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Master's Thesis

Advancing Aircraft Interior Design: Automated Solution for Optimized Cabin Layout in Aviation

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II. Abstract

Traditional aircraft design, which is divided into conceptual, preliminary, and detailed phases, has considerable limitations, particularly in the preliminary stages, when design decisions limit future possibilities and incur significant life-cycle costs. Multidisciplinary Design Optimization (MDO) has evolved as a solution, bringing together multiple disciplines early in the design process to enhance flexibility and information availability. However, successfully applying MDO requires several challenges, including managing competing ideal techniques and developing cultures.

This thesis focuses on the integration of cabin and fuselage design, which is sometimes overlooked during the early design stages. This study proposes an "Inside-out" methodology that starts with cabin design considerations and shapes the fuselage, thereby promoting a holistic and adaptive design approach. Existing solutions for preliminary aircraft design and optimization, such as “PreSTo” and “ParaFuse” are limited in their ability to execute atypical fuselage layouts and compatibility limitations.

The thesis enhances this method by utilizing CAFE module (Cabin and Fuselage Design Environment) which is an environment use inside BLADE (Bauhaus Luftfahrt Aircraft Design Environment), a substantial Python-based framework based on the CPACS (Common Parametric Aircraft Configuration Schema). This concept enabled a wide range of cabin configurations, including unconventional layouts such as Sleeper Class, Group seating with tables, etc., non-standard seat configuration, multiple seat abreast layout within the same class type, multiple deck layout, multiple class layout and cargo deck layout while maintaining EASA compliance. By automating the design process and minimizing user input, the CAFE module enhances productivity and design utility while also providing critical parameters such as centre of gravity, operating and furnishing mass.

Furthermore, the thesis validates through examination of actual data from aircraft models especially the A320, A350, A220, ATR72, and A380. The length, width, galley area, and number of lavatories are compared to the real aircraft data and the results show very realistic and accurate cabin configurations. The current mass and centre of gravity data of each of the individual elements defined in CPACS have been provided by BHL and are taken as a reference for mass and centre of gravity calculations for subsequent aircraft models. This method produces more reliable and accurate results compared to traditional methods and these results will be beneficial for upcoming research work.

III. Declaration of Originality

Declaration

I hereby declare that this thesis is entirely my own work and that any additional sources of information have been duly cited.

I have clearly referenced all sources (either from a printed source, internet or any other source) used in the work.

This work has not been previously published and was not presented to a different examination authority.

Munich, July 2024

Y Gandhi

Yash Vijaykumar Gandhi

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V. List of Figures

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VII. List of Abbreviations

Abbreviation	Description
ATLAS	Air France (A), UTA (T), Lufthansa (L), Alitalia (A), Sabena(S)
BHL	Bauhaus Luftfahrt e.V.
BLADE	Bauhaus Luftfahrt Aircraft Design Environment
CAFÉ	Cabin and Fuselage Design Environment
CG/COG	Centre of Gravity
CPACS	Common Parametric Aircraft Configuration Schema
CS	Certification Specification
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FAR	Federal Aviation Requirements
KLM	Koninklijke Luchtvaart Maatschappij (nl.)
KSSU	KLM (K), SAS (S), Swissair (S), UTA (U)
LTH	Luftfahrttechnisches Handbuch
MDO	Multidisciplinary Design Optimization
OEM	Operating Empty Mass
PES	Passenger Entertainment Systems
RCE	Remote Component Environment
SAS	Scandinavian Airlines System
SPICE	Space Innovative Catering Equipment
ULD	Unit Load Devices
UTA	Union de Transports Aériens
XML	Extensible Markup Language

VIII. List of Symbols

K_{buf}	Definition of the galley factor
K_{lav}	Definition of the lavatory factor
N_{lav}	Number of Lavatory
N_{pax}	Number of Passenger
pax	passengers
R	Range

1 Introduction

Looking up at the sky often brings out the sight of airplanes soaring overhead, an honour to more than a century of aviation study and innovative thinking. Modern aircraft are marvels of engineering complexity and integration, having evolved from simple linen and wood constructions [1].

The traditional plane design approach consists of three stages: conceptual, preliminary, and specific layout. During the conceptual part, essential aircraft principles are developed through the use of actual data and formulas, laying the foundation for format, size, weight, and performance. This iterative process assesses several concepts before moving on to the preliminary phase, where coarse models are developed through computational approaches. Finally, the detailed design phase concentrates on subsystem-level design and produces manufacturing data [2].

The 'knowledge paradox' refers to the fact that design decisions made at the conceptual phase have a major impact on design freedom [3]. With up to 80% of the life-cycle cost committed during this phase [4], and primary attention focused on aerodynamics and propulsion, the restricted possibilities of the old approach become apparent. These include limited design exploration, reliance on simpler analysis methodologies, and knowledge loss because of retiring expertise.

Recognizing these constraints, the industry has made the transition to Multidisciplinary Design Optimization (MDO) [5]. MDO combines all disciplines early within the layout method, increasing layout freedom and expertise availability. However, there are boundaries in making use of MDO, such as handling competing premier solutions and allowing collaborative design settings. To cope with those troubles, complete MDO frameworks have to be advanced, which consist of evaluation tools, optimizers, and interfaces that permit for clean communique throughout disciplines [6].

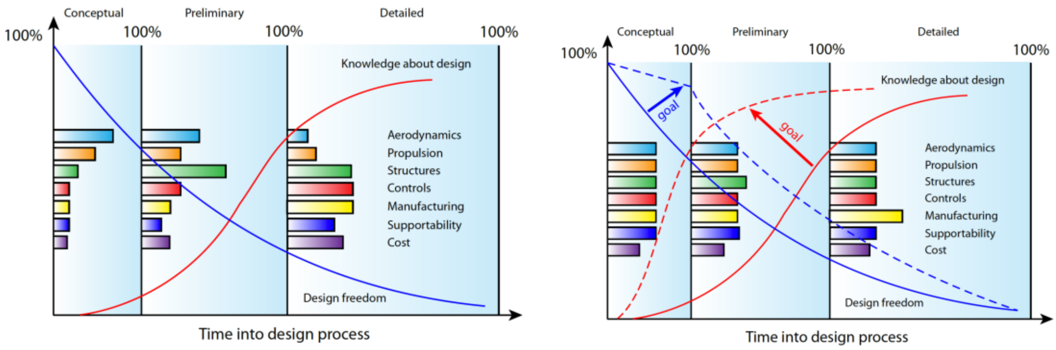


Figure 1-1: Overview of two different design process: Left side - Traditional aircraft design process Right side - MDO aircraft design process [7]

Cabin and fuselage layout are frequently overlooked in fundamental aircraft design studies, resulting in production delays and revenue loss. Furthermore, modern aircraft need to be constructed to meet the unique needs of their operators, resulting in a wide range of cabin layouts, load factors, and travel lengths of time. Understanding diverse airline business models is critical for fully exploring developments in technology in early design [8]. This thesis focuses on optimizing the cabin layout design process using the "Inside-out" methodology. This approach begins with cabin issues and actions outward to form the fuselage, fostering a complete, imaginative, and adaptive perspective.

Previous research results in significant solutions addressing plane layout and cabin layout optimization. Through the first glimpse, "PreSTo", evolved by means of the University of Applied Sciences Hamburg (HAW Hamburg), appears to be an Excel-primarily based platform for initial aircraft layout and optimization, with PreSTo-Cabin specializing in cabin layout challenges along with ground layouts and seating arrangements. While useful when developing traditional fuselage designs, those tools have limits in accommodating unconventional layouts like single-aisle and double-deck configurations [9]. Second, "ParaFuse" a one-of-a-type Python-powered device, transforms plane interior design via using simplified fuselage layout techniques. Although ParaFuse increases efficiency, mainly in conventional configurations, its applicability to unconventional designs is confined, and compatibility issues restricts its availability [10].

In this thesis, CAFE module (Cabin and Fuselage Design Environment) which is an environment use inside BLADE (Bauhaus Luftfahrt Aircraft Design Environment), emerges as a pioneering Python-based aircraft design framework. Leveraging the widely used CPACS (Common Parametric Aircraft Configuration schema) [11]. Its adaptable architecture empowers aircraft designers to tailor workflows to desired investigation levels easily, with a strong emphasis on automation [12]. CAFE is used to create and update fuselages, add hydrogen tank inside the fuselage, to update a cabin mass breakdown and to visualize the cabin in the TIGL viewer. Using the CAFE module, this thesis will enable a fully automated design approach that minimizes user input while supporting most typical airplane cabin designs. Furthermore, it will provide versatility with unrestricted seat abreast and multi-deck configurations, as well as unconventional layouts like Sleeper Class, Group seating with tables, etc., drawing inspiration from modern ideas such as the Flying V design [13], non-standard seat configuration, multiple seat abreast layout within the same class type, multiple deck layout, multiple class layout and cargo deck layout. Furthermore, the CAFE module will contain all cabin optimization in accordance with EASA regulations, ensuring safety while also providing full design utility. Beyond basic design visualization, this thesis will reveal crucial calculation parameters like centre of gravity (COG), operational & furnishing mass, allowing for a more comprehensive approach to aircraft design.

2 State of the Art

This chapter gives an overview of the aircraft's cabin design and puts lights on the EASA Standards and CS25 regulations. Moreover, the position of the cabin components is also assessed based on the current-going-class layout of multiple airlines and the general descriptions and specifications of the cabin components have been collected based on various known sources. Apart from that, this chapter gives vital information about the functionality of the Fuselage Design Components.

2.1 Overview of Cabin Modeling in Aircraft Design

The conceptual design phase is a very crucial phase of an aircraft design, like developing an aircraft for the complete project. And it is where ideas emerge, realistic or unrealistic possibilities are investigated, and the overall innovative vision begins to take shape. This phase's process entails the main factors of the aircraft. For example, its purpose, overall performance requirements, and other key attributes. Its integration fundamental research in aerodynamics, propulsion systems, structural design and tool integrations. In the current scenario, the cabin arrangement is designed, while keeping in mind various demands such as passenger comfort, seating arrangements and average design features. In a short overview, the conceptual layout segment provides the framework for the development process of the entire aircraft, driving subsequent stages toward the realization of a successful aircraft design.

During the conceptual design phase, designers carefully consider various elements like wing & fuselage shape, propulsion systems, weight & balance estimation, and system integration. The main goal is, at the end of the resulting aircraft configuration, to provide maximum performance with fuel efficiency, and take care of most of the safety and regulatory compliance which is established by EASA & FAA certification criteria.

Cabin design plays a vital role in conceptual design as it creates an impact on passengers' comfort, operational performance, safety, and financial elements. An optimized cabin design improves the overall experience of travellers and improves other factors which are mentioned above. As a result, it is extremely critical for an aircraft's competitiveness and overall performance in commercial aviation businesses.

Designing the interior of a cabin, there are many scenarios to be considered, such as seating arrangements, lavatories, galley equipment, and overhead bin compartments. These additives present a good quantity of the aircraft's bulk and encompass general electrical structures which includes galleys, which also needed to be integrated with details at some point of assembly. The main strategy to evaluate the position of these components emphasizes or fulfills the need of the cabin interior design and that is important for each visual appeal and aircraft stability. So, overall, the cabin interior plays key characteristics in optimizing an excellent, harmonious and efficient aircraft arrangement, influencing capabilities as well as appearance.

2.2 Regulatory Framework: EASA Standards and CS25 Regulations

The European Union Aviation Safety Agency (EASA) is in charge of assuring civil aviation safety and protection at various locations around Europe. It establishes strict policies or rules and procedures for the aviation industry to ensure safety, security and environmental responsibility of requirements. The certification specifications for Large Aircraft, also known as the CS-25 criteria, and this certification framework play a vital role in EASA's regulatory regulations. This specification provides the airworthiness criteria required for certifying large airplanes into various classes, which includes commercial planes, cargo planes and business jets [14].

CS-25 regulations take into consideration an extensive range of key parameters for aircraft design, construction, operation and maintenance also. They have set high criteria for structural integrity, performance abilities, tool or gadget functionality, and system specifications. Moreover, the CS-25 specification also covers fuselage and cabin design parameters, which lead to giving assurance of the airplane's inner protection, consultation, and capability. This includes cabin layout, seating placements, emergency exits, and emergency evacuation processes, all of which play a very important role in order to guarantee passenger protection and comfort for the duration of flights [14].

These necessities consist of requirements for fuselage and cabin design to ensure protection and inside capacity of the aircraft's interior. They are recognized for a variety of cabin layout and layout design that enhance passenger comfort and running effectiveness [14]. For instance, CS-25 specifies what passengers passenger seats layout should be and spaced between each seat's row to make sure there is good enough legroom and accessibility. It also establishes requirements for the layout and site of emergency exits, consisting of the size, location, and operation of doorways and windows, which provide brief evacuation in an emergency.

Furthermore, CS-25 rules have also specified some criteria which have to be followed in terms of installation and design of the major cabin components, such as lavatories, galleys, and storage compartments. The reason behind such restrictions is to maximize space consumption and functionality while taking care of safety as well as convenience of passengers and crew members. By taking assurance of all the standards and operational efficiency, which leads to overall passenger experience, indirectly develops trust and confidence in air travel.

2.3 Analysis of Current Cabin Layout and Component Positioning

Galleys and lavatories in an aircraft have to be in convenient places because galleys carry food and lavatories are required for refreshment. These are primarily placed near exit doors using the cabin factor area [15]. Regulations together with FAR 25.807 in the United States and CS 25.807 in Europe specify the placement and size of these exits, which are also called emergency exits. Typically, these exits are uniformly placed on each facet of the aircraft. For instance, cabin designs for essential airways, including Lufthansa, Air France, British Airways, and Emirates reveal that galleys and lavatories are placed after some intervals close to the emergency exit door. Mostly, the front and back doors are used for the passenger boarding and departure time or quick-haul time, while center exit doors are reserved for emergency exits. Galleys can pass, but lavatories are permanent due to structural regulations and special water plumbing [16]. In general, galleys and lavatories are generally located near emergency exits, but differences may arise based on the airlines and aircraft type.

2.4 Geometric Sizing and Weight of Cabin Components

The literature on aircraft and cabin pre-layout for passenger aircraft gives critical sources regarding dimensioning and accurate weight and overall performance data estimation. These resources frequently carry popular relationships, facts and layout requirements to act as hints. However, obtaining records from the modern-day market or cabin element manufacturers is probably unique because a few manufacturers' records aren't publicly available. Additionally, estimating the burden of cabin additives is difficult, as plane manufacturers often use proprietary calculation methods that are exceptionally guarded to maintain an edge in the market [2].

In terms of various scenarios, the examples provided may additionally be discussed with older planes, which may now not be beneficial in international flight operations. It may be essential to notice that the table and statistics presented in the following chapters are meant to provide a standard evaluation or compilation of statistics from diverse sources. The records on calculations, assessment, and choice of pertinent values for the modern CPACS-Python program can be supplied in Chapter 3.

2.4.1 Emergency Exits

In terms of the exit procedure of passengers in an emergency, a few criteria must be filled or present on the fuselage, such as the number and kind of emergency exits specified in EASA CS25 regulations. Furthermore, each exit type's minimum dimensions are defined. The minimum dimensions for each type of emergency escape are listed in the table below, and they are based on CS25.807 [14] and FA25.807 [17]. There is the possibility that an aircraft manufacturer typically uses greater dimensions as the main entrance to the aircraft, as shown in the Table 2-1.

Table 2-1 : Type of emergency exits as defined in FAR 25.807 [17] and CS 25.803 [14]

Exit Type	Location	Minimal Width [m]	Minimal Height [m]	Maximum Step-up inside the airplane [m]	Number of Passengers allowed through exit
Type I	Floor	0.61	1.22		45
Type II	Floor	0.51	1.12		40
Type II	Overwing	0.51	1.12	0.254	40
Type III	Overwing	0.51	0.91	0.51	35
Type IV	Overwing	0.48	0.66	0.74	9
Type A	Floor	1.07	1.83		110
Type B	Floor	0.813	1.83		75
Type C	Floor	0.762	1.22		55
Ventral	Bottom of fuselage	0.61	1.22		

In addition to the dimension of each exit type as stated in Table 2-1, CS 25.807 also specifies the number of exits required per passenger. They provide a summary of the total number of exits which are required on each side of the fuselage. Consider an example of deeper comprehension of the certification standard criteria. There is a required number of doors for 120 passengers, as per CS-25 rules, it is four Type-I and two Type-III. If passenger capacity exceeds 300, all exit doors must be a type of A. In such a 300-passenger scenario, the total number of exits is calculated by multiplying the number of exits by the 110-passenger capacity.

Table 2-2: CS25.807 Number and kind of emergency exits on each fuselage side [14]

	Type I	Type II	Type II	Type IV	Type A	Type B	Type C
N_{pax} < 10				1			
10 ≤N_{pax} < 20			1				
20 ≤N_{pax} < 40		1	1				
40 ≤N_{pax} < 65	2						
65 ≤N_{pax} < 75	2						
75 ≤N_{pax} < 110	1	2					
110 ≤N_{pax} < 140			1				2
140 ≤N_{pax} < 150		1					2
150 ≤N_{pax} < 170			2				2
170 ≤N_{pax} < 180	2						2
180 ≤N_{pax} < 200							4
200 ≤N_{pax} < 240						2	2
240 ≤N_{pax} < 280						4	
N_{pax} > 300					N_{pax} /110		

2.4.1.1 Emergency Exit Access

During aircraft design, ensuring passenger safety during emergency situations plays a crucial role and regulation criteria play an important part in attaining this goal. EASA CS 25.813 concerns not only the number but easy accessibility of the emergency exit within the fuselage, which shows the importance of adequate evacuation procedures.

As per aviation safety law, emergency exits have to be allotted as uniformly as possible across the entire fuselage. However, there might be the possibility of exits on each side being flexible, considering asymmetry if preferred by airlines as far as it follows safety rules. It is clear in CS 25.813 that Type 1, Type 2 and type A exit doors require clear passages.

Type 1 and Type 2 exits must have a door width around 0.51 meters to allow people to travel swiftly during evacuations, whereas Type A exits require passageways which are minimum 0.91 meters wide. These specifications are intended to improve efficiency and safe evacuation operation and also enhance standard passenger protection in nonideal conditions [10].

2.4.1.2 Minimum aisle width

Aisle width also comes into play during evacuation in emergency situations. So, for that reason, EASA CS 25.825 has been developed as minimal aisle width in fuselage to offer quick and safe evacuation operations. These requirements are

adjusted to the aircraft's passenger capacity, to make sure evacuation occurs speedily and effectively.
There might be a possibility that the value which is given in Table 2-3 may vary as per size of the aircraft. But it is worth mentioning that many aircraft manufacturers use more than the minimum aisle width value to opt for larger aisles to improve passenger comfort and accessibility.
By setting a minimum aisle width, CS 25.815 attempts to find a compromise between comfortable experiences and the safety of the passengers. Adequate aisle width is also a key characteristic to make the cabin more appealing and accommodating for passengers during normal operations.

Table 2-3: Minimum aisle width (CS 25.815) [18]

	< 0.64 meter (25 Inches) from floor	**≥ 0.64 meter (25 Inches) from floor**
$N_{pax} < 10$	0.30 (12 Inches)	0.38(15 Inches)
$10 < N_{pax} \leq 20$	0.30(12 Inches)	0.51(20 Inches)
$N_{pax} \geq 20$	0.38(15 Inches)	0.51(20 Inches)

A trolley has a width of about 0.30 m. If the aisle is 0.61 m wide, the trolley can pass a person standing in it. This improves passenger comfort. According to CS25 regulations, the aisle width should not be less than 0.38 m [10].

2.4.2 Galleys

Galleys and supporting equipment are acquired from a wide range of global suppliers in modern aviation. The industry mostly conforms to two recognized passenger aircraft standards: ATLAS and KSSU. These standards, particularly ATLAS, have emerged as the gold standard for international airlines. In the late 1960s, Air France, UTA, Lufthansa, Alitalia, and Sabena made a partnership to create ATLAS, which revolutionized European aircraft introduction. In contrast, KSSU, consisting of KLM, SAS, Swissair, and UTA, developed as an alternate consortium.
Airbus is now driving a revolutionary shift with its SPICE (Space Innovative Catering Equipment) effort. This innovative thinking method intends to change galley design by concentrating on three main goals:

- Lightweight Storage: Moving away from traditional trolleys and toward lightweight boxes for food tray storage, allowing for easier transportation with Folding Service Carts.

- Enhanced Safety Standards: Equipping galleys to satisfy high aviation safety criteria, freeing individual trolleys from these duties. Fire protection and door mechanisms protect the carts.
- Modular System: Introducing a new innovative gadget with 3 wonderful sizes of galley bins or components, differentiating versatility for most desirable space utilization and change primarily based on the aircraft configuration character.

There should be significant benefits from tendency. Airbus expects a larger amount of weight saving across its entire fleet of aircraft, and savings are around 600 kg for the planes for the A330 & A340 and more than 1 ton for the A380. Additionally, using SPICE should lead to the removal of one galley unit to accommodate more passengers in a luxurious economy [19].
Various data sets for galleys are presented below, from which suitable values are later selected for the cabin components in Fuselage Design.

2.4.2.1 Dimensioning

According to Jenkinson, Galleys have a floor area of 762×914 mm and may accommodate 10-60 passengers, depending on the class [15]. The smaller capacities correspond to first-class facilities. Figure 2-1 is an example of such a galley unit. Because such units are frequently situated at the cabin's facet, their outside shape on one side mirrors the fuselage's curve. Several compartments for various galley equipment are also visible.

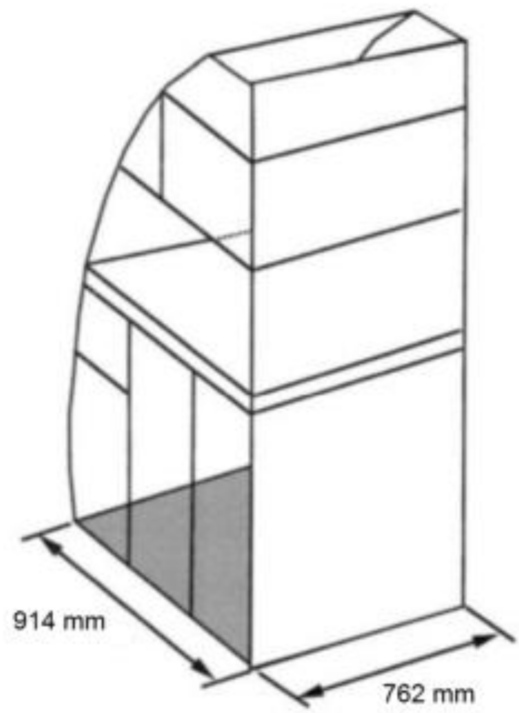


Figure 2-1: Example of the layout of a galley[15]

Table 2-4, on the other hand, shows the needed galley volume per passenger, as calculated by Raymer [20].

Table 2-4: Galley volume per passenger according to Raymer [21]

	Galley Volume per Passenger [m^3/ Passenger, ft^3/ Passenger]
First Class	0.14 - 0.23 (5-8)
Economy Class	0.03 - 0.06 (1-2)
Charter Aircraft	0 - 0.03 (0-1)

Below, Table 2-5 includes examples of specific galley dimensions in passenger aircraft. Although the aircraft types listed are older and several are no longer utilized nowadays, it is, as previously said, exceedingly difficult to find more up-to-date information.

Table 2-5: Examples of galley dimensions in some aircraft models according to Roskam [22]

Type of aircraft	Number of passengers	Range [km]	Galleys	
			Quantity	Dimension in inches [meter]
Boeing 737-200	115	3333.6	1	55 x 43 [1.4 x 1.1]
Boeing 727-200	163	2129.8	2	51 x 32 [1.3 x 0.81]
McDonnel Douglas DC-10	380	5556	1	240 x 162 [6.1 x 4.1] (lower deck galley)
Boeing 747	490	9260	4	79 x 25 [2.0 x 0.64]

2.4.2.2 Determining Weight

Table 2-6 contains the weights of the various galley units as covered by Torenbeek [16]. The "units" consist solely of the galley structures and fixed components of the aircraft fuselage and fittings. Drinking water and galley inserts are thus not provided.

Table 2-6: Weights for individual Galley units according to Torenbeek [16]

	Weight [kg/unit]
Main Galley	113.4
Pantry	45.3
Coffee Bar	29.5

Below Table 2-7 shows the weight estimations for the passengers' supplies stocks.

Table 2-7: Weights for galley equipment and supplies in Torenbeek [16][1]

<table>
<tr><th></th><th colspan="2"></th><th>Method for determining Weight [kg]</th></tr>
<tr><td rowspan="4">Removable galley bar equipment, meal service, consumable food, drinks, beverages, pillows, papers, magazine & entertainment</td><td colspan="2">Commuters</td><td>$0.453 \times N_{pax}$</td></tr>
<tr><td colspan="2">Snacks only</td><td>$2.27 \times N_{pax}$</td></tr>
<tr><td rowspan="2">Main meal</td><td>Short Range</td><td>$6.35 \times N_{pax}$</td></tr>
<tr><td>Long Range</td><td>$8.62 \times N_{pax}$</td></tr>
</table>

According to Roskam, below Table 2-8 uses a similar approach to compute the weight of meals and food carried onboard.

Table 2-8: Weight specification for food stocks according to Roskam [22][2]

<table>
<tr><th></th><th>Definition of the Factor K_{buf}</th><th>Weight of the food and the food [lbs]</th></tr>
<tr><td>Long Range</td><td>$K_{buf} = 5.68$</td><td rowspan="2">$K_{buf} (N_{pax})^{1.12}$</td></tr>
<tr><td>Short Range</td><td>$K_{buf} = 1.02$</td></tr>
</table>

Torenbeek combines the estimates in Table 2-9 which is situated below for the drinking water carried with the required lavatory chemicals. The number of lavatory units is denoted as N_{lav}.

Table 2-9: Torenbeek's weight standards for drinking water and lavatory chemicals [16]

<table>
<tr><th></th><th></th><th>Method for determining Weight [kg]</th></tr>
<tr><td rowspan="3">Portable Water and Toilet Chemical</td><td>Short Range</td><td>$36.3(N_{lav})$ or $0.68(N_{pax})$</td></tr>
<tr><td>Short/Medium Range</td><td>$54.4(N_{lav})$ or $1.36(N_{pax})$</td></tr>
<tr><td>Long Range</td><td>$90.7(N_{lav})$ or $2.95(N_{pax})$</td></tr>
</table>

The aviation industry has seen a considerable change in galley standards, most notably with the establishment of ATLAS and KSSU, as well as Airbus' adoption

[1] All figures for First Class include an additional 2.27 kilograms per passenger.
[2] To find the weight of food stock in kilos, multiply the obtained result by 0.454. This conversion factor turns pounds into kilograms.

of the SPICE standard, which aims to increase efficiency. Current advancements in technology, airlines using lightweight box storage for food trays and the implementation of an advanced and modernized system to give more flexibility. These developments are likely to lead to a good amount of saving weight as well as space, particularly in larger aircraft models. Access to detailed information on galley specs is particularly useful for both design and maintenance. Galley design is always being developed, with an emphasis on creating technology to enhance the passenger experience and operational efficiency.

2.4.3 Lavatories

The following analysis looks at the dimensions and weights of lavatories installed in passenger airplanes. Originating from the Latin phrase for a washroom, "lavatory," its use in aviation refers primarily to the restroom or lavatory facilities on board aircraft. It's worth noting that various datasets are offered here, providing a wide range of possibilities for consideration in this thesis. These databases do not deliver only vital records about the bodily capabilities of toilets, but additionally they spotlight the diverse range of requirements to be had in the aviation enterprise. Exploring these dimensions and weights provides a whole greater information about bathroom preparations on airplanes, which substantially enables greater problems with cabin layout and passenger comfort.

2.4.3.1 Dimensioning

In Figure 2-2 depicts a Lavatory unit with a base area of 914 x 914 mm and a three-dimensional shape resembling a round fuselage. A unit is meant for between 15 and 40 passengers (First to Economy Class) [15].

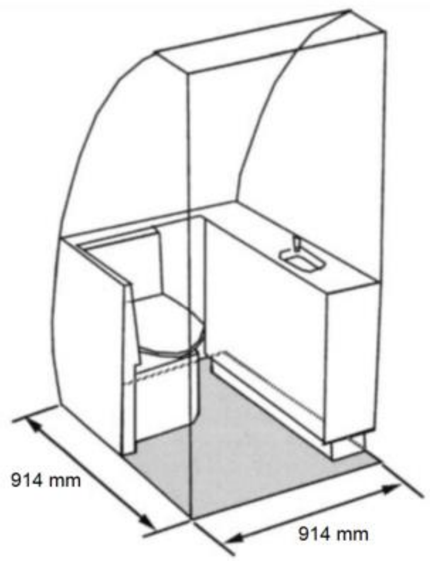


Figure 2-2: Example of a lavatory layout[15]

In [22, 23], the size of a lavatory unit is established at a floor space of one square meter, and the passenger counts indicated in below table are also provided for the specific classes or cabin layouts.

Table 2-10: Number of lavatories according to Schmitt [23][3]

	Economy Class	Business Class	First Class
Short Range R ≤ 3000 Nm	1/60 pax	-	-
Medium Range 3000 Nm < R < 5500 Nm	1/45 pax	-	1/14 pax
Long Range R≥5500 NM	1/45 pax	1/25 pax	1/14 pax

Table 2-11: According to Raymer, the passenger capacity of a lavatory unit [21]

	Number of passengers per lavatory unit (1m × 1m)
First Class	10-20
Business Class	20-40
Economy Class	40-60

2.4.3.2 Determining the Weight

According to Torenbeek [16], the weight of a lavatory unit can be calculated using the numbers shown in the Table 2-12. This data also includes the water systems required to operate the lavatories. However, like the galleys, these are "dry" units. The weights of the necessary water and chemicals must be added separately. However, this has already been mentioned in the previous Table of Torenbeek's weight criteria for drinking water and lavatory chemicals.

Table 2-12: Weights for various lavatory units in Torenbeek [16]

	Weight [kg/unit]
Medium and Long Distance	136
Short Distance	75
Commuters	38.5

The total weight is determined by the number of seats (Npax). Below Table 2-13 lists several calculation methods, organized by field of use.

[3] To discover results of the range in kilometers, please multiply result by 1.852.

Table 2-13: Weight specifications for lavatories according to Sadraey [2]

	Weight [kg]
Long Distance	$0.5(N_{pax})^{1.3}$
Short Distance	$0.13(N_{pax})^{1.3}$
Business Jet	$1.7(N_{pax})^{1.3}$

The calculation of the weight of the lavatories and water in Table 2-14 according to Roskam is similar.

Table 2-14: Weights for lavatories and water according to Roskam [22][4]

	Definition of the K_{lav} factor	Weight of the Lavatories and the water [lbs]
Long Distance	$K_{lav} = 1.11$	$K_{lav}\ (N_{pax})^{1.33}$
Short Distance	$K_{lav} = 0.31$	
Business Jet	$K_{lav} = 3.90$	

It has been mentioned that the calculating method is only one component of a larger formula for evaluating the total weight of cabin equipment. As a final output, the “miscellaneous” element of the formula (0.771 - (WTO/1000)) may still include weight components that must be added to lavatories or their equipment. Finally, real data from an internal collaboration project with Airbus is accessible, though it has not been publicized. These sources specify a total weight of around 290 kg for the bathrooms on the A320 with 164 seats, separated into 12 Business and 152 Economy seats. As per SeatGuru [24], Lufthansa, British Airways, and Air France contain the A320 variant, which has three lavatories. And the weight distribution is around 96.67 kg.

2.4.4 Seats

The cabin configuration procedure is mainly reliant on the required interior components and their dimensions. Seat pitch (distance between two rows of the seats), for example, has a major impact on the total length of the cabin, which directly affects fuselage length also. Thus, statistics on common seat measurements are crucial for the accuracy of the measurement of the cabin. Furthermore, the number of seats abreast influences the diameter of the passenger fuselage cross-section, highlighting the need to gather data on seat arrangements in relation to passenger capacity. Moreover, the availability of

[4] To calculate weights for lavatories and water according to Roskman in kilos, please double the result by 0.454

lavatories and galleys is critical in enhancing passenger comfort and service levels, with typical statistics for their numbers provided in this section.

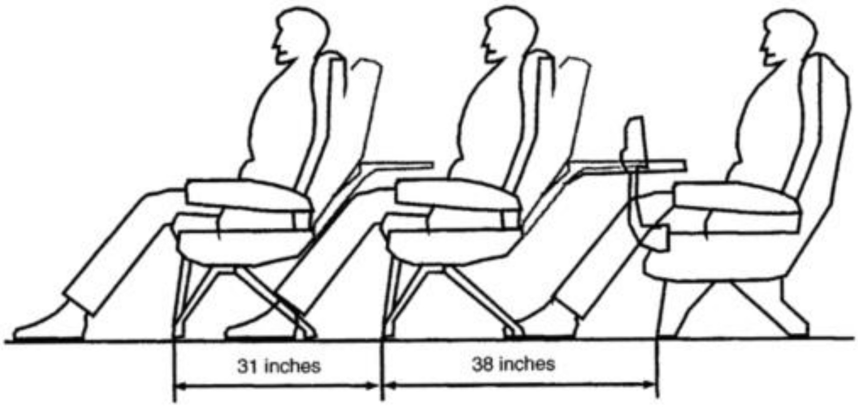


Figure 2-3: Definition of seat pitch in passenger aircraft[15]

Cabin layout consolation is motivated by the dimensions and seat pitch of the aircraft seats, which can be modified to meet airlines' aims. For instance, growing or low-cost companies first prioritize expanding passenger capability to provide low-cost tickets, whereas well established companies may additionally choose a cabin configuration that sacrifices the potential for expanded comfort, together with growing seat pitch. These layouts may differ according to client preferences. To provide insight into common seat size, data was gathered from the website http://www.seatguru.com, which hosts a comprehensive database of cabin statistics from multiple airlines. The mean values for seat pitch and width across different classes are calculated and shown in below Table 2-15. his realistic approach to cabin design guarantees that both operational efficiency and passenger comfort are maximized, resulting in a more delightful flying experience for passengers of all classes [10]. The following Table 2-15 to Table 2-19 show standard values from the literature for seat spacing and seat width. They are broken down according to the different classes.

Table 2-15: Mean Values for aircraft seat pitch and width [24]

	Seat Width [m]		Seat Pitch [m]	
Class	**Short Range**	**Long Range**	**Short Range**	**Long Range**
Economy	0.45	0.45	0.81	0.82
Premium Economy	0.48	0.48	0.97	0.97
Business	0.51	0.60	0.98	1.59
First	0.51	0.76	0.98	1.99

Table 2-16: Seat pitch and width according to Jenkinson [15]

	Seat Pitch [m]	Seat Width [m]
First Class	0.95 – 1.05	0.625 – 0.7
Business Class	0.9 – 0.95	0.575 – 0.625
Economy Class	0.775 – 0.85	0.475 – 0.525
Charter	0.7 – 0.775	0.4 – 0.420

Table 2-17: Seat pitch and width according to Raymer [20]

	Seat Pitch [m]	Seat Width [m]
First Class	0.97 – 1.02	0.51 – 0.71
Economy Class	0.86 – 0.91	0.43 – 0.560
Small Aircraft	0.76 – 0.81	0.41 – 0.46

Table 2-18: Seat pitch and width according to Sadraey [2]

		Seat Pitch [m]	Seat Width [m]
First Class		0.92 – 1.04	0.6 – 0.75
Economy Class	Tourist	0.75 – 0.86	0.48 – 0.55
	Tight seating	0.65 – 0.72	0.42 – 0.46
General Aviation		0.55 – 0.65	0.38 – 0.430

Table 2-19: Seat widths according to Roskam [25]

Seat Classification		Seat Width [m]
Luxury	Double	1.19 (1.17 – 1.23)
	Triple	-
Normal	Double	1.02 (0.99 – 1.04)
	Triple	1.52 (1.5 – 1.6)
Economy	Double	0.99 (0.97 – 1.02)
	Triple	1.57

The data in the above table are average values, with minimum and maximum values stated in brackets. The seat width in the above Table 2-19 refers to the whole width of a seat block (double or triple) including the armrests, not the seat surface.

2.4.4.1 Seat Model

Modern aircraft seats are in particular designed to maximize all functionality and passenger consolation. These seats have been examined and evolved to stick to pleasant safety standards at the same time as also offering ergonomic assistance and comfort abilities. There are various seat models spanning from economy class to first class to serve an extensive sort of airline alternatives and passenger demands. In the current situation, there may be a shift in the direction of light-weight substances and modular designs, which offer extra flexibility in cabin layouts at the same time as improving area efficiency. Modernized seat generation, which includes adjustable headrests and in-flight enjoyment structures, is getting extra regular throughout all seating lessons. Additionally, numerous novel seating preparations, like staggered layouts and private compartments are experienced to enhance the passenger experience and differentiate premium cabins. Overall, seat designs are improving to meet the converting needs of airlines and customers alike, ensuring a snug and enjoyable journey for all.

(a) Economy Class Seat

(b) Premium Economy Class Seat

(c) Business Class Seat

(d) First Class Seat

Figure 2-4: Modern Aircraft Seat Model[26]

Determining the weight: The weight of seats can be calculated using data from [16]. Below table shows masses for several seat combinations, organized by seat type or comfort degree and arrangement (single, double, or triple). According to Recaro Aircraft Seating's website [27], the Economy seat "SL3710" weighs 8 kg and is now one of the lightest types available. It is said to weigh 40-50% less than identical seats in the Economy class. However, when compared to the weight of a lightweight seat (6.4 kg) in Table 2-20, there is a significant difference. As a result, it raises doubts about whether Torenbeek's weight statistics E. Torenbeek

are still relevant today and what comfort level the indicated weight numbers include.
Similar data can be found in [2], where the weight of an Economy class passenger seat fluctuates between 13 and 16 kg, while a "Tourist" seat is believed to weigh 20 to 28 kg. The Aeronautical Engineering Manual [28, 29] also contains information about the weight of the In-flight Entertainment System. The electronics for the Passenger Entertainment System (PES) on each seat are assumed to weigh 0.4 kg each. This comprises both the wiring and the connection and control unit.

Table 2-20: Typical Seat weights for civil aircraft by E.Torenbeek [16]

Seat Classification		**Weight [kg]**	
		Medium/Long Distance	Short Distance
Luxury	Single	21.3	18.1
	Double	31.3	27.2
Normal	Single	13.6	10
	Double	25.4	19
	Triple	35.4	29
Economy	Single	10.9	9.1
	Double	21.3	17.7
	Triple	29.9	27.2
Commuters	Single	-	7.7
	Double	-	13.2
Lightweight seat		-	6.4
Flight attendant seat		8.2	6.4

Executive single seats are categorized in E. Torenbeek according to their weight as follows: VIP seats weigh roughly 22.7 kg, normal seats weigh around 18.1 kg, while seats built for small planes are about 14.5 kg [16].

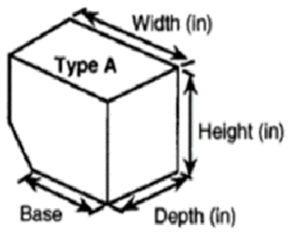
2.4.5 Cargo

The cargo compartment plays a vital role in aviation, primarily because it manages all the commercial flows, from bringing in goods to sending them abroad. There are standards heights, depths, widths and cargo handing procedure of all container ship has been available which is known as “Unit Load Devices” (ULDs). It is one of the most important concerns to address. They made our way to in recent times, the use of the way of reasoning and aware wondering to load reduce-wrapped parcels stored in ULDs within the plane. It can also range from popular shapes as own to pallet bins or igloo-shaped types that are predesigned to hold diverse kinds and sizes of shipment. Lastly additionally there is the internal structure that has been made in a manner that maximizes the usability of the distance onboard the aircraft.

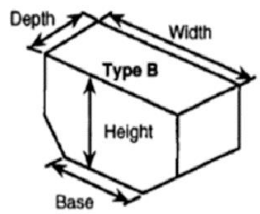
The truth that organizations make use of ULDs in dealing with cargo is a double-sided problem. Therefore, it is not certainly a means of standardization shipment paintings, but it also drastically raises performance in operations, reducing plane turnaround time. At the time, for the cargo of bulk items and airline fliers, they are very, very responsible for the airlifting of products in an organized manner, which includes perfect balanced loading. Consequently, it guarantees safety standards and at the same time, beautifies the ability of the aircraft.

As a result, the huge ULDs that may be transferred to this many aircraft are a contravention of this truth. Consequently, those keep rooms were engineered downwards to the central axle to the degree that adaptability is supplied for the various varieties of cargo which can be customized and now not widely widespread. At the pinnacle of the truth that the smaller plane is not simply ULD compliant, the same time-prevailing manner receives achieved greater successfully with the aid of distinctive feature of referred to aircraft contribution to the shipment carrying.

Nevertheless, a similar combo of ULDs and cargo bays chart depicts a strong shipment managing process in airline appointments. These improvements assure an amazing experience of receiving and delivering goods and substances and, this way, assures cohesion, to be affirmed by means of air movements, and general financial development everywhere in the world.



a)



b)

Figure 2-5: ULD Type: a) Half width ULD b) Full width ULD [15]

Table 2-21: ULD Dimensions and weight [15] [30]

Designation	Width [m]	Height [m]	Depth [m]	Base [m]	Tare mass [kg]	Load [kg]	Notes
LD-1	2.337	1.626	1.534	1.562	70-170	1588	Half width
LD-2	1.562	1.626	1.534	1.194	92	1225	Half width
LD-3	2.007	1.626	1.534	1.562	82	1588	Half width
LD-3 45	2.019	1.143	1.534	1.574	82	1588	Full width
LD-3 45W	2.007	1.626	1.534	1.430	98	1340	Full width
LD-4	2.438	1.626	1.534	2.438	120	2449	Rectangular
LD-5	3.175	1.626	1.534	3.175	173	3175	Rectangular
LD-6	4.064	1.626	1.534	3.175	230	3175	Full width
LD-7	3.175	1.626	2.23	3.175	105	6033	Rectangular
LD-7 Rectangular	3.175	1.626	2.032	3.175	105	6033	Rectangular
LD-8	3.175	1.626	2.032	2.438	127	2449	Full Width
LD-9	3.175	1.626	2.235	3.175	400	6033	Rectangular
LD-11	3.175	1.626	1.534	3.175	185	3176	Rectangular
LD-26	4.064	1.626	2.235	3.175	250	6033	Full width
LD-29	4.724	1.626	2.235	3.175	265	6033	Full width
LD-39	4.724	1.626	2.438	3.175	290	5035	Full width
PMC- P6P-PALLET	3.175	1.626-2.997	2.428	3.175	120		Rectangular Full Pallet
PNA HALF	2.438	1.626	1.626	2.438	83		Rectangular Half width
TYPE A PEN	3.175	2.438	2.235	3.175	610		Rectangular
MDP	3.175	1.626	1.534	3.175	410	11300	Rectangular
M-6	6.058	2.438	2.438	6.058	500	11340	Rectangular

2.5 Review of existing Cabin Layout Optimization Methods

When designing cabin layouts for aircraft, designers frequently use two approaches: the “Inside-out” method and the “Outside-in” way.

The “Inside-out” approach provides numerous benefits such as:

- Passenger Comfort and Experience: Starting from the interior allows for the design to be optimized for passenger comfort, space utilization, and experience from the early stage, without being constrained by an existing airframe.
- Customization: Allows for the creation of a cabin layout that meets specific market demands and regulatory requirements precisely, while offering a custom solution that satisfies customer expectations.
- Innovative Potential: With a clean sheet approach, designers can integrate the latest features into the cabin design, ensuring that the aircraft is competitive and future-proof.

In assessment, the “Outside-in” approach is defined by:

- Aerodynamic and Structural Optimization: Starting with the exterior allows designers to optimize the aircraft's aerodynamic performance and structural efficiency from the very beginning.
- Performance Focus: The design is driven by performance factors such as fuel efficiency, range, and speed, which are critical in developing a new, competitive aircraft.
- Integration Challenges: While it is possible to employ the outside-in method in a clean sheet design, this approach might limit the degree of innovation and customization possible in the cabin layout and passenger experience compared to the inside-out method.

Both strategies are deserved and are regularly employed to create cabin layouts that strike stability between passenger comfort, regulatory compliance, and operational performance. Designers may additionally enhance plane interiors to present an amazing journey experience while retaining safety and regulatory compliance by means of combining reading from both the inside-out and outside-in techniques. Let’s try to understand more about the “Inside-out” method.

Overview of Inside-out method: The inside-out fuselage design technique generates both the outside surface and internal cabin layout based on top-level criteria. The tool can generate fuselages for traditional low-wing passenger aircraft; therefore, passenger capacity and cargo type are the primary design considerations. Figure 2-6 presents an overview of the “Inside-out” fuselage design approach. The primary activity of the inside out design process is the creation of the main fuselage cross-section. The main cross-section sizing procedure section describes this technique. The cabin configuration technique is then used to establish the fuselage's exterior dimensions. The cabin configuration

method is detailed in Section Cabin configuration. After cabin setup, the final fuselage surface is generated using the external dimensions and user inputs, such as nose and tail cone fineness ratios. This approach is similar to that mentioned by de Jonge [10].
To develop the interior layout of the middle fuselage section, then inside-out design techniques play a very important role. This approach showcases how internal structure may create an impact on the outer parameters of the fuselage. In this method, in the initial case, the length of the fuselage is unknown and that is a challenge of this method. Therefore, the system starts by means of positioning the remaining seats and even thinking about passenger comfort, accessibility, and protection regulations. Once the seating arrangement is set up, attention shifts to strategically set exits to ensure passenger protection for the duration of emergencies. Based on the exit locations, other elements such as lavatories, galleys, luggage storages and dividers are optimally placed while ensuring no change is made to the seating arrangement, ensuring a cohesive cabin layout.

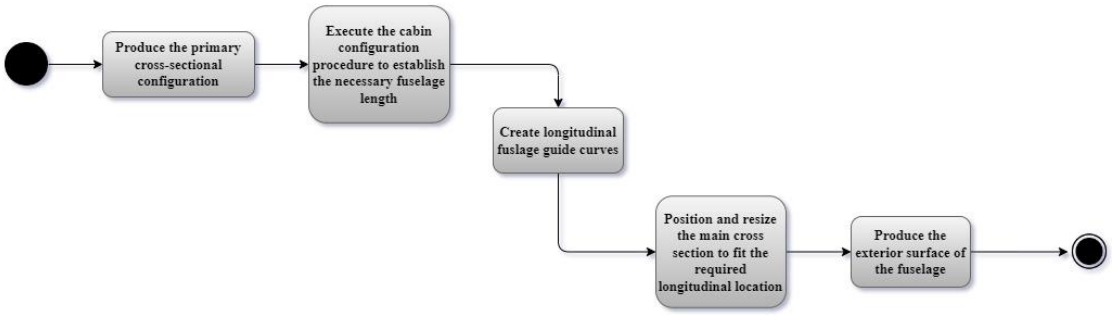


Figure 2-6: An overview of the inside-out fuselage design method [10]

While the cabin configuration process normally incorporates the nose cone, middle portions and tail cone, the focus of this study will be on the inside-out cabin configuration procedure used on the middle section of the fuselage. This will be explored in chapter 3.1.

2.6 Exploration of Unconventional Cabin Designs and Configurations

Exploration of unconventional cabin designs and configurations includes investigating innovative layouts and mixtures inside plane cabins. This creates goals to challenge traditional cabin layouts and seating configurations as a way to improve the passenger experience, maximize space utilization, and increase operational efficiency. It must consist of staggered seating preparations, adjustable cabin configurations to deal with an extensive variety of passenger choices, modular cabin designs for easy reconfiguration, and one-of-a-kind functions or services that decorate comfort and convenience. The purpose is to push the bounds of conventional cabin layout to create aircraft interiors which are each adaptable and passenger oriented.

There is an increasing emphasis on environmentally friendly aircraft and format, with many companies experimenting with unusual cabin layouts. TU Delft undertook sizable research into this issue, specifically with their Flying V plane concept, which differs from not unusual round fuselage designs. The article underlines the want for some designs to efficiently accommodate human beings. It integrates data from passenger surveys that show a need for additional room, a variety of sitting alternatives, and comfortable sleeping arrangements [13]. It integrates information from passenger surveys that show a desire for additional room, a lot of sitting options, and comfortable slumbering arrangements. The paper additionally appears at the boundaries that corporations experience when touring together, in addition to the disruptions produced by means of flight pain. To cope with those concerns, TU Delft released an assignment in which 22 pupil corporations were given specialist lectures on airplane interiors. These agencies then provided their answers, which were evaluated by a panel of experts from KLM, Safran, Airbus, and TU Delft, culminating in the choice of the pinnacle 4 seat standards [13]. Let’s look at a quick summary of the four chosen seat concepts: chaise longue, group space, beds, and staggered seats.

The Chaise longue idea unveils configurable seating solutions that cater to an in-depth variety of passenger alternatives. It lets passengers take a seat upright for sports, which includes eating or operating and reclining for rest or sleep. Seats are placed on the plane's ceiling framework, maximizing cabin area. Rails facilitate seat movement, making an allowance for extra flexible seating arrangements. Figure 2-7 indicates 3 seats fixed to the ground and 3 linked to the ceiling, minimizing floor space even and providing versatile seating configurations. Furthermore, arrangements are also hooked up for passenger motion at some stage in ingress and egress [13].

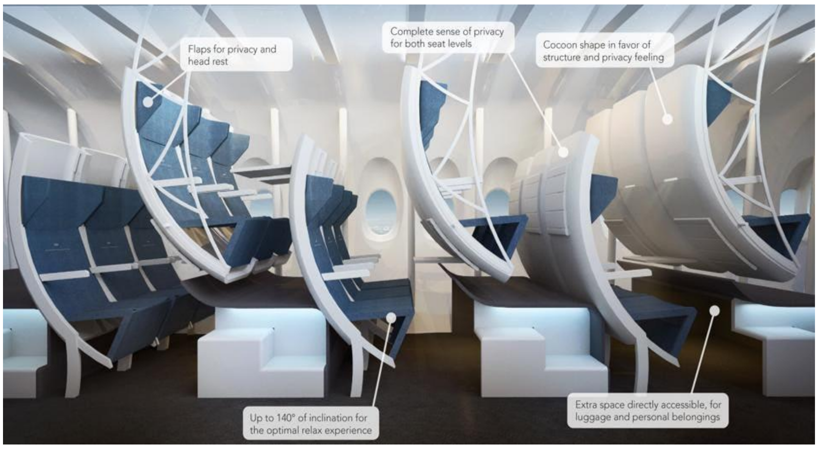


Figure 2-7: Chaise longue seat concept[31]

The Group Space concept consists of two pairs of seats placed opposite each other, separated by a table. A folding part of the table allows for easy ingress and egress. These four seats (organized in a 2x2 layout) assume less than 64 inches of longitudinal cabin space, allowing for private proximity between acquaintances. This layout also allows for a narrower width than two separate seats, which improves visibility and shoulder room. Furthermore, the space between the seat frames provides storage for personal things [13].

Figure 2-8: Group space seat concept [13]

The Beds concept provides a flatbed arrangement for passenger relaxation, with a changed frame structure and a 70 cm gap between square frames. This configuration includes a delegated slumbering location of 140 cm in length. However, because of evacuation issues, lying flat at some point between take-off and landing is unlawful. To keep passenger capacity, a portion of the bed area can be chaired with the aid of lifting the center mattress section and flipping down a portion of the lower bed vertically, accommodating 3 people. Figure 2-9 suggests this arrangement, with the three left beds in a slumbering role and the proper three in a sitting stance [13].

Figure 2-9: The bed concept[13]

The Staggered Seat idea stays an ordinary seat format even as introducing seats angled at 26 levels relative to the longitudinal route. Despite the angle amendment, the seat width and pitch stay steady at 18 and 32 inches, respectively. The seat pan may be folded for simpler ingress and egress, a design characteristic pioneered by way of Rebel Aero (see Figure 2-11). This innovation has the advantage of allowing passengers to temporarily exchange positions in the foldable seat. Staggered seating also reduces the chance of passengers' shoulders and elbows touching the armrests, which improves comfort. Rotating the seats allows for legroom like a 38-inch pitch [13].

Figure 2-10: Staggered seat concept[13]

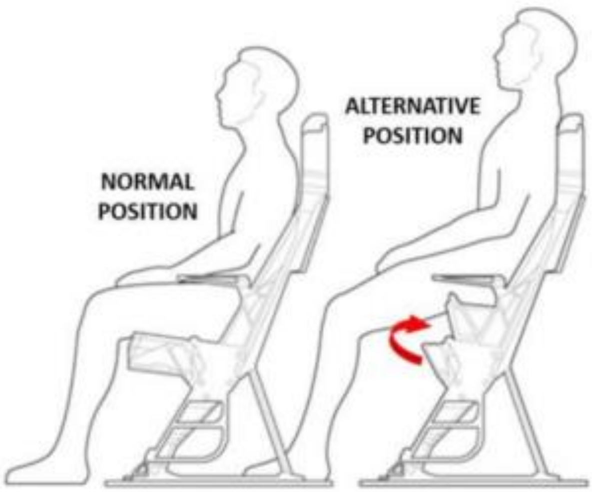


Figure 2-11: The principle of folded aircraft seat developed by seat manufacturer Rebel Aero[13]

3 Methodology and Revision of Cabin Layout Design

3.1 Cabin Configuration Method

Cabin configuration comes into play once tools have overall data and dimension of the main cross-section in the procedure of the inside-out method to evaluate or define fuselage external parameters. This procedure is separated into three stages, each handling the fuselage's nose cone, middle portion, and tail cone separately. The focus of this thesis is on the cabin layout configuration process (middle portion), which will now be explained:

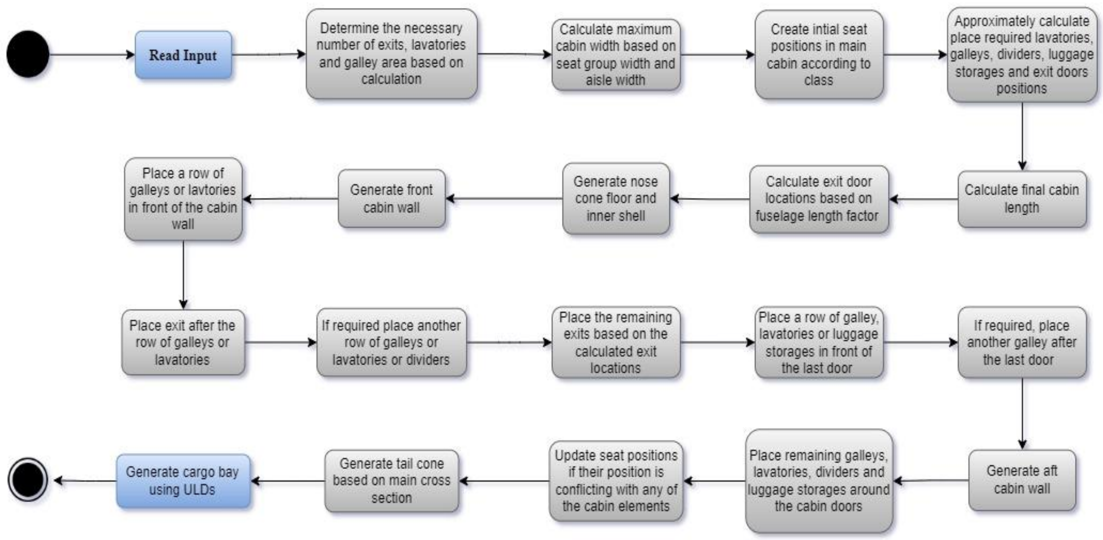


Figure 3-1: Inside-out cabin configuration process

The number of exits, lavatories, and galleys required at the start of the cabin configuration process is governed by the passenger capacity. Parameters such as passenger capacity (for each class), seat abreast, seat model and seat pitch are obtained from XML data files, as described in chapter 3.3. When numerous seating classes are present, the number of first, business, and premium economy class seats are converted into an equal number of seats in a high-density arrangement. The number of exits is then determined based on the number of seats that would fit within the cabin in a high-density seating layout, which is a typical methodology used by aircraft makers. Following that, the inside-out cabin configuration procedure begins by creating the surface of the fuselage section in question and placing the inside components accordingly. Because I concentrated primarily on the middle piece, this phase only applies to that portion. Figure 3-1 depicts an activity diagram illustrating the entire cabin configuration process, and Table 3-1 has a thorough list of the input parameters used during the procedure.

Table 3-1: Required inputs for cabin design using the inside-out design routine, including example values from A320neo

Parameter	Type	Value
Economy Class Passengers	int	126
Business Class Passengers	int	42
Economy Class seats abreast	str	3_3
Business Class seats abreast	str	3_3
Economy Class seats pitch	float	0.7422
Business Class seats pitch	float	0.8564
Seat model of Economy Class	float	Acro_3IFE
Seal model of Business Class	float	Acro_7
Flight range	float	3400 [Nm]
Number of lavatories (Economy Class)	int	2
Number of lavatories (Business Class)	int	1
Aisle Width (Economy Class)	float	0.38 [m]
Aisle Width (Business Class)	float	0.38 [m]
Total cabin width (group width + aisle width)	float	3.67 [m]
Passenger Deck Height	float	2.21 [m]
Start point of passenger cabin	float	4.5 [m]
Cross section shape (Circular" or "Elliptical")	str	circle
Cargo type ("containerized" and 'bulk')	str	Containerized
ULD type (if cargo type == "containerized" and "bulk")	str	LD3
Container clearance	float	0.05 [m]
Passenger Deck Length	float	27.76 [m]
Cargo Deck Length	float	25.072 [m]
Exit Doors	int	4
Crew Members	int	3

3.2 Definition of Cabin Components

As mentioned in the preceding Chapter 2.4, the shape of the fuselage Design Configuration document has previously been described. Galleys, lavatories, walls, and seats are currently defined as individual classes or consistent with plane descriptions. In addition, the galley and lavatory sizes are standardized, with a fixed capacity per class. The aim of constraining fuselage design is to obtain a single specification of all cabin factor parameters (galleys, lavatories, dividers, and seats). With the addition of multiple sizes, more specific dimensioning for the numerous passengers and sophisticated layouts can be achieved. The determination of individual parameters using the values found in chapter 2.4 is detailed below. The next chapter describes the software-associated enhancements made to the optimization tool. It should be cited that information selection is primarily based in element on comparisons with actual facts units carried out in chapter 3.2.

3.2.1 Galleys

While developing aircraft cabin layouts, the configuration and placement of galleys are key characteristics. Each galley’s capacity and dimensions are precisely optimized to fulfill the unique desire of the distinct passenger classes. A variety of permanent galley types are described in order to provide a complete description of these galley units, including weight information. These alternatives are carefully chosen by fuselage designers, who consider numerous aircraft specs and passenger metrics resulting from the layout.

While there is no standardized norm or restriction which indicates or means that it is mandated to create a galley in each class. But one should take care that the galley area should be large enough to handle the total number of passengers. This enables equal access to galley facilities for passengers of all classes, resulting in a smooth and comfortable onboard experience.

While there are no statutory restrictions mandating a galley in each class, industry norms require that the galley area be large enough to manage the total number of passengers. This enables equal access to galley facilities for passengers of all classes, resulting in a smooth and comfortable onboard experience.

Also, there will be a lack of standardized manual or bulk data available for each galley unit, but the tool still tries to make assumptions based on conventional dimensions and weight values. This optimization or assumption is based on internal BHL data. According to this data, a total galley area of around 4.08m2 weighs approximately 283.5 kg.

Following that, the code includes a way for distributing the weight of the galley throughout the cabin layout. For example, if the normal galley measurements are 0.762 meters by 0.914 meters (standard galley dimensions [15]), the total area of the galley is 0.696468 square meters. With a recognized weight of 69.485 kg/m2 for this conventional galley, the weight in step with the rectangle of the galley region is about 48.394 kg.

After putting in place the whole location allotted for galleys within the cabin format, the code can calculate the full weight of the galleys through multiplying the entire area with the aid of the weight in step with a rectangular meter. This basic weight can then be divided throughout the individual galleys in the plan, making sure that every galley's weight is proportionately assigned relying on its place in the cabin. Weight calculations include a variety of components vital to passenger comfort and service, in addition to distributing cargo for galleys and passengers using predetermined formulas. These include removable galley bars, meal services, consumable food and beverages, and comforts such as pillows, reading materials, and entertainment alternatives, which are all described in previous chapter 2.4.2 and more in detail will explain in chapter 3.5.1.2.

This calculation method enables a more flexible estimation of weight distribution, including differences in passenger loads and flight paths. The tool optimizes airplane operations by dynamically altering payload allocations based on real-time user data such as passenger count and floor area availability.

3.2.2 Lavatories

Lavatory standards are also missing, like galleys, in the aviation industry. This python code still managed to be applied to the lavatory using an advanced method. There are also possibilities that airlines could also have individual requirements and possibilities for lavatory parameters such as length and distribution. The code has developed in such a way that it counts on EASA and aviation industry standards but also allows flexibility to manipulate a different variety of operational situations.

Here in this thesis the tool which has been developed using industry standards recommended by specialists such as E. Torenbreek [16]. The two have been developed in such a way that they have precisely tuned the weight of the lavatories to fulfill the needs of various flying levels. According to internal BHL data, each of these standard sized lavatories weighs about 91.517 kg. This nuanced approach demonstrates the code’s dedication to mirroring current global operational concerns and maximizing resource utilization.

Lavatory calculation in the tool is a dynamics procedure that adapts intelligently to each character dynamic seating configuration. This bendy technique is seen within the lavatory provision throughout exclusive flight segments. For instance, on quick-haul flights, the tool usually specifies one restroom for every 60 passengers in economy magnificence, acknowledging the elevated passenger density and shorter duration of such flights. On medium and long-distance flights, wherein passenger consolation and comfort are crucial, lavatories are allocated at a rate of one in line with 45 passengers in economic class and premium economical system, one according to 25 passengers in business class, and one in step with 14 passengers in first class.

It's worth noting that the tool assumes similar lavatory dimensions across all installations, demonstrating its commitment to simplicity and efficiency. The code streamlines the allocation process by standardizing lavatory size, lowering complexity, and allowing for easy integration into a wide range of aircraft designs. The code always tries to allocate the placement of the lavatories in such a way that within the aircraft cabin layout, passengers feel comfort and convenience. When the total number of lavatories is greater than four, the code has placed lavatories perfectly at the front and rear sides of the fuselage. This kind of positioning opens several advantages for the premium class passenger. Mostly, premium class passengers and crew members such as pilots and flight attendants use front lavatories due to easy access, while economy class public use of aft lavatories overall helps to maintain comfort as well as privacy.

The tool is developed effectively so that it always tries to put lavatories near the exit (emergency door) and, so, behind, this ensures easy accessibility and convenience for all passengers. The tool also places lavatories in such a manner that there is a gap between two lavatories and reduces disruption to the cabin layout.

When there are less than four lavatories, the tool adjusts its placement technique as a result. Typically, in the front, one lavatory is located, and located at the aft of two lavatories are located. This layout maximizes capacity while ensuring lavatory access for passengers along the course of the aircraft.

Overall, this tool highlights how cleverly lavatories are available by using a counting method by industry standards. The tool ensures lavatory provision throughout a wide range of flying conditions and considers flexibility to cope with numerous necessities.

3.2.3 Seats

Seats play a vital role in the aircraft design phase because they influence passenger comfort and overall design layout. Each travel class has its own seat width and seat pitch, but it may differ according to airline choice also. To suit these functionalities, the current version of the tool has already provided more than 10 different seat models. Mostly provided variant of seat for economy class which currently on high demand in market, but there are also present few examples model of the business and premium economy class.

There is one model which allows users to set seat widths based on personal preferences, and it is called “User Manual Input”. When users do not specify a specific width, the tool defaults to a conventional average seat width calculated from reliable sources such as SeatGuru, Jenkinson, and Raymer. This flexibility gives customers the chance to select seats which are in high demand in the market, as well as users happily modifying seat configurations as per their preference.

The tool selects seat widths based on the flight class and range. The width of economy class seats is set at 0.45 meters for both short and long-haul flights. The seat width in premium class remains consistent at 0.48 meters across aircraft ranges. However, if the aircraft includes business class, the seat width increases to 0.51 meters for short-distance journeys and 0.60 meters for long-distance flights. Similarly, the first-class seat width is 0.51 meters for short-haul flights and 0.76 meters for long-haul flights.

The current version of the tool follows E. Torenbreek's book for the calculation of the seat mass. But there is one drawback of this book is that the max 3 seats group weight value is given, so how to overcome the problem if the seat group

contains 4 or more than 4 seats. To overcome the problem, there are some necessary assumptions made for accurate calculations.
For example, when faced with a scenario in which Torenbreek's book defines weights for seat groups of one, two, and three seats as 9.1 kg, 17.7 kg, and 27.2 kg the algorithm dynamically modifies its methods [16]. It cleverly distributes the combined weight of these groups among each seat within the bigger grouping. Using this approach, the weight of each seat in a group of four would be calculated by averaging the individual weights of the smaller seat groups. In this scenario, the calculation yields 9 kilograms for each seat, for a total weight of 36 kg for the complete group of four chairs.
This method shows and provides correct seat mass estimates, but also highlights accuracy of the tool in the aviation cabin design simulations. By organizing logical assumptions and adjusting to converting situations, the tool correctly addresses the restrictions posed through restricted fact availability, improving its effectiveness in realistic layout programs.
Overall, by offering a range of seat models and a user manual model in which users configure as per their requirements, the tool enables designers to create a customized cabin a layout that improves passenger comfort and operational efficiency, which indirectly improves the overall flying experience.

3.2.4 Dividers

Divider (Curtain) in aircraft cabin play curial role because it uses as distinguishing between different travel classes, assuring passengers privacy and comfort. However, due to lack of available standard data, the parameters of dividers are usually susceptible to assumptions made by developers, airlines, and supervisors. The tool calculates the partition length depending on the seating configuration of each class, while the width is considered to be 0.25 meters, a size typical of modern airplane cabin designs.
There is no data available for the weight estimation of the dividers. So, in this code Divider weight is allocated 2.5kg while thinking structural strength and fuel efficiency. The tool accurately computes divider weights using a conversion factor based on known dimensions, resulting in better cabin layouts and overall flight performance. In essence, dividers play a vital role in cabin design, and the tool adeptly models their dimensions and weights to enhance passenger comfort and operational effectiveness in commercial aviation.

3.2.5 Luggage Storages

Luggage storage, an unusual but ingenious addition to the aircraft cabin's design tool, is crucial for maximizing space utility. Mostly, these elements are placed next to lavatories, optimizing available space while providing easy access for passengers and crew members alike.

There is one problem in luggage storage parameters and weight calculations because standard data is not available openly. To solve this, the tool takes a practical approach by replicating the size of neighboring items, especially lavatories, which are usually located near the authorized storage places. These locations are clearly defined in the generated cabin layout photos, which provide a visual representation of their location within the aircraft.

To manage the difficulty of determining the weight of luggage storage, the tool takes a realistic method influenced by professional ideas. The tool considers that luggage storage compartments weigh about half as much as lavatories due to their similar structural qualities. For example, for short and long-distance flights with a lavatory weighing approximately 91.517 kg, the weight of luggage storage is computed as follows: 91.517 times the luggage storage area divided by 0.835396.

It is important to note that, while the current method is practical, the method for determining luggage storage mass may change in response to latest information or professional input. This adaptability demonstrates the tool’s willingness to conform to changing design preferences and business standards, ensuring its usefulness in improving cabin layouts.

3.3 Comprehensive Workflow of CPACS-Python Integration

In Chapter 3.2, Examining the predominant additives of the passenger deck and their required parameters for tool layout, the primary aim is to apprehend the relationship between CPACS and Python.

Let's begin by means of integrating with CPACS. CPACS (Common Parametric Aircraft Configuration Schema), is an open-supply software framework that lets in for seamless statistics sharing and integration across many aircraft layout disciplines.

Now let's look at the CPACS-Python integration workflow (see Figure 3-2). CPACS contains all the modules required for aircraft design, including the fuselage, engine, wings, and vertical stabilizer. The primary focus is on cabin design. The cabin components define the objects required to create the cabin environment, such as galleys, lavatories, dividers, seats, and doors, and each is associated with a certain template. This tool creates the passenger and freight decks while calculating cabin mass and center of gravity. This data is then integrated into the elements and templates, ensuring that the cabin components have all the necessary data, along with positions and mass. This output is ultimately sent to the Fuselage module in CPACS, where it is covered into the

CPACS.xml record. Finally, the integrated workflow generates the final result, which is offered as a complete aircraft design photograph.

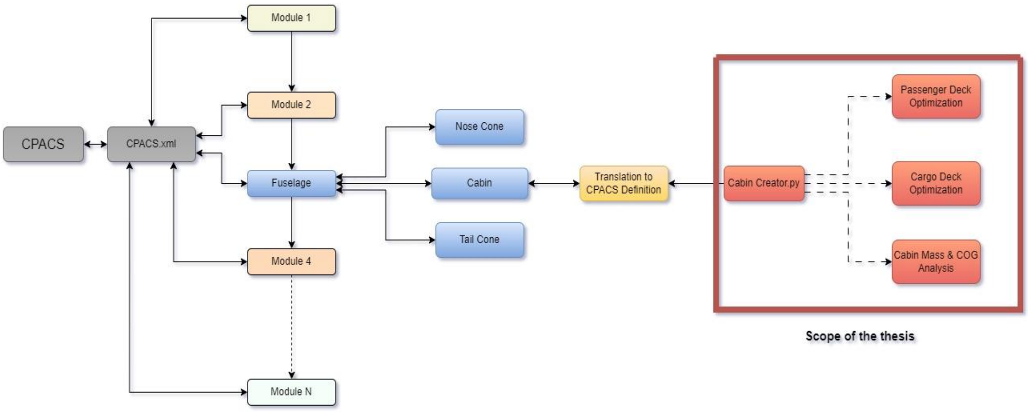


Figure 3-2: The integrated CPACS and Python workflow

3.4 Comprehensive Workflow Overview of the Optimization Tool

3.4.1 Cargo Deck Optimization Workflow

Cargo plays a very important role in terms of generating significant revenue and also providing smooth transport of various goods and services in aviation. In optimization of weight distribution, the cargo compartment creates impact. The integration not only enhances payload capacity but also ensures the stable transportation of a wide range of cargo, for example, from commercial products to essential medical supplies.

The tool was designed in such a way that, while developing fuselage design, it focused on the cargo deck as well. By following guidelines to measure cargo weight and capacity. So, overall, the tool helps to improve the aircraft's functionality and cost-efficiency.

The user has to select the desired cargo model before running the tool from the given models of standard cargo models. This desire technique guarantees that the tool can adapt to the requirements of various airways and operational conditions. The uniqueness of the tool is that, firstly, the user has to provide the total number of cargos they want to distribute. Once a number has been given, while the tool is running, code automatically optimizes excellent cargo allocation and maximizes available space even by following protection and regulatory norms.

When executed, Figure 3-3, it clearly shows that the algorithm checks input data, including the eventual cabin length, and adjusts cargo arrangement accordingly. It carefully evaluates aspects such as cargo base size, length, width, height, and weight, as well as "single" and "double" configuration options. In a "double" design, adjacent cargo decks are purposely arranged to improve capacity utilization and operational efficiency. In contrast, in a "single" scheme, decks are stacked sequentially to ensure a logical progression throughout the cargo space.

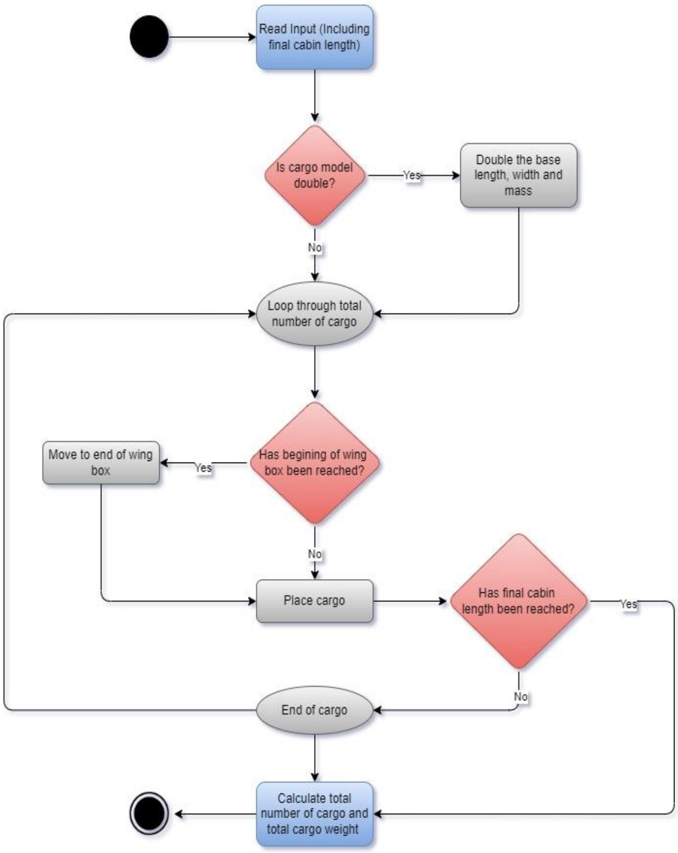


Figure 3-3: Flow chat of the detailed explanation of cargo compartment design

Cargo placement occurs iteratively until the desired number of cargoes is achieved. While allocating cargo, it is prioritizing proximity to prioritizing the wing. This algorithm ensures that cargo placement avoids interfering with crucial aircraft components, for instance the wing box, and maximizes storage space. Then cargo placement again resumes after jumping the wing box area is cleared. During the process, the code checks how far it has travelled compared to the total cabin length to place cargo correctly in line with the fuselage design. If the desired length isn't reached, cargo placement continues until the goal is achieved. When it reaches the maximum cabin length, the code recalculates the number of cargoes needed and their total weight. This method ensures accurate cargo placement, improves aircraft performance, and boosts overall efficiency and profitability.

3.4.2 Passenger Deck Optimization Workflow

Cabin design is critical for airlines, influencing passenger comfort, safety, and flight efficiency. It's all about arranging the space inside the plane so that passengers are comfortable and satisfied. Good cabin design also allows airlines to make better use of space by fitting in seats as well as necessary amenities such as lavatories and storage areas. Furthermore, creative design selections can help the aircraft use less fuel and fly better, highlighting its importance in the field of aviation.

The tool is developed in compliance with EASA requirements for standard cabin designs. Furthermore, it was designed to be adaptable, allowing for a variety of configurations, such as unconventional seat placements or group seating. Its adaptability extends to addressing a wide range of requirements, such as providing sleeping classes or seating for a bigger group. Whatever possible modifications to the layout of items, such as galleys and bathrooms, the tool ensures proper fit and adherence to established criteria. Thus, it accommodates a wide diversity of aircraft configurations while continually prioritizing passenger comfort and safety rules.

It is important to note that, while the tool attempts to align with typical cabin layouts, variations may occur due to its generalizability across different aircraft configurations. However, its versatility demonstrates its usefulness in supporting a wide range of design options and operating requirements. The tool is useful for enhancing cabin layout design for various aircraft types and operating environments, since it maintains a balance between regulatory compliance, passenger comfort, and flexibility in diverse layouts.

Let’s try to understand passenger deck workflow (see Figure 3-4) before executing the tool, users are required to enter critical inputs such as information on various flight classes, including seat abreast configurations and seat pitch. Once this basic information is provided, the tool goes into action. Initially, it reads the input data and asks users to specify their flight range in nautical miles. Once the tool has information about the user range and the total number of passengers with all the travel classes which have been selected by the user, then the total lavatories value calculated as discussed in the previous section on lavatories. Then, after, the tool specifies the cabin’s total width, and it is evaluated using a combination of seat group and aisle widths. Aisles with criteria must be carefully studied to comply with EASA standards rules. The tool periodized the presence of economy class, premium economy class, business class and first class respectively, while computing the entire width of the cabin.

With these statistics, the tool prompts customers to offer the seat width for every model, which is specifically essential if the "User Input Seat Model" option is enabled. The set of rules applies these records to decide the aisle width for each class, which is vital for compliance with regulations and comfort for passengers. As a result, the tool consists of significant statistics concerning flight range, lavatory necessities, seat pitch widths, and aisle widths, as well as advanced cabin layout and format making-plans gear.

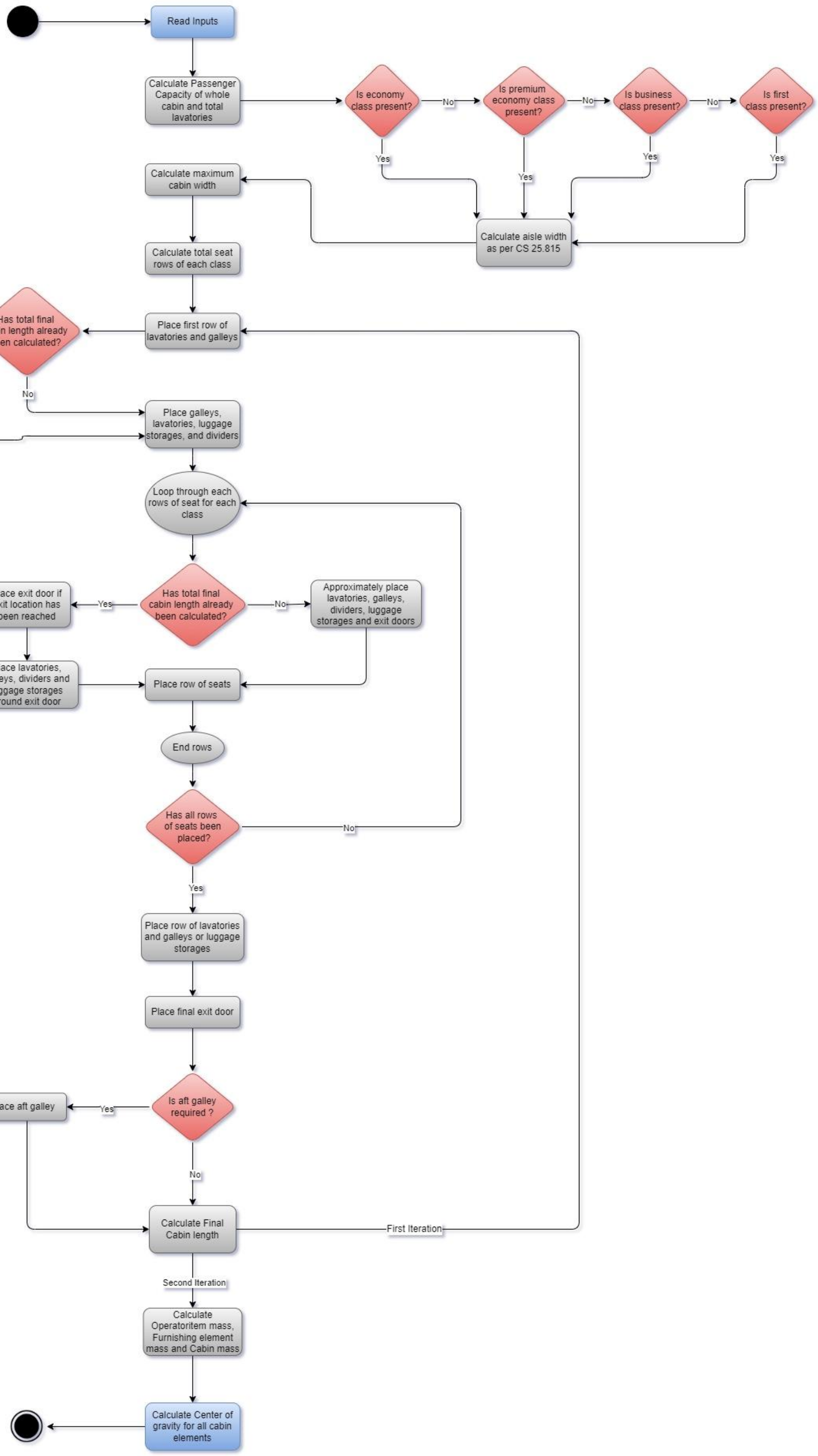


Figure 3-4: Flow chat of the detailed explanation of passenger compartment design

The cabin layout optimization process is directed by two important loops, as shown in the flow chart Figure 3-4. The ultimate cabin length is crucial to these loops, as it drives the operations of the tool. Initially, in the absence of specific data on fuselage cabin length, the tool predicts the location of seats, lavatories, galleys, dividers, luggage storage, and escape doors based on flight range and passenger count. Once the initial layout has been created, the tool evaluates the very last cabin length, which serves as a critical determination for cabin optimization using the Inside-Out technique. With this important value, the tool assures conformity with EASA Standard norms, inclusive of cabin design and safety rules.

It is worth mentioning that within the first generation, the computed final length usually deviates by means of 5-10% from the actual fuselage cabin length. This minor distinction allows for situations wherein lavatories or galleys might also overlap with exit doors, forcing alterations to optimize layout alignment for advanced functionality and passenger consultation.

Once the length of the fuselage is determined, the tool starts to allocate galleys and lavatories at the front side of the cabin. Then, after using the fuselage length factor, exit door placement will decide. The first door usually is allocated without delay to the back of the first actual row, occupied by way of galley and lavatory installation.

Once the primary exit door has been created, the tool algorithm awareness sets seating preparations based on class parameters and seat abreast configuration which is given with the aid of person input value before, code runs. This systematic technique gives the most privacy and capability during the cabin. Until all seating requirements are met, the tool attempts to allocate passengers seats rows with the aid of in the row interior in every travel class. It additionally dynamically adds extra lavatories, galleys, luggage storage locations, and dividers as needed, ensuring that passenger facilities are allotted appropriately and enhancing cabin performance.

Following the seating configuration, the tool prioritizes lavatories, galleys, and luggage storage spaces before placing the final exit door. It then decides whether an additional galley is necessary in the back of the cabin based on seat abreast and passenger numbers. After completing all placements in the second iteration, the tool checks the calculated ultimate length of the cabin and begins the mass calculation and centre of gravity determination processes, both of which are critical components covered in the following chapters.

The tool's Inside-Out design method focuses heavily on the first and final exit door locations. It places the first exit door at the front, labelled as position 1.0, and the last exit door after all seats have been set. While this method is not strictly followed, it is used to avoid potential disruptions, such as limiting access to galleys stocked with necessities such as food and water. The tool's goal is to enable seamless passenger movement and accessibility across the cabin layout by deliberately placing the exit doors in this manner.

3.5 Determining the Total Mass and Centre of Gravity

3.5.1 Weight Prediction

This chapter mainly focuses on weight prediction, and it is a critical part of aircraft design that ensures controllability and stability during operations. Previously mentioned components are taken into consideration while various weight estimation methods are investigated. First, in this chapter, we showcase weight prediction methods and will talk about the pros and cons of them. Then, following that chapter we will explain in detail about the key parameters which influence the measurement of the "Operatoritem" and "Furnishing" elements mass, offering further information on the previous weight computations. Overall, this chapter builds upon the fundamental framework for weight and COG analysis.

Weight Estimation Fundamentals: In this section, various methods which help to determine the weight of airplane cabin elements are examined, which may differ depending on the available data. Early in aircraft design, weight calculations played a crucial role, wherein data is restrained. These approaches fall into 3 classes: statistical, reference, and physical-based simulation.

The statistical method employs historical data samples to generate equations relating to various parameters. However, it may not be suitable for sophisticated concepts that necessitate advanced materials. The reference approach predicts the weight of new components by comparing them to the existing parts' weight, using a scaling factor. Physical-based simulations are used later in the design process once the information about the shape and load conditions is known. In this approach, structural analysis and material of the properties are evaluated by the weight of the components.

To select the best weight prediction method, available or easily accessible data must be considered. It is important to note that the early design stages provide the best potential effect on aircraft weight at a low cost, hence precise weight prediction becomes essential for successful product development [16, 21].

This thesis investigates advanced cabin concepts in which accurate parameters and material data are unknown. As a result, physical-based approaches are ineffective at estimating the prevalence of these beliefs. Instead, handbook methods and statistical approaches are used, with equations from well-known engineers and data from sources such as the Luftfahrt Technisches Hanbuch (LTH) [32] for weight estimation. Only “Furnishing” and “Operatoritem” mass are used to anticipate the weight of aircraft systems and cabin monuments, allowing for easier comparison of different cabin layout plans.

3.5.1.1 Calculation of weight of furnishing elements

“Furnishing” or “Manufacturing Furnishing Mass”, is a critical element of an aircraft's weight prediction. This segment includes various key traits like crew seats, freshwater systems, lavatories, and overhead bins. As it should calculate the whole weight of the furnishing elements, it's far from essential to reference the CPACS documentation [33], which is publicly available on-line and affords distinctive recommendations on the necessary terms and factors to consist of in this calculation. It is possible that now not all characteristic factors and resources online are to be had which play an essential position in the calculation of the “Furnishing” elements' mass value. Understanding the total mass of furnishing elements is crucial for aircraft designers as they assess weight, fuel efficiency, and structural integrity.

Crew seats in aircraft cabins are built for flight crew comfort and safety, with controls conveniently located for simple access and stability throughout all flight phases. In this thesis, crew seat weights are determined based on internal BHL data. Each seat is estimated to weigh 38.308 kg.

Fresh Water Systems: Aviation freshwater systems guarantee that both crew and passengers have access to safe drinking water while in flight. To supply drinking water and maintain hygienic conditions on board, it is built with tanks, pumps, filters, and pipelines.

Guidelines for figuring out an aircraft's freshwater system weight are provided by internal BHL data. For instance, from BHL data, on A320, for a total of 168 passengers, the total freshwater weight is 125.88 kg. This comes to about 0.749kg of freshwater per passenger.

Overhead bins: In aircraft cabins, overhead bins are useful storage containers located above passenger seating locations. They provide empty space for travelers to store other personal belongings and their carry-on baggage in flight.

Data from BHL can be used to approximate the weight of overhead bins. The weight per meter of overhead bin for different aircraft models is indicated in kilograms. Based on this information, an average weight of 15.41kg/m is calculated.

Lavatories weight, as previously described in Chapter 3.2.2, is critical in establishing the overall weight distribution within the airplane cabin.

In Chapter 3.5.1.1, various factors are explored influencing the calculation of “Furnishing” mass (Manufacturer Furnishing Mass), including cabin insulation, cockpit and cabin lining, floor carpet, cargo deck lining, cargo loading lining, and general data [33]. These elements are crucial for establishing the overall mass distribution of the aircraft. However, accessing this vital information online can be challenging due to security concerns and privacy laws. While it would be highly beneficial to utilize authentic data obtained from sources like BHL for specific aircraft models such as the Airbus A320, privacy constraints limit immediate access to such data.

To address the mentioned issues, the current version of the tool incorporates a conversion factor based on realistic data from the A320 aircraft model, provided by BHL. By defining these conversion variables, the tool can be adapted for different aircraft configurations and scenarios, ensuring adaptability and usability across various contexts. It is important to note that the "Furnishing" elements values derived from this method may differ from current data, especially for aircraft models other than the A320. Despite this limitation, the developed tool remains an asset in the aircraft design process. The results produced by the tool are based on real data and a conversion factor developed from the A320 model, rather than on assumptions made by individuals or companies. This approach allows designers to approximate "furnishing" mass values with greater accuracy and efficiency, enhancing the overall design process.

3.5.1.2 Calculation of weight of Operatoritems

The “Operatoritems”, or operational mass, consists of essential objects such as catering supplies, group people, emergency gadgets, galleys, seats, and dividers. These essential variables, in the facet of a lot of different standards, contribute to the general “Operatoritems”, that's important to the plane's operational efficacy and safety. To precisely determine the overall weight of the “Operatoritems”, consult the CPACS guide [34], that's openly available online. This documentation consists of particular steerage on what phrases and elements to encompass in this calculation. However, protection concerns may make it difficult to recap full records of approximately those components on-line.

Catering, which includes the weight of meals and snacks, is critical for limiting aircraft weight. It includes the provisions required to sustain passengers and crew members during flights, with the weight determined by parameters such as flight time, passenger count, and travel class classifications. Based on the internal BHL data, for A320, for a total of 168 passengers, the catering weight is 718.07 kg and is distributed based on the galley position and dimensions.

Cabin crew members are responsible for catering for passenger safety and comfort during flights. They are intensively trained in emergency scenarios, customer service, and their presence is vital to the successful running of airlines. The Python code complies with the CS 25.803 regulations for determining the total staff count. It assigns one crew member for every 50 passengers [35] ensuring any fraction of passengers above this threshold results in an additional crew member. For example, with 400 passengers, 8 crew members are required, whereas 401 passengers require 9 crew members. This method ensures adherence to safety requirements and operational standards. Furthermore, the average weight of crew members, as determined by internal BHL data, is set at 83.92 kg, allowing for precise weight estimates and thorough aircraft design.

Emergency equipment: Life jackets (safety equipment), oxygen systems, and evacuation components are examples of emergency gadgets that are critical for

aircraft protection. Properly placed within the cabin, this tool allows convenient accessibility in case of an emergency at the same time as complying with aviation policies defending both passengers and crew.
The weight assessment for emergency equipment in this thesis and its supporting tool is based on internal BHL data. The overall emergency equipment weight includes safety equipment, oxygen systems, and escape arrangements, ensuring complete preparedness for any situation. Based on the internal BHL data, for A320, for a total of 168 passengers, the emergency equipment weight is 368.13kg.
The weight of the **galleys**, **seats**, and **dividers**, as detailed in Chapters 3.2.1, 3.2.3, and 3.2.4 is critical to the airplane cabin's balance and stability. Weight distribution is important for the flight's overall performance and safety.
This tool calculates the cabin weight by combining “Furnishing” elements mass (Manufacturer Furnishing Mass) and “Operatoritems” elements mass (operational mass). The Furnishing mass includes all manufacturer-installed furnishings, while the Operatoritems mass covers operational items added by the airline. This approach ensures an accurate estimate of the cabin weight, essential for precise aircraft design and performance evaluation.

3.5.2 Centre of Gravity Estimation Framework

The preceding subchapters covered various systems, cabin monuments, and methods for forecasting their mass. This subchapter provides a framework for evaluating various cabin layouts and system placements in respect to the aircraft's mass and centre of gravity.
Framework Architecture: The tool is composed of object-oriented containing one class for the cabin furnishings, the systems, the cargo, the weight estimation, and the CG estimation. The different classes with their contents are listed in Table 3-2 below.

Table 3-2: Classes and Class Content

Classes				
Cabin	**Systems**	**Cargo**	**Weight**	**CG**
Galley (+Food Weight)	Potable Water	Container	Cabin	Cabin
Lavatory			System	System
Luggage Storage			Cargo	Cargo
Divider				
Seat (+Overhead Bin)				
Cabin Door				

The framework intends to estimate the weight of systems and cabin monuments using the methods described in the previous subchapter of the Weight class.

Once weight projections are obtained, the CG position may be calculated. The inputs and outputs for each component of the cabin subitems are defined in Table 3-3.

Table 3-3: Overview of In-and Output parameter of the class Cabin

	Galley (+Food Weight)	**Lavatory**	**Luggage Storage**	**Divider**	**Seat (+Overhead Bin)**	**Cabin Door**
Input	- Number of galleys - Size per galley and along that distribute d food - Position [x, y] of each galley and food	- Number of lavatories - Size per lavatory - Position [x, y] of each lavatory	- Number of luggage storages - Size per luggage storage - Position [x, y] of each luggage storage	- Number of dividers - Size per divider - Position [x, y] of each divider	- Number of seats per class - Cabin dimensions - Position [x, y] and size of monuments - Position [x, y] and size of aisles	- Number of doors - Size per door - Position [x, y] of each door
Output	- Weight - CG Position	- Weight -CG Position	- Weight -CG Position	- Weight -CG Position	- Weight -CG Position	- Weight -CG Position

Workflow: begins by describing the airplane and its cabin, including the allocation of passenger numbers for each class. In the following step, identify each elements’ sizes and location and elements are lavatories, galleys, luggage storages, dividers and exits door. The seats are placed in an empty space in a wide cabin area while avoiding overlap with the above-mentioned elements. Following this, install overhead bins on both sides of the aisles with seats and adjust the number and width of aisles, as necessary. Finally, incorporate system and cargo compartment parameters based on the plane type and specific characteristics, adjusting them to fit within the framework.

Weight estimation is feasible as soon as the cabin layout, system setups, and cargo compartment specifications have been determined. Additional facts can be required to estimate the weight of systems and cabin furnishings. For example, to calculate the weight of overhead bins, add the lengths of all bins on each side of the aisle. After determining the positions, numbers, and individual component weights, the aircraft's centre of gravity (CG) position can be approximated. This calculation is normally conducted using a CG-specific equation:

$$[CG = Total\ Moment/Total\ Weight] \tag{3.1}$$

The moment is calculated by multiplying the weight of a component by its arm, which reflects the distance between the data and the weighing point. The data, positioned at the nose of the aircraft, acts as a reference point. Meanwhile, the weighing point is commonly regarded to be the middle of a rectangular space for cabin monuments or the ground connection point for systems [36].

4 Unconventional Cabin Configuration

A survey conducted in 1692 visitors to the Flying V mock-up revealed a range of tastes, with imaginative cabin designs being the most popular. Although the idea of "Group Space," which allowed for communal seating comparable to train compartments, became popular, concerns were voiced over its comfort on lengthy flights. The Sleeping bed idea received excellent comments for addressing the sleep issue; nevertheless, discomfort during extended visits and meal intake caused challenges. Despite the attractiveness of the Chaise Longue and Staggered Seats, visitors highlighted practical concerns about comfort and privacy [13]. These findings led to the prioritization of the Group Space and Bed concepts based on their perceived worth in enhancing passenger satisfaction and enjoyment. Time restrictions and the difficulties of implementing unusual designs also played a role in the selecting process, which is why the Chaise Longue and Staggered Seats got less focus altogether.

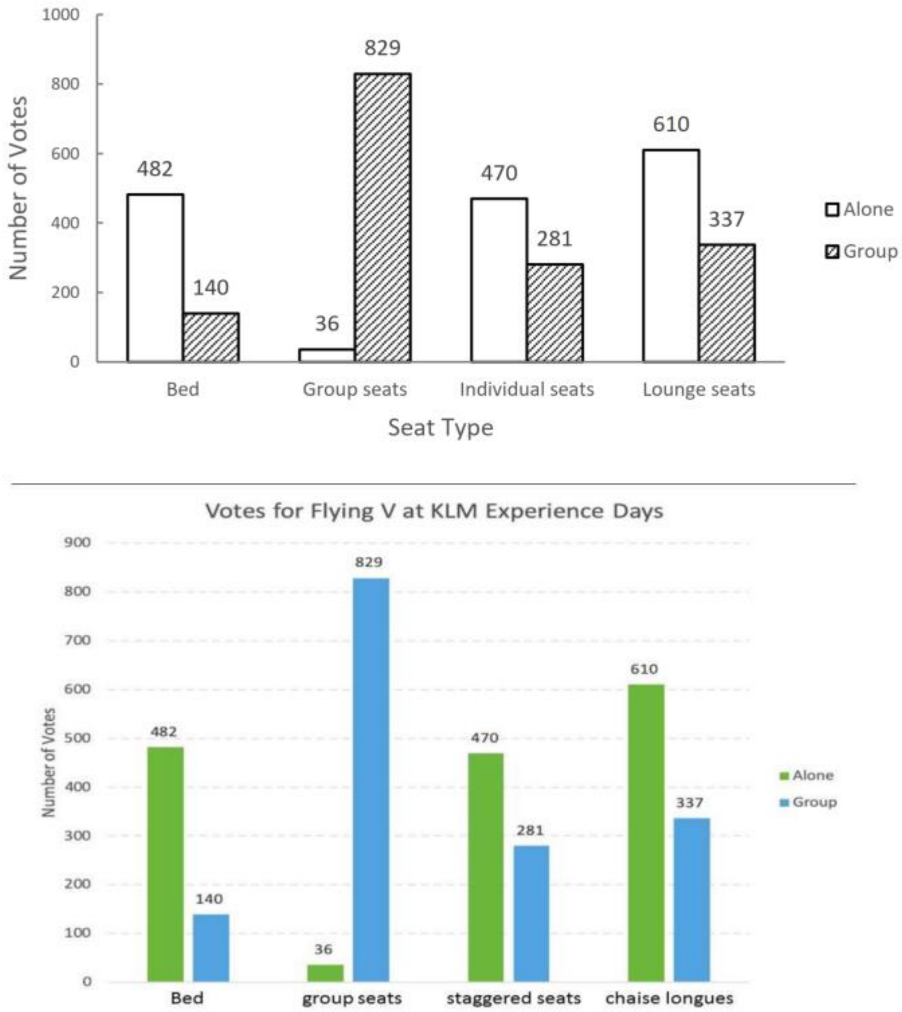


Figure 4-1: Votes of 1692 visitors for the concept [13]

Sleeper Class, as explained in chapter 2.6, considers dimensions such as length and breadth. Improvements have been made to the tool to assure its practicality. For example, a bed length of 1.72 meters was selected based on the typical human height. Additionally, the breadth was enlarged to 0.75 meters for greater versatility. The tool modifies the seat configuration based on the total cabin width. For example, if there are two classes (Sleeper and Economy) with total cabin widths of 5.92 meters and 4.72 meters, the code prioritizes the Economy class width to preserve aerodynamic balance. As a result, the Sleeper class arrangement is adjusted appropriately in order to ensure ideal spacing while considering factors like aisle width, which is typically 0.38 meters in accordance with EASA regulations. To optimize the cabin, the sleeper layout could be modified. For instance, from 1_1_1 with a total width of 5.92 meters to 1_1 with an aisle width of 1.28 meters.

Group Class concept, described in the previous chapter 2.6, if user is intended to accommodate four seats in a 2x2 configuration while occupying less than 64 inches of longitudinal cabin area for a private seating environment. Although, the tool development has been done in such a way that it provides users as well as airlines company flexibility that they may modify as per their desire. But when the overall cabin width from all classes is less than the group class width, the seating arrangement automatically modifies to make room for the extra space. To put it another way, this tool modifies 2_2 instead of 2_2_2 etc. The user can choose to play around 1_2_1 or 2_3_2, for example. The number of passengers will also depend on the seat abreast; if 2_3 is the seat abreast, there will be 5 passengers in each row.

The **"Flexible Class"** is a novel concept that serves as a transition between business and premium economy classes. This class itself provides passengers with a unique experience due to the novel sitting arrangement with tables. The major goal is that these tables have two functions: they give a convenient surface for passengers to store their items, such as bags or books, while simultaneously forming a barrier that improves privacy between surrounding passengers. Such kinds of features are commonly found in business class, like more spacious legs and adjustable seating; the Flexible Class, offers a premium experience at a reduced price.

Furthermore, the Flexible Class cabins are designed to meet the increasing demands and tastes of modern customers. The layout, which emphasizes flexibility and adaptability, allows passengers to alter their sitting arrangements based on their tastes. Whether passengers want to work, relax, or socialize on their journey, the Flexible Class offers a customizable atmosphere that meets a wide range of customer needs. The Flexible Class redefines the comfort and convenience of air travel.

5 Validation Cases

In this chapter, the cases that have been generated to validate the inside-out fuselage sizing and cabin configuration method are presented. For each of the cases, a figure with the cabin layout of the actual aircraft and cabin layout generated by the CPACS-Python integration method is included. The cabin layout of the current aircraft has been taken from BHL, Aircraft characteristics, Airport Planning documents and the internet. BHL documents contain a large amount of information regarding aircraft dimensions and characteristics.

The tool generates a cabin model with a specific colour scheme to represent different components. Lavatories are displayed in light blue, and galleys in natural grey. Dividers, often known as curtains, are shown in pale goldenrod. Tables are tan, whereas doors are portrayed in red. Cargo containers and people are represented by medium grey and bright green, respectively, with staircases depicted in pink.

Seats are color-coded by class: economy seats are brighter dark blue, premium economy seats are darker greyish blue, business class seats are yellow-orange, and first-class seats are brown. Unconventional classes such as sleeper, group, and flexible classes are represented in cyan, blue, and teal, respectively. Purple hues are used to depict crew chairs. As seen in the Figure 5-1 , this color-coding method makes it easier to recognize all elements.

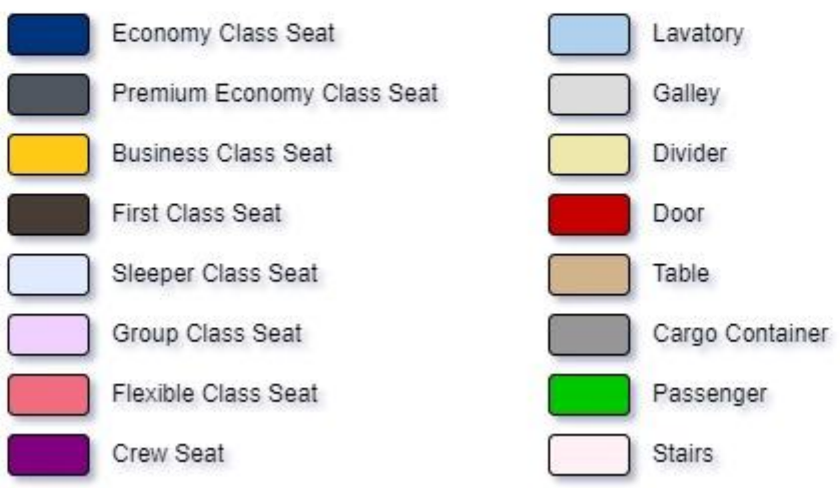


Figure 5-1: Color-Coded Legend for Cabin Components

The “Inside-out” technique develops the fuselage around a certain seating configuration. For example, if the user selects a 0_3_0 layout, the model will generate this configuration without error, but there will be vacant slots where no passengers are assigned. If the user modifies the layout to 3_3_3, the number of passengers may increase beyond the limits of the original cabin layout.

5.1 Airbus A320neo

Table 5-1: A320neo - Comparison between Calculated data and BHL internal data

A320neo		BHL data	Calculated	Differences
Total Number of Passengers	[-]	168	168	-
Business Class Passengers	[-]	42	42	-
Business Class Seat Pitch	[m]	0.8564	0.8564	-
Economy Class Passengers	[-]	126	126	-
Economy Class Seat Pitch	[m]	0.7422	0.7422	-
Cabin Length	[m]	27.57	27.76	0.6%
Cabin Width	[m]	3.70	3.67	0.8%
Number of Lavatories	[-]	3	3	-
Galley area	[m^2]	4.36	4.08	6.4%
Operator items	[kg]	-	3819.564	
Furnishing	[kg]	-	3109.14	
Total mass (Furnishing + Operator items)	[kg]	6944.0	6928.703	0.2%

Table 5-2: A320neo – Calculated COG data

	Evaluated Mass [kg]	Estimated COG Position [m]	
		X	Y
Total Cabin Elements	7177.883	13.225	0.005

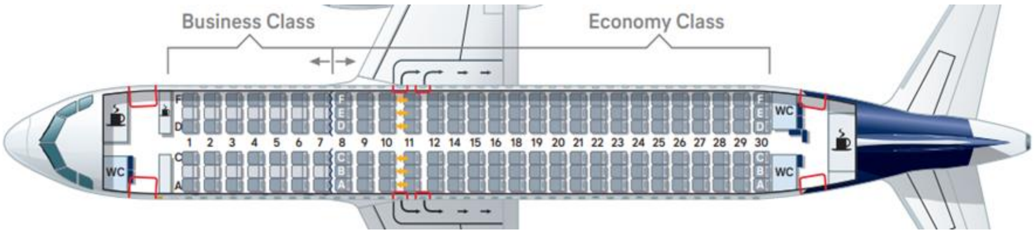
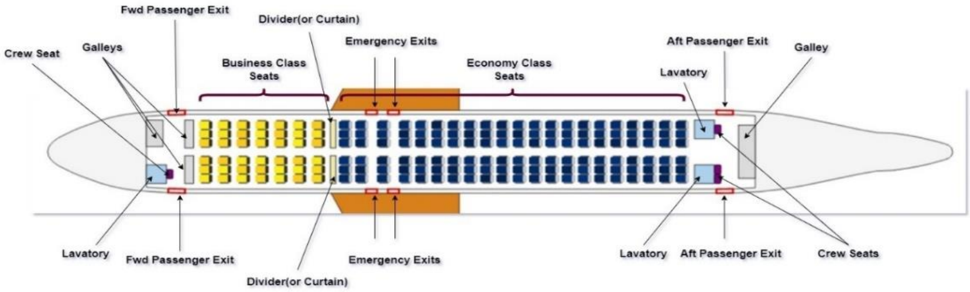
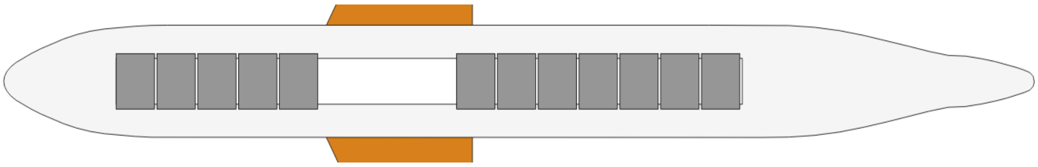


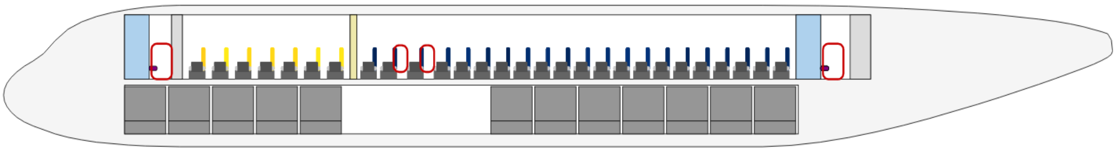
Figure 5-2: Airbus A320neo cabin layout [37]



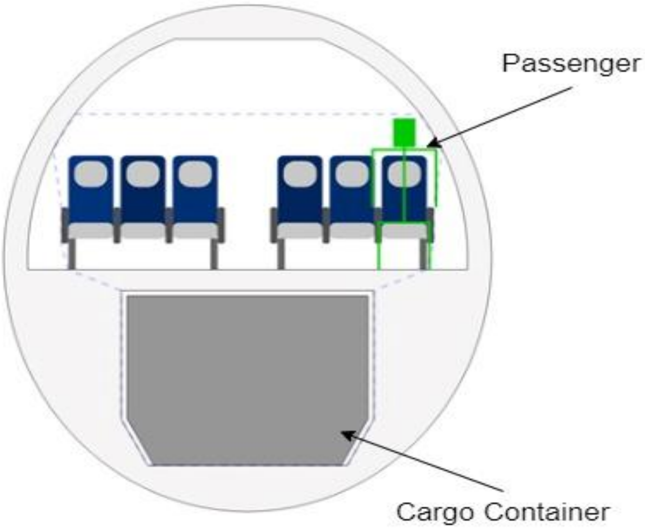
a) Top View



b) Bottom View



c) Side View



d) Main Cross Section View

Figure 5-3: Cabin layout of the Airbus A320neo generated using the proposed tool

A320 neo Cabin Evaluation View

Cabin validation succeeded

'main_passenger_deck' Design Report

Type	Result
Area	101.59m²
Average Seat Pitch in BUSINESS	0.86m (33.7")
Average Seat Pitch in ECONOMY	0.77m (30.2")
CS-25 Aisle Width	0.35m (13.8") at row 1
CS-25 Aisle Width	0.35m (13.8") at row 2
CS-25 Aisle Width	0.35m (13.8") at row 3
CS-25 Aisle Width	0.35m (13.8") at row 4
CS-25 Aisle Width	0.35m (13.8") at row 5
CS-25 Aisle Width	0.35m (13.8") at row 6
CS-25 Aisle Width	0.35m (13.8") at row 7
CS-25 Aisle Width	0.37m (14.7")
CS-25 Max Seat Abreast	ok
Deck size	27.76m x 3.67m
Galley Area (Actual)	4.09m²
Galley Area (Recommended)	4.36m²

'main_passenger_deck' Port Door Report

Type	Result
CS-25 299+ PAX	ok
CS-25 Max Exit Capacity	ok
CS-25 Min Door Amount	ok
CS-25 Min Door Distance	ok
CS-25 Min Door Distance	ok
CS-25 No doors	ok
CS-25 Nominal Exit Offset	Exit (Row 0) offset ok
CS-25 Nominal Exit Offset	Exit (Row 28) offset ok
CS-25 Nominal Exit Offset	Exit (Row 9) offset ok
CS-25 Zone Capacity	ok (Rows 1 to 9)
CS-25 Zone Capacity	ok (Rows 10 to 28)

'main_passenger_deck' Starboard Door Report

Type	Result
CS-25 299+ PAX	ok
CS-25 Max Exit Capacity	ok
CS-25 Min Door Amount	ok
CS-25 Min Door Distance	ok
CS-25 Min Door Distance	ok
CS-25 No doors	ok
CS-25 Nominal Exit Offset	Exit (Row 0) offset ok
CS-25 Nominal Exit Offset	Exit (Row 28) offset ok
CS-25 Nominal Exit Offset	Exit (Row 9) offset ok
CS-25 Zone Capacity	ok (Rows 1 to 9)
CS-25 Zone Capacity	ok (Rows 10 to 28)

Figure 5-4: Airbus A320neo cabin layout validation

The results in Figure 5-3 to Figure 5-4 clearly show that when comparing the output data to the real data of passenger numbers and seats abreast from Table 5-1, there is only a 0.6% difference in cabin length and a 0.8% difference in cabin width. Furthermore, the number of lavatories and galley area closely resemble real data, and the number and location of doors are identical to those on an actual aircraft. This data shows that the model not only effectively corresponds to EASA regulations, but also demonstrates our tool's accuracy. Moreover, in the final output, the mass values for operational items and furnishing elements are within 0.2% of the actual data sourced from BHL. Due to privacy concerns, individual mass values are not displayed. Instead, the total combined mass of operational items and furnishing elements is shown. There is no real source material available in BHL or online to compare the results of the center of gravity (COG) calculations obtained from the tool with current data.

Figure 5-4 depicts the design and validation report produced as output when the user executes the code based on their settings. This report reveals that all elements, such as doors, galleys, etc., were arranged in accordance with EASA guidelines. To minimize needless pages, no validation report will be provided in subsequent aircraft cabin layouts; however, these layouts will fully comply with EASA regulations.

Table 5-1 and Table 5-2 display the mass and center of gravity (COG) data. However, it is important to note that the total mass (Operator items mass + Furnishing mass) differs from the total cabin elements mass between these tables. This difference arises as the calculation method for operator items and furnishing elements follows the CPACS Documentation [33, 34], while the total cabin element mass is calculated differently. Detailed descriptions, including the most crucial elements, are provided in Appendix A. Additionally, the COGx and COGy position values are shown with respect to the deck.

5.2 Airbus 350-900

Table 5-3: A350-900 - Comparison between Calculated data and BHL internal data[5]

A350-900		BHL data	Calculated	Differences
Total Number of Passengers	[-]	319	318	-
Business Class Passengers	[-]	36	36	-
Business Class Seat Pitch	[m]	1.732	1.732	-
Premium Economy Class Passengers	[-]	21	21	
Premium Economy Class Seat Pitch	[m]	1	1	
Economy Class Passengers	[-]	262	261	-
Economy Class Seat Pitch	[m]	0.95	0.95	-
Cabin Length	[m]	52.85	50.06	5.2%
Cabin Width	[m]	5.61	5.61	0%
Number of Lavatories	[-]	8	8	-
Galley area	[m^2]	7.81	8.70	11.39%
Operator items	[kg]	-	7690.931	
Furnishing	[kg]	-	8641.511	
Total mass (Furnishing + Operator items)	[kg]	23011.0	16332.44	29.02%

Table 5-4: A350-900 – Calculated COG data

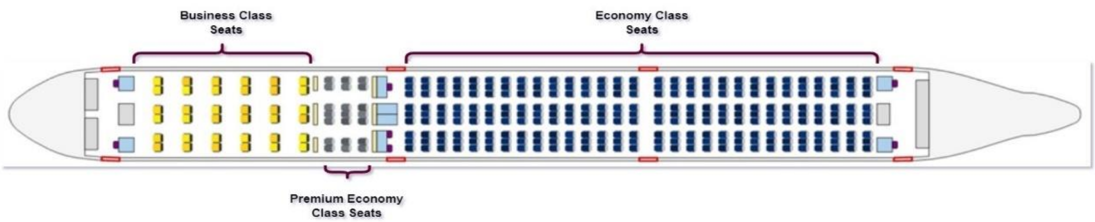
	Evaluated Mass [kg]	Estimated COG Position [m]	
		X	Y
Total Cabin Elements	18246.557	24.229	-0.004

The results in Figure 5-6 clearly show that when comparing the output data to the real data of passenger numbers and seats abreast from Table 5-3, there is only a 5.2% difference in cabin length and no difference in cabin width. Furthermore, from the figures, you easily notice that the quantity of lavatories and galley areas intently resembles real records, and the exit doors are also equal to the ones on a real aircraft. However, the door positions have changed. The placement of doors depends on the fuselage length factor, and the device is designed to test that if there is only one row left of the same class after placing the door, then the

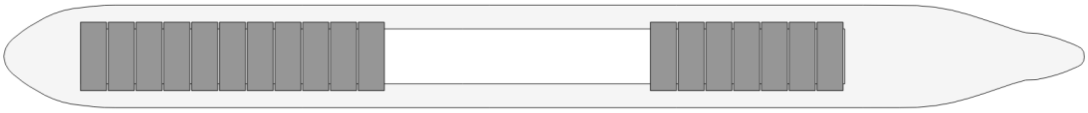
[5] The source data of mass from BHL may not match the real manufacturing values because no such data is openly available. The mass values mentioned in Table 5-3 are assumed by BHL during their research work.

device tries to push the door to be placed after the last row of the same class. The tool has been developed in such a way that it always tries to follow the EASA standard, which says that there will be no gap of more than 18.3 meters between two doors. The final output shows a 29.02% difference between the BHL records and the tool's mass values for operational items and furnishings. The BHL mass value was calculated a few years ago, providing only the total mass, but current results are more reliable, offering detailed mass data for each element. A detailed description of the mass and COG values, along with the affecting parameters, is provided in Appendix B.

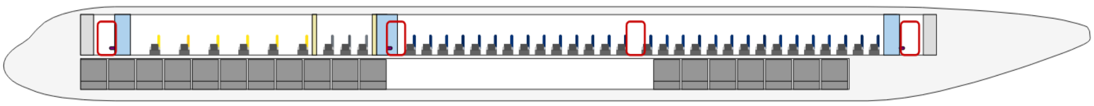
Figure 5-5: Airbus A350-900 cabin layout [38]



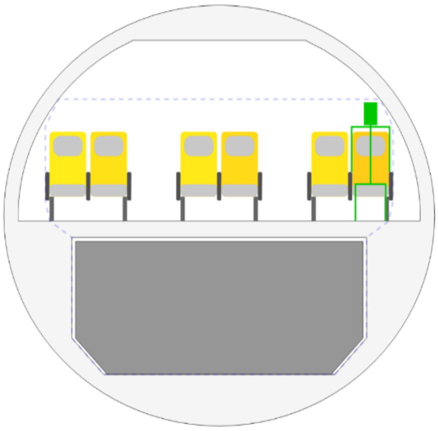
a) Top View



b) Bottom View



c) Side View



d) Main Cross Section View

Figure 5-6: Cabin layout of the Airbus A350-900 generated using the proposed tool

5.3 Airbus 220-300

Table 5-5: A220-300 - Comparison between Calculated data and BHL internal data[6]

A220-300		BHL data	Calculated	Differences
Total Number of Passengers	[-]	137	137	-
Business Class Passengers	[-]	10	12	-
Business Class Seat Pitch	[m]	0.9398	0.9398	-
Economy Class Passengers	[-]	127	125	-
Economy Class Seat Pitch	[m]	0.8128	0.8128	-
Cabin Length	[m]	27.5	28.92	5.1%
Cabin Width	[m]	3.28	3.24	1.2%
Number of Lavatories	[-]	2	2	-
Galley area	[m^2]	3.65	3.28	10.13%
Operator items	[kg]	-	3104.993	
Furnishing	[kg]	-	2985.2	
Total mass (Furnishing + Operator items)	[kg]	6036.9	6090.193	0.8%

Table 5-6: A220-300 – Calculated COG data

	Evaluated Mass [kg]	Estimated COG Position [m]	
		X	Y
Total Cabin Elements	6450.843	14.257	0.024

The results in Figure 5-8 clearly show that when comparing the output data to the real data of passenger numbers and seats abreast from Table 5-5, there is only a 5.1% difference in cabin length and 1.2% difference in cabin width. Furthermore, the number of lavatories and galley areas closely resembles the real data, and the number of doors is the same as in actual aircraft, but positions have minor changes. The tool ensures that there is no gap greater than 18.3 meters between two doors and these findings adhere to EASA regulations, which means that the cabin layout is optimal. In the final output, the difference between the BHL data and the tool's mass values for operational items and furnishings is 0.8%. A detailed description of the mass and COG values, along with the affecting

[6] The source data of mass from BHL may not match the real manufacturing values because no such data is openly available. The mass values mentioned in Table 5-5 are assumed by BHL during their research work and how they assume that is mystery. So, the new value which are received from tool help BHL to update their assumption for further research work.

parameters, is provided in Appendix C. Additionally, the COG_x and COG_y position values are shown with respect to the deck.

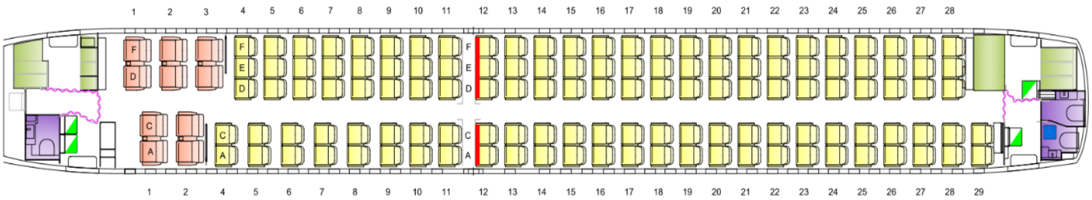
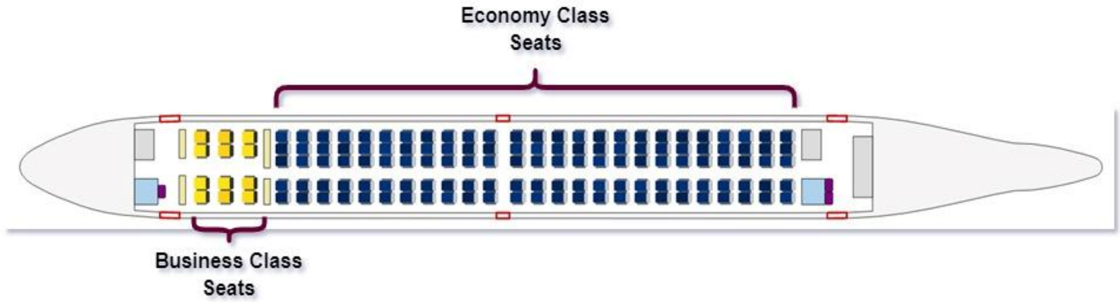
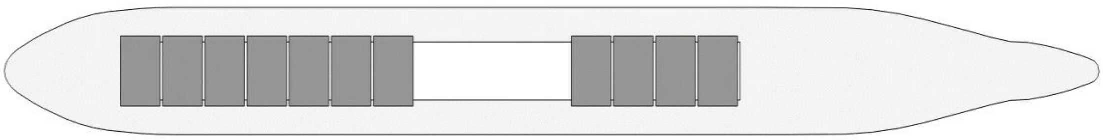


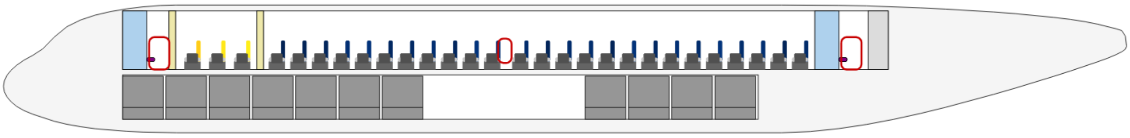
Figure 5-7: Airbus A220-300 cabin layout [39]



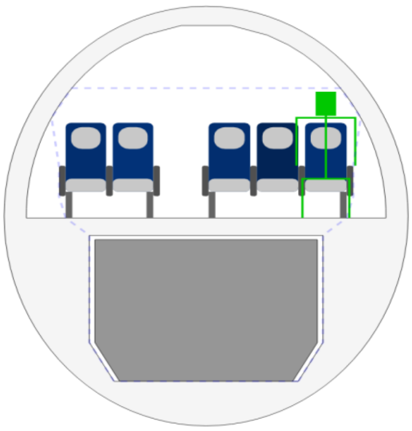
a) Top View



b) Bottom View



c) Side View



d) Main Cross Section View

Figure 5-8: Cabin layout of the Airbus A220-300 generated using the proposed tool

5.4 ATR72

Table 5-7: ATR72 - Comparison between Calculated data and BHL internal data[7]

ATR72		BHL data	Calculated	Differences
Total Number of Passengers	[-]	70	72	-
Economy Class Passengers	[-]	70	72	-
Economy Class Seat Pitch	[m]	0.7366	0.7366	-
Cabin Length	[m]	17.95	17.13	4.5%
Cabin Width	[m]	2.57	2.83	10.11%
Number of Lavatories	[-]	1	1	-
Galley area	[m^2]	2.16	1.94 m^2	10.1%
Operator items	[kg]	-	1769.455	
Furnishing	[kg]	-	1288.541	
Total mass (Furnishing + Operator items)	[kg]	2324	3057.996	31.58%

Table 5-8: ATR72 – Calculated COG data

	Evaluated Mass [kg]	Estimated COG Position [m]	
		X	Y
Total Cabin Elements	2658.331	8.153	-0.003

The results in Figure 5-10 clearly show that when comparing the output data to the real data of passenger numbers and seats abreast from Table 5-5, there is only a 4.5% difference in cabin length and 9.18% difference in cabin width. Furthermore, the number of lavatories closely resembles the real data and galley areas have around 10% differences, and the number of doors and positions are identical to those on an actual aircraft and these findings demonstrate that the model not only effectively adheres to EASA regulations but also highlights the accuracy of our tool and ensures the cabin layout is optimal. Moreover, in the final output, the difference between the BHL data and the tool's mass values for operational items and furnishings is 31.58%. This tool is designed for versatility rather than perfect layout matching. It generally provides the correct number of lavatories and galley areas compared to real data, though some elements, as seen in Figure 5-9, may not be accurately executed. The cross-section includes a cargo compartment consideration, which the ATR72 lacks, affecting accuracy.

[7] The source data of mass from BHL may not match the real manufacturing values because no such data is openly available. The mass values mentioned in Table 5-7 are assumed by BHL during their research work.

However, this thesis focuses on cabin design, which matches real aircraft configurations accurately. A detailed description of the mass and COG values, along with the affecting parameters, is provided in Appendix D. Additionally, the COG_x and COG_y position values are shown with respect to the deck.

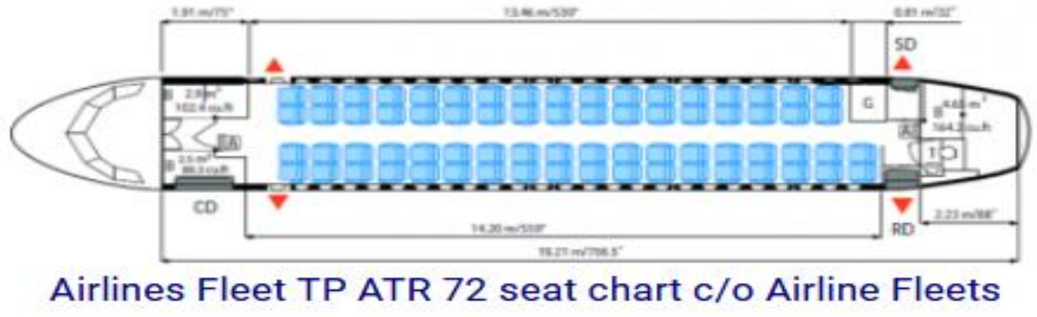
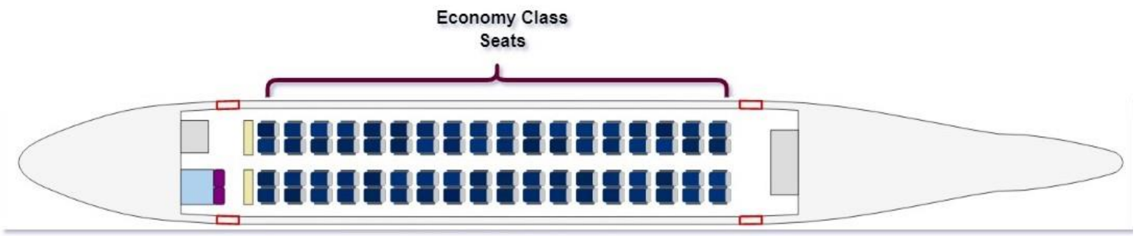
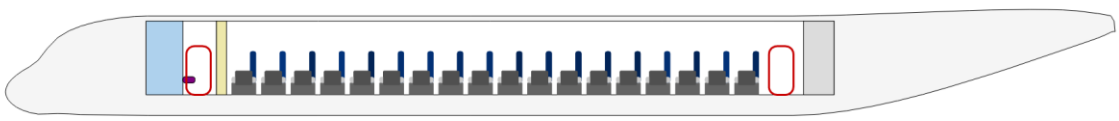


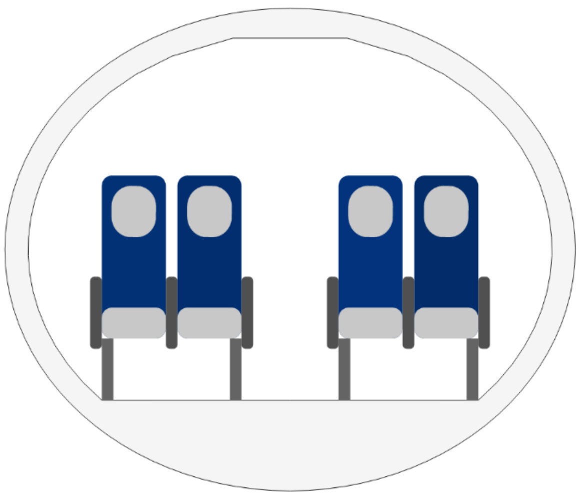
Figure 5-9: Airbus ATR72 cabin layout[40]



a) Top View



c) Side View



d) Main Cross Section View

Figure 5-10: Cabin layout of the Airbus ATR72 generated using the proposed tool

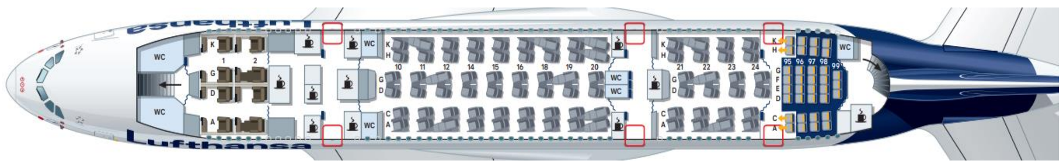
5.5 Airbus 380-800

Table 5-9: A380-900 - Comparison between Calculated data and BHL internal data

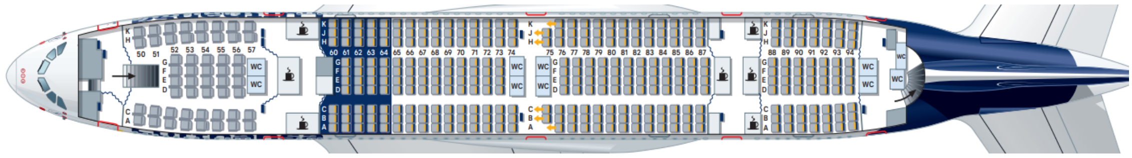
A380-800		BHL data	Calculated	Differences
Upper Deck				
Total Number of Passenger	[-]	121	118	-
First Class Passengers	[-]	8	8	-
First Class seat pitch	[m]	2.05	2.05	-
Business Class Passengers	[-]	78	78	-
Business Class Seat Pitch	[m]	1.626	1.626	-
Economy Class Passengers	[-]	35	32	-
Economy Class Seat Pitch	[m]	0.7874	0.7874	-
Cabin Length	[m]	44.93	39.07	13.04%
Cabin Width	[m]	5.8	5.35	7.75%
Number of Lavatories	[-]	5	5	-
Galley area	[m^2]	-	5.65	-
Operator items	[kg]	-	3822.989	
Furnishing	[kg]	-	4538.302	
Main Deck				
Total Number of Passenger	[-]	388	396	-
Premium Economy Class Passengers	[-]	52	56	-
Premium Economy Class Seat Pitch	[m]	0.9652	0.9652	-
Economy Class Passengers	[-]	336	340	-
Economy Class Seat Pitch	[m]	0.7874	0.7874	-
Cabin Length	[m]	49.9	48.26	3.28%
Cabin Width	[m]	6.5	5.66	12.9%
Number of Lavatories	[-]	10	9	-
Galley area	[m^2]	-	11.52	-
Operator items	[kg]	-	11385.569	
Furnishing	[kg]	-	8469.657	
Total mass (Furnishing + Operator items)	[kg]	-	28216.517	

Table 5-10: A380-800 – Calculated COG data

	Evaluated Mass [kg]	Estimated COG Position [m]	
		X	Y
Upper Deck			
Total Cabin Elements	7903.161	19.344	-0.007
Main Deck			
Total Cabin Elements	21802.151	23.243	0.0

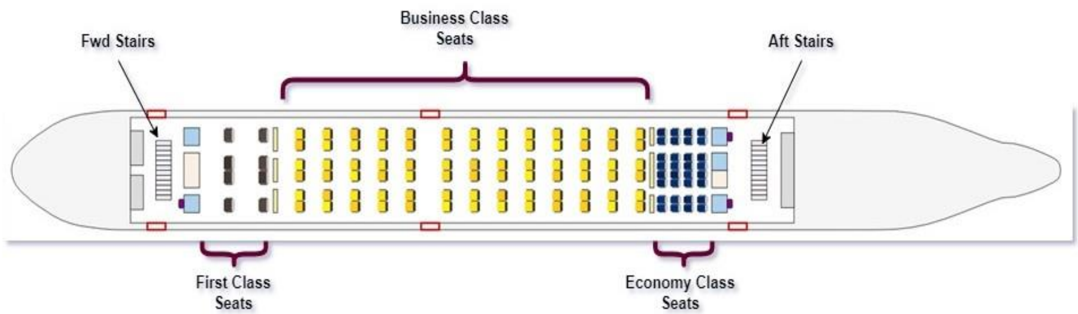


(a)

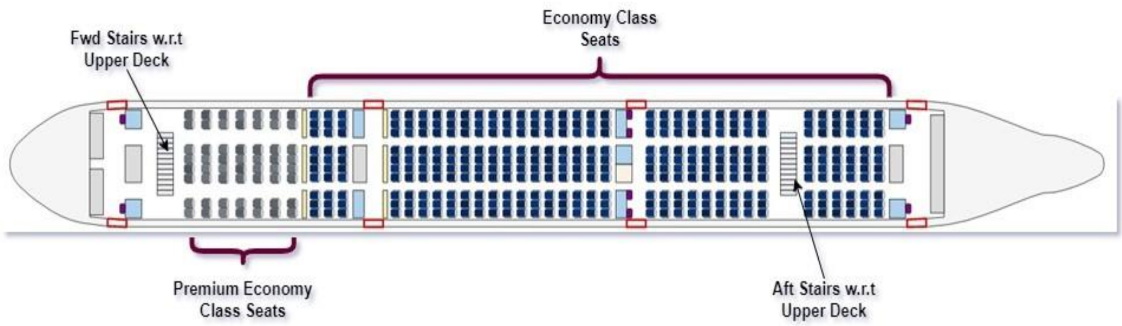


(b)

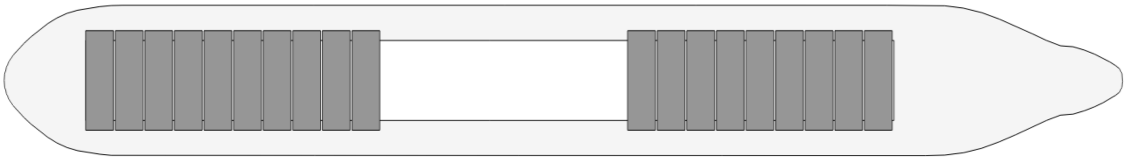
Figure 5-11: Airbus A380-800 cabin layout: a) Upper Deck b) Main Deck [41]



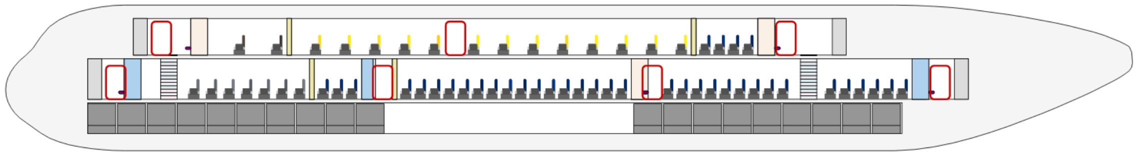
a) Top View of Upper Deck



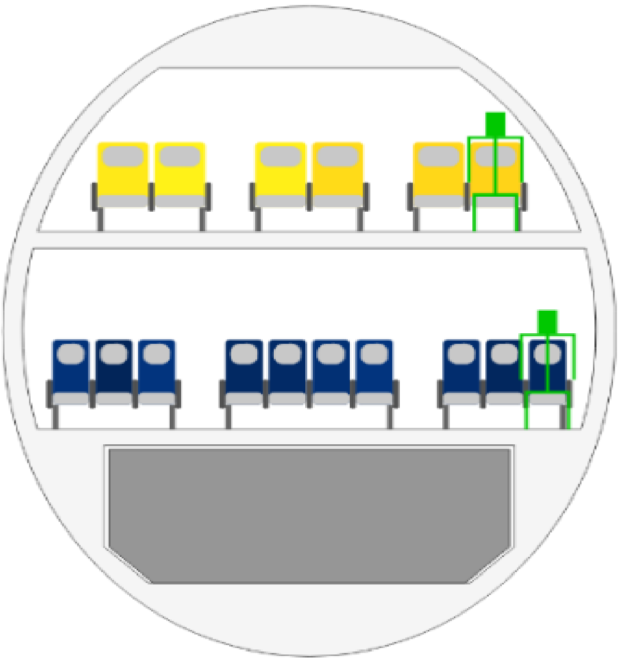
b) Top View of Main Deck



c) Bottom View



d) Side View



e) Main Cross Section View

Figure 5-12: Cabin layout of the Airbus A380-900 generated using the proposed tool

The results in Figure 5-12 clearly show that when comparing the output data to the real data of passenger numbers and seat abreast from Table 5-9, there is only a 3.28% difference in cabin length and a 12.9% difference in cabin width on the main deck, while the Upper Deck shows an 13.04% difference in cabin length and a 7.75% difference in cabin width. Furthermore, the total number of lavatories closely matches the current aircraft configuration, while on the other hand, the galley areas show significant differences. Now we are talking about exit doors, and the number of exit doors is also the same as current aircraft, but their positions differ due to the Upper Deck, which includes more galley areas, which affects the cabin design layout. Consequently, there is a difference noticed in the length of the Upper Deck in the output result, whereas the stair position also varies from the real data. These findings demonstrate that while the model does not identically match the real configuration, it still effectively adheres to EASA regulations, highlighting the accuracy of our tools and ensuring an optimal cabin layout.

Moreover, BHL does not provide sources regarding the mass of operational items and furnishing elements, so a comparison is not possible. One thing I need to note is that this tool is designed to work under most conditions rather than match each aircraft model's layout perfectly. The tool generally provides the correct number of lavatories and galley areas compared to real data, but certain additional elements, as seen in Figure 5-11, may not be accurately executed by this tool. A detailed description of the mass and COG values, along with the affecting parameters, is provided in Appendix E. Additionally, the COG_x and COG_y position values are shown with respect to the deck.

5.6 Overview

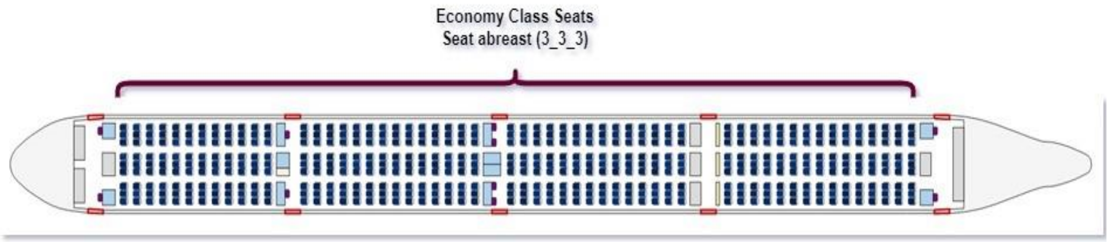
Chapter 5 demonstrates that the tool's output closely resembles real data, with an accuracy of about 5% in cabin length and 10% in cabin width, except for unique elements developed by specific airline demands. These unique elements are not fulfilled by the current version of the tool. Conflicts in mass calculations may develop because accurate mass data for aircraft other than the A320 is not available in BHL or on the internet. However, this thesis ensures that if the method typically matches with the A320, then using the same strategy to compute mass for other aircraft should provide more reliable and accurate information. Furthermore, the tool is programmed to position the first door in the x-direction at +1.0, with the following doors positioned according to the fuselage length factor. This can be viewed as a constraint of the current version of the tool.

6 Application

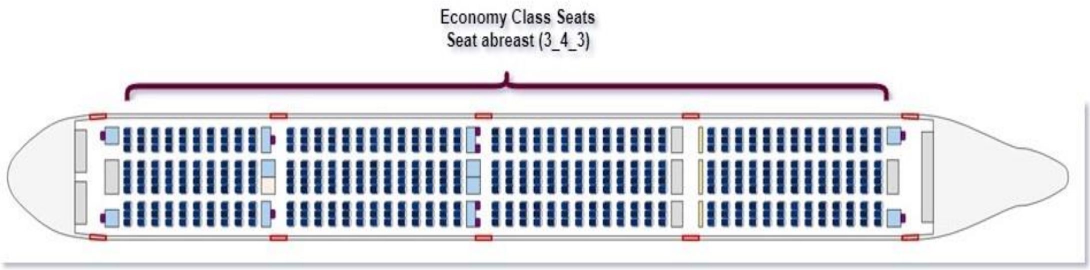
This chapter highlights the tool's capabilities and the flexibility it provides for users. In this chapter demonstrates how airlines can use this tool to optimize their cabin layouts in response to market demand. This versatility enables more efficient use of space and resources, which in the end, improves the overall experience of the passengers as well as increases operating efficiency.

1. Non-Standard Seat Configurations

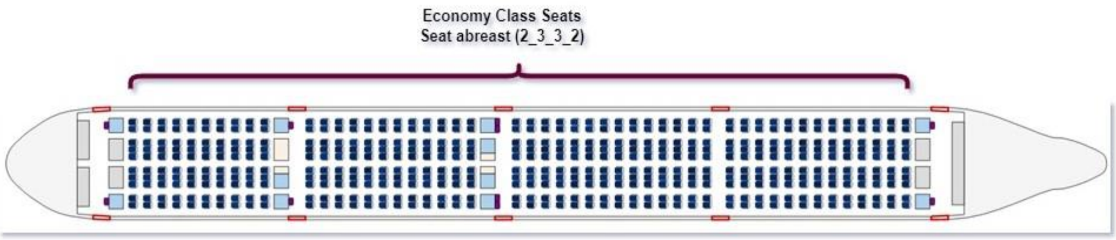
This section demonstrates that there is no strict boundary on the number of seats abreast in a row, which can exceed 11 seats. This flexibility allows for the inclusion of additional elements, such as hydrogen tanks, without altering the overall fuselage length (See Figure 6-1).



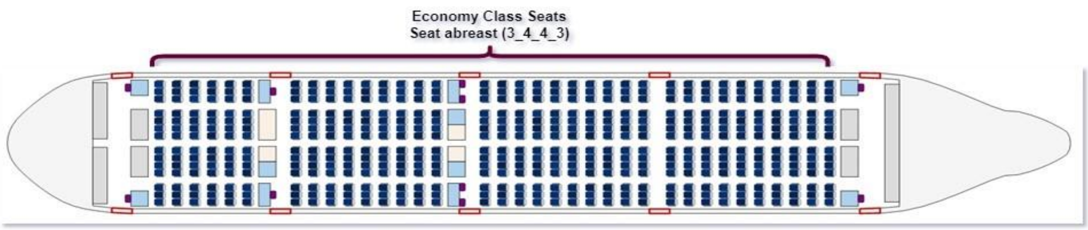
a)



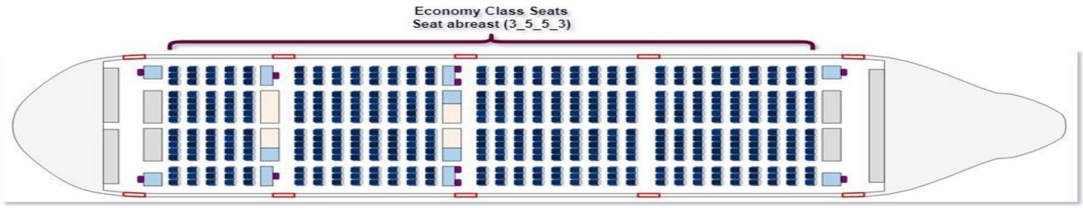
b)



c)



d)



e)

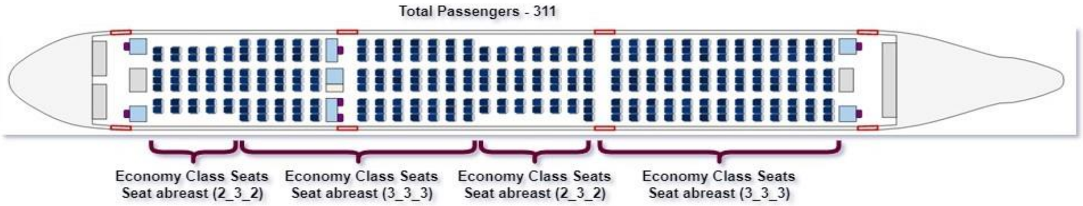
Figure 6-1: Various Seat Configurations for the Same Number of Passengers

2. **Multiple seats abreast in same class type**

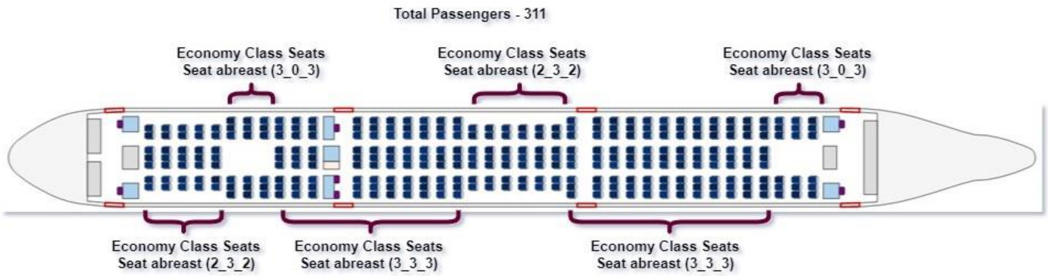
   This section describes how the tool allows for different seat layouts inside the same class. The tool allows for different seat abreast possibilities, which increases cabin layout versatility and accommodates varying passenger desires and preferences within a single class type.

a)

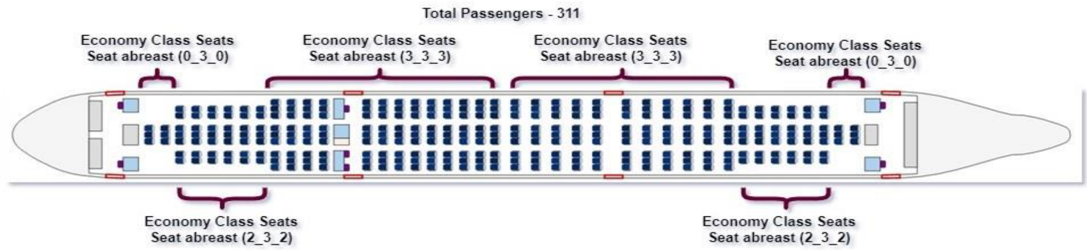
b)



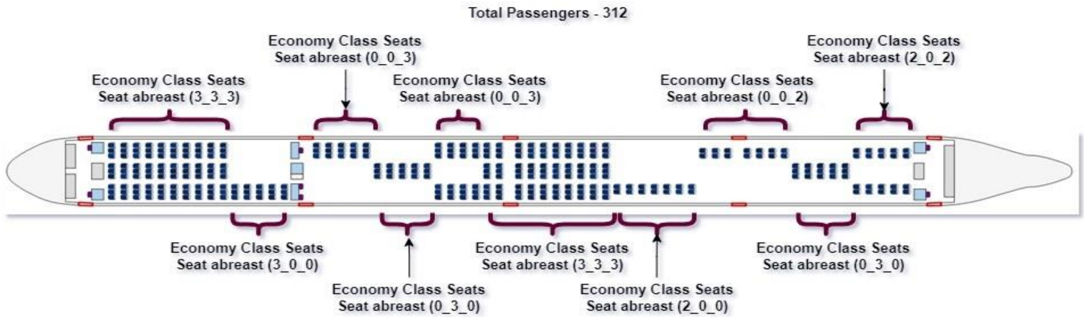
c)



d)



e)



f)

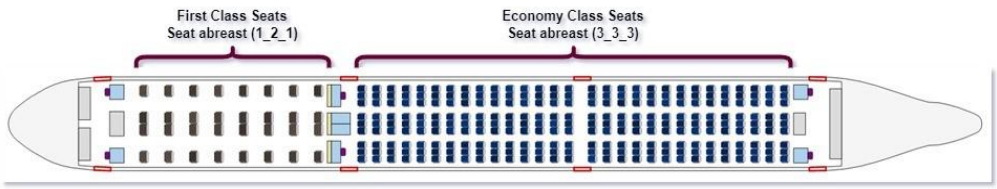
Figure 6-2: Variable Seat Configurations Within the Same Class

In Figure 6-2, part (a) illustrates that the user initially selects a conventional seat abreast configuration which is commonly used in the current aviation industry. Part (b) then shows two distinct seat abreast layouts in the same cabin, namely 2-3-2 and 3-3-3. Parts (c), (d), (e), and (f) show that the tool's flexibility configurations allow the user or manufacturer to configure seat anywhere in the cabin, rather than just at the beginning or aft.

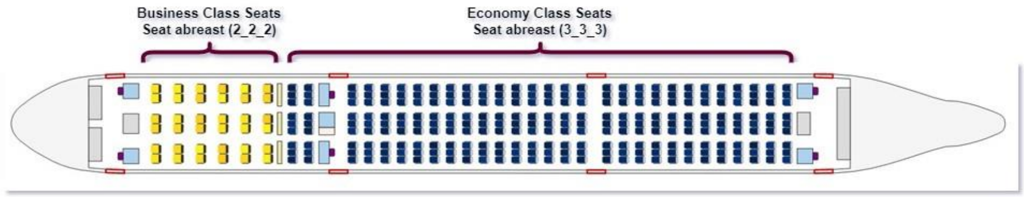
The current version of the tool has a limitation, which also presents an opportunity for future updates. As shown in Figure 6-2 part (f), the blank spaces can be filled with additional elements such as wheelchair compartments, medical rooms, etc.

3. Multiple classes

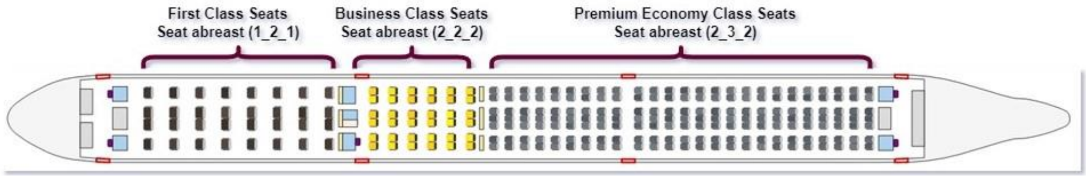
This section explains how the tool supports multiple classes within a single cabin. By allowing different seat configurations, the tool increases layout versatility and meets diverse passenger preferences. It also provides flexibility in placing different classes throughout the cabin.



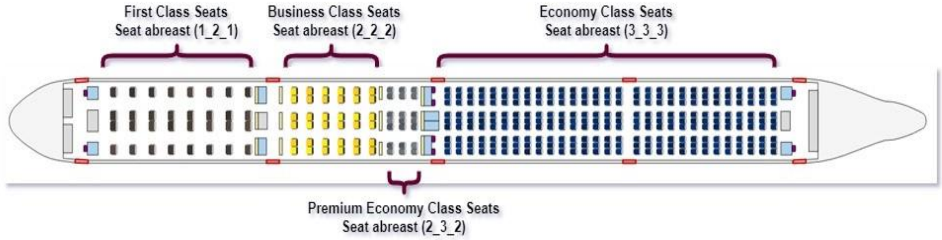
a)



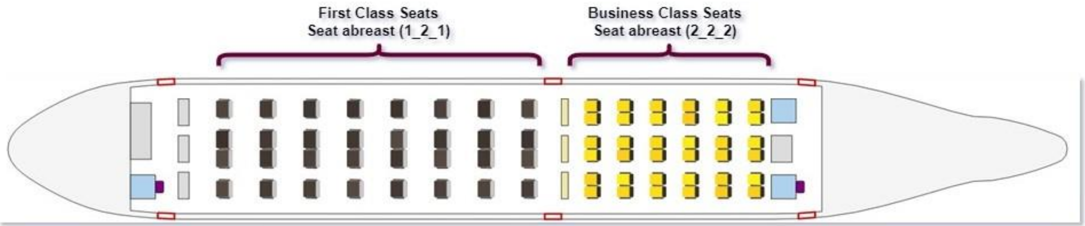
b)



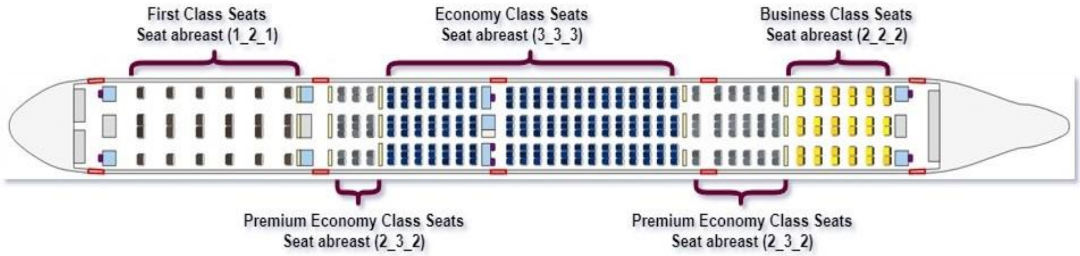
c)



d)



e)



f)

Figure 6-3: Diverse Passenger Class Configurations Within a Single Cabin

In Figure 6-3, parts (a) to (e) demonstrate the multiple class options available within the tool, highlighting its flexibility with various seat configurations across different passenger classes. Part (f) highlights that the tool not only supports multiple class options but also allows flexible placement and the use of the same class more than once.

4. Cargo Deck

This section highlights the crucial role cargo layout plays in the development of an aircraft's outer shape. The tool has been developed in such a manner that it tries to include most standard cargo types and their dimensions, as mentioned in Chapter 2.4.5. Before running the code, users must select the type of cargo they want to use in their airplane. The Figure 6-4 below illustrates how different cargo types can influence the aircraft's shape.

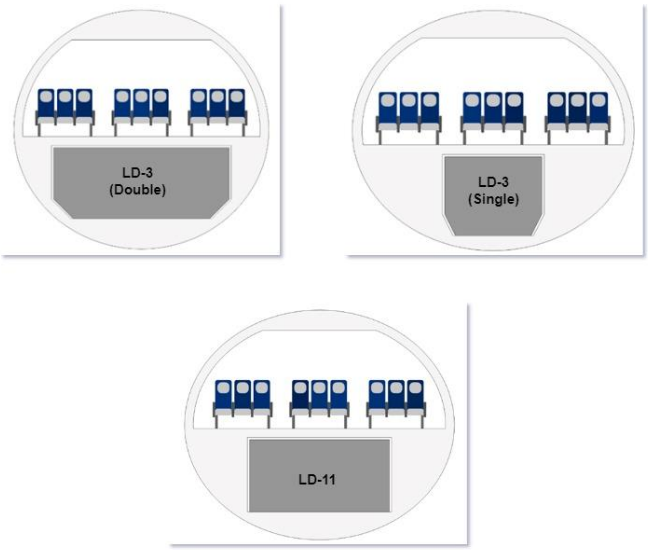


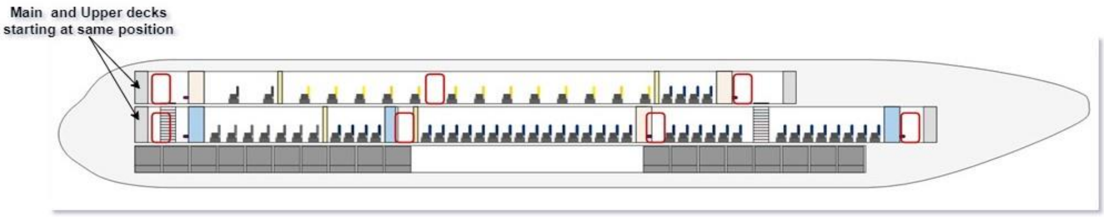
Figure 6-4: Influence of Cargo Types on Aircraft Design

Users should select the cargo type carefully. For example, if a user selects only LD-3 containers for a double-decker airplane, the output may not be optimal. While the tool aims to provide as much flexibility as possible, it may not be able to meet all user requirements.

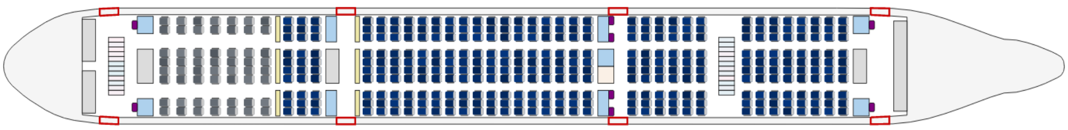
5. Upper Deck Placement

This section aims to demonstrate that the current tool not only enables the unlocking of double-deck passenger compartments but also provides users with the flexibility to select the starting position of the upper deck. Figure 6-5 illustrates how the cabin configuration and stair position change when users select different starting positions for the upper deck.

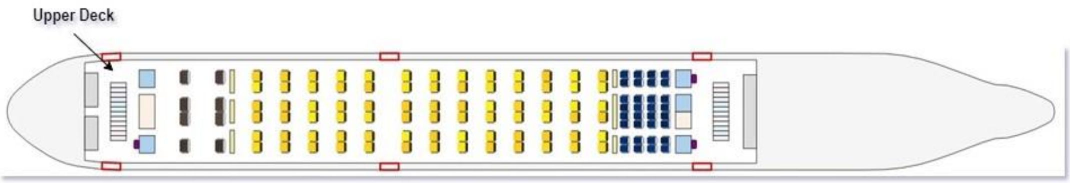
1. Distance = 0.0



a) Side view

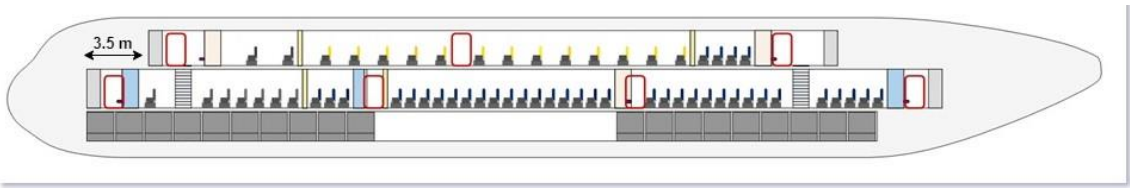


b) Top View of Main Deck

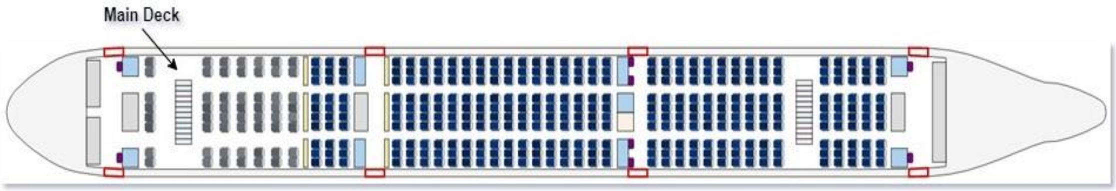


c) Top View of Upper Deck

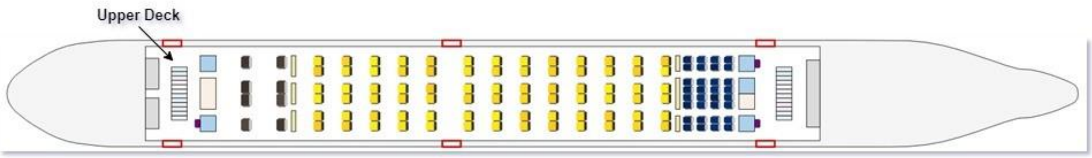
2. Distance = 3.5



a) Side View

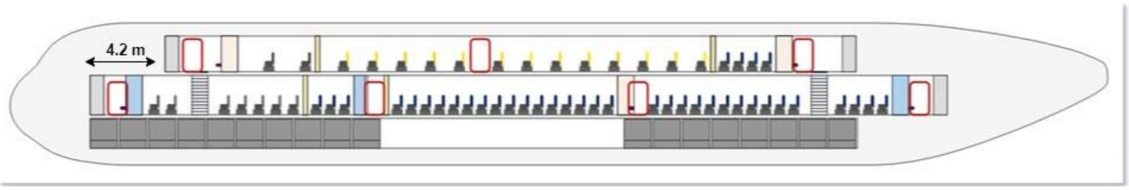


b) Top View of Main Deck

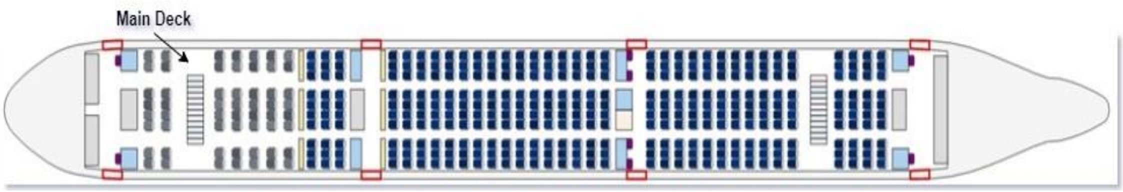


c) Top View of Upper Deck

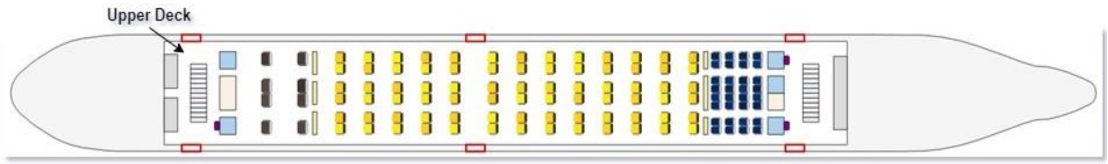
3. Distance = 4.2



a) Side View



b) Top View of Main Deck

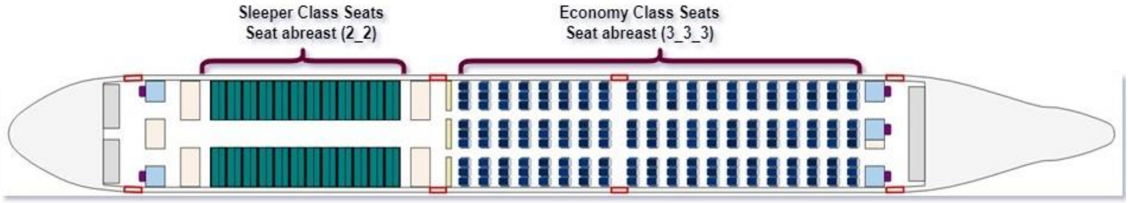


c) Top View of Upper Deck

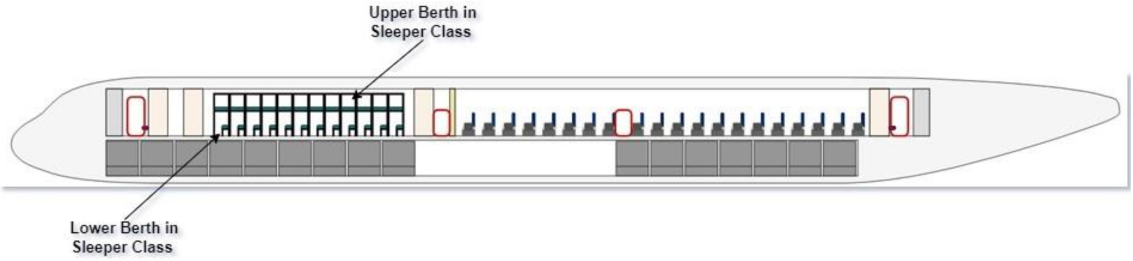
Figure 6-5: Effects of Upper Deck Starting Points on Cabin Layout and Stair Configuration

6. Unconventional Cabin Layout

Sleeper Class: This section illustrates the outcomes discussed in Chapter 4, highlighting the design and layout of the sleeper class. It also explains how these additional features are integrated into the cabin class, enhancing passenger comfort and overall cabin functionality.

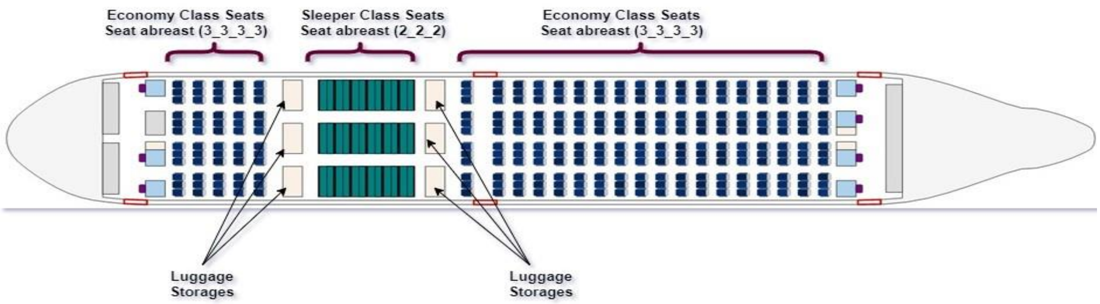


a) Top View

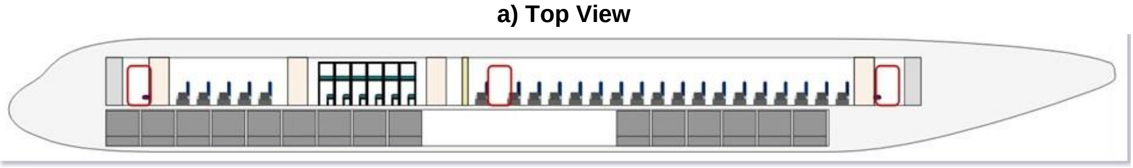


b) Side View

Figure 6-6: Single-Aisle Sleeper Class Configuration Generated by the Tool



a) Top View

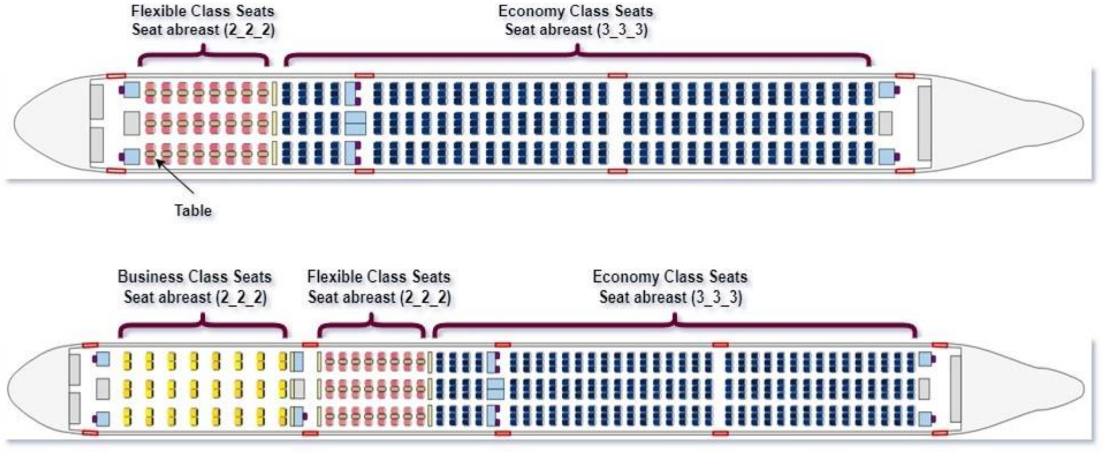


b) Side View

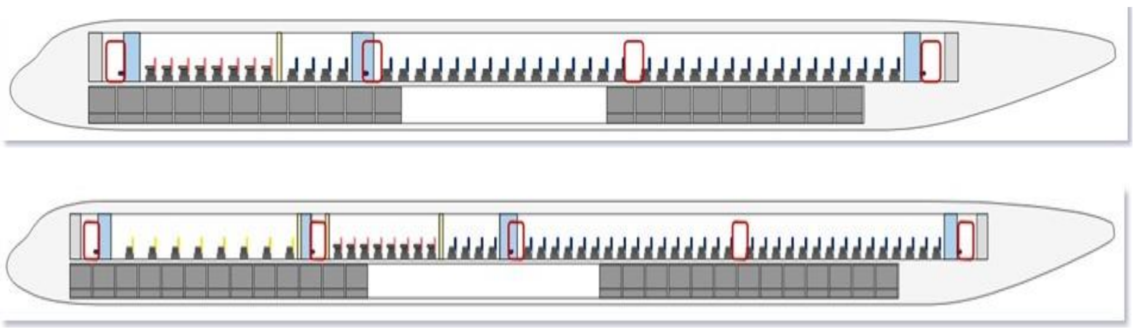
Figure 6-7: Twin-Aisle Sleeper Class Configuration generated by the tool

As illustrated in Figure 6-6, each sleeper class cabin has two berths, one higher and one lower, like those found in trains. Figure 6-6 and Figure 6-7 clearly show that luggage storage is at the beginning and end of the sleeper class portion. This design is owing to the sleeper compartments reaching the entire cabin height, leaving no room for carry-on bags within them. Furthermore, the bottom of a bed is designed to mimic a seat and is convertible. Travelers can sit during take-off and landing, then change the seats into sleeping arrangements for the remaining time of the travel.

Flexible Class: As discussed in Chapter 4, this class introduces an additional option between premium economy and business class. It features a table between two seats, offering passengers increased privacy and a comfortable seating arrangement. The table provides space for personal items such as books, enhancing the overall travel experience.



a) Top View

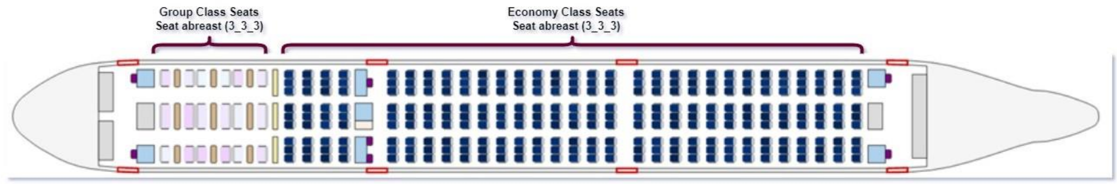


b) Side View

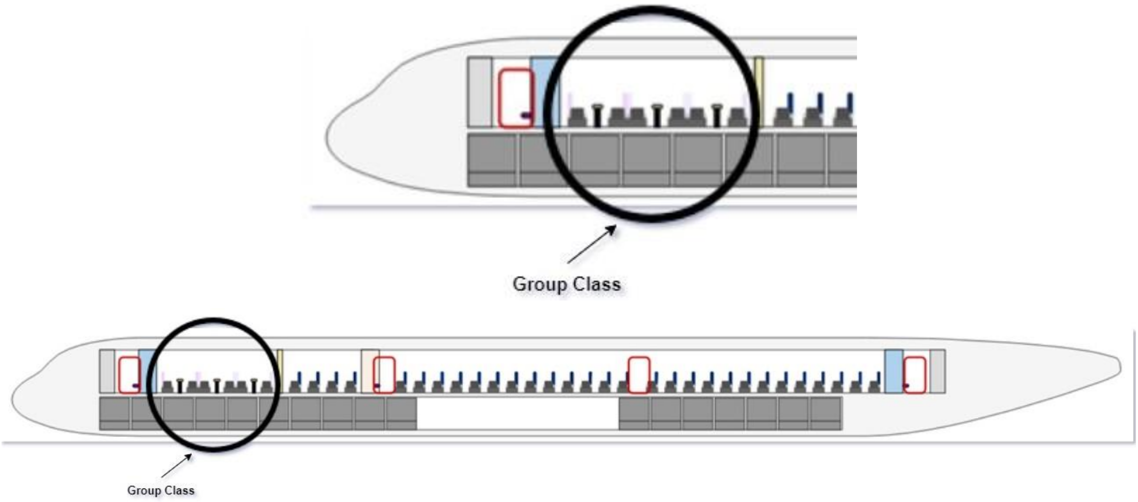
Figure 6-8: Flexible Class Configuration generated by the tool

Figure 6-8 illustrates the flexibility offered by this class, demonstrating how it can be strategically positioned anywhere within the cabin. This versatility allows airlines to optimize the cabin layout and cater to varying passenger needs. The adaptable design ensures that the class can seamlessly integrate into different sections of the aircraft, enhancing overall cabin functionality and passenger comfort.

Group Class: As elaborated in Chapter 4, this class is inspired by the railway seat arrangement system. It offers privacy for groups of people traveling together, allowing business or corporate teams to discuss ideas or hold meetings productively without disturbing other passengers. This class is designed to provide a conducive environment for collaboration and communication, making travel time more efficient and valuable (see Figure 6-9).



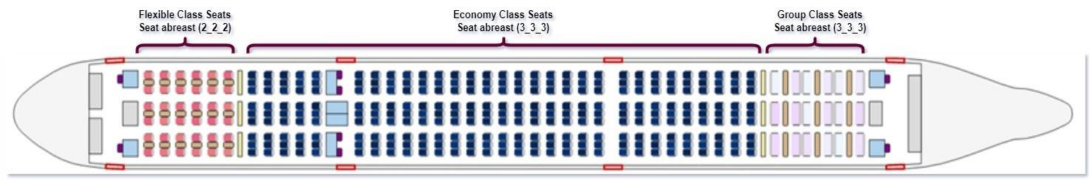
a) Top View



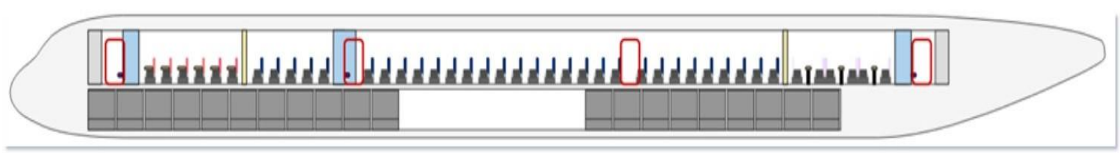
b) Side View

Figure 6-9: Group Class Configuration generated by the tool

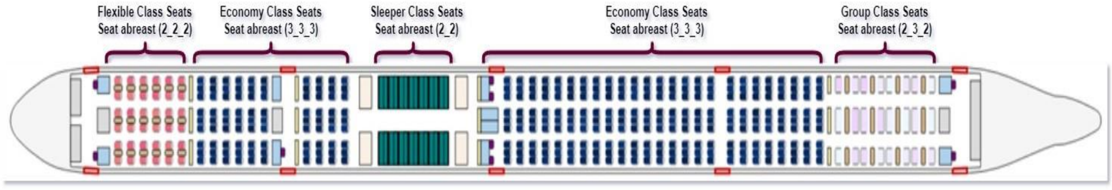
Figure 6-10 below shows that the CPACS-Python tool not only supports a single unconventional class, but also allows users to create multiple types of unconventional cabin layouts. Additionally, the tool allows for flexibility in placing each of these layouts.



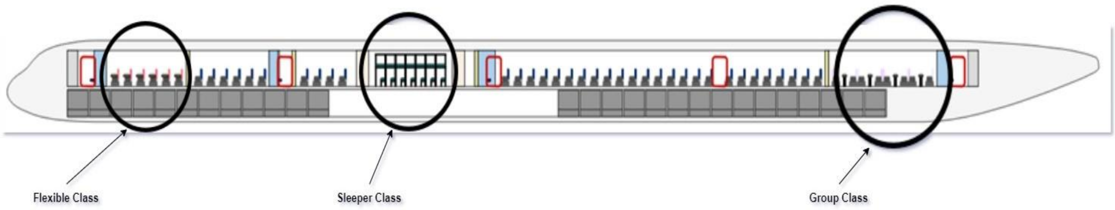
a)



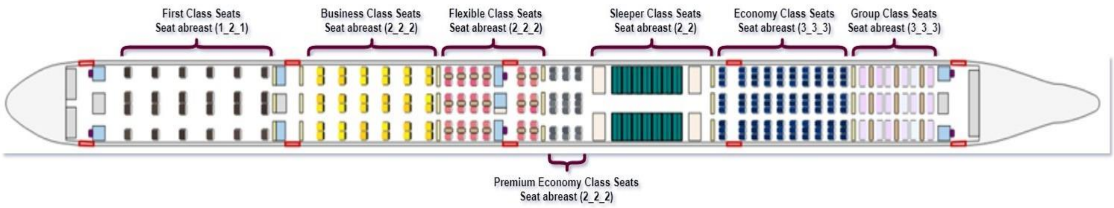
b)



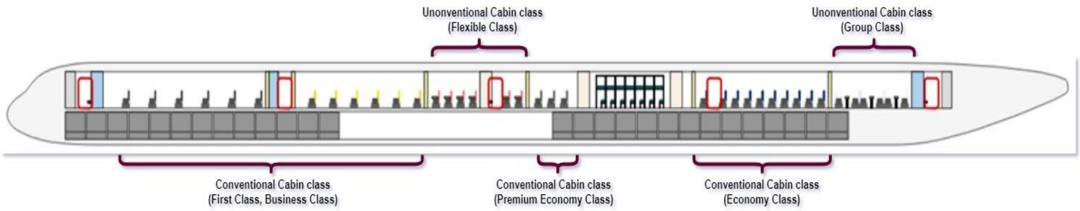
c)



d)



e)



f)

Figure 6-10: Conventional and Unconventional Cabin Classes

As shown in the unconventional layout, the current version of the tool provides multiple travel classes with flexible placement. However, users should be aware of one limitation: the Sleeper Class and Group Class must be placed between doors. This is because the current version of the tool always tries to position elements such as lavatories and galleys near doors. Placing doors in continuation of the classes results in a suboptimal layout. Future versions of the tool may overcome this limitation and provide enhancements in this area.

7 Conclusion and Outlook

The fundamental goal of this thesis was to create a tool that bridges the gap between cabin and fuselage design, which may have been overlooked during the early design stages. The idea was to give customers a variety of design alternatives while requiring minimal input. As demonstrated in Chapter 5, the accuracy of the tool was validated by comparing the cabin layouts of five existing aircraft models: the A320neo, A350-900, A220-300, ATR72, and A380-800. The results are summarized in Table 7-1 below.

Table 7-1: Validation Data

Model	BHL data	Calculated Length	Difference	BHL data	Calculated Mass	Difference
A320neo	27.57	27.76	0.6%	6944	6928.703	0.2%
A350-900	52.85	50.06	5.2%	23011*	16332.44	29.02%
A220-300	27.5	28.92	5.1%	6036.9	6090.193	0.8%
ATR-72	17.95	17.13	4.5%	2324*	3550.812	31.5%
A380-800 (Upper Deck)	44.93**	39.07	13.04%		8427.627	-
A380-800 (Main Deck)	49.9	48.26	3.28%		19877.273	-

* - Obtained mass from BHL is old and needs to be updated

** - Original Cabin length is longer due to excess galley structures

From Table 7-1, we observe that the maximum difference in length is around 5% (the A380-800 upper deck has a very unconventional cabin design, hence indicating a large difference in length) demonstrating a high level of accuracy for the tool. The A320neo showed the most accurate results in terms of length, width, and mass, with detailed analysis provided in Appendix A.

The overall (operational and furnishing) mass of the A320neo has an accuracy of 0.2% as compared to the actual mass obtained from internal BHL data. Using this method for mass calculation for the other cabin layouts results in a more reliable and accurate set of results in the conceptual cabin design phase and which can be used for subsequent research. It must be noted that these mass results may vary from the original manufacturer data due to unique mass calculation methods for each specific cabin layout.

Previous research tools such as PreSTo[9] and ParaFuse [10] have shown limitations that our tool addresses. PreSTo, developed at the University of Applied Sciences Hamburg (HAW Hamburg), offers an Excel-based platform for preliminary aircraft design and optimization, focusing on cabin design issues such as floor layouts and seating arrangements. However, it is limited to conventional fuselage designs and only compatible with Microsoft Excel. ParaFuse, a Python-powered tool, enhances efficiency in standard configurations but is restricted in handling unconventional designs and has compatibility constraints.

Our tool, as detailed in Chapter 6, overcomes these limitations by enabling features such as:

- Non-standardized seat configurations
- Multiple seat configurations within the same class
- Various conventional class layouts
- Diverse options for cargo decks
- Unconventional layouts like Sleeper Class, Group Class, and Flexible Class

The tool allows users to implement unconventional designs effectively while maintaining EASA standard rules. It successfully fulfills the aims outlined at the beginning of this thesis, providing a trustworthy solution for early-stage aircraft cabin and fuselage design integration.

Outlook

From a design perspective, several potential improvements can be made to the tool:

- **Increased Seat Abreast:** There is a possibility to rise in the number of seats abreast if demand arises in the future.
- **Exploration of Unconventional Seating Arrangements:** There is an opportunity to explore other unconventional seating arrangements apart from the current version of the tool which has been given, such as staggered class layouts.
- **Increased Lavatory Capacity:** Currently, the tool supports a maximum of 12 lavatories per deck. This number could be increased to accommodate larger aircraft.
- **Realistic Lavatory and Galley Designs**: Instead of using block designs for lavatories and galleys, the tool could be updated to generate more realistic designs.
- **Variety in Stair Designs:** Unique designs, sizes, and positions for stairs may be integrated to provide more flexibility in the multiple-deck cabin layout.
- **Cross-Section Shapes:** At present, the tool only supports circular and elliptical cross-sections. There will be a possibility to add other shapes, such as the oval, which could enhance its versatility.
- **Flexible Door Placement:** Currently, doors are placed parallel to each other on both sides. The tool could be modified to allow for different door positions as per user demand while complying with EASA standards.

- **Overhead Bin Design:** The addition of overhead bin designs would provide a more comprehensive cabin layout.

These enhancements would further improve the tool's capability to generate innovative and efficient aircraft cabin designs.

It is essential to update Torenbreek's [16] weight estimation processes, which have been used to evaluate the mass of a few elements. Those formations are more than 30 years old. Because of advances in substances and production processes, the weight of cutting-edge components can range substantially. A calibration factor based on present day data must be integrated to enhance the overall accuracy of weight estimation.

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Appendix

Appendix A

Table Appendix A-1: Detailed Mass and Center of Gravity Data for the A320neo Generated by the Tool

a) Result of Mass

Element	Sub element	Value [kg]
Operator items	Total Food Weight	718.07
	Total Crew Weight	503.52
	Total Emergency Equipment Weight	368.13
	Total Galley Weight	283.169
	Total Seats Weight	1548.4
	Total Divider Weight	6.825
	Total Door Weight	242.15
	Total miscellaneous Weight	149.3
Total Operator items Weight		**3819.564**
Furnishing	Total Overhead Bins Weight	665.11
	Total Crew Seat Weight	153.23
	Total Fresh (Portable) Water Weight	125.88
	Total Lavatory Weight	274.55
	Cabin Insulation Weight	197.57
	Cabin Lining Weight	604.2
	Floor Carpet Weight	187.118
	Cargo Deck Lining Weight	330
	Cargo Loading System Weight	332.06
	Cabin Lighting Weight	220.301
	General Weight	19.12
Total Furnishing Weight		**3109.14**
Total Mass (Operator items + Furnishing)		**6928.703**

Element	Sub element	Value [kg]
Payload	Passenger [168 x 76.3]	12818.4
	Crew Seats [(4+2) x 83.92]	503.52
	Passenger Luggage [Carry-On] [168 x 7.7]	1293.6
	Crew Luggage [Carry On] [(4+2) x 10]	60.0
	Passenger Luggage [Check-In] [168 x 11]	1848.0
	Crew Luggage [Check-In] [(4+2) x 8.7]	52.2
	Cargo [11 x 82.0]	902.0
Total Payload Weight		**17477.72**

b) Result of COG

Elements	Quantity	Total Weight	COG X [m] [w.r.t Deck]	COG Y [m] [w.r.t Deck]
Galley	4	283.169	13.979	0.22
Food	-	718.07	13.979	0.22
Lavatory	3	274.55	17.116	-0.366
Luggage Storages	-	-	-	-
Divider	2	6.825	8.52	0.0
Table	-	-	-	-
Staircase	-	-	-	-
Crew seat	4	153.23	19.806	-0.549
Bed	-	-	-	-
Seat	168	1548.4	13.889	0.0
Overhead Bin	-	665.11	13.889	0.0
Door	8	242.14	12.701	0.0
Fresh (Portable) water	1	125.88	8.25	0.0
Cargo	11	902	13.281	0.0
Emergency Equipment	168	368.13	13.822	0.0
Cabin Insulation	1	197.57	13.882	0.0
Cabin Lining	1	604.2	13.882	0.0
Floor Carpet	1	187.118	13.882	0.0
Cargo Deck Lining	1	330.0	10.902	0.0
Cargo Loading	1	332.06	10.902	0.0
Cabin Lighting	1	220.301	13.882	0.0
General	1	19.12	13.882	0.0
Total Cabin Elements		**7177.883**	**13.225**	**0.005**

Appendix B

Table Appendix B-1: Detailed Mass and Center of Gravity Data for the A350-900 Generated by the Tool

a) Result of Mass

Element	Sub element	Value [kg]
Operator items	Total Food Weight	1359.204
	Total Crew Weight	755.28
	Total Emergency Equipment Weight	696.817
	Total Galley Weight	604.255
	Total Seats Weight	3296.55
	Total Divider Weight	18.2
	Total Door Weight	678.02
	Total miscellaneous Weight	282.604
Total Operator items Weight		**7690.931**
Furnishing	Total Overhead Bins Weight	2523.603
	Total Crew Seat Weight	268.152
	Total Fresh (Portable) Water Weight	238.273
	Total Lavatory Weight	732.133
	Cabin Insulation Weight	868.115
	Cabin Lining Weight	1089.38
	Floor Carpet Weight	526.676
	Cargo Deck Lining Weight	655.762
	Cargo Loading System Weight	1288.394
	Cabin Lighting Weight	397.206
	General Weight	53.816
Total Furnishing Weight		8641.511
Total Mass (Operator items + Furnishing)		16332.442

Element	Sub element	Value [kg]
Payload	Passenger [318 x 76.3]	24263.4
	Crew Members [(7+2) x 83.92]	755.28
	Passenger Luggage [Carry-On] [318 x 7.7]	2448.6
	Crew Luggage [Carry On] [(7+2) x 10]	90.0
	Passenger Luggage [Check-In] [318 x 11]	3498.0
	Crew Luggage [Check-In] [(7+2) x 8.7]	78.3
	Cargo [36 x 82.0]	2952.0
Total Payload Weight		**34085.58**

b) Result of COG

Elements	Quantity	Total Weight	COG X [m] [w.r.t Deck]	COG Y [m] [w.r.t Deck]
Galley	5	604.255	25.109	0.22
Food	-	1359.204	25.109	0.22
Lavatory	8	732.133	21.356	0.0
Luggage Storages	-	-	-	-
Divider	6	18.2	15.65	0.0
Table	-	-	-	-
Staircase	-	-	-	-
Crew seat	7	268.152	21.998	-0.249
Bed	-	-	-	-
Seat	318	3296.55	28.256	0.0
Overhead Bin	-	2523.603	28.256	0.0
Door	8	678.02	24.998	0.0
Fresh (Portable) water	1	238.278	28.256	0.0
Cargo	36	2952.0	21.06	0.0
Emergency Equipment	318	696.817	22.434	0.0
Cabin Insulation	1	868.115	25.029	0.0
Cabin Lining	1	1089.38	25.029	0.0
Floor Carpet	1	526.676	25.029	0.0
Cargo Deck Lining	1	655.762	21.664	0.0
Cargo Loading	1	1288.394	21.664	0.0
Cabin Lighting	1	397.206	25.029	0.0
General	1	53.816	25.029	0.0
Total Cabin Elements		**18246.557**	**24.229**	**-0.004**

Appendix C

Table Appendix C-1: Detailed Mass and Center of Gravity Data for the A220-300 Generated by the Tool

a) Result of Mass

Element	Sub element	Value [kg]
Operator items	Total Food Weight	585.569
	Total Crew Weight	419.6
	Total Emergency Equipment Weight	300.201
	Total Galley Weight	228.205
	Total Seats Weight	1236.5
	Total Divider Weight	11.375
	Total Door Weight	201.792
	Total miscellaneous Weight	121.751
Total Operator items Weight		**3104.993**
Furnishing	Total Overhead Bins Weight	713.139
	Total Crew Seat Weight	114.922
	Total Fresh (Portable) Water Weight	102.652
	Total Lavatory Weight	183.033
	Cabin Insulation Weight	149.976
	Cabin Lining Weight	629.323
	Floor Carpet Weight	166.385
	Cargo Deck Lining Weight	338.597
	Cargo Loading System Weight	340.71
	Cabin Lighting Weight	229.462
	General Weight	17.001
Total Furnishing Weight		**2985.2**
Total Mass (Operator items + Furnishing)		**6090.193**

Element	Sub element	Value [kg]
Payload	Passenger [137 x 76.3]	10453.1
	Crew Seats [(3+2) x 83.92]	419.6
	Passenger Luggage [Carry-On] [137 x 7.7]	1054.9
	Crew Luggage [Carry On] [(3+2) x 10]	50.0
	Passenger Luggage [Check-In] [137 x 11]	1507.0
	Crew Luggage [Check-In] [(3+2) x 8.7]	43.5
	Cargo [11 x 82.0]	902.0
Total Payload Weight		**14430.1**

b) Result of COG

Elements	Quantity	Total Weight	COG X [m] [w.r.t Deck]	COG Y [m] [w.r.t Deck]
Galley	3	228.205	20.995	0.394
Food	-	585.569	20.995	0.394
Lavatory	2	183.033	13.529	-0.87
Luggage Storages	-	-	-	-
Divider	4	11.375	3.535	0.038
Table	-	-	-	-
Staircase	-	-	-	-
Crew seat	3	114.922	18.493	-0.87
Bed	-	-	-	-
Seat	137	1236.5	14.603	0.042
Overhead Bin	-	713.139	14.603	0.042
Door	6	201.792	14.216	0.0
Fresh (Portable) water	1	102.652	12.059	0.0
Cargo	11	902.0	12.546	0.0
Emergency Equipment	137	300.201	14.603	0.042
Cabin Insulation	1	149.976	14.459	0.0
Cabin Lining	1	629.323	14.459	0.0
Floor Carpet	1	166.385	14.459	0.0
Cargo Deck Lining	1	338.597	11.186	0.0
Cargo Loading	1	340.71	11.186	0.0
Cabin Lighting	1	229.462	14.459	0.0
General	1	17.001	14.549	0.0
Total Cabin Elements		**6450.843**	**14.257**	**0.024**

Appendix D

Table Appendix D-1: Detailed Mass and Center of Gravity Data for the ATR72 Generated by the Tool

a) Result of Mass

Element	Sub element	Value [kg]
Operator items	Total Food Weight	307.744
	Total Crew Weight	335.68
	Total Emergency Equipment Weight	157.77
	Total Galley Weight	133.428
	Total Seats Weight	637.2
	Total Divider Weight	4.5
	Total Door Weight	129.147
	Total miscellaneous Weight	63.986
Total Operator items Weight		**1769.455**
Furnishing	Total Overhead Bins Weight	408.636
	Total Crew Seat Weight	76.615
	Total Fresh (Portable) Water Weight	53.949
	Total Lavatory Weight	91.517
	Cabin Insulation Weight	59.898
	Cabin Lining Weight	372.805
	Floor Carpet Weight	80.931
	Cargo Deck Lining Weight	-
	Cargo Loading System Weight	-
	Cabin Lighting Weight	135.931
	General Weight	8.27
Total Furnishing Weight		**1288.541**
Total Mass (Operator items + Furnishing)		**3057.996**

Element	Sub element	Value [kg]
Payload	Passenger [72x 76.3]	5493.6
	Crew Seats [(2+2) x 83.92]	335.68
	Passenger Luggage [Carry-On] [72 x 7.7]	554.4
	Crew Luggage [Carry On] [(2+2) x 10]	40.0
	Passenger Luggage [Check-In] [72 x 11]	792.0
	Crew Luggage [Check-In] [(2+2) x 8.7]	34.8
	Cargo [0 x 0.0]	0.0
Total Payload Weight		**7250.48**

b) Result of COG

Elements	Quantity	Total Weight	COG X [m] [w.r.t Deck]	COG Y [m] [w.r.t Deck]
Galley	2	133.428	11.293	0.223
Food	-	307.744	11.293	0.223
Lavatory	1	91.517	0.457	-0.633
Luggage Storages	-	-	-	-
Divider	2	4.5	1.875	0.0
Table	-	-	-	-
Staircase	-	-	-	-
Crew seat	2	76.615	1.064	-0.633
Bed	-	-	-	-
Seat	72	637.2	8.692	0.0
Overhead Bin	-	408.626	8.692	0.0
Door	4	129.147	8.652	0.0
Fresh (Portable) water	1	53.949	8.565	0.0
Cargo	-	-	-	-
Emergency Equipment	72	157.77	8.692	-0.0
Cabin Insulation	1	59.898	8.565	0.0
Cabin Lining	1	372.805	8.565	0.0
Floor Carpet	1	80.067	8.565	0.0
Cargo Deck Lining	-	-	-	-
Cargo Loading	-	-	-	-
Cabin Lighting	1	135.931	8.565	0.0
General	1	8.27	8.565	0.0
Total Cabin Elements		**2658.331**	**8.153**	**-0.003**

Appendix E

Table Appendix E-1: Detailed Mass and Center of Gravity Data for the A380-800 Generated by the Tool

a) Result of Mass – Main Deck

Element	Sub element	Value [kg]
Operator items (Main Deck)	Total Food Weight	1692.594
	Total Crew Weight	839.2
	Total Emergency Equipment Weight	867.735
	Total Galley Weight	801.791
	Total Seats Weight	4086.2
	Total Divider Weight	22.75
	Total Luggage Storage Weight	45.358
	Total Door Weight	678.02
	Total miscellaneous Weight	351.921
	Total Staircase Weight	2000.0
Total Operator items Weight		**11385.569**
Furnishing (Main Deck)	Total Overhead Bins Weight	2066.615
	Total Crew Seat Weight	306.46
	Total Fresh (Portable) Water Weight	296.717
	Total Lavatory Weight	823.65
	Cabin Insulation Weight	1001.267
	Cabin Lining Weight	1050.368
	Floor Carpet Weight	555.407
	Cargo Deck Lining Weight	650.798
	Cargo Loading System Weight	1278.641
	Cabin Lighting Weight	382.982
	General Weight	56.751
Total Furnishing Weight		**8469.657**
Total Mass (Operator items + Furnishing)		**19855.226**

Element	Sub element	Value [kg]
Payload (Main Deck)	Passenger [396 x 76.3]	30214.8
	Crew Seats [(8+2) x 83.92]	839.2
	Passenger Luggage [Carry-On] [396 x 7.7]	3049.2
	Crew Luggage [Carry On] [(8+2) x 10]	100.0
	Passenger Luggage [Check-In] [396 x 11]	4356.0
	Crew Luggage [Check-In] [(8+2) x 8.7]	87.0
	Cargo [38x 82.0]	3116.0
Total Payload Weight		41762.2

b) Result of Mass – Upper Deck

Element	Sub element	Value [kg]
Operator items (Upper Deck)	Total Food Weight	504.359
	Total Crew Weight	419.6
	Total Emergency Equipment Weight	258.567
	Total Galley Weight	397.108
	Total Seats Weight	1475.4
	Total Divider Weight	18.1
	Total Luggage Storage Weight	136.474
	Total Door Weight	508.515
	Total miscellaneous Weight	104.865
Total Operator items Weight		**3882.989**
Furnishing (Upper Deck)	Total Overhead Bins Weight	1749.768
	Total Crew Seat Weight	114.922
	Total Fresh (Portable) Water Weight	88.416
	Total Lavatory Weight	457.583
	Cabin Insulation Weight	556.568
	Cabin Lining Weight	850.342
	Floor Carpet Weight	372.582
	Cabin Lighting Weight	310.049
	General Weight	38.07
Total Furnishing Weight		**4538.302**
Total Mass (Operator items + Furnishing)		**8361.291**
Total Mass ((Operator items + Furnishing) (Main Deck + Upper Deck)		**28216.517**

Element	Sub element	Value [kg]
Payload (Main Deck)	Passenger [118x 76.3]	9003.4
	Crew Seats [3x 83.92]	419.6
	Passenger Luggage [Carry-On] [118 x 7.7]	908.6
	Crew Luggage [Carry On] [3 x 10]	50.0
	Passenger Luggage [Check-In] [118 x 11]	1298.0
	Crew Luggage [Check-In] [3 x 8.7]	43.5
Total Payload Weight		**11723.1**

c) Result of COG – Main Deck

Elements	Quantity	Total Weight	COG X [m] [w.r.t Deck]	COG Y [m] [w.r.t Deck]
Galley	6	801.791	23.005	0.0
Food	-	1692.594	23.005	0.0
Lavatory	9	823.65	24.145	0.05
Luggage Storages	1	67.405	30.253	-0.457
Divider	6	22.75	14.552	0.0
Table	-	-	-	-
Staircase	2	2000.0	21.981	0.0
Crew seat	8	306.46	27.304	0.0
Bed	-	-	-	-
Seat	396	4086.2	25.763	-0.0
Overhead Bin	-	2066.615	25.763	0.0
Door	8	678.02	23.5	0.0
Fresh (Portable) water	1	296.717	19.188	0.0
Cargo	38	3116.0	23.492	0.0
Emergency Equipment	396	867.735	25.763	0.0
Cabin Insulation	1	1001.267	24.132	0.0
Cabin Lining	1	1050.368	24.132	0.0
Floor Carpet	1	555.407	24.132	0.0
Cargo Deck Lining	1	650.798	21.5	0.0
Cargo Loading	1	1278.641	21.5	0.0
Cabin Lighting	1	382.982	24.132	0.0
General	1	56.751	24.132	0.0
Total Cabin Elements		**21802.151**	**23.243**	**0.0**

d) Result of COG – Upper Deck

Elements	Quantity	Total Weight	COG X [m] [w.r.t Deck]	COG Y [m] [w.r.t Deck]
Galley	3	397.108	20.303	0.0
Food	-	504.359	20.303	0.0
Lavatory	5	457.583	22.258	0.091
Luggage Storages	2	202.81	13.938	-0.152
Divider	6	18.1	19.686	0.0
Table	-	-	-	-
Staircase	-	-	-	0.0
Crew seat	3	114.922	24.533	-0.581
Bed	-	-	-	-
Seat	118	1475.4	21.565	0.0
Overhead Bin	-	1749.768	21.565	0.0
Door	6	508.515	18.477	0.0
Fresh (Portable) water	1	88.416	19.188	0.0
Emergency Equipment	118	258.567	21.565	0.0
Cabin Insulation	1	556.568	19.537	0.0
Cabin Lining	1	850.342	19.537	0.0
Floor Carpet	1	372.582	19.537	0.0
Cabin Lighting	1	310.049	19.537	0.0
General	1	38.07	19.537	0.0
Total Cabin Elements		**7903.161**	**19.344**	**-0.007**