AEROSPACE RECOMMENDED PRACTICE	ARP217™	REV. D
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Testing of Airplane Installed Environmental Control Systems (ECS)

RATIONALE

ARP217D has been reaffirmed to comply with the SAE five-year review policy.

1. SCOPE:

This document deals with ground and flight test of airplane installed Environmental Control Systems (ECS), Figure 1. The ECS provide an environment, controlled within specified operational limits of comfort and safety, for humans, animals, and equipment. These limits include the following: pressure, temperature, humidity, ventilation air velocity, ventilation rate, wall temperature, audible noise, vibration, and environment composition (ozone, contaminants, etc.). The ECS are composed of equipment, controls, and indicators that supply, distribute, recycle and exhaust air to maintain the desired environment.

1.1 Purpose:

This document defines recommended tests and test procedures for airplane installed ECS. The purpose of these tests is to:

a. verify system pressure integrity (leakage),

b. verify integration and compatibility of ECS with other airplane systems, and

c. determine overall system performance in conditions representative of those which may be encountered during operations.

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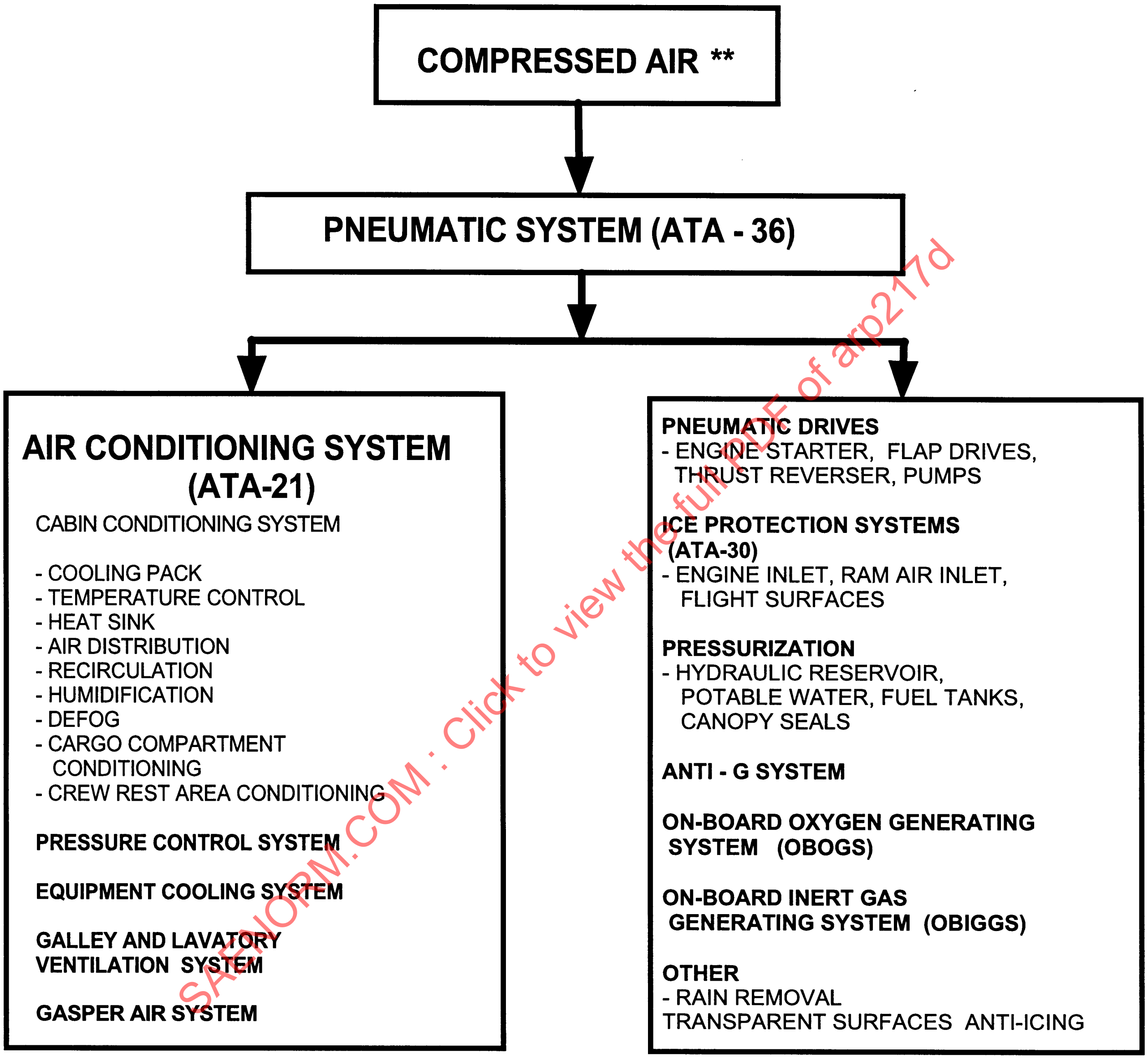

** FROM ONE OR MORE OF THE FOLLOWING
- ENGINE COMPRESSOR
- ON -BOARD COMPRESSOR (ENGINE SHAFT OR ELECTRCALLY DRIVEN)
- AUXILIARY POWER UNIT (APU)
- GROUND EQUIPMNT

FIGURE 1 - Environmental Control Systems

1.2 Field of Application:

These tests (and procedures) may be used for commercial and military airplane certification (test of first article) or for production airplane (to ensure built as design) tests. The selection of the appropriate test conditions, instrumentation, and test procedures depends on a large number of variables (airplane configuration, system concept, hardware, integration with other on-board systems, certification or production airplane, etc.). Thus, these are addressed in general terms. This document is intended to serve as a guide in the planning and conduct of tests. The specification or contractual or regulatory (Federal Aviation Regulations (FAR), Joint Airworthiness Regulations (JAR)) requirements should be considered. The test plan and procedure should be coordinated with the appropriate agency.

Test data may be used to show compliance with the applicable airplane specification, contractual, or regulatory requirements and to verify analytical simulation models. If the former is intended, it is extremely important to obtain prior approval of the test plan and procedure from the appropriate agency.

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 laws unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-001.

ARP1307	Measurement of Exterior Noise Produced by Airplane Auxiliary Power Units and Associated Equipment during Ground Operations
ARP1323	Type Measurement of Airplane Interior Sound Pressure Levels in Cruise
AIR806	Air Conditioning Design Information for Cargo and High Density Passenger Transport Planes
AIR1266	Fault Isolation in Environmental Control Systems of Commercial Transports
AIR1706	The Advanced Environmental Control Systems (AECS) Computer Program for Steady State Analysis and Preliminary System sizing
AIR1823	Transient ECS Computer Program
AIR1826	Airplane Environmental Systems Acoustical Design Considerations
ARP85	Air Conditioning Equipment, General requirements for Subsonic Airplanes
ARP89	Temperature Control Equipment, Automatic Airplane Compartment
ARP292	Air Conditioning, Helicopter, General requirements for
ARP699	High Temperature Pneumatic Duct Systems for Airplane

2.1.1 (Continued):

ARP731	General Requirements for Application of Vapor Cycle Refrigeration Systems for Airplane
ARP1270	Airplane Pressurization Control Criteria
ARP1796	Engine Bleed Air Systems for Airplane
ARP4073	Air Cycle Air Conditioning Systems for Military Air Vehicles

2.2 Other Applicable References:

AFGS 87145	General Design Specification Environmental Control, Airborne
MIL-D-8708	Demonstration Requirements for Airplanes
MIL-E-18927	Environmental Control Systems, Airplane, General Requirements for
MIL-T-18606	Test Procedures for Airplane Environmental Systems
STANAG 2895	Extreme Climate Conditions and Derived Conditions for Use in Defining Design/Test Criteria for NATO Forces

2.3 Acronyms:

ACM	Air Cycle Machine
AFB	Air Force Base
APU	Auxiliary Power Unit
ARP	Aerospace Recommended Practice
ATA	Air Transport Association
BITE	Built-In-Test Equipment
CFR	Code of Federal Regulations
DER	Designated Engineering Representatives
DMIR	Designated Manufacturing Inspection Representatives
ECS	Environmental Control Systems
EGT	Exhaust Gas Temperature
EICAS	Engine Indicating and Crew Alerting System
EPR	Engine Pressure Ratio
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
JAA	Joint Aviation Authorities
JAR	Joint Airworthiness Regulation
OBOGS	On-Board Oxygen Generating System
OBIGGS	On-Board Inert Gas Generating System
PRSOV	Pressure Regulating and Shut Off Valve
TAI	Thermal Anti-Ice

3. ENVIRONMENTAL CONTROL SYSTEMS:

The ECS typically consists of the following two major systems.

3.1 Pneumatic System (ATA 36):

The pneumatic system delivers compressed air from the source(s) to on-board services such as, the air-conditioning system packs; engine inlets, ram air inlets and flight surfaces anti-icing or de-icing systems; drives for thrust reverser, flaps, hydraulic pumps, and engine start motor; pressurization of hydraulic fluid reservoir, fuel tanks, and potable water; rain removal and anti-icing of transparencies; etc.

In military airplane, the system may also service the following systems.

a. On-Board Oxygen Generating System (OBOGS) which extracts oxygen from the air for crew and passengers use;

b. On-Board Inert Gas Generating System (OBIGGS) which extracts nitrogen from the air for fuel tank inerting;

c. Canopy seals;

d. Anti-G system that utilizes the pressure and flow of air to pressurize the anti-g suit. The suit on pressurization restricts the flow of blood to the lower extremities thus providing protection (loss of consciousness) against gravitational (Gz) forces.

e. Radar pressurization system.

There are no restrictions on the use of pneumatic power for operating other systems. The above list identifies systems commonly serviced by the pneumatic system.

The typical air-sources of the pneumatic system are the propulsive engines, on-board compressors, on-board Auxiliary Power Unit (APU), and external ground air supply (ground air cart or terminal built-in-compressed air supply system). The system receives compressed air from the above sources, controls its routing, and delivers it to the using systems. Cross-bleed and isolation valves are included in the distribution manifold to maintain essential functions in the event of supply or using system failure. Check that pressure regulating and shut off valves are incorporated to ensure delivery of air within pressure limits to the using systems. Heat exchangers, temperature controllers and over-temperature shut-off features are added to control and/or limit supply air temperature. To ensure proper operation, monitoring of performance, and to facilitate trouble-shooting and maintenance, sensors and controllers are added as required. A typical pneumatic system is described in 4.4.

3.2 Air Conditioning System (ATA 21):

The air conditioning system consists of the following significant subsystems.

a. The cabin (passenger and flight crew compartments) conditioning system controls and conditions cabin air supply (fresh and recirculated). It consists of the air conditioning pack(s) including heat sink(s), the cabin-air recirculation system components, and the air distribution and exhaust ducting. It interfaces with the pneumatic system at the flow control valve of the pack. Cabin temperature controllers and cabin temperature sensors are part of this system. A cabin-air humidification system may form a part of the cabin conditioning system. This system increases the relative humidity of selected compartments, such as flight deck, crew rest and passenger.

b. The cabin pressure control system controls air flow overboard to maintain cabin altitude and altitude rates of change within designed limits. It consists of the pressure controller, selector, and valve(s) to control overboard discharge of cabin air to limit maximum and minimum cabin pressures. Safety valves (positive and negative pressure) are included to safeguard structure during failure or abnormal conditions.

c. The equipment cooling system provides cooling air for the electrical or electronic equipment. In military airplane the system may also have liquid coolant loops for cooling high density avionics or dielectric coolant.

d. The galley and lavatory ventilation systems provide for removal of odors.

e. Defog system prevents fog formation on transparent surfaces; this provides improved visibility.

f. Large transports may have a cargo compartment conditioning (or heating) system for the carriage of animals and perishable cargo.

g. On long range airplanes, special areas may be reserved for crew rest and they may have air conditioning systems that can be independently controlled.

h. Emergency ventilation (ram-air) system for cabin conditioning in the event of loss of all in-flow or for smoke evacuation.

i. Heating provisions for areas such as galleys, doors, etc., that tend to get cold during flight.

j. In military airplane air conditioning system may include special filters (or equipment) to protect the occupants from nuclear biological and chemical agents.

3.3 Applicable Regulations and Requirements:

The regulations and requirements applicable to ECS depend on the airplane category.

3.3.1 Civil Airplane: In the United States, the Federal Aviation Administration (FAA) of the Department of Transportation has jurisdiction to certify civil aircraft as safe. Other nations have similar agencies. Twenty-nine Authorities in Europe have formed Joint Aviation Authorities (JAA). JAA has developed Joint Aviation Requirements (JARs) in the field of design and manufacture, operations and maintenance of aircraft and in the field of personnel licensing. It ensures uniform implementation of JARs so that certificates, approvals, licenses, etc., granted by one of its full members can be accepted by the others. Its goal is to promote European Safety System world-wide.

Code of Federal Regulations (CFR), Title 14 Parts 23 and 25 contain FAA transport category airplane airworthiness standards. Part 23 deals with normal, utility, acrobatic and commuter category airplanes, and Part 25 deals with transport category airplanes. JAR-25 contains JAA airworthiness standards for large turbine airplanes and JAR-23 contains JAA airworthiness standards for normal, aerobatics, utility and commuter categories. This ARP deals primarily with Part 25 airplanes. However, the tests and procedures presented herein, with modifications due to differences in regulations, may be used for Part 23 airplanes. The FAR Part 25 and JAR Part 25 regulations relevant to ECS, for transport category airplanes, are as follows:

FAR or JAR Section

25.831	Ventilation
25.832	Cabin Ozone Concentration
25.833	Heating Systems
25.841	Pressurized Cabins
25.843	Tests for Pressurized Cabins
25.857	Cargo Compartment Classification
25.1301	Function and Installation
25.1309	Equipment, Systems, and Installations
25.1322	Warning, Caution, and Advisory lights
25.1438	Pressurization & Pneumatic Systems
25.1439	Protective Breathing Equipment
25.1461	Equipment containing high energy rotors

The above regulations specify minimum acceptable design requirements and performance standards. However, airplane designed to a manufacturer's proprietary airplane specification (model specification) may contain more demanding design or performance standards. It is suggested that the test engineer review the applicable documents prior to planning of tests and preparation of test procedures.

3.3.2 Military Airplane: Military airplane performance and test requirements are contained in the airplane specification and the referenced specifications. Military specifications commonly referenced are:

AFGS 87145	General Design Specification Environmental Control, Airborne
MIL-D-8708	Demonstration Requirements for Airplanes
MIL-E-18927	Environmental Control Systems, Airplane, General Requirements for
MIL-T-18606	Test Procedures for Airplane Environmental Systems
STANAG 2895	Extreme Climate Conditions and Derived Conditions for Use in Defining Design /Test Criteria for NATO Forces

A review of the airplane and its referenced specifications is suggested prior to the start of test plan development.

3.4 Test Planning and Coordination:

The planning and coordination depend on the intent of the test. The effort required for development and certification test (new airplanes) is significantly different from that required for production airplanes.

3.4.1 Development and Certification Airplanes: The intent of these tests is to (1) develop the ECS and (2) to demonstrate compliance to the applicable specification, contractual or certification requirements.

Airplane ground and flight tests require large resources. Significant savings can be achieved by planning and coordination with other disciplines (propulsion, performance, etc.). For example, resources can be shared by concurrent ground test of engine bleed-air system and engine nacelle cooling. Similar opportunities also exist in the conduct of flight tests. Such opportunities must be investigated.

In test planning, efforts should be made to conduct tests under controlled conditions (ambient temperature and pressure, flight Mach number and engine power conditions, heat load, etc.) representative of conditions in the specification. This facilitates compliance demonstration and validation of the analytical simulation model. A simulation model validated by test may then be used to estimate system performance at extreme environment conditions. The use of such an approach to show compliance with specification, contractual or certification requirements should be coordinated with the appropriate agency in advance.

In addition to performance tests, the test plans should make provisions to verify and evaluate other system attributes such as, indication and warning, protective devices, Built-In-Test Equipment (BITE), and selected failure modes that can only be verified by airplane tests. These tests assure integration and compatibility with on-board systems.

3.4.2 Production Airplanes: The intent of these tests is to verify that the systems have been properly installed and that they perform intended function. Some of these tests (pressure integrity or leakage) may be conducted in the factory and others during airplane check out during ground and flight operations. Coordination between various groups is thus essential.

3.5 Instrumentation:

In planning for instrumentation, the test purpose should be kept in mind as instrumentation of installed systems and acquisition of data is difficult. In addition to the installation bosses required for sensors to be actually installed in the test item, provisions should be made available for other sensors that may be required to debug failures or perform other tests. Removing sensors from one location and reinstalling them in another location for other tests can save investments.

3.5.1 Development and Certification Airplanes: To minimize instrumentation requirements should be a goal. However, if performance testing is to be performed in environments less stringent than those specified, and computer models are to be used to predict performance, additional instrumentation may be necessary to validate the computer model. To minimize instrumentation channels, use of airplane installed instruments and data buses should be considered. However, precaution must be taken to ensure such use does not compromise system performance or test data.

In planning for instrumentation, one should also consider the instrumentation requirements of the interface systems. Preparation of an instrumentation list, identifying sensor location, type, range, accuracy, sampling rate, recording method, etc., is suggested. The effect of each sensor failure on the success of the test should be evaluated and a list of critical sensors for the success of each test should be prepared. Time synchronized video cameras provide an effective method to record flight deck data.

If digital data acquisition equipment is used, the selected scanning rate should be compatible with the intent of the test. Provisions should be made on the airplane for real time scanning of items critical for safety.

The test ambient conditions, sensor range, and accuracy of instrumentation must be carefully evaluated to assure compatibility. All test limits should be adjusted to allow for instrumentation tolerance.

3.5.2 Production Airplane: Production airplane tests are verification tests conducted to ensure that the systems are properly installed and that they perform as intended. These tests are generally conducted using airplane installed instruments, special tooling (for leakage and pressurization), and portable instrumentation.

3.6 Test Airplane Configuration:

Equipment and installation that may influence system under test should be representative of the production configuration. To successfully test the air conditioning system, the pneumatic system, air-conditioning packs, the cabin air distribution and recirculation systems, fuselage insulation, and distribution ducts should be representative of the production configuration. It is desirable that seats, partitions, galleys, lavatories, and other compartments be installed during development and certification tests. However, heat loads and their distribution may be simulated. The data is more useful when the test airplane configuration is closer to the production airplane.

3.7 Test Environment:

Integration and compatibility tests are not sensitive to the test environmental conditions. Performance tests should be conducted under representative conditions (outside air temperature, pressure, humidity, flight Mach number and engine power conditions, heat load, etc.). It is easier to demonstrate compliance when the test environment is closer to the specified environment. The test environment or airplane configuration depends on the test objectives. Some tests can be successfully performed in everyday environment with the airplane and interface systems not in full production configuration. Therefore, an understanding of the test objective is extremely important. For example:

a. High humidity and outside air temperature are desirable to determine the maximum cooling capability of an air-conditioning pack. This test can be performed with air supplied by any source, provided the air supply and heat sink conditions are representative of the test conditions. Also, generation of internal heat loads is not necessary. The pack can be made to supply conditioned air at the lowest (cooling mode) temperature by manipulations of the temperature controller. Similarly, low ambient temperature is not necessary to determine the maximum heating capability of the pack.

b. The overall heat conductance of the airplane structure can be determined by tests in warm or hot ambient by determining the supply air temperatures required to maintain the airplane interior at a desired steady state temperature. The test can be successfully performed using conditioned air from an external conditioned air source.

For military airplane, use of the Climatic Chamber at Eglin Air Force Base (AFB) is an acceptable method for obtaining specification conditions for performance testing.

4. TESTS ON INSTALLED SYSTEMS:

Typical ground and flight tests that are conducted on the airplane are discussed in this section. It should be recognized that the presence of a test in this section doesn't imply that the defined test must be conducted. Similarly, the absence of a test doesn't imply that the conduct of the missing test is undesired. The decision to perform a test depends on the organization responsible for system design, and the contracting or regulatory agency. Tests that have previously been performed on the equipment and subsystem during the development and qualification phase, technology used in system design, etc., should be considered in the decision process. Early mutual understanding between parties on the acceptable method to demonstrate compliance with the requirements is important.

4.1 Prerequisites:

Tests on the airplane should only be performed using components that have successfully completed at least safety related and minimum acceptable endurance tests in the equipment qualification program. The safety related tests typically include vibration, proof and burst pressure, electromagnetic interference (electrical equipment) and containment in the case of rotating machinery. The test levels may be reduced from equipment qualification requirements, on case by case basis. In the United States, FAA Designated Engineering Representatives (DER) have the authority to evaluate qualification test data of equipment intended for use on commercial airplanes, and to approve (or recommend approval of) it. It is suggested that the DER be consulted. If the approval is conditional or limited, the conditions and limitations should be strictly followed. JAA does not use DER system.

The system installation should be checked to ensure it is per the installation drawing. In the United States, FAA Designated Manufacturing Inspection Representatives (DMIR) have the authority to perform this inspection. Test data, on a system previously inspected by a DMIR and the test witnessed by the DER (on behalf of the FAA when so authorized), can be used to show compliance with FAR. JAA does not use DMIR system.

For military programs, the appropriate government representatives should be requested to perform inspections and provide approvals, as appropriate.

The system and instrumentation should be functionally checked and the calibration of all instrumentation verified. The function and operation of system safety devices must be verified prior to the start of the test. For example, if the cooling pack incorporates a thermal switch which on activation shuts off the pack, the operation of this protective feature should be checked to ensure that it would perform the designed function, if needed during the test.

In summary, a thorough understanding of the system and its limitations is essential to assure its instrumentation and protective devices will perform as intended.

4.2 Ground Tests:

The following ground tests are typically performed on ECS.

4.2.1 Pressure Integrity or Leakage: This test is performed to ensure that the installed system can withstand maximum normal operating pressures, the clearances under pressure load conditions are as designed, and that the leakage is within acceptable limits. These tests are described in greater detail, using typical pneumatic and air conditioning systems, in 4.4.1.1 and 4.5.1.1.

4.2.2 Integration and Compatibility: The integration test is performed to ensure that the system operates in harmony with other on-board systems and ground support equipment. The compatibility test verifies the system ability to operate with other systems as designed. Note, successful integration does not automatically result in compatibility because integration test is qualitative and the compatibility test is a quantitative. These tests are described in greater detail, using typical pneumatic and air conditioning systems, in 4.4.1.2 and 4.5.1.2.

4.2.3 Performance: These tests are conducted to ensure that the system meets performance (design) requirements. For example, if the system includes a pressure regulator designed to regulate the downstream pressure to 40 psig ± 5 psig (276 kPa ± 34 kPa gage), the performance test evaluates the operation of the installed regulator under various steady-state and transient operating conditions. Typical performance tests are described in detail in 4.4.1.3 and 4.5.1.3.

4.2.4 Built-In-Test (BIT) System: This test is performed to ensure that BIT system (hardware and software) performs the intended function. For example, a system may include BIT to record air temperature excursions above a design threshold. Typical BIT tests are described in greater detail in 4.4.1.4 and 4.5.1.4.

4.3 Flight Tests:

Flight tests are performed to further verify integration and compatibility and to obtain performance data. Flight tests supplement ground tests and should be conducted after successful completion of the ground tests. These tests are described in greater detail, using typical pneumatic and air conditioning systems, in 4.6 and 4.7.

4.4 Typical Pneumatic System:

A typical commercial airplane pneumatic system, using bleeds from two on-board engines, is shown in Figure 2. Each engine bleed air system extracts pressurized air from one or more bleed ports of each engine, controls its pressure and temperature, and delivers it to the distribution manifold. Compressed air from alternate sources such as the APU or high pressure ground cart (or airport ground based system) can be connected to the distribution manifold via the ground connection. The distribution manifold receives compressed air from the above sources, controls its routing, and delivers it to the using systems. In the Figure 2 system, some of the engine air is shown taken prior to delivery to the distribution manifold to satisfy engine pneumatic demands such as cowl thermal anti-ice. Cross-bleed and isolation valves are provided in the distribution manifold to maintain essential functions in the event of supply or user system failure. Check valves are provided to prevent reverse flow through the bleed air sources (engines, APU, or ground-air connection).

The typical engine bleed air system, Figure 2, is designed to perform the following functions during normal operations. The pressures and temperatures are indicated only for example and are not universally applicable.

a. Automatically select the low and high stage bleed based on the available high stage pressure. The high stage valve is closed when the high stage compressor pressure is greater than 90 psig (621 kPa gage) and open when the pressure is less than 90 psig (621 kPa gage).

b. Regulate the pressure downstream of the high stage valve to 55 psig ±5 psig (379 kPa ± 34 kPa gage). This function is performed by the high stage valve that functions as a pressure regulating valve when open.

c. Control the supply air temperature downstream of the precooler to 380 °F ± 20 °F (193 °C ± 11 °C). This function is performed by the precooler through which fan air flows as the cooling air. The fan air valve, in response to signals from the temperature sensor, regulates cooling air flow.

d. Regulate supply air pressure to 45 psig ±5 psig (310 kPa ± 34 kPa gage). This function is performed by the pressure regulator valve.

The pneumatic system may include other functions such as, ozone converter to dissociate ambient ozone and or air filters to remove particulate matter.

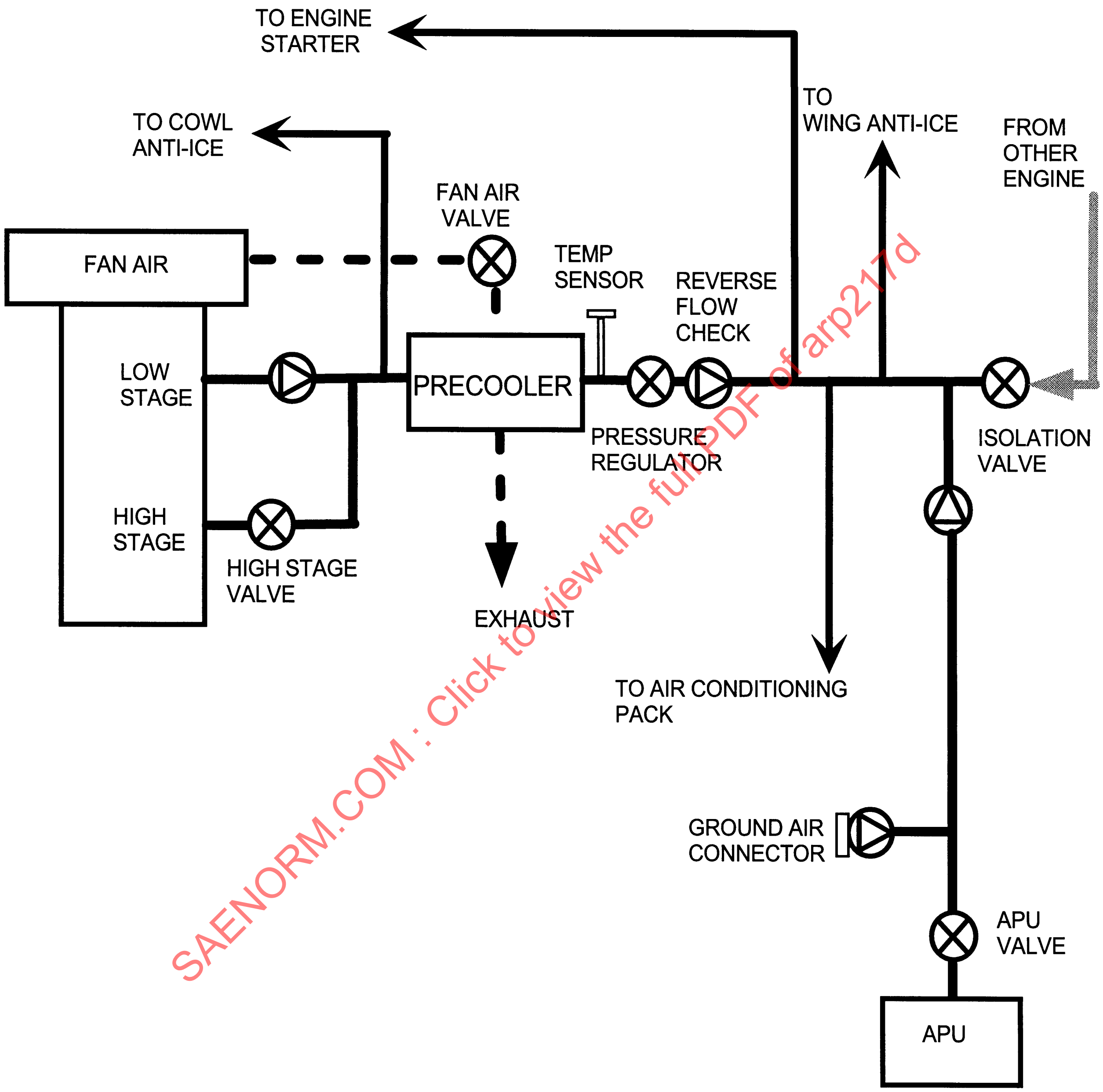

FIGURE 2 - Typical Pneumatic System

4.4.1 Pneumatic System Ground Tests: The following describes ground tests that are generally performed on the Pneumatic System.

4.4.1.1 Pressure Integrity or Leakage: The purpose of this test is to ensure that the system (i) can withstand normal operating pressures, (ii) the clearances under pressure load conditions are as defined in design documentation, (iii) the ducting connections have been properly assembled within acceptable leakage limits, and (iv) there is no concentrated leakage and the overall leakage is below estimate. This test is typically conducted using an external high pressure supply connected to the ground air connection. A flow measuring device (flow meter or calibrated flow tube) is installed between the compressed air supply and the ground connection to measure the flow required to maintain the duct system at a constant pressure. The compressed air supply should be able to provide flow greater than the estimated leakage at the maximum test pressure.

To prepare for the test, the control valves of the user systems are closed, the engine bleed air ports are blanked, and system check valves that would prevent system pressurization removed and replaced by duct sections. The external high pressure supply is connected to the distribution system and the system pressurized to a low pressure, 5 psig ±1 psig (31 kPa ± 7 kPa gage). Flow required to maintain the duct system at the selected pressure is determined and compared to the estimated leakage at the test pressure. The estimate should include the internal leakage of the control valves exhausting out of the duct system. If leakage is greater than the estimate, the leakage source is determined (feeling for air movement, listening for noise, observing for soap solution bubbles, etc.) and corrected. The duct system is inspected for deflections under pressure loading to assure clearances around system components are as designed.

On satisfactory completion of the low pressure test and inspection, the system is progressively pressurized to higher pressures, and flow required to maintain the system at constant pressure determined. Extreme caution should be exercised in the conduct of the test as failure of system components can cause equipment damage and personnel injury.

4.4.1.2 Integration and Compatibility: The purpose of this test is to ensure that the system has been integrated properly and that it works in harmony with the other on-board systems. Refer to Figure 2. The pneumatic system consists of APU bleed-air supply, engine bleed-air supply and ground air supply. To verify the APU supply system, start and operate the APU per its operating procedures. Open the APU valve. Observe the manifold gage pressure (flight deck or installed instrumentation). Open and close the isolation valve and the pack valve(s) to confirm compatibility between the APU and the user systems, i.e., there are no undesirable overshoots in the APU Exhaust Gas Temperature (EGT), distribution manifold pressure oscillations are damped, and that there is no adverse effects on the APU driven services (e.g., electrical generator). Conduct this test with all possible combinations of ECS valve positions.

4.4.1.2 (Continued):

The integration and compatibility between the engine bleed-air system and the user systems is verified in a manner similar to the APU test, described above. At fixed throttle settings, the user systems are operated individually and in combinations of probable in-service conditions. The pressures downstream of the high stage valve and the pressure regulating valve (i.e., control valve), temperature downstream of the precooler, and engine instruments are monitored to and verify that they perform as expected. The test is repeated with throttles at various settings, from idle to takeoff power to verify compatibility with the engine at steady state conditions. Compatibility with the bleed air leak detection system is verified by operating at critical power settings and flow rates. Deflection measurements under pressure and thermal loads are used to verify structural load calculations. Check expansion joints to confirm compression and expansion type bellows function properly and the duct loads on installed equipments are as specified. System operation under electrical voltage excursions is used to establish compatibility with electrical power system. Compatibility with data busses, on board computers, etc., as necessary, is also verified during these tests.

On successful completion of the steady-state test, compatibility during transient engine conditions is verified. The throttle is advanced (up to allowable limits) and retarded at various rates simulating normal and abnormal throttle operations. There should be no undesirable over- or under-shoots and protective devices, if provided, should perform the intended functions. The cockpit indications should be correct and there should be no effect on the operation of other instruments.

Ground air supply (ground air cart or terminal air supply) and on-board services compatibility is verified in a manner similar to the APU test, described above. The intent of the test is to ensure that the ground air connector and suggested maximum hose length are compatible with on board services.

4.4.1.3 Performance: The purpose of the performance test is to verify that the installed system performs its design function. The instrumentation required depends on system functions.

For example, the engine bleed air system of Figure 2, is designed to (i) automatically select the low or high stage bleed-air based on high stage compressor pressure, (ii) regulate the pressure downstream of the high stage valve to 55 psig ±5 psig (379 kPa ± 34 kPa gage), (iii) control the supply air temperature downstream of the precooler to 380 °F ± 20 °F (193 °C ± 11 °C), and (iv) regulate supply air pressure to 45 psig ± 5 psig (310 kPa ± 34 kPa gage). To conduct performance tests of this system, the test engineer would install a pressure sensor upstream of the high stage valve, pressure sensors downstream of the high stage valve and pressure regulator, and a temperature sensor downstream of the precooler. Additional instrumentation may be provided to measure bleed-air flow, fan-air flow, valve positions, etc., to obtain data for validation of the pneumatic system simulation model.

Various services are operated (individually and in probable combinations), at fixed throttle settings from idle to takeoff power and data recorded during steady-state conditions. Transient data may be recorded if response of system components is of interest.

4.4.1.3 (Continued):

Features added in the engine bleed air system to accommodate faults of system control elements (e.g., pressure regulator back up flow control function, bleed air temperature limiting) should also be tested. The test is necessary to verify proper integration and function of back up controls. Extreme caution should be exercised in conducting this test as a subsequent failure can cause damage. [The intent of this test can also be accomplished by test on a ground test rig followed by a simple integration test on the airplane.]

4.4.1.4 Built-In-Test (BIT) System: BIT system tests are performed to ensure that it performs the intended function. The probable failure signals are generated and system response verified. Over-heat and over-pressure signals can be generated by exposing system sensors to external inputs. Performance of installed sensors is verified to ensure they provide accurate information to the BIT system. Generally, a BIT system that can detect short or open circuits between components and controller is desirable.

4.5 Typical Air Conditioning Systems:

Two types of systems are commonly used to condition the air supplied to the interior of fixed wing airplanes. These are referred to as vapor cycle and air cycle; the latter type being more common.

A typical air cycle air conditioning pack of a fixed wing aircraft is shown in Figure 3. The pack consists of an air cycle machine (ACM) of the bootstrap type, two heat exchangers, a water separator, a cooling air fan, and necessary valves and controls. On commercial airplane there are usually two packs. One pack is controlled by the flight deck temperature controller and the other by the passenger cabin temperature controller.

Refer to Figure 3. The flow control and shut off valve controls the flow of high pressure and high temperature air from the pneumatic system. Downstream of the valve the air splits in two paths. During maximum cooling mode of operation, a major portion flows through the primary heat exchanger and rejects its heat to the ram air. It then flows to the compressor section of the ACM. The compressor compresses the air and delivers it at higher pressure and temperature to the secondary heat exchanger wherein the air rejects heat to the ram air. Moderate temperature and high pressure air then enter the turbine section of the ACM. The air generates work in the turbine and reduces in temperature. The compressor absorbs the power produced by the turbine. The low temperature turbine exhaust flows to the water separator wherein the condensed moisture (present in the pack supply air) is removed. A temperature sensor, 35 °F, continuously monitors the temperature in the water separator. It causes the 35 °F control valve to open and provide warm air, from downstream of the primary heat exchanger, when the temperature falls below 35 °F. This prevents freezing of moisture in the water separator. The mix valve controls the cold air and hot air flows. Filtered recirculation mixes with pack supply air in the distribution manifold. Air mixture is ducted to the various sections for distribution. The distribution air temperature (mix valve position) is controlled by the cabin temperature controller. The air is at the temperature required to meet the cooling requirements of the hottest zone. Other zones are trimmed up by hot air supplied to each zone by

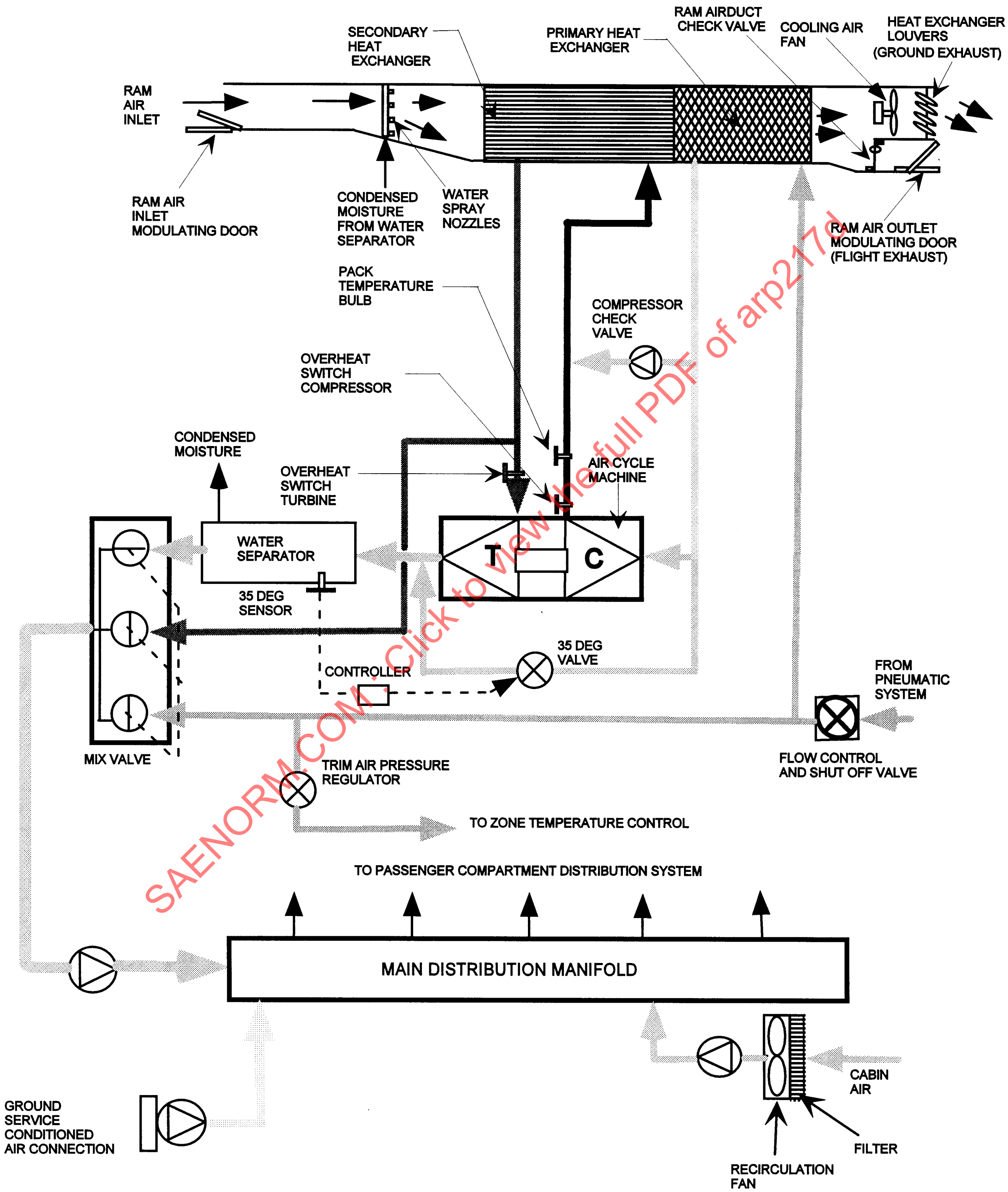

FIGURE 3 - Typical Air Cycle Air Conditioning Pack

4.5 (Continued):

the zone temperature control system, not shown. The mix valve causes greater portions of supply air to bypass the cooling pack when less cooling is required. This causes reduction in pressure downstream of the primary heat exchanger and reduction in pack cooling capability. At low supply pressure the air bypasses the compressor and the turbine. Sensors are provided at various locations in the pack for control (ram-air inlet modulating door), and safety (over temperature protection).

The ram-air duct houses the primary and secondary heat exchangers. The pack cooling fan (electrical shown) induces outside air on ground and at low speeds. At high speeds the forward speed causes the air to flow through the ram air duct.

The air supply to the pack is controlled by a pack flow control and shut off valve. Temperature sensors are installed downstream of the compressor to modulate ram air inlet and exit areas to maintain temperature within design limits. Thermal switches are incorporated in the compressor discharge and turbine inlet ducts to detect system anomalies and automatically take preventive actions. A temperature sensor is installed in the water separator inlet duct to sense water separator inlet air temperature and command the 35 °F (2 °C) valve to supply warm air to maintain the temperature above 35 °F (2 °C). This prevents freezing of moisture in the water separator. Cabin air is recirculated by electrical fans. They provide filtered spent cabin air to the distribution manifold. The recirculated air mixes with the conditioned air, supplied by the packs, before distribution inside the cabin. Recirculation enhances ventilation rate. It allows reduction of outside air for a constant ventilation rate.

Fighter airplane typically do not recirculate cabin air. Expended cabin air is exhausted overboard; directly or after use for equipment cooling. Fighter airplane typically has one pack.

A typical vapor cycle air conditioning pack is shown in Figure 4. The pack consists of an evaporator, a thermal expansion valve, a compressor, a condenser, a receiver, a hot gas bypass valve, a quench valve, a cooling air fan, and necessary valves and controls. Supply air (manifold air or cabin recirculation air or a mixture of manifold and cabin air) flows through the evaporator and transfers its heat energy to the refrigerant. The air becomes cool and flows to the distribution manifold. The refrigerant changes from liquid-vapor to gaseous state on absorption of heat. The refrigerant gas is drawn in by the compressor. The compressor raises the pressure and temperature of the warm refrigerant gas to a higher level and delivers it to the condenser. In the condenser the gas is cooled by outside ambient air. On ground and at low speeds, the cooling fan draws ambient air through the condenser. In flight, above a designed flight speed, ambient air flows through the condenser due to ram pressure and the fan ceases to operate. In the condenser the refrigerant gas condenses to a liquid which is stored in the receiver. The refrigerant system is "closed" loop in which the refrigerant gas is compressed, condensed to a liquid, expanded to a liquid-vapor mixture, and finally evaporated back to the gaseous state. A pressure sensor, located in the condenser continuously monitors the pressure. This pressure signal is used by the ram air modulation system to position the ram air inlet and exit doors so that a pressure corresponding to the preselected condensing temperature is maintained.

Fighter airplane typically has one pack. Some military airplanes have both air cycle and vapor cycle systems; air cycle for cabin conditioning and a vapor cycle for avionics cooling.

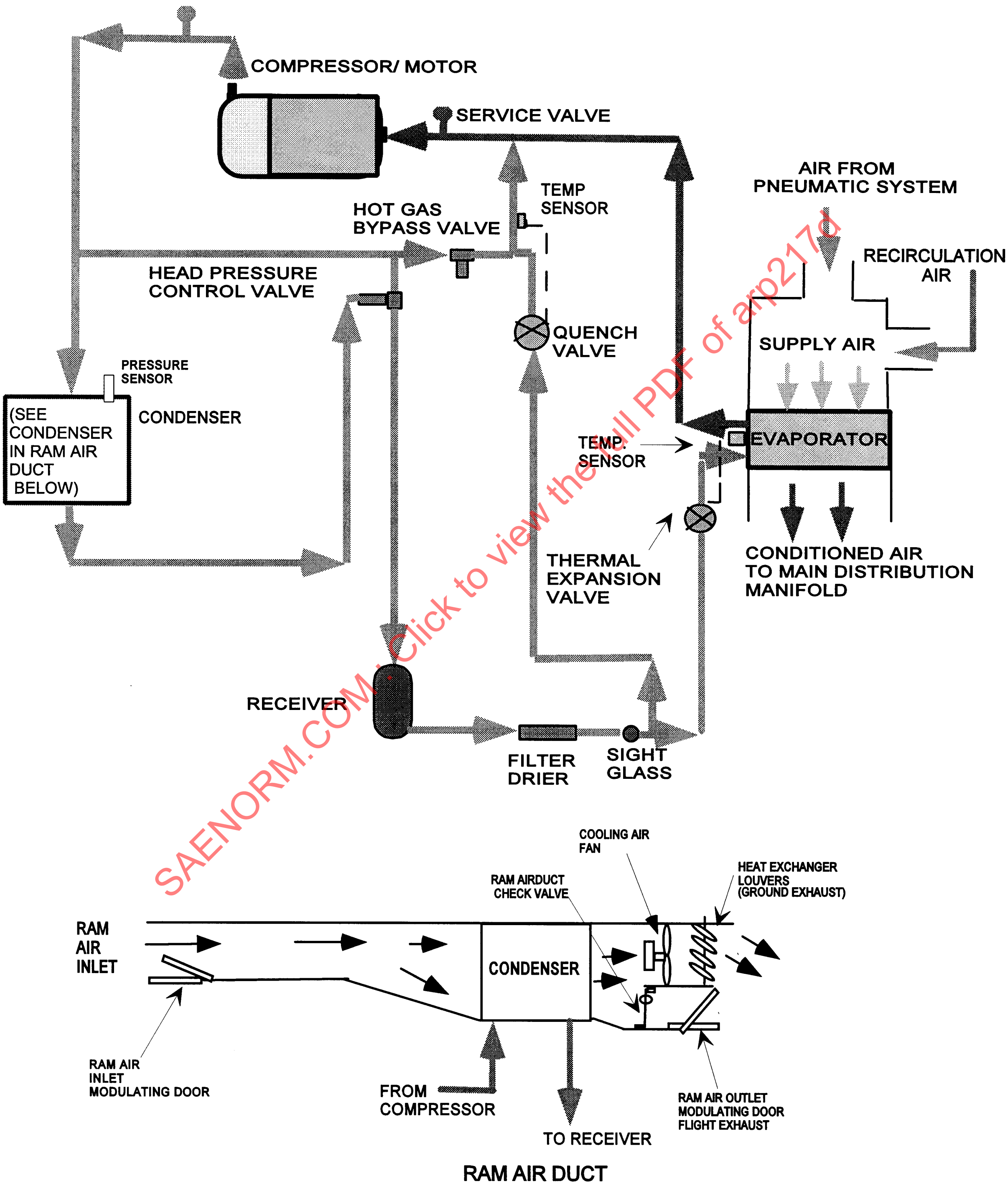

FIGURE 4 - Typical Vapor Cycle Air Conditioning Pack

4.5.1 Air Conditioning System Ground Tests: Ground tests typically performed on an air conditioning system are described in this section.

4.5.1.1 Pressure Integrity or Leakage: The purpose of this test is to ensure that the system (i) can withstand normal operating pressures, (ii) the clearances under pressure load conditions are as defined in design documentation, (iii) the ducting connections have been properly assembled within acceptable leakage limits, and (iv) there is no concentrated leakage and the overall leakage is below estimate. This test uses an external pressure supply connected such that desired sections of the system can be pressurized. The test is conducted in two parts: upstream and downstream of the ACM. Caution should be exercised not to pressurize any component greater than the normal operating pressure. A flow measuring device (flow meter or calibrated flow tube) is installed between the compressed air supply and test section connection to measure the flow required to maintain the section at a constant pressure. The compressed air supply should be able to provide flow greater than the estimated leakage at the maximum test pressure.

To conduct the test, one end of the section to be tested is blanked and compressed air supply connected to the other end by appropriate means. Any check valves in the test section that would prevent a section to be pressurized are removed and replaced by duct sections, as necessary. The external high pressure supply is connected to the test section and pressurized to a low pressure (approximately 10% of the design pressure). Flow required to maintain the test section at the selected pressure is determined and compared to the estimated leakage. The estimate should include the internal leakage of the control valves exhausting out of the duct system. If the leakage is greater than the estimate, leakage source is determined (feeling for air movement, listening for noise, observing for soap solution bubbles, etc.) and corrected. The duct system is inspected for deflections under pressure loading to ensure the clearances are as defined in design documentation.

On satisfactory completion of the low pressure test and inspection, the system is progressively pressurized to higher pressures, and the flow required to maintain the system at constant pressure is determined. Extreme caution should be exercised in the conduct of the test as failure of system components can cause equipment damage or personnel injury.

Typically, an ACM type air-conditioning system test consists of three parts: (1) pack inlet to turbine inlet, (2) pack discharge to pressure bulkhead, and (3) collection and distribution ducting within the pressurized volume.

After system check, removed equipment is re-installed and an additional check made of the overall system.

4.5.1.1 (Continued):

Pressure integrity and leakage test of the closed loop refrigerant system are performed during pack manufacture and assembly. Test of the refrigerant loop of the installed vapor cycle pack is not necessary. However, if any connections are made during pack installation they should be leak tested using suitable leak detecting instruments. Typically, the air supply system of a VCM type air-conditioning system consists of three parts: (1) pack inlet to evaporator, (2) evaporator discharge to pressure bulkhead, and (3) collection and distribution ducting within the pressurized volume.

After system check, removed equipment is re-installed and an additional check made of the overall system.

4.5.1.2 Integration and Compatibility: This test verifies that the air conditioning system is properly integrated and it is compatible with other on-board systems.

Refer to Figures 3 and 4. The air-conditioning system is operated with engine bleed or APU bleed or ground air. To verify integration and compatibility, the pack is operated using each source of air in turn. Different temperature selections are made and the operation of the pack, interface systems, and airplane instruments are observed.

To verify pack integration and compatibility with the APU, the pressure upstream of the flow control valve is observed when the pack is turned on and off. The pressure should be stable with no large overshoots or undershoots. The APU (load compressor and surge valve if applicable) should automatically adjust to changes in APU bleed flow. After completion of the test the conditioned air supply duct and the distribution manifold should be checked to verify there is no undesirable accumulations of condensed moisture.

The pack compatibility with the engine bleed air system is verified in a similar manner. The engine bleed-air system is operated at various engine power settings and with all probable combinations of bleed-air loads. All (standby, auto) operating modes of the temperature controller are exercised and various temperature settings are selected. The response of indicators to manual inputs is verified. Recirculation fans, are switched on and off to verify that they operate satisfactorily.

The test procedure for air cycle and vapor cycle type air conditioning systems is essentially the same.

The operation of the distribution system is checked by examining various sections of the compartment for stagnant air or high noise areas. The distribution outlets are checked for dripping water. Operation of the galley and lavatory vent system is checked . The operation and control logic of the equipment, galley and lavatory fans, if integrated with the pack, are verified.

Airplane doors are closed and with the packs operating normally, the integration and compatibility of the pressure control system is verified. The cabin-to-ambient differential pressure is observed and verified to be less than the maximum allowable limit as defined in design documentation. Various selector options are exercised to ensure that there are no undesirable cabin altitude excursions and the indications are true.

4.5.1.2 (Continued):

If the conditioned air is used for defogging, equipment cooling, gasper air or other services, then these services are operated to ensure that they are integrated properly and they are compatible with other on-board systems. System valves are operated to verify that there is no objectionable noise.

After completing the engine bleed air system and air conditioning system integration and compatibility verification at steady state engine power conditions, the compatibility during transient engine power conditions is verified. The throttle is advanced and retarded, within allowable limits, at various rates simulating normal and abnormal throttle operations. It is verified that there are no undesirable over- and under-shoots, or unstable behavior, the protective devices perform the intended functions, and the cockpit indications are true. Features added in the air conditioning system to accommodate faults (e.g., high flow schedule for one pack failure) or other constraints (e.g., reduced flow schedule to accommodate flow demands of air turbine hydraulic pump) should be tested as appropriate.

4.5.1.3 Performance: Maximum cooling and heating capability of the pack may be determined during the ground test. This test requires the pack, the distribution system and the recirculation systems to be functionally equivalent of the production configuration. The temperature, humidity and flow rate are measured at pack discharge (water separator discharge for air cycle pack and evaporator discharge for vapor cycle pack) to determine maximum cooling and heating capabilities.

It is desirable to run the cooling test in high temperature (ambient temperature 20 °F (11 °C) greater than desired cabin temperature, minimum) and high humidity ambient conditions. (Humidity of pack supply air can be increased to the desired level by injecting moisture in the pack supply air.) However, conduct of the test at the critical specification condition is not necessary since the performance can be estimated by the use of a validated simulation model. The test is conducted using "specification" air supply (engine or APU bleed for air cycle pack, cabin air or engine bleed for vapor cycle pack) and by operating the pack in the maximum cooling mode. One may elect to install additional instrumentation (compressor discharge, turbine inlet, ram air system etc.) to obtain data for validation of the pack simulation model.

It is desirable to run the heating test at low ambient temperature. Conduct of the test at critical specification condition is not necessary as a validated simulation model can be used to predict performance. The conduct and instrumentation requirements of this test are similar to those of the cooling test, described above, except that the pack is operated in the maximum heating mode.

4.5.1.3 (Continued):

The pull-down test is similar to the maximum cooling test. It is run with a heat-soaked airplane (cabin interior air temperatures essentially equal to outside ambient and at least 20 °F (11 °C) greater than desired cabin temperature). Interior temperature can be greater than outside ambient due to solar radiation in compartments that have large transparent areas. The temperature increase depends on a number of factors: radiation intensity, incidence angle, transmissivity of transparent surfaces, form factor, etc. Temperature stability of the interior is assumed to occur when the rate of change of cabin temperature is less than 2 °F/h (1 °C/h). Heat loads specified in the specification are simulated and the pack operated in the automatic mode using APU (or engine) bleed. Cabin temperature history is recorded together with selected pack, distribution system, airplane configuration, and ambient parameters. The test should be performed on an airplane representative of production configuration as airplane thermal inertia significantly impacts pull-down time. The pack is run in the automatic mode until a steady state cabin temperature is reached. The cabin-temperature/ time characteristic is used to determine cabin pull down time constant. This constant may be used to determine pull down capability at the specification condition.

The pull-up test is similar to the pull-down test except that it is conducted in low ambient temperatures (ambient temperature at least 20 °F less than desired temperature) and with heat loads representative of cold weather operating conditions. The pull-up temperature constant is determined from the cabin temperature/ time history. This constant may be used to determine system pull-up capability at the specification condition.

Additional tests using engine bleed, with the engine at various power settings, may also be performed. To minimize testing, good understandings of the engine bleed air system and pack interface are important. The engine bleed air system described in 5.4 incorporates a pressure regulator valve that limits downstream pressure to 45 psig ±5 psig (310 kPa ± 34 kPa gage). Also, the system incorporates a precooler temperature control system which controls precooler discharge air temperature to 380 °F ± 20 °F (193 °C ± 11 °C). It would be apparent that once these conditions, downstream of the pressure regulator valve, are achieved tests at higher power settings (engine bleed air pressures or temperatures) do not provide any useful data.

Heat gain (or loss) in the distribution system ducting, water extractor efficiency, and operation of the 35 °F (2 °C) outlet temperature control can also be evaluated during the pack steady state performance test by incorporation of appropriate instrumentation.

To evaluate water removal efficiency, one may inject water in the pack supply air to increase its specific moisture content (maximum 200 grains per pound (59 mg/g) suggested). Generally, detailed test of the cooling package components is not cost effective in an airplane ground test. Such tests should be performed in the laboratory where test conditions can be controlled.