PreSTo-Cabin

A Preliminary Sizing Tool for Passenger Aircraft Cabins

Documentation and User's Manual *

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Report

* Extracted from:
Report No.: PBH300128 "PreSTo" by Lucía Núñez at Hamburg University of Applied Sciences

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Summary:

This report was extracted by Lucía Núñez at Hamburg University of Applied Sciences from the Report No.: PBH300128 “PREliminary Sizing TOol PreSTo”.

The Preliminary Sizing Tool PreSTo - Cabin is an Excel/VBA based application for aircraft cabin preliminary design. PreSTo-Cabin provides the preliminary sizing and the interactive step-by-step design of the cabin. PreSTo-Cabin supports the seat rail positioning inside the airplane fuselage and offers the possibility to define the distance between seat rails depending on the cabin layout.

PreSTo-Cabin was jointly developed by Bishop GmbH and Aero - Aircraft Design and Systems Group, Hamburg University of Applied Sciences. It is one module of the main large Program PreSTo (Preliminary Sizing Tool) for Aircraft design, which was started under the Green Freighter Project (http://GF.ProfScholz.de) with Kolja Seeckt.

This report can be regarded as a Manual. A description of the sheets and the general layout of the program are provided, as well as a guide for the users on how to work with this tool.

For further information and software download, please refer to:
http://PreSTo.ProfScholz.de

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Table of Contents

List of Tables

List of Figures

Abbreviations

Abbreviation	Description
AC	Advisory Circular
ACN	Aircraft Classification Number
BWB	Blended Wing Body
CEASIOM	Computerised Environment for Aircraft Synthesis and Integrated Optimisation
CFD	Computational Fluid Dynamics
CG	Center of Gravity
COMFAA	Computer program for ACN calculation, provided by the FAA
CS	Certification Specifications, from EASA
DOC	Direct Operating Costs
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements, from JAA
MTOW	Maximum Take-Off Weight
NACA	National Advisory Committee for Aeronautics
PrADO	Preliminary Aircraft Design and Optimization program
PreSTo	Preliminary Sizing Tool
ULD	Unit Load Device

List of symbols

Symbol	Units	Description
a,b	m	Parameters for describing an ellipse
c, C	m	Chord
c	-	Coefficient
C	m	Circumference
d	m	Distance or diameter
g	m/s²	Earth acceleration
h	m	Altitude or height
k	-	Factor
l	m	Length
L	N	Lift
m	kg	Mass
M	-	Mach number
n	-	Indicate the number of elements
p	Pa	Pressure
R	m	Range
s	m	Distance
S	m²	Surface
t	m	Thickness
t	s	Time
t/c	-	Relative thickness
V	m/s	Velocity
w	m	Width
x,y	-	Axis used in 2D charts
x	m	Distance from a reference point parallel to the cabin floor in the direction of the tail
y	m	Distance from the plane of symmetry of the aircraft in the direction of the span
z	m	Distance from a reference point situated in the (x,y) plane in upward direction
α	°	Angle of attack or angle used in ellipse descrip tion
ρ	kg/m³	Air density
Δ	-	Indicates a difference (used as a prefix)

List of indices

Indices for aircraft components

$()_{aisle}$	Aisle
$()_{cabin}$	Cabin
$()_{CC}$	Cargo compartment
$()_{doorstep}$	Door step
$()_{f}$	Fuselage
$()_{floor}$	Floor
$()_{galley}$	Galley
$()_{LD}$	Lower Deck
$()_{nose}$	Fuselage nose
$()_{OS}$	Overhead stowage
$()_{tail}$	Tail plane
$()_{W}$	Wing

Other indices

$\bar{()}$	Medium value
$()_{0}$	Sea level
$()_{armrest}$	Armrest
$()_{armrest\text{-}wall}$	Refers to a distance from the armrest to the wall
$()_{backrest}$	Seat backrest
$()_{baggage}$	Baggage
$()_{bottom}$	Bottom
$()_{cargo}$	Cargo
$()_{ce}$	Central
$()_{cushion}$	Cushion
$()_{cylinder}$	Cylinder
$()_{E}$	Glide
$()_{ellipse}$	Ellipse
$()_{eqv}$	Equivalent
$()_{eye}$	Refers to passenger eye
$()_{head\text{-}wall}$	Refers to a distance from passenger head to the wall
$()_{i}$	Inner or used as index
$()_{k}$	Used as index
$()_{last\_seat}$	Last seat
$()_{lat}$	Lateral

$()_{left}$	Left
$()_{max}$	Maximum
$()_{md}$	Minimal drag
$()_{midshoulder}$	Passenger “midshoulder” [NASA]
$()_{o}$	Outer
$()_{OE}$	Operating empty
$()_{PAX}$	Passenger, pax
$()_{PL}$	Payload
$()_{rail}$	Seat rail
$()_{rectangle}$	Rectangle
$()_{ref}$	Reference
$()_{right}$	Right
$()_{rows}$	Rows
$()_{SA}$	Seats abreast
$()_{seat}$	Seat
$()_{seatrail}$	Seat rail
$()_{shoulder}$	Passenger shoulder
$()_{shoulder-wall}$	Refers to a distance from passenger shoulder to the wall
$()_{side\ seat\_rail}$	Refers to a side seat rail
$()_{submerged}$	Submerged
$()_{top}$	Top
$()_{tot}$	Total
$()_{water}$	Water

Definitions

Aft pressure bulkhead: Component of all large commercial aircraft. It is an airtight bulkhead located between the cabin and the fin. Its purpose is to seal the rear of the plane and thus maintain cabin pressure, and as such it is a vital part of the aircraft.

Airliner: Large fixed wing aircraft for transporting passengers and.

Binary search algorithm: Algorithm for locating the position of an item in a sorted.

Buoyancy: Upward acting force, caused by fluid pressure, that opposes an object's weight. If the object is either less dense than the liquid or is shaped appropriately (as in a boat), the force can keep the object afloat.

1 Introduction

1.1 Description of PreSTo

The Preliminary Sizing Tool (PreSTo) is an Excel spreadsheets tool based on Prof. Dieter Scholz aircraft design lecture [Scholz 1999]. This project from the university HAW Hamburg aims to allow users to quickly design an aircraft and optimize it, starting from the basic requirements such as the number of passengers or the flight range, and then designing its big parts (fuselage, wing, tail and landing gear) until the calculation of masses and direct operating costs (see Fig. 1.1). The connection between PreSTo and other software (PrADO and CEASIOM) enable further analysis such as CFD, flight dynamics, etc. Since PreSTo needs more than 10 modules, for design or analysis, it is a gathering of different student works. Therefore the task was not only to develop new abilities but also to integrate them and make them work together.

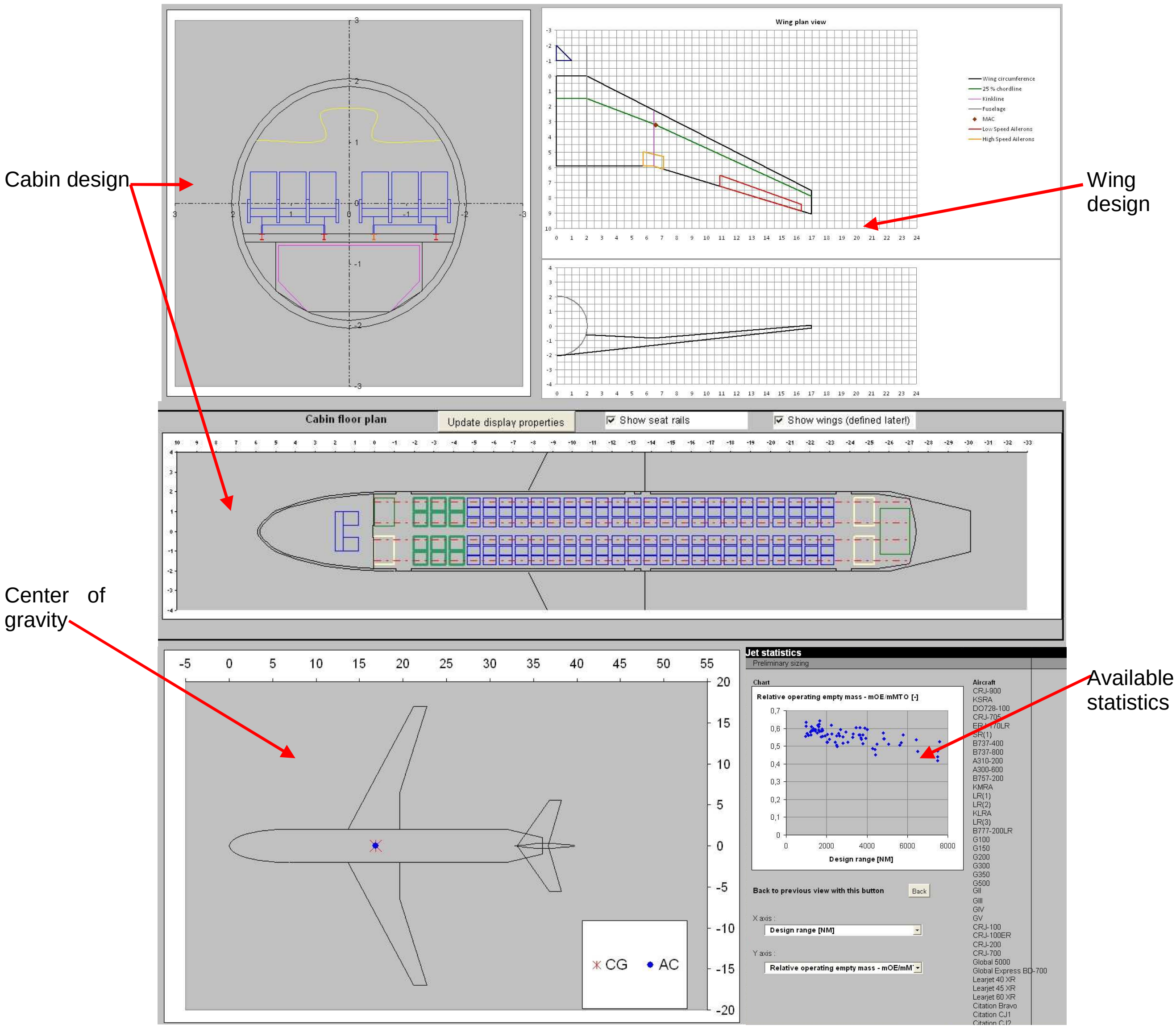


Fig. 1.1 Design of an aircraft in PreSTo

1.2 Features

In order to complete its task of designing an aircraft, PreSTo offers the following features, among others.

General
PreSTo is able to design airliners and executive jets as well as general or regional turboprop. Parts of the airplane which can be designed with the tool are: cabin, wings and high lift systems, tail plane and landing gear. Analyses are available for mass calculation, center of gravity position and travel during the flight and calculation of direct operating costs.

Included database
Since 8 basic requirements are needed for the design, help is provided to the user with data of existing aircrafts. This data from 75 jets and 26 turboprops describes several parameters such as masses, speeds, geometry, aerodynamics, fuel consumption, etc. Statistics are also available for more than 100 jet engines concerning their dimensions and performances. For both airplanes and jet engines the user can display a (x,y) chart with the data he wants on both axis, allowing him to make a connection between two parameters.

Connection to other software
A connection with the design tools CEASIOM and PrADO is enabled which provides a 3D drawing of the aircraft and CFD analysis.

PreSTo-Cabin
The cabin and fuselage module from PreSTo is also available as a stand alone program. The module which is also a module from the much larger PreSTo has these features:

Cabin design
Cabin can be designed with 3 classes. Floor plan drawing is displayed to the user. Elements such as seats, lavatories, galleys, overhead bins, exits/emergency exits and seat rails are included. PreSTo and PreSTo-Cabin offer an automatic optimization of fuselage cross section depending on various parameters such as passenger dimensions. Uses of classical “1 inch” seat rail or new concept of “1 centimeter” seat rail are both available. A list of 16 standard ULD containers is given with their dimensions. Check of uniform spacing of exits according to the Advisory Circular AC25.807-1 and water line checking are provided too.

1.3 Limits

The “Fuselage” module is only compatible with cylindrical fuselages. Blended Wing Body (BWB) cannot be designed in PreSTo-Cabin. Double deck cabins are not implemented either. the cabin must have one or two aisles. Incomplete seating rows are forbidden.

PreSTo-Cabin is compatible with Microsoft Excel 2003 and its newer versions. It is incompatible with Open Office.

1.4 Layout

PreSTo-Cabin has a standard layout so all the modules look similar to the user. This standard layout was defined by [Wolf 2009]. “Look and feel” is the philosophy of PreSTo-Cabin layout. This means that the graphic template must appear clear and intuitive to the user.

In general, a module consists of three types of fields:

- Module title
- Sub-module title
- Calculation & Presentation

Each of them has a particular task. Both “Module title” and “Sub-module title” fields give the name of a particular module or sub-module. All the elements and objects such as input cells, graphs, buttons and drop-down lists are placed in the “Calculation & Presentation” fields. Fig. 1.2 shows the general layout in PreSTo-Cabin.

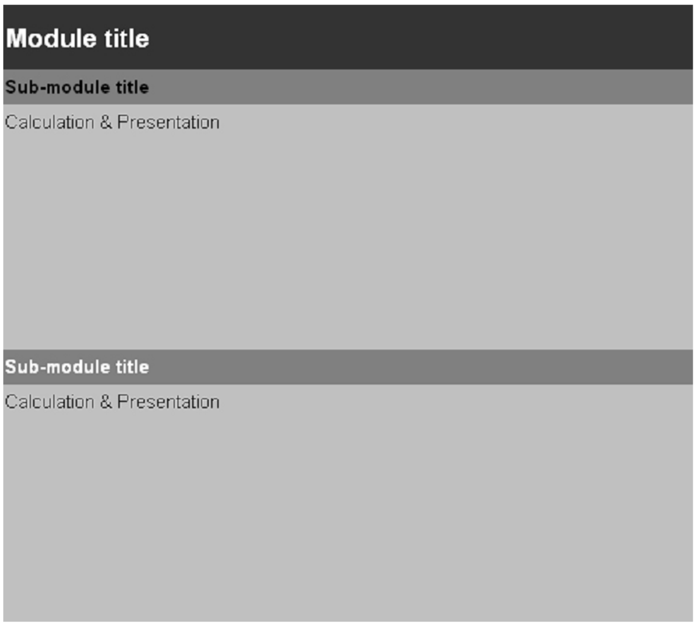


Fig. 1.2 General layout in PreSTo modules

Width of columns is also standardized so that the user does not need to scroll the sheet on the right or left to see important information. Basically all the information has to be displayed on the screen with the 100% zoom.

Apart from titles the modules contain only “Calculation & Presentation” fields. All input cells and cells filled in with previously given values are placed on the left side (Fig. 1.3). All calculations and results of these calculations are on the right side. Input cells have a white background colour whereas other cells whose content cannot be modified by the user keep the same colour as the normal background (grey 25%). Black arrows can also be added to show a direct relationship between an input cell and a result cell. With this layout the calculation process seems clear to the user.

If statistical data is available, a “Stat” button is placed close from the input cell. A click on this button opens another “Statistics” spreadsheet containing the desired data.

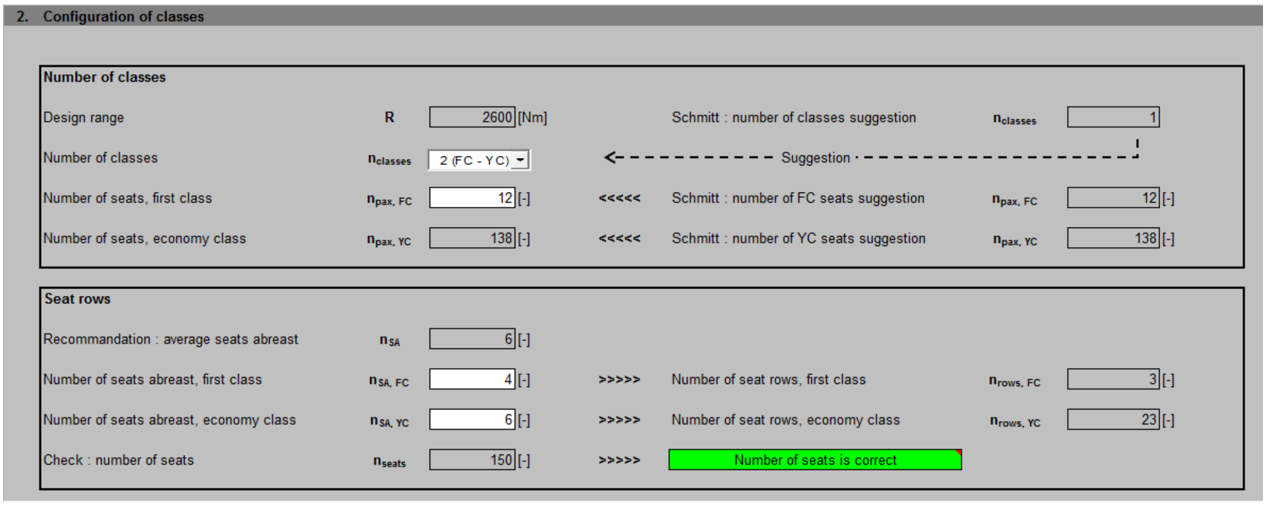


Fig. 1.3 Design philosophy for layout

5 to 10% of results indicate a verification of a hypothesis or the compliance with regulations. In order to catch the attention from the user, the display of this result has to be highlighted. A message giving the compliance or no-compliance is written in a large cell on the centre of the screen. If the result is positive, the background cell has to be green whereas it is red for a negative result. Fig. 1.4 shows how the verifications are highlighted in PreSTo-Cabin.

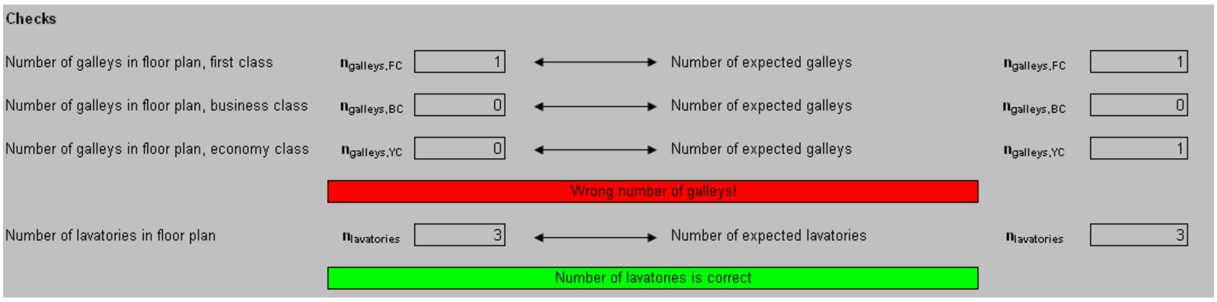


Fig. 1.4 Display of check in PreSTo-Cabin

In order to make these verifications useful for the user, a comment is written on the cell, with explanations on how to correct this error. Then when the user moves the cursor on the cell, this comment appears and using this recommendation he can fix the error (Fig. 1.5).

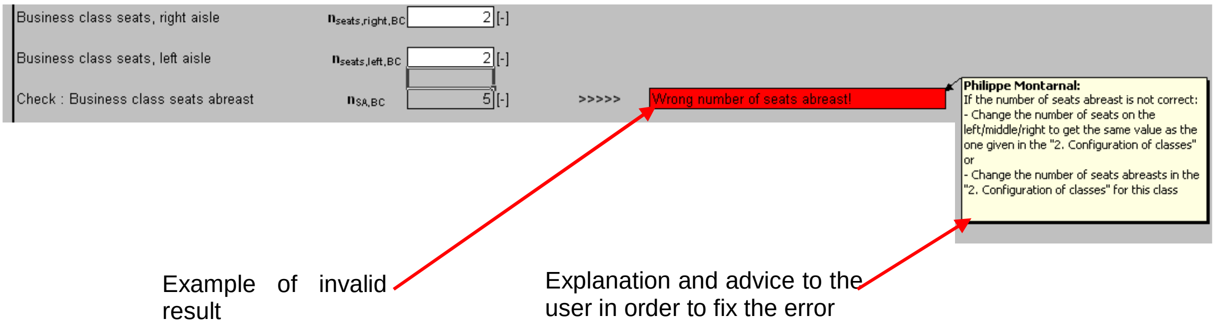


Fig. 1.5 Help provided to the user through comments

Nevertheless, attention must be paid that the input cells and calculation cells are displayed in an appropriate order. For example a calculation cell cannot be the result of an input cell placed 30 lines deeper in the spreadsheet. Otherwise the calculation process appears unclear to the user. Errors will also appear without the user being able to notice them because they happen much upper in the sheet.

1.5 Description of the sheets

PreSTo-Cabin consists of a gathering of 4 spreadsheets. One of them is hidden because of its non-interest for the basic user. In particular, PreSTo-Cabin consists of:

Title Page
The tab consists of logos, names, summary, copyright statement and link to the GNU licence agreement.

Fuselage
The cabin is designed in this spreadsheet. Basically, important input parameters in this sheet are the number of aisles and classes, dimensions of seats and passengers, choice of lower deck container. Cabin cross section and floor plan are designed. Water line calculation is checked there, and results of uniform distribution of exits are displayed.

Data Fuselage
This is the hidden sheet related to the “fuselage” sheet. It is divided in three main parts. The first part is the definition of cross section dimension including the calculation of the coordinates of 10 important points described further in this document. Second every line or curve that is on the cross section drawing is calculated. Finally lines and curves for the cabin floor plan are calculated. This last part needs about 2000 rows in the spreadsheet: 22.000 cells are computed. All these lines are displayed in the “Fuselage” spreadsheet through a basic (x, y) plot chart.

Analysis
This sheet offers to study up to five different versions of an aircraft. 250 values are saved here and can be compared to support the user to take the best decision.

1.6 Fuselage

1.6.1 Cabin cross section

Fuselage is the first designed part of the aircraft. In most conventional aircraft the payload is carried here.
Payload consists in passengers, luggage and cargo. Passengers sit in the main deck. Small passenger luggage is placed in *overhead bins* or under the seats. Bigger luggage and cargo are located in the lower deck.

The cabin can be divided in 3 classes. Usually the sharing between these 3 classes is (Table 1-1):

Table 1-1 Percentage of seats of each class [Schmitt 88]

	Economy class [%]	Business class [%]	First class [%]
Short range R ≤3000 Nm	100	-	-
Middle range 3000Nm<R<5500Nm	90 - 92	-	8 – 10
Long range R≥5500 Nm	73 – 77	18 - 20	5 - 7

Once the number of passengers in each class is known, the number of seats abreast has to be defined, for each class. This number describes how many seats there are on a seats row.
This number is usually determined by the equation:

$$n_{SA} = 0{,}45\sqrt{n_{PAX}} \qquad (1.1)$$

This number is limited by the FAR 25 regulation (see Fig. 1.6).

FAR 25.817 : [Maximum number of seats abreast.]

[On airplanes having only one passenger aisle, no more than 3 seats abreast may be placed on each side of the aisle in any one row.]
Amdt. 25-15, 10/24/67

Fig. 1.6 Regulation for number of seats abreast

Therefore the number of aisles and the number of seats abreast are related. A single aisle aircraft cannot have more than six seats abreast whereas a twin aisle is limited to twelve seats abreast.

The next step is to find the dimensions of the cabin. Since the fuselage is considered to be a cylinder, its cross section has a great importance.
The fuselage cross section can be circular, double bubble, elliptic, etc. In PreSTo-Cabin the cross section is considered as elliptic. The user has the ability to change its shape so it can make it higher or wider.

Fig. 1.7 presents three ellipses with different shapes:

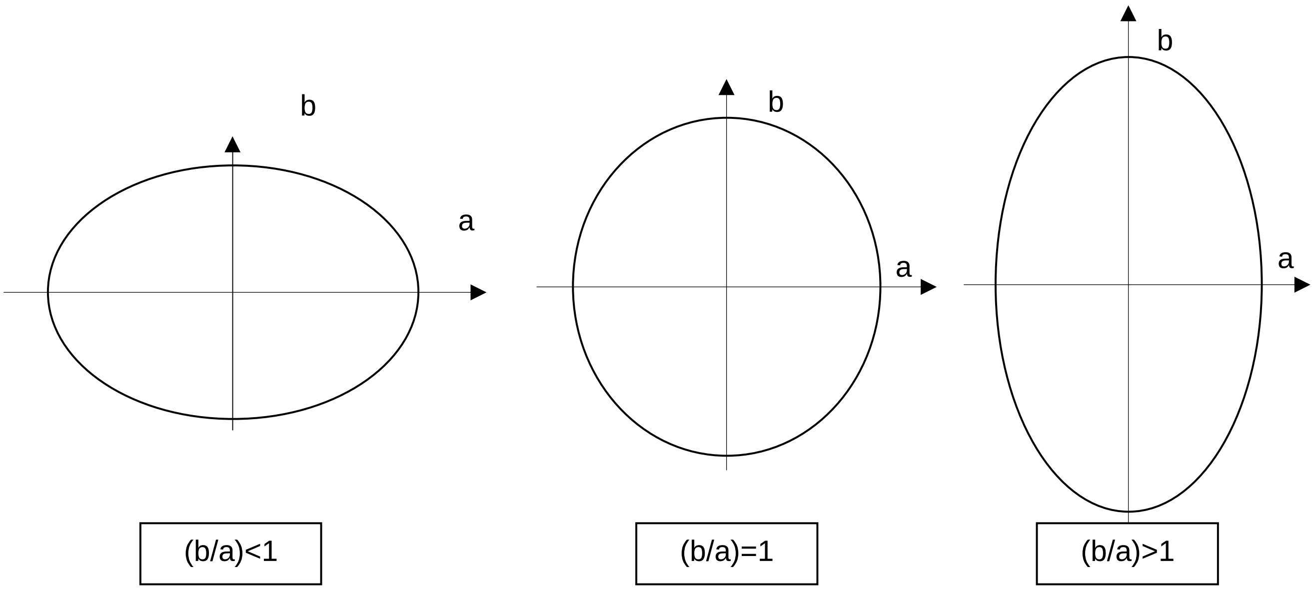


Fig. 1.7 Various shapes for the elliptic cabin cross section

Several parameters are taken into account for the cross section dimensions: dimensions of the seats, the passengers, the aisles and the lower deck are used. The user is asked to give each one of these values (see 2.1.3 Cross section).
PreSTo delivers default values for the passenger dimensions, using the 95% American male from NASA (see Fig. 1.8).

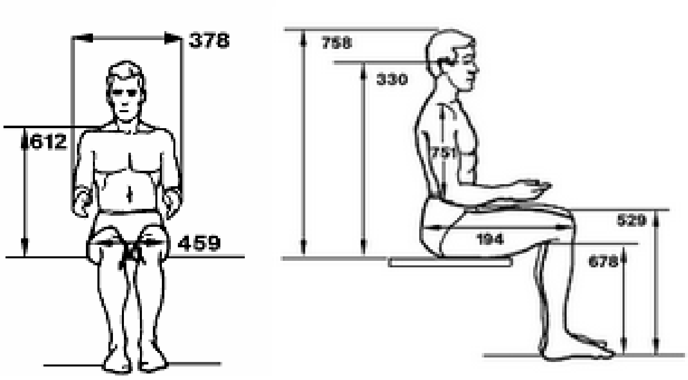


Fig. 1.8 Definition of anthropometric dimensions for American Male [NASA]

In PreSTo-Cabin, only the economy class is used to calculate the cross section dimensions. First and business class are placed after in the cabin, using the aisle width as a variable. Indeed the economy class has always more seats abreast than business and first classes, and even if the economy class seats are smaller the limitations occur almost always on economy class. Verification is made though, that the resulting widths of business and first class aisles are bigger than the one in economy class.

These values from the user lead to the calculation of ten points that must be inside the cabin: they describe aisles, seats, passenger and cargo. The cross section is then designed around these ten points (see Fig. 1.9).

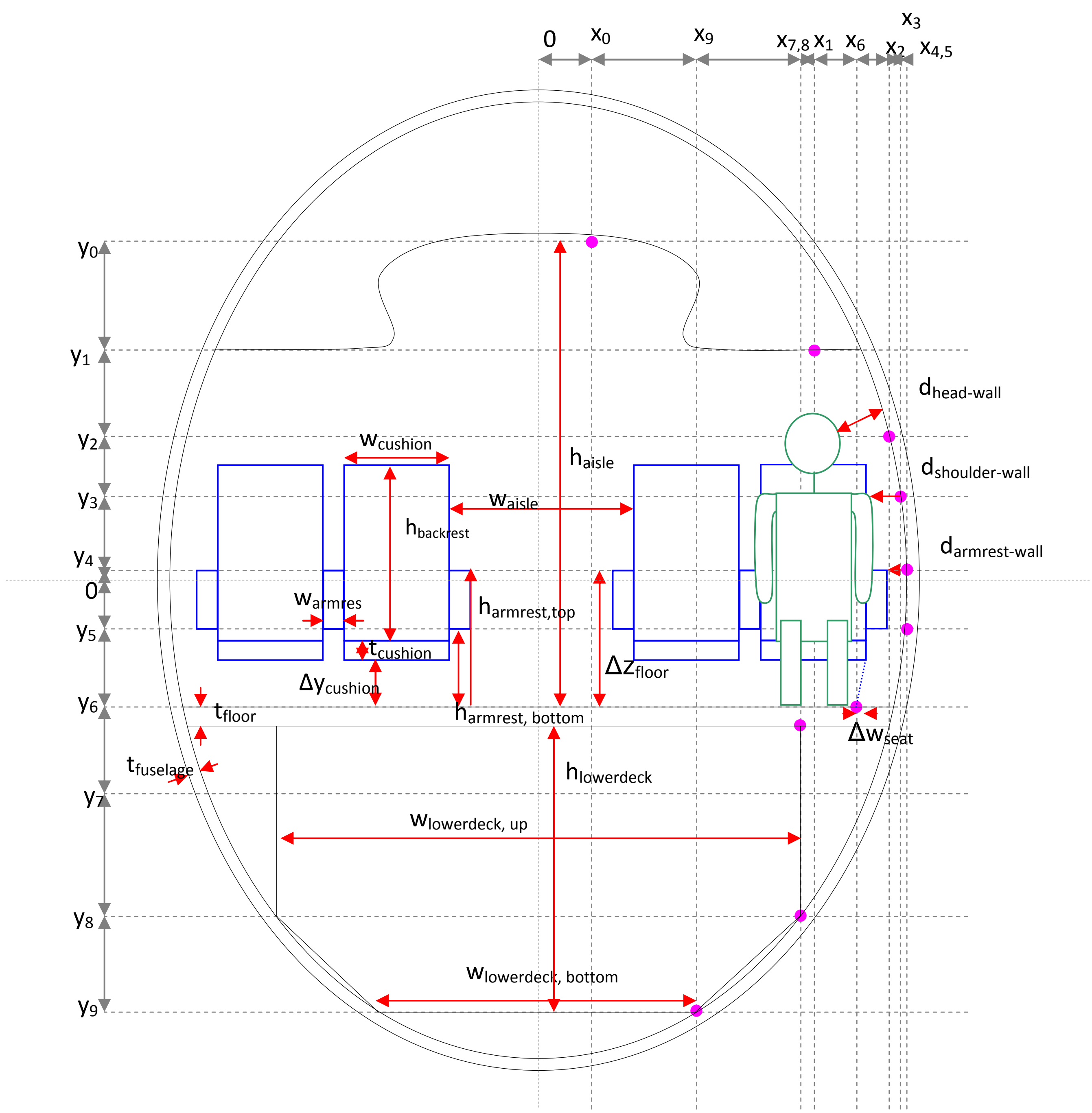


Fig. 1.9 Definition of generic cross section of an aircraft as used in PreSTo-Cabin

The cross section is considered as elliptic. Equations referring to the Fig. 1.9 are given in the appendix.

Each point used for these measures can be on a different ellipse. Since all these points have to be inside the fuselage, the biggest of the ten resulting ellipses will describe the inner fuselage.
For each point, the parameters that describe its associated ellipse (a and b) are calculated. Since the user chooses a shape for the ellipse (the ratio between height and width, so b/a), both these parameters are related. Therefore only a is needed to describe the dimensions of each ellipse:

$$a_i = \sqrt{x_i^2 + \frac{y_i^2}{(b/a)^2}} \tag{1.2}$$

The biggest value of the ten various a will give the value for a_{cabin} describing the inner fuselage.

$$a_{cabin} = \max(a_i) \tag{1.3}$$

Then the value of b_{cabin} is calculated through the given ratio (b/a):

$$b_{cabin} = a_{cabin} \cdot (b/a) \tag{1.4}$$

Once the dimensions of the ellipse are known, the cabin height and width are calculated. The inner dimensions are:

$$\begin{cases} h_{f,i} = 2b_{cabin} & (1.5) \\ w_{f,i} = 2a_{cabin} & (1.6) \end{cases}$$

The thickness of the fuselage is estimated by [Marckwardt 1998] through the equation:

$$t_f = 0{,}084 + 0{,}045 \cdot d_{f,i} \tag{1.7}$$

As the fuselage is considered elliptic in PreSTo-Cabin, the equivalent diameter of the inner fuselage is defined as:

$$d_{f,i} = \sqrt{h_{f,i} \cdot w_{f,i}} \tag{1.8}$$

Then the external dimensions of the fuselage are:

$$\begin{cases} h_{f,o} = h_{f,i} + 2t_f & (1.9) \\ w_{f,o} = w_{f,i} + 2t_f & (1.10) \end{cases}$$

The floor thickness is estimated by [Schmitt 1988] to:

$$t_{floor} = 0{,}035 \cdot d_{f,o} \tag{1.11}$$

With $d_{f,o} = \sqrt{h_{f,o} \cdot w_{f,o}}$ (1.12)

The calculation of cross section is an iterative process: the floor thickness is calculated at the end, while it is an input value too. This can be seen on Fig. 1.10:

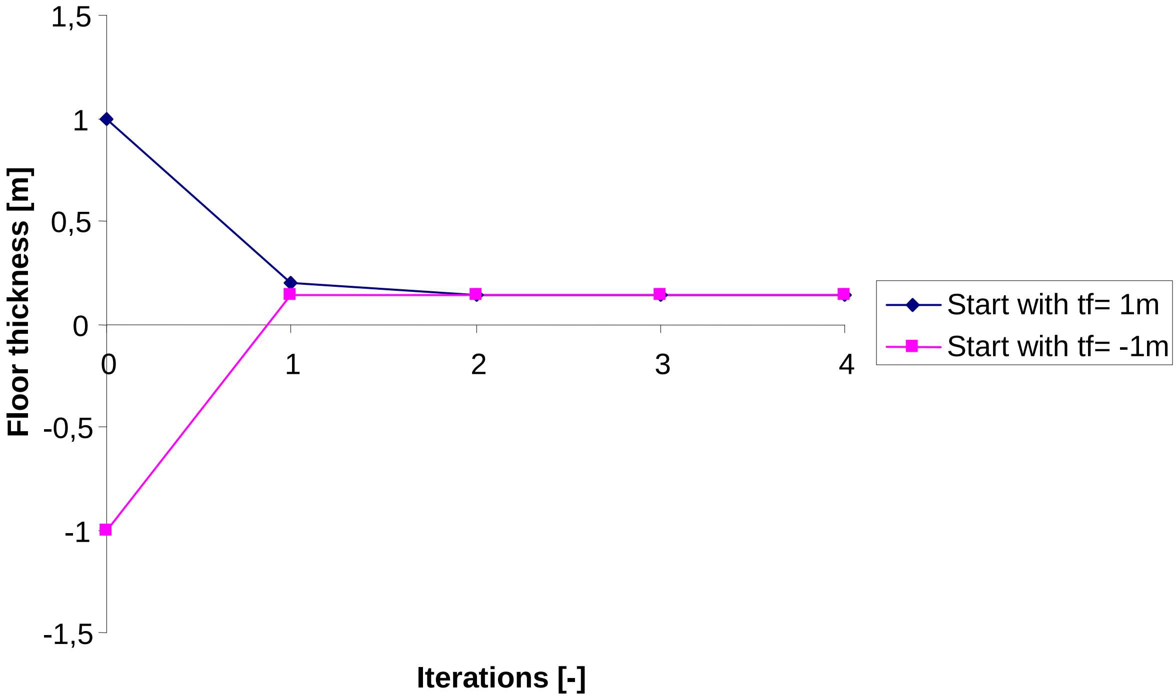


Fig. 1.10 Evolution of floor thickness value through four iterations

Fig. 1.11 shows how calculations are performed to find the cabin cross section dimensions.

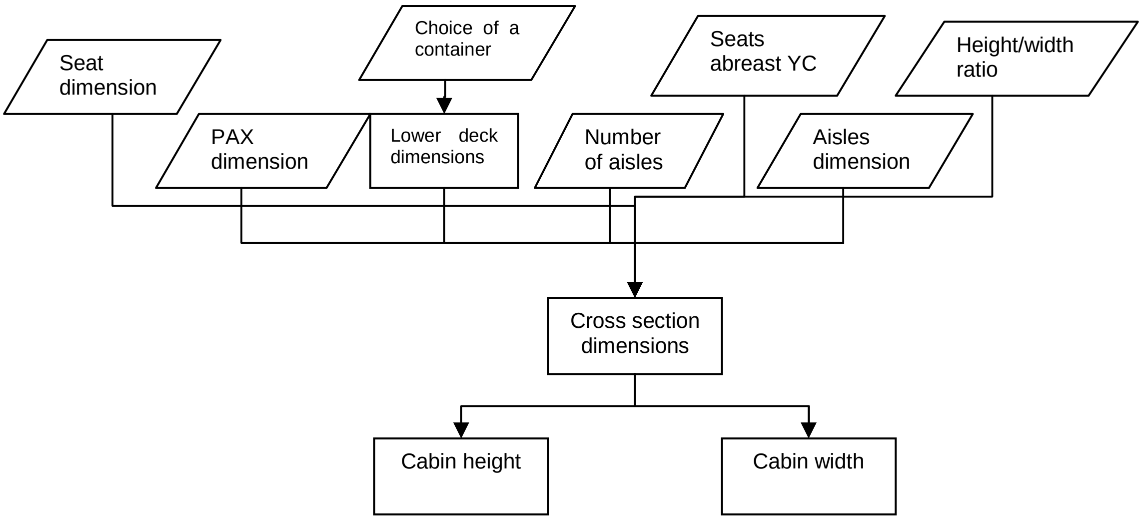


Fig. 1.11 Calculation of cabin cross section dimensions

1.6.2 Seat rail configuration

After the definition of the cross section, it is possible to set the seat rails in the aircraft. For each side of the aisles (right and left for a single aisle; right, middle and left for a wide body) the number of rails has to be given. Then the position of the seat rails has to be set.
In order to set the seat rails on one side of the aisle, it is possible to define the distance between the first seat and the first seat rail, and then the distance between two consecutive seat rails.
Fig. 1.12 shows how to do this on a single aisle.

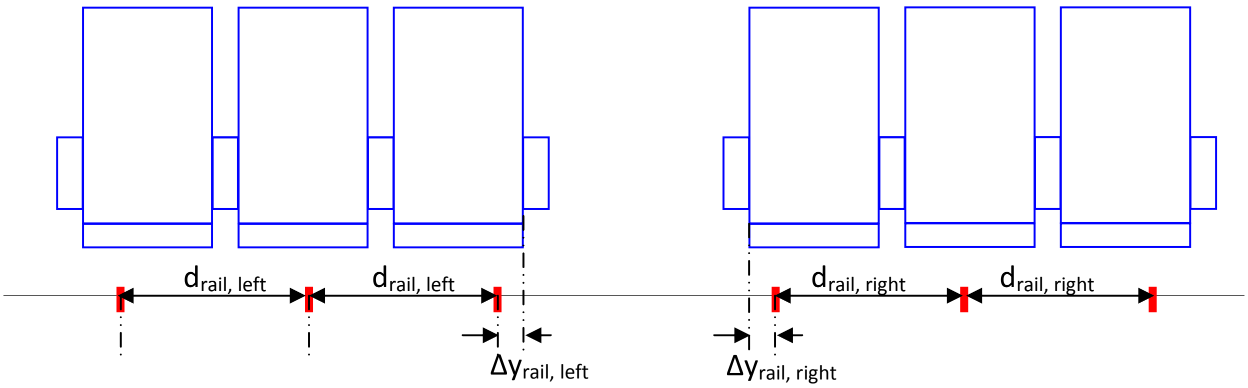


Fig. 1.12 Positioning of seat rails on a single aisle

If the aircraft is a wide body, there are seats on the middle of the cabin (between both aisles). With the assumption that the cabin is symmetric there is no need to give the distance between the first seat and the first seat rail: the only variable here is the distance between 2 consecutives seat rails.

Considering that the seat rails configuration can be symmetric on each side of an aisle, one variable disappears. Only the distance between the seats extremity and seat rails extremity remains and the distance between two consecutive seat rails is constrained (see Fig. 1.13):

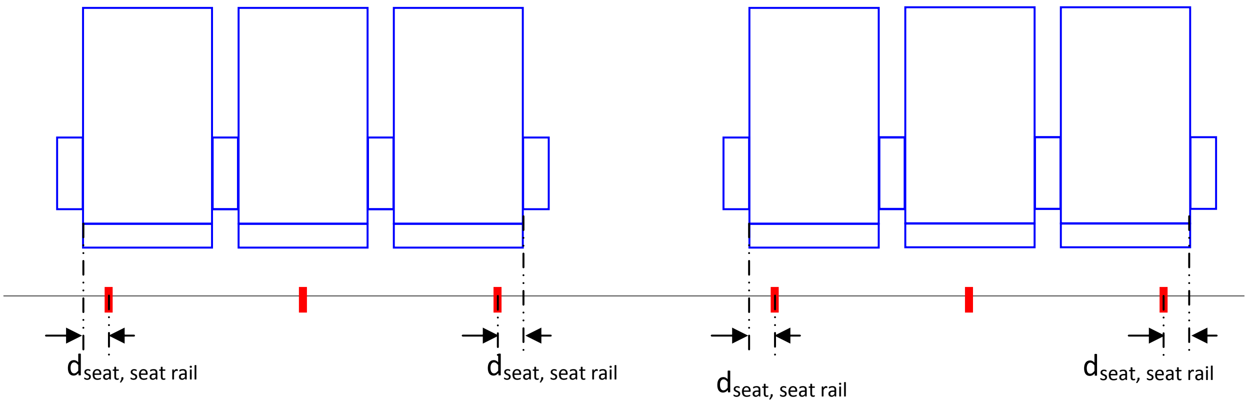


Fig. 1.13 Positioning of seat rails on a single aisle (using symmetry)

It is also possible to use side seat rails. In this case the seat rails on the extremity are located on the fuselage. The user gives the height of the rail and its lateral position is calculated to set the rail on the fuselage. Both configurations presented before remain available using a side seat rail. The only difference is that the rails on the sides are positioned on the fuselage. Fig. 1.14 shows how the side seat rails are positioned in the cabin.

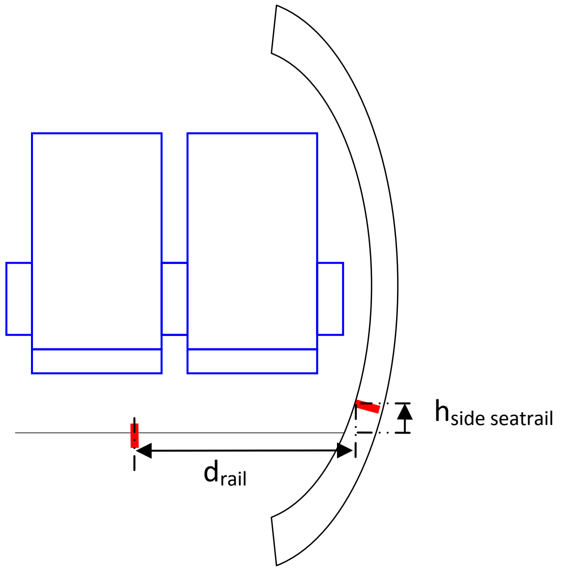


Fig. 1.14 Positioning of side seat rails

1.6.3 Cabin floor plan

Once the cross section is known the cabin floor plan must be set. The cabin floor plan will give the cabin length.
From the upper view, the cabin can be considered as three classes containing rows of seats, galleys and lavatories plus the cross aisles needed for the exits. The classes are set in the following order along the cabin: first class then business class then economy class.

Seats
The number of seats as well as the number of seats abreast has already been defined before for each class. The number of rows in a class is:

$$n_{rows} = round\left(\frac{n_{pax}}{n_{SA}}\right) \tag{1.13}$$

Note: since only entire rows are available in PreSTo-Cabin, n_{pax} must be a multiple of n_{SA} in each class.

The pitch between two seat rows is given by the user, in inches or centimeters. Therefore this allows comparing an aircraft using a “1 inch seat rail” with an aircraft using a “1 cm seat rail”.

Lavatories
The number of lavatories per passenger depends on the flight length and on the class. Table 1-2 displays statistics concerning the number of lavatories per passengers:

Table 1-2 Number of lavatories [Schmitt 1988]

	Economy class	Business class	First class
Short range R ≤3000 Nm	1/60 pax	-	-
Middle range 3000Nm<R<5500Nm	1/45 pax	-	1/14 pax
Long range R≥5500 Nm	1/45 pax	1/25 pax	1/14 pax

The area used by lavatories on the floor is: usually $1{,}03\,\mathrm{m}^2$ [Raymer 89] or $1{,}20\,\mathrm{m}^2$ [Marckwardt 1998].

Galleys

The surface needed for the galleys is estimated by [Marckwardt 1998] through the equation:

$$S_{galley} = k_{galley} \cdot \frac{n_{pax}}{1000} + \frac{1}{2} m^2 \tag{1.14}$$

Table 1-3 gives typical values for k_{galley} depending on the flight destination:

Table 1-3 Values for k_{galley} by Marckwardt 98

Flight from Germany to:	k_{galley} [m²]
Germany and neighborhood	16
Europe	23
North Atlantic, Middle East	32
South Atlantic, Far East, South Africa	41

Since PreSTo-Cabin is not only aimed to German users, this table must be updated, using the flight range as a parameter (Table 1-4):

Table 1-4 Values for k_{galley} in PreSTo-Cabin

Flight range [Nm]	k_{galley} [m²]
<700 Nm	16
700 to 1500 Nm	23
1500 to 4000 Nm	32
≥4000 Nm	41

Exits

Exits must be included in the cabin floor plan. FAR 25 regulations define several types of exits with their minimal dimensions (Table 1-5):

Table 1-5 Types of exits as defined in FAR 25.807

Exit type	Minimal width	Minimal height	Maximum step-up inside the airplane	Number of passengers allowed through exit
Type I	24”	48”	-	110
Type II	20”	44”	10” if wing exit	75
Type III	20”	36”	20”	55
Type IV	19”	26”	29”	45
Type A	42”	72”	-	40
Type B	32”	72”	-	35
Type C	30”	48”	-	9

Cross aisles

Cross aisles provide an access to the exits. The minimal width of these cross aisles is given in FAR 25 regulations (Fig. 1.15):

> (1) [The escape route from each Type A or Type B passenger emergency exit, or any common escape route from two Type III passenger emergency exits, must be at least 42 inches wide; that from any other passenger emergency exit must be at least 24 inches wide; and]

Fig. 1.15 FAR 25.810 Regulation regarding cross aisles width

Cabin length

Once each element of the cabin (seat, galley, lavatory, exit and cross aisle) has been placed in the cabin floor plan, the cabin length is measured as the distance between the first and the last element (see Fig. 1.19).

Nose and tail lengths

Nose and tail lengths can be approximated thanks statistics. [Schmitt 1988] wrote that the ratio between nose length and fuselage outer diameter is usually around $1{,}7$ (Fig. 1.16 and Fig. 1.17) and between tail length and fuselage outer diameter around $3{,}5$ (Fig. 1.18).

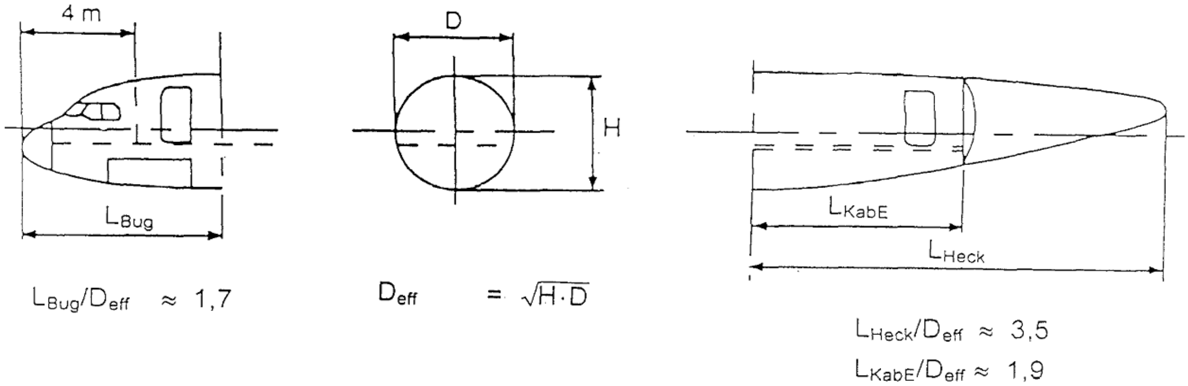


Fig. 1.16 Nose length and tail length [Schmitt 1988]

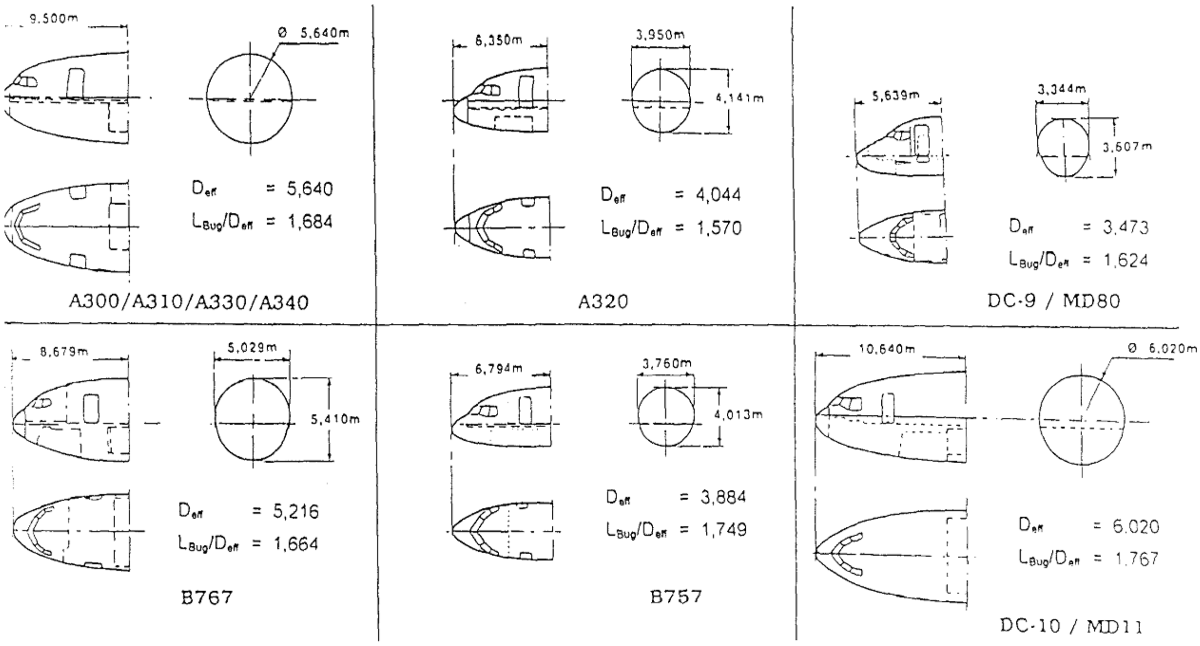


Fig. 1.17 Nose length of existing airliners [Schmitt 1988]

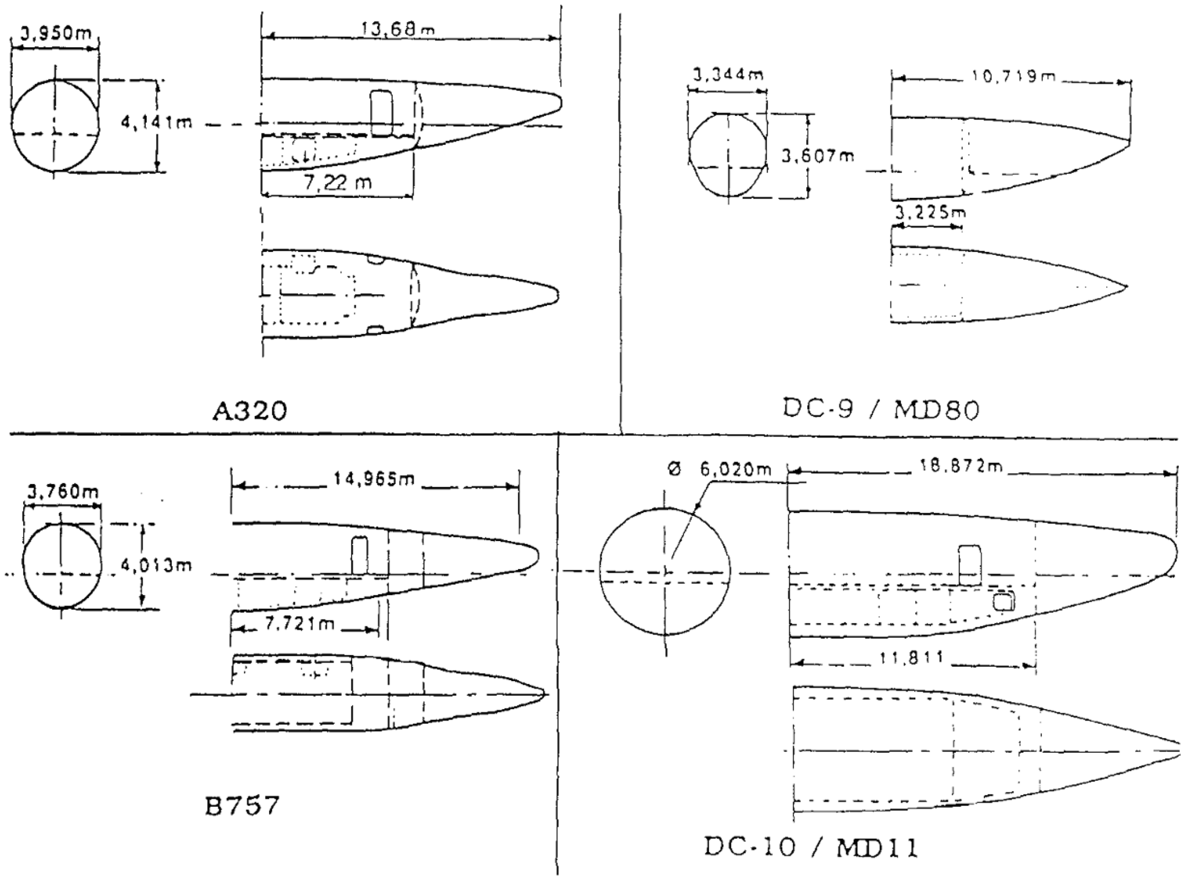


Fig. 1.18 Tail length of existing airliners [Schmitt 1988]

Since a part of the cabin can be in the nose or in the tail, two values are asked to the user in PreSTo-Cabin, defining which cabin length is in tail Δx_{tail} and in nose Δx_{nose} .

Fuselage length

Length of the fuselage is calculated with cabin, tail and nose length (see Fig. 1.19):

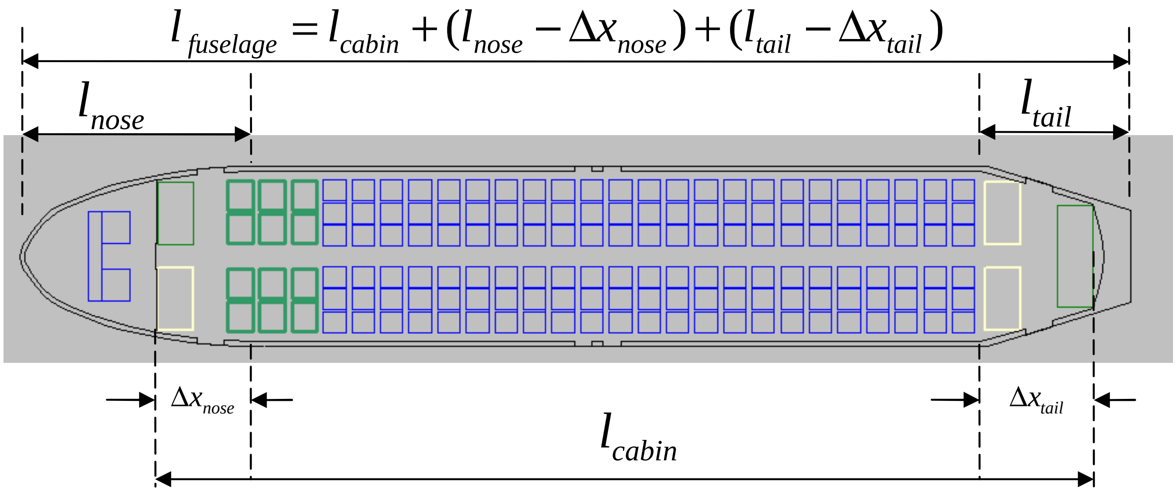


Fig. 1.19 Calculation of the fuselage length

Fig. 1.20 describes the process for the calculation of cabin and fuselage length:

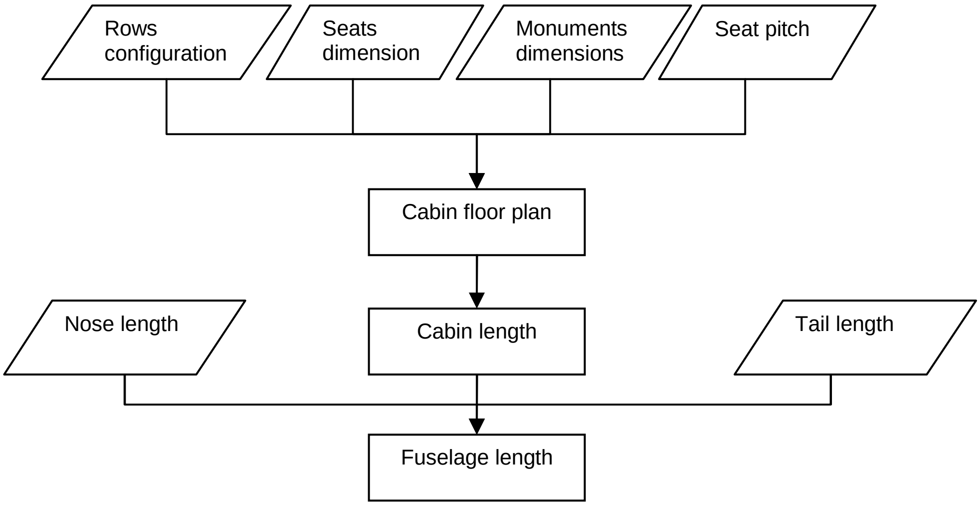


Fig. 1.20 Calculation of cabin and fuselage length

1.6.4 Verification of cargo compartment volume

Once the cabin cross section and cabin length are known, it is possible to check if the cargo volume of the airplane is big enough to carry the luggage from passengers and the cargo. The method used in PreSTo-Cabin is described by [Nita 2010].

The volume of the cargo compartment must be enough to accommodate the cargo plus the baggage that can not fit in the cabin:

$$V_{CC} \geq V_{cargo} + \left(V_{baggage} - V_{OS}\right) \tag{1.15}$$

Where:

V_{CC} Volume of the cargo compartment

V_{cargo} Volume of cargo

$V_{baggage}$ Volume of baggage

V_{OS} Volume of overhead stowage

The volume of the cargo compartment is:

$$V_{CC} = l_{fuselage} \cdot k_{CC} \cdot S_{CC} \tag{1.16}$$

Where:

l_{CC} Proportion of the fuselage length used for cargo, ranging from 0,35 to 0,55

S_{CC} Cross section of the cargo compartment

The cross section of the cargo compartment is calculated from the dimensions given previously (see Fig. 1.9), considering that the lower deck has a 45° ang le on its lower part.:

$$S_{CC} = w_{LD,top} \cdot h_{LD} - \left(\frac{w_{LD,top} - w_{LD,bottom}}{2}\right)^2 \tag{1.17}$$

The other volumes are calculated:

$$V_{baggage} = m_{baggage} / \rho_{baggage} \quad (1.18)$$

$$V_{cargo} = m_{cargo} / \rho_{cargo} \quad (1.19)$$

$$V_{OS} = S_{OS,tot} \cdot l_{OS} \quad (1.20)$$

$$S_{OS,tot} = n_{OS,lat} \cdot S_{OS,lat} + n_{OS,ce} \cdot S_{OS,ce} \quad (1.21)$$

$$l_{OS} = k_{OS} \cdot l_{cabin} \quad (1.22)$$

Where:

m_B	Mass of baggage
m_{cargo}	Mass of cargo, from the requirements (see 2.1.1 Input data from previous design phases)
ρ_B	Density of baggage, typical value: 170kg/m^3
ρ_{cargo}	Density of cargo, typical value: 160kg/m^3
$S_{OS,tot}$	Total cross section of the overhead stowages, calculated as a sum of the cross sections of lateral stowages $S_{OS,lat}$ and central stowages $S_{OS,ce}$
$n_{OS,lat}$	Number of lateral rows of overhead stowages, typical value: 2
$n_{OS,ce}$	Number of central rows of overhead stowages: $n_{OS,ce} = n_{aisles} - 1$
l_{OS}	Total length of the overhead stowages (lateral and central)
k_{OS}	Proportion of the cabin length occupied by the overhead stowages, typical values: 0,723 for a single aisle aircraft and 0,751 for a twin aisle aircraft

In PreSTo-Cabin, the inequality (2.61) is checked to make sure that the cargo compartment volume is big enough.

1.6.5 Compliance with FAA regulations

Water line

The waterline must be known to make sure that the emergency exits are above it, according to the CS-25.808 regulation.

PreSTo-Cabin checks that the waterline is below the doorstep and gives the maximum allowed mass. If the maximum take of weight is higher than this maximum allowed weight, exits are considered as too low. The buoyancy of the aircraft must be calculated depending on the mass of the aircraft and on the height of the waterline.

Only the fuselage is taken into account for the calculation: nose and tail are used as well as the “cylindrical” part, but not the wings.

As written before, the cross section of the fuselage is elliptic. The waterline can be above or below the symmetry axis of the ellipse.

Waterline below the axis of symmetry:

If the waterline is below the axis of symmetry, the area below the waterline can be considered as shown on Fig. 1.21:

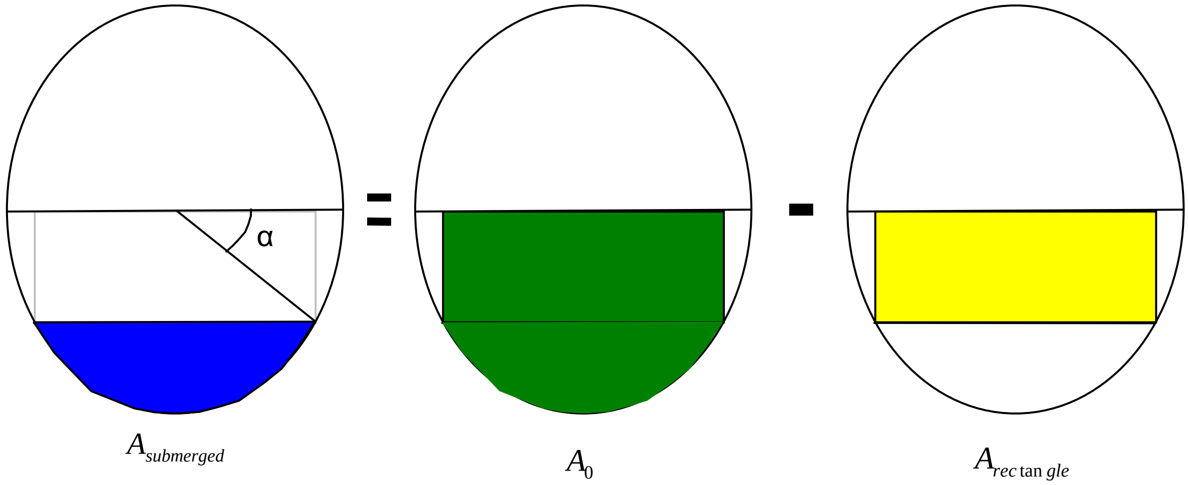
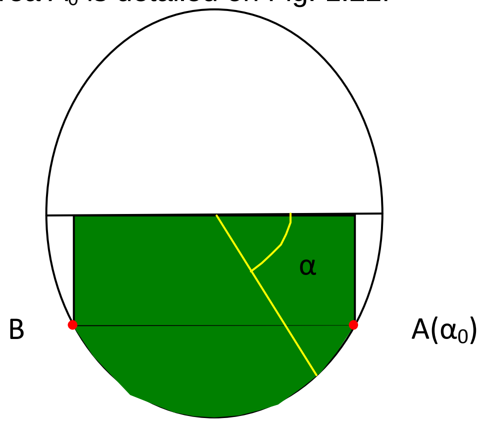


Fig. 1.21 Description of fuselage submerged area (α<0)

The green area A_0 is detailed on Fig. 1.22:



$$A_0 = \left| \int_A^B b\sqrt{1-\frac{x^2}{a^2}}dx \right|$$

Fig. 1.22 Area A_0 used for waterline

The result of the integral is:

$$A_0 = ab\left(\frac{\pi}{2} + \alpha - \sin\alpha\cos\alpha\right)$$

And the area $A_{Rectangle}$ is:

$$A_{rectangle} = -2 \cdot ab \cdot \sin\alpha\cos\alpha$$

Then:

$$A_{submerged} = A_0 - A_{rectangle}$$

$$A_{submerged} = ab\left(\frac{\pi}{2} + \alpha - \sin\alpha\cos\alpha\right) + 2 \cdot ab \cdot \sin\alpha\cos\alpha$$

$$A_{submerged} = ab\left(\frac{\pi}{2} + \alpha + \sin\alpha\cos\alpha\right)$$

So if the waterline is below the ellipse axis of symmetry, the submerged area of the fuselage is:

$$A_{submerged} = ab\left(\frac{\pi}{2} + \alpha + \sin\alpha\cos\alpha\right) \tag{1.23}$$

Waterline above the axis of symmetry:

If the waterline is above the ellipse axis of symmetry, the area below the waterline can be considered as shown on Fig. 1.23:

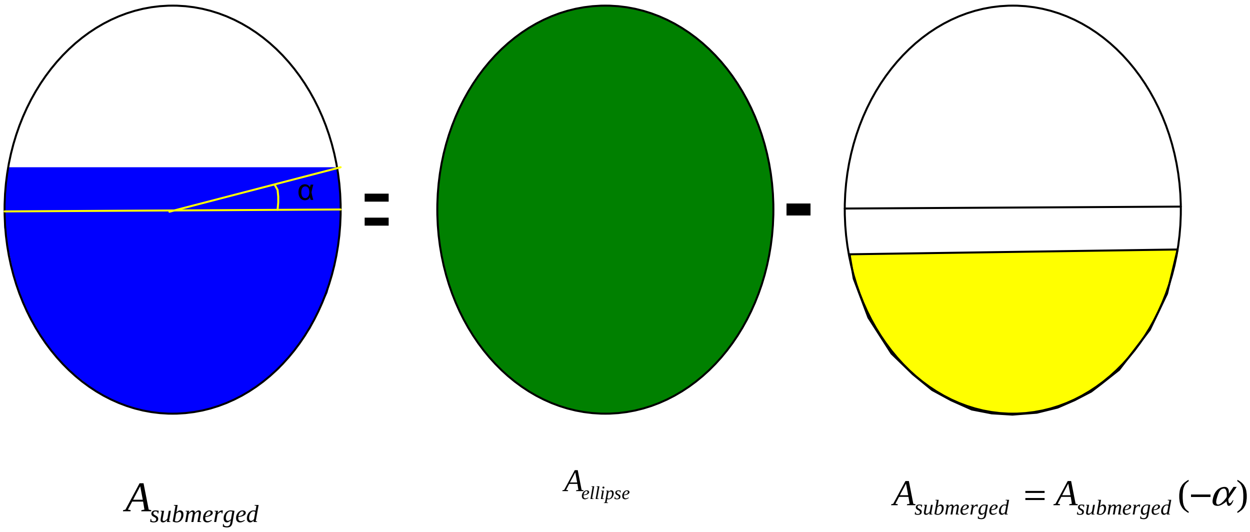


Fig. 1.23 Description of the fuselage submerged area (α>0)

Here,

$$A_{ellipse} = \pi ab$$

$$A_{submerged}(-\alpha) = ab\left(\frac{\pi}{2} - \alpha - \sin\alpha\cos\alpha\right)$$

$$A_{submerged} = \pi ab - ab\left(\frac{\pi}{2} - \alpha - \sin\alpha\cos\alpha\right)$$

$$A_{submerged} = \pi ab + ab\left(-\frac{\pi}{2} + \alpha + \sin\alpha\cos\alpha\right)$$

$$A_{submerged} = ab\left(\frac{\pi}{2} + \alpha + \sin\alpha\cos\alpha\right) \tag{1.24}$$

Conclusion:

Whether the waterline is above or below the axis of symmetry of the ellipse, the submerged area is always:

$$A_{submerged} = ab\left(\frac{\pi}{2} + \alpha + \sin\alpha\cos\alpha\right) \tag{1.25}$$

Since the aim is to know the maximum allowed weight of the airplane leading to doorstep at the waterline height, α is:

$$\alpha = \arcsin\left(\frac{y_{doorstep}}{b}\right) \tag{1.26}$$

or

$$\alpha = \arcsin\left(\frac{-\Delta z_{floor}}{h_{f,o}/2}\right) \tag{1.27}$$

The maximum allowed weight of the aircraft is:

$$W_{\max} = m_{\max} \cdot g \tag{1.28}$$

And the buoyancy of the fuselage is:

$$B = \rho_{water} \cdot V_{submerged} \cdot g \tag{1.29}$$

$$B = \rho_{water} \cdot A_{submerged} \cdot l_{cylinder} \cdot g \tag{1.30}$$

With the length of the cylinder:

$$l_{cylinder} = l_{cabin} - \Delta x_{nose} - \Delta x_{tail} \tag{1.31}$$

The maximum allowed weight is equal to the buoyancy:

$$W_{\max} = B$$

Then

$$m_{\max} = \rho_{water} \cdot A_{submerged} \cdot l_{cylinder}$$

$$m_{\max} = \rho_{water} \cdot ab\left(\frac{\pi}{2} + \alpha + \sin\alpha\cos\alpha\right) \cdot \left(l_{cabin} - \Delta x_{nose} - \Delta x_{tail}\right)$$

$$\begin{aligned} m_{\max}(cylinder) = &\left[\frac{\pi}{2} + \arcsin\left(\frac{-\Delta z_{floor}}{h_{f,o}/2}\right) + \left(\frac{-\Delta z_{floor}}{h_{f,o}/2}\right) \cdot \cos\left(\arcsin\left(\frac{-\Delta z_{floor}}{h_{f,o}/2}\right)\right)\right] \\ &\times \rho_{water} \cdot \frac{h_{f,o} \cdot w_{f,o}}{4} \times \left(l_{cabin} - \Delta x_{nose} - \Delta x_{tail}\right) \end{aligned} \tag{1.32}$$

The nose and the tail have also a buoyancy. They can both be considered as cones. Their respective buoyancies will be estimated as the third of the buoyancy of a straight cylinder which would have the same length.

$$m_{\max}(nose) = \frac{1}{3}\rho_{water} \cdot \frac{h_{f,o} \cdot w_{f,o}}{4}\left[\frac{\pi}{2} + \arcsin\left(\frac{-\Delta z_{floor}}{h_{f,o}/2}\right) + \left(\frac{-\Delta z_{floor}}{h_{f,o}/2}\right) \cdot \cos\left(\arcsin\left(\frac{-\Delta z_{floor}}{h_{f,o}/2}\right)\right)\right] \cdot l_{nose} \tag{1.33}$$

$$m_{\max}(tail) = \frac{1}{3}\rho_{water} \cdot \frac{h_{f,o} \cdot w_{f,o}}{4}\left[\frac{\pi}{2} + \arcsin\left(\frac{-\Delta z_{floor}}{h_{f,o}/2}\right) + \left(\frac{-\Delta z_{floor}}{h_{f,o}/2}\right) \cdot \cos\left(\arcsin\left(\frac{-\Delta z_{floor}}{h_{f,o}/2}\right)\right)\right] \cdot l_{tail} \tag{1.34}$$

Then the maximum take of mass has to be smaller than the maximum allowed mass:

$$m_{MTO} \le m_{\max}(cylinder) + m_{\max}(nose) + m_{\max}(tail) \tag{1.35}$$

Uniform distribution of exits

FAR25.807 imposes a uniform distribution of exits in the cabin (see Fig. 1.24):

(e) *Uniformity.* Exits must be distributed as uniformly as practical, taking into account passenger seat distribution.

Fig. 1.24 Regulations about the uniform distribution of exits

Since this article does not clearly define this distribution the FAA wrote the Advisory Circular AC25.807-1 in 1990. This circular introduces a method in order to reach the compliance with uniform distribution of exits. Additional information is available about this in 2.3.3 Uniform distribution of exits.

2 Use of PreSTo-Cabin to design an aircraft: fuselage

2.1 Description of the main sheet

After the preliminary sizing of the aircraft is done, the next thing to be designed is the cabin and fuselage. This is done with the module PreSTo-Cabin.

2.1.1 Input data from previous design phases

Open the main spreadsheet. The number of passengers must be given, it is written at the top of the sheet (Fig. 2.1). Other input data required are “cargo mass”, “maximum take-off weight”, “design range”.

Fig. 2.1 Input data sub-module

2.1.2 Configuration of classes

Open the “configuration of classes” sub-module (Fig. 2.2).
Give the *number of classes*. You can choose one class (only economy), two (economy and first class) or three (economy, business and first). PreSTo-Cabin suggests a value for this number of classes, depending on the design range: short range aircrafts have usually one or two classes whereas long range airplanes have three classes.
Set the *number of seats in each class*. PreSTo-Cabin offers a suggestion for this repartition of seats within the three classes.
Write the *number of seats abreast* in each class. There is a recommendation but only for the average seats abreast in the aircraft. For each class give a value between one and twelve. The number of needed seat rows is then calculated for each class.
Pay attention that PreSTo-Cabin can only work with complete seat rows. If the values you gave lead to incomplete rows, a message “Wrong number of seats!” will appear with a red background color. In this case adjust the number of seats abreast or the number of seats in each class in order to get only complete rows.
Decide the *number of aisles* in the airplane. If one class of the airplane has more than six seats abreast, the regulations impose at least two aisles. Otherwise both one and two aisles configurations are available.
Table 2-1 presents the values that apply to the redesign of an Airbus A320.

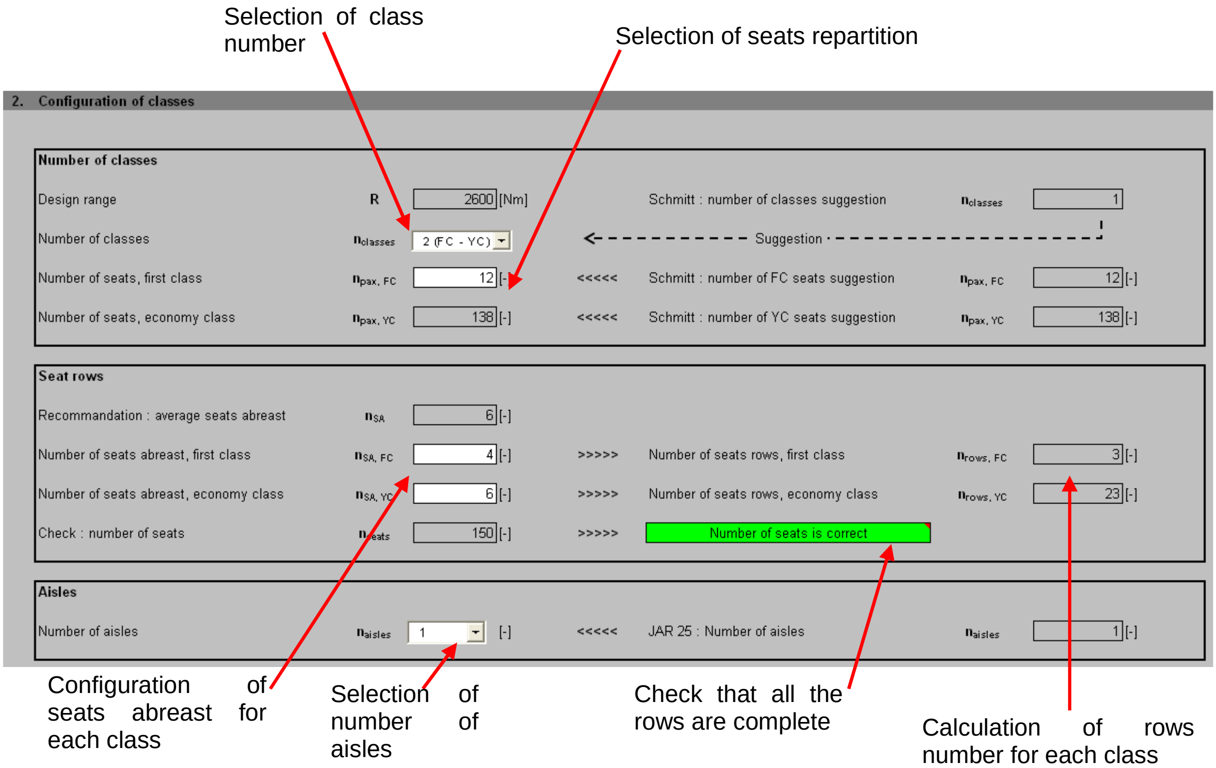


Fig. 2.2 Configuration of classes

Table 2-1 Input values for the redesign of an Airbus A320 (Configuration of classes)

Parameter	**Value**
Number of classes	2
Number of seats	FC : 12 YC : 138
Number of seats abreast	FC : 4 YC : 6
Number of aisles	1

If the check concerning the number of seats is correct (green cell displaying: “Number of seats is correct”), you can go to the next step.

2.1.3 Cross section

The cabin cross section is a decisive step in the fuselage design. Several parameters must be set here in order to calculate and draw the cross section.

Seat dimensions, economy class

Several dimensions regarding the seat are asked here. You can give them either in meters or in inches. If you do not know which values to use, you can leave the ones already written. Fig. 2.3 describes the seat dimensions as used in PreSTo-Cabin. Fig. 2.4 presents the seat dimensions section in PreSTo-Cabin.
Table 2-2 presents the values that apply to the redesign of an Airbus A320.

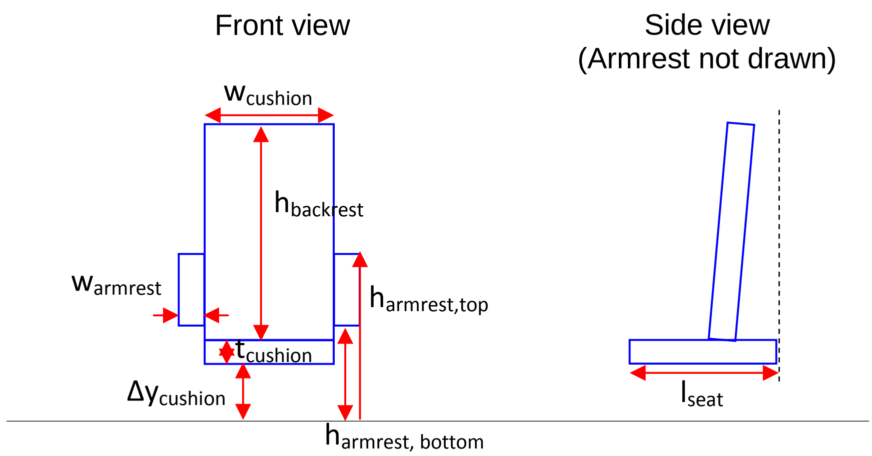
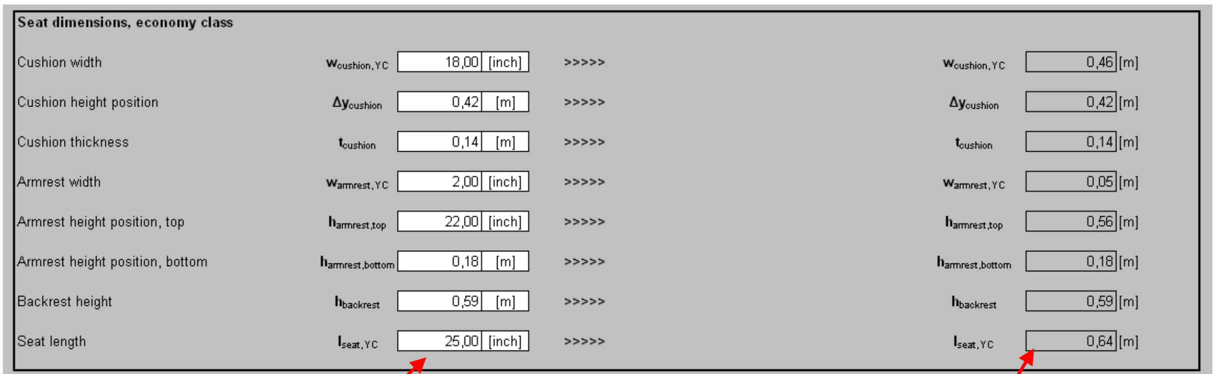


Fig. 2.3 Definition of seat dimensions



Seat dimensions, economy class

Cushion width	$w_{cushion,YC}$	18,00	[inch]	>>>>>	$w_{cushion,YC}$	0,46	[m]
Cushion height position	$\Delta y_{cushion}$	0,42	[m]	>>>>>	$\Delta y_{cushion}$	0,42	[m]
Cushion thickness	$t_{cushion}$	0,14	[m]	>>>>>	$t_{cushion}$	0,14	[m]
Armrest width	$w_{armrest,YC}$	2,00	[inch]	>>>>>	$w_{armrest,YC}$	0,05	[m]
Armrest height position, top	$h_{armrest,top}$	22,00	[inch]	>>>>>	$h_{armrest,top}$	0,56	[m]
Armrest height position, bottom	$h_{armrest,bottom}$	0,18	[m]	>>>>>	$h_{armrest,bottom}$	0,18	[m]
Backrest height	$h_{backrest}$	0,59	[m]	>>>>>	$h_{backrest}$	0,59	[m]
Seat length	$l_{seat,YC}$	25,00	[inch]	>>>>>	$l_{seat,YC}$	0,64	[m]

Input values in inches or meters

Values in meters

Fig. 2.4 Seat dimensions, economy class

Table 2-2 Input values for the redesign of an Airbus A320 (Seat dimensions, eco)

Parameter	Value
Cushion width	18 in
Cushion height position	0,42 m
Cushion thickness	0,14 m
Armrest width	2 in
Armrest height position, top	22 in
Armrest height position, bottom	7 in
Backrest height	0,59 m
Seat length	25 in

Seats dimensions, first class

If the cabin has a first class, you must configure the seat dimensions for this class (Fig. 2.5). Parameters asked here are the cushion and armrest width as well as the seat length. The other dimensions of the seat are considered to be the same as for the economy seat.
Table 2-3 presents the values that apply to the redesign of an Airbus A320.

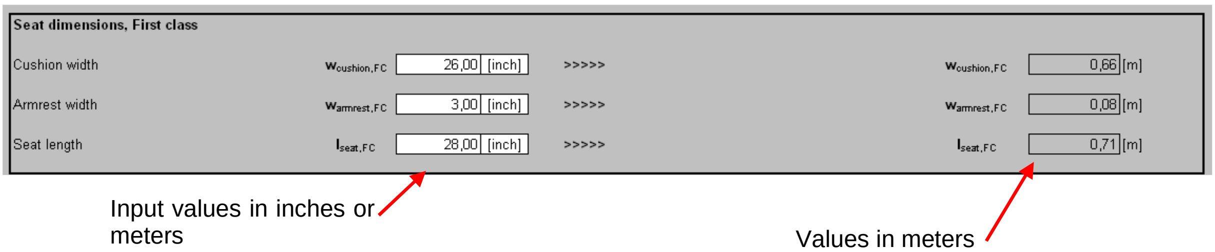


Fig. 2.5 Seat dimensions, first class

Table 2-3 Input values for the redesign of an Airbus A320 (Seat dimensions, first class)

Parameter	Value
Cushion width	26 in
Armrest width	3 in
Seat length	28 in

Seats dimensions, business class

This section is the same as the previous one but applies to the business class seats.

Passenger dimensions

This section makes use of anthropometric measures of the passengers. “95% American Male” is set as a reference. You can give your own values or select the default values by clicking on the grey button “Default values (95% American Male)”on the right. Fig. 2.6 describes the passenger dimensions as used in PreSTo-Cabin. Fig. 2.7 presents the passenger dimensions section in PreSTo-Cabin.
Table 2- displays the values that apply to the redesign of an Airbus A320.

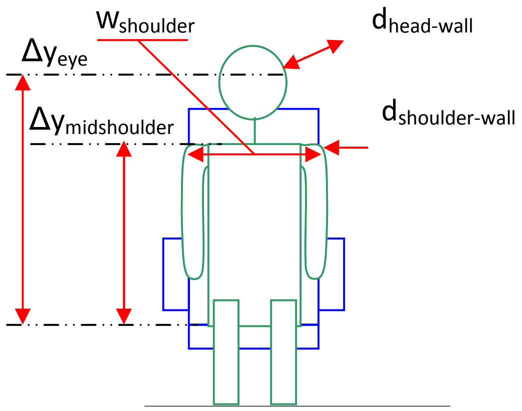


Fig. 2.6 Definition of passenger dimensions

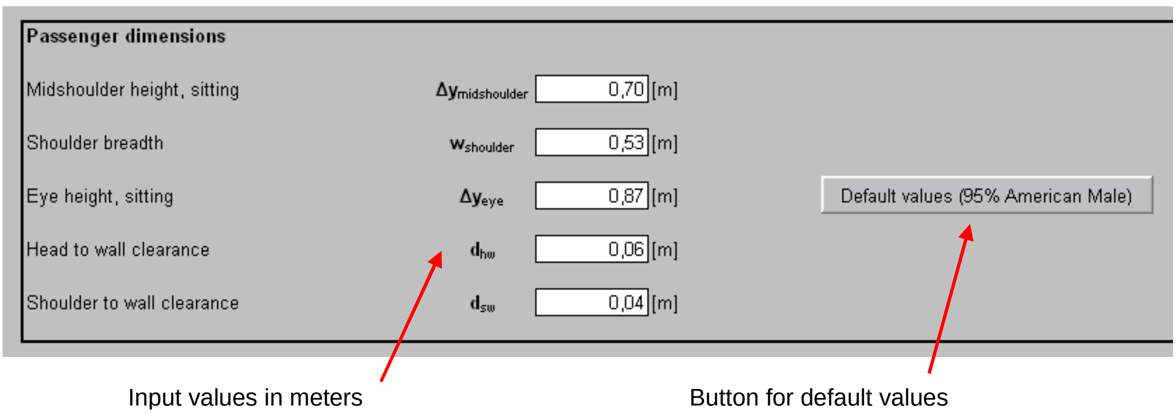


Fig. 2.7 Passenger dimensions configuration

Table 2-4 Default values for passenger dimensions

Parameter	Value
Midshoulder height, sitting	0,70 m
Shoulder breadth	0,53 m
Eye height, sitting	0,869 m
Head to wall clearance	0,06 m
Shoulder to wall clearance	0,04 m

Aisle dimensions (economy class)

Choose the values for the height and the width of the economy class aisle. You can give them in inches or in meters (Fig. 2.8). Table 2-5 presents the values that apply to the redesign of an Airbus A320.

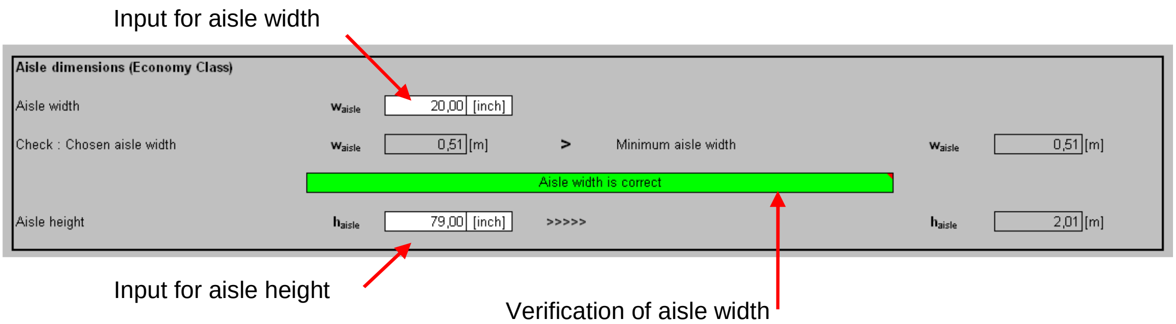


Fig. 2.8 Configuration of aisle dimensions

Table 2-5 Input values for the redesign of an Airbus A320 (Aisles dimensions)

Parameter	Value
Aisle width	20 in
Aisle height	79 in

Lower deck

The dimensions of the lower deck depend on the container it contains. Select a container among a list of the sixteen ones provided in PreSTo-Cabin (Fig. 2.9). Four of the sixteen containers are half sized: in this case you can place two of these containers side by side in the lower deck. Dimensions of containers provided in PreSTo-Cabin are displayed in Table 2-6.
If you do not wish to set a lower deck in your aircraft, select “None”.

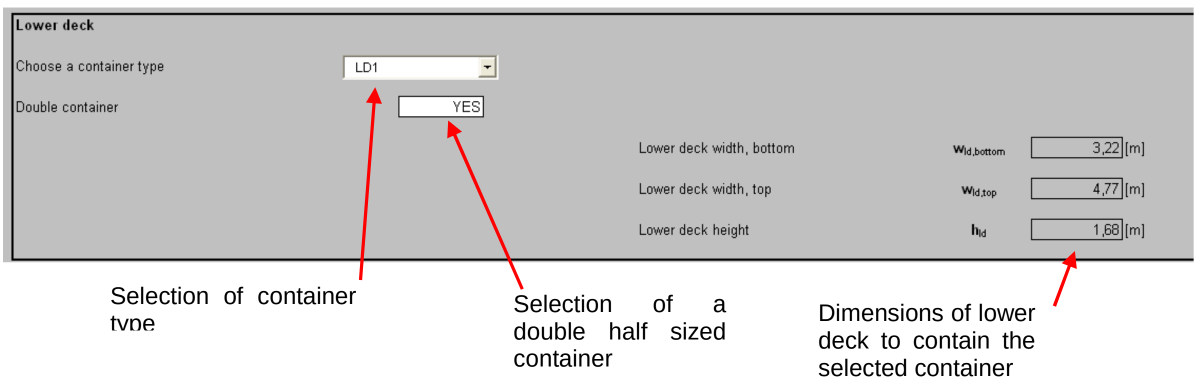


Fig. 2.9 Configuration of lower deck

For the redesign of an Airbus A320, select a LD3-45W container.

Table 2-6 Dimensions of typical containers

Container	Base width	Overall width	Depth	Height	Half sized
LD1	1,56 m	2,34 m	1,53 m	1,63 m	YES
LD11	3,18 m	3,18 m	1,53 m	1,63 m	NO
LD2	1,20 m	1,56 m	1,53 m	1,63 m	YES
LD26	3,18 m	4,06 m	2,24 m	1,63 m	NO
LD29	3,18 m	4,72 m	2,24 m	1,63 m	NO
LD3	1,56 m	2,01 m	1,53 m	1,63 m	YES
LD3-45	1,56 m	2,01 m	1,53 m	1,14 m	YES
LD3-45 (Rectangular)	1,56 m	1,56 m	1,53 m	1,14 m	NO
LD3-45W	1,43 m	2,43 m	1,42 m	1,09 m	NO
LD39	3,18 m	4,72 m	2,44 m	1,63 m	NO
LD4	2,44 m	2,44 m	1,53 m	1,63 m	NO
LD6	3,18 m	4,06 m	1,53 m	1,63 m	NO
LD7	3,18 m	4,06 m	2,24 m	1,63 m	NO
LD7 (Rectangular)	3,18 m	3,18 m	2,24 m	1,63 m	NO
LD8	2,44 m	3,18 m	1,53 m	1,63 m	NO
LD9	3,18 m	3,18 m	2,24 m	1,63 m	NO

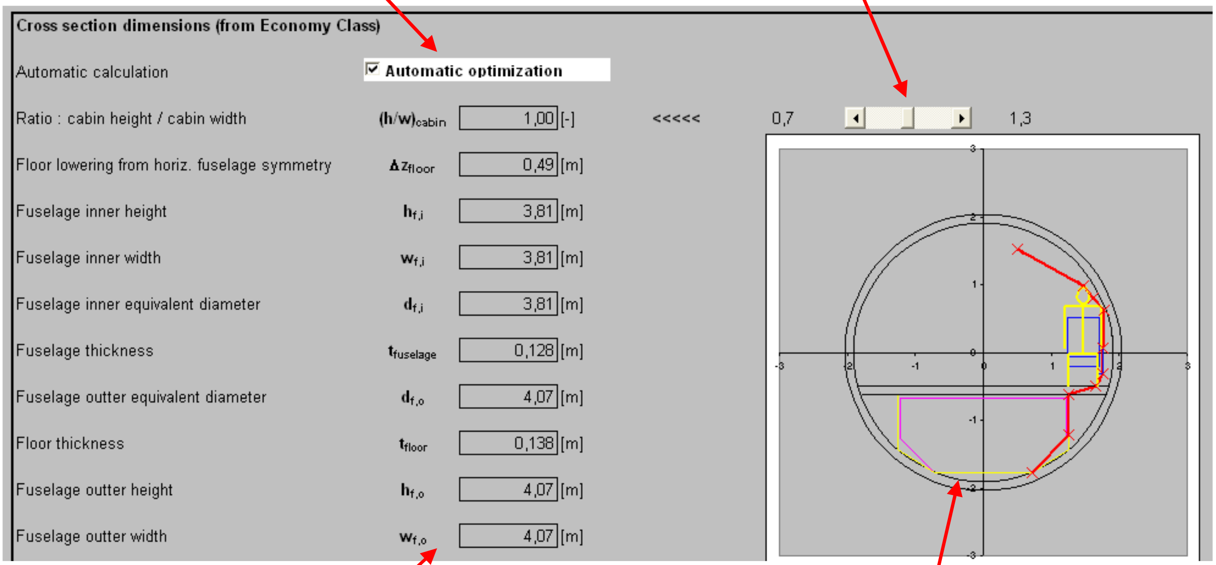
Cross section dimensions

Dimensions of items giving the cross section (seats, passengers, aisle and lower deck) are now known. This section will define the cross section height and width of the inner and outer fuselage (see Fig. 2.10). The main parameter is the *cabin height to width ratio* (see 1.6.1Cabin cross section).
Besides you can choose an automatic optimization or set two parameters manually: the *floor lowering from horizontal fuselage symmetry* and the *floor thickness*.
If you want to optimize these both parameters, there is no point to choose the manual mode: the automatic mode gives immediately an optimal result.
The inner and outer width and height of the fuselage are calculated and displayed, as well as the fuselage and floor thicknesses.
All the points needed to calculate the cross section are displayed in red on the graph. These points are linked through a red line. A seat with a seated passenger is also drawn as well as the container in the lower deck. Fig. 2.11 presents a detailed view of the cabin cross section.
Table 2- shows the values that apply to the redesign of an Airbus A320.

Fig. 2.10 Configuration of cross section dimensions

Button for automatic optimization

Selection of cabin height to width ratio



Cross section dimensions

Display of cabin cross section

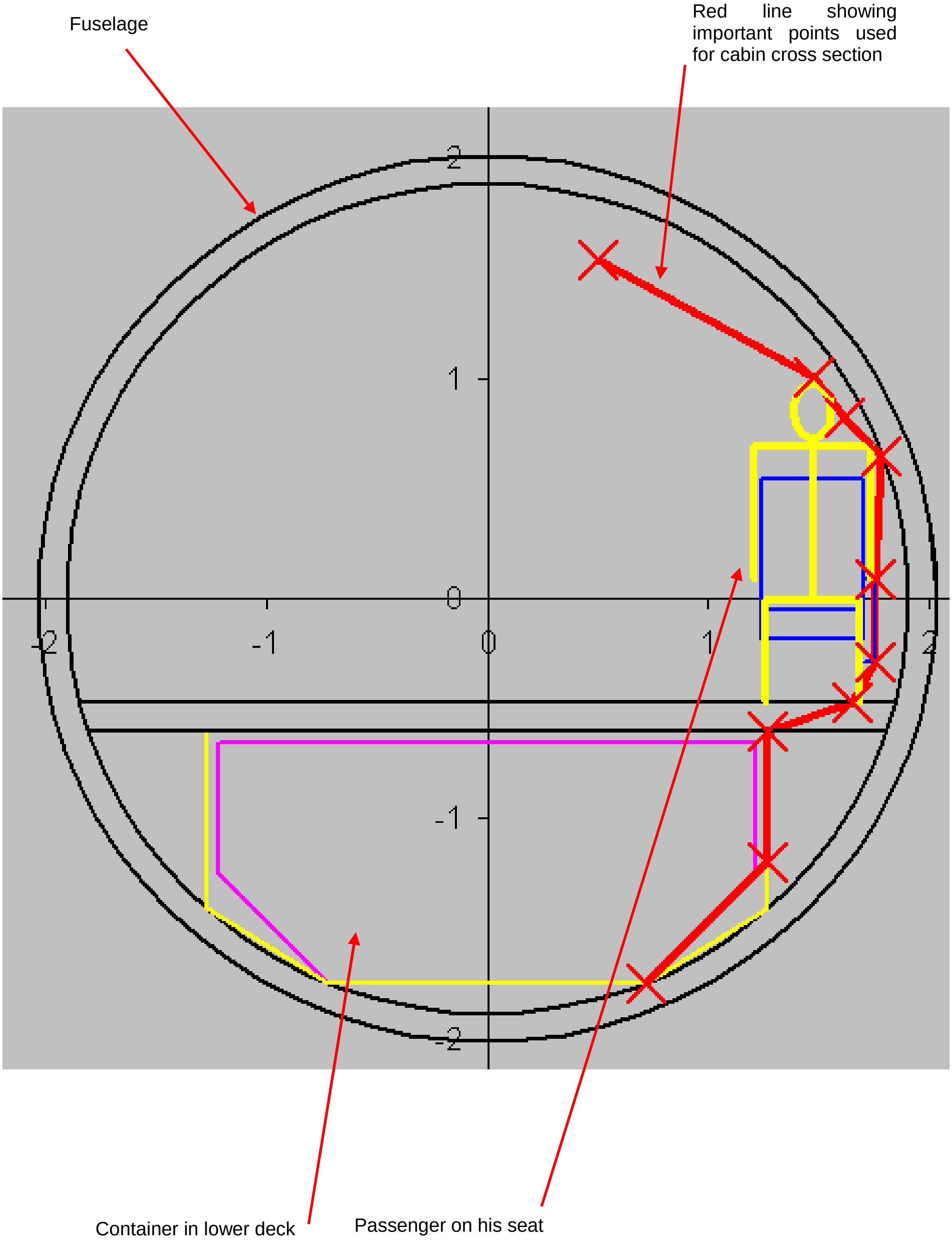


Fig. 2.11 Detailed view of the cabin cross section

Table 2-7 Input values for the redesign of an Airbus A320 (Cross section dimensions)

Parameter	Value
Cabin height to width ratio	1,00

Cross section layout

The fuselage cross section has been defined. Set the number of seats on each side of the aisle(s). Fig. 2.12 shows the configuration of cross section layout.
Please note that because of the regulations you cannot set more than three seats on the right and left and not more than six on the middle.
For each class there is a cell for a check. This must be green otherwise you cannot continue with the design of the cabin. If it is red, the number of the seats abreast you gave in "2. Configuration of classes" does not match the sum of seats on each side of the aisles. Then you have two possibilities: change the number of seats on each side or change the number of seats abreast at the beginning. This second option has to be avoided because it would have huge consequences leading to a redesign of a cabin or even a redesign in the preliminary sizing.
The last element, a dropdown list, is used to choose which class you wish to display on the cross section drawing.
Table 2-8 presents the values that apply to the redesign of an Airbus A320.

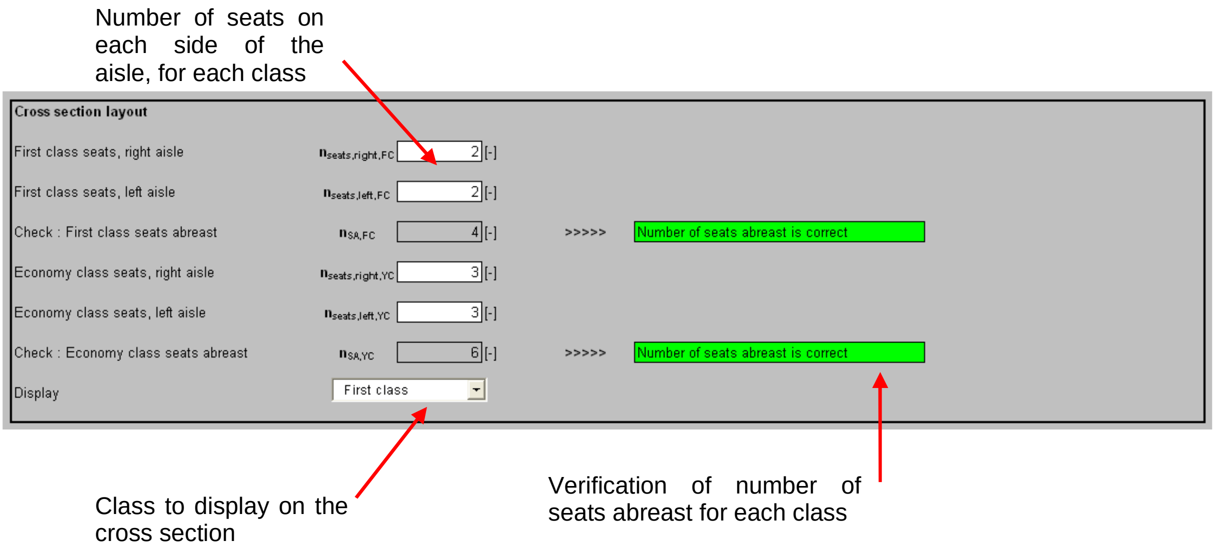


Fig. 2.12 Configuration of cross section layout

Table 2-8 Input values for the redesign of an Airbus A320 (Cross section layout)

Parameter	Value
First class seats	2-2
Economy class seats	3-3

Seat rails

Configure the seat rails that are used in the cabin (see Fig. 2.13). You can make use of “normal” or side seat rails. The automatic positioning is another available option that helps you to decrease the number of variables.
Select the number of seat rails on each side. Set the height of side seat rail if necessary, and then the distance between the external seat rails and the side of the seats. In this version, the automatic positioning is unmodfiable, so the rails are always placed automatically.

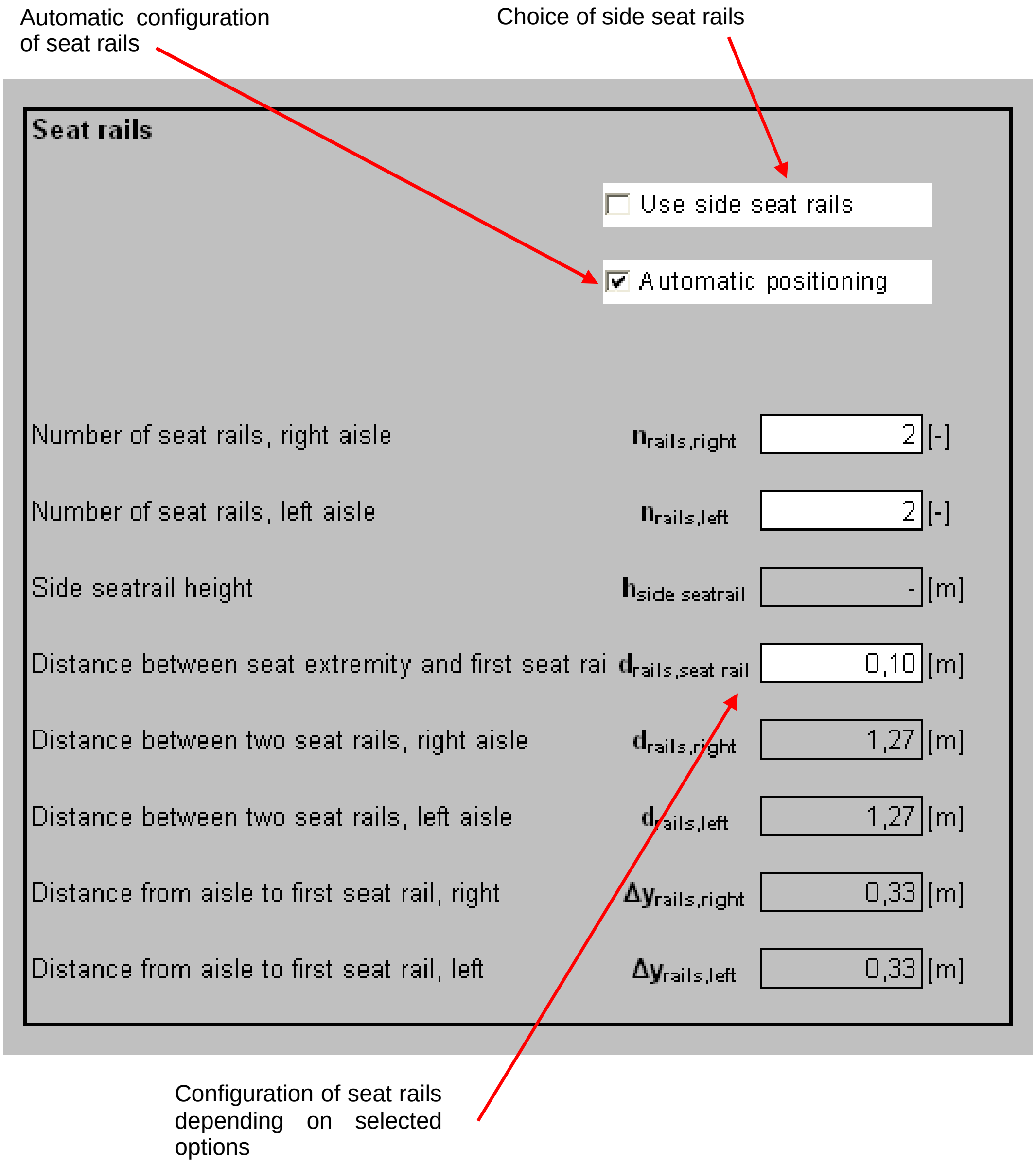


Fig. 2.13 Configuration of seat rails

Check of aisle width

The aisle width of first class and business class is compared to the width in economy class (Fig. 2.14). First and business class aisles have to be wider than economy class. If not, a message is displayed in order to inform about this issue. In that case, the solution is to increase the business and/or first class aisle width by decreasing their seat and armrest widths.

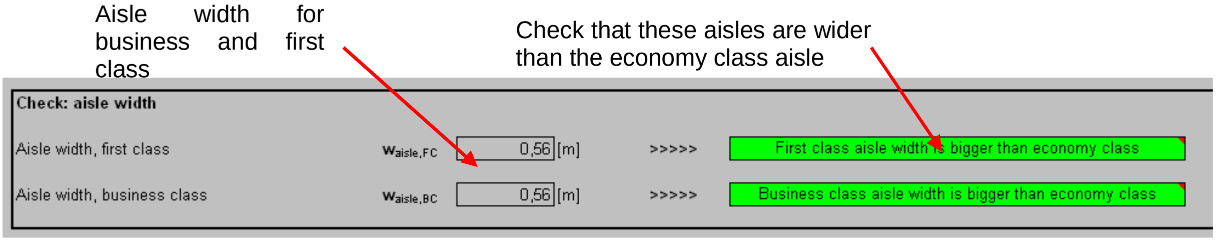


Fig. 2.14 Check of aisles width

Display of cabin cross section

Once all the previously parameters have been given, PreSTo-Cabin offers a view of the cabin cross section for the class you specified previously (Fig. 2.15).
All the items which dimensions have been given previously are drawn here: fuselage, seats, floor, lower deck, seat rails. Moreover the overhead bins are displayed here, but only to provide a more realistic view of the cabin cross section: their dimensions have not been specified.

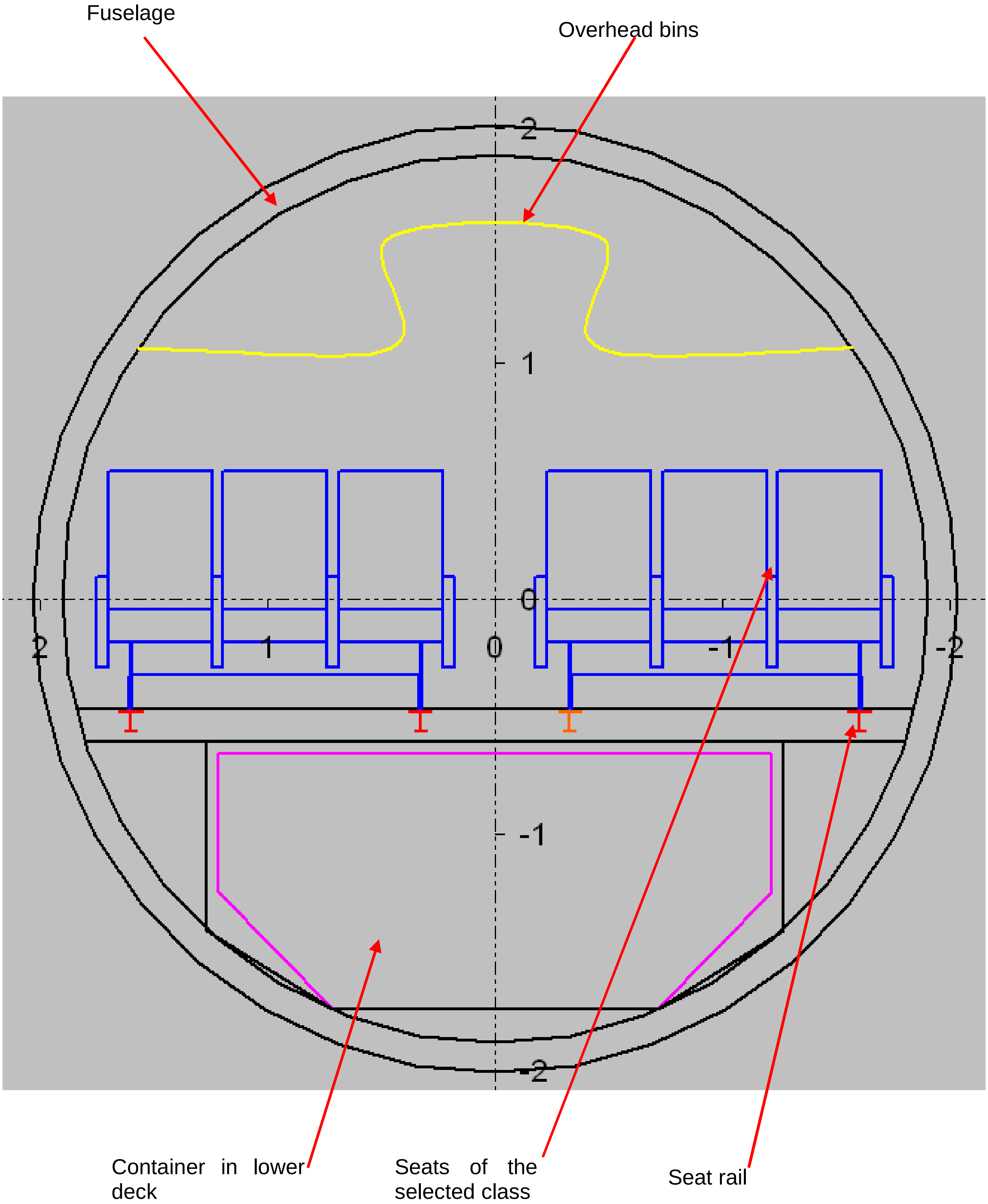


Fig. 2.15 Display of the cabin cross section

2.1.4 **Cabin floor plan**

The following items must be configured in order to draw the cabin floor plan.

Lavatories

Specify the number of lavatories for each class and their dimensions. Recommendations on the right help you to choose the appropriate values (see Fig. 2.16)
Table 2-8 presents the values that apply to the redesign of an Airbus A320.

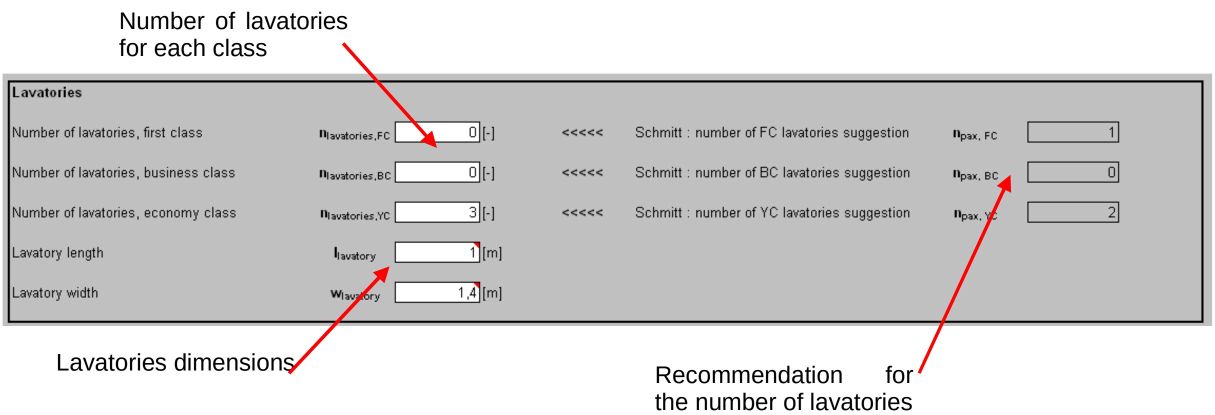


Fig. 2.16 Configuration of lavatories

Table 2-8 Input values for the redesign of an Airbus A320 (Lavatories)

Parameter	**Value**
Number of lavatories	1 FC/ 2 YC
Lavatory length	1,00 m
Lavatory width	1,40 m

Galleys

Give the number of galleys and their dimensions for each class (Fig. 2.17). The overall galley surface has to be between 10% less and 10% more than the recommendation.
Table 2-9 presents the values that apply to the redesign of an Airbus A320.

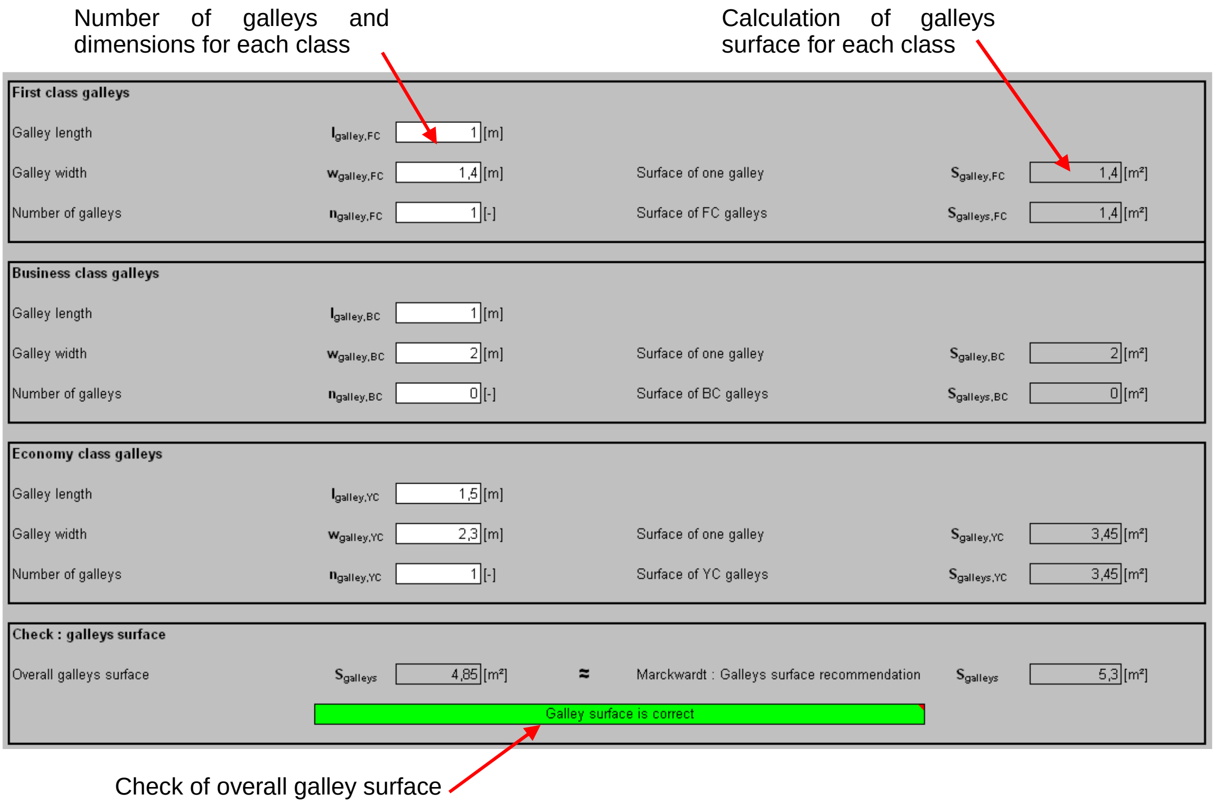


Fig. 2.17 Configuration of galleys

Table 2-9 Input values for the redesign of an Airbus A320 (Galleys)

Parameter	**Value**
First class galleys length	1,00 m
First class galleys width	1,40 m
Number of first class galleys	1
Economy class galleys length	1,50 m
Economy class galleys width	2,30 m
Number of economy class galleys	1

Seat pitch

Give the seat pitch for each class, in inches or in centimeters (Fig. 2.18).

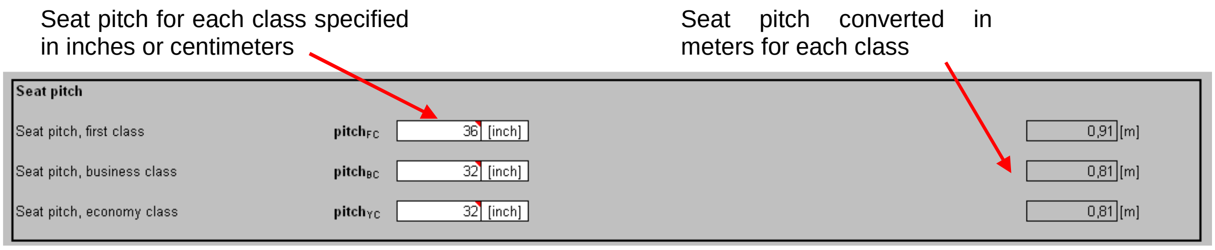


Fig. 2.18 Configuration of seat pitch

Table 2-0 presents the values that apply to the redesign of an Airbus A320.

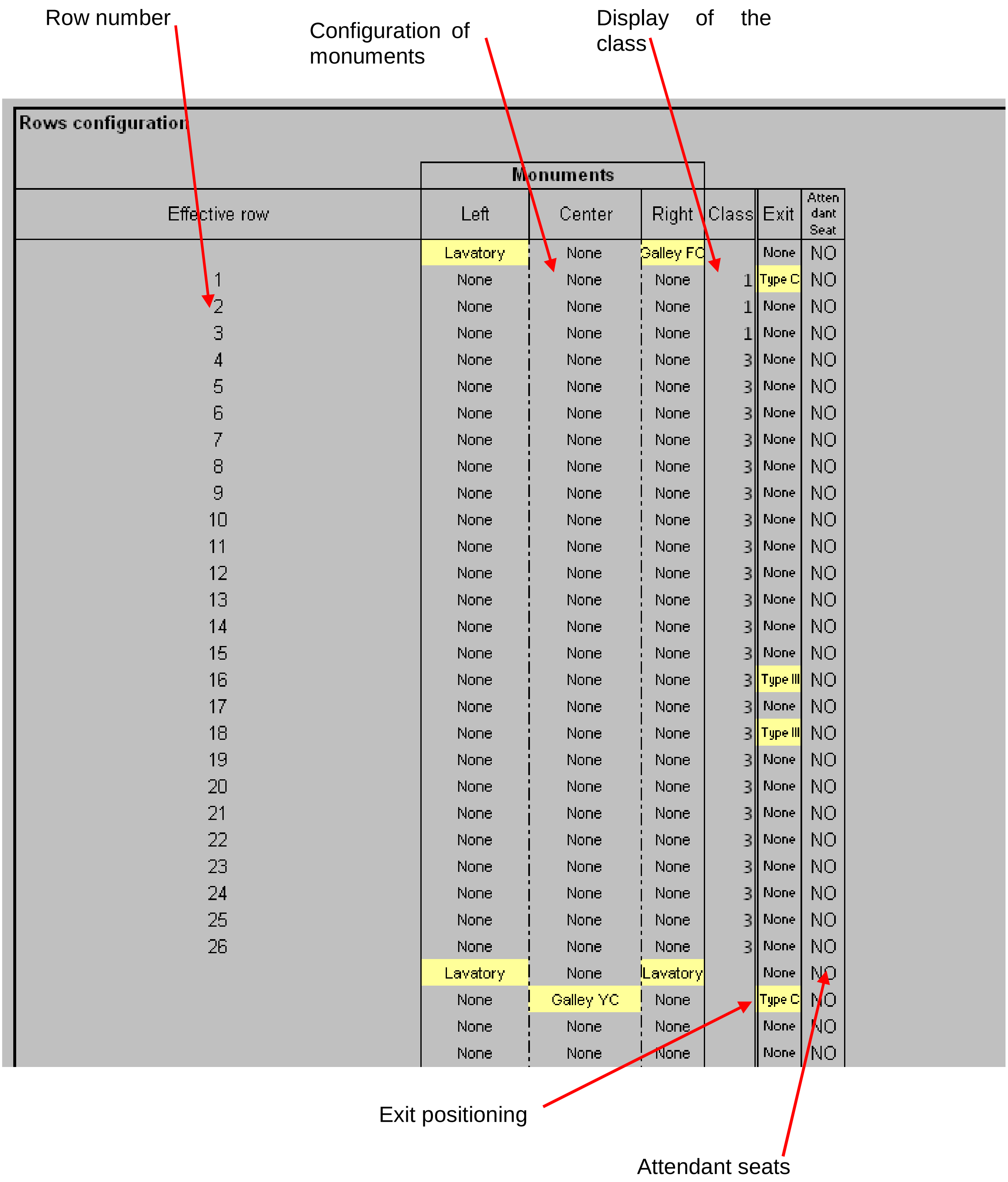
Table 2-10 Input values for the redesign of an Airbus A320 (Seat pitch)

Parameter	Value
First class pitch	36 in
Economy class pitch	32 in

Rows configuration

For each row in the aircraft you can set monuments (galley or lavatory). If you do not place any monument, the row will be a seating row but if you place a monument there will be no seats on this row. You can also set the exits on the fuselage. Cabin attendant seats can be set in the cabin too.
Please note that the number of rows is limited to 65 because of Excel limitations: it needs 300 calculations for each row so this cannot be unlimited. This means that you cannot design an aircraft with more than 65 rows containing seats or monuments. This limitation fits to any actual aircraft: for example the A340-600 needs 55 rows.

Input values for the redesign of an Airbus A320: configure as shown on Fig. 2.19.



Effective row	Monuments Left	Center	Right	Class	Exit	Attendant Seat
	Lavatory	None	Galley FC		None	NO
1	None	None	None	1	Type C	NO
2	None	None	None	1	None	NO
3	None	None	None	1	None	NO
4	None	None	None	3	None	NO
5	None	None	None	3	None	NO
6	None	None	None	3	None	NO
7	None	None	None	3	None	NO
8	None	None	None	3	None	NO
9	None	None	None	3	None	NO
10	None	None	None	3	None	NO
11	None	None	None	3	None	NO
12	None	None	None	3	None	NO
13	None	None	None	3	None	NO
14	None	None	None	3	None	NO
15	None	None	None	3	None	NO
16	None	None	None	3	Type III	NO
17	None	None	None	3	None	NO
18	None	None	None	3	Type III	NO
19	None	None	None	3	None	NO
20	None	None	None	3	None	NO
21	None	None	None	3	None	NO
22	None	None	None	3	None	NO
23	None	None	None	3	None	NO
24	None	None	None	3	None	NO
25	None	None	None	3	None	NO
26	None	None	None	3	None	NO
	Lavatory	None	Lavatory		None	NO
	None	Galley YC	None		Type C	NO
	None	None	None		None	NO
	None	None	None		None	NO

Fig. 2.19 Configuration of rows

Cabin floor plan

The cabin floor plan is drawn taking into account every choice/dimension given before.
You can hide the seat rails by clicking on the button “Show seat rails”.
Clicking on “Update display properties” button will update the colors and the zoom of the cabin floor plan.
Fig. 2.20 presents the cabin floor plan of an A320 displayed in PreSTo-Cabin.

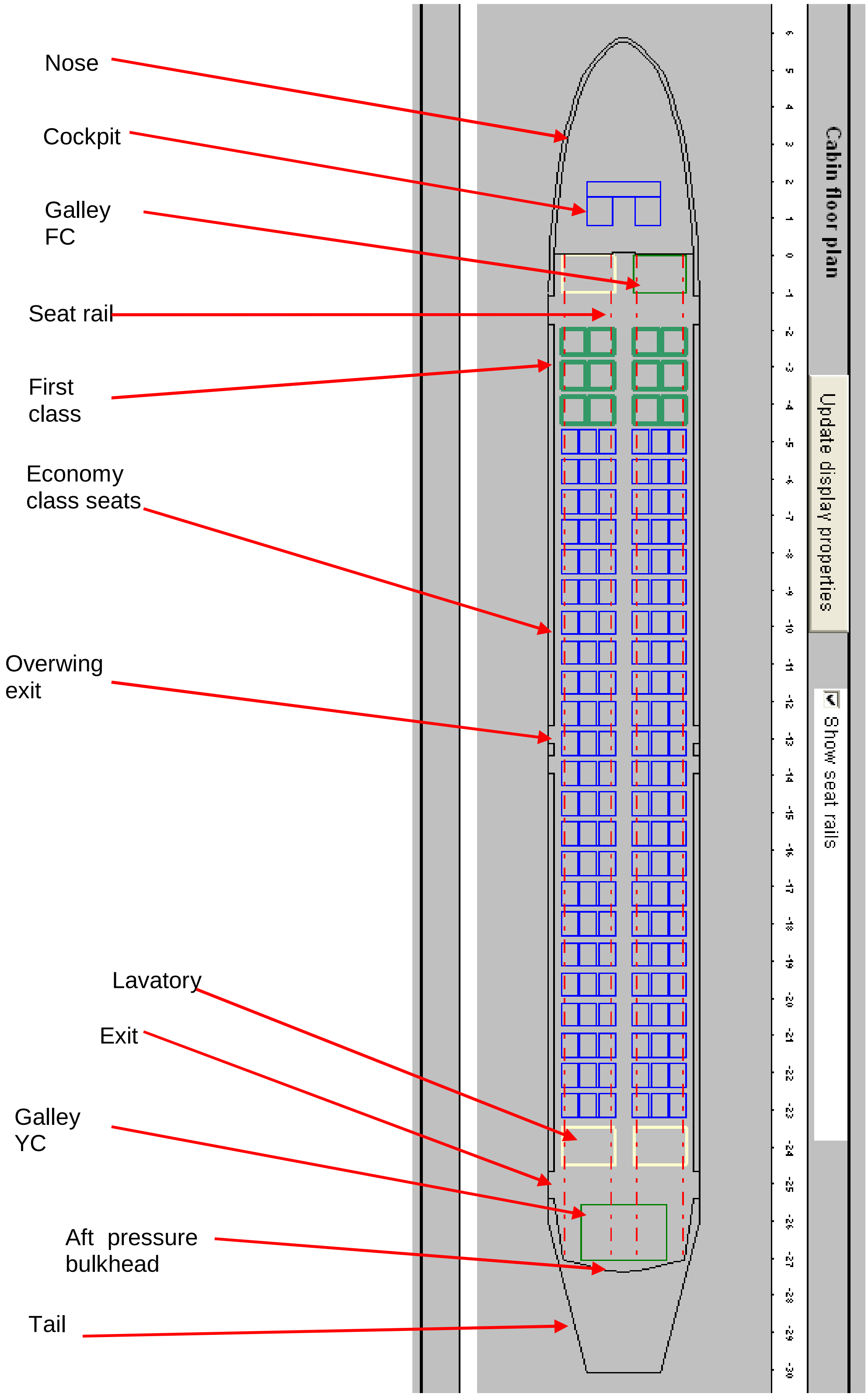


Fig. 2.20 Cabin floor plan display

2.1.5 **Results**

Fuselage length

Define the ratio between nose/tail length and fuselage diameter. Give the nose and tail offsets (which describe the length of cabin included in the tail or in the nose). The cabin length has been calculated from the cabin floor plan. Then the fuselage length is defined (see Fig. 2.21).
Table 2-11 presents the values that apply to the redesign of an Airbus A320.

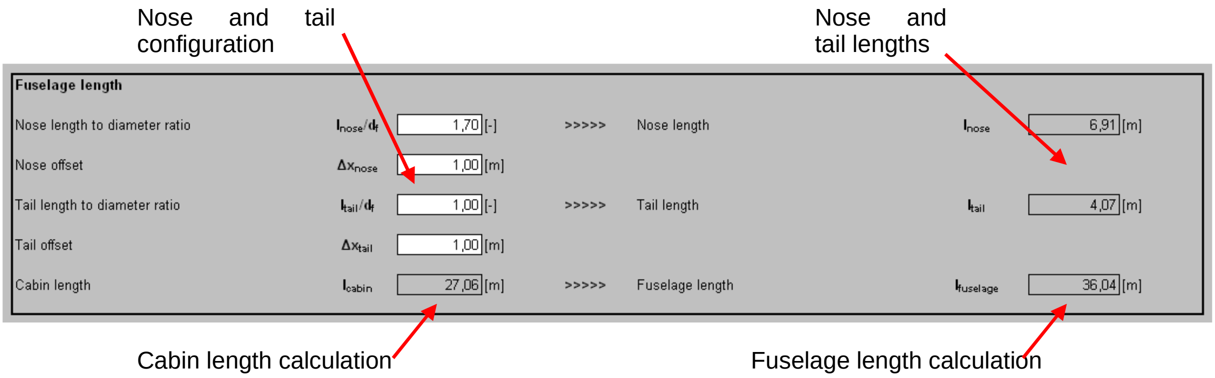


Fig. 2.21 Calculation of fuselage length

Table 2-11 Input values for the redesign of an Airbus A320 (Fuselage length)

Parameter	**Value**
Nose length to diameter ratio	1,70
Nose offset	1,00 m
Tail length to diameter ratio	1,00
Tail offset	1,00 m

Verification of monuments

The number of monuments in the cabin floor plan (chosen in “rows configuration”) is compared to the number of monuments specified previously. If these numbers do not match, a message with red background colour is displayed to inform of this issue. If these numbers do match, a message with green background colour informs that it is correct. Fig. 2.22 presents this verification in PreSTo-Cabin.

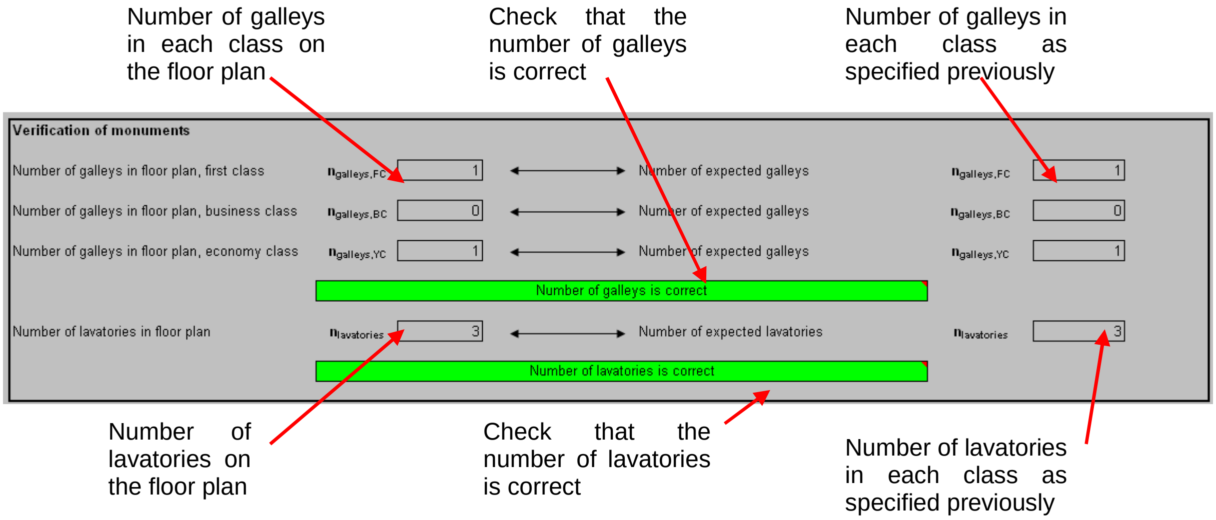


Fig. 2.22 Verification of monuments

Verification of cargo compartment volume

The volume needed to accommodate the cargo and the baggage that does not fit in the cabin must be compared with the available volume in the cargo compartment. The available volume must be larger than the needed volume for cargo.

Give the dimensions of the cargo compartment and of the overhead stowage, as well as the average mass for passenger baggage.
PreSTo-Cabin suggests a value for the cargo compartment cross section (see equation (2.63)),
Statistical values from [Nita 2010] are provided for the overhead stowages cross section, for the proportion of fuselage length used for cargo and for the proportion of cabin length occupied by overhead stowages.

At the end of the section, if the available volume is larger than the needed volume, a message with green background is displayed. Otherwise a message with red background informs that the cargo compartments volume is too small. In this case, you have to update the lower deck dimensions or use bigger overhead stowage.

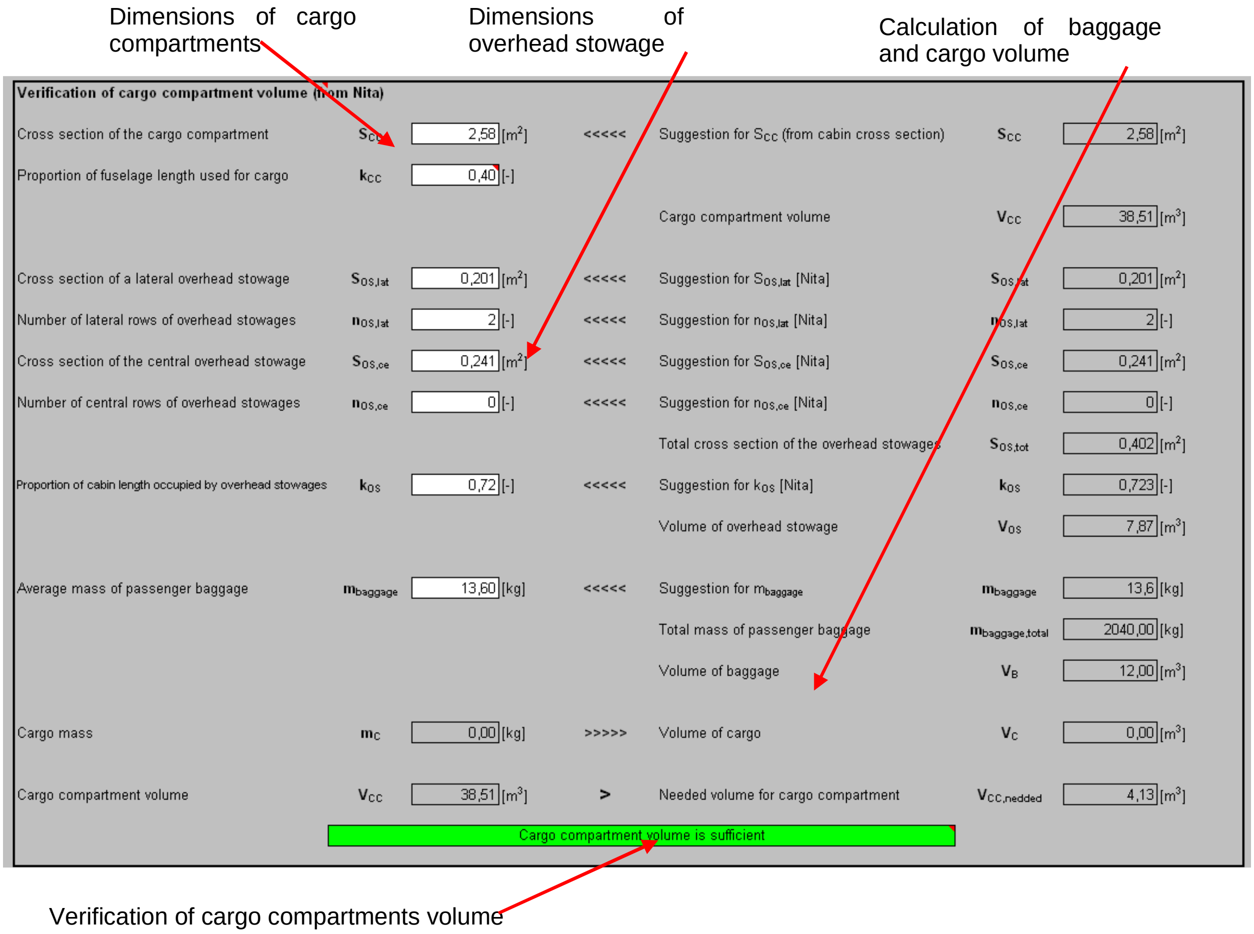


Fig. 2.23 Verification of cargo compartments volume

Waterline

In this section PreSTo-Cabin checks that the door steps are above the waterline (see Fig. 2.24).
The maximum allowed mass avoiding the water ditching is compared to the maximum take off mass. If the first mass is bigger, there is no risk for water ditching. Otherwise you need to redesign the fuselage so the door steps are always above the waterline.
You can include the nose and the tail sections or ignore them for this calculation.

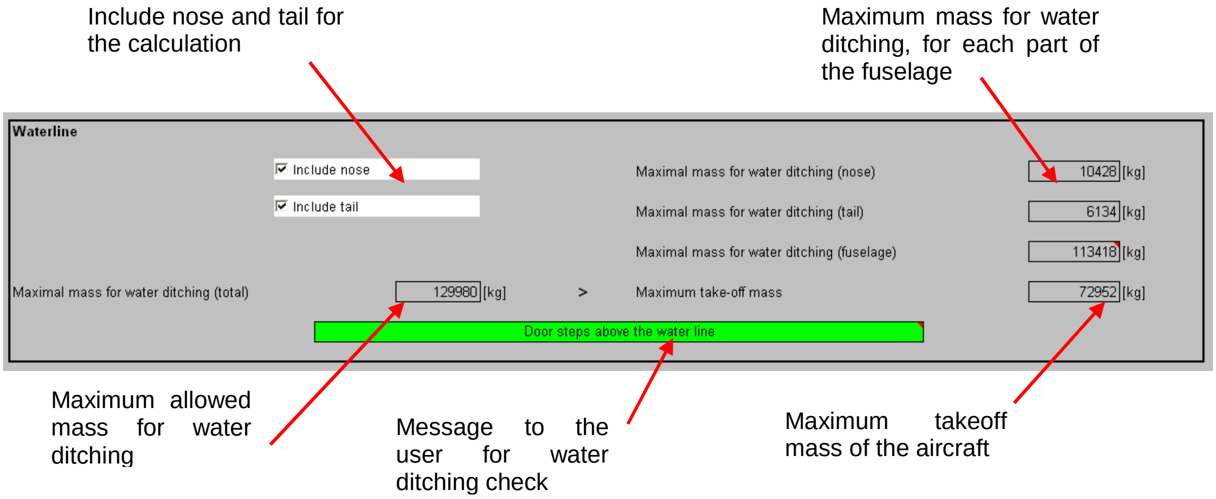


Fig. 2.24 Calculation of waterline

Exit distribution

The objective of this section is to check the compliance with the regulations concerning the *uniform distribution of exits*. This verification is done with a macro: click on the button “Exit distribution analysis” to run it.
The following error messages can appear on the screen:

- If there is no exit in the airplane, a message informs you about it. Go to the configuration and add at least one exit in the airplane.
- If there are too many seats in a zone (between two consecutive doors) you must move one of the exits so that the zone contains a fewer number of seats.
- The same message concerning consecutive zones can also appear
- When there are more seats in the airplane than allowed for the number and type of exit, you must add an extra exit or increase the dimensions of an existing one.
- If the exit location is too far from the location it should be (more than 15% of the cabin length) you have to move this exit in the rows configuration section: set this exit a few rows before or after the actual position.
- There’s a maximum exit doors spacing of 60 ft (around 18.3 m). A message will prompt if the exits don’t meet this requirement.
- On the contrary, two exits cannot be too close the one from the other. In this case, move the exit and check that the new configuration complies with the regulations.

In the case you get an error message, look at the tables that display the results. They will help you solving the issues. Errors are highlighted in red.
If no error message appears on the screen, then the aircraft complies with the regulations. In this case you can have a look on the three areas that display the results (Fig. 2.25).
The first area indicates if the number of allowed passengers in cabin is above the actual number of passengers. The second area is about the different zones. The third area gives the nominal and actual positions of emergency exits as well as the offset and the number of allowed passengers to go through the exit.

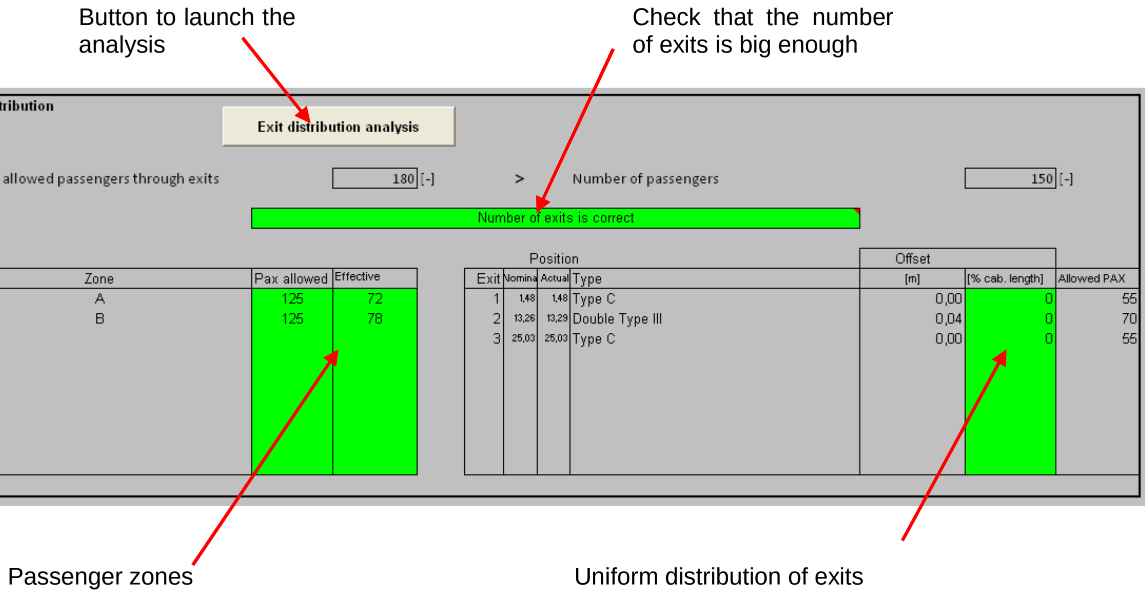


Fig. 2.25 Compliance with "uniform distribution of exits"

2.2 Description of “data_fuselage” sheet

The spreadsheet “data fuselage” is essential for the fuselage design. The dimensions for the fuselage cross section are calculated in this sheet as well as the coordinates of all the points needed to draw the cabin cross section and the cabin floor plan. Moreover the cabin length is determined in this sheet as well as the exit positions.
Because of the importance of this sheet for the design it is necessary to explain how it works.

2.2.1 Cabin cross section dimensions

The first purpose of this sheet is to get the ten dimensions of cabin cross section (Fig. 2.26). As written in 1.6.1 “Cabin cross section”, the coordinates of 10 important points have to be calculated, as well as the parameters of the ellipse going through this point. Eventually the ten ellipses are compared and the biggest one is selected so each point will fit in it.
Needed parameters are taken from the “Fuselage” sheet. Results are “a ellipse” and “b ellipse”.

Results

Cabin height-to-width ratio

	y position of left seat	1,4732						
	Δ width seat(ground)	0,05						
	a ellipse :	1,90425116		>> r equiv:	1,894705979			
	b ellipse :	1,89						
						b/a	0,99	
	Level	Total width	Semi width	Height	Height (abs)	a	b	Is max
w0	aisle ceiling	1,0033	0,50165	1,536780	1,54	1,63134834	1,61503486	0
w1	seated top of head level	2,9464	1,4732	1,004660	1,00	1,78889734	1,77100836	0
w2	seated eye level	3,2344	1,6172	0,818660	0,82	1,81635566	1,79819211	0
w3	shoulder level	3,5564	1,7782	0,649660	0,65	1,89542155	1,87646733	0
w4	seat armrest level, top	3,5052	1,7526	0,088980	0,09	1,75490312	1,73735409	0
w5	seat armrest level, bottom	3,5052	1,7526	-0,292020	0,29	1,77724896	1,75947647	0
w6	floor level	3,3036	1,6518	-0,469820	0,47	1,71862032	1,70143412	0
w7	lower deck level (top)	2,53078	1,26539	-0,607608	0,61	1,40637674	1,39231297	0
w8	lower deck level (middle)	2,53078	1,26539	-1,196888	1,20	1,750097	1,73259603	0
w9	lower deck level (bottom)	1,43002	0,72	-1,747268	1,75	1,90425116	1,88520865	1

Coordinates of the 10 various points

Calculation of ellipse going through each point

The biggest ellipse is highlighted

Fig. 2.26 Calculation of cabin cross section dimensions

2.2.2 Drawing of cabin cross section

The second purpose of “Data_fuselage” sheet is to get the coordinates of the points to draw the cabin cross section. There are two drawings of the cabin cross section. The first one is only about displaying the fuselage, the lower deck and one passenger with his seat, as well as the points that were needed previously to find the cabin dimensions. The second gives a more detailed view with all the seats, overhead bins and seat rails.

Cross section for fuselage dimensions

The cross section of fuselage is basically the combination of two ellipses: one for the inner and the other for the outer fuselage. The drawing of an ellipse (as for a circle) consists in calculating the x and y coordinates for different angles going from 0 to 360° (see Fig. 2.27). As written in the appendix, the equations used to draw an ellipse are:

$$\begin{cases} x = a\cos(\theta) & (2.36) \\ y = b\sin(\theta) & (2.37) \end{cases}$$

Therefore ellipses of inner and outer fuselage are drawn using the respective *a* and *b* parameters from inner and outer fuselage.

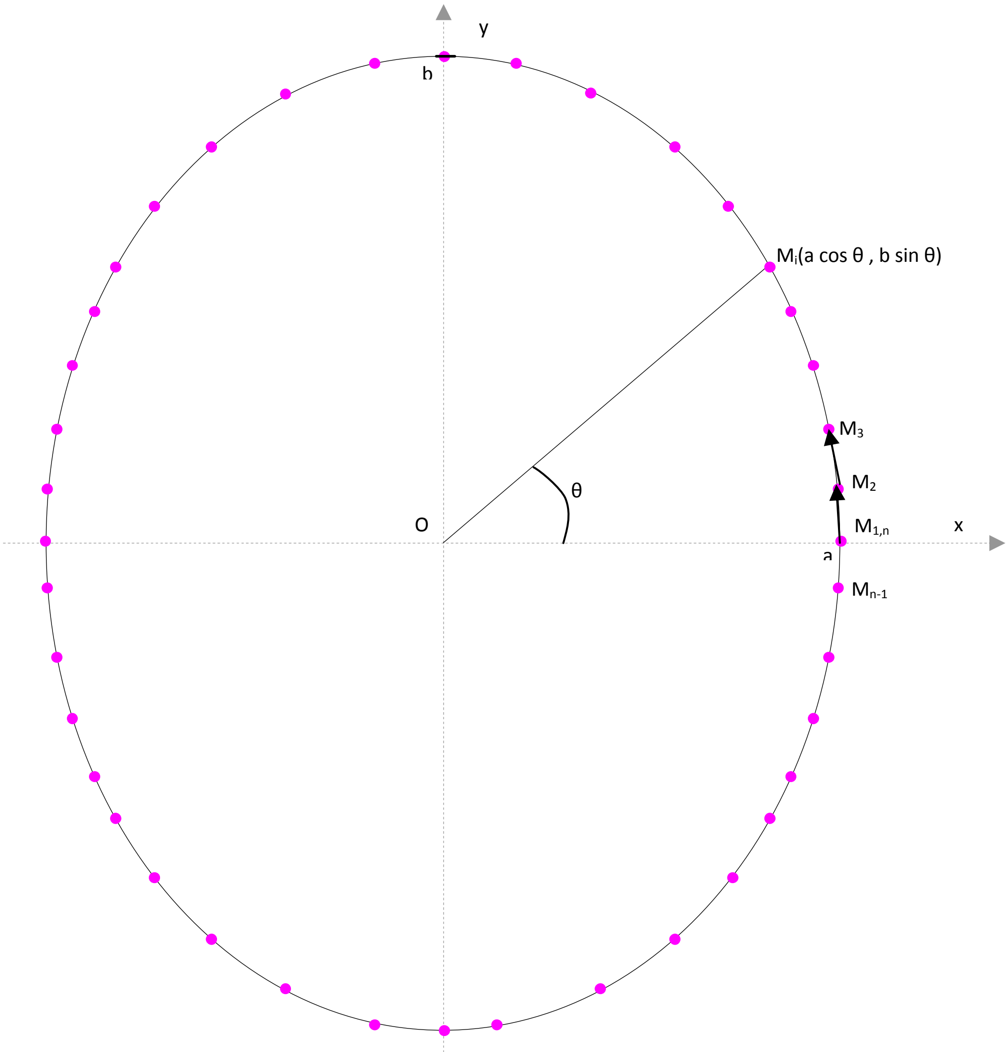


Fig. 2.27 Points used to draw an ellipse

Dimensions of lower deck have already been described in 1.6.1 “Cabin cross section” with the three points needed to draw one side of the lower deck. These points are the second, the third and the fourth on Fig. 2.28. Apart from first and eighth point, other points are symmetric to these three points:

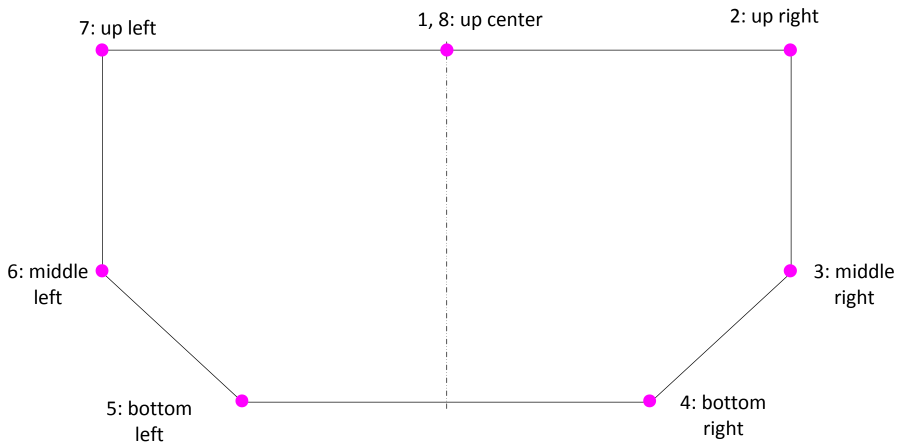


Fig. 2.28 Points used to draw the lower deck

Drawing of the container has the same shape as the lower deck drawing but dimensions differ.

The passenger is drawn in the easiest way: four points for the legs, four points for the arms and two for the body; the head is considered as elliptic and therefore calculated as shown previously for the fuselage (Fig. 2.27). Connections are made between points A to D (legs), E to H (arms) and I and J (body) as displayed on Fig. 2.29:

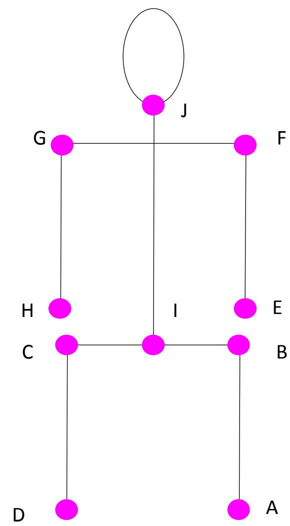


Fig. 2.29 Description of used points for passenger drawing

The drawing of the seat needs six points for the seat itself and four more points for the armrest. Points A to D describe the seat as well as I and J; points E to H are used for the armrest (Fig. 2.30).

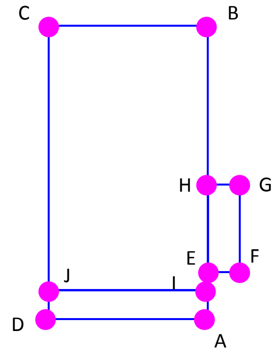


Fig. 2.30 Drawing of the seat

At the end the drawing of the floor, separation of main and lower decks, consists in two parallel lines (Fig. 2.31).

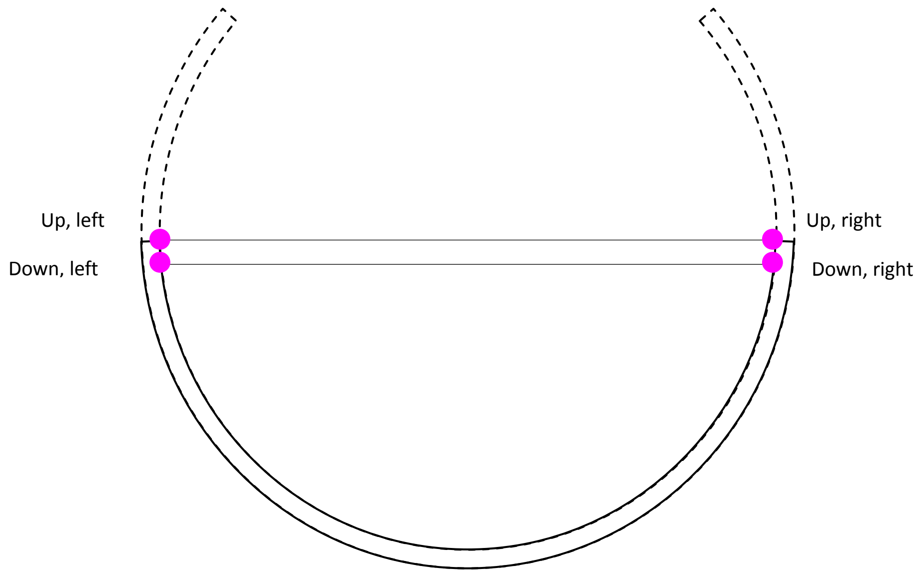
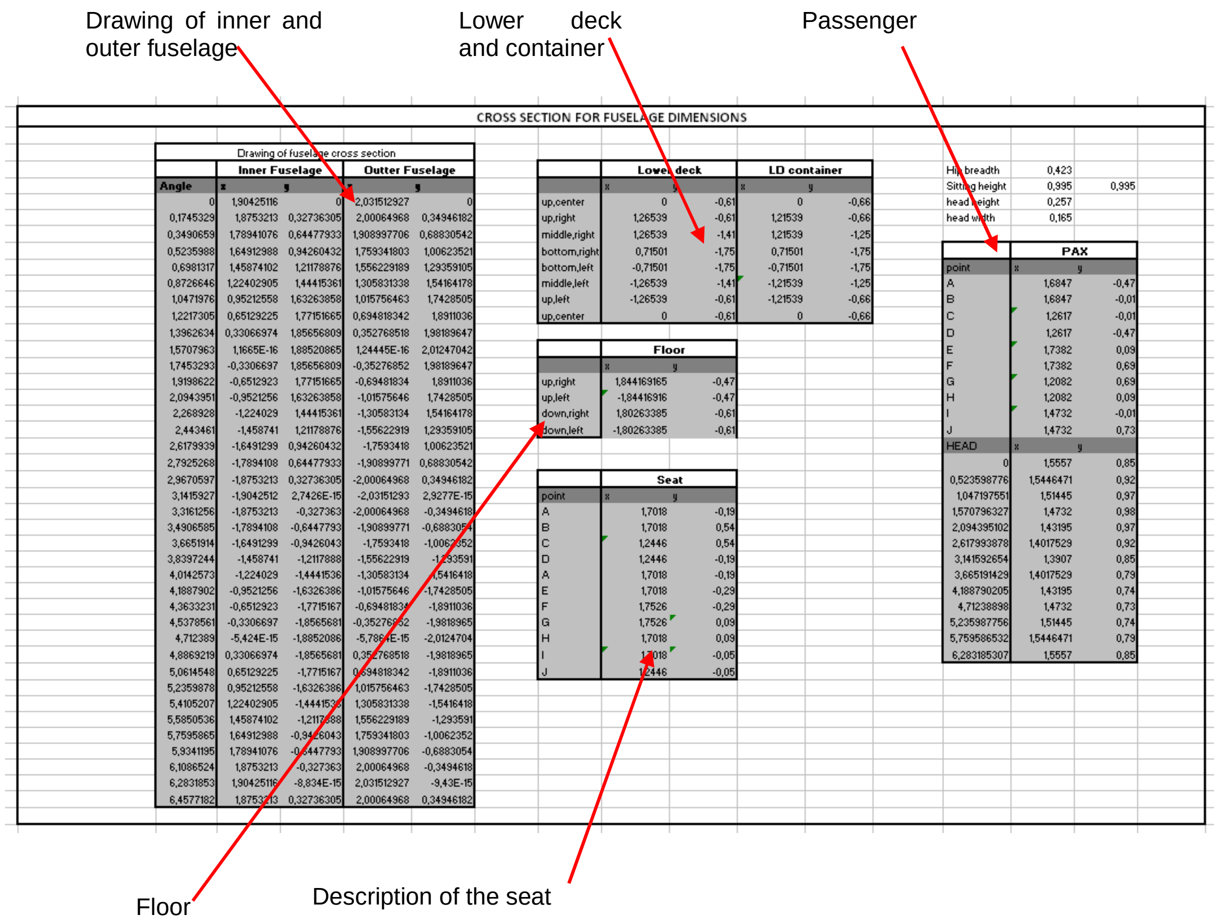


Fig. 2.31 Drawing of the floor

Fig. 2.32 shows the cells used in PreSTo-Cabin to calculate the coordinates of points displayed in the cross section.



Drawing of fuselage cross section

	Inner Fuselage		Outter Fuselage	
Angle	x	y	x	y
0	1,90425116	0	2,031512927	0
0,1745329	1,8753213	0,32736305	2,00064968	0,34946182
0,3490659	1,78941076	0,64477933	1,908997706	0,68830542
0,5235988	1,64912988	0,94260432	1,759341803	1,00623521
0,6981317	1,45874102	1,21178876	1,556229189	1,29359105
0,8726646	1,22402905	1,44415361	1,305831338	1,54164178
1,0471976	0,95212558	1,63263858	1,015756463	1,7428505
1,2217305	0,65129225	1,77151665	0,694818342	1,8911036
1,3962634	0,33066974	1,85656809	0,352768518	1,98189647
1,5707963	1,1665E-16	1,88520865	1,24445E-16	2,01247042
1,7453293	-0,3306697	1,85656809	-0,35276852	1,98189647
1,9198622	-0,6512923	1,77151665	-0,69481834	1,8911036
2,0943951	-0,9521256	1,63263858	-1,01575646	1,7428505
2,268928	-1,224029	1,44415361	-1,30583134	1,54164178
2,443461	-1,458741	1,21178876	-1,55622919	1,29359105
2,6179939	-1,6491299	0,94260432	-1,7593418	1,00623521
2,7925268	-1,7894108	0,64477933	-1,90899771	0,68830542
2,9670597	-1,8753213	0,32736305	-2,00064968	0,34946182
3,1415927	-1,9042512	2,7426E-15	-2,03151293	2,9277E-15
3,3161256	-1,8753213	-0,327363	-2,00064968	-0,3494618
3,4906585	-1,7894108	-0,6447793	-1,90899771	-0,6883054
3,6651914	-1,6491299	-0,9426043	-1,7593418	-1,0062352
3,8397244	-1,458741	-1,2117888	-1,55622919	-1,293591
4,0142573	-1,224029	-1,4441536	-1,30583134	-1,5416418
4,1887902	-0,9521256	-1,6326386	-1,01575646	-1,7428505
4,3633231	-0,6512923	-1,7715167	-0,69481834	-1,8911036
4,5378561	-0,3306697	-1,8565681	-0,35276852	-1,9818965
4,712389	-5,424E-15	-1,8852086	-5,7864E-15	-2,0124704
4,8869219	0,33066974	-1,8565681	0,352768518	-1,9818965
5,0614548	0,65129225	-1,7715167	0,694818342	-1,8911036
5,2359878	0,95212558	-1,6326386	1,015756463	-1,7428505
5,4105207	1,22402905	-1,4441536	1,305831338	-1,5416418
5,5850536	1,45874102	-1,2117888	1,556229189	-1,293591
5,7595865	1,64912988	-0,9426043	1,759341803	-1,0062352
5,9341195	1,78941076	-0,6447793	1,908997706	-0,6883054
6,1086524	1,8753213	-0,327363	2,00064968	-0,3494618
6,2831853	1,90425116	-8,834E-15	2,031512927	-9,43E-15
6,4577182	1,8753213	0,32736305	2,00064968	0,34946182

	Lower deck		LD container	
	x	y	x	y
up,center	0	-0,61	0	-0,66
up,right	1,26539	-0,61	1,21539	-0,66
middle,right	1,26539	-1,41	1,21539	-1,25
bottom,right	0,71501	-1,75	0,71501	-1,75
bottom,left	-0,71501	-1,75	-0,71501	-1,75
middle,left	-1,26539	-1,41	-1,21539	-1,25
up,left	-1,26539	-0,61	-1,21539	-0,66
up,center	0	-0,61	0	-0,66

	Floor	
	x	y
up,right	1,844169165	-0,47
up,left	-1,84416916	-0,47
down,right	1,80263385	-0,61
down,left	-1,80263385	-0,61

	Seat	
point	x	y
A	1,7018	-0,19
B	1,7018	0,54
C	1,2446	0,54
D	1,2446	-0,19
A	1,7018	-0,19
E	1,7018	-0,29
F	1,7526	-0,29
G	1,7526	0,09
H	1,7018	0,09
I	1,7018	-0,05
J	1,2446	-0,05

Hip breadth	0,423	
Sitting height	0,995	0,995
head height	0,257	
head width	0,165	

	PAX	
point	x	y
A	1,6847	-0,47
B	1,6847	-0,01
C	1,2617	-0,01
D	1,2617	-0,47
E	1,7382	0,09
F	1,7382	0,69
G	1,2082	0,69
H	1,2082	0,09
I	1,4732	-0,01
J	1,4732	0,73
HEAD	x	y
0	1,5557	0,85
0,523598776	1,5446471	0,92
1,047197551	1,51445	0,97
1,570796327	1,4732	0,98
2,094395102	1,43195	0,97
2,617993878	1,4017529	0,92
3,141592654	1,3907	0,85
3,665191429	1,4017529	0,79
4,188790205	1,43195	0,74
4,71238898	1,4732	0,73
5,235987756	1,51445	0,74
5,759586532	1,5446471	0,79
6,283185307	1,5557	0,85

Fig. 2.32 Overview of the calculations for cross section drawing

Cross section for seating configuration display

The second cross section drawing presented on Fig. 2.15 is more complex than the first one (Fig. 2.11): indeed up to twelve seats are drawn, as well as overhead bins, seat rails and seat legs (see Fig. 2.33).

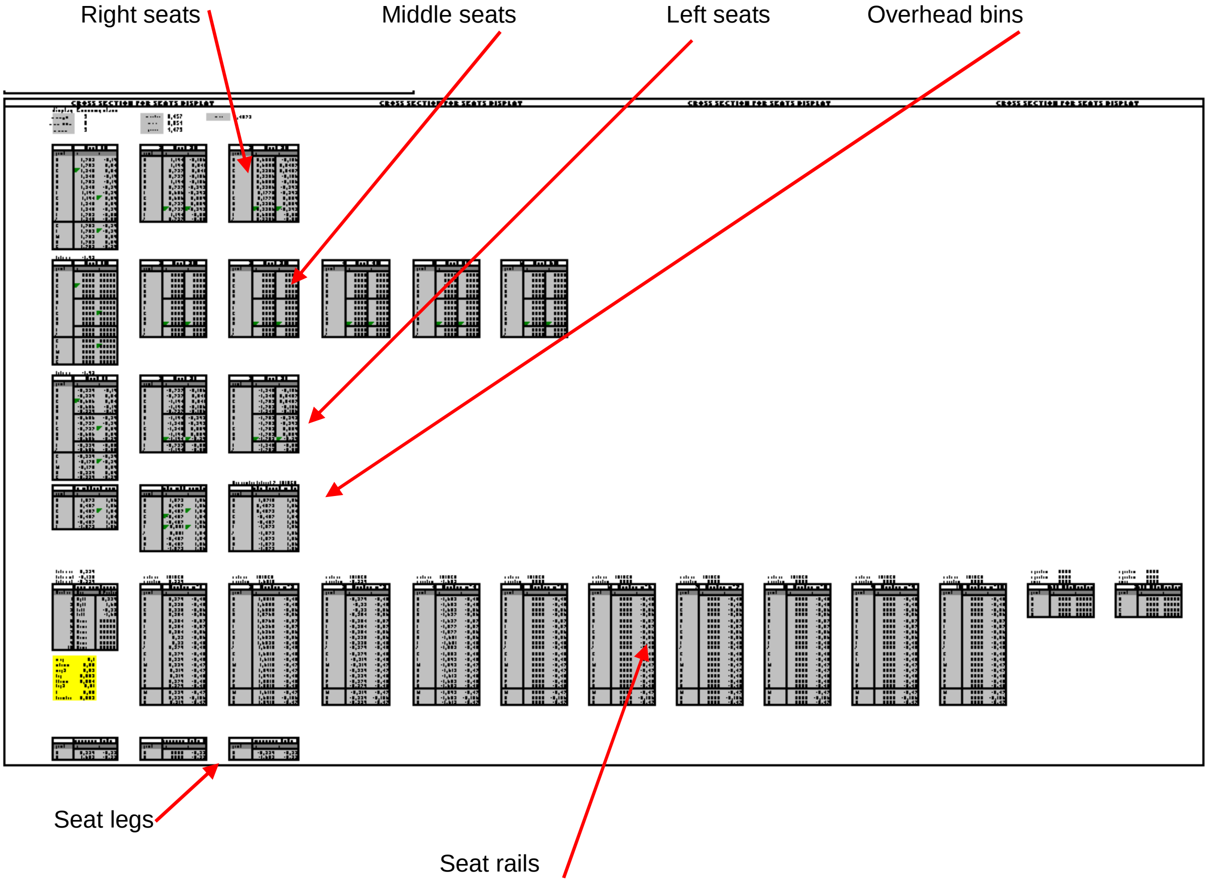
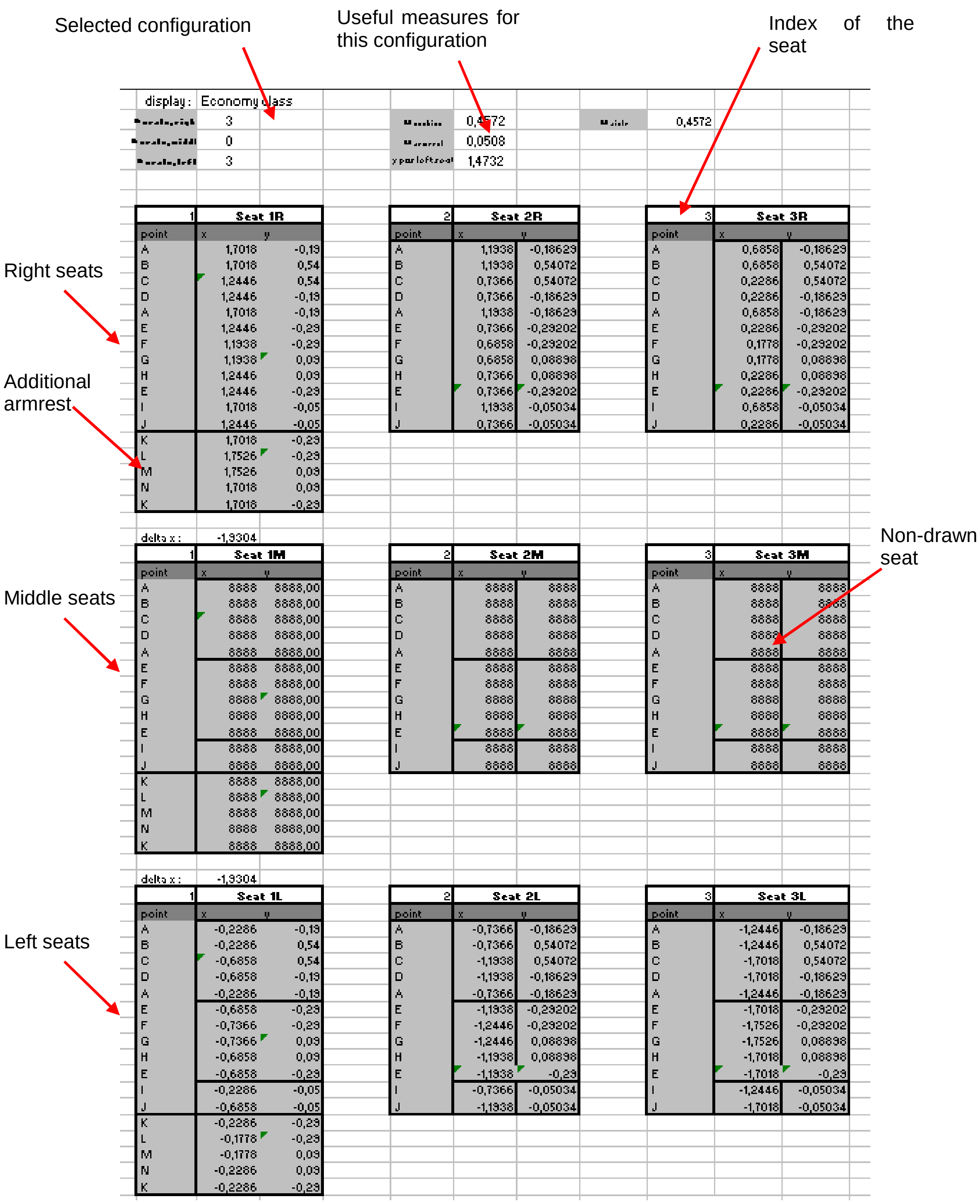


Fig. 2.33 Overview of calculation for seating configuration display

Several parameters are imported from the “fuselage” sheet; they involve the class the user wants to display (number of seats abreast, aisle and cushion widths…).
The seats are calculated as written previously. The difference here is that there are twelve seats (three on the right, six on the middle and three others on the left). If less seats need to be displayed, for example in the case of a 3-3 seats abreast, then these non drawn seats get coordinates with high values (x=8888 and y=8888) so they will not appear on the cross section (see Fig. 2.34).
Since there are always more armrest than seats, the first seat of each side of the aisles will have two armrests and the others only one.



[illegible]	3	[illegible]	0,4572	[illegible]	0,4572
[illegible]	0	[illegible]	0,0508		
[illegible]	3	y par left seat	1,4732		

point	1 Seat 1R x	1 Seat 1R y	point	2 Seat 2R x	2 Seat 2R y	point	3 Seat 3R x	3 Seat 3R y
A	1,7018	-0,13	A	1,1938	-0,18623	A	0,6858	-0,18623
B	1,7018	0,54	B	1,1938	0,54072	B	0,6858	0,54072
C	1,2446	0,54	C	0,7366	0,54072	C	0,2286	0,54072
D	1,2446	-0,13	D	0,7366	-0,18623	D	0,2286	-0,18623
A	1,7018	-0,13	A	1,1938	-0,18623	A	0,6858	-0,18623
E	1,2446	-0,23	E	0,7366	-0,29202	E	0,2286	-0,29202
F	1,1938	-0,23	F	0,6858	-0,29202	F	0,1778	-0,29202
G	1,1938	0,03	G	0,6858	0,08898	G	0,1778	0,08898
H	1,2446	0,03	H	0,7366	0,08898	H	0,2286	0,08898
E	1,2446	-0,23	E	0,7366	-0,29202	E	0,2286	-0,29202
I	1,7018	-0,05	I	1,1938	-0,05034	I	0,6858	-0,05034
J	1,2446	-0,05	J	0,7366	-0,05034	J	0,2286	-0,05034
K	1,7018	-0,23						
L	1,7526	-0,23						
M	1,7526	0,03						
N	1,7018	0,03						
K	1,7018	-0,23						

delta x : -1,9304

point	1 Seat 1M x	1 Seat 1M y	point	2 Seat 2M x	2 Seat 2M y	point	3 Seat 3M x	3 Seat 3M y
A	8888	8888,00	A	8888	8888	A	8888	8888
B	8888	8888,00	B	8888	8888	B	8888	8888
C	8888	8888,00	C	8888	8888	C	8888	8888
D	8888	8888,00	D	8888	8888	D	8888	8888
A	8888	8888,00	A	8888	8888	A	8888	8888
E	8888	8888,00	E	8888	8888	E	8888	8888
F	8888	8888,00	F	8888	8888	F	8888	8888
G	8888	8888,00	G	8888	8888	G	8888	8888
H	8888	8888,00	H	8888	8888	H	8888	8888
E	8888	8888,00	E	8888	8888	E	8888	8888
I	8888	8888,00	I	8888	8888	I	8888	8888
J	8888	8888,00	J	8888	8888	J	8888	8888
K	8888	8888,00						
L	8888	8888,00						
M	8888	8888,00						
N	8888	8888,00						
K	8888	8888,00						

delta x : -1,9304

point	1 Seat 1L x	1 Seat 1L y	point	2 Seat 2L x	2 Seat 2L y	point	3 Seat 3L x	3 Seat 3L y
A	-0,2286	-0,13	A	-0,7366	-0,18623	A	-1,2446	-0,18623
B	-0,2286	0,54	B	-0,7366	0,54072	B	-1,2446	0,54072
C	-0,6858	0,54	C	-1,1938	0,54072	C	-1,7018	0,54072
D	-0,6858	-0,13	D	-1,1938	-0,18623	D	-1,7018	-0,18623
A	-0,2286	-0,13	A	-0,7366	-0,18623	A	-1,2446	-0,18623
E	-0,6858	-0,23	E	-1,1938	-0,29202	E	-1,7018	-0,29202
F	-0,7366	-0,23	F	-1,2446	-0,29202	F	-1,7526	-0,29202
G	-0,7366	0,03	G	-1,2446	0,08898	G	-1,7526	0,08898
H	-0,6858	0,03	H	-1,1938	0,08898	H	-1,7018	0,08898
E	-0,6858	-0,23	E	-1,1938	-0,23	E	-1,7018	-0,23
I	-0,2286	-0,05	I	-0,7366	-0,05034	I	-1,2446	-0,05034
J	-0,6858	-0,05	J	-1,1938	-0,05034	J	-1,7018	-0,05034
K	-0,2286	-0,23						
L	-0,1778	-0,23						
M	-0,1778	0,03						
N	-0,2286	0,03						
K	-0,2286	-0,23						

Fig. 2.34 Calculation of seats coordinates in cabin cross section

Overhead bins are considered as a curve connecting four or eight points, depending on the presence of a central bin (Fig. 2.35). Both configurations are calculated. Then a selection is made to keep the one which has to be displayed.

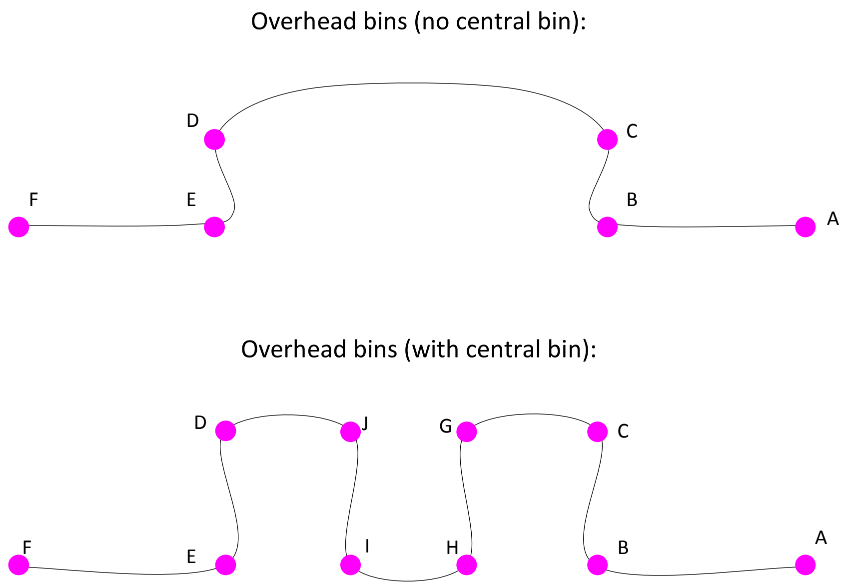


Fig. 2.35 Description of overhead bins

A standard seat rail can be represented as shown on Fig. 2.36. The dimensions have been measured on an Airbus A320 seat rail. Up to ten seat rails can be displayed.

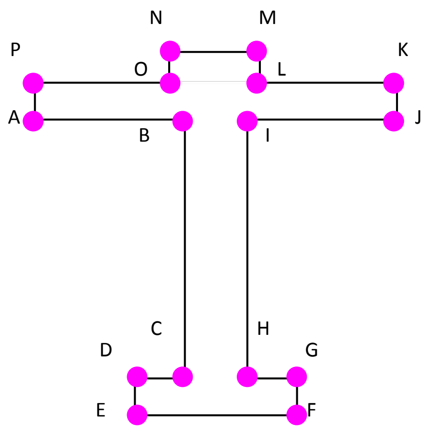


Fig. 2.36 Drawing of a seat rail

A leg is drawn over each seat rail and a transversal tube connects the legs (Fig. 2.37). This drawing could be improved in further developments of PreSTo-Cabin.

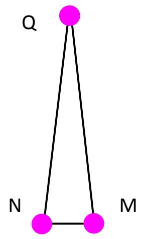


Fig. 2.37 Drawing of a seat leg

Fig. 2.38 presents the calculation of overhead bins, seat rails and seat legs position in PreSTo.

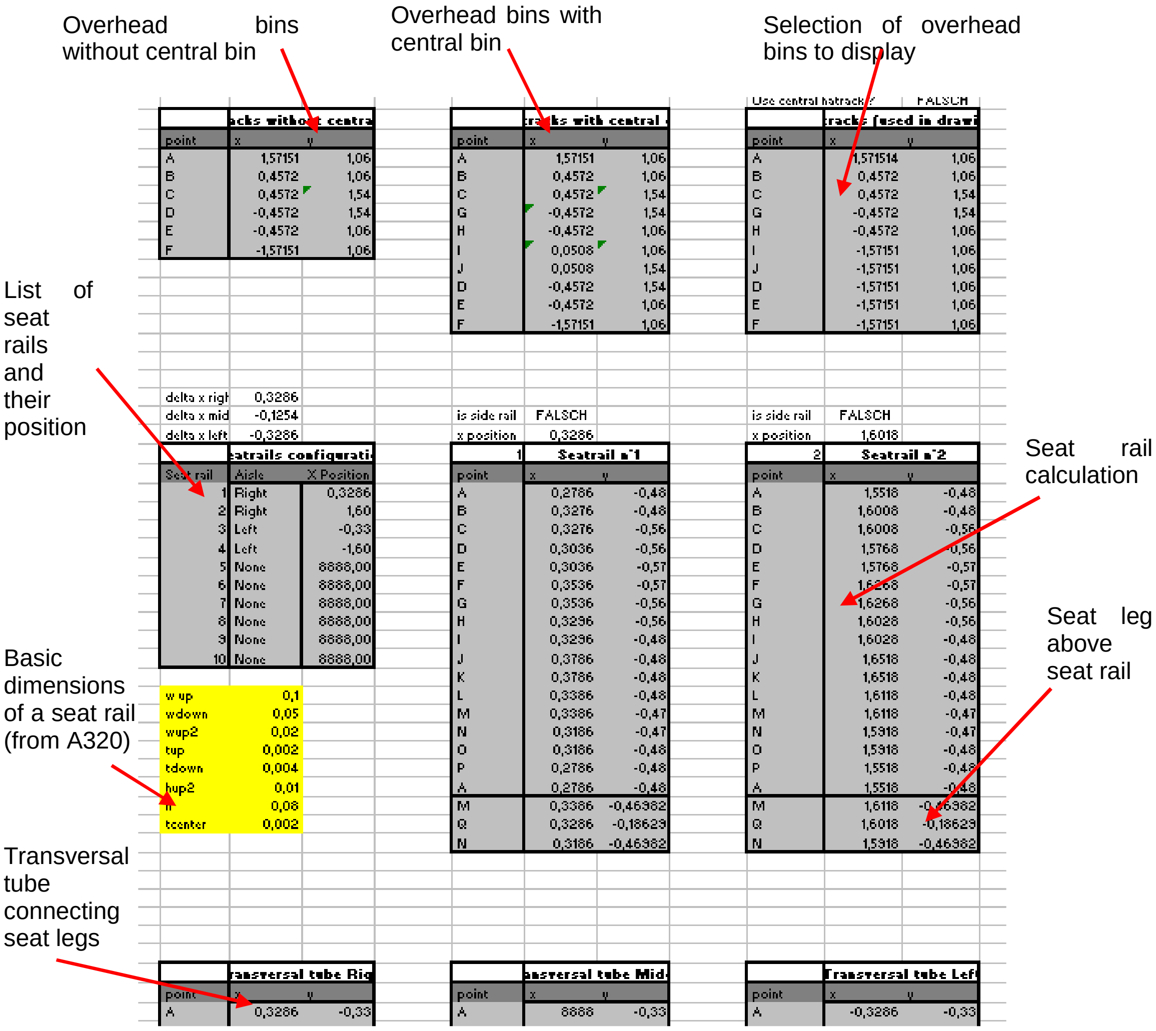


Fig. 2.38 Calculation of various items coordinates for cross section display

2.2.3 Drawing of cabin floor plan

Calculations for the cabin floor plans consist in displaying the seats or monuments present on a row, for a list of 65 rows on the airplane. For this reason these calculations need about 2000 lines in the sheet. Fig. 2.39 presents an overview of this section:

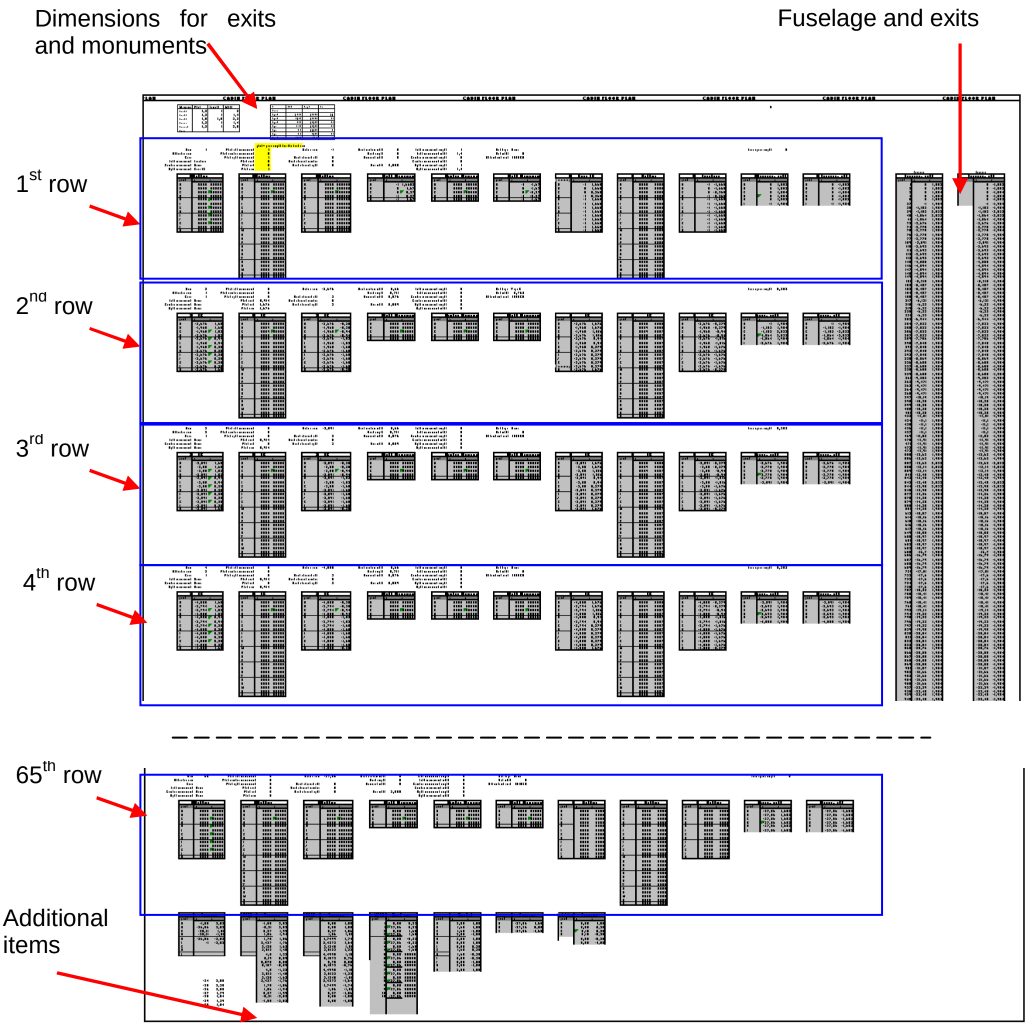


Fig. 2.39 Overview of needed calculations for cabin floor plan

Dimensions for monuments and exits are copied from the “fuselage sheet”. For each monument, a minimum pitch value is determined as the length of the monument plus 30 extra centimetres (Fig. 2.40).

Monument	Pitch	Length	Width
Galley BC	1,3	1	2
Galley FC	1,3	1	1,4
Galley YC	1,8	1,5	2,3
Lavatory	1,3	1	1,4
Lavatory(x2)	1,3	1	2,8
None			

Exit	Width "	Height "	Pax
None	0	0	0
Type A	1,0668	1,8288	110
Type B	0,8128	1,8288	75
Type C	0,762	1,2192	55
Type I	0,6096	1,2192	45
Type II	0,508	1,1176	40
Type III	0,508	0,9144	35
Type IV	0,4826	0,6604	9

Fig. 2.40 Monuments and exits dimensions

For each row and according to the list of rows given in the “fuselage” sheet (see 2.1.4 Cabin floor plan) the configuration of the row is imported: type of row (seat, monuments), class of seating row, monuments, exits and attendant seats.
If the row is a seating row, the dimensions of seats are also copied (depending on the class). Otherwise, if the row has monuments, then the dimensions of the monuments are copied.
Then the pitch of the row is defined as the maximum value of the pitches needed for the seats, for the several monuments or for the exit.
The rear line of the current row (“delta x row”) is defined as the rear line of the previous row minus the pitch of the current row (the x axis direction is the same as the flight direction).
Whether the row is a seating row or a row with monuments, position for seats (Fig. 2.41) and monuments (Fig. 2.42) are calculated. Fig. 2.43 and Fig. 2.44 display these calculations in PreSTo-Cabin. Then there is a selection to keep only the monuments or the seats.

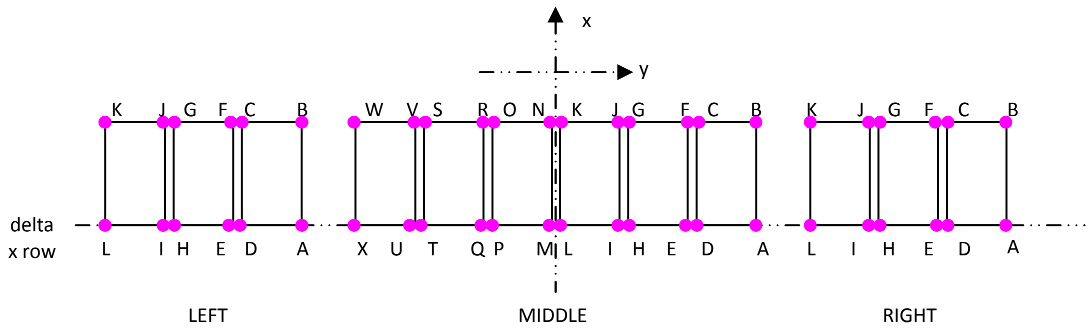


Fig. 2.41 Description of seat row drawing

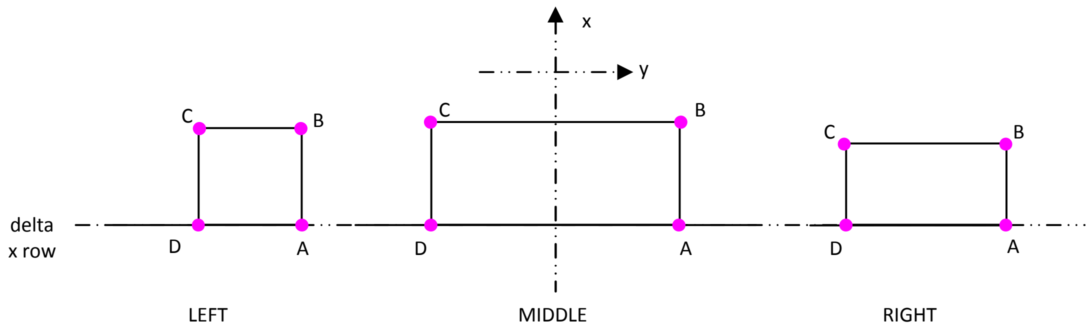
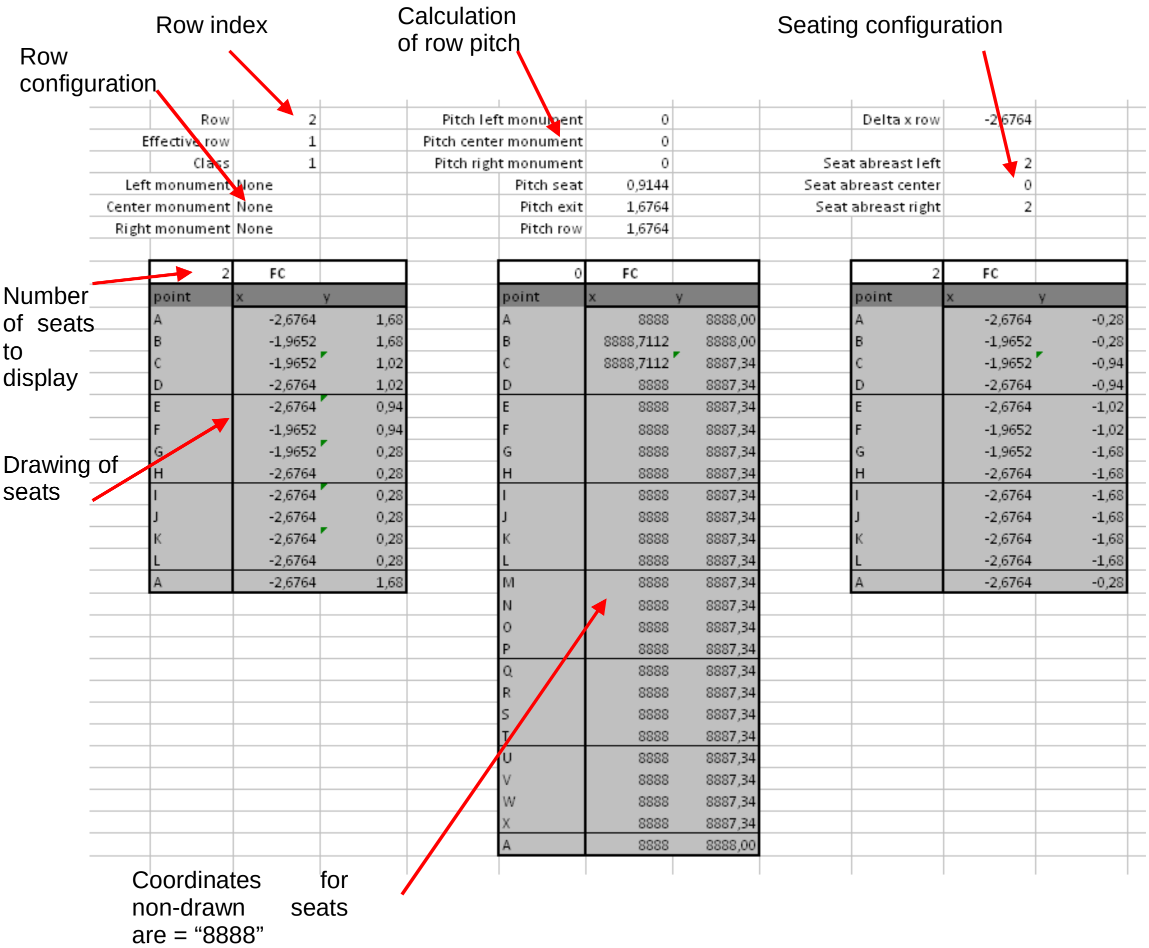


Fig. 2.42 Description of a row containing monuments



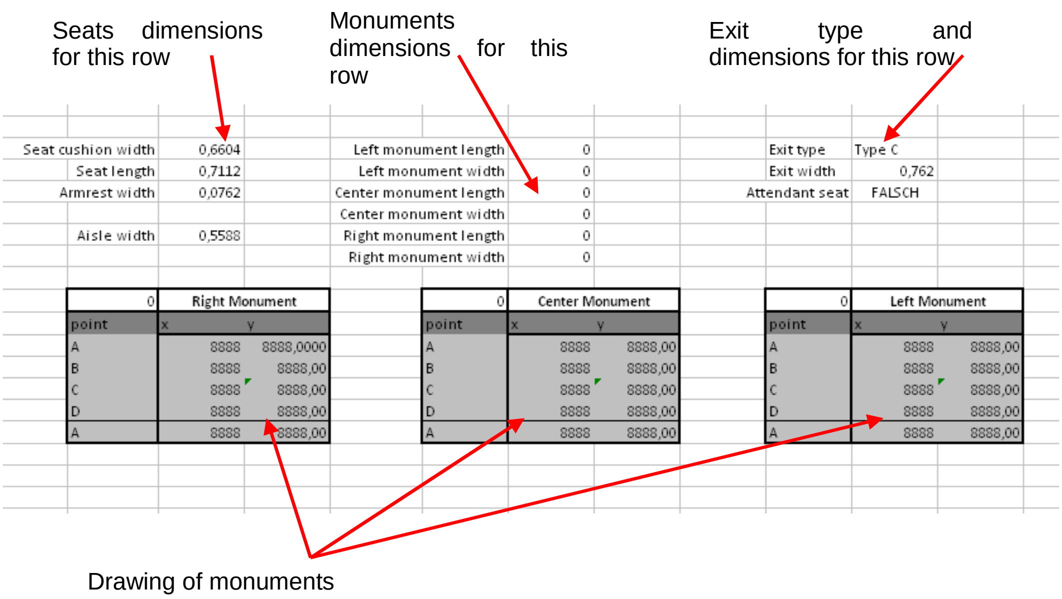
Row	2	Pitch left monument	0	Delta x row	-2,6764
Effective row	1	Pitch center monument	0		
Class	1	Pitch right monument	0	Seat abreast left	2
Left monument	None	Pitch seat	0,9144	Seat abreast center	0
Center monument	None	Pitch exit	1,6764	Seat abreast right	2
Right monument	None	Pitch row	1,6764		

2	FC	
point	x	y
A	-2,6764	1,68
B	-1,9652	1,68
C	-1,9652	1,02
D	-2,6764	1,02
E	-2,6764	0,94
F	-1,9652	0,94
G	-1,9652	0,28
H	-2,6764	0,28
I	-2,6764	0,28
J	-2,6764	0,28
K	-2,6764	0,28
L	-2,6764	0,28
A	-2,6764	1,68

0	FC	
point	x	y
A	8888	8888,00
B	8888,7112	8888,00
C	8888,7112	8887,34
D	8888	8887,34
E	8888	8887,34
F	8888	8887,34
G	8888	8887,34
H	8888	8887,34
I	8888	8887,34
J	8888	8887,34
K	8888	8887,34
L	8888	8887,34
M	8888	8887,34
N	8888	8887,34
O	8888	8887,34
P	8888	8887,34
Q	8888	8887,34
R	8888	8887,34
S	8888	8887,34
T	8888	8887,34
U	8888	8887,34
V	8888	8887,34
W	8888	8887,34
X	8888	8887,34
A	8888	8888,00

2	FC	
point	x	y
A	-2,6764	-0,28
B	-1,9652	-0,28
C	-1,9652	-0,94
D	-2,6764	-0,94
E	-2,6764	-1,02
F	-1,9652	-1,02
G	-1,9652	-1,68
H	-2,6764	-1,68
I	-2,6764	-1,68
J	-2,6764	-1,68
K	-2,6764	-1,68
L	-2,6764	-1,68
A	-2,6764	-0,28

Fig. 2.43 Calculation of seats position for the cabin floor plan



Seat cushion width	0,6604	Left monument length	0	Exit type	Type C
Seat length	0,7112	Left monument width	0	Exit width	0,762
Armrest width	0,0762	Center monument length	0	Attendant seat	FALSCH
		Center monument width	0		
Aisle width	0,5588	Right monument length	0		
		Right monument width	0		

0	Right Monument	
point	x	y
A	8888	8888,0000
B	8888	8888,00
C	8888	8888,00
D	8888	8888,00
A	8888	8888,00

0	Center Monument	
point	x	y
A	8888	8888,00
B	8888	8888,00
C	8888	8888,00
D	8888	8888,00
A	8888	8888,00

0	Left Monument	
point	x	y
A	8888	8888,00
B	8888	8888,00
C	8888	8888,00
D	8888	8888,00
A	8888	8888,00

Fig. 2.44 Calculation of monuments position for cabin floor plan

Depending on the row configuration (seats or monument), a selection is applied between the drawing of seats and the drawing of monuments calculated previously (Fig. 2.45):

1	FC	
point	x	y
A	-2,6764	1,6764
B	-1,9652	1,6764
C	-1,9652	1,016
D	-2,6764	1,016
E	-2,6764	0,9398
F	-1,9652	0,9398
G	-1,9652	0,2794
H	-2,6764	0,2794
I	-2,6764	0,2794
J	-2,6764	0,2794
K	-2,6764	0,2794
NACA 65-21(	-2,6764	0,2794
A	-2,6764	1,6764

1	FC	
point	x	y
A	8888	8888
B	8888,7112	8888
C	8888,7112	8887,3396
D	8888	8887,3396
E	8888	8887,3396
F	8888	8887,3396
G	8888	8887,3396
H	8888	8887,3396
I	8888	8887,3396
J	8888	8887,3396
K	8888	8887,3396
L	8888	8887,3396
M	8888	8887,3396
N	8888	8887,3396
O	8888	8887,3396
P	8888	8887,3396
Q	8888	8887,3396
R	8888	8887,3396
S	8888	8887,3396
T	8888	8887,3396
U	8888	8887,3396
V	8888	8887,3396
W	8888	8887,3396
X	8888	8887,3396
A	8888	8888

1	FC	
point	x	y
A	-2,6764	-0,2794
B	-1,9652	-0,2794
C	-1,9652	-0,9398
D	-2,6764	-0,9398
E	-2,6764	-1,016
F	-1,9652	-1,016
G	-1,9652	-1,6764
H	-2,6764	-1,6764
I	-2,6764	-1,6764
J	-2,6764	-1,6764
K	-2,6764	-1,6764
L	-2,6764	-1,6764
A	-2,6764	-0,2794

Fig. 2.45 Selection of seats or monuments for cabin floor plan

For each row, the part of fuselage on both sides of the row is drawn. This section can include an exit or not, as shown on Fig. 2.46:

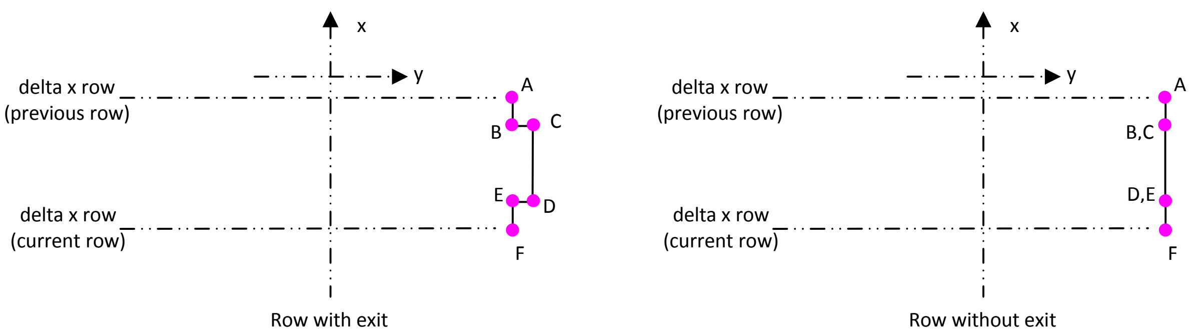


Fig. 2.46 Drawing of fuselage for cabin floor plan

Note: if there is an exit, this exit is centered on x direction.

Fig. 2.47 shows how this calculation is performed in PreSTo-Cabin.

Calculation of free space in order to center the exit

free space length	0,2032

1	Fuselage, right	
point	x	y
A	-1	1,90425116
B	-1,1016	1,90425116
C	-1,1016	2,03151293
D	-1,8636	2,03151293
E	-1,8636	1,90425116
F	-2,6764	1,90425116

1	Fuselage, left	
point	x	y
A	-1	-1,9042512
B	-1,1016	-1,9042512
C	-1,1016	-2,0315129
D	-1,8636	-2,0315129
E	-1,8636	-1,9042512
F	-2,6764	-1,9042512

Right part of fuselage

Left part of fuselage

Fig. 2.47 Calculation of fuselage parts for each row of the cabin floor plan

Since Excel needs a complete list of points in order to draw a curve, each part of fuselage is gathered in one unique big list (Fig. 2.48):

Right part of fuselage

Left part of fuselage

Index to get the coordinates

	Fuselage			Fuselage	
	Fuselage, right			Fuselage, left	
line	x	y	line	x	y
1	0	1,88322198		0	-1,883222
2	0	1,88322198		0	-1,883222
3	0	1,88399749		0	-1,8839975
4	0	1,88399749		0	-1,8839975
5	0	1,88322198		0	-1,883222
37	-1	1,90425116		-1	-1,9042512
38	-1,1016	1,90425116		-1,1016	-1,9042512
39	-1,1016	2,03151293		-1,1016	-2,0315129
40	-1,8636	2,03151293		-1,8636	-2,0315129
41	-1,8636	1,90425116		-1,8636	-1,9042512
73	-2,6764	1,90425116		-2,6764	-1,9042512
74	-2,778	1,90425116		-2,778	-1,9042512
75	-2,778	1,90425116		-2,778	-1,9042512

1st row

2nd row

3rd row

Fig. 2.48 Gathering of each part of fuselage for cabin for plan

All the previous calculations have to be done for each row (apart from the gathering of points for the fuselage drawing which is done only once).
All the void rows (from the last row containing a seat or a monument to the 65th row) have no pitch. Then the "delta x row" of the 65th row (which is equal to the "delta x row" of all other void rows) is the aft extremity of the cabin.

The last items to draw for the cabin floor plan are the outer fuselage (with tail) and the nose as well as the cockpit and the seat rails.
The outer fuselage is basically composed of five lines describing the cylinder and the tail (Fig. 2.49):

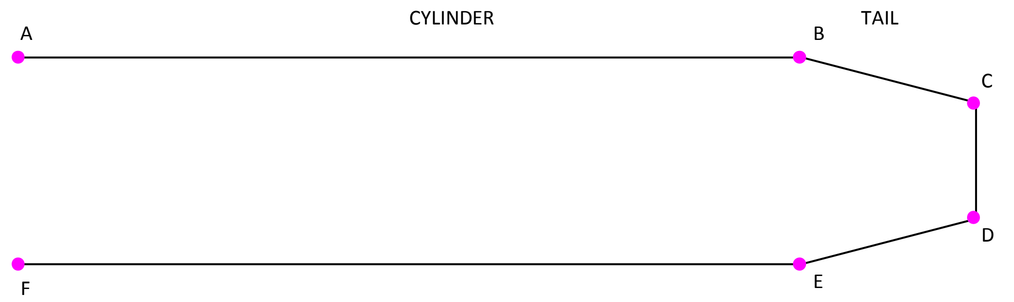


Fig. 2.49 Description of outer fuselage including tail

The nose is considered as elliptic. It is composed of two parts: an inner and an outer part (Fig. 2.50).

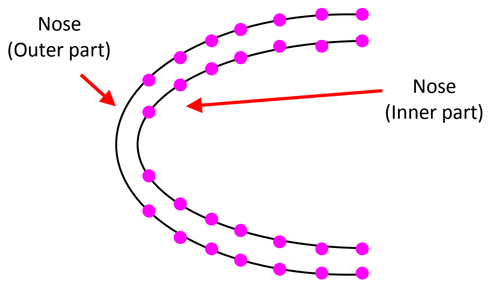


Fig. 2.50 Description of nose

The cockpit is drawn with two seats facing a command panel (Fig. 2.51):

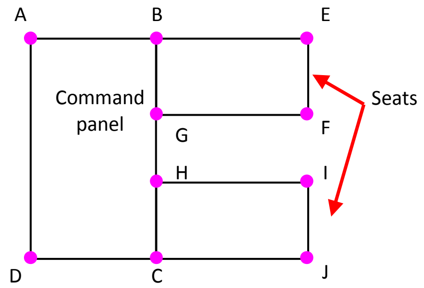


Fig. 2.51 Description of cockpit

On the cabin floor plan, seat rails are drawn as simple lines running through the complete length of the cabin.

Fig. 2.52 shows the calculation of fuselage, tail and nose.

Outer fuselage and tail

	Fuselage	
point	x	y
A	-1,00	2,03
B	-26,06	2,03
C	-30,11	1,01
D	-30,11	-1,01
E	-26,0616	-2,03
F	-1	-2,03
G		
H		
I		

Inner part of nose

NOSE	Fuselage	
point	x	y
	-1,00	2,03
	-0,31	2,02
	0,37	1,99
	1,06	1,94
	1,74987614	1,86
	2,43734517	1,76
	3,12481421	1,63
	3,81228324	1,45
	4,49975227	1,22
	5,19	0,89
	5,87469034	0,00
	5,18722131	-0,89
	4,49975227	-1,22
	3,81228324	-1,45
	3,12481421	-1,63
	2,43734517	-1,76
	1,74987614	-1,86
	1,06	-1,94
	0,37	-1,99
	-0,31	-2,02
	-1,00	-2,03

Outer part of nose

NOSE	Fuselage	
point	x	y
	0,00	1,88
	0,00	1,88
	0,37	1,86
	1,06	1,81
	1,749876137	1,74
	2,437345171	1,64
	3,124814206	1,51
	3,81228324	1,33
	4,499752274	1,10
	5,187221309	0,76
	5,75	0,00
	5,187221309	-0,76
	4,499752274	-1,10
	3,81228324	-1,33
	3,124814206	-1,51
	2,437345171	-1,64
	1,749876137	-1,74
	1,06	-1,81
	0,37	-1,86
	0,00	-1,88
	0,00	-1,88

Fig. 2.52 Calculation of outer fuselage, tail and nose

Fig. 2.53 displays the calculation of seat rails, cockpit and aft pressure bulkhead.

Seat rails position

WAHR	Seat rails	
point	x	y
1	0,00	0,33
1	-27,06	0,33
2	0,00	1,60
2	-27,06	1,60
3	0,00	-0,33
3	-27,06	-0,33
4	0,00	-1,60
4	-27,06	-1,60
5	0,00	8888,00
5	-27,06	8888,00
6	0,00	8888,00
6	-27,06	8888,00
7	0,00	8888,00
7	-27,06	8888,00
8	0,00	8888,00
8	-27,06	8888,00
9	0,00	8888,00
9	-27,06	8888,00
10	0,00	8888,00
10	-27,06	8888,00

Cockpit

	Cockpit	
point	x	y
A	2,00	1,00
B	1,60	1,00
C	1,60	-1,00
D	2,00	-1,00
A	2,00	1,00
E	0,80	1,00
F	0,80	0,30
G	1,60	0,30
H	1,60	-0,30
I	0,80	-0,30
J	0,80	-1,00
D	2,00	-1,00
A	2,00	1,00

front x position	2
panel width	2
panel length	0,4
seat length	0,8
seat width	0,7

Basic dimensions for the cockpit

Aft pressure bulkhead

TAIL	Fuselage	
point	x	y
A	-27,06	1,65
B	-27,36	0,00
C	-27,06	-1,65

Cockpit door

Cockpit door	Fuselage	
point	x	y
A	0,05	1,88
B	0,05	0,30
C	0,10	0,30
D	0,10	-0,30
	0,05	-0,30
	0,05	-1,88

Fig. 2.53 Calculation of seat rails, cockpit and aft pressure bulkhead

2.3 Description of macros

2.3.1 Optimization of cross section

In order to optimize the cabin cross section, the inputs and the outputs have to be identified: what is the aim and which values can be modified to reach this goal?

Two outputs can be taken into account: the equivalent diameter or the circumference of the ellipse. The first is used to estimate the fuselage thickness and the length of nose and tail, the second influences the the aircraft wetted area which induces drag.
Analyzing this both parameters will help to find an answer on which parameters need to be optimized.

Equivalent diameter of the ellipse

The equivalent diameter of an ellipse is:

$$d_{eqv} = \sqrt{a \cdot b} \tag{2.38}$$

$$d_{eqv} = a\sqrt{\frac{b}{a}} \tag{2.39}$$

Therefore for a given $\left(\frac{b}{a}\right)$, d_{eqv} is minimum when a is minimum.

Circumference of the ellipse
An approximation for the circumference of an ellipse is given by Ramanujan [**Wikipedia 2010**]:

$$C = \pi\left[3(a+b) - \sqrt{(3a+b)\cdot(a+3b)}\right] \tag{2.40}$$

$$C = \pi\left[3\left(a + a\left(\frac{b}{a}\right)\right) - \sqrt{\left(3a + a\left(\frac{b}{a}\right)\right)\cdot\left(a + 3a\left(\frac{b}{a}\right)\right)}\right]$$

$$C = \pi\left[3a\left(1 + \left(\frac{b}{a}\right)\right) - \sqrt{a\left(3 + \left(\frac{b}{a}\right)\right)\cdot a\left(1 + 3\left(\frac{b}{a}\right)\right)}\right]$$

$$C = \pi \cdot a\left[3\left(1+\frac{b}{a}\right) - \sqrt{\left(3+\frac{b}{a}\right)\cdot\left(1+3\frac{b}{a}\right)}\right] \tag{2.41}$$

Then, for a given $\left(\frac{b}{a}\right)$, C is minimum when a is minimum.

Therefore whether the objective is to get the smallest equivalent diameter or the smallest circumference, a must be minimal.
So the parameter to optimize will be the value of a. This will both optimize the circumference and the equivalent diameter of the ellipse.
Now it is important to find which parameters can be modified in order to reach this best value. As written before, there are 10 couples of (x, y) equations. Most of the values can be considered as requirement (ex: $n_{aisle}, w_{aisle} \ldots$)
The only variables are Δz_{floor} and t_{floor}. The first one is the distance between the floor and the axis of symmetry of the ellipse. The second describes the floor thickness.
According to [Schmitt 1988], the floor thickness is related to the fuselage equivalent outer diameter:

$$t_{floor} = 0{,}035 \cdot d_{f,o} \quad (2.42)$$

The outer diameter itself is related to the inner equivalent diameter, as written by [Marckwardt 1998]:

$$d_{f,o} = 0{,}048 + 1{,}045 \cdot d_{f,i} \quad (2.43)$$

As the inner fuselage is the ellipse that is being calculated, the inner equivalent diameter is an output. Therefore the outer equivalent diameter and then the floor thickness are not real inputs.

As a conclusion the only variable that can be used to optimize the cabin cross section is Δz_{floor} .
Fig. 2.54 shows the algorithm to calculate the a parameter.

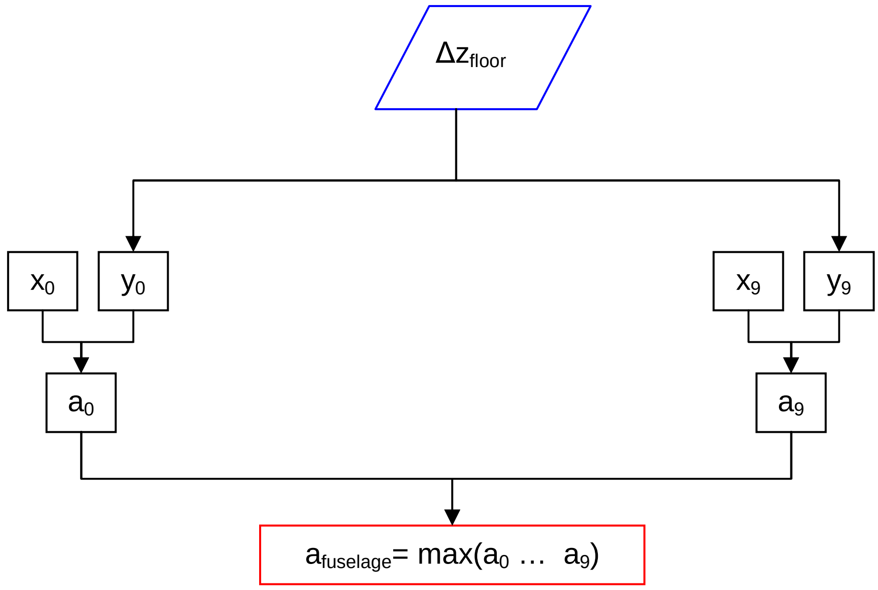


Fig. 2.54 Calculation of the a parameter depending on Δz_{floor}

A Binary search algorithm is used to find the best value for Δz_{floor} as shown on Fig. 2.55:

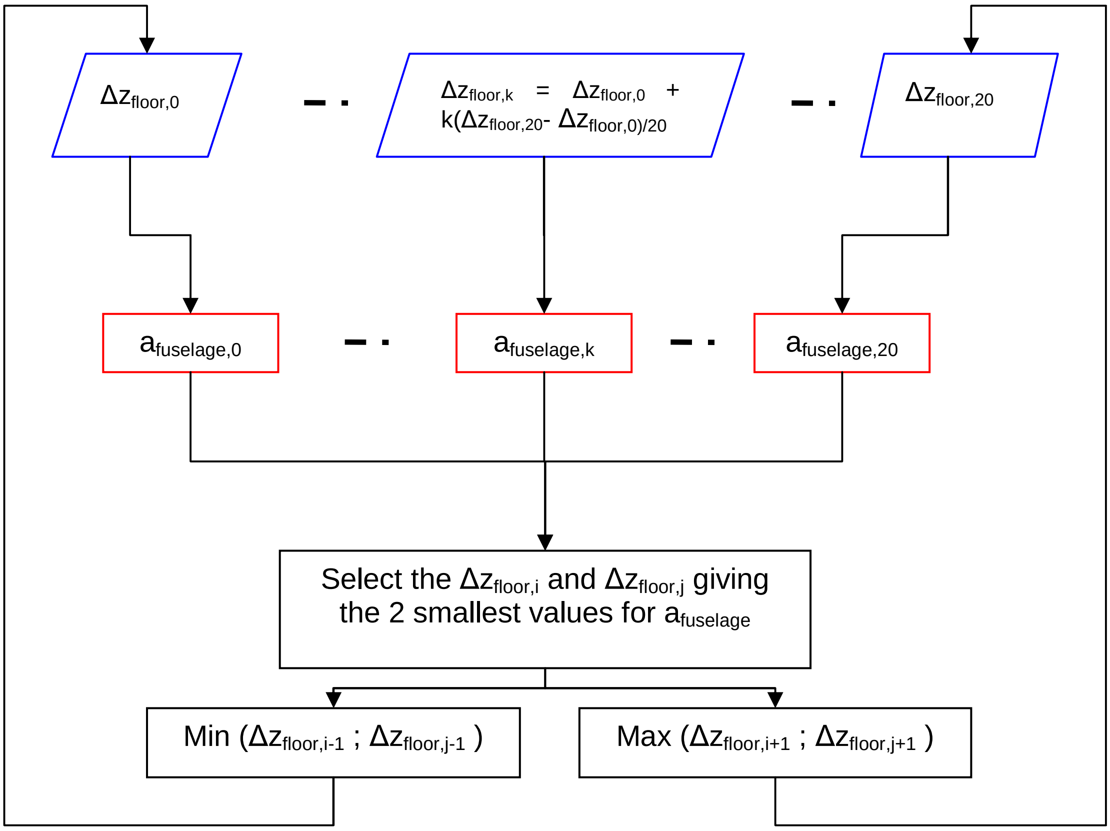


Fig. 2.55 Loop used to find the optimal value for Δz_{floor}

The loop is executed 5 times. After this, the optimum value for Δz_{floor} is found (Fig. 2.56) and set in the "Fuselage" spreadsheet.

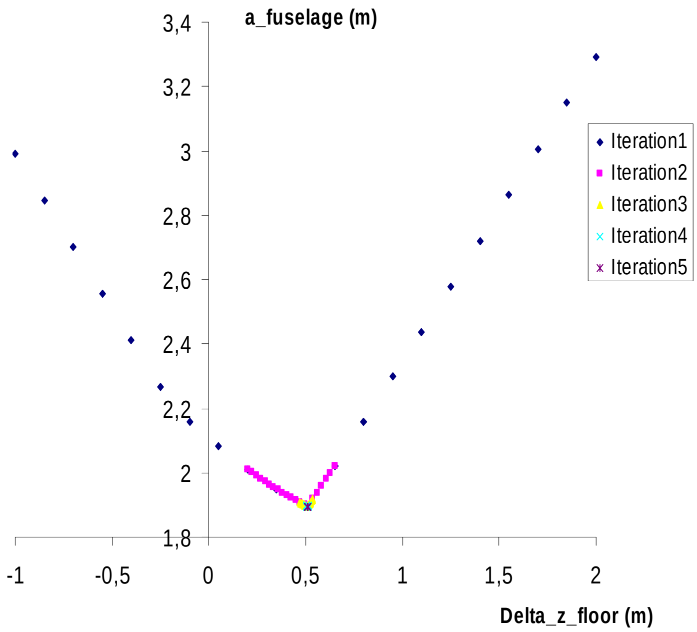


Fig. 2.56 Evolution of fuselage semi height through five iterations

2.3.2 Saving of a scenario

Once an aircraft has been designed it is possible to save the parameters and the results and compare them with other designs. By selecting different values for a parameter, it is possible to find an optimum.

In the spreadsheet “Analysis” a click on the button “Analysis” opens a User form (Fig. 2.57).

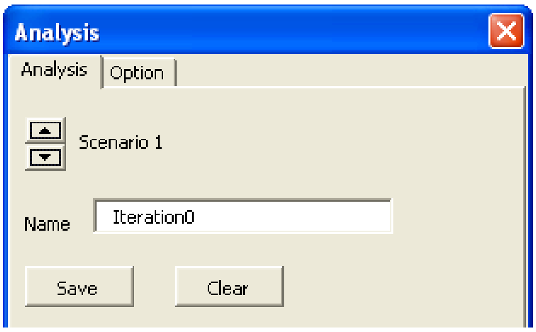
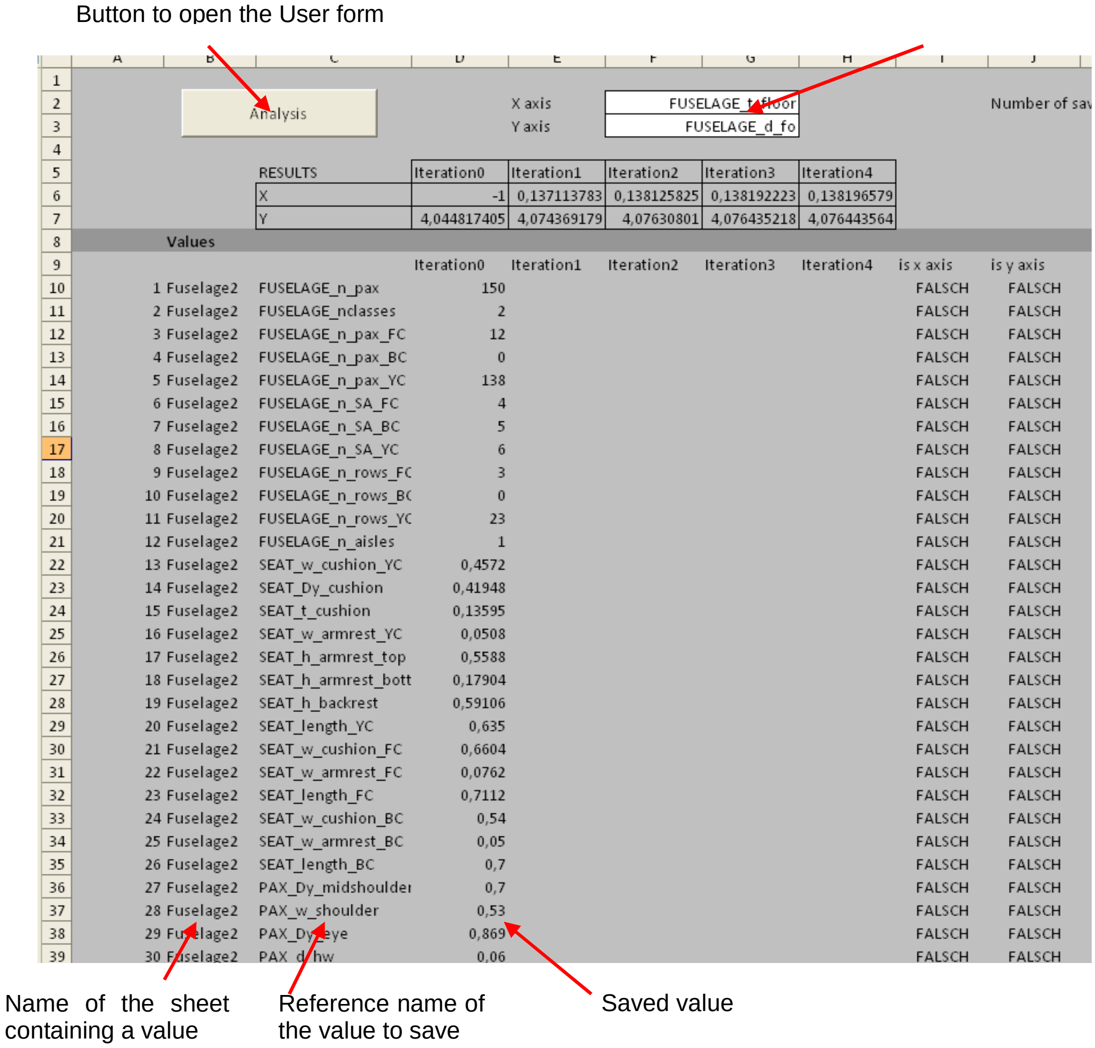


Fig. 2.57 User form for scenario analysis

The user can select the name of the scenario and save it. It is also possible to clear a scenario. In order to save the values, the macro “SaveScenario” works this way: for each value to save, the macro reads the name of the sheet containing the value and also its reference name. Then each value is read in the spreadsheets and saved in a temporary array. Eventually when each value has been saved in the array, the whole array is copied in the “Analysis” spreadsheet (Fig. 2.58).



	A	B	C	D	E	F	G	H	I	J
1										
2		Analysis			X axis	FUSELAGE_t_floor				Number of sav
3					Y axis	FUSELAGE_d_fo				
4										
5			RESULTS	Iteration0	Iteration1	Iteration2	Iteration3	Iteration4		
6			X	-1	0,137113783	0,138125825	0,138192223	0,138196579		
7			Y	4,044817405	4,074369179	4,07630801	4,076435218	4,076443564		
8		Values								
9				Iteration0	Iteration1	Iteration2	Iteration3	Iteration4	is x axis	is y axis
10	1	Fuselage2	FUSELAGE_n_pax	150					FALSCH	FALSCH
11	2	Fuselage2	FUSELAGE_nclasses	2					FALSCH	FALSCH
12	3	Fuselage2	FUSELAGE_n_pax_FC	12					FALSCH	FALSCH
13	4	Fuselage2	FUSELAGE_n_pax_BC	0					FALSCH	FALSCH
14	5	Fuselage2	FUSELAGE_n_pax_YC	138					FALSCH	FALSCH
15	6	Fuselage2	FUSELAGE_n_SA_FC	4					FALSCH	FALSCH
16	7	Fuselage2	FUSELAGE_n_SA_BC	5					FALSCH	FALSCH
17	8	Fuselage2	FUSELAGE_n_SA_YC	6					FALSCH	FALSCH
18	9	Fuselage2	FUSELAGE_n_rows_FC	3					FALSCH	FALSCH
19	10	Fuselage2	FUSELAGE_n_rows_BC	0					FALSCH	FALSCH
20	11	Fuselage2	FUSELAGE_n_rows_YC	23					FALSCH	FALSCH
21	12	Fuselage2	FUSELAGE_n_aisles	1					FALSCH	FALSCH
22	13	Fuselage2	SEAT_w_cushion_YC	0,4572					FALSCH	FALSCH
23	14	Fuselage2	SEAT_Dy_cushion	0,41948					FALSCH	FALSCH
24	15	Fuselage2	SEAT_t_cushion	0,13595					FALSCH	FALSCH
25	16	Fuselage2	SEAT_w_armrest_YC	0,0508					FALSCH	FALSCH
26	17	Fuselage2	SEAT_h_armrest_top	0,5588					FALSCH	FALSCH
27	18	Fuselage2	SEAT_h_armrest_bott	0,17904					FALSCH	FALSCH
28	19	Fuselage2	SEAT_h_backrest	0,59106					FALSCH	FALSCH
29	20	Fuselage2	SEAT_length_YC	0,635					FALSCH	FALSCH
30	21	Fuselage2	SEAT_w_cushion_FC	0,6604					FALSCH	FALSCH
31	22	Fuselage2	SEAT_w_armrest_FC	0,0762					FALSCH	FALSCH
32	23	Fuselage2	SEAT_length_FC	0,7112					FALSCH	FALSCH
33	24	Fuselage2	SEAT_w_cushion_BC	0,54					FALSCH	FALSCH
34	25	Fuselage2	SEAT_w_armrest_BC	0,05					FALSCH	FALSCH
35	26	Fuselage2	SEAT_length_BC	0,7					FALSCH	FALSCH
36	27	Fuselage2	PAX_Dy_midshoulder	0,7					FALSCH	FALSCH
37	28	Fuselage2	PAX_w_shoulder	0,53					FALSCH	FALSCH
38	29	Fuselage2	PAX_Dy_eye	0,869					FALSCH	FALSCH
39	30	Fuselage2	PAX_d_hw	0,06					FALSCH	FALSCH

Fig. 2.58 Values saved in "Analysis" spreadsheet

2.3.3 **Uniform distribution of exits**

Uniform distribution of exits is a part of the FAR25 Regulations. In order to check the compliance with this, the Advisory Circular AC25.807-1 introduces a method. In PreSTo-Cabin a macro is present to apply automatically this method.

First step of this "uniformDistributionOfExits" macro is to locate the first and the last seating rows, as well as the position and the type of each exit. If there is no exit in the airplane, the macro stops with an error message to the user requesting to add an exit.
The macro then looks for the *x* position of the start and end of the cabin.
According to the method written in the circular, the *x* positions of start and end of the cabin are respectively the front of the first and last seat row. In several particular cases they can be the position of first or last exit.
The macro searches if there are "Double Type III" exits. In this case the list of exits is updated, with the mention of a "Double Type III" exit instead of two consecutive "Type III" exits. Position of this double exit is set as the centreline between both exits.

Next step is to calculate the individual zone passenger capacities. It is basically about counting how many passengers are between two consecutive exits and how many passengers are allowed to be in this zone. A list of zones is created to gather this information. If too many passengers are seating in one zone, a message is displayed to the user to inform about the situation. Same work is done with consecutive zones from nose to tail and tail to nose. The number of allowed passenger in the whole airplane is then compared to the number of passenger allowed in the airplane. Each time a problem is detected a message is displayed to inform the user (see 2.1.5 Results for more explanations).

Then the macro checks the exit distribution. Length of the cabin is calculated as the distance between the beginning and the end of the cabin. “Exits units” are calculated for each zone. The sum of exits units from each zone gives the total number of exits units in the airplane. The macro then determines the nominal location of each exit and compares it to their real location. Absolute value of the offset has to be less than 15% of the cabin length. Then distance between two consecutive exits is checked because exits cannot be too close one the one from the other and there is also a limitation on maximum door spacing, meeting the requirements of CS25.807 (7).

Eventually the results are written in the “Fuselage” spreadsheet so the user can see each one of the results concerning the passenger zones and the exits locations. Any issue is highlighted.

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Appendix

Description of an ellipse

The equation of an ellipse as shown on Fig A.1 is:

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1 \tag{A.1}$$

or

$$\begin{cases} x = a\cos(\theta) & \text{(A.2)} \\ y = b\sin(\theta) & \text{(A.3)} \end{cases}$$

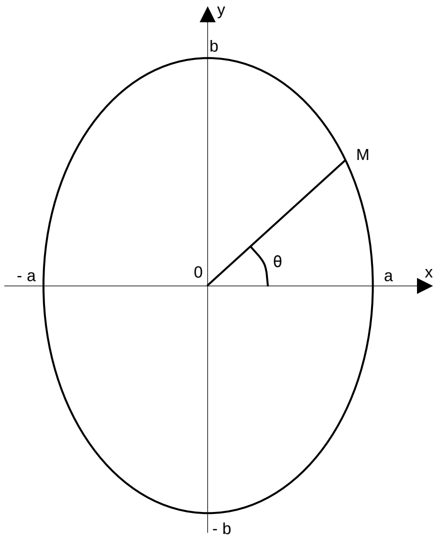

Fig. A. 1 Description of an ellipse

The equations of the ten points shown in Fig. 1.9 are:

$$\begin{cases} x_0 = \frac{1}{4} h_{aisle} \cdot n_{aisle} & \text{(A.4)} \\ y_0 = h_{aisle} - \Delta z_{floor} & \text{(A.5)} \end{cases}$$

$$\begin{cases} x_1 = x_{last\_seat} & \text{(A.6)} \\ y_1 = \Delta y_{eye} + \Delta y_{cushion} - \Delta z_{floor} + 0{,}126 + d_{head-wall} & \text{(A.7)} \end{cases}$$

$$\begin{cases} x_2 = d_{head-wall} + 0{,}084 + x_{last\_seat} & \text{(A.8)} \\ y_2 = \Delta y_{eye} + \Delta y_{cushion} - \Delta z_{floor} & \text{(A.9)} \end{cases}$$

$$\begin{cases} x_3 = d_{shoulder-wall} + \frac{1}{2} w_{shoulder} + x_{last\_seat} & \text{(A.10)} \\ y_3 = \Delta y_{midshoulder} + \Delta y_{cushion} - \Delta z_{floor} & \text{(A.11)} \end{cases}$$

$$\begin{cases} x_4 = \frac{1}{2}\left[n_{SA} \cdot w_{cushion} + n_{aisle} \cdot w_{aisle} + (n_{SA} - n_{aisle} + 1) \cdot w_{arnrest}\right] & \text{(A.12)} \\ y_4 = h_{armrest,top} - \Delta z_{floor} & \text{(A.13)} \end{cases}$$

$$\begin{cases} x_5 = \frac{1}{2}\left[n_{SA} \cdot w_{cushion} + n_{aisle} \cdot w_{aisle} + \left(n_{SA} - n_{aisle} + 1\right) \cdot w_{armrest}\right] \\ y_5 = h_{armrest,bottom} - \Delta z_{floor} \end{cases} \quad \begin{matrix} \text{(A.14)} \\ \text{(A.15)} \end{matrix}$$

$$\begin{cases} x_6 = x_4 - \Delta w_{floor,seat} - w_{armrest} \\ y_6 = -\Delta z_{floor} \end{cases} \quad \begin{matrix} \text{(A.16)} \\ \text{(A.17)} \end{matrix}$$

$$\begin{cases} x_7 = w_{LD,top} \\ y_7 = -\Delta z_{floor} - t_{floor} \end{cases} \quad \begin{matrix} \text{(A.18)} \\ \text{(A.19)} \end{matrix}$$

$$\begin{cases} x_8 = w_{LD,top} \\ y_8 = -\Delta z_{floor} - t_{floor} - h_{LD} + \frac{w_{LD,top} - w_{LD,bottom}}{2} \end{cases} \quad \begin{matrix} \text{(A.20)} \\ \text{(A.21)} \end{matrix}$$

$$\begin{cases} x_9 = w_{LD,bottom} \\ y_9 = -\Delta z_{floor} - t_{floor} - h_{LD} \end{cases} \quad \begin{matrix} \text{(A.22)} \\ \text{(A.23)} \end{matrix}$$

With $x_{last\_seat} = x_4 - w_{armrest} - \frac{w_{cushion}}{2}$ (A.24)

Note: equation (A.4) concerning x_0 has no real meaning. Its only aim is to get a point describing the ceiling height.

Note: for y_8, the lower deck is considered having a 45° angle o n its lower part.