Thermal Comfort and Air Flow Regimes inside Aircraft Cabins

By

Eng.Mohamed Abd El Sadek Youssif

**A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Mechanical Power Engineering**

**Faculty of Engineering, Cairo University
Giza, Egypt**

2017

Thermal Comfort and Air Flow Regimes inside Aircraft Cabins

By

Eng.Mohamed Abd El Sadek Youssif

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Mechanical Power Engineering

Under supervision of

Prof.Dr.Essam E. Khalil
Professor
Mechanical Power Department
Faculty of Engineering
Cairo University

Prof.Dr.Ahmed F.Abd El-Azim
Professor
Mechanical Department
Faculty of Engineering
Zagazig University

Prof.Dr.Moustafa Rizk
Professor
Mechanical Power Department
Faculty of Engineering
Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2017

Acknowledgment

I hereby would like to express my deep gratefulness and thanks to Prof.Dr. Essam E. Khalil, Prof.Dr.Ahmed F.Abd EL-Azim and Prof. Dr. Moustafa Rizk for their support, continuous encouragement and distinctive supervision throughout the course of this work. They helped providing me with up to date technical references and information from unpublished sources, old out-of-print references which were difficult to find.

Also, I cannot find words to express my thanks and gratitude to my family for its great and continuous help and support, they provided me to accomplish this thesis in a suitable form.

Nevertheless, I cannot forget the support of my colleagues in the Mechanical Power Engineering department as well as from my Professors for their encouragement and concern throughout the scope of the work.

Finally, I should express my appreciation for the FLUENT® Inc for their kind interest in the current project and their support via supplying us with a free license of the ANSYS FLUENT 17.2 CFD package.

Table of Contents

List of Tables

List of Figures

Nomenclature

Symbol	Quantity
a_o	Speed of sound (m/s)
CO	Carbon monoxide
C_p	Specific heat of air at constant pressure (J/kg.k)
D_c	Contaminant density (kg/m^3)
D_o	Contaminant density in outside air (kg/m^3)
g_O	Gravitational acceleration (m/s^2)
H_c	Convection heat transfer coefficient (w/m^2. k)
H_r	Radiative heat transfer coefficient (w/m^2. k)
L	Thermal load (J)
M	Metabolic rate generation per unit area ($kg/s.m^2$)
M_o	Ventilation rate of outside air (kg/s)
M_s	Conditioned air flow rate (kg/s)
M_w	Molecular weight for the contaminant
N	Number of Occupants
O_3	Ozone
P_O	Pressure (N/m^2)
Po_2	Oxygen partial pressure N/m^2
Q	Amount of heat that must be removed from cabin (J)
R	Real gas unit (J/Kg.k)
S	Strength of the contaminant source
T_c	Temperature of air in Cabin (^oc)
T_O	Temperature (^oc)
T_s	Temperature of air supplied to Cabin (^oc)
V_o	Ventilation rate of outside air (m^3/s)

Greek Letters

β	Thermal expansion coefficient, K^{-1}
Δ	Change interval of any property
$\mathit{\Delta}$	Elemental interval
E	Turbulence dissipation rate m^2/s^3
Γ	Diffusivity
ρ	Density, kg/m^3
ϕ	Donates Scalar property (i.e. density, energy, etc.) Relative humidity, %
H	Shear Stress, kg/ms^2
H_{ij}	Subgrid-scale stress
$\bar{\bar{\tau}}$	Stress tensor
Ψ	Gaussian random number
∇	Gradient
μ	Molecular viscosity, kg.m/s
Ω	Vorticity
κ	Von Kármán constant
$\partial/\partial t$	Local derivative

List of Abbreviations

3D	Three dimensional configurations
ACH	Air Changes per Hour
AOA	Age of air
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATC	Air Traffic Control
CFD	Computational Fluid Dynamics
DNS	Direct Numerical Simulation
ECS	Environmental Control System
FAR	Federal Aviation Regulations
HEPA	High Efficiency particulate air filters
HVAC	Heating, Ventilation and Air-Conditioning
EPS	Environmental Protection System
IAQ	Indoor Air Quality
ICAO	International civil Aviation Organization
ISA	International Standard Atmosphere
LES	Large Eddy Simulation
MSL	Mean Sea Level
PA	Pressure Attitude
PIV	Particle image velocimetry
PMV	Predicted Mean Vote, Dimensionless
PPD	Predicted Percentage of Dissatisfied, Dimensionless
RANS	Reynolds average Navier- Stokes equations
PSV	Particle Streak velocimetry
PTV	Particle tracking velocimetry
RH	Relative Humidity
RNG	Renormalization group
RSM	Reynolds Stress Model
SARS	Severe acute respiratory syndrome
TSMV	Thermal Sensation Mean Vote
UA	Ultrasonic anemometry
VPSV	Volumetric Particle streak velocimetry
VPTV	Volumetric Particle tracking velocimetry

ABSTRACT

The main objective of this thesis is to study the applied ventilation system inside the economy section of the Airbus A-350 cabin and to compare it with modified designs by adjusting the conditions of the inlet and outlet diffusers aiming to reach the optimum design.

In order to achieve this main objective, it seems important to make the environment for passengers at cruise conditions at 12,200 m altitude to be normal, where the surrounded air pressure falls to about one-fifth the atmospheric pressure and the relative humidity may record 10% or less.

In order to achieve the optimum ventilation design, some properties and functions should be determined such as (Temperature, Flow Velocity, Relative humidity, PMV and PPD), where a numerical solution will be implemented in order to measure these properties.

A Computational Fluid Dynamics (CFD) software determine used to solve continuity, momentum and energy equations for the flow of air inside the cabin.

Using the latest version of ANSYS Fluent (17.2) the flow was solved by dividing the selected cabin's control volume into about 9,000,000 elements and applying the governing equations to each element and solving the realizable k-ε turbulence model.

Three different ventilation designs were compared. The first was the currently applied design in which the supply air was supplied through two ceiling inlets vertically to the cabin and extracted via two return ducts in the side walls near the floor. The second (modified) design depended on adjusting the directions of the supply air to ensure better distribution of the conditioned air, while in the third design the air was returned through two intermediate ducts mounted on the cabin aisles in addition to the basic two side returns.

It is concluded here that the shorter the flow path, the better the ventilation characteristics and the better is the indoor air quality, since the best PMV & PPD values are obtained through adding extra return ducts, ensuring a homogeneous flow.

Chapter (1)
Introduction

1.1 General

The aircraft cabin is basically similar to any indoor environments, for example offices, homes and malls, in that people are exposed to a mixture of fresh and recirculation air. However, the cabin environment is different in many issues—such as, the high occupant density, the inability of occupants to leave at will, and the need for pressurization.

In flight, people encounter a combination of environmental factors that includes low humidity, reduced air pressure, and potential exposure to air contaminants, such as ozone (O_3), carbon monoxide (CO), various organic chemicals, and biological agents beside the hazard of infectious transmission.

Commercial jet aircrafts operate in an external environment that varies widely in temperature, air pressure, and relative humidity as they move from taxiing and takeoff through cruise to descent and landing. To transport passengers and crew through environmental extremes, an aircraft is equipped with an environmental control system (ECS) designed to maintain a safe, healthy, and comfortable environment for the passengers and crew.

The air provided to the passengers and crew on jet aircraft is typically a combination of outside air brought in through the engines and air that is taken from the cabin, filtered, and recirculation. The ECS is designed to minimize the introduction of harmful contaminants into the cabin and to control cabin pressure, ventilation, temperature, and humidity.

It is well known that the average altitude which a commercial airplane can reach is around 10,500m (34,500ft), so it is a must to study the conditions of the air in the airplane cabin to reach the optimum condition which supply suitable air to passengers.

At this high altitude the air conditions such as Pressure, Humidity, Density and Temperature are different from it at the sea level, so it is a minor issue to discuss the environmental status.

The first standard atmospheric models were developed in the 1920's in both Europe and the United States. The slight differences between the models were reconciled and an internationally accepted model was introduced in 1952 by the International Civil Aviation Organization (ICAO). The International Standard Atmosphere (ISA) is defined in ICAO Document 7488/2. The ISA assumes the mean sea level (MSL) conditions as given in Table (1.1).

Table (1-1) International Standard Atmosphere, Mean Sea Level Conditions

Pressure (P_0)	101325 N/m^2
Temperature (T_0)	288.15 K (15°c)
Density (ρ_0)	1.225 KG/m^3
Speed of Sound (a_0)	340.294 m/s
Acceleration of Gravity (g_0)	9.80665 m/sec^2

1.1.1 Temperature Modeling

Temperature decreases with altitude at a constant rate of -6.5°C/1000m (-1.98°C/1000ft) up to the tropopause. The standard tropopause altitude is 11,000 m (36,089 ft.). Therefore, the air which is considered as a perfect gas in the international Standard Atmosphere (ISA) model presents the following characteristics within the troposphere [1]:

$$T = T0 - 6.5 \frac{h\,(m)}{1000} \qquad (1)$$

This ISA model is used as a reference to compare real atmospheric conditions and the corresponding engine/aircraft performance.

And here is shown below a schematic to illustrate the variation of the Temperature at high altitudes.

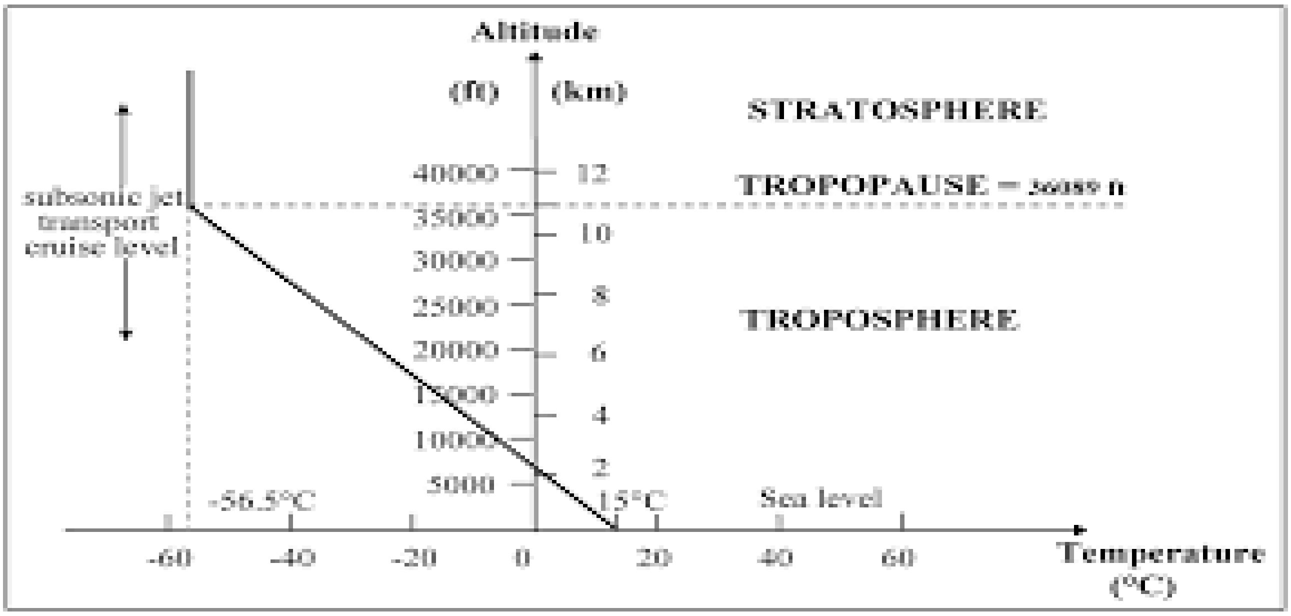

Figure (1-1) International Standard Atmosphere temperature variation [1]

1.1.2 Pressure Modeling

To calculate the standard pressure P at a given altitude, the temperature is assumed standard, and the air is assumed as a perfect gas. The altitude obtained from the measurement of the pressure is called pressure altitude (PA). Both Table 1.2 and Figure 1.2 show variation of the pressure altitude as a function of the pressure. The last column of Table 1.2 shows