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DESIGN OF AN AIR-CONDITIONING SYSTEM FOR A DOMESTIC AEROPLANE

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ABSRTACT

Air conditioning system for a passenger aircraft is a very essential and an important aspect in maintaining temperature in the cabin which provides a suitable environment for passengers and maintaining proper working conditions of equipment present overboard which will further help in an efficient flight time. Due to excess radiation from sun the atmospheric air inside and outside of the cabin differs and variation of temperature and pressure with increasing and decreasing altitude brings a major discomfort for the passengers present which would lead to major health problems. So in order to sustain such harsh conditions we design an air conditioning system which is suitable for the maximum work load or heat dissipation. Equipment such as heat exchanger, condenser and evaporators with suitable dimensions and capacities are employed.

1. INTRODUCTION

Environmental control system (ECS) is a generic term used in the aircraft industry for the systems and equipment associated with the ventilation, heating, cooling, humidity control, and pressurization in the occupied compartments, cargo compartments, and electronic equipment bays. The primary function of the cabin air conditioning and pressurization system is to maintain an aircraft environment that will ensure the safety and comfort of the passengers and crew during all flight operational conditions and provide adequate avionics cooling. This includes a supply of conditioned air for heating and cooling the cockpit and cabin spaces. . Therefore, the aircraft air-conditioning packs must provide essentially dry, sterile, and dust free conditioned air to the airplane cabin at the proper temperature, flow rate, and pressure to satisfy these pressurization and temperature control requirements. Also aircraft systems must be light, accessible for quick inspection and servicing, highly reliable, tolerant of a wide range of environmental conditions, able to withstand aircraft vibratory and maneuvour loads, and able to accommodate failures occurring during flight. Hence, design conditions for aircraft purposes differ in several ways from other air conditioning applications. Air cycle refrigeration is a tried and tested technology that has long been the basis of aircraft cabin cooling since air is free, safe and harmless to the environment. The use of air as a refrigerant is based on the principle that when a gas expands isentropically from a given temperature, its final temperature at the new pressure is much lower. The resulting cold gas can then be used as a refrigerant, either directly in an open system, or indirectly by means of a heat exchanger in a closed system. The efficiency of such systems is limited to a great extent by the efficiencies of compression and expansion, as well as those of the heat exchangers employed. Hence, the air cycle machine has evolved as a widely used means of providing cooling for aircraft and helicopters. Compressed air extracted from one or more stages of the engine compressor expands through a turbine with the power extracted used to drive a fan a compressor both. The power extraction and expansion of the compressor air across the turbine results in a significant temperature decrease. This air provides cooling for the aircraft occupied compartments and avionics. Some of the bleed air from the engines can be bypassed around the air-conditioning pack if warm is need in the cabin. It is well known that weight and space results in severe fuel penalties for aircraft applications. Air cycle machine presents lower coefficient of performance (refrigerating effect unit per required power) than a vapour-compression system but provides weight advantages due to no heat exchanger required at the cold cycle end (low pressure/temperature), as detailed in . Moreover, a common turbo compressor for both the propulsion turbine and refrigeration plant results in a greater overall power saving.

Some additional advantages of an air cycle with regard to its application in aircraft refrigeration can be listed as follows:

i. High ventilation rate necessary for the pressurized aircraft cabin.
ii. High flow rate of compressed air for cabin pressurization.
iii. Part of compression work can be attributed to cabin pressurization (also necessary if other refrigeration cycle is used).
iv. One equipment for cooling/heating load (an independent heating equipment is necessary for another refrigeration cycle).

1.2 Flight scenario and air cycle machines

Flight Scenario and Air Cycle Machines Cabin altitude and pressure changes are much smaller in magnitude on today's high altitude pressurized jets than they were during past flights. Although the percentage of oxygen in cabin air remains virtually unchanged (21 percentile) at all normal flight altitudes compared to sea level, the partial pressure of oxygen decreases with increasing altitude. This is because with increasing altitude air is less densely packed, resulting in fewer molecules of oxygen available for each occupant breathing cycle. At a maximum cabin altitude of 8,000 feet, the partial pressure of oxygen is about 74 percentile of the sea level value requiring an adequate pressurization system to maintain a suitable comfort level to the passengers and crew. A typical flight will cruise at 36,000 feet (~11,000 m), resulting in a cabin altitude of 6,000 feet (~1,800 m). Figure 1 shows a typical cabin and airplane altitudes schedule. An air-conditioning pack is an air cycle refrigeration system that uses the air passing through and into the airplane as the refrigerant fluid. Fresh air is bled from the compression stages of the engine and supplied, after conditioning, to the cabin to control such factors as temperature, pressure, and contaminant level, which may greatly influence passengers' perceptions of the cabin environment. This is accomplished by a combined turbine and compressor machine, valves for temperature and flow control, and heat exchangers using outside air to dispense waste heat. The ACM must provide essentially dry, sterile, and dust free conditioned air to the airplane cabin at the proper temperature, flow rate, and pressure to satisfy pressurization and temperature control requirements.

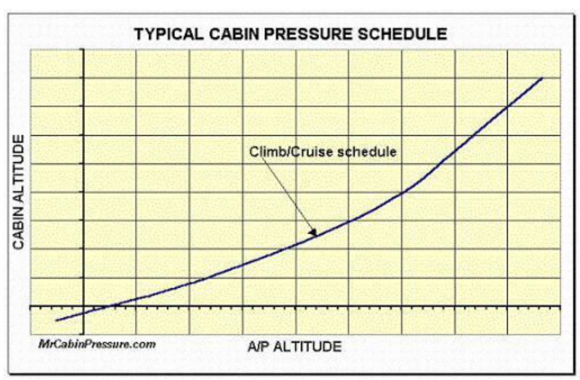

Fig 1: Typical Cabin And Airplane Altitudes Schedule.

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BOOT-STRAP AIR COOLING SYSTEM

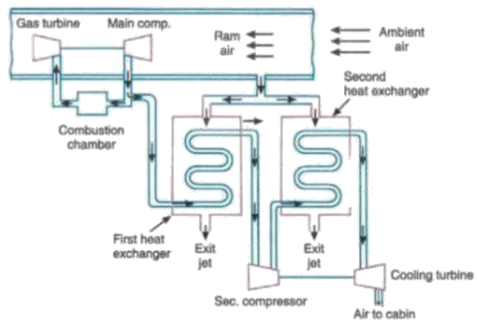

Fig 2: Bootstrap Air Cooling System

There are three basic configurations of ACM where compressed air extracted from one or more stages of the propulsion turbine compressor is cooled (by one or more heat exchangers) and expanded through a turbine.

In the simple cycle, all the ACM turbine work is consumed by the heat exchanger exhaust fan while in the full bootstrap cycle this power work is used only to drive the ACM compressor. A mixed configuration is achieved by sharing part of the ACM turbine useful work between the ACM compressor and the exhaust fan.

2. LITERATURE REVIEW

1. **Al-Garni et al. (1998)** presented a tool for extracting management information from field failures of aircraft cooling systems. Their techniques allow engineers to quickly identify the failure trends, misbehaving systems, unusual behaviours, and effects of environmental conditions, maintenance practices, and repair actions for ECS system maintenance.

2. **Cakir et al. (2003)** have presented a study about air conditioning system in commercial aircrafts and comfort. They have explained the importance of air conditioning system as it is not easy to provide comfortable and fast trips at high altitudes.

3. **Conceição et al (2006)** developed a thermodynamic model of an air-cycle machine under flight and ground operating conditions. Their results showed that the thermodynamic advantages of the four-wheel in relation to the three-wheel machine are maximized when considering critical cooling conditions for hot days

4. **Zhao et al. (2007)** an experimental study on the off-design performance and dynamic response of an aircraft environmental control system (ECS) has been conducted. A bootstrap air cycle refrigeration system with high pressure water separation was employed and both the static and the dynamic tests were performed

5. **Yoo et al. (2008)** developed an air-cycle machine modelling program including a phase change heat exchanger to estimate its effect in various aircraft flight conditions such as take-off, maneuvour, cruise, and landing.

6. **Arslan et al. (2009)** have investigated the air-conditioning system of an aircraft and its effect to inner air quality. In their study, Boeing 737-800 has been used and they have stated that the filters, sensors, indicators and the control and maintenance of the equipment are substantial for the air-conditioning system of the aircraft.

7. **Dumas et al. (2014)** have defined a design methodology for the global thermodynamic performance of an airship cabin for high altitude. A fundamental cabin sizing and energetic performance of cabin thermal insulation have been provided.

8. **Chen et al. (2015)** have studied on hot air distribution of ship cabin air-conditioning. They have pointed out that the ship cabin air-conditioning formed suitable air distribution for characteristics of variable air volume, big air volume and high air velocity.

9. **Oliveira et al. (2015)** have evaluated the passive aircraft cooling systems for variable thermal conditions. The fuselage condenser performance has been tested for the temperature range between -30 °C and 50 °C. They have determined that heat removal capacity of the fuselage was more dominant in terms of forced convection acting on all condensers.

10. **Yang et al. (2015)** have researched on the numerical simulation of aircraft cabin smoke as it is a threat for the flight safety severely. They have analysed the flow regularity of smoke in the aircraft cabin and also the influence of ventilation on cabin smoke diffusion. It is certain that high level of ventilation could decrease the smoke and temperature distributions, effectively.

11. **Yao et al. (2015**) have examined the flow characteristics and turbulence simulation for an aircraft cabin environment. They have utilized BV2fAM simulation and have theoretically showed that topological structure of flow fields in the cabin was unstable.

12. **Zhu et al. (2015)** have considered the air distribution with natural convection effect of passengers in an air cabin mockup by using PIV experimental setup. They have observed the interaction between natural convection from the passengers and forced convection from the supply air diffusers. They have measured the air flow jet in a 7-row cabin mock up and have concluded that air jet decay rate was slower with increment of natural convection.

13. **Čavka et al. (2016)** have dealt with energy efficiency in aircraft cabin environment in the context of safety and design. They have emphasized that cabin air temperature, cabin noise, cabin evacuation time and accident rate were the certain parameters for the consideration of aforementioned issue

3. METHODOLOGY

3.1 MODELING OF AN AEROPLANE AND ITS CABIN IN CATIA

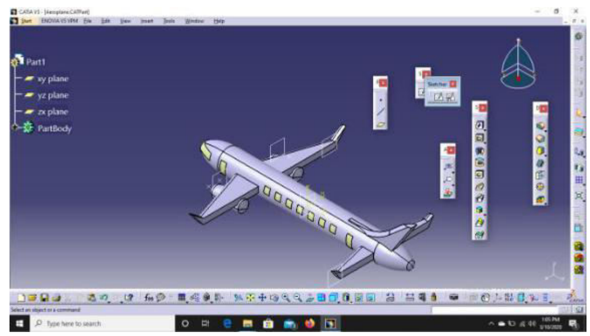

Fig 3: Aeroplane Body

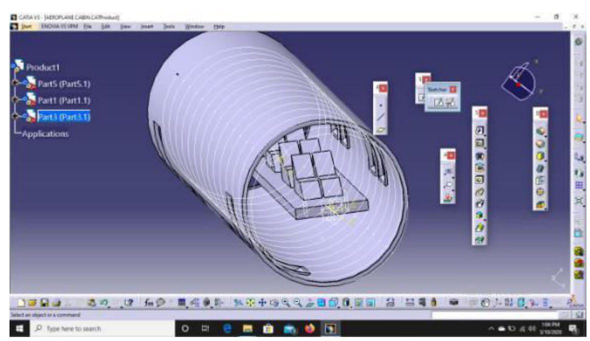

Fig 4: Aeroplane Cabin

3.2 COOLING CAPACITY

Cooling capacity gives an idea of the ability of the pack to take out the available heat load. Cooling capacity of ECS pack can be found from the conservation of energy equation.

$$= \dot{m} \quad (\quad - \quad)$$

3.3 SAMPLE CALCULATION OF HEAT LOAD

Case: Hot Day 7000 M Cruise

$\dot{m}b = 0.047$ Kg/s
Cp = 1.005 KJ/Kg oK
Trc = 296.15 oK
To = 242.65oK

$= \dot{m}(-)$
$Qc = 0.047 * 1.005 * (296.15 - 242.65)$
= 2.52 KW

Case: Cold Day 10000 M Cruise

mb= 0.047 kg/s
cp = 1.005 KJ/Kg oK
Trc= 296.15 oK
To= 223.15 oK

$= \dot{m}(-)$
$Qc = 0.047 * 1.005 * (296.15 - 223.15)$
= 3.44 KW

3.4 TEMPERATURE AND PRESSURE DIFFERENCE WITH RESPECT TO THE ALTITUDE

Altitude, m	Temperature, °C	Pressure, kPa
–500	18.2	107.478
0	15.0	101.325
500	11.8	95.461
1000	8.5	89.875
1500	5.2	84.556
2000	2.0	79.495
2500	–1.2	74.682
3000	–4.5	70.108
4000	–11.0	61.640
5000	–17.5	54.020
6000	–24.0	47.181
7000	–30.5	41.061
8000	–37.0	35.600
9000	–43.5	30.742
10 000	–50	26.436

Fig 5:Standard Atmospheric Data Upto Altitude 10000m

4. CONCLUSION

This project mainly focuses on the aeroplane cabin heating and cooling at different altitudes taking many number of factors such as radiation emitted from the sun, radiation emitted by the equipment present onboard and the heat exerted by the human body into consideration and getting a desired output for the comfort of human beings present. This heating and cooling of the cabin is done with the help of an onboard equipment knows as Environmental Control System (ECS), from the above estimated calculations it can be seen that the temperature and pressures keep changing with respect to the altitude. It can be concluded that the ECS plays a vital role in maintaining the required suitable environmental conditions for the comfort of human beings as well as for an effective flight time. A temperature of 24˚C and 1 atm pressure must be maintained at all altitudes for everything to run as smoothly

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