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Environmental Control System for Military & Civil Aircraft

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The technology used for air conditioning of all types of Military/Civil aircrafts is predominantly Air Cycle air Conditioning. Based upon Joule or Reversed Brayton Cycle, the system utilizes the high temperature, high pressure bleed air extracted from compressor of main engine/APU. It not only enjoys the advantage of simplicity and inherent compactness of pneumatic equipment but also meets the integrated cooling and pressurization requirements of an aircraft.

Both air-cycle based refrigeration system which lowers the enthalpy level of air by transforming heat energy into work and conventional vapor compression cooling system that extracts heat by evaporating a suitable liquid refrigerant have their own limitations.

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ENVIRONMENTAL CONTROL SYSTEM FOR MILITARY CIVIL AIRCRAFT

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Environmental Control System for Military & Civil Aircraft

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Therefore, off late, efforts are underway to integrate both the cooling systems to provide the most cost effective solution to the problem of dissipation of heat - generated both within (personnel, flight control systems, avionics, etc.) as well as outside (aerodynamic heating & solar radiation) the aircraft The technological challenges that the industry is currently facing in this sector are – reduction of power consumption, better overall reliability with free of scheduled maintenance and improved passenger comfort. While improved control through the use of digital controller, re-circulation and increase in individual efficiency factor would minimize power input, better constancy of temperature, faster air-conditioning of cabin/cockpit and lower noise level might cater to a more comfortable air conditioning system. A better overall reliability may be achieved by incorporating cutting-edge technologies like air-foil bearing in ACM. Air-foil bearing increases the reliability of high speed. A pack concept is also employed nowadays for major ECS components to ease the installation and maintenance in the aircraft and also to reduce overall weight.

Keywords : Air Management System, ventilation, humidity/ contaminant control windshield demisting, aerofoil anti-icing, door-sealing, fuel-tank pressurization engine bay ventilation and pressurization within aircraft.

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I. Introduction

Environmental Control System or Air Management System, as it is popularly called nowadays, is a generic term used in aircraft industry for system and equipment associated with cooling, heating, ventilation, humidity / contaminant control and Pressurization within aircraft occupied compartments, cargo compartments and electronic equipment bays. It also caters to other pneumatic demands like windshield demisting, aerofoil anti-icing, door-sealing, fuel-tank pressurization and engine bay ventilation. The real challenge for an ECS is to operate and supply adequate cooling over a wide range of ground and flight conditions in a most reliable and efficient manner. Both air-cycle based refrigeration system which lowers the enthalpy level of air by transforming heat energy into work and conventional vapor compression cooling system that extracts heat by evaporating a suitable liquid refrigerant have their own limitations. Therefore, off late, efforts are underway to integrate both the cooling systems to provide the most cost effective solution to the problem of dissipation of heat - generated both within (personnel, flight control systems, avionics, etc.) as well as outside (aerodynamic heating & solar radiation) the aircraft. The areas of concern in ECS which are also drawing much attention nowadays are reduction in power consumption, packaging, schedule free maintenance, easy diagnosis & trouble shooting of malfunction, passenger/pilot comfort and environmental compatibility.

II. Design Technology

a) Air Cycle Air Conditioning

The air cycle refrigeration is the predominant means of air conditioning for commercial and military aircraft of all types. It not only enjoys the advantage of simplicity and inherent compactness of pneumatic equipment but also meets the integrated cooling and pressurization requirements of an aircraft.

Based on Joule or Reversed Brayton air cycle, this system utilizes high pressure, high temperature bleed air, extracted from the compressor of either main engine or APU. It is first routed through a primary heat exchanger where temperature is brought close to the ram-air temperature. After having the pressure of the air

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boosted by the compressor of the Air Cycle Machine (ACM) it is again led through a secondary heat exchanger for further removal of heat. It is finally expanded in the turbine to obtain sufficiently cold air. This air is then delivered into the cabin/cockpit for cooling, ventilation, and air pressurization requirements. A water separator, normally placed at the exit of the ACM, helps in removing the moisture condensed during expansion process.

Heating is achieved by mixing controlled amount of hot bleed-air, after by-passing the ACM, with the cold air that comes out of it. ECS generally consists of three major sub-systems;

i. *Engine Bleed Air System (EBAS)*

This pneumatic system includes equipment and ducting that supply bleed air from the power source to the air conditioning system. Here the air, tapped from the compressor of the engine/APU, flows through bleed air shut-off-valve (BASOV), Non-Return Valve (NRV) and Pressure Regulating and Shut-Off Valve (PRSOV) before entering the air conditioning system. The solenoid operated BASOV opens when air-conditioning is selected. The NRV is normally fitted to prevent cross flow between engines in the event of single engine operation. The PRSOV limits the bleed air pressure to suit the system requirement.

The technology growth has enabled EBAS, nowadays, to handle bleed air at high temperature. The proprietary Ni-alloy (HAYNES 25 BS HR 40, DEVA Grade 7218/20, etc.) Sealing Rings & Bushes and Carbon Gaskets & Bearings, made out of St. Steel reinforced graphite laminated foils and Carbon Le Carbon JP 600 .Most often, there are two air-conditioning packs for safety (3 packs on B747 and DC10), nominally supplying 50% of air needs, but able to operate at their 180% nominal flow rate in case of one failures. On twin-engine aircraft, each engine bleeding is designed to supply half the total air flow (although the two bleedings are connected). On three-engine aircraft, the third engine bleed is on stand-by for redundancy. On 4-engine aircraft each bleeding only supplies ¼ of the total design flow.

Control valves in all the bleed system below protect against flow reversal, and maximum bleeding (e.g. in case of a break)

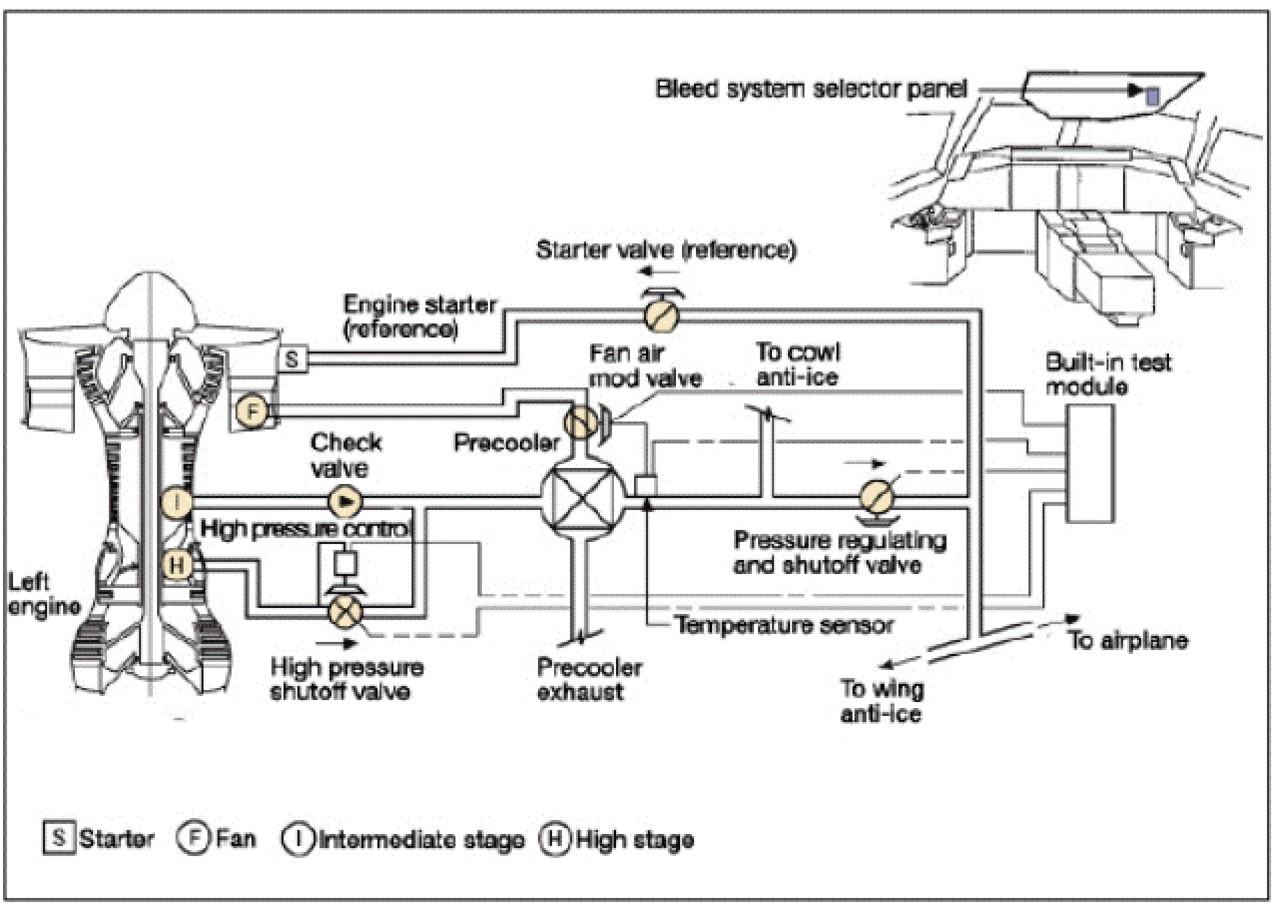

Fig : showing Some of the control valves in the bleed system (from Boeing)

Flow rate multiplier. If only hot air is needed, a small amount of bled air at 250 kPa and 180 ^{o}C may be used to pump the necessary total flow rate (5 L/(s•pax)) from outside air (at 25 kPa, 250 K) with:

- A jet pump.
- A compressor, driven by a turbine in the bled stream.

Respectively are fitted to the high temperature valves and their control units. This enables the system to tap air at a temperature of 550^{o}C to 650^{o}C from high-pressure stages of compressor thus providing higher operational pressure for ECS.

The system has also gained capability of providing altitude compensated pressure regulation of bleed air where the pressure of the bleed-air flowing out of it is regulated with the aircraft altitude thus optimizing the tapping of bleed air in accordance with the cooling load of the aircraft. As for example, the pressure regulation characteristic of PRSOV used in LCA is a smooth curve that limits the pressure to 6.5, 5.0 and 4.3 bar at a height of 0, 7 and 15 km from the sea-level respectively. As a system protection device, when PRSOV fails open, EBAS incorporates an overpressure switch. The function of this switch is to sense the rising pressure downstream of the PRSOV and send signal to close all SOVs. The overpressure switch used in LCA EBAS has an over pressure setting of 7.35 $\pm$ 0.35 bars to restrict the max. transient downstream pressure of the PRSOV to this value.

ii. *Air conditioning System*

The design of air conditioning system always centers around its air cycle machine. Modern day's system has evolved from simple low flow turbo-cooler based refrigeration with low pressure water separator, manual temperature control and water-air/air-air radiator to intelligent digital controller based air conditioning & temperature Control System configured with 2-wheel, 3-wheel or 4-wheel boot strap air cycle machine, high pressure water extraction, regenerative heating and light weight air-to-air heat-exchangers.

a. *Digital Controller*

The digital controller based ECS not only maintain cabin/cockpit temperature with a high degree of precision but also offers numerous options such as digital temperature displays and inputs, digital bus connectivity (to on-board computer) Laptop based diagnostics s/w and re-programmable control equation inputs. Sensor at the inlet of the cabin/cockpit allows it to precisely control the temperature of air entering the cabin as control algorithms constantly calculate the inflow temperature required to meet the changing temperature requirements. The system is also capable of maintaining the correct air temperature entering the ACM through a sensor located at the d/s of the primary heat exchanger and then controlling the amount of by-pass bleed air for the Primary Heat Exchanger. This results in an optimum inlet condition for the ACM and guarantees an efficient operation of the unit.

The digitally controlled inflow control system also have the unique ability to set multiple inflow rates for multiple flight conditions as against single or dual flow setting system typically found in pressure regulator or flow limiting orifice based bleed flow control system. All these facilities reduce the pilot load tremendously.

b. *High Pressure Water Removal*

High pressure water extraction loop comprise of condenser, high pressure water separator and re-heater. This moisture removal technology eliminates icing at ACM outlet, enables turbine exit temperature to attain sub zero state and avoids the usage of complex condensing type heat exchanger. It also obviates regular maintenance involved in conventional type low-pressure water separator and complexity of ducting.

c. *Air Cycle Machine*

The design of ECS normally centers around a high efficiency air cycle machines. These are generally 2-wheel units comprising of either centrifugal compressor and radial turbine or radial/axial fan and a radial/axial turbine mounted on the same shaft. However, technology improvement has introduced 3 wheel ACM consisting of a turbine, compressor and fan and 4 wheel ACM consisting of two turbines, a compressor and a fan to achieve a high level of cooling capacity for ECS. These ACMs are in operation particularly in commercial aircraft/Helicopters. A pair of patented Hamilton-Sundstrand four wheel ACMs form the heart of the air management system on the world's largest twinjet the Boeing 777. The centrifugal/axial fans, used in the above units, are either to load the turbines or to induce air flow through heat exchangers or to discharge air over board.

The space and weight constraints in airborne application render the rotating elements in the ACM to extremely small sizes of O/D 75 to 100 mm. Therefore to handle huge air mass flow rate required by the system and also to effect a large enthalpy drop, these turbomachines have a very high rotational speed of 60,000 to 90,000 RPM. Hence criticality of design of these units involves handling of seal leakage, bearing lubrication, balancing of rotating assemblies and counter balancing the end thrusts for all flight conditions

The manufacturing of various detail parts of an air cycle machine maintaining close dimensional and geometrical tolerances is a major challenge to the industry. Generally, 4 or 5-axis CNC machines are used to fabricate Aluminium/Stainless Steel turbine wheels or titanium compressor impellers/blowers. The closeness of the tolerances can be gauged from the fact that the bore dia. of the wheels are maintained within 8-9 microns with ovality restricted to within 3 – 4 microns. The inducers and the exducers of the turbine wheel/compressor matched sets are fabricated using precise investment casting technology.

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The Scroll Sheet Metal Sub-Assy. is made out of 1 mm thick stainless steel sheet using argon gas welding to get the correct volute area distribution. The diffuser ring, which provides a divergent passage for the air at the Scroll Assy. inlet is manufactured through either investment casting or CNC milling and integrated with the cover plate using Electron Beam Welding technology.

The Drilled-hole Nozzle, made out of stainless steel, after fabrication is coated with tungsten-carbide to eliminate the erosion problem associated with high temperature air flow. The holes in this component are drilled in two rows to reduce vibrational effects and increase the endurance life of the expander. Due to space constraint, the two rows are staggered.

The Torus Assembly which houses torus inlet to receive and direct air it to nozzle inlet, torus-outlet for discharging cold air and bypass inlet is manufactured using investment casting.

The assembly of ACM is also equally challenging. The fits and clearances of the mating parts are to be precisely maintained to contain the internal vibration of the unit and prevent rubbing between two parts which leads to undesirable temperature rise within the unit. The rotating elements are also separately balanced in a balancing machine for a min. unbalance of 14 mgm-in. This prevents rotational vibration and ensures a service life of the unit that match with the other rotables fitted in the aircraft. The clearances between the stator and the rotor of the turbomachines e.g. the compressor wheel and the scroll assy. or the turbine wheel and nozzle are maintained to around 0.25 –0.3 mm since the efficiency of the turbo machines is very sensitive to this parameter.

The critical aspect of testing of Air Cycle Machines is accurate measurements of performance parameters at controlled/design inlet conditions. The temperatures are measured by using K type thermocouple or 4 wire RTD. The pressure values are sensed using the static pressure tapping and ceramic sensing elements based pressure transducers. Orifice plates and electronic multivariable flow transmitter are used to measure the mass flow. The vibration level & RPM of the unit is measured and dispayed through accelerometer & magnetic pick up respectively. While the Bourden tube pressure gauges, single/multiple channel digital temperature indicators display the reading on the panels, the output of the RTD, pressure transducer, variable flow transmitter, accelerometer and magnetic pick up are also simultaneously sent to data acquisition system for on line data logging /display and future data analysis and presentation.

iii. *Pressurization system*

The pressurization system comprises of pressurization control, outflow valve, positive pressure relief valve, vaccum/inward relief valve and pressurizing indicating and warning. The system controls absolute pressure of the cabin/cockpit by modulating the outflow of air from it through one or more outflow valve and the rate of pressure change. While the positive pressure relief valve prevents over-pressurizing the aircraft occupied space the vaccum/inward relief valve prevents the pressure inside the cockpit/cabin from becoming less than that desired. Pressure indicators are provided to allow monitoring of cabin altitude, differential pressure and rate of pressure change. Normally the control of cabin altitude in a civil aircraft is isobaric type and maintained around 8000 feet. The warning system sounds alarm if the cabin altitude exceeds approximately 10000 feet. For military aircraft this can be less stringent. Above a certain height the constant differential pressure control overrides the isobaric control and a constant difference between cockpit and ambient pressure of around 5 psi is maintained till the ceiling altitude.

Normally these pressure controllers are electrically operated. However, with the advent of digital controller the pressure controller can be electronically controlled. Algorithms for cabin pressure control can be programmed into the controller to enable maintenance of accurate and comfortable pressure levels inside the cabin/cockpit.

a. *Vapor Cycle System*

The Air cycle refrigeration system, operating on bleed air drawn from the engine, imposes a major fuel penalty on the aircraft. The associated large ram-air drag and icing at the exit of the turboexpander due to moisture content also restricts its application to a certain degree. The vapor cycle systems are free from these deficiencies. It has a high and fairly constant COP compared to air-cycle system whose COP falls with the aircraft Mach No.

The main components of this system are evaporator, compressor, condenser, refrigeration receiver, expansion valve, refrigerant filter drier, high-pressure cut-out switch & blow-out plug. The cooling of occupied and equipment compartment is accomplished by re-circulation of compartment air through the evaporator. Make-up air is generally ducted to the compartment to maintain pressurization and ventilation requirement. Heating is accomplished in the same manner as it is done in the air cycle system.

The filter-drier absorbs moisture and removes foreign matters, acid, sludge etc. As a safety device, the high-pressure cut-off switch shuts down the compressor in the event of excessive refrigerant vapor pressure and protects the system against operational overloads. Provisions are also made to prevent frosting of the evaporator during low cooling load condition and facilitate collecting and draining overboard the moisture.

The main advantage of vapor compressor cycle system is its packaged configuration that facilitates its

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installation, removal and maintenance in the aircraft. Also, reliability and life span of high performance flight control systems and avionics warrants supply of air at low and constant operating temperature with reduced humidity that is easily obtained using vapor cycle system.

Today, Hamilton-Sundstrand VCS, using high efficiency Nonazeotropic Refrigerant Mixture (NARM) are found in NH NATO helicopter, Sikorsky S-92 Civil Helicopter and USAF F-16. Hybrid systems are also becoming quite popular. Still a proprietory concept of companies like Honeywell, this new technology combines both Vapor Cycle and Air Cycle system to provide air conditioning in the cabin. The system switches from bleed-air to closed loop refrigerant in flight.

The reliability and life span of high performance flight control systems and avionic increase with low & constant operating temperature and reduced humidity and pollution. Only dedicated liquid cooling system can meet this environmental specifications needed for modern avionics. USAF is thus contemplating on integrating electrically driven on-board vapor cycle heat pump into the F-16's current cooling system so that the aircraft may be retrofitted with advanced, reliable avionics and electronics modules at low cost.

III. Conclusions

The technological challenges that the industry is currently facing in this sector are – reduction of power consumption, better overall reliability with free of scheduled maintenance and improved passenger comfort. While improved control through the use of digital controller, re-circulation and increase in individual efficiency factor would minimize power input, better constancy of temperature, faster air-conditioning of cabin/cockpit and lower noise level. All these cater to a more comfortable air conditioning system. A better overall reliability may be achieved by incorporating cutting-edge technologies like air-foil bearing in ACM. Air-foil bearing increases the reliability of high speed turbomachines more than tenfold. It enables the turbomachines to rotate at a higher speed. Since no lubrication is required, these bearings can withstand severe environmental conditions. It also eliminates routine maintenance and oil filling of rotating element bearings. A pack concept is also employed nowadays for major ECS components to ease the installation and maintenance in the aircraft and also to reduce overall weight. It is worth noting that the quality of the volume ofair is maintained from the time it enters the aircraft's engineto the time it is expelled overboard is very high. All of the processesinvolved maintain or reestablish the purity of the air volume.The results of many cabin air quality tests reinforce thisconclusion. As this brief paper illustrates, the ECS of today's jetliners is carefully engineered to provide superior cabin air.

IV. Abbreviations

ACM : Air Cycle Machine
APU : Auxiliary Power Unit
EBAS : Engine Bleed Air System
ECS : Environmental Control System
NATO : North Atlantic Treaty Organization
PSOV: Priming Shut off Valve
RTD : Resistance temperature detectors or resistive thermal devices (RTDs)
USAF : United States Airforce
VCS : Vapor Cycle System

References References Referencias

1. De Doncker, R., Pulle, D. and Veltman A., "Advanced Electrical Drives: Analysis, Modeling, Control", Springer, New York, 2010
2. John Croft, "MRO USA: Engine Diagnostics: GE opens the envelope", http://www.flightglobal.com /articles / 2010/ 04/ 20/ 340710 / mro - usa - engine diagnostics-ge-opens-the-envelope.html, 2010
3. Gerstler, W.D., and Bunker, R.S., "Aviation Electric Power". Mechanical Engineering, December 2008, pp 74-75
4. Moir, I. and Seabridge, A., "Aircraft Systems, mechanical, electrical and avionics subsystems integration", 3rd edition, John Wiley & Sons, Chichester, England, 2008.
5. Faith, L.E., Ackerman, G.H., and Henderson, H.T., "Heat Sink Capability of Jet A Fuel: Heat Transfer and Coking Studies", Shell Development Co., S–14115, NASA CR–72951, 1971.
6. USAF Scientific Advisory Board, "New World Vistas: Air and Space Power for the 21st Century", Materials Volume, Washington, D.C., 1996.
7. David R. Space and Dr. Fred E. Tilton[1] De Doncker, R., Pulle, D. and Veltman A., "Advanced Electrical Drives: Analysis, Modeling, Control", Springer, New York, 2010.
8. Commercial Airliner Environmental control System: Engineering aspects of Cabin Air Quality by: Elwood H. Hunt, Dr. Don H. Reid,
9. De Doncker, R., Pulle, D. and Veltman A., "Advanced Electrical Drives: Analysis, Modeling, Control", Springer, New York, 2010.
10. John Croft, "MRO USA: Engine Diagnostics: GE opens the envelope", http://www.flightglobal.com/ articles/2010/04/20/340710/mro-usa-engine-diagnostics-ge-opens-the-envelope.html, 2010.
11. Gerstler, W.D., and Bunker, R.S., "Aviation Electric Power". Mechanical Engineering, December 2008, pp 74-75.
12. Moir, I. and Seabridge, A., "Aircraft Systems, mechanical, electrical and avionics subsystems

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integration", 3rd edition, John Wiley & Sons, Chichester, England, 2008.

13. Faith, L.E., Ackerman, G.H., and Henderson, H.T., "Heat Sink Capability of Jet A Fuel: Heat Transfer and Coking Studies", Shell Development Co., S–14115, NASA CR–72951, 1971.
14. USAF Scientific Advisory Board, "New World Vistas: Air and Space Power for the 21st Century", Materials Volume, Washington, D.C., 1996.
15. http://en.wikipedia.org/wiki/Environmental_Control_System.
16. http://www.liebherr.com/ae/en/products_ae.asp?menuID=106050!160-0. Liebherr-Aerospace has designed, developed, manufactured and serviced airplane and helicopter air conditioning systems for more than 50 years.
17. Neese, B., 1999, "Aircraft Environmental Systems", Endeavor Books.
18. Pérez-Grande, I., Leo, T., 2002, "Optimisation of a commercial aircraft environmental control system", Applied Thermal Engineering 22 (17), pp. 1885–2004.
19. Leo, T., Pérez-Grande, I., 2005, "A thermo-economic analysis of a commercial aircraft environmental control system", Applied Thermal Engineering 25, pp. 309–325.Cebeci, T., Kafyeke, F., 2003, "Aircraft icing", Annu. Rev. Fluid Mech. 35:11–21.
20. Fortin, G., Laforte J.L., Ilinca A., 2006, "Heat and mass transfer during ice accretion on aircraft wings with an improved roughness model", International Journal of Thermal Sciences 45, 595–606.Saeed, F., 2002, "State-of-the-Art Aircraft Icing and Anti-Icing Simulation". ARA Journal, Vol. 2000-2002, No. 25-27.

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