SOCIETY OF AUTOMOTIVE ENGINEERS, Inc.
485 LEXINGTON AVENUE
NEW YORK 17, N.Y.

AEROSPACE RECOMMENDED PRACTICE

ARP 731

GENERAL REQUIREMENTS FOR APPLICATION OF VAPOR CYCLE REFRIGERATION SYSTEMS FOR AIRCRAFT

Issued 5-31-63
Revised

Section 8.3 of the SAE Technical Board rules provides that: "All technical reports, including standards approved and practices recommended, are advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. There is no agreement to adhere to any SAE standard or recommended practice, and no commitment to conform to or be guided by any technical report. In formulating and approving technical reports, the Board and its Committees will not investigate or consider patents which may apply to the subject matter. Prospective users of the report are responsible for protecting themselves against liability for infringement of patents."

OUTLINE

SAENORM.COM : Click to view the full PDF of arp731

Copyright 1963 by Society of Automotive Engineers, Inc. Printed in U. S. A.

1. PURPOSE:

1.1 The purpose of this ARP is to establish recommendations for the design, installation and testing of aircraft vapor cycle refrigeration systems. These recommendations are representative of the present state-of-the-art.

1.2 The recommendations of this ARP are primarily intended to be applicable to civil aircraft whose prime function is the transporting of passengers or cargo. The recommendations will apply, however, to a much broader category of civil and military aircraft where vapor cycle refrigeration systems are applicable.

2. SCOPE:

2.1 Recommendations of this ARP refer specifically to the application of closed cycle vapor cycle refrigeration systems as a source of cooling in an aircraft air conditioning system. General recommendations for an air conditioning system which may include a vapor cycle system as a cooling source are included in ARP 85, Air Conditioning Equipment, General Requirements for Subsonic Airplanes, ARP 292, Air Conditioning, Helicopters, General Requirements For, and AIR 806, Air Conditioning Design Information for Cargo and High Density Passenger Transport Airplanes, and are not included herein.

SAENORM.COM : Click to view the full PDF of arp731

2.2 Vapor cycle refrigeration system design recommendations are presented in this ARP 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. SYSTEM DESIGN RECOMMENDATIONS:

3.1 System Definition:

3.1.1 The basic vapor cycle refrigeration system includes the following necessary elements:

a. Refrigerant Compressor
b. Evaporator
c. Condenser
d. A cooling load
e. A heat sink
f. Refrigerant
g. Refrigerant piping
h. System performance controls
i. Refrigerant expansion device
j. Power source

3.1.2 The system may also include the following elements:

a. Protective devices
b. Refrigerant quantity gauge
c. Condenser cooling device (ground operation)
d. A device for removing condensed moisture from the evaporator air
e. Liquid refrigerant receiver
f. Refrigerant moisture removal device
g. Trouble shooting and system monitoring instrumentation
h. Surge control device
i. Lubrication system
j. Cold start provisions
k. Sub coolers
l. Flash coolers
m. Access hardware for system servicing

3.2 Performance Characteristics:

3.2.1 Required Performance: The cooling capacity of the system should be sufficient to satisfy the aircraft cooling requirements established in the latest revision of ARP 85 for both ground and flight operation over the entire aircraft operating envelope.

3.2.2 Performance Analysis: The cooling capacity of a specific configuration of vapor cycle system may be determined analytically by the methods described in the SAE Aerospace Applied Thermodynamics Manual.

3.2.3 Off Design Performance: The system should be capable of operating at cooling loads ranging from maximum capacity to zero without undesirable effects such as refrigerant compressor surge or control oscillation. However, operation at light load with some conventional thermostatic expansion valves at values below 10 - 20 per cent capacity may be unstable and should be avoided if these controls are used.

3.2.4 Evaporator Temperature: The evaporator should be controlled to a temperature sufficiently high to prevent freezing of condensing moisture in the evaporator, or defrost cycles should be provided.

3.2.5 Optimum System Design Considerations: Consideration 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 performance penalty on the aircraft. Where considerable reduction in cooling capacity and cooling power requirements exists for a large portion of the flight, as for example, high altitude subsonic cruise, consideration should be given to sink control and power control to minimize aircraft performance penalty.

SAENORM.COM : Click to view the full PDF of arp731

3.2.6 Evaporator Water Carryover: The evaporator air circuit should incorporate adequate water traps and drains to eliminate condensed water droplets from the cooled air stream. Water collected should be routed to the condenser for added cooling if the system design shows sufficient performance advantage is realized.

3.2.7 Extreme Temperatures and Pressures: When returned to the normal range of operating pressures and temperatures after exposure to the extreme conditions outlined in paragraphs 3.2.7.1 through 3.2.7.5, the system should be capable of design cooling capacity. In addition, the system should 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.

3.2.7.1 After 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.

3.2.7.2 After exposure to the maximum temperature, caused by normal operation of the heating system coincident with minimum (-65°F) condenser temperatures with the system not operating.

3.2.7.3 After exposure to ambient compartment temperatures from -65°F to 160°F while not operating on the ground.

3.2.7.4 After exposure, while not operating, to ambient temperatures as low as -65°F in flight from sea level to maximum airplane altitude.

3.2.7.5 After exposure, while not operating, to ambient pressures as low as may exist at the maximum airplane altitude.

3.2.8 Life: The system should be designed to be capable of trouble-free performance while producing rated refrigeration for a minimum service period of 3000 system operating hours without overhaul of its components. During this service period minor maintenance operations such as lubrication or cleaning should not be required more often than every 1000 hours of system operation.

3.3 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. For a detail discussion of the factors to be considered and methods for evaluating possible refrigerants as well as the physical properties of those currently available, refer to the SAE Aerospace Applied Thermodynamics Manual.

3.4 Construction:

3.4.1 Pressure Loads:

3.4.1.1 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.

SAENORM.COM : Click to view the full PDF of arp731

3.4.1.2 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 the maximum design pressure which can occur in the component without permanent deformation.

3.4.1.3 Burst Pressure: All system components subjected to internal pressure should be designed to be capable of withstanding a minimum pressure of 2.5 times the maximum design pressure without bursting.

3.4.2 Externally Induced Loads: The system must be designed to withstand all externally induced loads incident to its installation in an aircraft. 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 aircraft roll, yaw, or pitch. In addition, consideration must be given to loads imposed by aircraft structural and thermal deflections.

3.4.3 Fatigue Strength: The fatigue strength of the system components should be sufficient to provide the system minimum life recommendation of paragraph 3.2.8 as a minimum. To provide minimum overhaul costs, however, the majority of the system components should have sufficient fatigue strength to provide a life several times this value. The expected life of the aircraft is a more desirable objective.

3.4.4 Vacuum Loads: All system components designed to contain refrigerant should be capable of withstanding repeated collapsing pressure differentials of 30 inches of mercury without permanent deformation or failure.

3.4.5 Refrigerant Leakage: The system leakage rate should be essentially zero. For systems that incorporate components with dynamic seals, that cannot meet zero leakage, a minimum of 1200 hours or four calendar months of system operation without requiring replenishing is recommended. These systems should incorporate special provisions to allow rapid and accurate replenishing.

3.5 Failure Protection and Safety:

3.5.1 Rupture Protection: The system should incorporate a positive overpressure device designed to relieve within 5% of the proof pressure. The overpressure device should be readily replaceable or reset and easily accessible when the equipment is installed in the aircraft.

3.5.2 Release of Refrigerant: The physical location of the components of the system in the aircraft shall be such that toxic quantities of released refrigerant cannot accumulate in occupied areas.

3.5.3 Rotor Failure: Failure of any high energy rotor incorporated in the system should not result in fire or other hazardous conditions. The rotor case or auxiliary protective shield should 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 addition, if an electric drive is used, a motor protector relay should be incorporated to prevent rotor case penetration in the event of an electrical fault.

SAENORM.COM : Click to view the full PDF of arp731

3.5.4 Compressor Protection:

3.5.4.1 Pneumatic Drive: The refrigerant compressor and drive should incorporate a separate overspeed shut-off, 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 overspeed shut-off device shall be located on the driver unit.

3.5.4.2 Electric Drive: The electric driven refrigerant compressor should incorporate motor overload, phase differential, and phase open motor protection.

3.5.5 Loss of Condenser Heat Sink: The system should be designed to prevent permanent damage in the event single failures or accumulation of non-condensibles allow the system to operate without a condenser heat sink. Such operation results in excessively high refrigerant temperatures and pressures which may represent a hazardous condition to the aircraft and its occupants. Certain commonly used halogenated hydrocarbon refrigerants experience a violent exothermic reaction in the presence of aluminum and other metals at high supercritical temperatures and may cause fire or explosion.

SAENORM.COM : Click to view the full PDF of arp731

3.6 Control and Instrumentation:

3.6.1 Control Configuration: Selection of the system control elements and arrangements is dependent to a large extent on the system configuration and to the air conditioning system in which the refrigeration system is incorporated. Generally, the major control elements required are:

a. Evaporator refrigerant temperature, pressure, or flow.
b. Compressor suction superheat, or evaporator discharge superheat.
c. Compressor speed (pneumatically driven centrifugal machines).
d. Compressor inlet pressure (electrically driven centrifugal machines).
e. Condenser heat sink control.
f. Compressor surge control (centrifugal machines).

For a detailed discussion of vapor cycle refrigeration system control see WADC TR 53-338 dated October 1953 by Mason, Burriss and Connelly.

3.6.2 Control Performance: The system control must be capable of smoothly and automatically varying system refrigeration capacity in accordance with the demands of the aircraft air conditioning system. This demand may range from zero to full cooling load at a rate compatible with the specific aircraft transient response.

Alternate or manual override facilities may be desirable to allow "In-flight" by-passing of automatic controls to allow system operation by direct control of the expansion valve, compressor, temperature control valve, and other necessary components.

3.6.3 Instrumentation:

3.6.3.1 Cockpit: Sufficient instrumentation should be provided with corresponding cockpit display to indicate normal operation of the refrigeration system to the aircrew. This instrumentation should be held to a minimum to reduce the aircraft installation complexity and to minimize aircrew misinterpretation of system performance.

If manual override controls are installed adequate instrumentation must be installed to allow proper monitoring during manual operation.

3.6.3.2 Service Connections: Sufficient quick disconnect or "plug-in" instrumentation provisions should be incorporated in the system to allow rapid trouble shooting during ground maintenance. Variables to be measured may include compressor suction and discharge pressure, evaporator refrigerant temperature, compressor speed, condenser refrigerant temperature, and evaporator air inlet and outlet temperatures. For electric driven compressors, motor current and voltage may be preferred to compressor speed.

SAENORM.COM : Click to view the full PDF of arp731

3.7 Packaging and Installation:

3.7.1 All individually removable components of the system should be interchangeable and selective matching of system components should not be necessary.

3.7.2 Direction of rotation of all unidirectional equipment should be clearly marked with markings which are visible when the equipment is installed in the aircraft.

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

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

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

3.7.6 Consideration should be given to packaging of multiple components in a single compact easily removable package to eliminate detailed trouble shooting on the aircraft and minimize aircraft dispatch delays. If compact packaging cannot be accomplished consideration should be given to making individual components easily removable.

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

3.7.8 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 with the appearance of gas bubbles, with the system operating, an indication of low charge of refrigerant.

3.7.9 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, or local high air velocities.

3.7.10 When ram air is used, the inlets should be located to preclude ingestion of hot engine exhaust gases during thrust reverser operation.

4. COMPONENT DESIGN RECOMMENDATIONS:

4.1 Refrigerant Compressor:

4.1.1 Configuration: Two basic types of refrigerant compressors are available for use in aircraft applications. These are positive displacement machines or centrifugal machines. The proper type to be used for a given application depends on an optimization study of several factors.

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

a. Suction and condensing temperature
b. Type of drive available
c. Refrigerant to be used
d. Load variation
e. Size and weight
f. Reliability

SAENORM.COM : Click to view the full PDF of arp731

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

a. Reciprocating
b. Rotary vane
c. Rotary lobed

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

4.1.2.1.1 The reciprocating compressor may be applied as an 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 High density refrigerants (R12 or R22) should be used. With R12, suction temperatures to 35°F may normally be used with condensing temperature to 160°F. With R22, condensing temperature should not exceed 150°F.

4.1.2.1.4 When used as an open compressor (drive through a shaft seal) care should be taken to compensate for vibration. A flywheel and shock mounts are normally required.

4.1.2.1.5 The reciprocating compressor is very sensitive to liquid ingestion and even small amounts of liquid can cause failure. In larger size commercial machines, spring loaded cylinder heads are often used to reduce the chances of mechanical failure due to liquid at the compressor suction. Also a liquid-suction heat exchanger may be used to eliminate liquid at the compressor inlet.

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

4.1.2.2 The rotary vane compressor is employed for applications similar to the reciprocating machine.

4.1.2.2.1 The maximum speed limitation is a function of life requirements rather than performance. Applications to 6000 RPM have been reported.

4.1.2.2.2 For small capacity applications (as food storage refrigeration) rotary vane machines have been used with R114.

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

4.1.2.3.1 Speeds to 30,000 RPM are practical.

4.1.2.3.2 The compressor characteristic is such that volumetric efficiency increases with increasing speed and overall efficiency is relatively constant.

4.1.2.3.3 Large quantities of liquid can be ingested without mechanical damage.

4.1.2.3.4 Pressure ratios of 8:1 with R12, 22, 114 and 11 can be accomplished in a single stage.

4.1.3 <u>Centrifugal Compressors:</u>

4.1.3.1 For moderate capacity (5-15 tons) the centrifugal compressor is used with low density refrigerants (R114 and R11) at speeds to 30,000 RPM. For the same capacity range, applications with R12 operate at speeds to 90,000 RPM.

4.1.3.2 System capacity control should recognize the surge phenomenon associated with centrifugal compressors and low flow at high pressure ratio must be avoided.

4.1.4 The suction line to the refrigerant compressor should of sufficient size to avoid excessive pressure drop, however, not oversized so that it will prevent carrying entrained oil if lubricating oil is in the refrigerant.

SAENORM.COM : Click to view the full PDF of arp731