Project

Department of Automotive and Aeronautical Engineering

**Simulation of Components from the
Environmental Control System**

Author: Mathieu Kwiatkowski

Examiner: Prof. Dr.-Ing. Dieter Scholz, MSME
Support: Dr. Christian Müller

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Abstract

The aim of this project is to create a part of the Functional Library of the Environmental Control System (FLECS). It means especially to simulate in the most accurate way, thanks to the software MALAB Simulink, the working of an airplane air conditioning system. Such a system is obviously quite complex and can be divided in several subsystems, like temperature control, pressurization control, and moisture control systems. This project focuses on the simulation of the cabin temperature control system. First of all, it defines the basic blocks like mixer unit, trim air valve and cabin blocks which constitute a first part of the cabin temperature control library. Then it develops the multi-compartment cabin temperature control model using the blocks built up previously. To get realistic results, parameters like heat capacity of the equipment inside the cabin, or passengers presence, which completely alter the dynamic of the system, have to be taken into account. It enables also to see the influence of each parameter on the regulation. However, this survey which is only a first step in the global FLECS project, aims at explaining more the way to build up the system structure using MATLAB Simulink than to constitute an accurate air conditioning system model. For industrial use, the accuracy of the model must be improved yet with a deeper study of different factors.

Hochschule für Angewandte Wissenschaften Hamburg

Hamburg University of Applied Sciences

Simulation of Components from the Environmental Control System

Task for a *Projekt 2*

Background

This task is part of the research project FLECS (Functional Library of the Environment Control System) – a simulation environment for computer-assisted design of innovative environmental control systems for passenger aircraft. FLECS is based on the commercially available package MATLAB/Simulink.

Task

Various components from the environmental control system need to be simulated in FLECS – this project should try to make a contribution. Starting from simple resistance elements from the air distribution network like valves, check valves and filters, the project should develop into modelling of more sophisticated components like fans, compressors or turbines.

The report has to be written according to German DIN standards on report writing!

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List of symbols

D	Diameter
H	Enthalpy
k	Boltzmann constant
L	Duct lenght
m	Mass
n	Amount of gas
N	Number of particles
p	Pressure inside the cabin
R	Ideal gas constant
T	Temperature
U	Internal energy
V	Cabin volume
C_p, C_V	Specific heat capacity
Re	Reynolds number

Greek symbols

ν	Kinematic fluid viscosity
λ	Flow resistance coefficient
μ	Fluid dynamic viscosity
ζ	Flow resistance coefficient
ρ	Density
$\bar{\omega}$	Average speed of the air flow

List of abbreviations

ATA   Air Transport Association

AVP   Absolute vapor pressure

FLECS   Functional Library of the Environmental Control System

RH   Relative humidity

SVP   Saturate vapor pressure

List of key words and definitions

Enthalpy

The enthalpy is especially used in thermodynamics: it enables to quantize the heat content of a chemical or physical system.

Considering a system, the enthalpy is a thermodynamic function of this system, defines like the sum of the internal energy of the system plus the product of its volume multiplied by the pressure exerted on it by its surroundings:

$$H = U + pV \tag{1}$$

where

    H is the enthalpy (J)
    U is the internal energy (J)
    p is the pressure on the system (Pa)
    V is the volume (m^3)

The enthalpy can also be defined using the heat capacity of a system

$$C_p = \left(\frac{\partial H}{\partial T} \right)_P \tag{2}$$

Where C_p is the specific heat capacity measured under constant pressure (J mol^{-1} K^{-1})

It is the measure of the heat energy required to raise the temperature of a specific quantity of a substance (thus, the name "specific" heat) by a certain amount, usually one kelvin, under constant pressure.

If we assume that the transformation is isobaric, we can also write

$$H = mC_p T \tag{3}$$

That is the formula used to model most of the components in this project.

Humidity

Humidity is the concentration of water vapor in the air. The concentration can be expressed as *absolute* humidity, *specific* humidity, or *relative* humidity.

Relative humidity (RH) is the ratio of the current vapor pressure of water in any gas (especially air), known as the absolute vapor pressure (AVP), to the saturation vapor pressure (SVP), at which the gas is called saturated at the current temperature, expressed as a percentage.

$$RH = \frac{AVP}{SVP} \tag{4}$$

A gas is saturated when the vapor pressure of water is at the saturation vapor pressure. It corresponds to the possibility of dew or fog forming.

Psychrometric chart

The psychrometric chart is a graph of the properties of air (temperature, relative humidity, etc.). It is used to determine, among other things, relative humidity of the air which is a measure of how much moisture is present compared to how much moisture the air could hold at a certain temperature and a certain pressure.
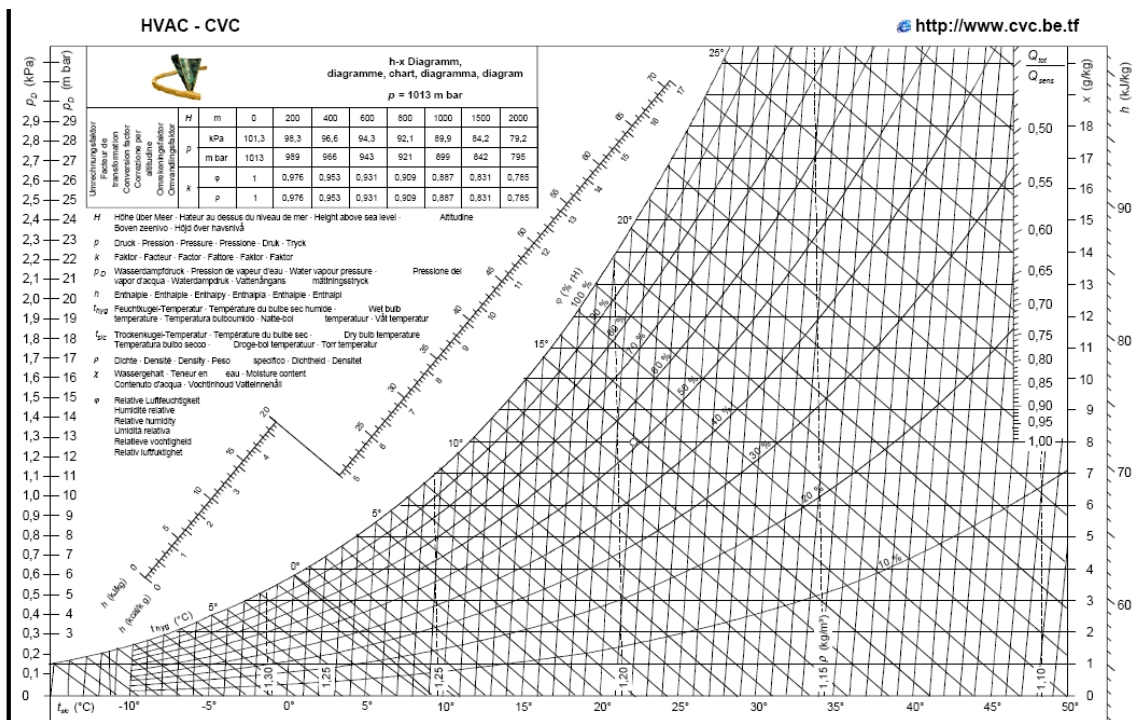
Figure 1.1: Psychrometric chart

Ideal gas

An ideal gas or perfect gas is a hypothetical gas consisting of identical particles of negligible volume, with no intermolecular forces. Additionally, the constituent atoms or molecules undergo perfectly elastic collisions with the walls of the container. Real gases do not exhibit these exact properties, although the approximation is often good enough to describe real gases. The approximation breaks down at high pressures and low temperatures, where the intermolecular forces play a greater role in determining the properties of the gas.

The thermodynamic properties of an ideal gas can be described by two equations. The equation of state of a classical ideal gas is given by the ideal gas law.

$$pV = nRT = NkT \tag{5}$$

The internal energy of an ideal gas is given by:

$$U = c_V nRT = c_V NkT \tag{6}$$

where

c_v is a constant (e.g. equal to 3/2 for a monatomic gas)

U is internal energy (J)

p is the pressure (Pa)

V is the volume (m^3)

n is the amount of gas (mol)

R is the ideal gas constant (J mol^{-1} K^{-1})

T is the absolute temperature (K)

N is the number of particles

k is the Boltzmann constant (joule per kelvin per particle),

nR=Nk is the amount of energy in the gas per Kelvin (J K^{-1}).

Reynolds number:

The Reynolds number is the most important dimensionless number in fluid dynamics. It is the ratio of inertial forces ($\rho\,\bar{\omega}$) to viscous forces (μ/L) and is used for determining whether a flow is laminar or turbulent.

$$Re = \frac{\rho\bar{\omega}L}{\mu} = \frac{\bar{\omega}L}{\nu} \qquad (7)$$

Where

    ρ is the fluid density (kg m^{-3})

    $\bar{\omega}$ the flow average speed (m s^{-1})

    L characteristic length (equal to diameter D if a cross-section is circular)

    μ dynamic fluid viscosity

    ν is the kinematic fluid viscosity: $\nu = \dfrac{\mu}{\rho}$

Laminar flow occurs at low Reynolds numbers, where viscous forces are dominant, and is characterized by smooth, constant fluid motion, while turbulent flow, on the other hand, occurs at high Reynolds numbers and is dominated by inertial forces, producing random eddies, vortices and other flow fluctuations.

The transition between laminar and turbulent flow is often indicated by a critical Reynolds number (Re_{crit}), which depends on the exact flow configuration and must be determined experimentally. Within a certain range around this point there is a region of gradual transition where the flow is neither fully laminar nor fully turbulent, and predictions of fluid behaviour can be difficult.

1 Introduction

1.1 Motivation

This project is a part of the research project FLECS (Functional Library of the Environment Control System). The aim is to build up a database composed of various environment component blocks. Thereby, each user will be able to simulate different kind of environmental control system and foresee its performances. Thus, it could be used to proportion some components, in order to improve the performance and save some weight, power and then fuel.

1.2 Definitions

Simulation
Act of creating a representation or a model of a physical system using, in our case, the computer science.

To foresse the performance of a technical system, the most practical way out nowadays is to use the computer technology. Numerous softwares enable to make easier the work and to solve quickly difficult mathematical equations.

FLECS project is based on the commercially available package MATLAB/Simulink. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. The principle on which this software works allows to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non interactive language such as C or Fortran. MATLAB is also an interpreter. Instructions are interpreted and executed line by line.

Simulink is a graphic interface for modeling, simulating, and analyzing dynamic systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Simulations are interactive, so you can change parameters on the fly and immediately see what happens. The preprogrammed blocks, composing each library, enable to earn a lot of time compared to a conventional MATLAB programmation.

Air conditioning system
Units and components which furnish a mean of pressurizing, heating, cooling, moisture controlling, filtering and treating the air used to ventilate the areas of the fuselage within the pressure seals.

Functionnal library
A Functional Library is a MATLAB Simulink menu which puts together different preprogrammed blocks of a same category. For instance, the "continuous" library gathers derivate, integrator, transfer function blocks... Functional Libraries enable users to copy preprogrammed blocks into their models from external libraries and automatically update the copied blocks when the source blocks change. Using libraries allows users who develop their own block libraries, or who use those provided by others (such as blocksets), to ensure that their models automatically include the most recent versions of these blocks.

1.3   Task

Various components from the environmental control system need to be simulated in FLECS. This project should try to make a contribution. Starting from simple elements of the air distribution network like ducts, flow resistance and valves, this project develops a multi-cabin temperature control program.

Several parameters, like temperature, pressure, humidity, CO_2 amount have a paramount importance in a cabin compartment. Considering all these parameters together, the simulation becomes too complex. That is why, in this project which is a first step about the environment control system, we focus on the temperature control. In the paragraph ... of this report, some way out are purposed to include other parameters like humidity control, but the block purposed is just an outline to what could be done to take such a parameter into account.

1.4   Background

The **Functional Model Library of the Environmental Control Systems (FLECS)** project is a joint research project. The partners involved in this project are the **Hamburg University of Applied Sciences (HAW)**, the company **CeBeNetwork,** based in Bremen and **Airbus** with its Hamburg office. The HAW is acting as project leader.

The project's aim is to support design activities for innovative air conditioning systems in future passenger aircraft. In order to achieve this, a model library based on the commercial standard software MATLAB/Simulink is being programmed. The library will contain simulation models of all relevant components that can be found in the air conditioning system and thermally relevant components in the aircraft cabin. The model library will support design engineers to find optimum configurations for air conditioning systems that improve passenger comfort with respect to temperature, pressure, humidity, and flow velocities.

The HAW is financially supported in this project with a grant from the government of Hamburg. CeBeNetwork receives funding from the government of Bremen. In total 2.5 member of staff work on this project with further support of many students.

1.5   Structure of work

Chapter 2
Explains the absolute necessity to use an airconditioning system in jumbojets due to temperature and pressurization problems. Presents the different main components of an airplane air conditionning system and how they work. Precises also the system specifications required according the ATA standard.

Chapter 3
Describes the way used to modelize each component of the air conditioning system: the assumptions about the working of the system, the equations which follows. This chapter also shows how to use MATLAB Simulink to build the components according the model accepted, describing the library blocks used to build up each simulation.

Chapter 4
Describes the building up of more complex systems putting together blocks created in the chapter 3. The first program simulates a single compartment cabin which is the simpliest model but not so realistic. The next step is a multi-compartment cabin according the different classes inside the cabin (economic, business, first, cargo hold). In this model, a two compartment cabin is considered. Moreover, in order to have a realistic model usable in the industrial field, it is essential to include additional parameters like cabin equipment, passenger presence, valve mechanical delay, which is done in the last part of this chapter.

Chapter 5
Purposes an idea to control the humidity rate in addition to the temperature control .
It also focuses on the parameters simulation problems, especially the choice of the time step.

2 Presentation of an airplane air conditioning system

According the altitude of which an airplane flies, temperature and pressure of the air is totally different. In the troposphere, the air temperature decreases with increasing altitude. In the stratosphere ,above 11000 m (36 089 ft), the air temperature is constant, equals to -56,5°C. The air pressure also decreases with altitude. Althought the oxygen amount is independant of the altitude- approximately 21% *en mol d'air* – the partial pressure of oxygen drops with increasing altitude. Our body is used to a partial oxygen pressure of about 0.21 times sea level pressure. Thus, if we want to survive at high altitudes: the oxygen fraction has to be increased using an oxygen system, or the total pressure has to be maintained close to the sea level pressure using a pressurization system.

The purpose of an airplane air conditioning system is to make the interior environment of an aircraft comfortable for human beings. It means the system has to control the temperature, the pressurization but also the amount of fresh air and its humidity. Depending on the kind of aircraft, this may involve only ventilation of the cabin by supplying a flow of fresh air. If the temperature must be adjusted, some device of heating and cooling are required. Moreover, in some part of the world, the relative humidity is quite high. Water extractors are therefore used for dehumidification of the cabin air. This is necessary to increase passenger comfort, but also to prevent damage to electrical and electronic equipment.

The air conditioning system is a safety-critical system because passengers and crew depend on its proper function. As any other equipment, the certification requirements include minimum standards. (cf Chapter 2.2)

2.1 The main components

Thus, the aim of an air conditioning system is to maintain the air in the pressurized fuselage compartments at the correct levels of :
-pressure
-temperature
-freshness
To achieve this aim, several complex systems play a part:

Figure 2.1:   Airplane air conditioning system structure example and main components
Regulation temperature systems:

An aircraft may encounter situations where cooling is necessary, and in other cases, heating is necessary. Airplanes fly most of the time at high altitudes, it means in low ambient temperature. However, it has been observed that an aircraft fuselage has to be cooled more often than heated. That is why temperature control is based on the supply of cold air. Bleed air available from the engines or from the APU is hot compressed air which has, first of all, to be cooled by air conditionning packs. Then, hot bleed air can be mixed to the cold air from the air conditioning packs, if necessary, to provide the desired temperatures in each cabin compartment.

Cooling system

Air conditioning packs decrease the temperaure of the hot bleed air coming from the pneumatic system. This is done by heat exchangers in each pack and an air cycle machine consisting of compressor, turbine and fan. The air cycle machine first compresses the air and then expands it. A condenser condenses the water contained in the air, and a water extractor removes this water.

The bleed air coming from the engines and the APU enters the pack cooling via the pack flow control valve and is ducted to the primary heat exchanger where it is cooled with ambiant ram air. The cooled bleed air is then compressed to a higher pressure and temperature in the compresor section of the air-cycle machine . It is cooled again in the main heat exchanger with ambient ram air.

The air now enters the high pressure water extraction loop. The high pressure water extraction loop has a reheater, a condensor and a water extractor. The rehetaer uses the turbine inlet air of the air-cycle machine to cool the air to about its dew point. Then the condenser uses cold turbine air to further cool the air below its dew point. The condensed water is extracted and drained from the air as it passes through the high pressure water extractor. At last, behind the water extractor, the air enters the reheater again and the temperature increases to assure that no free water enters the turbine.
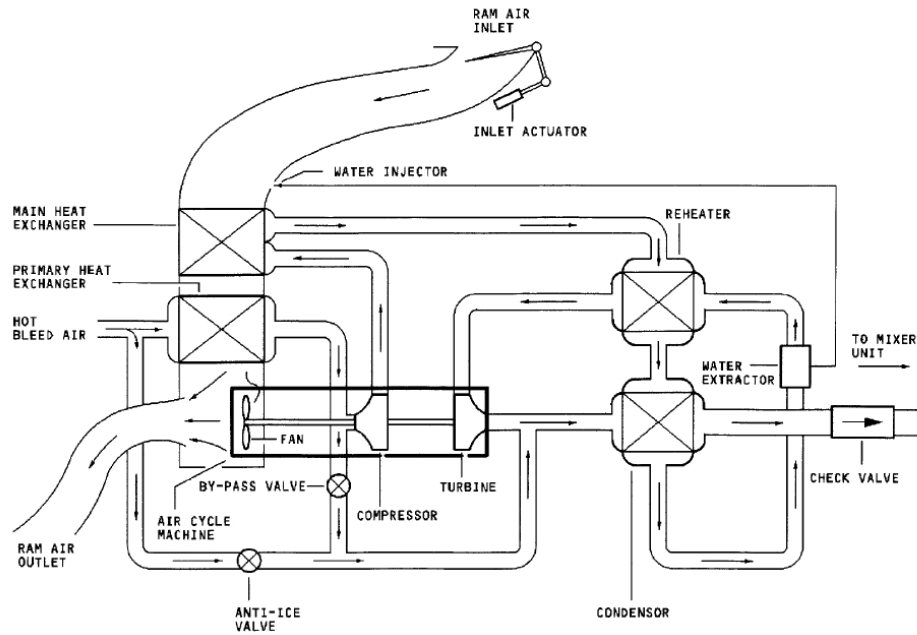
Figure 2.2:   Air conditioning pack

Temperature sensors are installed at the pack flow control valve inlet, at the compressor out-let, at the water compressor outlet and at the turbine outlet. The pack controllers control the packs by means of data from temperature and pressure sensors.

Air distribution and recirculation

A mixer unit, installed under the cabin floor mixes fresh conditioned air with recycled cabin air. The cabin air which has entered the underfloor area is drawn through recirculation filters by recirculation fans. They blow the air to the mixing unit. In normal operation, beetween 37% and 51% of the air in the mixer unit comes from recirculated cabin air, the rest of the flow is fresh conditioned air from the packs.

The passenger cabin is divided into the forward and aft distribution zones. Each distribution zone has main supply ducts and small riser ducts. The outlets, located above the doors, are connected to the main supply ducts by L-shaped riser ducts.
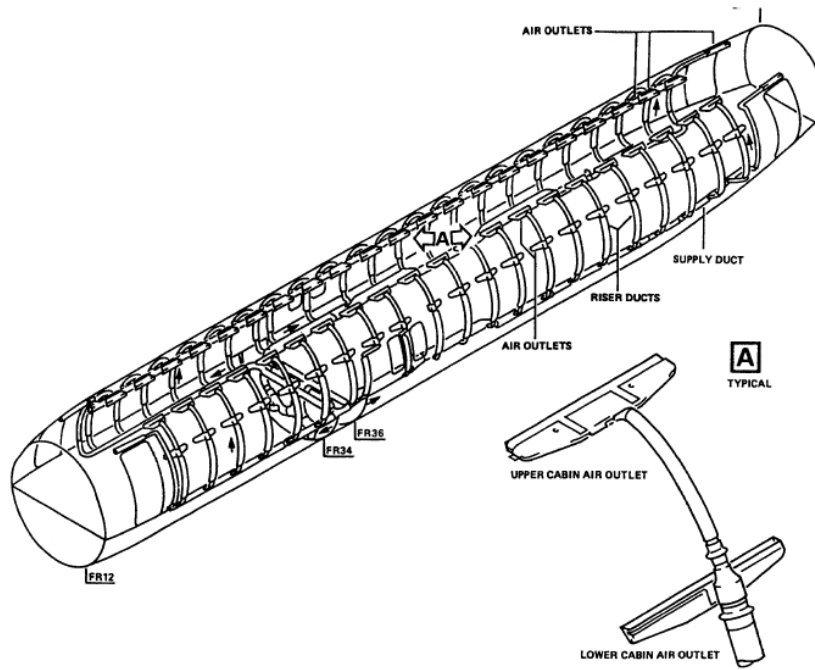
Air distribution cabin
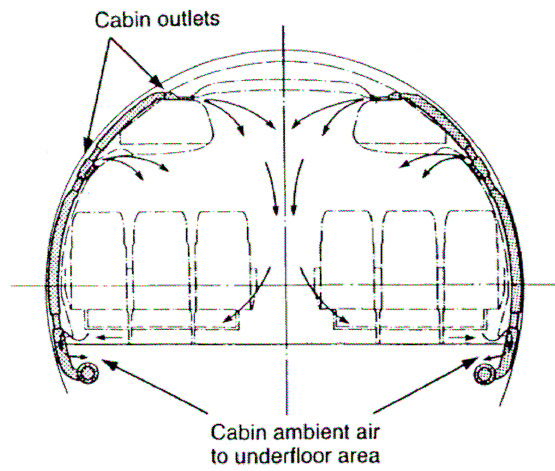
Air distribution cabin

Figure 2.3: Air outlets position inside the cabin

Pressurization control

Its aim is to make sure that the pressure in the pressurized fuselage is save for passengers and crew. Although the aircraft is actually flying e.g. at 39000 ft, the cabin is kept at a higher pressure equivalent to an altitude of 8000 ft. The pressure schedules work with a dedicated rate limit to guarantee passenger comfort. Two cabin pressure controllers (CPC) control fully automatically the quantity of air that flows out of the fuselage through an outflow valve located in the aft pressure bulkhead. Air flows constantly into the aircraft thanks to air conditioning. Cabin pressure decreases with outflow rates higher than inflow rates and increases with outflow rates lower than inflow rates.

2.2   Main specification requirements

Flights in nonpressurized cabins without supplemental oxygen are limited to an altitude of 10000 ft. In order to save fuel and for other environmental considerations, it is better for commercial jumbojets to fly at an altitude of about 30000 ft. By the way, to ensure the passengers comfort, the use of an air conditioning system is compelled.

Concerning the **ventilation system**

Under normal conditions, 4.7 l/s are required for each crew member. Manufacturers typically provide a minimum of about 7.8 l/s for each person in the aircraft. In case of failure, the supply of fresh air shoud not be less than 3.1 l/s per person.

In order to avoid draughts, the air velocity in the cabin should be limited to 0.2 m/s in the vicinity of passengers. Thus, conditioned air may enter the cabin through cabin outlets at not more than 2.0 m/s.

Concerning the **temperature control**

The temperature control may typically be possible in a range between 18°C and 30°C.
An air conditioning system in civil subsonic aircraft should be able to:
-Heat the cabin of a cold soaked airplane from -32°C to 21°C in 30 minutes (no passengers, no internal heat loads, doors closed).
-Cool the aircraft from 46°C to 27°C in 30 minutes (no passengers, no internal heat loads, doors closed).

Concerning the **pressure control**

Under normal conditions, the cabin altitude in pressurized cabins musnt not be more than 8000 ft. In case of failure, cabin altitude must not be more than 15000 ft.

3 Simulation of components of the air conditioning system

General assumptions:

In the following programs, we assume, to simplify the equations and the calculations that:

-Air is a perfect gas. Thus we can use the ideal gas law

$$pV=nRT \tag{3.1}$$

-All the transformations are made under constant pressure, so the simplify enthalpy equation can be write:

$$H = mC_pT \tag{3.2}$$

3.1 Duct

The most basic components in an air contioning system are the ducts: they enable to link other complex system beetween them (pack flow, mixing unit, trim air valve) and to provide the carrying of the air in the several cabin and cargo sections. In this model, we have chosen to care about the flow resistance generated by the surface of the duct.

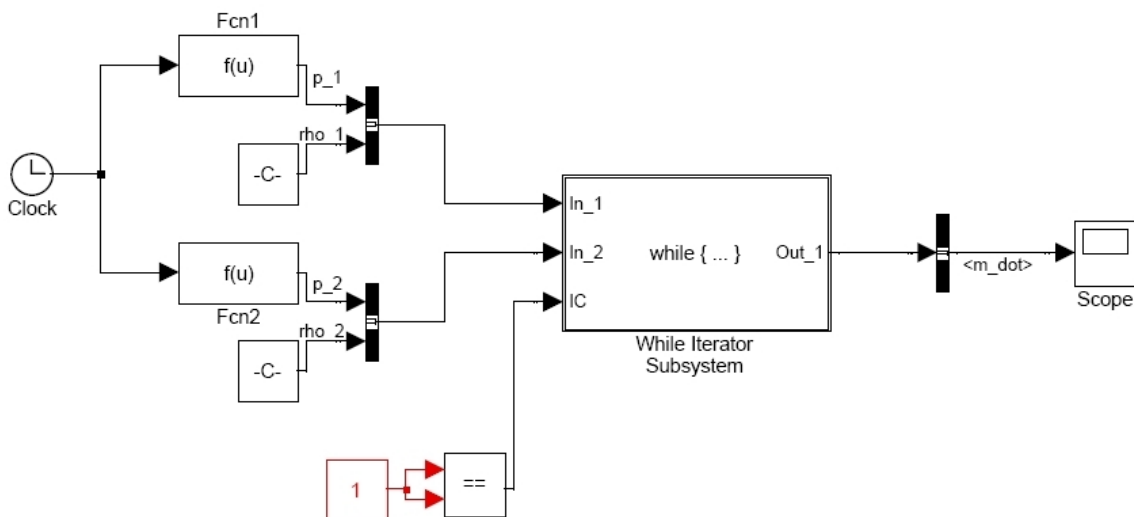The model of the duct built up with MATLAB Simulink is the following :

Figure 3.1: Duct model under MATLAB Simulink

We assume the pressure evolution in input and output are known. They are defined by the pressure fonction :

In input, $p_1(t)=105000-2500(1-exp(-2t))$

In output, $p_2(t)=100000+2500(1-exp(-2t))$

We also assume that the density of the air is known upstream and downstream of the duct.(cf program for the values).

In this model, a "While Iterator Subsystem" is used to calculate the duct output mass flow :
The "While Iterator Subsystem" block is a subsystem block that is preconfigured to repeat an instruction while an internal condition (IC) is satisfied during a simulation time step.
Here, this block is used to determine the duct output mass flow according the differencial pression between input, output and also according the flow resistance onto the duct surface.

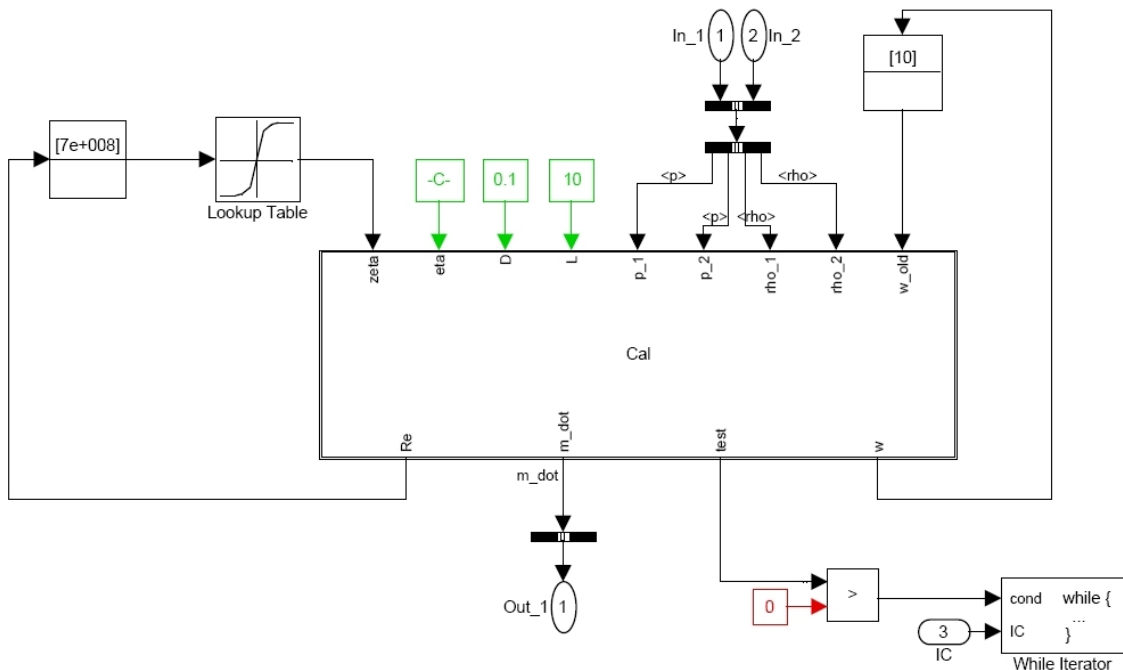The subsystem inside the "While Iterator Subsystem" is:

Figure 3.2: duct output mass flow calculating block

Due to the friction onto the inner surface of the duct, the air flow decreases. That is the point we care about in this simulation.

The inputs of the calculator are the η coefficient, the duct diameter D and its length L. They enable to determine the air flow Reynolds number.

Reynolds number:

Firstly, we have to calculate the critical Reynolds number for the duct we study. According the formula we talked about in „Keywords and Definitions":

$$Re = \frac{\rho \overline{\omega} D}{\eta} = \frac{\overline{\omega} D}{v} \quad (3.3)$$

We have to calculate v, the kinematic fluid viscosity: $v = \frac{\eta}{\rho}$

We know that $\eta = 17.4 \cdot 10^{-6}$ S.I. and $\rho = 1.225\, \text{kg.m}^{-3}$

Then $v = \frac{17.4}{1.225} = 14.5 \cdot 10^{-6}$

We assume the duct diameter is D=0.1 m and that ρ =1.225 kg.m^{-3}

So, $Re_{crit} = \frac{1.225 \cdot 10 \cdot 0.1}{14.5 \cdot 10^{-6}} = 8.45 \cdot 10^{-8}$ S.I.

This is the critical Reynolds number which enables to determine if the flow is laminar or turbulent.

Inside the duct, the flow resistance is linked to the pressure drop by the equation:

$$\Delta p = \zeta . 1/2 . \rho . \overline{\omega}^2 \quad (3.4)$$

Where

Δp: pressure drop in the duct (Pa)
ζ: flow resistance coefficient due to the friction between the fluid and the inner surface of the duct.
ρ: density of the fluid flowing inside the duct (kg m^{-3})
$\overline{\omega}$: average speed of the fluid flow (m s^{-1})

We also know that :

$$\zeta = \lambda \cdot \frac{L}{d} \qquad (3.5)$$

with

λ : flow resistance coefficient between the different layers inside a fluid

$\lambda = \dfrac{64}{Re}$ in laminar flow (i.e. Re<Re$_{crit}$)

$\lambda = 0,316\,Re^{-0.25}$ in turbulent flow (i.e. Re>Re$_{crit}$)

L : length of the duct
d : diameter of the duct

At each time, the subsystem calculates the λ value and then determines the ζ, Re, ω and the output mass flow new values.The new ζ value is determined thanks to a lookup table. λ coefficient is the input of the lookup table. The relation beetween ζ and Re is known. Therefore the table gives in output the associate ζ value. This ζ value is used to calculate the new Re number and λ coefficient. Then this calcul loop is made as many times as necessary until the pressure balance beetween each side of the duct is reached.

3.2 Fan

It enables to circulate the fluid inside the duct without carrying about the pressure drop beetween the part before and after the fan.

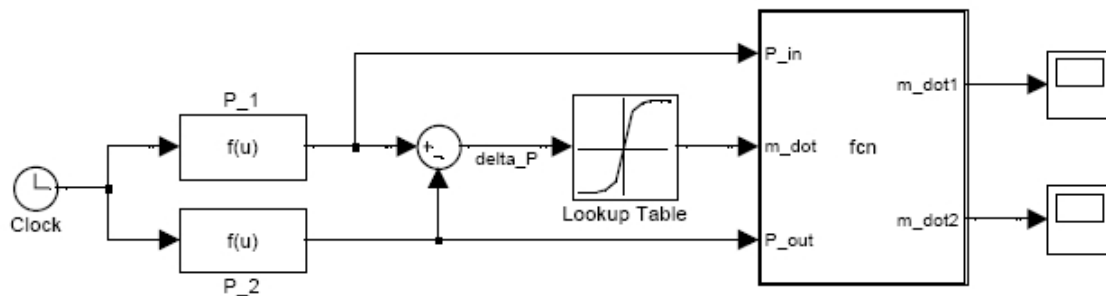The model of the fan built up with MATLAB Simulink is the following :

Figure 3.3: Fan model under MATLAB Simulink

This is an oversimplify fan model, which is more a way to become acquainted with the working of MATLAB Similink working and libraries. The sign of the mass flow depends on the direction movement of the flow:
If the pressure upstream the fan is higher than downstream the sign will be positive,
if the pressure upstream is lower than downstream, it will be negative.

We assume, once more, that the pressure evolution is known in input and output of the fan, and also that we know the relation beetween the pressure drop and the mass flow. This relation is used by a lookup table which knowing the pressure drop, deducts the mass flow getting through the fan.

3.3 Mixing unit

The mixing unit is just like a tanker where conditioned air from the pack and recycled air from the cabin are mixed.

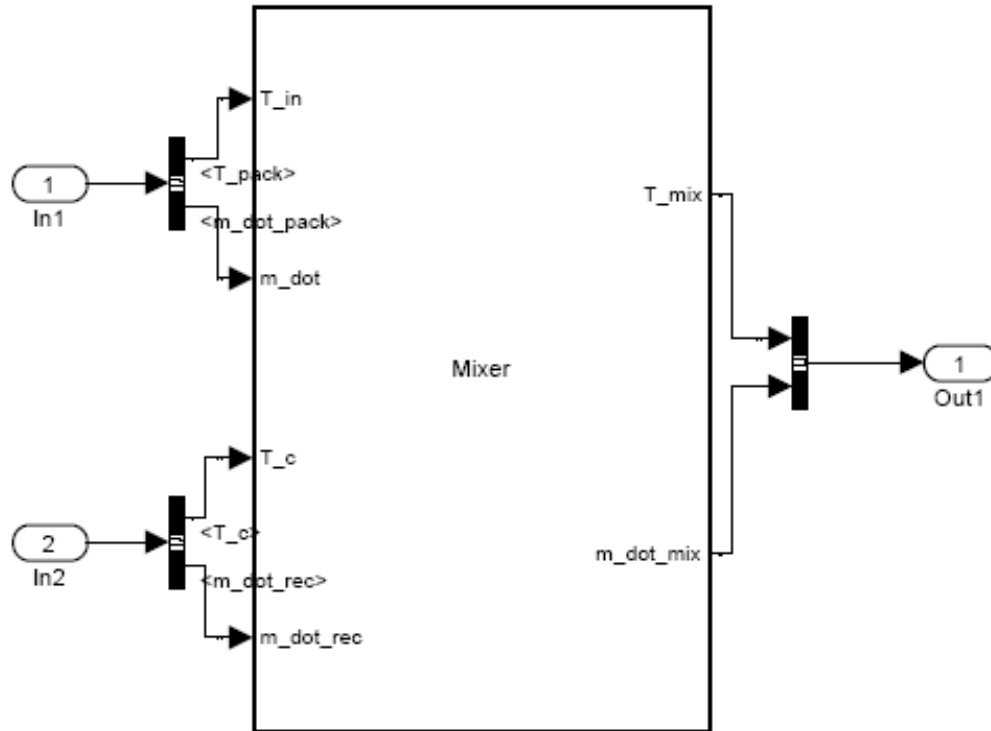The model of the mixing unit built up with MATLAB Simulink is the following :

Figure 3.4: Mixer unit model under MATLAB Simulink

To modelize such a component, we assume that there is not heat transfer beetween the mixing unit and the outside environment. It means the enthalpy coming in the mixing unit is equal to the enthalpy getting out of the system:

$$H_{IN} = H_{OUT}$$

$$m_{DOT}C_pT_{IN} + m_{DOT\,REC}C_pT_C = m_{DOT}C_pT_{MIX} + m_{DOT\,REC}C_pT_{MIX}$$

Strictly speaking, the specific heat capacity depends on the temperature. As the incoming and the outcoming air flows do not have the same temperature, it means they have different C_p. But to simplify the equations, we assume that the C_p value does not depend on the temperature.

And then we get :

$$T_{Mix} = \frac{m_{dot} \cdot T_{in} + m_{dot}^{rec} \cdot T_C}{m_{dot} + m_{dot}^{rec}}$$

(3.5)

Actually, on a real several cabin compartment aircraft, the system is buit up in the way that the mixing unit provides the coldest temperature asked by all the comparments.

3.4 Trim air valve

This component enables to add some hot air to the flow coming from the mixing unit, in order to reach the desired temperature in each cabin compartment.

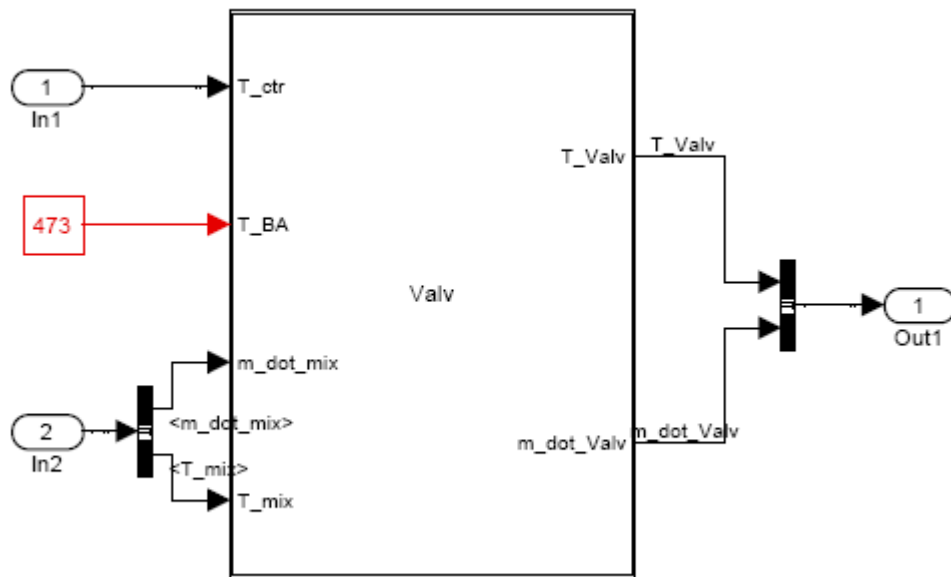The model of the mixing unit built up with MATLAB Simulink is the following :

Figure 3.5: Trim air valve model under MATLAB Simulink

The accurate amount of hot air to add at the mixing unit flow is determined once again thanks to an enthalpy equation. We assume, like for the mixing unit, that no heat transfer exists beetween the valve and the outside environment.

4 Simulation of a multi-cabine air temperature control

The air temperature is one of the most critical parameter in an air conditioning system. Other important variables are the pressure and the humidity. As a first step, we have decided to focus on the temperature parameter and to build up an air temperature control system.

The real structure of such a system is given by the diagram below :

Figure 4.1: A321 air conditioning system structure

Now, we have created all the necessary blocks to build up a complex system like an air temperature control system. However, to achieve this aim, it needs to be sure that each „component block" built up in chapter 3 is compatible with each other. Thanks to the ATA, we know how an airplane air conditioning system works and its main specifications.

All the values used for the following calculations all allong the chapter correspond to the A321 configuration.

In the following simulations, the air conditioning packs are simulated in an oversimplify way. As we have seen in chapter 2, air conditioning pack is a complex system made up with : heat exchangers, an air-cycle consisting of compressor turbine and fan, a water extractor. In the following programs we have just considered the temperature control function of the packs.

In the same way, the air is assumed to be a perfect gas.

4.1 Single cabin air temperature control

The first step is to consider a single compartment cabin airplane. We assume that the initial temperature in the compartment is 30°C and that the ideal temperature would be 22°C. Therefore, the system has to refresh the cabin of 8°C.

To simulate the air temperature control system, the structure given by the figure 4.1 is respected:

In this simulation the air flow resistance is not cared about. It means the duct model is not used. Actually, three different pre-programmed blocks are used in this simulation : a mixing unit, a trim air valve and a cabine block. Some equations need to be checked in order to affirm that the blocks are compatible with each other :

In the **mixing unit**, some fresh air comes from the packs and some recycled air from the cabin. As we have already explained, we assume the enthalpy in the mixing unit is constant:

$$H_{in} = H_{out}$$

We assume also that the mass flow and the temperature of the mass flow coming from the packs are known and constant. So we exactly know the enthalpy, from the packs, coming in the mixing unit :

The mass flow of the recycled air, coming from the cabin is fixed by the pilot (beetween 37% end 51% of the total mass flow coming in the mixing unit). And the cabin temperature is calculated by the system at each time thus we also know the enthalpy coming from the cabin.

Obviously, there are no leak and no other source of air mass flow than the packs or the cabin. It means:

$$m_{DOT\,MIX} = m_{DOT} + m_{DOT\,REC}$$

By the way, writing the enthalpy inside the mixing unit is constant, the mixing unit ouput temperature can be infered :

$$T_{MIX}(m_{DOT} + m_{DOT\,REC}) = m_{DOT}T_{IN} + m_{DOT\,REC}T_C$$

$$T_{MIX} = \frac{m_{DOT}T_{IN} + m_{DOT\,REC}T_C}{m_{DOT} + m_{DOT\,REC}} \tag{4.1}$$

Afterwards, the signal reaches the **trim air valve block**. The trim air valve calculates the necessary amount of hot air to reach as quickly as possible the reference temperature in the cabin.

Once more, the amount of hot air is calculated thanks to an enthalpy equation :

$$m_{DOT\,BA}(T_{CTR} - T_{BA}) = m_{DOT\,MIX}(T_{MIX} - T_{CTR})$$

$$m_{DOT\,BA} = \frac{m_{DOT\,MIX}(T_{MIX} - T_{CTR})}{(T_{CTR} - T_{BA})} \tag{4.2}$$

The **trim air valve controller** is actually a proportionnal controller. Comparing the reference temperature set by the pilot, with the cabin temperature, it gives a control temperature to the trim air valve block. This control temperature is used to calculate the hot air mass flow and the trim air valve output temperature of the mixed air :

$$T_{VALV} = \frac{m_{DOT\,BA}T_{BA} + m_{DOT\,MIX}T_{MIX}}{m_{DOT\,BA} + m_{DOT\,MIX}} \tag{4.3}$$

The last main block in this simulation is **the cabin block**. The inputs of such a block are :
-the initial mass inside the cabin
-the mass flow and the temperature of the air coming from the trim air valve
-the "old" cabin temperature

The outputs are :

The **mass flow getting out of the cabin**. One part of this mass flow composes the recycled air, the other part is discharged into the atmosphere. The amount of *outflow cabin air* used as recycled air is settled by the pilot. We assume that the mass flow getting out of the cabin is equal to the mass flow coming in at each time, in order to have a constant air mass inside the cabin.

The temperature inside the cabin is the main parameter we want to control. As we work with a dynamic system, we have to use differential equations to model it. Moreover, an integration block is available in a Simulink library. That is why it is more convenient to have dT in output of the cabin block, and not T directly.

The equation describing the temperature evolution is also got thanks to the enthalpy principle. We assume that the enthalpy is constant inside the cabin :

$$H_{TOT} = m_{AIR} Cp_{AIR} T_{CAB}$$

$$\frac{dH_{TOT}}{dt} = \left(m_{DOT\,IN} - m_{DOT\,OUT} \right) Cp_{AIR} T_{CAB} + m_{AIR} Cp_{AIR} \frac{dT_{CAB}}{dt} \qquad (E1)$$

We can also write, according the formula expounded in the introduction:

$$H_{TOT} = U_{TOT} + P_{TOT} V$$

So, $$\frac{dH_{TOT}}{dt} = \frac{dU_{TOT}}{dt} + V \frac{dP_{TOT}}{dt}$$

$$\frac{dH_{TOT}}{dt} = \left(m_{DOT\,IN} Cp_{AIR} T_{IN} - m_{DOT\,OUT} Cp_{AIR} T_{OUT} \right) + V \frac{dP_{TOT}}{dt}$$

And $P_{TOT} = \sum R_i \rho_i T_{CAB} = m_{AIR} \rho_{AIR} T_{CAB}$

$P_{TOT} V = m_{AIR} R_{AIR} T_{CAB}$

$R_{AIR} = Cp_{AIR} - Cv_{AIR}$ then $P_{TOT} V = m_{TOT} \left(Cp_{AIR} - Cv_{AIR} \right) T_{CAB}$

$$V \frac{dP_{TOT}}{dt} = \left(m_{DOT\,IN} - m_{DOT\,OUT} \right) \left(Cp_{AIR} - Cv_{AIR} \right) T_{CAB} + m_{AIR} \left(Cp_{AIR} - Cv_{AIR} \right) \frac{dT_{CAB}}{dt}$$

Then:

$$\frac{dH_{TOT}}{dt} = \left(m_{DOT\,IN}Cp_{AIR}T_{IN} - m_{DOT\,OUT}Cp_{AIR}T_{OUT}\right) + \left(m_{DOT\,IN} - m_{DOT\,OUT}\right)\left(Cp_{AIR} - Cv_{AIR}\right)T_{CAB}$$

$$+ m_{AIR}\left(Cp_{AIR} - Cv_{AIR}\right)\frac{dT_{CAB}}{dt} \qquad (E2)$$

E1 and E2 give:

$$\left(m_{DOT\,IN} - m_{DOT\,OUT}\right)Cp_{AIR}T_{CAB} + m_{AIR}Cp_{AIR}\frac{dT_{CAB}}{dt} =$$

$$\left(m_{DOT\,IN}Cp_{AIR}T_{IN} - m_{DOT\,OUT}Cp_{AIR}T_{OUT}\right) + \left(m_{DOT\,IN} - m_{DOT\,OUT}\right)\left(Cp_{AIR} - Cv_{AIR}\right)T_{CAB} + m_{AIR}\left(Cp_{AIR} - Cv_{AIR}\right)\frac{dT_{CAB}}{dt}$$

$$\frac{dT_{CAB}}{dt}\left(m_{AIR}Cp_{AIR} - m_{AIR}\left(Cp_{AIR} - Cv_{AIR}\right)\right) = \left(m_{DOT\,IN}Cp_{AIR}T_{IN} - m_{DOT\,OUT}Cp_{AIR}T_{OUT}\right)$$

$$+ \left(m_{DOT\,IN} - m_{DOT\,OUT}\right)\left(Cp_{AIR} - Cv_{AIR}\right)T_{CAB} - \left(m_{DOT\,IN} - m_{DOT\,OUT}\right)Cp_{AIR}T_{CAB}$$

$$\frac{dT_{CAB}}{dt}m_{AIR}Cv_{AIR} = m_{DOT\,IN}\left(Cp_{AIR}T_{IN} - Cv_{AIR}T_{CAB}\right) - m_{DOT\,OUT}\left(Cp_{AIR}T_{OUT} - Cv_{AIR}T_{CAB}\right)$$

Finally, $\qquad \dfrac{dT_{CAB}}{dt} = \dfrac{Cp_{AIR}\left(m_{DOT\,IN}T_{IN} - m_{DOT\,OUT}T_{OUT}\right) - Cv_{AIR}T_{CAB}\left(m_{DOT\,IN} - m_{DOT\,OUT}\right)}{m_{AIR}Cv_{AIR}} \qquad (4.4)$
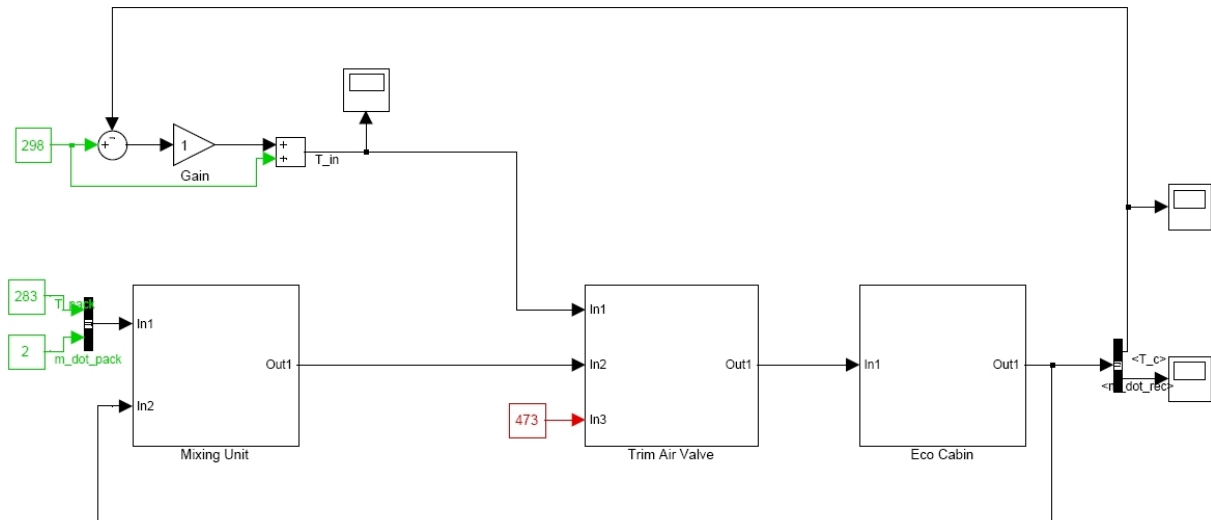

Figure 4.2:   Single cabin air temperature control program

Other parameters to care about in order to have an usable model :

The program built up until now is just the first step of the modelisation. And it could not be used in the industrial field if we don't care about other parameters like the stuff inside the cabin (seats, plastics, galley,...), the passenger presence, the delay of the trim air valve,... which totally change the dynamic of this system.

Performance analysis about this simulation:

The only parameter we can alter in this simulation is the mass flow coming from the pack. According the ATA requirements for an air conditioning system, the conditioned air should enter the cabin through cabin outlets at not more than 2.0 m/s.

Playing with the different parameters, we can note that the heat capacity of the stuff inside the cabin is the most restrictive parameter in the model, what is absolutely logic. Heating or cooling the air mass inside the cabin is much quicker than the necessary time the cabin material needs to reach the reference temperature. That is why the Cp coefficient of the cabin equipment is the main parameter to define the dynamic of the system.

4.2 Multi-cabin air temperature control

In a real airplane, the cabin structure is generally divided into several zones :
-the cockpit
-the cargo compartment
-the passenger cabin usually divided into 2 or 3 parts :

      Economic class
      Business class
      Sometimes also a First class

Each temperature zone has to be controlled and regulated by the air conditionning system which then works according the following way :
The air conditioning packs work in order to provide air flow at the minimum temperature required by all the compartments :
For instance, the desired temperature is fixed to:
293 K into the economic class,
298 K into the business class.
Then the packs will provide an air flow of 293 K (approximately, we will see that, due to the recycled air from the cabine, the pack air flow temperature must be under 293 K).

Obviously there are some modifications in the structure of the program to take into account the other compartments :
The following simulation we consider a two compartment cabin : an economic class and a business class, but no cargo hold. By the way, we need two „cabin blocks", two „trim air valve blocks", each trim air valve gets its controller. That's the only way out for the system to work. However, there is always only one mixing unit. Finally, we get exactly the structure indicated on page 29.

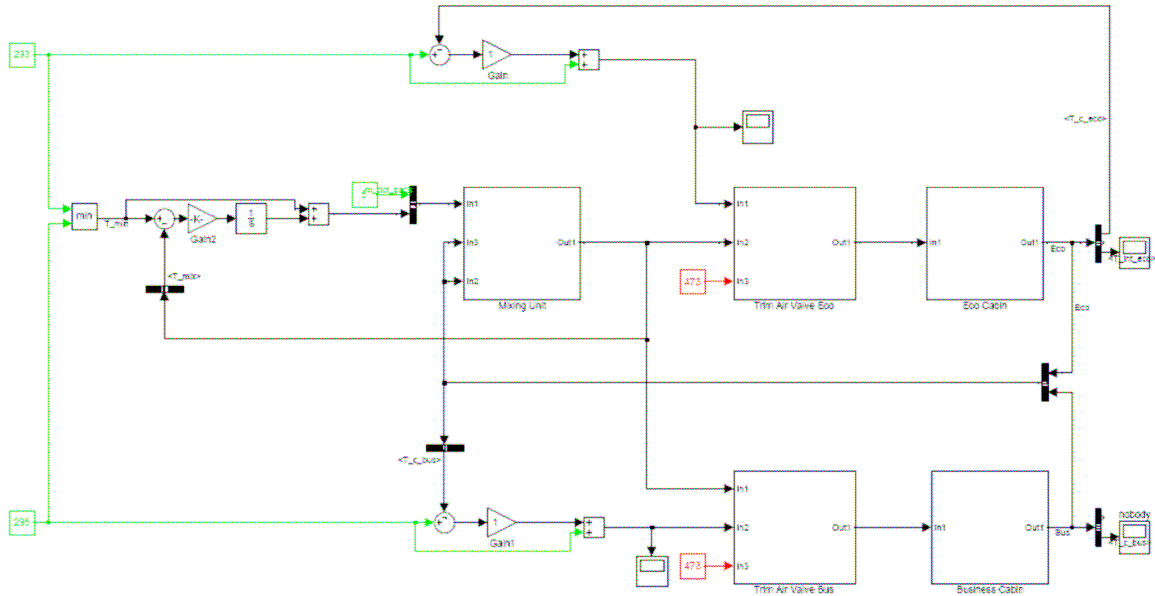The structure of the program on Matlab is the following :

Figure 4.3:   Two compartiment cabin air temperature control program

The principles to write the equations in each block are always the same. So the form of most equations is not altered. There are just more terms to take into account due to the presence of the second cabin.

The main modification concerned the controller of the air packs.
It is a proportional integral controller (PI) made up of a comparator, a gain and a simple integrator. It enables to control the packs temperature to provide air at the coldest temperature asked by the compartments.
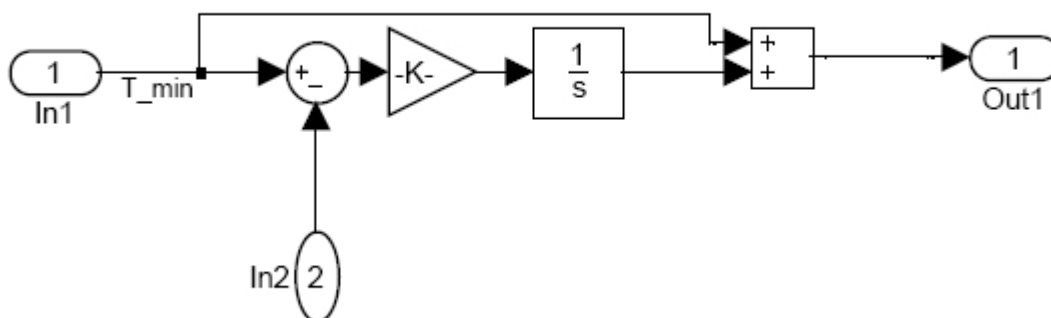
Figure 4.4:   Air pack controller structure
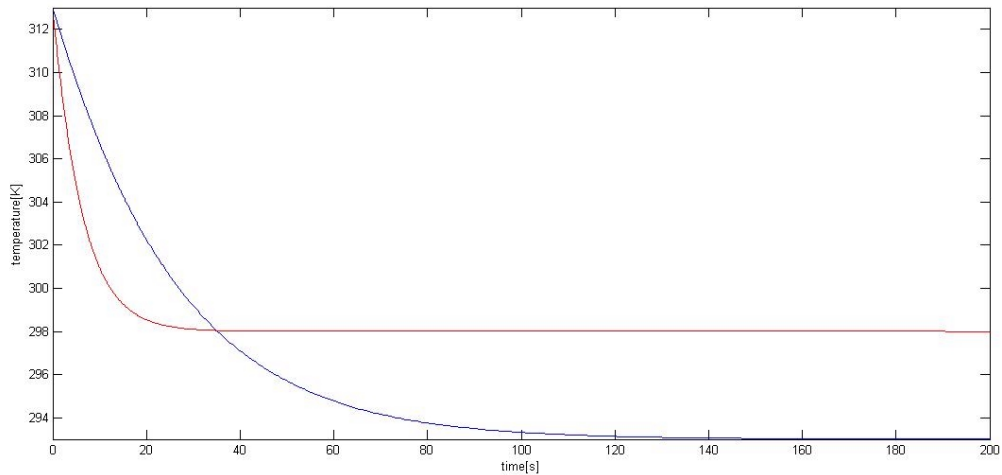
Figure 4.5:   Profil of temperature regulation in business and economic cabin

This graph, giving the temperature according the time, shows the necessary time to reach the reference temperature in each compartment:

Red curve: business cabin; only 30 seconds are necessary with the parameters chosen.
Blue curve: economic cabin; the volume is nearly 4 times larger, so the necessary time to cool down the cabin is 130 seconds.

Obviously, the time required to reach the reference temperature depends on:
-The cabin volume
-The initial temperature inside the cabin and the desired temperature
-The maximum mass flow allowed in the system
Altering these different parameters, the necessary time may be quite different.

4.3   Cabin equipment influence

Stuff inside the cabin :

Each body or object is able to stock and to exchange some heat, which is mathematically represented by the **heat capacity** (usually denoted by a capital **C**, often with subscripts). It is a measurable physical quantity that characterizes the ability of a body to store heat as it changes in temperature. It is defined as the rate of change of temperature as heat is added to a body at the given conditions and state of the body (foremost its temperature). In the International System of Units, heat capacity is expressed in units of joules per kelvin. It is termed an "extensive quantity" because it is sensitive to the size of the object (for example, a bathtub of water has a greater heat capacity than a cup of water). Dividing heat capacity by the body's mass yields a specific heat capacity (also called more properly "mass-specific heat capacity" or more loosely "specific heat"), which is an "intensive quantity," meaning it is no longer dependent on a-mount of material, and is now more dependent on the type of material, as well as the physical conditions of heating.

We assume that the material specific heat capacity inside the cabin is C_p=840 kJ kg^{-1} K^{-1} (value deducted from Airbus documentation)
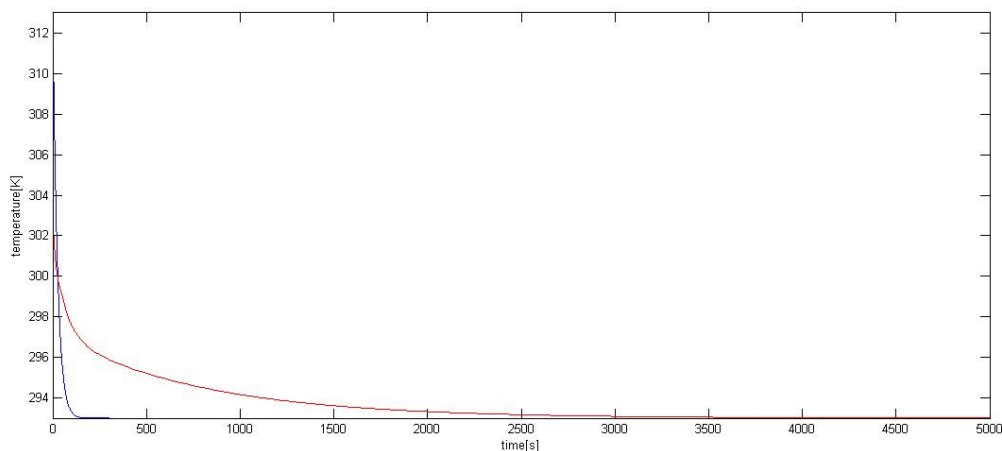

Figure 4.6:   Influence of cabin equipment on the dynamic of the system

This graph shows the paramount inflence of the heat capacity of the cabin equipment:
The dynamic of the system is totally altered:
If the material heat capacity is not taken into account, only 150 seconds are necessary to reach the reference temperature whereas with the equipment influence, the time required reaches now about 3000 seconds: it means 20 times more time.

4.4   Passenger presence influence

Each passenger is a source of CO_2, vapour, and of course heat. By the way, in a jumbo jet, the presence of 150 passengers or more can alter significantly the necessary time for the air conditioning system to refresh the cabin to the reference temperature. That is why we have to take this parameter into account. Some surveys have been led on the thermic transfer of a human body and give some formula to model the heat capacity of a human body.

The most conveneint way to take the passengers presence into account is to create a „passengers block". In this way, you have just to use put this block in the program if you consider passengers inside the cabin and erases it you consider that nobody is inside the cabin.

The structure of the „passengers block" with Simulink is the following :
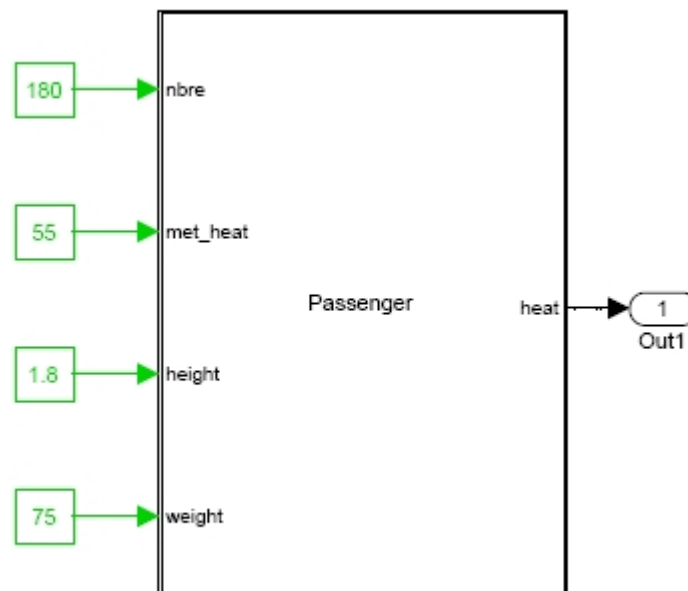
Figure 4.7:   **Passenger presence block**

The "passengers block" inputs are :
-number of passengers
-the body average heat production
-the passenger average height
-the passenger average weight

Actually, for a body at rest, the total heat production, written Q_b, is beetween 40 to 70 $W.m^{-2}$
Then to calculate the pasengers total heat production, we need to know the average surface of a human body (A_{DU}). A good approximation of this area is given by the Dubois expression :

$$A_{DU}=0.202\,(W_b\,)^{0.425}\,(h_b\,)^{0.725}$$ (4.5)

With W_b : weight of the body (kg)

h_b : height of the body (m)

So, to calculate an average of the total heat transfer we fix :

Q_b=70 W.m^{-2} , W_b=75 kg, h_b=1.80 m

Then A_{DU}=0.202.(75)$^{0.425}$.(1.8)$^{0.725}$ $=1.94$ **m^2**

Finally, $$Q_{pass} = Q_b \cdot A_{DU} \cdot Nbpassenger \qquad (4.6)$$
$$Q_{pass} = 70 \cdot 1.94 \cdot 150 = 20370 \text{ W}$$

4.5   Trim air valve delay influence

The trim air valve is a machanical component. By the way, it is obviously slower than all the electronic devices than control it, and needs a certain time to execute the order given by the trim air valve controller.

It is really easy to simulate the valve delay since a specific block already exists in the MATLAB Simulink library : such a block is called "Integer delay" and can be found in the "discrete" menu of the "Simulink" library. You have just to indicate the number of delay steps you want to define.
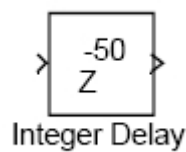

Figure 4.8:   Integer delay block

The necessary delay to open the valve in the right position has quite an important influence concerning the dynamic of the system. According the value of this delay, oscillations can even appear in the cabin temperature regulation:
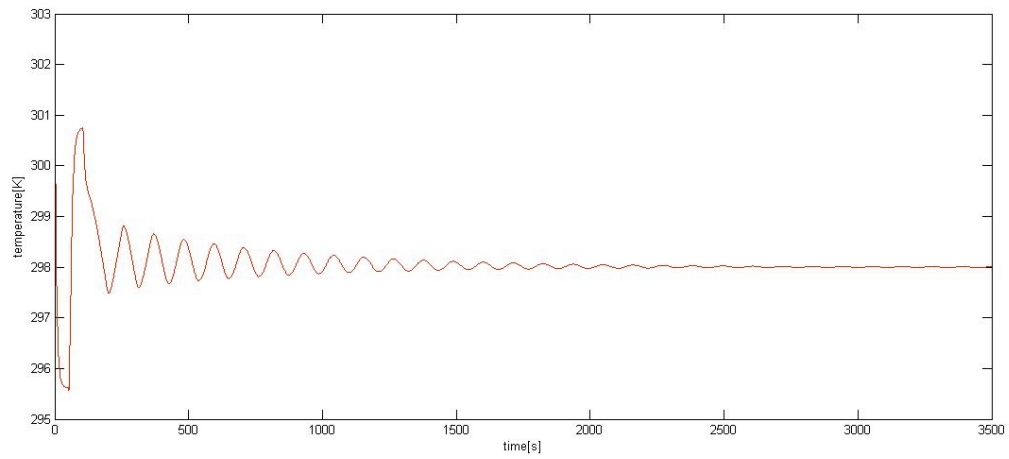
Figure 4.9:   Influence of trim air valve delay on the dynamic of the system

This graph shows the oscillations created by the response time of the valve.

5 Some comments about the programs achieved

5.1 Improvements which could be introduced

Moisture control system :
Another main parameter which has to be controlled in order to ensure passenger comfort is the humidity rate inside the cabin. It could be conceivable to take this variable into account creating a devoted block "humidity control block".
Using the model of the psychometric chart presented in the introduction, il can be possible to create a lookup table giving the amount of water according the humidity rate inside the cabin. Then this information could be compared to a reference humidity rate chosen by the pilot.

5.2 Simulation configuration problems

Time step:
An important parameter in order to make the simulation working is the choice of a time step value. Indeed, even if there is no syntax error inside the simulation programs and in its structure (compatibility between blocks is good), a bad time step choice could lead to an error and prevent the work of the simulation.

MATLAB Simulink can work according two different modes:
Variable step solver
Fixed step solver

In this project, we work with fixed step solver, because we want to combine the programs we built up previously with real time machines. And these real time machines can only work with fixed step solver.

The choice of the time step value in fixed step solver is a compromise between the stability and the necessary time to carry out the calculations of the simulation: the bigger the time step will be, the quicker the simulation will be. Unfortunately, if the time step is too big, oscillations can appear in plots of the simulation. These oscillations are not physical oscillations of the system, they are just generated by a bad time step choice which produces a problem with the simulation algorithm. Finally, the only mean to find an adapted time step for a simulation is to make several tests with different time step values in order to determine the most convenient one.

6   Conclusions

The aim of this project was to search and develop several MATLAB Simulink programs in order to simulate a temperature control system.

The first step is obviously to understand what the air conditioning system main components are and how they work together, which is presented in chapter 2. Then, the most difficult part is to select the simplifying assumptions in order to be able to model the system quite simply. But the program results must be as close to the reality as possible. For instance, we have assumed air as a perfect gas, or that the transformations were isobaric, which enables to simplify a lot the equations in the different simulations.

Then, we were able to create a Simulink block for each main component of the air conditioning system. The next step was to put all these blocks together, settling the compatibility problems beetween them, to get the complete system.

This project is only a first approach of the environmental control system simulation: the results obtained with the different simulations give an idea of the dynamic of a working air conditioning system but can not be exploited in the industrial field yet. It needs to be improved according to different ways:
-reconsidering the simplifying assumptions in order to find a mathematic model more realistic.
-precising the parameters values (ρ, P, C_p,...) which in most programs are quite rough, for the influence of passengers, cabin stuff.
-taking into account the humidity rate.

List of references

Beuth 2000   BEUTH (Hrsg.): *Introduction à MATLAB Simulink.*

Deiss 1999   DEISS, Jean Louis: *Cours de thermodynamique –*
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Le Huy 1998   LE HUY, Hoang: *Introduction à MATLAB et Simulink* Université Laval, Québec, Canada, 1998

Appendix A

List of MATLAB Simulink blocks used to buid up each program

The following explanations aim at setting out the different MATLAB Simulink blocks used to build the different programs of this project. However, this is not a technical presentation. This part is intended for all people who are not accustomed to use Simulink and do not know the basic blocks, in order to give them the essential knowledge to understand the structure of each program.

For each block, you will find the library where you can find it, its main function and properties.

Clock

Figure A.1:   Clock block

This block can be found in the „sources" library.
This block displays and provides the simulation time. It outputs the current simulation time at each simulation step. It is useful for other blocks that need the simulation time.

Bus creator, Bus Selector
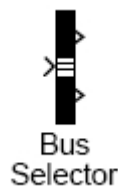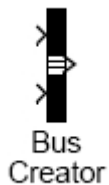
Figure A.2:   Bus creator, Bus selector

These blocks belong to the library „signal routing".

The „bus creator", as its name indicates, enables to gather in one signal (only one wire) several signals of different kind. The new signal is called a bus.
Once a bus created, you need to use a „bus selector" to choose the parameter you are interested in.
These blocks are especially used to reduce the number of wires in a program and to make easier the program reading.
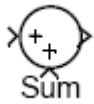
Sum

Figure A.3:   Sum block

This block is a part of the „Math operations" library.

The Sum block performs addition or subtraction on its inputs. This block can add or subtract scalar, vector, or matrix inputs. It can also collapse the elements of a single input vector. You just have to specify the operations of the block with the list of signs parameter. Plus (+), minus (-), and spacer (|) characters indicate the operations to be performed on the inputs.

Gain

Figure A.4:   Gain block

This block belongs to the „Math operations" library.

The Gain block multiplies the input by a constant value (gain). The input and the gain can each be a scalar, vector, or matrix. You specify the value of the gain in the gain parameter.
This block is often used to build up proportional controllers. Indeed basic elements to make such a controller are „sum" and „gain" blocks (see chapter 3.1 and 3.2).

Integer delay
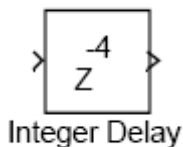
Figure A.5:   Integer delay

It belongs to the „Discrete" library.

The Integer Delay block delays its input by N sample periods. The block accepts one input and generates one output, both of which can be scalar or vector. If the input is a vector, all elements of the vector are delayed by the same sample period.
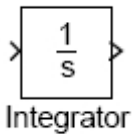
Integrator

Figure A.6:　　　Integrator block

This block can be found in the „Continuous" library.

The Integrator block outputs the integral of its input at the current time step. The following equation represents the output of the block y as a function of its input u and an initial condition y_0, where y and u are vector functions of the current simulation time t.

$$y(t) = \int_{t_0}^{t} u(t)dt + y_0$$

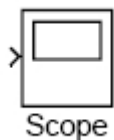This block is used in this project to build up proportional integral controller.

Scope

Figure A.7:　　　Scope block

It is a part of the „Sinks" library.

The Scope block displays its input with respect to simulation time. The Scope block can have multiple axes (one per port); all axes have a common time range with independent y-axes. The Scope allows you to adjust the amount of time and the range of input values displayed. You can move and resize the Scope window and you can modify the Scope's parameter values during the simulation.
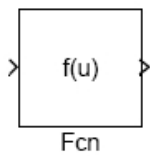
User defined function (Fcn)

Figure A.8:   Fcn block

This block can be found in the „user defined functions" library.
It enables to apply a specified expression to the input of a following block.
In several program of this project, this block is used to generate the pressure evolution inside the duct. (see Chapter 3.1 Duct, Chapter 3.2 Fan)
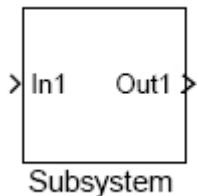
Subsystem

Figure A.9:   Subsystem block

It belongs to the „Ports & Subsystems" library.

A Subsystem block represents a subsystem of the system that contains it.

You create a subsystem in these ways:
-Copy the Subsystem block from the „Ports & Subsystems" library into your model. You can then add blocks to the subsystem by opening the Subsystem block and copying blocks into its window.
-Select the blocks and lines that are to make up the subsystem using a bounding box, then choose Create Subsystem from the Edit menu. Simulink replaces the blocks with a Subsystem block. When you open the block, the window displays the blocks you selected, adding Inport and Outport blocks to reflect signals entering and leaving the subsystem.

The number of input ports drawn on the Subsystem block's icon corresponds to the number of Inport blocks in the subsystem. Similarly, the number of output ports drawn on the block corresponds to the number of Outport blocks in the subsystem. For instance, in chapter 3.3 the „mixer unit" block, which is a subsystem of the air conditioning system, has 2 inputs and 1 output.

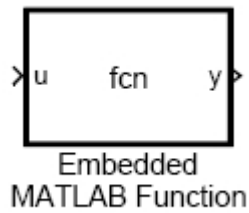# Embedded MATLAB function

Figure A.10:   Embedded MATLAB function

This block can be found in the „User-Defined Functions" library.

An Embedded MATLAB Function block lets you compose a MATLAB function in a Simulink model. The function accepts multiple input signals and produces multiple output signals.

In this project, This block is of paramount importance in order to be able to program thermodynamic functions and simulate the behaviour of most of the air conditioning system components. For example, the model accepted for the trim air valve is written in the following way.

Function[T_mix,m_dot_mix]=Mixer(T_in,m_dot,T_c_eco,m_dot_rec_eco,T_c_bus,m_dot_rec_bus)

m_dot_mix=m_dot+m_dot_rec_eco+m_dot_rec_bus;
T_mix=(m_dot*T_in+m_dot_rec_eco*T_c_eco+m_dot_rec_bus*T_c_bus)/(m_dot+m_dot_rec_eco+m_dot_rec_bus);

Appendix B

List of components created for the FLECS library

This appendix collects the blocks created for the Functional Library of the Environmental Control System. Here you can just find the drawing and the programs written for each simulation without more informations. To have more explanations about the way to base the equations, just go and see the corresponding part into the report.
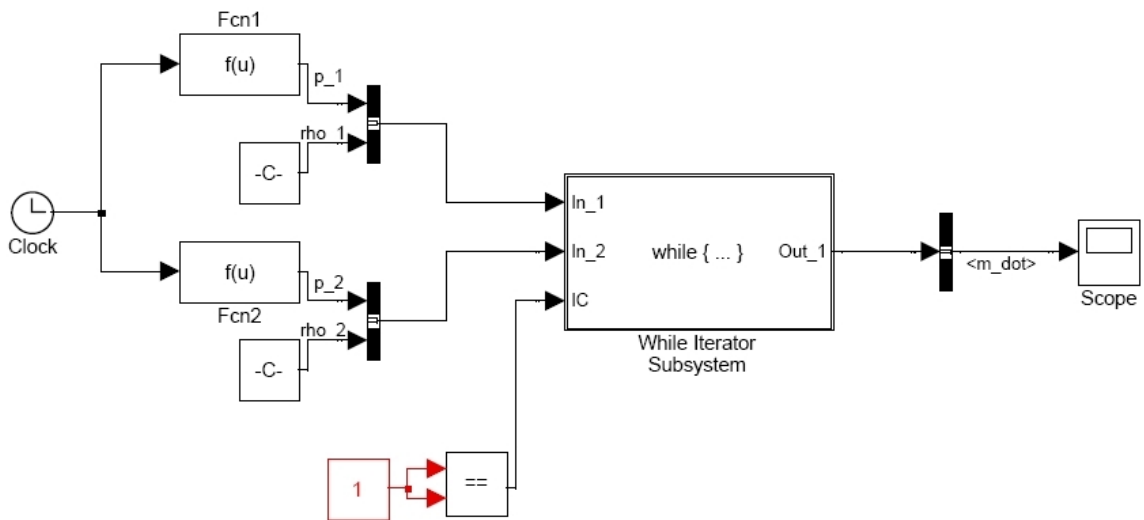
B.1   Duct

Figure B.1:   Duct structure

Pressure functions (assumed)

$P_1(t)=105000-2500(1-\exp(-2t))$

$P_2(t)=100000+2500(1-\exp(-2t))$

Structure inside the While Iterator Subsystem:
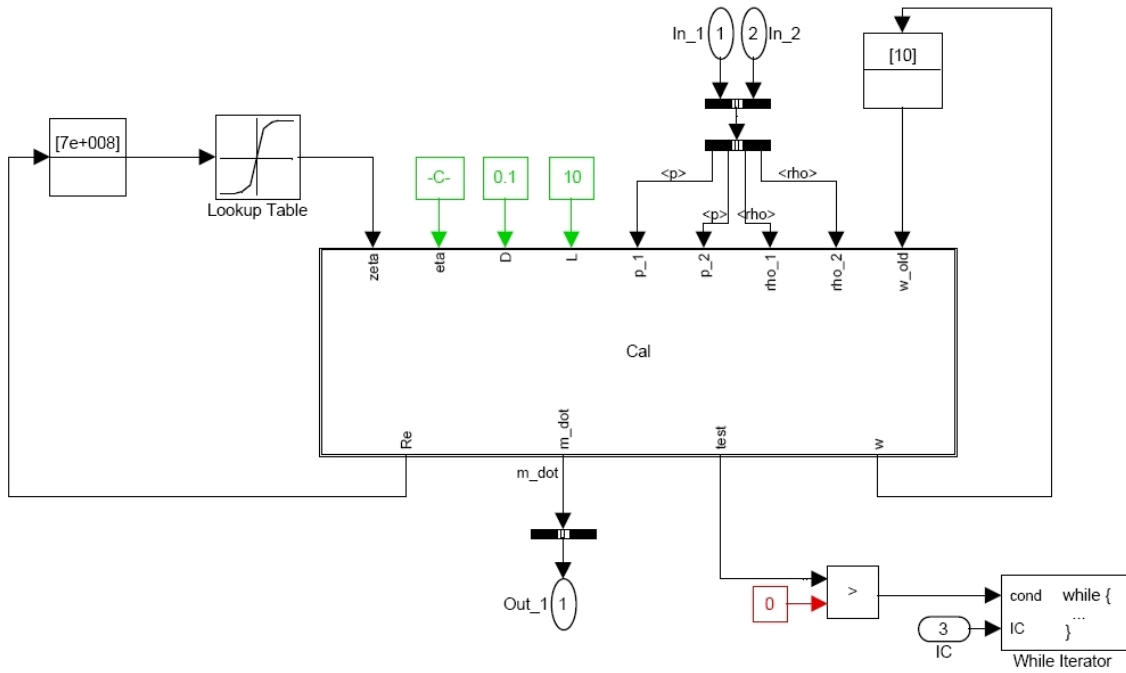
Figure B.2: Duct calculator structure

Program inside the Calculator block

function [Re,m_dot,test,w]=Cal(zeta,eta,D,L,p_1,p_2,rho_1,rho_2,w_old)

```
w=w_old;
A=(pi*(D/2)^2);
if p_1>=p_2
  rho=rho_1;
else
  rho=rho_2;
end
eta_kin=eta/rho;
Re=(w*D)/eta_kin;
test=1;
if Re<1187.384382
  if Re==0
    Z_w=0;
  else
    lambda=64/Re;
    zeta_G=(lambda*L/D)+zeta;
    Z_w=sqrt(abs(p_1-p_2)/(zeta_G*rho/2));
  end
  if abs(w-Z_w)>(0.001*w)
    test=1;
```

```
  else
    test=0;
  end
  w=Z_w;
  Re=(w*D)/eta_kin;
else
  lambda=0.3164*((Re)^(-0.25));
  zeta_G=(lambda*L/D)+zeta;
  Z_w=sqrt(abs(p_1-p_2)/(zeta_G*rho/2));
  if abs(w-Z_w)>(0.001*w)
    test=1;
  else
    test=0;
  end
  w=Z_w;
  Re=(w*D)/eta_kin;
end
m_dot=A*rho*w;
```
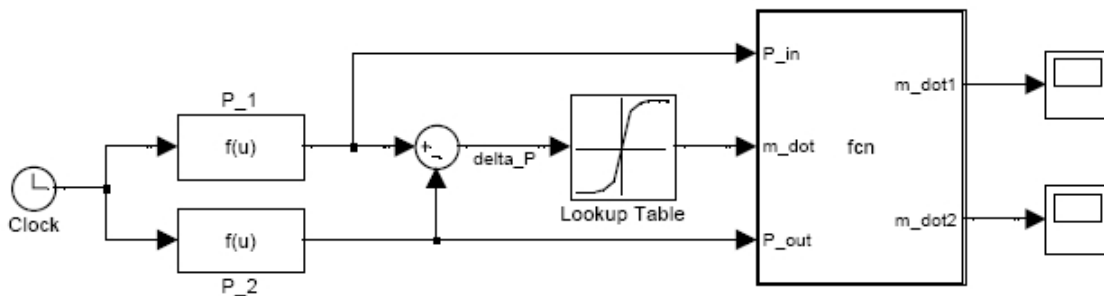
B.2   Fan

Figure B.3:   Fan structure

Pressure functions

$P_1(t)=105000-2500(1-\exp(-2t))$

$P_2(t)=100000+2500(1-\exp(-2t))$

Program inside the Fonction block

function [m_dot1,m_dot2]=fcn(P_in,m_dot,P_out)

if P_in>=P_out
  m_dot1=m_dot;
  m_dot2=-m_dot;
else
  m_dot2=m_dot;
  m_dot1=-m_dot;
end

B.3   Mixer unit

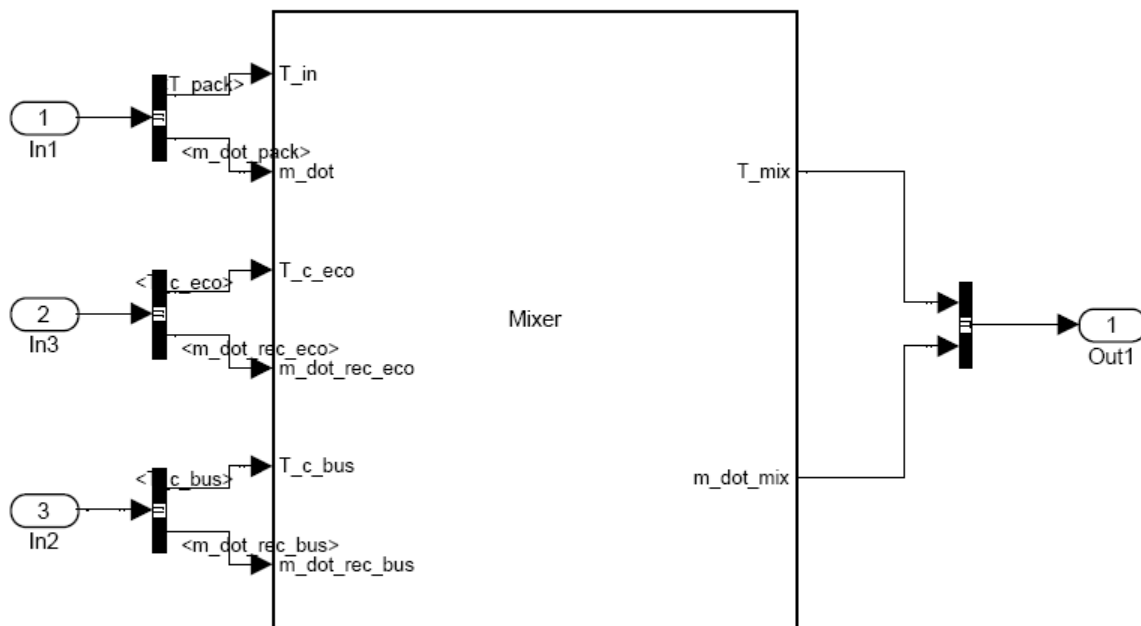**Figure B.4**   Mixer unit structure

Program inside the Mixer block

**function
[T_mix,m_dot_mix]=Mixer(T_in,m_dot,T_c_eco,m_dot_rec_eco,T_c_bus,m_dot_rec_bu
s)**

m_dot_mix=m_dot+m_dot_rec_eco+m_dot_rec_bus;
T_mix=(m_dot*T_in+m_dot_rec_eco*T_c_eco+m_dot_rec_bus*T_c_bus)/(m_dot+m_dot_re
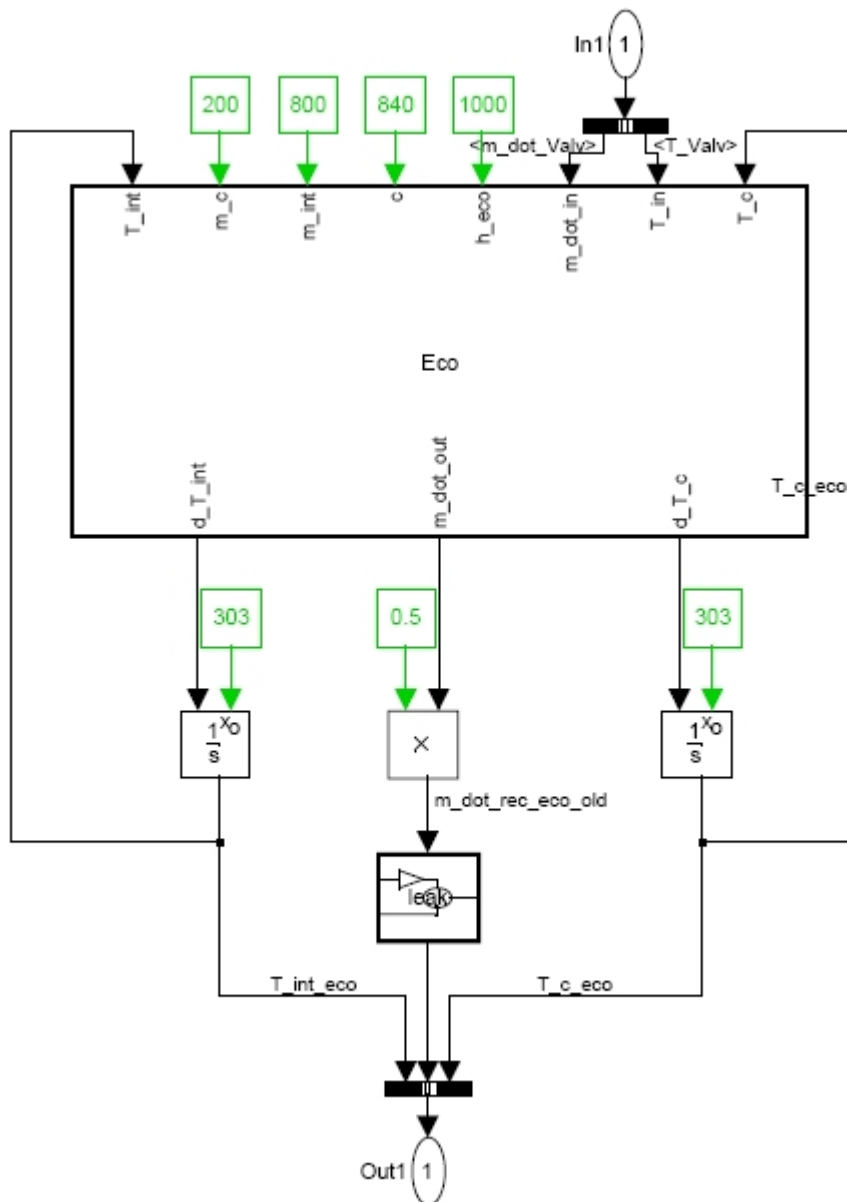c_eco+m_dot_rec_bus);

B.4 Cabin

Figure B.5: Cabin structure

Program inside the Cabin block

function [d_T_int,m_dot_out,d_T_c] =Eco(T_int,m_c,m_int,c,h_eco,m_dot_in,T_in,T_c)

m_dot_out=m_dot_in;
Q_dot=h_eco*(T_int-T_c);
d_T_c=(Q_dot+m_dot_in*((7/2)*287.058*T_in-(5/2)*287.058*T_c)-
m_dot_out*((7/2)*287.058*T_c-(5/2)*287.058*T_c))/(m_c*(5/2)*287.058);
d_T_int=-(Q_dot)/(c*m_int);

Program inside the leak block

function m_dot_rec_eco = leak(m_dot_rec_eco_old)

if m_dot_rec_eco_old<=0.95
  m_dot_rec_eco=m_dot_rec_eco_old;
else
  m_dot_rec_eco=0.95;
end
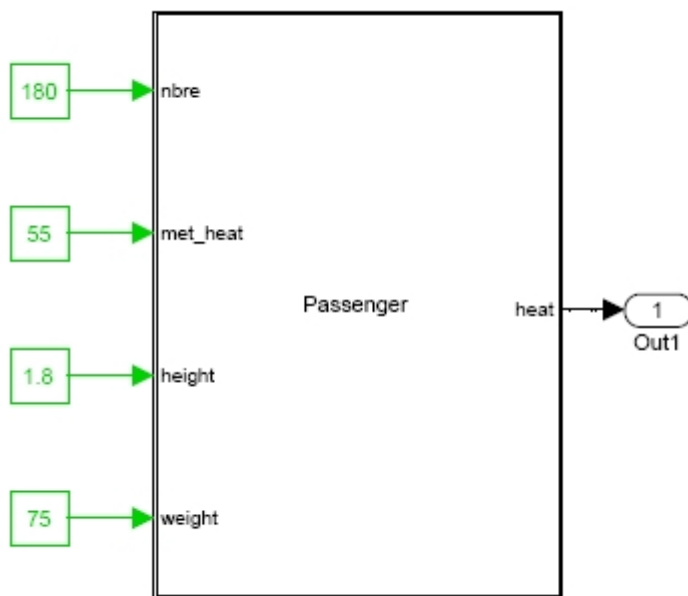
B.5   Passenger presence additional block

Figure B.6:   Passenger presence block

Program inside the passenger block

function heat = Passenger(nbre,met_heat,height,weight)

heat = nbre*met_heat*0.202*(weight^0.425)*(height^0.725);