eliminate condensed water droplets from the cooled air-stream. Water traps such as a demister should be considered provided adequate space is available and it does not affect the evaporator fan performance effectiveness. Proper water drainage should be provided in the air vehicle to remove and transport any water condensed by the evaporator to a suitable location within the air vehicle or overboard.

3.3.7 Extreme Temperatures and Pressures: When returned to the normal range of operating pressures and temperatures after exposure to the extreme conditions outlined in 3.3.7.1 through 3.3.7.5, the system shall be capable of providing the design cooling capacity. In addition, the system shall not suffer damage, loss of charge or actuation of overpressure protective devices when exposed to these conditions, during non-operating periods or when starting the system.

3.3.7.1 Maximum Load and Sink Temperatures: Exposure on the ground or in flight, while operating or not operating, to the maximum attainable evaporator inlet air temperature simultaneously with the maximum attainable condenser heat sink temperature.

3.3.7.2 Heating: After exposure to the maximum temperature, caused by normal operation of the heating system coincident with minimum condenser temperature of -54 °C (-65 °F) with the system not operating.

3.3.7.3 Minimum and Maximum Compartment Temperatures: After exposure to minimum and maximum ambient required compartment temperatures from -54 to 71 °C (-65 to 160 °F) while not operating on the ground.

3.3.7.4 Non-Operating to Minimum or Maximum Sink Temperatures: After exposure, while not operating, to typical ambient temperatures as low as -54 to 95 °C (-65 to 203 °F) or higher depending on the application.

3.3.7.5 Non-Operating to Minimum Ambient Pressures: After exposure, while not operating, to ambient pressures as low as may exist at the maximum aircraft altitude.

3.3.8 Service Period: The system should be designed to provide design-rated cooling performance for a minimum service period consistent with system operating hours without overhaul of its components. During this service period, minor maintenance operations such as lubrication or cleaning of heat exchanger surfaces (evaporator and condenser) should not be required more often than every 1000 hours (or specified in equipment specification) of system operation, depending on environmental conditions during system operation.

3.4 Refrigerant Selection:

Proper selection of the refrigerant for a specific vapor cycle refrigeration system application is essential for safe, reliable, efficient operation of the system.

3.4.1 Refrigerant Selection Consideration: A refrigerant should be selected with performance characteristics of air vehicle operational envelope ambient temperature (ram air heat sink) requirements.

3.4.1.1 Characteristics: Refrigerants are the vital working fluids in vapor cycle cooling systems. They absorb heat from one area, such as an air-conditioned space, and reject it into another area, usually ambient air, through evaporation and condensation processes, respectively (see Figure 1). The design of the refrigeration equipment depends strongly on the properties of the selected refrigerant. Selection of the refrigerant depends strongly on the range of temperatures of the heat source and the heat sink.

A refrigerant must satisfy many requirements, some of which do not directly relate to its ability to transfer heat. Chemical stability under conditions of use is the most important characteristic. Safety codes may require a non-flammable refrigerant of low toxicity for some applications. Low toxicity is essential if refrigerant can enter occupied compartments. Cost, availability, and compatibility with compressor lubricants and materials with which the equipment is constructed are other concerns.

Refrigerant selection also involves compromises between conflicting desirable thermodynamic properties. To minimize compressor power requirements, a refrigeration system has to be designed for an evaporator pressure as high as possible and, simultaneously, a condenser pressure as low as possible. High evaporator pressures imply high vapor densities, and thus a greater system capacity for a given compressor. However, the compressor's efficiency at higher pressures is lower, especially as the condenser pressure approaches the refrigerant’s critical pressure.

3.4.1.1 (Continued):

Latent heat of vaporization is another important property. On a molar basis, fluids with similar boiling points have almost the same latent heat. Since the compressor operates on volumes of vapor, refrigerants with similar boiling points produce similar capacities in a given compressor. Fluids with low vapor heat capacity achieve the maximum efficiency of a theoretical vapor compression cycle. This property is associated with fluids having a simple molecular structure and low molecular weight.

Transport properties of thermal conductivity and viscosity affect the performance of heat exchangers and piping. High thermal conductivity and low viscosity are desirable.

3.4.2 Materials Compatibility: The refrigerant of choice must be compatible with the oil and all materials it will contact within the system. Numerous studies have been conducted to address refrigerant and lubricant properties. Compatibility of refrigerant-lubricant mixtures were tested with metals, motor insulating materials, elastomers, plastics, desiccants, process fluids, and lubricant additives. System related issues include lubricant circulation, fractionation of blends, effects of system contaminants, products of motor burn-outs, flushing and clean-out methods, and the effectiveness of desiccant driers. Reports describing the results of these studies are available from refrigerant manufactures, Air-conditioning & Refrigeration Institute (ARI), and other sources.

3.4.2.1 Metals: Halogenated refrigerants can be used satisfactorily under normal conditions with most common metals, such as steel, cast iron, brass, copper, tin, lead and aluminum. Under more severe conditions, various metals affect such properties as hydrolysis and thermal decomposition in varying degrees. The tendency of metals to promote thermal decomposition of halogenated compounds is in the following order: (Least decomposition) Inconel<stainless steel <nickel<copper< steel<aluminum<bronze<brass<zinc<silver (most decomposition).

This order is only approximate and exceptions may be found for individual compounds or for special use conditions. The effect of metals on hydrolysis is probably similar.

Magnesium, zinc, and aluminum alloys containing more than 2% magnesium are not recommended for use with halogenated compounds where even trace amounts of water may be present.

Ammonia should never be used with copper, brass, or other alloys containing copper. When water is present in sulfur dioxide systems, sulfurous acid is formed and can attack iron or steel rapidly and other metals at a slower rate.

3.4.2.2 Elastomers: Testing to assess the effects of long-term exposure of a refrigerant on candidate elastomer materials should be conducted. Swelling data is used in comparing the effect of refrigerants in elastomers. Additionally, other factors such as the amount of extraction, the tensile strength and the degree of hardness of the exposed elastomer and fluid resistance must be considered. When other fluids, such as oil, are present in addition to the refrigerant, the combined effect on elastomers should be considered.

3.4.2.3 Plastics: The effect of a refrigerant on plastic material in the system should be thoroughly examined under the conditions of intended use. Plastics are often mixtures of two or more basic types, and it is difficult to predict the effect of the refrigerant. Swelling data can be used as a guide, but as with elastomers, the effect on the properties of the plastic should also be examined.

3.4.3 Regulations:

3.4.3.1 Clean Air Act and EPA Policies: There are federal, state, local, and DoD laws, which regulate the sale and handling of refrigerants, used in the vapor cycle system industry. Currently, the industry is faced with the mandated phase out and eventual elimination of CFC/HFC-based refrigerants. New refrigerants have been developed, as well as lubricants that are compatible with them. New service techniques are required and service technicians must be certified using EPA guidelines.

The Clean Air Act and follow-on regulations prohibit the venting of CFC, HFC and HCFC-based refrigerants, requiring the recovery of all refrigerants from vapor cycle systems prior to disassembly, and the certification of personnel who use recovery equipment (effective January 1992). It restricts the sale of refrigerant to certified service professionals only, effective November 1992. Recovery equipment certification is also required. A complete list of approved certification programs (technician and equipment) may be obtained via the EPA's Stratospheric Hotline. Additional state and local government regulations also exist which may be more stringent than Federal standards.

3.4.4 Refrigerant Recovery: EPA requires the recovery of HFC-based refrigerants and has established a certification program for recovery equipment. Under the program, EPA requires that equipment manufactured on or after November 15, 1993, be tested by an EPA-approved testing organization to ensure that it meets EPA requirements. A list of EPA-approved recovery equipment is available from the American Refrigeration Institute (ARI). Since July 1, 1992 it has been illegal to release any refrigerants into the atmosphere.

3.4.4.1 Recovery Equipment and Procedures: Recovery equipment intended for use with vapor cycle equipment must be tested under ARI 740 test protocol. The EPA is requiring recovery efficiency standards that vary depending on the size and type of the vapor cycle equipment being serviced. Also, when acquiring recovery equipment, the rate of recovery, the size and weight of the equipment, as well as its durability and cost should be considered. Recovery consists of removing the refrigerant from a system and storing the refrigerant in an external container. The external container may be part of a dedicated recovery machine or a freestanding storage cylinder. The recovery equipment is usually also used to purge non-condensables, remove moisture, acid, particles, and oil from the system.

3.4.4.1 (Continued):

The focus of recovery is refrigerant removal only. When the condition of the refrigerant becomes a concern (for example a burnout occurs), then the refrigerant must be recycled or reclaimed before it is returned to the system. The terms recover, recycle, and reclaim refer to the level of purity of the refrigerant has been filtered by the recovery unit. The term recover refers to merely removing the refrigerant. The recycled refrigerant has been filtered, but not to levels dictated by ARI 700. Generally, reclaimed refrigerant is safe to re-use directly in a new or repaired system, whereas recovered or recycled refrigerant may contain some impurities that may impair system performance or reliability.

Refrigerant can be recovered in either vapor or liquid form. In vapor recovery, refrigerant in the system's evaporator is drawn off by means of a compressor in the recovery machine. The recovered vapor will be condensed in the recovery machine and stored in a storage container. Liquid recovery can be as simple as drawing a vacuum on a storage cylinder, opening valves and allowing the system's refrigerant to flow into the storage cylinder. However there is a good chance that not all of the refrigerant will be removed from the system using this method. Any refrigerant remaining in the system cannot legally be vented, so all remaining refrigerant must somehow be removed.

3.4.4.2 Vapor Versus Liquid Rrecovery: Vapor recovery is slower than liquid recovery. Liquid recovery should be the method of choice; however, there are many factors to consider. Some of these factors are: equipment availability, system operation and quantity and boiling point of refrigerant. Many times it is possible to recover liquid first and then finish the recovery process in vapor form. By employing liquid recovery first, recovery will take a shorter time. After the maximum quantity of liquid is recovered, vapor recovery will complete the process.

3.4.5 Lubricants: Since HFC-based refrigerants are not miscible with the traditional mineral oils used as lubricants in CFC systems, new lubricants were developed to ensure the efficiency and long-term reliability of HFC systems. To meet this need, lubricant suppliers developed Polyolester-based oil (POE) and Poly Alkylene Glycol (PAG). POE and PAG lubricants are compatible with most materials used in refrigeration systems and inhibit wear on the various parts inside the compressor. Because of its various desirable characteristics POE-based oil is the current lubricant of choice in HFC (R-134a in particular) vapor cycle applications in both retrofitted and new equipment.

3.4.6 Refrigerant Properties: Table 1 shows the critical properties of refrigerants available for consideration for use in various Vapor Cycle refrigeration systems.

TABLE 1 - Properties of Commonly Used Refrigerants

Number	Chemical Formula	Ozone Depletion Potential	Boiling Point at 1 Atmosphere °C (°F)	Critical Temperature °C, (°F)	Critical Pressure, kPa (psia)
22	$CHClF_2$	0.05	-41 (-41)	96 (205)	4979 (722)
*12	CCl_2F_2	1.0	-30 (-22)	112 (234)	4117 (597)
134a	CF_3CH_2F	0	-26 (-15)	101 (214)	4069 (590)
124	$CHFClCF_3$	0.02	-13 (8)	123 (253)	3662 (531)
*114	$CClF_2CClF_2$	0.7	4 (39)	146 (294)	3262 (473)
236fa	$CF_3CH_2CF_3$	0	-1 (30)	131 (267)	3172 (460)

Note: *Refrigerants are out of production due to US EPA regulations.

3.5 Pressure Loads:

3.5.1 Maximum Design Pressure: A maximum design pressure should be determined for each system component with due consideration given to the component internal and external temperatures and the pressure versus temperature strength characteristics of the materials involved. The maximum design pressure in the refrigeration circuit may be induced either by extreme limits of normal system operation or by extreme high ambient temperatures with the system not operating (storage).

3.5.2 Proof Pressure: All system components which are subjected to internal pressures, including the refrigerant piping, should be designed to be capable of withstanding a minimum proof pressure of 1.5 times (or factor acceptable to the regulatory agency) the maximum design pressure taking in to effect the operating temperatures on material properties which can occur in the component without permanent deformation.

3.5.3 Burst Pressure: All system components subjected to internal pressure should be designed to be capable of withstanding a minimum pressure of 3.0 times (or factor acceptable to the regulatory agency) the maximum design pressure taking in to effect the operating temperatures on material properties. Permanent deformation is allowed.

3.5.4 Externally Induced Loads: The system must be designed to withstand all externally induced loads incident to its installation in an air vehicle. These external loads include up and down, fore and aft and sideways acceleration loads, vibration, shock and gyroscopic loads induced in components with rotating parts caused by air vehicle roll, yaw, or pitch. The design shall consider superimposition of internal pressure loads with external loads. In addition, consideration must be given to loads imposed by air vehicle structural and thermal deflections both during flight to withstand crash landing.

3.5.5 Fatigue Strength: The fatigue strength of the system components should be sufficient to provide operation for the design life of the air vehicle.

3.5.6 Vacuum Loads: All system components designed to contain refrigerant should be capable of withstanding repeated collapsing pressure differentials of 102 kPa (30 in Hg) without deformation or failure.

3.5.7 Refrigerant Leakage: The system leakage rate should be essentially zero. For systems that incorporate components with dynamic external seals that cannot meet zero leakage, a minimum of 1200 hours (or specified in procurement specification) or four calendar months of system operation without requiring replenishing is recommended. These systems should incorporate special provisions to allow rapid and accurate replenishing. A criteria of establishing a leakage of less than 14 g/year (0.5 oz/year) can also be considered.

3.6 Failure Protection:

3.6.1 Overpressure Protection: The system shall incorporate a positive overpressure device designed to relieve pressure within an acceptable margin below proof pressure. A rupture disc (overpressure rupturing device) or a relief valve (automatic resetting device) shall be considered. The overpressure device shall be easily accessible when the equipment is installed in the air vehicle.

3.6.2 Rotor Failure: Failure of any high-energy rotor incorporated in the system shall not result in fire or other hazardous conditions. The rotor case or auxiliary protective shield shall be sufficiently strong to contain a three segment rotor hub burst at the highest rotor speed expected either in normal operation or as a result of any single control element failure. Other elements of the refrigeration system may be arranged to provide this protection in military applications containment within the case or housing will be required. In addition, if an electric drive is used, a motor protector shall be incorporated to prevent rotor case penetration in the event of an electrical fault.

3.6.3 Compressor Protection:

3.6.3.1 Pneumatic Drive: The refrigerant compressor and drive shall incorporate a separate overspeed shut-off device, in addition to any modulating control that may be required for normal system operation, where damage or permanent deformation can occur due to overspeed The detecting element of an over speed shut-off device shall be located on the driver unit. Requirements for rotating equipment containment must be considered.

3.6.3.2 Electric Drive: The electric driven refrigerant compressor shall incorporate motor overload, phase differential and phase open motor protection. Phase order protection should be added, to prevent running in wrong sense.

3.6.4 Loss of Condenser Heat Sink: In the event of a condenser failure, the system shall be designed to prevent permanent damage or accumulation of un-condensable refrigerant allowing the system to operate without a condenser heat sink. The design of the emergency shutdown system shall be included in the aircraft hazard analysis. Such operation results in excessively high refrigerant temperatures and pressures that may represent a hazardous condition to the air vehicle and its occupants. A refrigerant pressure switch should be considered to activate system shut down under these conditions. Certain commonly used halogenated hydrocarbon refrigerants experience a violent exothermic reaction in the presence of aluminum and other metals at high super critical temperatures and may cause fire or explosion. The Underwriters Laboratory states "that the products of decomposition of fluorinated refrigerants have a very acrid, irritating odor, and their presence is intolerable in concentrations below the toxic level. Under practical conditions, the amounts of decomposition products formed are so small that they do not create a hazard in the use of these refrigerants."

3.7 System Control:

3.7.1 Control Configuration: Selection of the system control elements and arrangements is dependent to a large extent on the system configuration and the cooling system in which the refrigeration system is incorporated. Generally, the major control elements that may be required are:

a. Evaporator refrigerant temperature, pressure or airflow
b. Condenser subcooling, or evaporator superheat
c. Compressor speed (pneumatically /electrically driven centrifugal machines)
d. Compressor inlet pressure (electrically driven centrifugal machines)
e. Condenser heat sink control and discharge pressure
f. Compressor surge control (centrifugal machines)
g. Compressor lubrication control (positive displacement machines)
h. Economizer
i. Temperature Control for the heat transfer media

3.7.1.1 Cockpit: Sufficient sensor input from the cooling system interface should be provided with corresponding cockpit display to indicate normal operation of the refrigeration system to the aircrew and provide for fault detection and isolation for the various components. A duplicate of this display on the cooling machine itsels can also be provided. Adequate instrumentation shall be installed to allow the required system operation.

3.7.1.2 Service Connections: For maintenance sufficient ports should be incorporated in the system to allow rapid troubleshooting during ground maintenance. Variables to be measured may include compressor suction and discharge pressure, evaporator refrigerant temperature, compressor speed, and condenser refrigerant temperature and evaporator air inlet and outlet temperatures. For electric driven compressors, motor current and voltage may be preferred to compressor speed.

3.8 Packaging and Installation:

3.8.1 All individually removable components of the system should be interchangeable with each other and selective matching of system components should not be necessary.

3.8.2 Direction of rotation of all unidirectional equipment should be clearly marked with permanent markings, which are visible, when the equipment is installed in the air vehicle.

3.8.3 Direction of flow of all fluids should be clearly indicated with markings that are visible when the components are installed in the air vehicle.

3.8.4 Similar or symmetrical components should be indexed or otherwise located to prevent inadvertent mislocation or "backward" installation.

3.8.5 Components should be clearly identified as to manufacturer's part number to facilitate location and replacement of parts.

3.8.6 Consideration should be given to packaging of multiple components in a single compact easily removable package to eliminate detailed troubleshooting on the air vehicle and minimize air vehicle dispatch delays. If compact packaging cannot be accomplished, consideration should be given to making individual components easily removable.

3.8.7 Control valve position indicators, which are visible with the system installed in the air vehicle, should be incorporated on applicable valves, such as expansion, surge and temperature control valves.

3.8.8 A device for checking refrigerant quantity in the system is highly desirable. This device may be a sight glass on the receiver or in the liquid line between the condenser and the expansion valve. The appearance of gas bubbles during the system operation is an indication of low charge of refrigerant.

3.8.9 When ram air is used as the heat sink, the air induction circuit should be designed to preclude damage to the heat exchange surfaces caused by rain, ice, hail ingestion, foreign object or local high air velocities/pressures.

3.8.10 When ram air is used, the inlets should be located to preclude ingestion of hot engine exhaust gases and runway debris thrown up by air vehicle tires and thrust reversers.

3.8.11 Scoop designed for ambient air intake should be efficient, and be designed for high-pressure recovery at most angles of attack but should not cause excessive drag to the air vehicle and create frequency resonance.

4. COMPONENT DESIGN RECOMMENDATIONS:

4.1 Refrigerant Compressor:

4.1.1 Configuration: Two basic types of refrigerant compressors are available for use in air vehicle applications. These are positive displacement machines and centrifugal machines. The proper type to be used for a given application depends on an optimization study of several factors. A positive displacement type with a constant refrigerant flow and consistent performance characteristics should be favored for system optimization for low capacity systems. A centrifugal compressor can be considered for larger capacity systems. The compressor drive may be electrical, hydraulic, or pneumatic.

4.1.1.1 The factors that will dictate the choice of refrigerant compressor include:

a. Reliability
b. System capacity and weight
c. Refrigerant to be used
d. Type of drive available
e. Suction and condensing temperature
f. Load variation
g. Volumetric efficiency

4.1.2 Positive Displacement Compressors: Four types of positive displacement compressors are of interest. These include:

a. Reciprocating
b. Rotary vane/rolling piston
c. Rotary lobed (screw machines)
d. Scroll

4.1.2.1 The reciprocating compressor finds maximum application for small capacity systems when the weight impact associated with this type of machine is not severe.

4.1.2.1.1 The reciprocating compressor may be applied as a hermetic, semi-hermetic, or open machine.

4.1.2.1.2 Maximum operating speed should not exceed that which results in rapid decay of volumetric efficiency and/ or reduction in operating life.

4.1.2.1.3 When used as an open compressor (driven through a shaft) seal care should be taken to compensate for vibration. Shock mounts are normally required. Refrigerant leakage through the seal shall be limited to 14 g/year (0.5 oz/year) at a differential pressure of 689 kPa (100 psig). Open shaft seal design should be avoided.

4.1.2.1.4 The reciprocating compressor is very sensitive to liquid ingestion, and even small amounts of liquid can cause failure. Spring-loaded cylinder heads are often used to reduce the chances of mechanical failure due to liquid at the compressor suction in larger size commercial machines. Also a liquid-suction heat exchanger may be used to eliminate liquid at the compressor inlet. A system refrigerant pump down cycle should be considered after each shut down period to eliminate any liquid collection in the compressor.

4.1.2.1.5 Where operation of vapor cycle equipment will be required at low ambient conditions, a heater is necessary to warm up the oil and to ensure the oil foaming does not reduce lubrication upon start up.

4.1.2.2 The rotary vane/rolling piston compressor is employed for application similar to the reciprocating machine. The maximum speed limitation is a function of life requirements rather than performance. Applications to 11,000 rpm have been reported.

4.1.2.2.1 For small capacity applications, rotary vane machines have been used with R-236fa and R-134a.

4.1.2.3 The rotary lobed screw compressor is a positive displacement machine that overcomes some of the disadvantages associated with the reciprocating or vaned rolling piston compressor.

4.1.2.3.1 Speeds to 30,000 rpm are practical with rotary lobed screw compressors. The compressor characteristic is such that volumetric efficiency increases with increasing speed and overall efficiency is relatively constant. Large quantities of liquid can be ingested without mechanical damage.

4.1.2.3.2 Pressure ratios of 8:1 with the new low ozone depleting refrigerants can be accomplished in a single stage. The refrigeration system can easily be managed in terms of thermal stability and power management. Variable speed operation of the compressor will enhance system start up, surge current management and may reduce the refrigeration control valve usage. The rotary compressor exhibits desirable low induced vibration to air vehicle structure from pulse free compression cycles.

4.1.2.4 Scroll compressors are orbital motion, positive-displacement machines that compress with two interlocking (or meshing), spiral-shaped scroll members. To function effectively, the scroll compressor requires close tolerance machining of the scroll members. The positive-displacement, rotary motion compressor includes performance features, such as high efficiency and low noise. Scroll compression embodies a fixed, built- in volume ratio that is defined by geometry of the scrolls and by discharge port location. This feature provides the scroll compressor with different performance characteristics than those of conventional reciprocating or rotary compressors.